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CARBENES AND NITRENES MEDIATED STEREOCONTROLLED

GLYCOSYLATIONS

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**CARBENES AND NITRENES MEDIATED STEREOCONTROLLED
GLYCOSYLATIONS**

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY

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Dedication

I dedicate this dissertation to my beloved parents, Ms. Mithlesh Devi and Mr. Jai Kishan Singh. Your sacrifices, resilience, and unconditional love have been the guiding force behind my journey. You have always been my superheroes, and every achievement of mine stands upon the strength and support you have given me throughout my life.

Abstract

Carbenes and nitrenes represent a unique class of highly reactive organic intermediates. These isoelectronic, neutral species have been known since the nineteenth century and have become powerful tools in modern synthetic chemistry. In recent decades, both intermediates have enabled a wide range of transformations, including C–H functionalization, single-atom C/N transfer, heteroatom insertion, rearrangements, and cycloaddition reactions. However, their application in carbohydrate chemistry remains largely unexplored. Glycosylation, the chemical process that links carbohydrate units to construct oligosaccharides and glycoconjugates, is essential for accessing biologically relevant molecules. Despite their significance, the stereoselective construction of glycosidic linkages remains challenging due to the structural complexity of carbohydrate building blocks. This work investigates the strategic use of carbene and nitrene intermediates to develop new catalytic glycosylation approaches for the precise synthesis of complex glycosylated molecules.

In Chapter 2, two new classes of glycosyl donors were developed for stereocontrolled glycosylation: (1) enynal-based donors (first-generation) and (2) diazo-thioglycoside donors (second-generation). Both donors generate copper carbenes under catalytic conditions using earth-abundant copper catalysts. These donors are readily synthesized from commercially available starting materials and exhibit excellent bench stability. The developed systems enable efficient formation of both 1,2-*cis* and 1,2-*trans* glycosides with a broad range of glycosyl acceptors and allow iterative synthesis of trisaccharides. Mechanistic investigations highlight the critical role of the enynal linker and thioglycoside moiety in enabling effective donor activation. Together, these studies establish two complementary carbene-based glycosyl donor platforms operating under catalytic conditions.

In pursuit of a more sustainable activation approach for stereocontrolled glycosylation, Chapter 3 introduces an MDMPA-based glycosyl donor that can be activated either by $\text{Fe}(\text{OTf})_3$ catalysis or by photosensitizer-free visible-light irradiation. These donors are compatible with a wide range of protecting group patterns, including disarmed, armed, and superarmed systems. The use of earth-abundant iron catalysis and

visible-light activation provides mild, sustainable, and scalable conditions for glycosylation. Mechanistic studies reveal that donor activation is independent of anomeric purity. The method demonstrates broad applicability across numerous glycosyl donors, including glucose, mannose, galactose, rhamnose, xylose, 2-deoxyaminoglucose, lactose, ribose, and arabinose, and diverse nucleophiles such as primary, secondary, and tertiary alcohols, phenols, carboxylic acids, glycosyl thiols, and amino acids. Importantly, the method enables the synthesis of complex hexasaccharides, glycosylated drug derivatives, and one-pot trisaccharide assemblies.

Following the development of these donor systems, the work further explores mild activation approaches for readily accessible, widely used, bench-stable conventional thioglycosides in chapters 4 and 5. Iron-carbene-mediated activation was first employed to access challenging 1,2-*cis* furanosides. In this system, iron coordinates with a nucleophile chelated at the C2-O position, delivering the nucleophile selectively from the *cis* face. This strategy was effective for ribose and arabinose substrates and tolerated primary, secondary, and tertiary alcohol nucleophiles, enabling the synthesis of a challenging 1,2-*cis* ribotetrasaccharide. Building on this intermolecular iron-carbene strategy, photochemically generated sulfenylnitrenes were subsequently introduced as a mild activation platform for thioglycosides. Unlike traditional activation methods, which often lead to anomeric epimerization in furanosides, the sulfenylnitrene approach proceeds under neutral and mild conditions that prevent epimerization. In addition, a C5 steric and electronic control model was developed to achieve 1,2-*cis* selectivity. This concept proved general across sulfenylnitrene-mediated, iron-carbene-mediated, and related activation strategies. The approach enabled the synthesis of challenging α -deoxyribosides and 1,2-*cis* xylosides and demonstrated compatibility with diverse nucleophiles, including carboxylic acids, silylated olefins, amino acids, and complex bioactive molecules such as dehydrocholic acid and ciprofibrate. The methodology was further applied to the synthesis of a challenging 1,2-*cis* ribopentasaccharide. Notably, sulfenylnitrenes selectively react with glycosyl anomeric thioethers while remaining inert toward non-glycosylated thioethers.

Overall, this dissertation establishes carbenes- and nitrenes-mediated activation as powerful platforms for glycosylation chemistry, providing sustainable catalytic strategies for the stereoselective synthesis of complex glycosides and glycoconjugates.

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List of Abbreviations

°C	degree centigrade/celcius
α	alpha anomer
Å	angstrom
Ac	acetyl
ACN	acetonitrile
Aq	aqueous
β	beta anomer
BAr ^F	Tetrakis[5-bis(trifluoromethyl)phenyl]borate
Bn	benzyl
Bphen	bathophenanthroline
Bz	benzoyl
calc.	calculated
Cbz	benzyloxy carbonyl
CIP	contact ion pair
cm	centimeter
CSA	camphorsulfonic acid
d	doublet
DBU	1,8-diazabicyclo[5.4.0]undec-7-ene
DCC	dicyclohexylcarbodiimide
DCM	dichloromethane
dd	doublet of doublets
DIPA	diisopropyl amine
DIPEA	diisopropylethyl amine
DMAP	4-dimethylamino pyridine
DMF	dimethylformamide
DPSO	diphenylsulfoxide
dr	diastereomeric ratio
DTBMP	2,4,6-di- <i>tert</i> -butyl methyl pyrimidine
EDCI	1-ethyl-3-(3-dimethylaminopropyl)carbodiimide

EDG	electron-donating group
equiv.	equivalent
ESI	electrospray ionization
esp	$\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,3-benzenedipropionate
Et	ethyl
EtOAc	ethyl acetate
EWG	electron-withdrawing group
FDA	food and drug administration
FT	Fourier transform
g	gram
h	hour
HRMS	high-resolution mass spectrometry
Hz	Hertz
IR	infrared
IUPAC	International union of Pure and Applied Chemistry
J	coupling constant
L	liter
LAH	lithium aluminum hydride
LED	light-emitting diode
M	molar or mega
m	multiplet, mass, mili, meter, or mol
m/z	mass to charge ratio
M+Na	mass plus sodium
Me	methyl
mm	millimeter
mol	mole(s)
MS	molecular sieves
MTBE	methyl- <i>tert</i> -butyl ether
n.d.	not determined
n.r.	no reaction
NBS	<i>N</i> -bromosuccinamide

n BuLi	<i>n</i> -butyl lithium
NIS	<i>N</i> -iodosuccinamide
nm	nanometer
NMR	nuclear magnetic resonance
Nu	nucleophile
Oct	octanoate
OTf	triflate/trifluoromethanesulfonate
<i>p</i>	para
<i>p</i> -ABSA	<i>para</i> acetamidobenzenesulfonyl azide
PG	protecting group
Ph	phenyl
pH	$-\log([H^+])$ in an aqueous solution
ppm	parts per million
Pr	propyl
pyr	pyridine
q	quartet
R	alkyl
R _f	retention factor
rt	room temperature
s	singlet
S _N 1	substitution nucleophilic unimolecular
S _N 2	substitution nucleophilic bimolecular
SSIP	solvent separated ion pair
t	triplet
TBAF	tetra- <i>N</i> -butyl ammonium fluoride
TBAI	tetra- <i>N</i> -butyl ammonium iodide
TBDPS	tetrabutyl-diphenylsilyl
TEA	triethyl amine
THF	tetrahydrofuran
TIPS	triisopropyl silyl
TLC	thin-layer chromatography

TMS	trimethyl silyl
Tol	toluene or <i>para</i> -tolyl
Ts	tosyl/toluene sulfonyl
TTBP	2,4,6-tri- <i>tert</i> -butyl pyridine
UV	ultraviolet
UV-vis	ultraviolet-visible spectroscopy
v	volume
x	anionic ligand or halide

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CHAPTER 1

Application of Carbene and Nitrene in Glycosylations

1.1 Introduction to Carbene and Nitrene

Carbenes constitute a unique and highly reactive class of organic intermediates characterized by a divalent carbon center bearing only six valence electrons.^[1-4] Although reactive divalent carbon species were recognized as early as the beginning of the twentieth century, the term “carbene” was formally introduced in the mid-1950s to describe these neutral intermediates.^[5-6] Fundamentally, carbenes exist in multiple electronic states depending on the spin alignment of the two nonbonding electrons at the carbon center.^[3,5,7] In singlet carbenes, the electrons possess antiparallel spins and occupy the same orbital, leaving a vacant p-orbital available for interaction.^[3,5,7-8] This electronic configuration imparts a distinctive ambiphilic character, enabling singlet carbenes to engage electrophiles via donation from the filled orbital while simultaneously accepting electron density from nucleophiles through the empty orbital (**Figure 1.1.1**).^[2,6,9]

In contrast, triplet carbenes contain two nonbonding electrons with parallel spins residing in separate orbitals, thereby minimizing electron–electron repulsion.^[3,5,7] Triplet carbenes may adopt either bent or linear geometries, with their relative stability governed by factors such as the mode of generation, substituent effects, and reaction conditions (**Figure 1.1.1**).^[3,5,7] When coordinated to transition metals, carbenes are commonly classified according to their electronic character: singlet metal carbenes are typically referred to as *Fischer-type* carbenes, whereas bent triplet carbenes correspond to *Schrock-type* carbenes.^[9-11] These distinctions have profound implications for their reactivity and catalytic behavior.^[2,12-13]

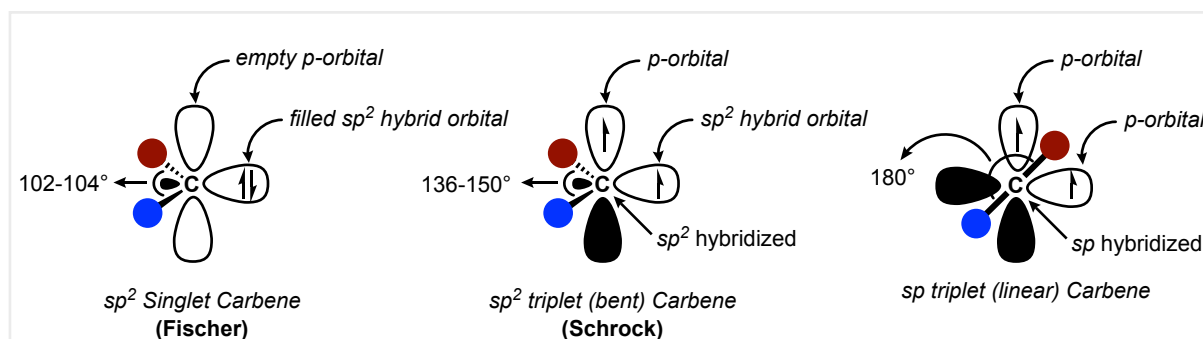


Figure 1.1.1: Structural understanding of carbene.

Nitrenes are closely related reactive intermediates in which nitrogen serves as the central atom.^[3,14-15] Although nitrogen-centered intermediates were employed in chemical transformations as early as the late nineteenth century, the term “nitrene” was established in the 1960s.^[3,14,16] Nitrenes are formally monovalent, neutral, six-electron nitrogen species and, like carbenes, can exist in multiple spin states.^[15] Singlet nitrenes, characterized by antiparallel electron spins, may exist as either closed-shell or open-shell species. Closed-shell singlet nitrenes exhibit pronounced ambiphilic reactivity, enabling simultaneous interaction with both nucleophilic and electrophilic partners, whereas open-

shell singlet nitrenes feature electrons occupying separate orbitals with opposite spins. Triplet nitrenes, on the other hand, possess two unpaired electrons with parallel spins distributed across two orbitals, leading to reactivity patterns distinct from their singlet counterparts (**Figure 1.1.2**).^[17-20]

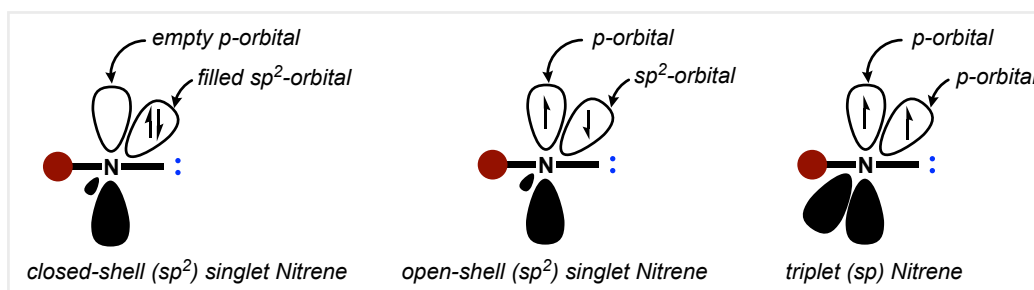


Figure 1.1.2: Structural understanding of Nitrene.

1.2 Importance of Glycosylations

Glycosylation reactions are among the most important transformations in carbohydrate chemistry, as they enable the formation of glycosidic bonds that ultimately determine the structures and functions of oligosaccharides, glycoconjugates, and many complex natural products.^[21-24] Glycosylated frameworks are widespread in biological systems and are involved in essential processes such as cell-cell communication, signal transduction, immune recognition, and the stabilization of biomolecules.^[25-27] Owing to these roles, glycosylation is a key step in the synthesis of numerous biologically active compounds, including antibiotics, antiviral and anticancer agents, vaccines, and other glycoconjugate-based therapeutics.^[28-30] In addition to their biological relevance, glycosyl groups can significantly alter physicochemical properties such as solubility, metabolic stability, and bioavailability.^[31-33] For these reasons, glycosylation has become an indispensable tool in medicinal chemistry and drug development, and the design of robust

and general glycosylation methods continues to be a central objective in modern synthetic organic chemistry.^[34-37]

1.3 Challenges in Glycosylations

Glycosylation is widely regarded as one of the most challenging bond-forming reactions in synthetic organic chemistry, primarily due to the inherent structural complexity of carbohydrate substrates.^[21,34,38-39] The presence of multiple hydroxyl groups with similar intrinsic reactivity often necessitates carefully designed protecting-group strategies, adding significant synthetic burden.^[40-42] At the same time, achieving precise control over anomeric stereochemistry remains a persistent difficulty, particularly in the formation of stereochemically demanding glycosidic linkages.^[34,43]

Additional challenges arise from competing reaction pathways, mismatches between glycosyl donors and acceptors, neighboring-group participation effects, and the pronounced sensitivity of many glycosyl donors to reaction conditions.^[36,44-45] These complications become even more severe during the synthesis of complex oligosaccharides, where successive glycosylation steps require exceptionally high levels of chemo-, regio-, and stereoselectivity.^[46-50] Consequently, the continued development of new glycosyl donors, activation modes, and catalytic strategies is essential for broadening the scope of glycosylation chemistry and enabling efficient access to structurally and biologically important carbohydrates.^[35,48,50]

1.4 Application of Carbene in Glycosylation Reactions

Although carbenes have been known since the late nineteenth century and have found widespread application in a variety of fundamental transformations, most notably C–C bond formation, C–H functionalization, and cyclopropanation, their use in the construction of glycosidic linkages has remained remarkably limited, even well into the twenty-first century.^[51-52] This disparity is striking, given the unique reactivity profile of carbenes and their potential to access highly reactive oxocarbenium ion intermediates relevant to glycosylation chemistry.^[34-35] As a result, early examples of carbene-based glycosylation represent important conceptual advances rather than broadly adopted synthetic methods.^[53-54]

A seminal contribution in this area was reported in 1989 by the French chemist Andrea Vasella, who pioneered the use of carbene intermediates for glycosyl donor activation and is widely regarded as a foundational figure in carbene-mediated glycosylation chemistry.^[4,54] Vasella developed glycosyl diazirines as masked carbene precursors, which were stable at low temperatures (below –30 °C) but could be activated thermally or photochemically to extrude dinitrogen and generate a glycosyl carbene in situ.^[54-55] This highly reactive species was proposed to rearrange to the corresponding oxocarbenium ion, which subsequently underwent nucleophilic trapping to form glycosidic bonds (**Figure 1.4.1**).^[54,56] Remarkably, this strategy enabled glycosylation with a broad range of nucleophiles, including aliphatic alcohols, phenols, unsaturated hydrocarbons, fluoroalkyl alcohols, ketones, and even sterically demanding substrates such as Buckminsterfullerene (**Figure 1.4.1**).^[57-59] Despite this impressive scope, the broader

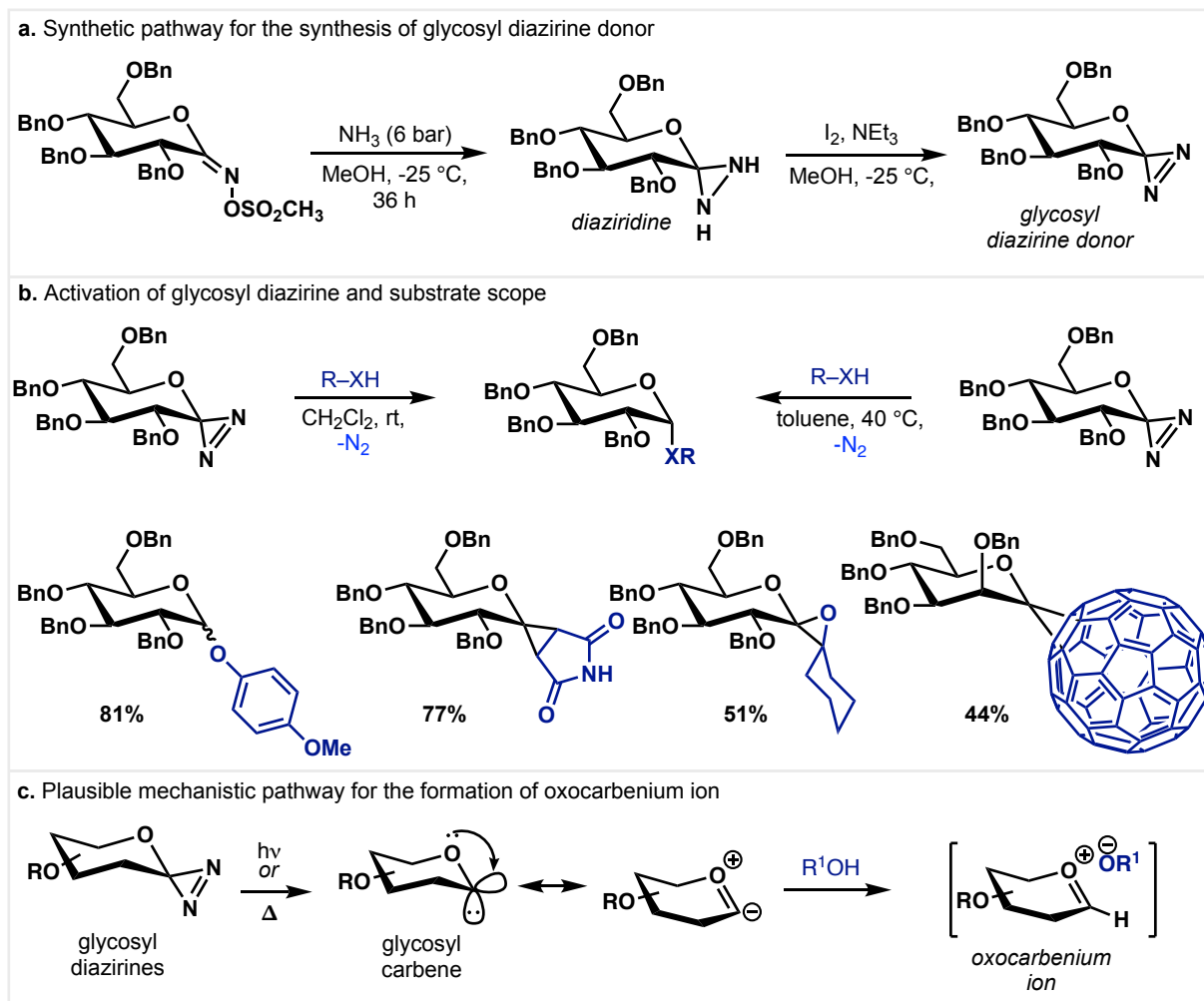


Figure 1.4.1: Vasella's pioneering work: glycosyl diazine donors. **(a)** Synthesis of glycosyl diazine donors; **(b)** Activation and substrate scope.

adoption of glycosyl diazine donors was limited by their intrinsic instability and handling challenges, which ultimately constrained their general applicability in synthetic carbohydrate chemistry.^[4,60]

Building on their initial discoveries, Andrea Vasella and co-workers further refined their donor design by introducing glycosyl hydrazones as alternative carbene precursors. The synthesis of these hydrazone-based donors was significantly improved, relying on readily accessible starting materials and more practical preparation protocols (**Figure 1.4.2**).^[55,61] Under photochemical activation, these donors generated glycosyl carbene

intermediates, which were proposed to rearrange to the corresponding oxocarbenium ions and subsequently undergo nucleophilic trapping by glycosyl acceptors to form glycosidic bonds.^[55,61]

In contrast to glycosyl diazirines, glycosyl hydrazone donors displayed markedly enhanced stability under ambient conditions and could be handled without special precautions. The substrate scope was largely comparable to that observed with diazirine-based donors; however, a notable advantage of the hydrazone system was its ability to access *N*-nucleosides and furanosylations, a particularly challenging class of glycosides. Owing to their improved stability, operational simplicity, and broader synthetic applicability, hydrazone-based glycosyl donors represented a significant advance over earlier carbene precursors and further demonstrated the potential of carbene-mediated strategies in glycosylation chemistry (**Figure 1.4.2**).^[55,60-62]

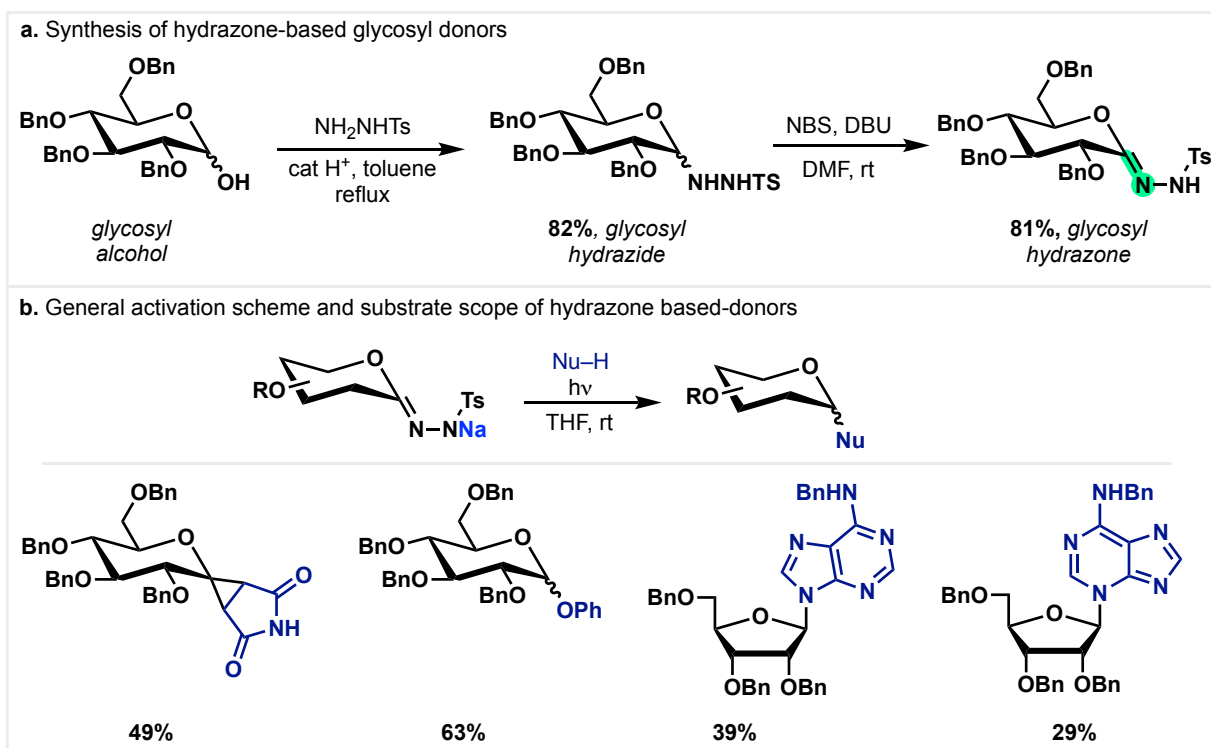


Figure 1.4.2: Vasella's improved design: hydrazone-based donors. (a) Synthesis of glycosyl-hydrazone donors; (b) Activation and substrate scope.

Building on the pioneering studies of Vasella on glycosyl diazirines and hydrazones, Nitz and co-workers reported a related carbene-based strategy in 2012 using glycosyl hydrazides, which serve as direct precursors to glycosyl hydrazones (**Figure 1.4.2a**).^[63] In this work, activation of the hydrazide with CuCl_2 was proposed to generate an anomeric carbene intermediate, enabling access to unprotected glycosyl phosphates under relatively mild conditions. Notably, this approach proved applicable to a diverse set of carbohydrate substrates, including glucose, galactose, mannose, xylose, and 2-deoxy-aminoglucose, highlighting the generality of carbene formation at the anomeric position (**Figure 1.4.3a**).

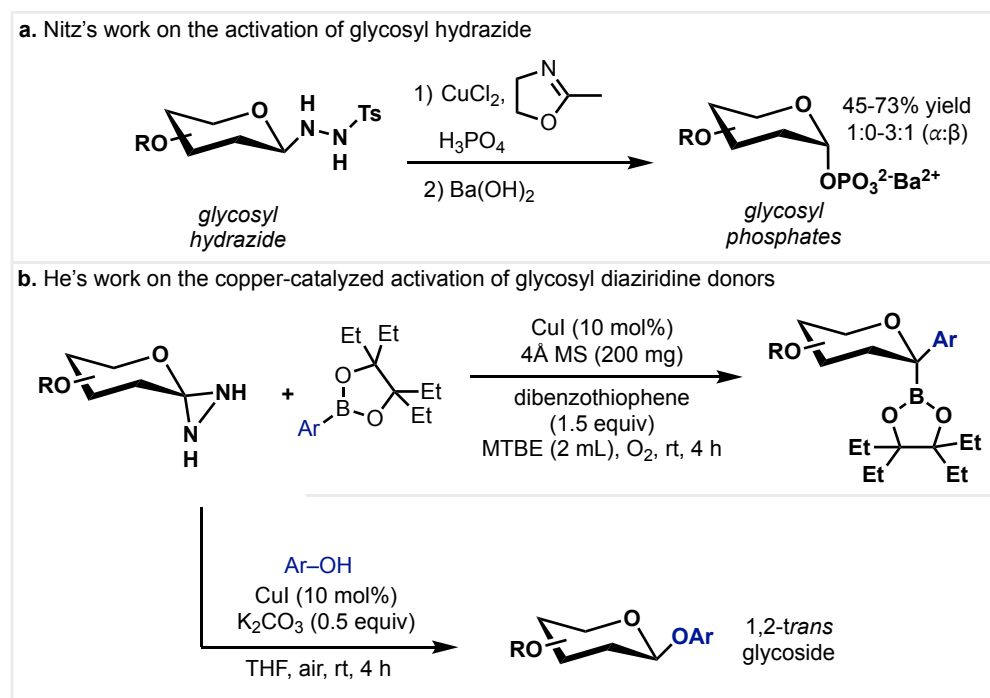


Figure 1.4.3: Other reports on the direct formation of anomeric carbene. (a) Nitz's work on the activation of glycosyl hydrazide; (b) He's work on the activation of glycosyl diaziridines.

More recently, He and co-workers further expanded the scope of carbene-mediated glycosylation through copper-catalyzed activation strategies. In 2024, they reported the activation of glycosyl diaziridines to generate glycosyl borates, enabling the formation of C-aryl glycosides across a wide range of pyranose and furanose substrates (**Figure 1.4.3b**).^[64] Subsequently, in early 2025, the same group demonstrated that this activation mode could also be applied to the construction of O-glycosides, particularly with phenolic acceptors, delivering products with high 1,2-*trans* stereoselectivity (**Figure 1.4.3b**).^[65] Collectively, the studies by Vasella, Nitz, and He establish carbene generation at the anomeric center as a viable strategy for coupling carbohydrates with diverse nucleophiles, enabling access to O-, C-, and N-glycosides as well as glycosyl phosphates and borates.

In addition to strategies based on the direct generation of a carbene at the anomeric position, indirect carbene-mediated activation of glycosyl donors has also been explored, albeit to a much more limited extent. A notable example was reported in 2019 by Wan and co-workers, who described an indirect activation pathway using conventional thioglycosides as glycosyl donors. In this approach, the thioglycoside does not form an anomeric carbene itself; instead, it interacts with an intermolecularly generated rhodium-carbene species (**Figure 1.4.4**).^[66]

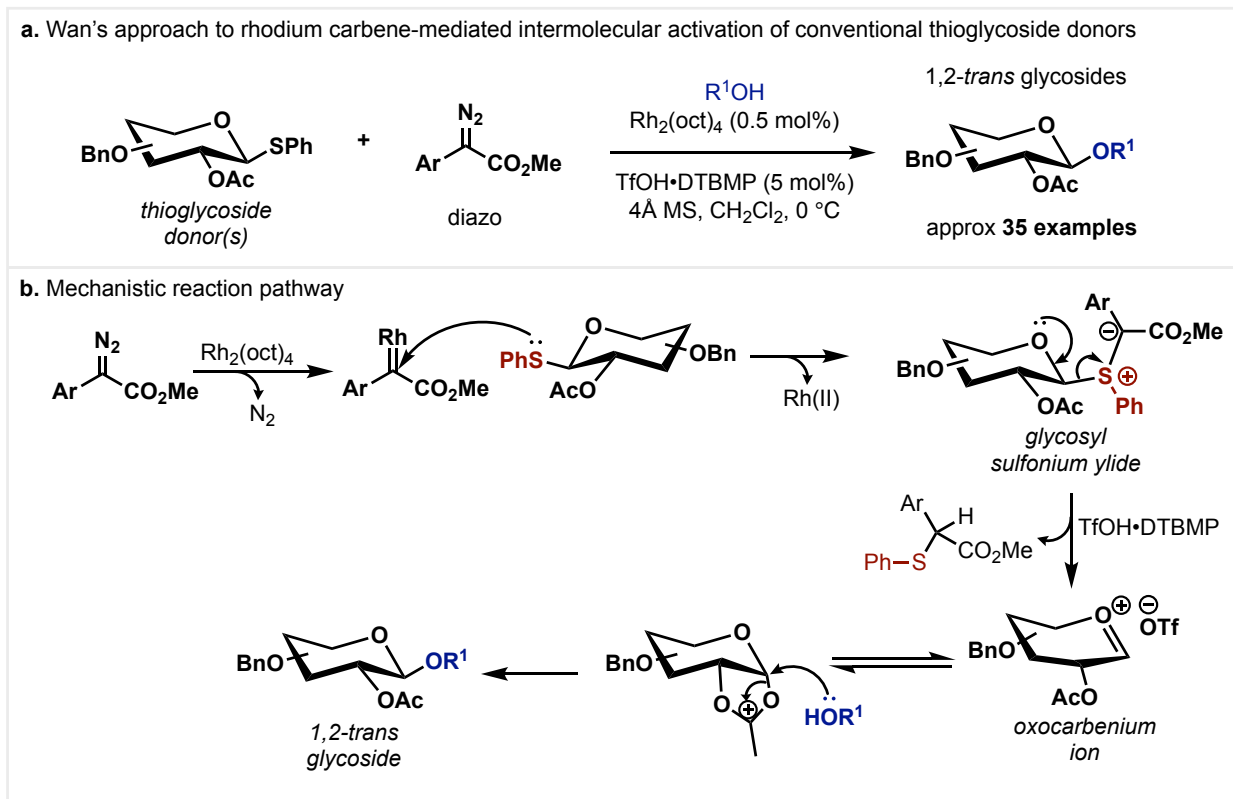


Figure 1.4.4: Wan's pioneering work on rhodium carbene-mediated activation of thioglycosides; (a) General reaction scheme; (b) Plausible mechanistic reaction pathways.

Mechanistically, the reaction of the thioglycoside with the rhodium carbene was proposed to give a sulfonium ylide intermediate, which subsequently underwent demetallation and rearrangement to generate a sulfonium ion. This species then served as a precursor to the corresponding oxocarbenium ion, which reacted with glycosyl acceptors to afford the desired glycosides. Using this strategy, a range of glycosyl donors, including glucose, mannose, galactose, and rhamnose, were successfully coupled with aliphatic and aromatic alcohol acceptors. Despite its conceptual novelty, a broader survey of the literature indicates that this report remains the only example of indirect carbene-mediated glycosyl donor activation, underscoring both the promise of the approach and the limited exploration of this activation mode to date.

Cyclopropanation represents another distinct way in which carbene chemistry has intersected with carbohydrate synthesis, particularly through the modification of glycols.^[67-68] In these approaches, a carbene adds across the C1–C2 double bond of a glycol to form a strained cyclopropane intermediate, which can then undergo ring opening under suitable activation conditions to provide 2-deoxy glycosides (**Figure 1.4.5**).^[67,69] An early example was reported by Madsen and co-workers in 2000, who prepared glycosyl 1,2-cyclopropanes from glycols using Simmons–Smith conditions. Subsequent platinum-catalyzed activation enabled nucleophilic ring opening to furnish 2-deoxyglycosides.^[70] In 2009, Chandrasekaran and co-workers employed rhodium catalysis with diazo compounds as carbene precursors to generate cyclopropanated glycols, which, upon treatment with *N*-iodosuccinimide (NIS), underwent functionalization to afford 2-deoxy *N*-nucleosides upon reaction with substituted pyrimidines (**Figure 1.4.5**).^[71-72] Further diversification of this strategy was demonstrated in 2012 by Rao, who utilized rhodium-catalyzed carbene transfer from 3-diazo-1-methyl-1,3-dihydro-2H-indol-2-one to synthesize spirooxindolyl sugar derivatives.^[73] More recently, Koenigs and co-workers reported cyclopropanation of D-glucal followed by Lewis acid-mediated transformation ($\text{Yb}(\text{OTf})_3$) to access C2–C3 lactone derivatives (**Figure 1.4.5**), further highlighting the synthetic versatility of cyclopropylated carbohydrate intermediates.^[74]

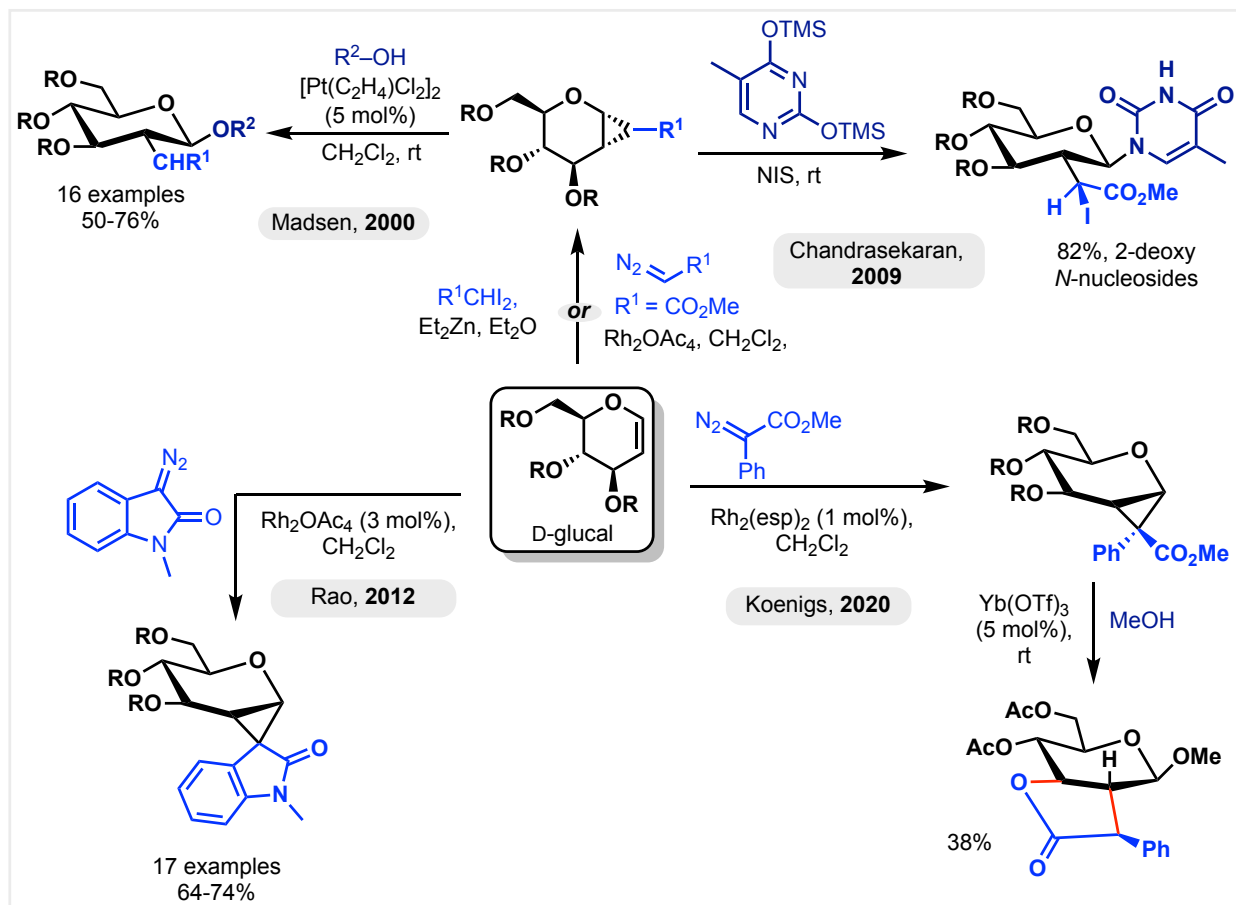


Figure 1.4.5: Cyclopropanation of D-glucal with carbenes followed by ring opening to access 2-deoxyglycosides.

Although cyclopropanation of glycals illustrates a unique aspect of carbene reactivity in carbohydrate chemistry, it generally serves as an indirect entry to glycosylation products.^[67-68,75] The cyclopropyl intermediate must undergo additional activation and ring-opening steps before glycosidic bond formation can occur.^[67,70,75] Consequently, while these strategies expand the structural diversity of carbohydrate scaffolds and enable access to 2-deoxy or spirocyclic derivatives, they do not directly address the challenges associated with selective anomeric activation and stereocontrolled glycosidic bond formation.^[34-35,73]

Carbene chemistry has also been applied to the direct functionalization of the anomeric C–H bond, offering an alternative to conventional glycosyl donor activation. In 2010, Thomas Lecourt and co-workers reported a rhodium(II)-carbene-mediated strategy to access α - and β -ketopyranosides through intramolecular C–H insertion.^[76] In their approach, a bromoacetate group was installed at the C2-O position of a protected pyranoside, serving a dual purpose: promoting stereoselective glycosylation via neighboring-group participation and, after conversion to a diazoacetate, acting as a carbene precursor. Upon treatment with catalytic $\text{Rh}_2(\text{OAc})_4$, the resulting rhodium carbene underwent highly regioselective insertion into the anomeric C–H bond to generate γ -lactone intermediates, which were subsequently transformed into ketopyranosides bearing a quaternary anomeric center (**Figure 1.4.5**). Notably, this

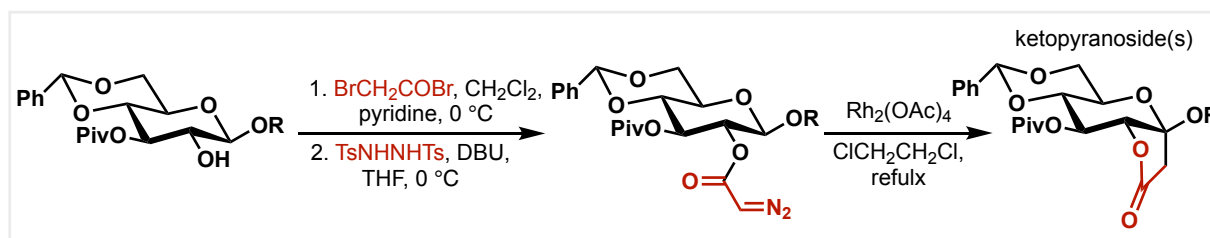


Figure 1.4.6: Rhodium carbene-mediated C–H activation to access ketopyranosides.

method allowed stereospecific access to both α - and β -anomers and was extended to more complex substrates such as disaccharides, representing a conceptually distinct strategy in which the anomeric C–C bond is constructed after glycosylation rather than before.^[53,76]

Site-selective O–H functionalization of carbohydrates has also been realized through carbene chemistry, most notably in studies from Tang and co-workers. In 2019, they demonstrated that rhodium-carbenes could undergo highly selective O–H insertion into glycosyl alcohols, with the site of insertion dictated by the anomeric configuration of

the substrate.^[77] Specifically, α -anomeric glycosyl precursors favored insertion at the C2–OH position, whereas β -anomers preferred insertion at the C3–OH position, revealing an intriguing stereochemical control element embedded within the carbohydrate framework.

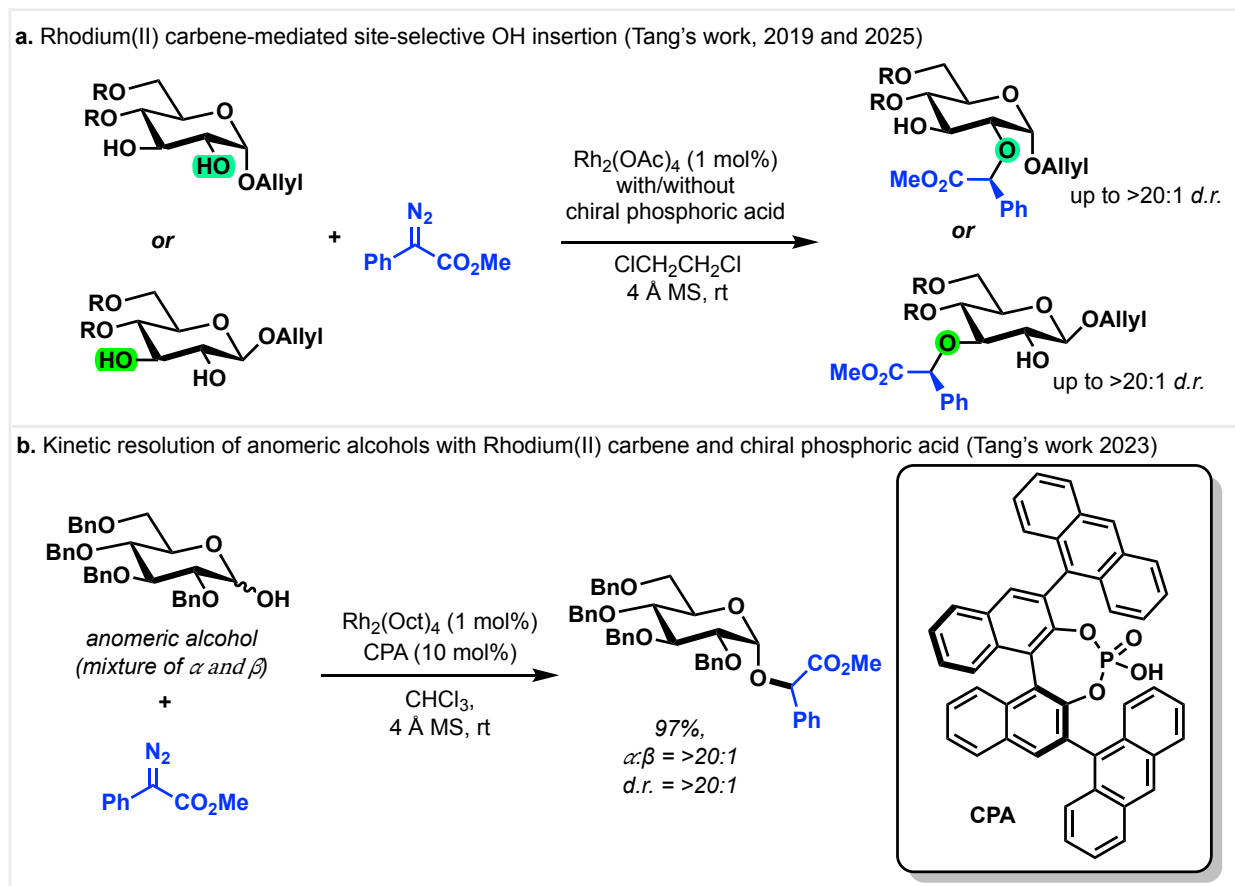


Figure 1.4.7: Application of rhodium carbene for site-selective O–H functionalization and kinetic resolution. (a) Site-selective OH insertions; (b) Kinetic resolution.

Building on this foundation, the same group later introduced chiral phosphoric acid (CPA) catalysis to refine the transformation further. The combination of Rh-carbene generation with CPA enabled diastereoselective O–H insertion, allowing deliberate control over the formation of a single diastereomeric product (**Figure 1.4.7a**).^[78] Beyond site selectivity, they also used the synergistic interplay between rhodium catalysis and chiral phosphoric acid to achieve kinetic resolution of anomERICALLY mixed glycosyl

alcohols, selectively enriching the thermodynamically more stable isomers in excellent yields (**Figure 1.4.7b**).^[79]

Collectively, these studies illustrate how carbene chemistry, when paired with appropriate catalytic design, can be harnessed not only for bond construction but also for precise stereochemical and site-selective control in carbohydrate functionalization.

1.5 Application of Nitrene in Glycosylation Reactions

Nitrene chemistry has been recognized since the mid-twentieth century; however, its application to glycosylation reactions has only recently begun to emerge. A notable advance was reported in 2024 by Xu and co-workers, who developed an iron-catalyzed nitrene-mediated strategy for 1,2-*cis* aminoglycosylation of protected glycals.^[80] In this approach, acyloxy carbamates were employed as nitrene precursors, which, under iron catalysis, generated an iron-bound nitrogen species capable of activating the glycal substrate (**Figure 1.5.1**). The method proved broadly applicable, enabling aminoglycosylation of diverse carbohydrate scaffolds, including glucose, galactose, rhamnose, and xylose derivatives, and tolerating a range of glycosyl acceptors such as primary and secondary alcohols as well as amino acid-derived alcohols. Mechanistically, the authors proposed a pathway involving an iron-associated nitrogen-centered radical intermediate. This species engages the electron-rich glycal to form a glycosyl radical, which subsequently undergoes single-electron transfer (SET) to Fe(III), generating a reduced Fe(II) species and a transient oxocarbenium ion. The coordinated iron-bound

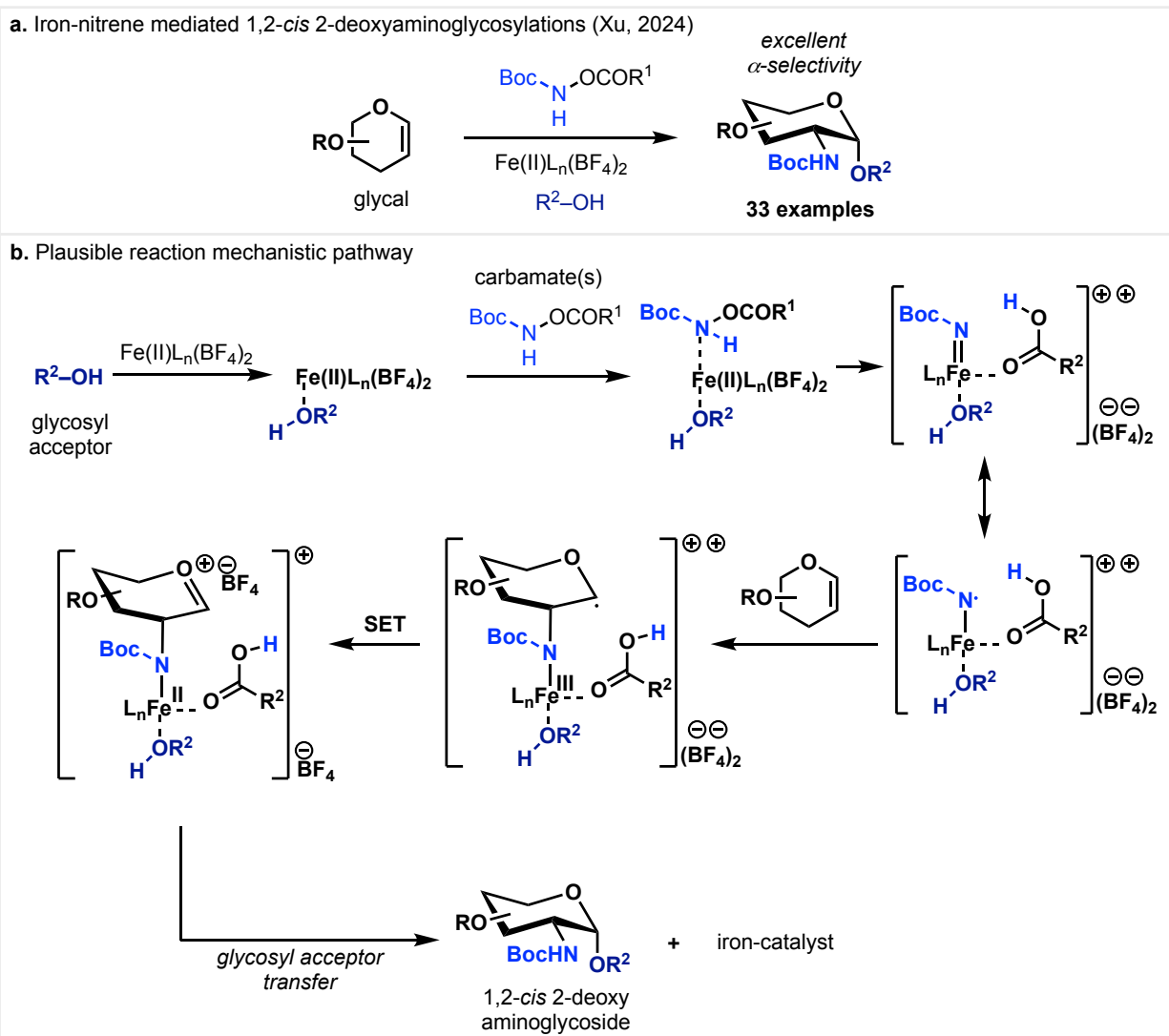


Figure 1.5.1: Application of iron-nitrene in glycosylations. (a) general scheme for iron-nitrene mediated aminoglycosylations of glycals; (b) Plausible reaction mechanistic pathway.

nitrogen then delivers the amine nucleophile to the oxocarbenium intermediate in a stereocontrolled fashion, favoring attack from the *cis* face to furnish the desired 1,2-*cis* aminoglycoside while regenerating the active iron catalyst. This work represents one of the first demonstrations of nitrene-mediated activation in carbohydrate chemistry and highlights the potential of earth-abundant iron-catalyzed stereoselective glycosylation.

Building on earlier advances in nitrene-mediated glycosylation, Chen and co-workers reported in early 2025 a significant breakthrough in the activation of conventional thioglycosides using iron- and ruthenium-based nitrene catalysis (**Figure 1.5.2a**).^[81] This development is particularly important because traditional thioglycoside activation typically requires strong Brønsted or Lewis acids, often at low temperatures.^[81] Such conditions can limit functional-group tolerance and restrict the range of compatible nucleophiles. In contrast, Chen's group introduced two complementary catalytic systems that operate

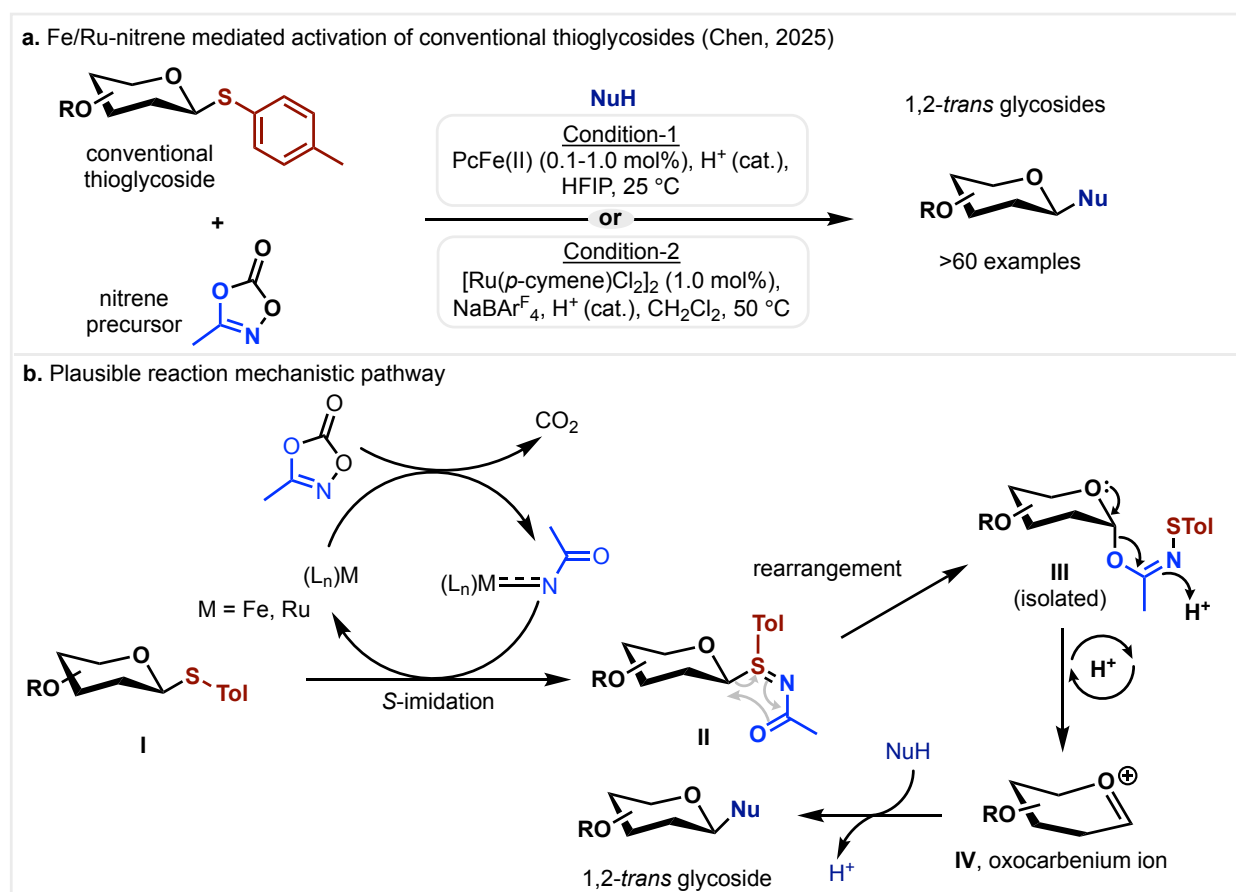


Figure 1.5.2: Iron-nitrene mediated activation of conventional thioglycosides. (a) general scheme for iron-nitrene mediated glycosylations; (b) Plausible reaction mechanistic pathway.

under milder and more practical conditions. The first system, based on iron(II) phthalocyanine (PcFe), showed broad applicability across a variety of thioglycoside donors, including glucose, fucose, galactose, arabinose, mannose, ribose, and 5-

deoxyribose derivatives. This protocol accommodated diverse nucleophiles, such as primary and secondary alcohols, carboxylic acids, and even structurally complex substrates. To further expand the scope, the authors developed a second catalytic system using $[\text{Ru}(\text{p-cymene})\text{Cl}_2]_2$, which in several cases proved more reactive than the iron catalyst. Notably, the ruthenium-based method enabled efficient coupling with *N*-nucleophiles to access *N*-nucleosides, an especially challenging class of glycosides that was inaccessible under iron catalysis. Mechanistic studies suggested that both systems operate through the generation of a metal-nitrene intermediate from 1,4,2-dioxazol-5-ones. The resulting metal nitrene undergoes S-amidation of the thioglycoside to form a sulfilimide intermediate **II**, which rearranges to an acetimidate species **III** and ultimately generates an oxocarbenium ion **IV**. This reactive intermediate is then intercepted by external nucleophiles to afford the glycosylation product (**Figure 1.5.2b**). Overall, this work introduced a fundamentally new way to activate thioglycosides, replacing classical acid-mediated approaches with a nitrene-based catalytic platform that offers broader scope and improved functional-group tolerance.

1.6 Conclusion

In summary, carbene and nitrene chemistry have gradually emerged as alternative platforms for activating glycosyl donors and stereocontrolled glycosylations. Carbene-based strategies have enabled diverse transformations, including direct and indirect anomeric activation, intramolecular C–H insertion, glycal cyclopropanation, and site-selective O–H functionalization, thereby broadening access to O-, *N*-, and C-glycosides beyond conventional acid-promoted methods. More recently, nitrene-mediated

approaches have introduced complementary activation pathways, allowing stereoselective aminoglycosylation of glycals and catalytic activation of thioglycosides under comparatively mild conditions.

1.7 Key Gaps

Despite the conceptual advances achieved through carbene- and nitrene-based glycosylation strategies, several important limitations remain unresolved.

- i. **Limitations in donor design and activation conditions:** The early carbene-based glycosyl donors developed by Vasella, including diazirines and hydrazones, represented pioneering work but suffer from practical drawbacks. Glycosyl diazirines are often unstable under ambient conditions and require multistep, demanding synthetic preparation. Hydrazone-based donors, although more stable, typically rely on ultraviolet irradiation for carbene generation, which restricts functional-group tolerance and scalability. In both cases, the substrate scope has largely been confined to relatively simple nucleophiles. Similarly, diaziridine-based systems developed more recently have primarily enabled access to aryl and phenolic glycosides, limiting their broader applicability across diverse glycosyl acceptors and donor classes.
- ii. **Restricted scope of indirect carbene activation and dependence on precious metal:** The indirect activation of conventional thioglycosides through rhodium-carbene intermediates represents an elegant mechanistic strategy; however, it remains limited in scope. Reported examples are largely confined to 1,2-*trans* pyranosylations, leaving challenging 1,2-*cis* systems underexplored. Moreover,

the reliance on rhodium, a platinum-group metal, raises concerns regarding cost, sustainability, and scalability, particularly for large-scale synthesis. These factors underscore the need for activation modes that employ earth-abundant metals or metal-free conditions while maintaining efficiency and stereocontrol.

- iii. **Underexplored furanose reactivity:** While carbene- and nitrene-based glycosylation strategies have been widely applied to pyranose systems, furanose sugars remain comparatively less studied. Given the significant biological importance of furanosides, this imbalance is noteworthy. The conformational flexibility of five-membered rings makes stereocontrol, particularly for 1,2-*cis* furanosylation, more challenging and less predictable. Consequently, there is a clear need for activation strategies specifically tailored to achieve reliable and stereoselective furanosylation under mild and general conditions.

1.8 Objectives of this Thesis

- i. **Development of glycosyl donors along with their activation with Earth-abundant metals or metal-free photochemical conditions:** The first objective of this thesis is to design and develop glycosyl donors incorporating intramolecular carbene precursors that can be activated under environmentally benign conditions. Specifically, these donors will be evaluated under (1) catalysis with earth-abundant metals, particularly iron, and (2) transition metal-free, photosensitizer-free visible light activation. The goal is to establish activation modes that operate under mild and practical conditions while maintaining broad substrate compatibility. These systems will be examined across both pyranose and furanose sugars and

assessed with a variety of protecting group patterns, including superdisarming, disarming, arming, and superarming donors. Ultimately, these donors will be used to construct structurally complex oligosaccharides to evaluate their synthetic utility.

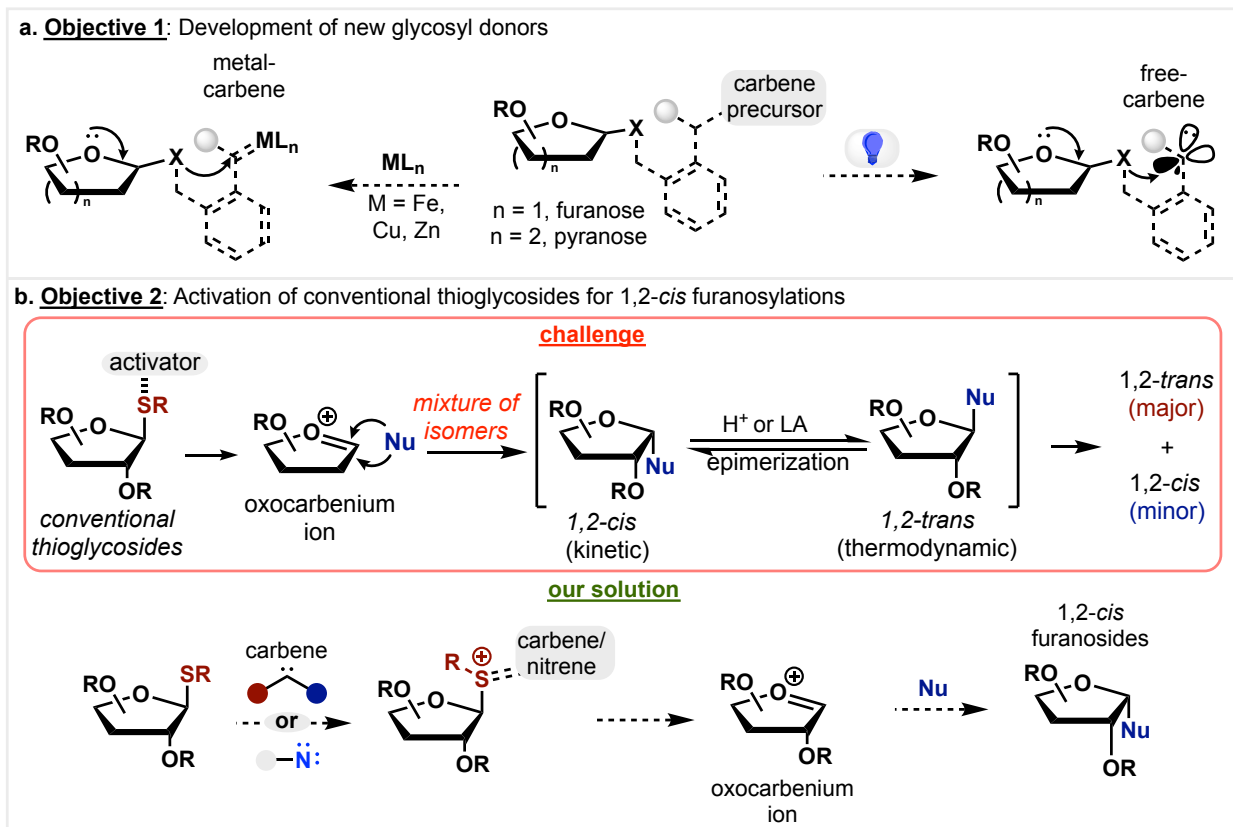


Figure 1.8: Objectives of this thesis. (a) Development of new glycosyl donors; (b) Activation of conventional thioglycosides for 1,2-*cis* furanosylations.

ii. Activation of conventional thioglycosides under mild, epimerization conditions, especially to access 1,2-*cis* furanosides: The second objective focuses on developing activation methods for conventional thioglycosides under mild conditions that minimize epimerization, particularly for the synthesis of 1,2-*cis* furanosides. Thioglycosides are among the most stable and versatile glycosyl donors; however, their activation typically requires strong acidic promoters and low temperatures. Such conditions can reduce functional-group tolerance and often

favor the formation of thermodynamically stable 1,2-*trans* products. This issue is especially pronounced in furanosides, where the anomeric center is more prone to epimerization due to the conformational flexibility of the oxocarbenium ion of the five-membered ring. Although several elegant donor designs have been reported to access 1,2-*cis* furanosides, these methods often rely on complex precursor synthesis or expensive metal catalysts. Therefore, this thesis aims to explore alternative activation strategies based on iron-carbene chemistry and chemoselective sulfonylnitrene-mediated activation, enabling reliable access to 1,2-*cis* furanosides from readily available thioglycoside donors under mild, sustainable conditions.

1.9 Outline of this Thesis:

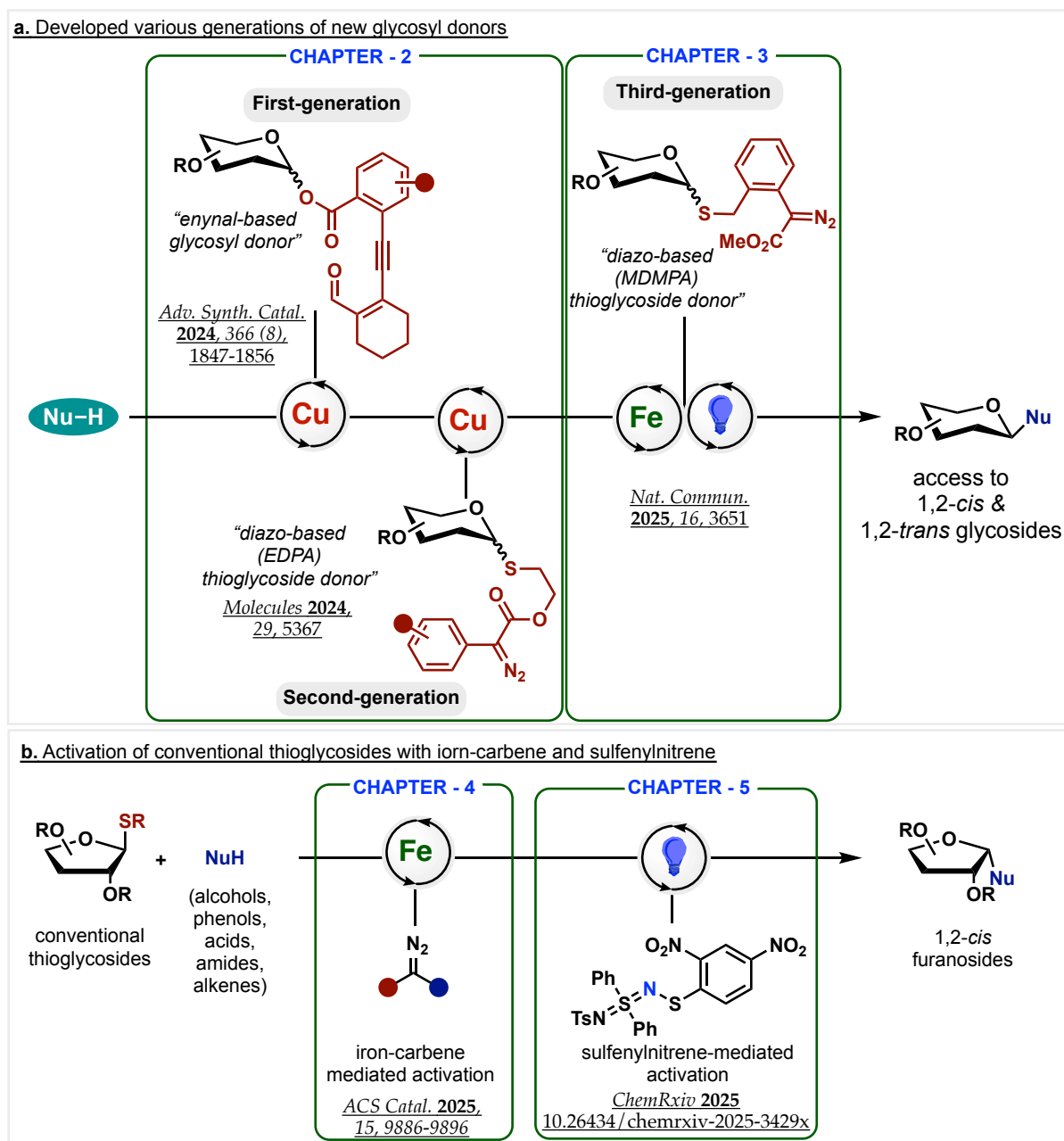


Figure 1.9: Outline of this thesis.

In alignment with the objectives outlined above, this dissertation describes the development of new glycosyl donor systems and activation strategies that address key limitations in carbene- and nitrene-mediated glycosylation chemistry.

In the first part of this work (**Figure 1.9a**), three generations of glycosyl donors were developed. The first generation consisted of enynal-based glycosyl donors designed to enable carbene generation under catalytic conditions. This was followed by second-generation diazo-based thioglycoside donors incorporating EDPA scaffolds. Both systems were primarily activated using copper (I) catalysis. Building on these findings, a third generation of diazo-based thioglycoside donors incorporating MDMPA scaffolds was developed. These donors demonstrated efficient activation under iron catalysis and, importantly, also under complementary visible-light-mediated conditions without the need for additional photosensitizers. The third-generation system proved particularly effective in enabling iterative and one-pot oligosaccharide synthesis, highlighting its practical utility.

Following the successful development of these donor platforms, the second part of this thesis focused on the activation of conventional thioglycosides under mild conditions, with particular emphasis on accessing 1,2-*cis* furanosides (**Figure 1.9b**). An iron-carbene-mediated activation strategy was developed, where mechanistic studies suggested coordination of the C2-oxygen to the iron center, facilitating preferential delivery of nucleophiles from the *cis* face. In addition, a highly chemoselective sulfenylnitrene-mediated activation method was established by leveraging a previously developed visible-light-induced sulfenylnitrene generation strategy. This approach enabled selective activation of glycosyl thioethers and revealed a distinct sulfenylnitrene–glycosyl thioether interaction. The method demonstrated compatibility with a broad range of nucleophiles, including alcohols, phenols, amides, and carbon nucleophiles.

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CHAPTER 2

Catalytic Copper-Carbene Mediated Stereocontrolled Glycosylations

2.1. Introduction

As discussed in Chapter 1, carbenes are versatile reactive intermediates that have enabled numerous transformations across synthetic organic chemistry.^[1-7] A variety of precursors are known to generate carbenes, including hydrazones, triazoles, sulfonium ylides, diazo compounds, and enynals/enynones.^[1-7] Among these, diazo compounds are the most widely used carbene precursors due to their reliability and compatibility with both precious metals and earth-abundant metals (EAMs) such as iron, copper, and zinc. Upon metal coordination, diazo compounds readily extrude dinitrogen to generate metal-carbene species.^[8]

In the context of developing activation strategies based on earth-abundant metals, we also considered alternative carbene precursors. Enynals and enynones attracted our attention because of their unique reactivity with EAMs (**Figure 2.1.1a**).^[9-11] Similar to diazo

compounds, enynals undergo metal-promoted 5-exo-dig cyclization to form a furyl-type intermediate, which subsequently generates a metal carbene species (**Figure 2.1.1b**). Depending on the activation mode, such carbenes can participate in cyclopropanation,^[12-16] heteroatom insertion,^[17-20] C–H functionalization,^[21-24] rearrangements,^[25-26] and cycloaddition reactions.^[27] Transition-metal carbene complexes have also found applications in polymerization^[28-30] and olefin metathesis^[31-34] and even in biomolecular labeling.^[35-40] Despite this broad utility, metal–carbenes remain comparatively underexplored in carbohydrate chemistry.^[41-53]

Early examples from the Vasella group demonstrated that anomeric carbenes^[41]

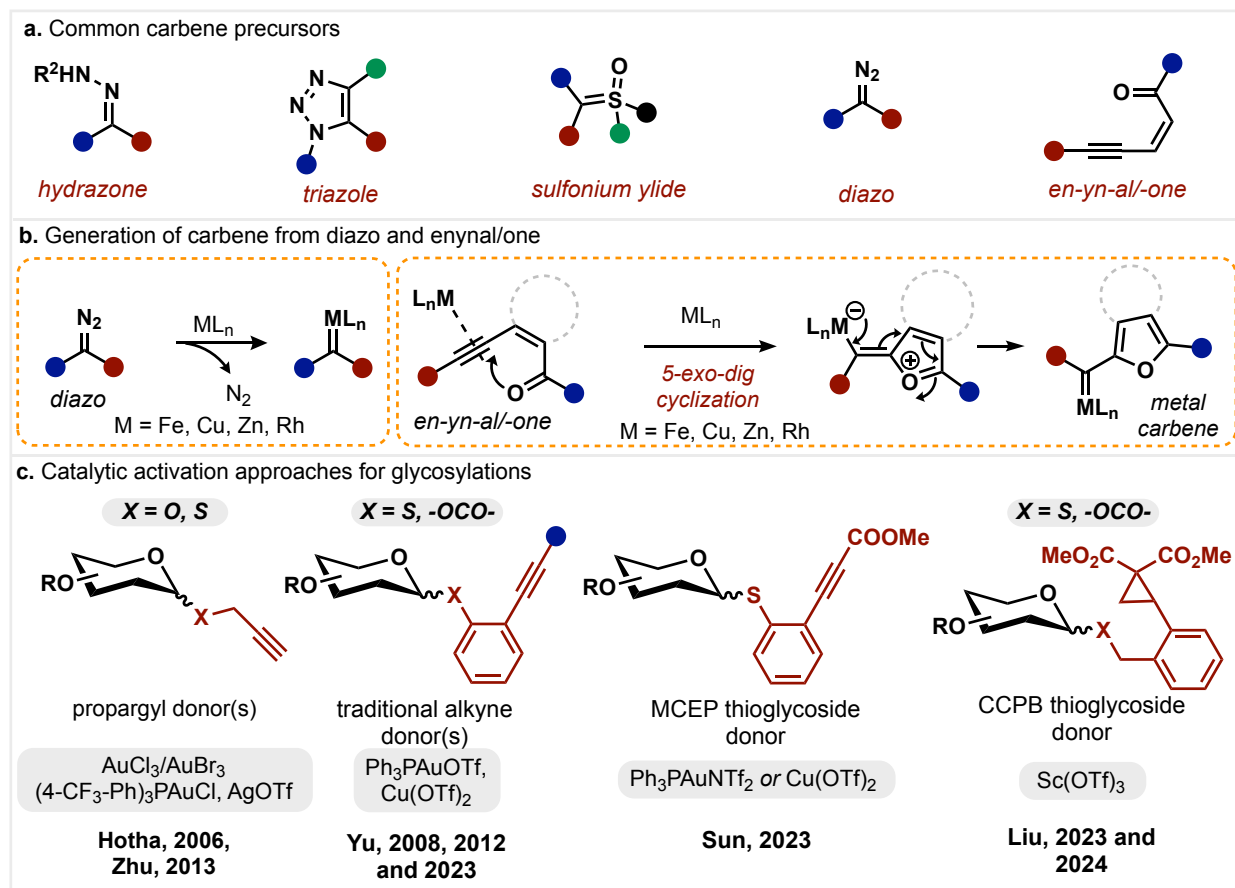


Figure 2.1.1: (a) Most common carbene precursors; (b) Generation of metal-carbene from diazo and enynal/enynones; (c) Most common catalytic glycosylation approaches.

could be generated from diazirines or N-tosylhydrazones to afford glycosides via O–H insertion (**Figure 1.4.1** and **1.4.2**). While conceptually important, these methods required excess nucleophiles and harsh photochemical conditions.^[41-53] More recently, indirect activation of thioglycosides using rhodium carbenes was reported, proceeding through sulfonium ylide intermediates that ultimately formed oxocarbenium ions (**Figure 1.4.4**).^[53] Although mechanistically elegant, this strategy relied on precious metal catalysis and did not fully resolve issues related to sustainability and orthogonality in glycosyl donor activation.

Since the seminal work of Koenigs and Knorr in 1901^[54], chemical glycosylation has progressed through successive donor classes and activation paradigms. The development of trichloroacetimidate donors by Schmidt,^[55] the widespread use of thioglycosides,^[56-57] glycosyl sulfoxides,^[58] and glycosyl fluorides,^[59] and the introduction of latent donor concepts such as *n*-pentenyl glycosides have significantly expanded synthetic flexibility.^[60] Nevertheless, many of these methods depend on stoichiometric promoters, strong acids, moisture-sensitive reagents, or low temperatures, which can limit functional-group tolerance and scalability.

To address these challenges, catalytic glycosylation strategies have emerged. Notable contributions include palladium-catalyzed coupling of anomeric stannates,^[61-62] bis-thiourea catalysis,^[63] phosphoric acid catalysis,^[64-65] activation of anomeric fluorides using B(C₆F₅)₃,^[66] and Bi(OTf)₃^[67]- or phenanthroline-mediated^[68] activation of anomeric halides. Among catalytic approaches, alkyne-based glycosyl donors have been extensively studied.^{[69-79],[80-81],[82]} First introduced by Hotha^[70] and further developed by Yu^[73] and others, these donors, often connected through ester or thioether linkages, are

typically activated using gold catalysts (**Figure 2.1.1c**).^{[69-79],[80-81],[82]} Subsequent modifications, including electron-withdrawing^[83] substituents and cyclopropyl-based^[84-85] systems, have broadened their applicability. However, many of these elegant designs rely on precious or platinum-group metals, raising concerns regarding cost and sustainability.

Considering these considerations, we sought to develop glycosyl donors that could be activated using earth-abundant metals, thereby avoiding reliance on precious metal catalysts. Guided by literature precedents and retrosynthetic analysis, we identified two promising carbene precursors suitable for incorporation into glycosyl donors: (1) an enynal group, which can be linked to carbohydrates through ester functionalities, and (2) diazo groups, which can be introduced via thioether linkages using established thioglycoside frameworks.

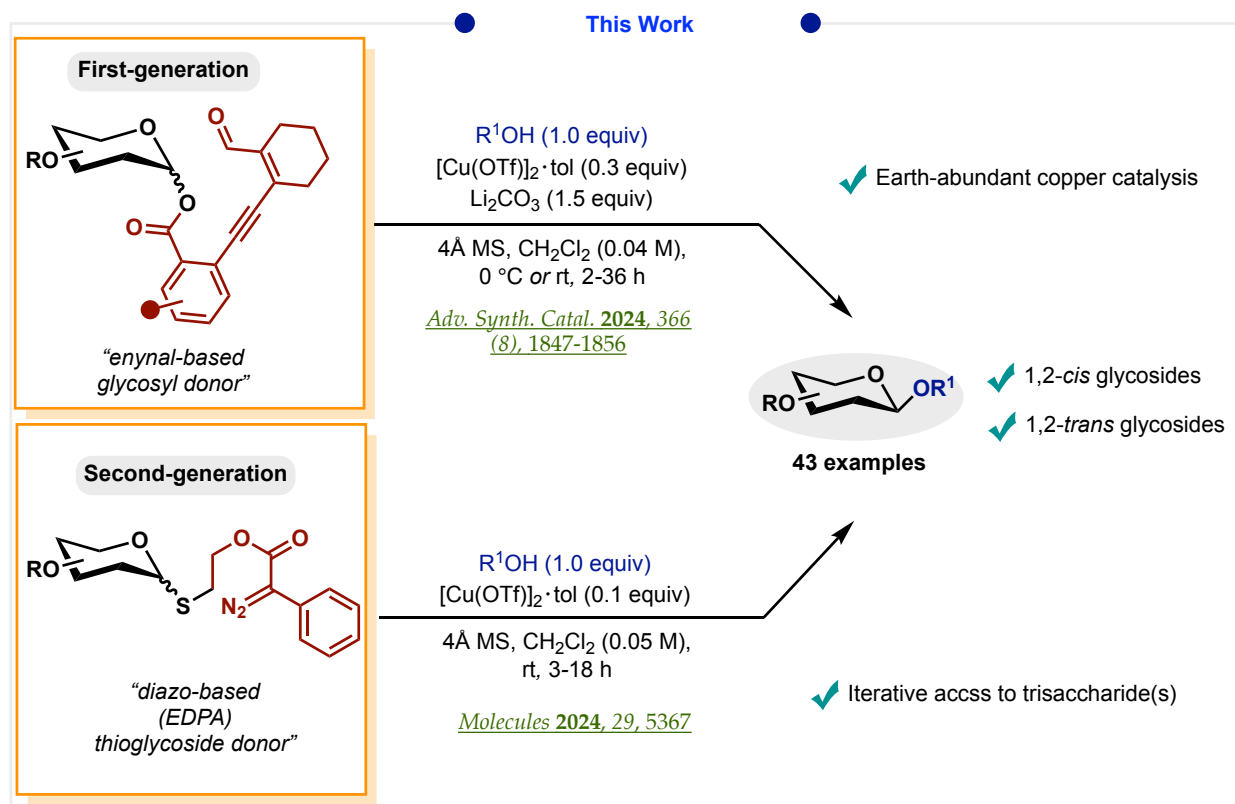


Figure 2.1.2: Present Work.

In this chapter, we report the development of two new glycosyl donors: 1) an enynal-based glycosyl donor (*first-generation*) and 2) diazo-based (EDPA) thioglycoside donors (**Figure 2.1.2**). Both donors were synthesized in a very straightforward manner and in high yields, along with various carbohydrate derivatives, including D-mannose, D-glucose, and 2-deoxy D-glucose. $[\text{Cu}(\text{OTf})]_2 \cdot \text{tol}$ was found as the optimum metal catalyst for the activation of both classes of donors. Upon activation, various nucleophiles were glycosylated, including primary, secondary, and tertiary alcohols, phenols, and carboxylic acids. Mechanistic studies revealed that the enynal functionality was a key feature of the first-generation donors. Whereas the substitution at the aryl ring in the second-generation donors indicated that the electron-donating or electron-withdrawing functional groups did not affect the reactivity. In the end, both glycosyl donors were effective for the iterative construction of trisaccharides.

2.2. Results and Discussions

2.2.1 Development of Glycosyl Donor(s)

2.2.1.1 Synthesis of enynal-based glycosyl (first-generation) donors

We initiated our work by synthesizing the first-generation glycosyl donors **2.4**. The synthesis of straightforward and begin by the coupling of easily accessible glycosyl alcohol **2.1** with 2-iodobenzoic acid, and produces pre-donor **2.2**. Then the pre-donor was coupled with enynal precursor **2.3** by using Sonogashira coupling to afford first-generation donor **2.4** (**Figure 2.2.1.1**). Specifically, a variety of carbohydrates, along with protecting groups, were used. More specifically, arming protecting groups like 4,6-O-benzylidene-D-mannose, 2,3,4,6-tetra-O-benzyl-D-mannose, -glucose, and -galactose, and 2-deoxy-

D-glucose were synthesized. Superarming protecting groups, such as 2-O-acetyl-3,4,6-tri-O-benzyl--D-mannose and D-glucose, were also synthesized.

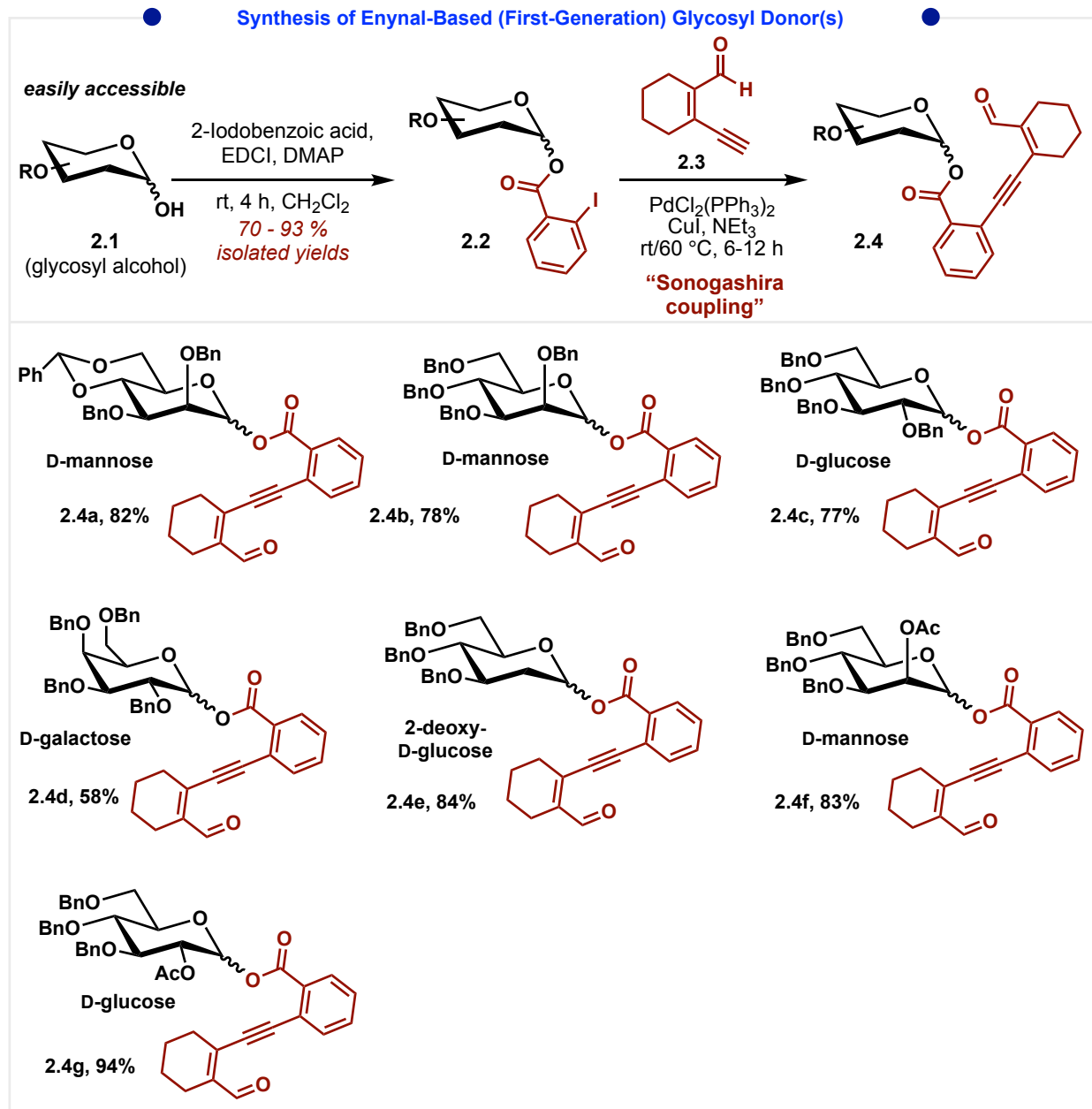


Figure 2.2.1.1: Synthesis of enynal-based (first-generation) glycosyl donors.

2.2.1.2 Synthesis of diazo-based (EDPA) thioglycoside (second-generation) donors

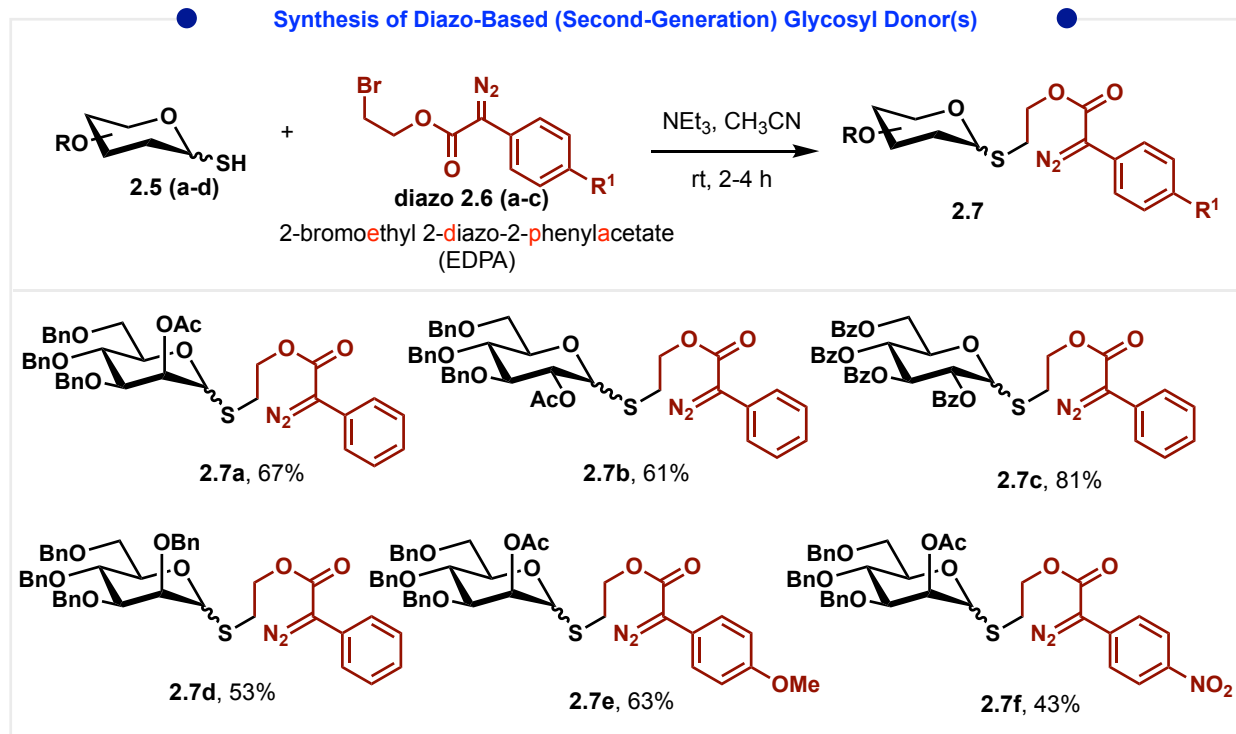


Figure 2.2.1.2: Synthesis of diazo-based (second-generation) glycosyl donors.

After successfully synthesizing the first-generation donors, we synthesized a diazo-based thioglycoside donor. To access these donors, we coupled benzylated/benzoylated glycosyl thiols, which were used without purification. The crude thiols were coupled with 2-bromomethyl 2-diazo-2-phenylacetate (EDPA) linker using triethylamine as a base and acetonitrile as a solvent (**Figure 2.2.1.2**). These donors were yellow solid and benchtop stable, showcasing the ease of practical utility. Using the same strategy, we synthesized both superarmed (2-O-Ac-3,4,6-tri-O-Bn) and disarmed (perbenzoylated) protecting groups with different classes of carbohydrates (glucose, mannose). Overall, synthesizing second-generation donors was simple and could be applied to various sugars.

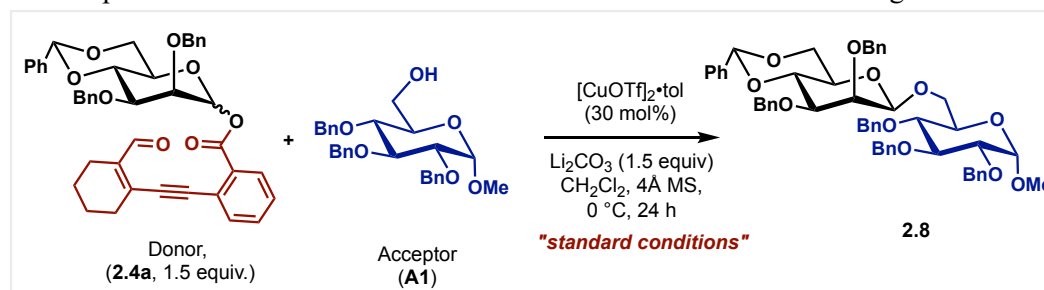
2.2.2 Optimization of Reaction Conditions

2.2.2.1 Optimization of the activation of first-generation glycosyl donors

We initiated our optimization study with the 4,6-O-benzylidene-2,3-di-O-benzyl-D-mannopyranosyl donor **2.4a** to showcase the compatibility of the acid-sensitive acetal moiety under our reaction conditions. Another factor for selecting the donor was the absence of any example in the previously established carbene-based glycosylation.^[53] Additionally, the impact of the 4,6-benzylidene locking group is known to enhance the β -1,2-*cis*-selectivity, as previously shown by Sharma and Crich.^[86-89] The methyl-tri-O-benzyl- α -D-glucopyranoside **A1** was selected as the acceptor to optimize the reaction conditions so that the resulting product can undergo global deprotection (Pd/C + H₂) to provide the unprotected disaccharide.^[90-91] We focused on identifying the optimal components among earth-abundant metal catalysts, acid scavengers, and solvents (**Table 2.2.2.1**). Through our studies, we determined that the highest yield (90%) and desired 1,2-*cis*-diastereoselectivity ($\alpha:\beta = 1:8$) could be achieved using 30 mol% Cu(I)OTf as the catalyst, lithium carbonate (1.5 equiv.) as the acid scavenger, CH₂Cl₂ as the solvent at 0 °C with 4Å molecular sieves in 24 h. Through our observations, we found that employing 1.5 equiv. The reaction of the donor resulted in the desired glycoside with excellent yield. A higher amount of the donor is attributed to a slight decomposition, leading to an unproductive pathway.

Next, the effect of different copper(I) counteranions was examined. Notably, the triflate counteranion was superior to the corresponding iodide, hexafluorophosphate, and tetrafluoroborate (entries 2–4). Following that, we examine the potential catalytic capability of copper(II) carbonate; nevertheless, no reaction was observed after 24 h (entry 5). Next, we aimed to explore the ideal temperature for the reaction. It was noted

Table 2.2.2.1. Optimization of the reaction conditions for the activation of the first-generation donor.^[a]



Entry	Deviations from standard conditions	Yield ^[b]	2.8, $\alpha:\beta$ ^[c]
1.	none	90%	1:8
2.	CuI as a catalyst	n.r.	n.d.
3.	Cu(CH ₃ CN) ₄]PF ₆ as a catalyst	51%	1:1.2
4.	Cu(CH ₃ CN) ₄]BF ₄ as a catalyst	20%	1:1.1
5.	CuCO ₃ as a catalyst, no Li ₂ CO ₃	n.r.	n.d.
6.	−20 °C instead of 0 °C	n.r.	n.d.
7.	−10 °C instead of 0 °C	20%	1:8
8.	rt instead of 0 °C	81%	1:5
9.	no Li ₂ CO ₃ , TfOH instead of [Cu(OTf) ₂] $\cdot$ tol	n.r.	n.d.
10.	No Li ₂ CO ₃	65%	1:4
11.	TTBP, instead of Li ₂ CO ₃	80%	1:4
12.	THF or ACN as solvents	n.r.	n.d.
13.	toluene or CH ₂ Cl ₂ /heptane as solvent	45%	1:4
14.	FeCl ₃ , instead of [Cu(OTf) ₂] $\cdot$ tol	<10%	1:2
15.	ZnCl ₂ instead of [Cu(OTf) ₂] $\cdot$ tol	18%	1:2
16.	Zn(OTf) ₂ , instead of [Cu(OTf) ₂] $\cdot$ tol	<10%	1:2
17.	Rh ₂ (OAc) ₄ instead of [Cu(OTf) ₂] $\cdot$ tol	n.r.	n.d.
18.	no [Cu(OTf) ₂] $\cdot$ tol, Li ₂ CO ₃ only	n.r.	n.d.

^[a] Reaction conditions: **2.4a** (0.075 mmol), **A1** (0.05 mmol), catalyst (30 mol%), additive (1.5 equiv.), solvent (0.04 M), 0° C – rt, 24 h. ^[b] Yield was determined by ¹H NMR using 1,3,5-trimethoxybenzene as the internal standard. ^[c] Diastereoselectivity was determined by analyzing ¹H NMR of crude sample; n.r. = no reaction; n.d. = not determined

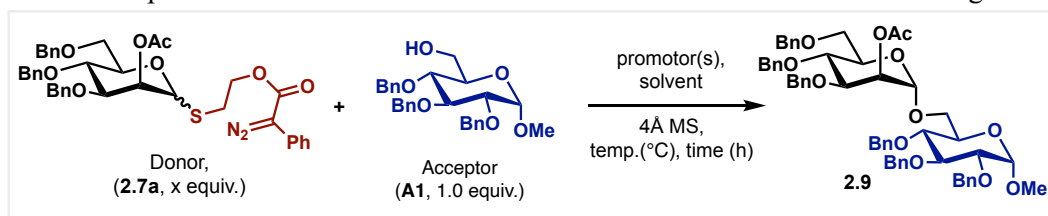
that at a lower temperature of −20 °C, the reaction did not occur. Upon raising the temperature to −10°C, the reaction proceeded at a slower rate, resulting in a reduced yield. However, the selectivity remained comparable to that of the original reaction. (entries 6, 7). Elevating the reaction temperature to room temperature resulted in a diminished yield and selectivity (entry 8). From here, we decided to perform control experiments on the necessity of each additive. As metal triflates can act as a mild source

of triflic acid (TfOH),^[92-94] the possibility of triflic acid as a catalyst was probed. With TfOH, we witnessed the complete decomposition of the donor without any desired glycoside (entry 9). A reaction without lithium carbonate decreased the yield and selectivity, highlighting the importance of an acid scavenger (entry 10). 2,4,6-tri-*tert*-butylpyrimidine (TTBP) as an alternative acid scavenger also worked, albeit in lower yield and selectivity (entry 11). Lewis basic solvents like tetrahydrofuran (THF) and acetonitrile (ACN) did not produce any reaction, likely due to solvent coordination with the copper catalyst (entry 12). Likewise, when the reaction solvent was switched to toluene or CH₂Cl₂/heptane (v/v = 1:1), as described by the Zhang group, the yield and α -selectivities were diminished (entry 13). Other catalysts known to activate the enynal systems in the literature, such as iron (III) chloride, zinc (II) chloride, zinc (II) triflate, and rhodium (II) acetate, decreased the product yield and anomeric selectivity (entries 14–17). Finally, no reaction was observed without a copper catalyst, highlighting its importance (entry 18).

2.2.2.2 Optimization of the activation of second-generation glycosyl donors

In our efforts for the optimization of the reaction conditions for the second-generation glycosyl donor, we chose 2-O-Ac-3,4,6-tri-O-Bn mannose (superarmed) EDPA thioglycoside **2.7a** as our model donor and methyl 6-OH, 2,3,4-tri-O-Bn-glucopyranoside **A1** as the model glycosyl acceptor (**Table 2.2.2.2**). In our first attempt, Cu(I)OTf was used as a catalyst, and 2-ethyl 2-diazo-2-phenylacetate thioglycoside (EDPAT) donor **2.7a** was coupled with glycosyl acceptor using CH₂Cl₂ as a solvent. To our delight, after 5 hours, both the starting materials were consumed, and the desired product was observed in 68% yield (entry 1). After a well-crafted initial success, we turned our attention to screening other metal-catalysts. In continuation of that, we screened

Table 2.2.2.2. Optimization of the reaction conditions for the activation of the second-generation donor.^[a]



entry	promoter(s)	(2.7a, x)	solvent(s)	time	temp.	2.9 (% yield) ^[b]
1.	[Cu(OTf)] ₂ •tol (30 mol%)	1.2	CH ₂ Cl ₂	5 h	rt	68% ^c
2.	Fe(BF ₄) ₂ •6H ₂ O (30 mol%)	1.2	CH ₂ Cl ₂	20 h	rt	<10%
3.	ZnCl ₂ (30 mol%)	1.2	CH ₂ Cl ₂	6 h	rt	trace
4.	Zn(OTf) ₂ (30 mol%)	1.2	CH ₂ Cl ₂	72 h	rt	n.r.
5.	Rh ₂ (OAc) ₄ (30 mol%)	1.2	CH ₂ Cl ₂	2 h	rt	<10%
6.	[Cu(CH ₃ CN) ₄]PF ₆ (30 mol%)	1.2	CH ₂ Cl ₂	2 h	rt	40%
7.	[Cu(CH ₃ CN) ₄]BF ₄ (30 mol%)	1.2	CH ₂ Cl ₂	72 h	rt	35%
8.	CuI (30 mol%)	1.2	CH ₂ Cl ₂	24 h	rt	n.r.
9.	Cu(OTf) ₂ (30 mol%)	1.2	CH ₂ Cl ₂	5 h	rt	61%
10.	TfOH (100 mol%)	1.2	CH ₂ Cl ₂	24 h	rt	n.r.
11.	[Cu(OTf)] ₂ •tol (30 mol%)	1.2	CH ₂ Cl ₂	24 h	0 °C	70%
12.	[Cu(OTf)] ₂ •tol (30 mol%)	1.5	CH ₂ Cl ₂	24 h	0 °C	74%
13.	[Cu(OTf)] ₂ •tol (30 mol%)	1.5	CH ₂ Cl ₂	5 h	rt	75%
14.	[Cu(OTf)] ₂ •tol (10 mol%)	1.5	CH ₂ Cl ₂	7 h	rt	75%
15.	[Cu(OTf)]₂•tol (10 mol%)	1.5	CH₂Cl₂	6 h	rt	88%^[c]
16.	Cu(OTf) ₂ (10 mol%)	1.5	CH ₂ Cl ₂	5 h	rt	77% ^c
17.	[Cu(OTf)] ₂ •tol (10 mol%)	1.2	CH ₃ CN	6 h	rt	28% ^c
18.	[Cu(OTf)] ₂ •tol (10 mol%)	1.2	THF	6 h	rt	<10%
19.	[Cu(OTf)] ₂ •tol (10 mol%)	1.2	Toluene	8 h	rt	56%
20.	[Cu(OTf)] ₂ •tol (10 mol%)	1.2	EtOAc	8 h	rt	<10%
21.	-	1.2	CH ₂ Cl ₂	24 h	rt	n.r.

^[a]Reactions were conducted with an acceptor (0.025 mmol), donor (0.030 – 0.0375 mmol), promoters (0.0025–0.0075 mmol, 10-30 mol%), 4Å molecular sieves (100 wt %), and CH₂Cl₂ (0.05 M). ^[b]% Yield was determined by ¹H NMR of crude sample by using 1,3,5-trimethoxybenzene as the internal standard. ^[c]isolated yields; n.r. = no reaction

Fe(BF₄)₂•6H₂O (entry 2), ZnCl₂ (entry 3), Zn(OTf)₂ (entry 4), and Rh₂OAc₄ (entry 5). None of these catalysts produced the desired disaccharide in significant amounts. These screenings indicated that copper, along with the triflate counter anion, is the best metal to provide a good yield of the desired product. To probe the role of counter-anion, we tested other counter-anions, such as PF₆ (entry 6), BF₄ (entry 7), and I (entry 8), still the triflate anion was the most optimum, further showcasing the importance of OTf in

carbohydrate chemistry.^[57] Our studies also found that the Cu(OTf)₂ was equally efficient in catalyzing the reaction (entry 9). Apart from the metal catalysts, we also screened the strong Brønsted acids (TfOH), known to decompose donor-acceptor diazo. Diazo remains unreacted, and TfOH got quenched by molecular sieves (entry 10), indicating no potential TfOH was generated *in situ* from metal triflates responsible for the transformation. The reaction was performed at 0 °C, which further led to a slight increase in yield but with a prolonged reaction time (entry 11). Increasing the amount of donor to 1.5 equivalents produces slightly higher yields (entry 12), while performing the reaction at room temperature produces a similar yield but with less reaction time (entry 13). We further reduced the catalyst loading (10 mol%), resulting in the exact yield as the desired product (entry 14). We further attempted to increase the yield and charged donors in portions. Adding donors in portions led to a significant increase in the product (entry 15). The portion-wise addition with Cu(OTf)₂ also led to a considerable increment in the product yield (entry 16). We also screened various solvents, such as CH₃CN (entry 17), THF (entry 18), toluene (entry 19), and EtOAc (entry 20). Toluene provided better yields from these solvents, but CH₂Cl₂ was still the most optimum solvent. In the end, we performed a reaction without the catalyst to further probe the role of the copper catalyst, leading to no decomposition of the donor.

Overall, we optimized reaction conditions for the activation of both donors. For the first-generation donor, the optimum conditions were donor **2.4a** (1.5 equiv.), acceptor (1.0 equiv.), Li₂CO₃ (1.5 equiv.), Cu(I)OTf (30 mol%) and CH₂Cl₂ (0.04 M). And for the second-generation donor, the best conditions were donor **2.7a** (1.5 equiv.), acceptor (1.0 equiv.),

Cu(I)OTf (10 mol%) and CH₂Cl₂ (0.05 M). More specifically, in both conditions, the portion-wise addition of the donor was the most suitable condition for the best results.

2.2.3 Substrate Scope Studies

With the optimized conditions for the first-generation donor, we investigated the substrate scope of varying alcohol acceptors with 4,6-O-benzylidene-2,3-di-O-benzyl-D-mannopyranosyl donor **2.4a** (Figure 2.2.3.1). We started with simple glycosyl acceptors, and isopropyl alcohol (**A2**) was coupled smoothly to produce the desired mannoside **2.10** efficiently. Other secondary and complex alcohols, such as cyclohexanol (**A3**), cholesterol (**A4**), and menthol (**A5**), proceeded smoothly to afford the corresponding products in excellent yield and 1,2-*cis*-selectivity (**2.11–2.13**). Electron-rich, 4-methoxyphenol (**A6**) was glycosylated with excellent yield and high *cis*-selectivity (**2.14**). Bulky tertiary alcohol acceptors like 1-adamantanol (**A7**) also provided good *cis*-selectivity (**2.15**). Various carbohydrate alcohol acceptors bearing different protecting groups were then screened. Likewise, acetonide-protected galactopyranoside acceptors (**A8**), benzyl-protected mannopyranoside acceptors (**A9**), and acetyl/benzoyl-protected glucopyranoside acceptors (**A10** and **A11**) provided the intended products in high yields, preferring 1,2-*cis*-selectivity (**2.16–2.19**). Notably, reaction yields, and selectivity were independent of protecting group influence for benzyl-, benzoyl-, and acetyl-protected glycosyl acceptors. We evaluated the catalytic glycosylation reaction with an amino acid alcohol acceptor (**A12**), affording the coupling product in good yield and *cis*-selectivity (**2.20**).

We then investigated other donors, such as tetra benzyl-protected mannopyranosyl (**2.4b**), glucopyranosyl (**2.4c**), galactopyranosyl (**2.4d**), and 2-deoxy glucopyranosyl donors (**2.4e**), lacking the 4,6-O-benzylidene protection. Glycosylation reactions of these synthesized donors with different alcohol acceptors proceeded in good

yields: however, no selectivity was observed (**2.21–2.29**).

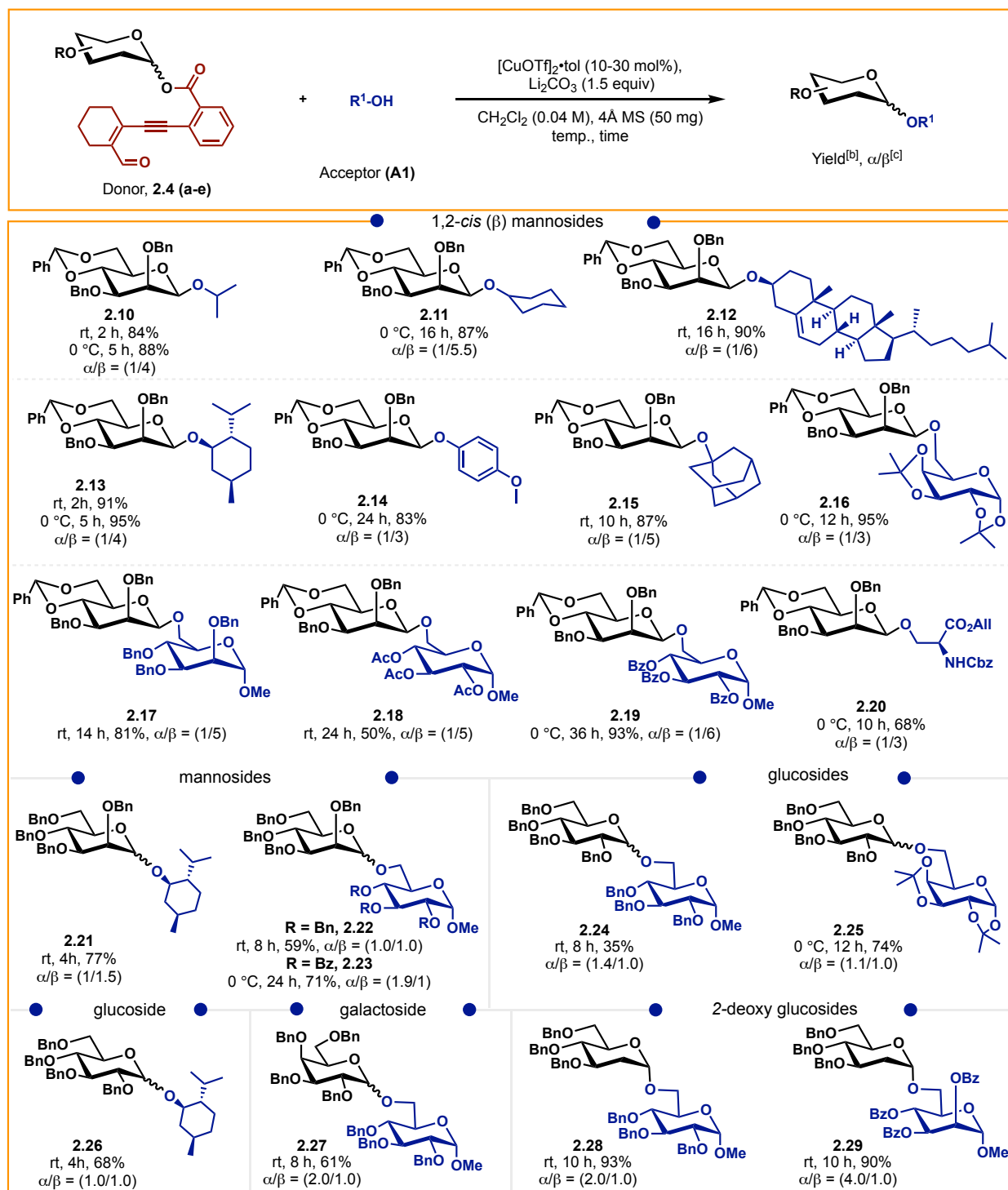


Figure 2.2.3.1: Substrate scope of 1,2-*cis* glycosylations with first-generation glycosyl donor(s).

Upon successful substrate scope exploration for 1,2-*cis* glycosylations, we identified two complementary methods using first- and second-generation donors to access 1,2-*trans* glycosides. Then the reaction conditions with superarmed donors **2.4f** and **2.7a**, we sought to broaden the scope of glycosyl donors and acceptors. We initially explored a range of primary glycosyl acceptors, including benzoyl-protected gluco- (**A11**) and mannopyranosides (**A13**) and benzyl mannopyranoside (**A9**), coupling them with donors **2.4f** and **2.7a**. These acceptors provided excellent yields of the desired disaccharides (**2.30–2.32**). Next, we tested a 2°-glycosyl acceptor (**A14**), which also delivered a good yield of disaccharide **2.33**, although requiring a longer reaction time for completion. With these successful glycosyl acceptor screenings, we turned our attention to other nucleophiles. As a nucleophile, we also tested non-glycosyl secondary alcohol (*l*-menthol, **A5**) and tertiary alcohol (1-adamantanol, **A7**), both of which produced the desired products (**2.34** and **2.35**) in excellent yields, and the coupling with 4-methoxyphenol (**A6**) gave a good yield of the desired product **2.36**. Furthermore, we demonstrated the tolerance of donor **2.7a** by glycosylating the bioactive molecule cholesterol **2.37**, again achieving excellent yields. The success of mannosyl superarmed donors **2.4f** and **2.7a** with a broad range of O-nucleophiles motivated us to investigate other glycosyl donors. We next screened glucosyl donors **2.4g** and **2.7b** with various glycosyl acceptors, including benzyl-protected glucose (**A1**) and mannose (**A9**), benzoyl-protected glucose (**A11**), and acetonide-protected galactose (**A8**). All these acceptors reacted well with donors **2.4f** and **2.7a**, yielding the desired disaccharides (**2.39–2.41**) in excellent yields. Similarly, 2°, and 3°-nucleophiles such as chiral menthol (**A5**), bioactive cholesterol (**A4**), and adamantanol (**A7**) provided the expected products (**2.42–2.44**) with

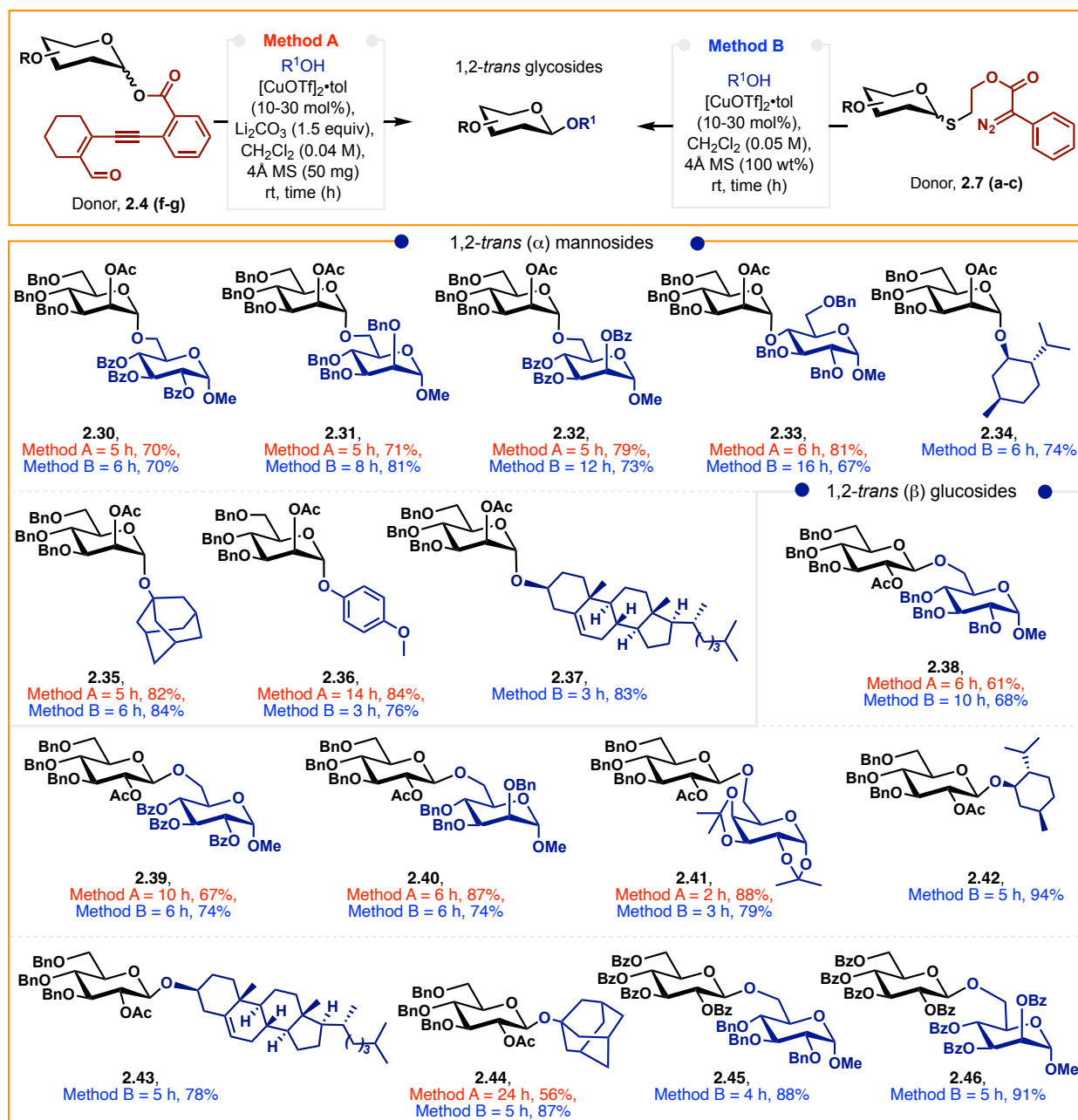


Figure 2.2.3.2: Substrate scope of 1,2-*trans* glycosylations with first- and second-generation glycosyl donor(s).

good yields. After successfully testing the superarmed donors **2.4 (f, g)** and **2.7 (a, b)** with a wide range of nucleophiles, we focused on screening a disarmed glycosyl donor. Using our synthesized glycosyl, EDPAT disarmed donor **2.7c**, we coupled it with various glycosyl acceptors (**A1** and **A13**), achieving excellent results and yielding the desired

products (**2.45** and **2.46**).

2.2.4 Iterative Orthogonal Access to Trisaccharide

After successfully screening the various first- and second-generation glycosyl donors and glycosyl acceptors, we focused on accessing the oligosaccharides utilizing the orthogonal reactivity of our donors. We synthesize literature known acceptors bearing traditional alkyne **A15** and thioglycoside **A16** functional groups at the anomeric position. We coupled these acceptors with donors **2.4f** and **2.7a** under the standard methods (**A** and **B**, **Table 2.2.2.1** and **2.2.2.2**, and **Figure 2.2.3.2**), and ecstatically, both couplings work with excellent yields of the disaccharides (**2.47** and **2.48**), further providing evidence for the

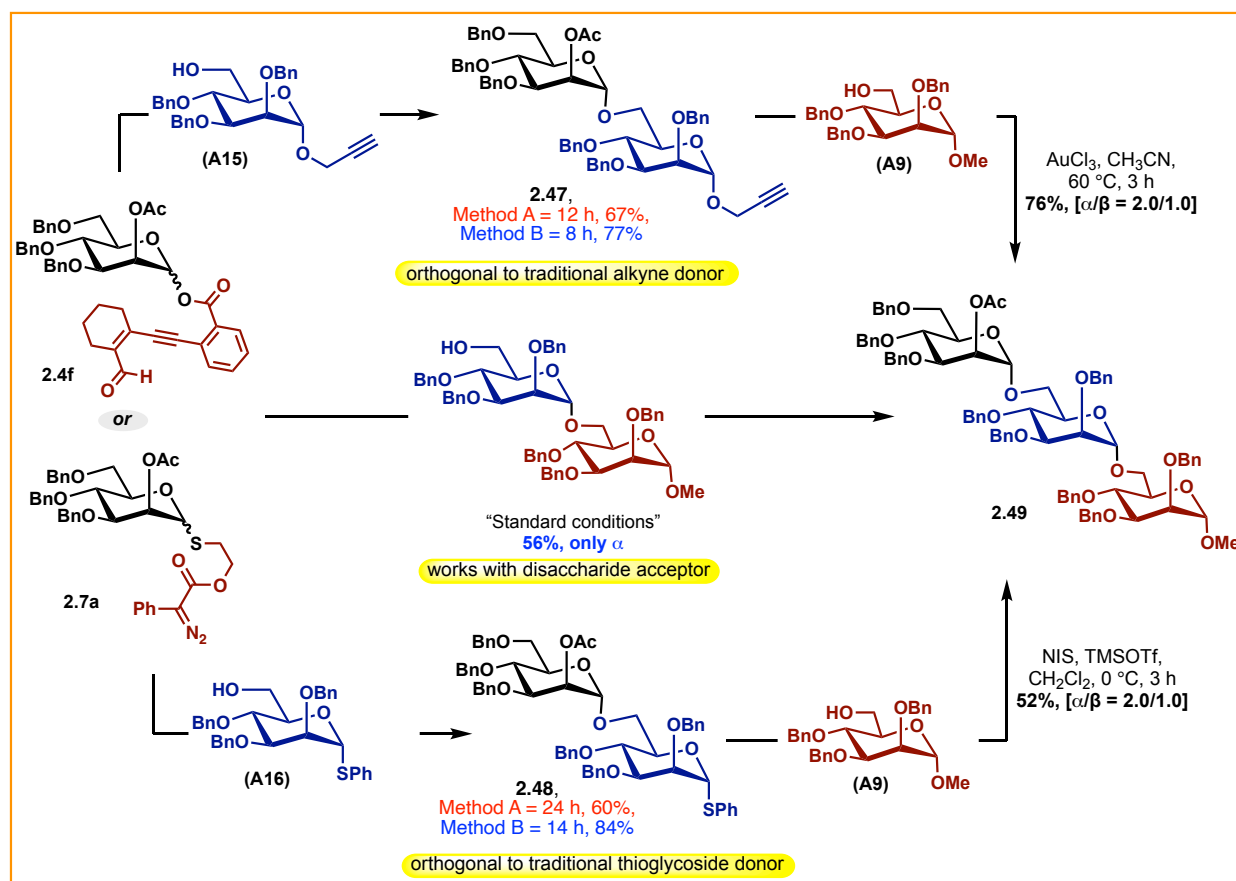


Figure 2.2.4: Orthogonal iterative synthesis of trisaccharide by using first- and second-generation donors.

orthogonal reactivity. Furthermore, these disaccharides were activated under well-established reaction conditions (**Figure 2.2.4**) to access the trisaccharide **2.49**. More specifically, disaccharide **2.48** bearing a thioglycoside moiety that underwent activation with NIS/TMSOTf^[95] to give the trisaccharide **2.49**. Additionally, orthogonal reactivity is harnessed with an alkyne bearing disaccharide **2.47**, which was activated in this iterative sequence with Au-catalyzed conditions,^[70] to furnish the trisaccharide **2.49** with good yield. After this orthogonal iterative synthesis of trisaccharide, we also synthesized disaccharide acceptor **A17** and coupled it with both donors to afford the same trisaccharide **2.49** in moderate yield (**Figure 2.2.4**).

2.2.5 Mechanistic Studies

After successfully applying both activation methods for the iterative synthesis of trisaccharides. Next, we investigated the importance of -en, -yn, and -al functionalities within our innovative en-yn-al glycosyl donor. As expected, the synthesized en-yn donor **2.4h** and yn-al donor **2.4i** exhibited complete stability under the reaction conditions, as shown in **Figure 2.2.5a**. We then tested the reactivity of a well-established thioglycoside donor (**2.4j**) under our standard reaction conditions. Interestingly, the donor was completely stable, indicating orthogonal reactivity to our designed enynal donor. Likewise, the commonly used alkyne donor **2.4k** showed no activity towards the glycosylation reactions under the optimized reaction conditions. We also investigate the effect of aromatic ring electronics on glycosylation by synthesizing the donors (**2.4l**, and **2.4m**) bearing electron-donating (-OMe) and electron-withdrawing (-NO₂) groups *para* to the ester moiety (**Figure 2.2.5b**). The methoxy donor (*p*-OMe) **2.4l** provided a faster reaction (~10h) compared to the parent (*p*-H) donor (~24h), while the glycosylation

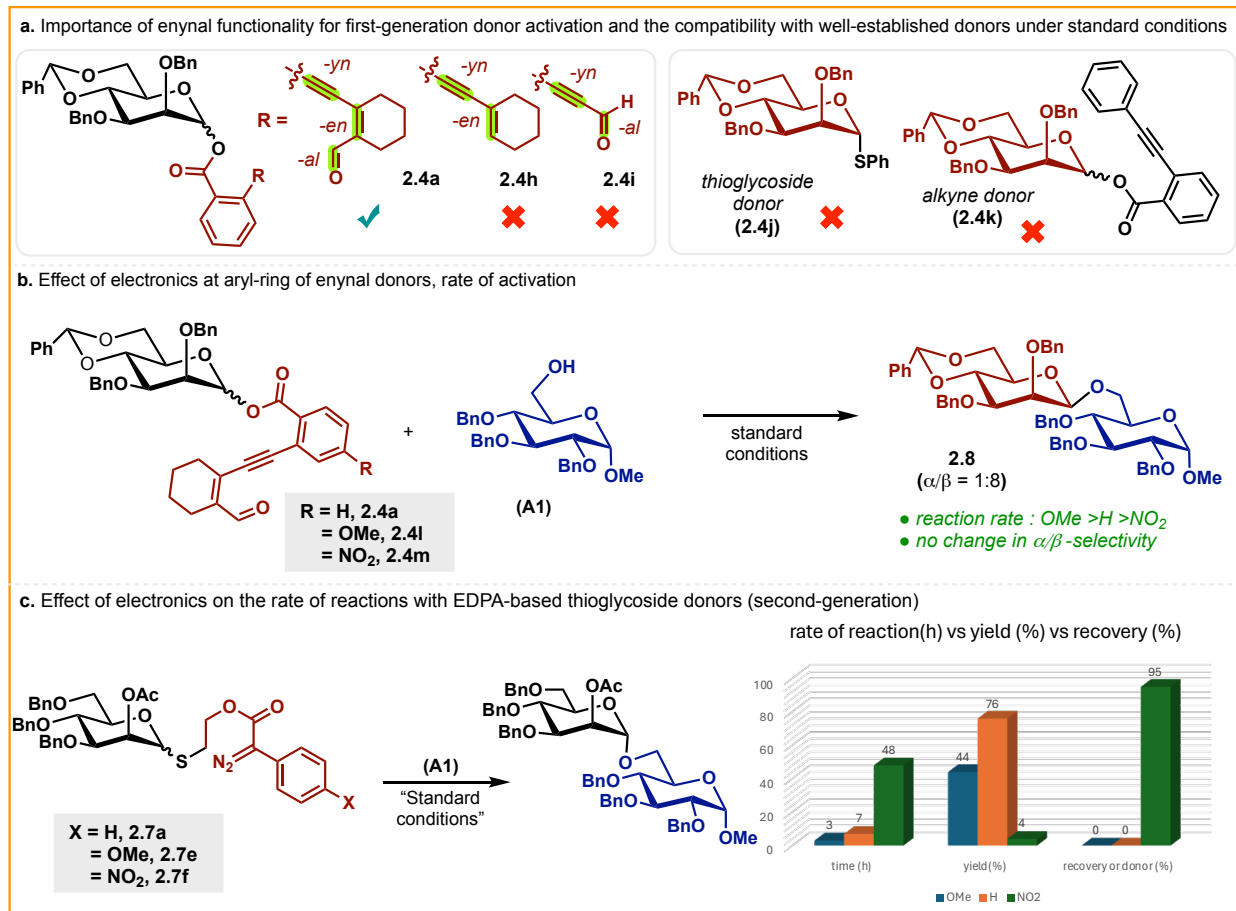


Figure 2.2.5: Mechanistic studies. (a) Importance of enynal functionality for first-generation donor activation and the compatibility with well-established donors; (b) Effect of electronics at the aryl-ring of enynal donors, and the rate of activation; (c) Effect of electronics on the rate of reaction with EDPA-based thioglycoside donors.

reaction with the nitro donor (*p*-NO₂) **2.4m** was sluggish (~36h). The methoxy (*p*-OMe) afforded a similar yield (88%) to the parent donor (*p*-H), while the nitro donor provided the product with a slightly lower yield (67%). However, there was no change in the anomeric selectivity of the product with either donor (**2.4a**, **2.4l**, and **2.4m**), suggesting that the reaction proceeds through a common oxocarbenium ion intermediate in all cases.

In the end, we also synthesized EDPA thioglycoside donors having different electronic functional groups, OMe (**2.7e**) and NO₂ (**2.7f**), at the para position of the phenyl ring of diazo functionality. The coupling of these three donors (**2.7a**, **2.7e**, and **2.7f**) with

the glycosyl acceptor **A1** demonstrates the effect of electronics. Specifically, donor **2.7e** decomposes rapidly, only providing 44% yield of the desired product **2.9**, while **2.7f** was found to be less reactive under these conditions, providing the recovered yield of unreacted donor in 95%. The diazo compounds employed in this study belong to the donor–acceptor class, in which the stability and reactivity of the diazo functionality are strongly influenced by substituent effects. Incorporation of electron-withdrawing groups enhances diazo stability, whereas electron-donating substituents tend to destabilize the diazo moiety. For example, introducing an electron-donating group such as OMe at the para position of the phenyl ring decreases the stability of the diazo compound, promoting rapid formation of the corresponding copper carbenoid. This results in a higher concentration of highly reactive carbene species in the reaction medium, which in turn leads to undesired side reactions. In contrast, a strongly electron-withdrawing substituent such as NO₂ at the para position significantly stabilizes the diazo group, making carbene generation under mild copper-catalyzed conditions less efficient.

Overall, all these mechanistic experiments provide an understanding of the activation of both classes of donors under catalytic copper conditions. Therefore, we proposed the mechanistic pathway for the generation of oxocarbenium ion in both classes and the generation of 1,2-*cis* selectivity.

2.2.6 Proposed Mechanistic Pathways

Based on the above-described results and literature precedence,^[57,89,96-102] we hypothesized a plausible mechanism for the activation of first-generation donors and explained the 1,2-*cis*-selectivity with 4,6-benzylidene donor (**Figure 2.2.6a**). First, the enynal moiety in the presence of copper(I) triflate forms the copper carbene intermediate

(ii) via a 5-*exo-dig*-cyclization.^[103-104] The resulting copper carbene activates the anomeric ester to form an oxocarbenium ion (**iv**). The oxocarbenium intermediate (**iv**) exists in equilibrium as a solvent-separated ion pair (SSIP) or contact-ion pair (CIP), or more stable α -covalent triflate (**v**) (thermodynamic product). In the context of CIP, the proximal triflate anion shields the α -face of the glycosyl oxocarbenium ion, forming the β -mannopyranosides. On the other hand, in SSIP, the anomeric effect predominantly influences the formation of α -mannopyranosides. A subsequent S_N2 attack on the α -covalent species would furnish the β -anomer. As described by Crich, the role of the 4,6-benzylidene group is to lock the C6–O6 bond in an antiperiplanar conformation to the C5–O5 bond, effectively enhancing its electron-withdrawing effect. This destabilizes the glycosyl oxocarbenium ion and drives the equilibrium strongly toward the covalent triflate form. This shift promotes *cis*-selectivity and facilitates the desired outcome of the reaction. Without the locking effect, the acceptor can capture the oxocarbenium ion intermediate from any face, forming both the α - and β - stereoisomers of the glycosidic bond. On the other side, the induction of 1,2-*trans* selectivity is derived from the well-known anchimeric assistance.

After understanding the mechanistic pathway for first-generation glycosyl donors, we proposed plausible reaction pathways for the activation of second-generation donors (**Figure 2.2.6b**). The reaction begins with the formation of copper-bound diazo complex **I**, which provides the copper-carbenoid **II** intermediate upon extrusion of the dinitrogen molecule. The copper-carbenoid coordinates with the sulfur atom, bringing it near the in-situ generated carbene through chelation. Inserting the sulfur atom into copper carbene produces the copper-bound glycosyl sulfonium ion **III**. The copper-bound C-enolate then

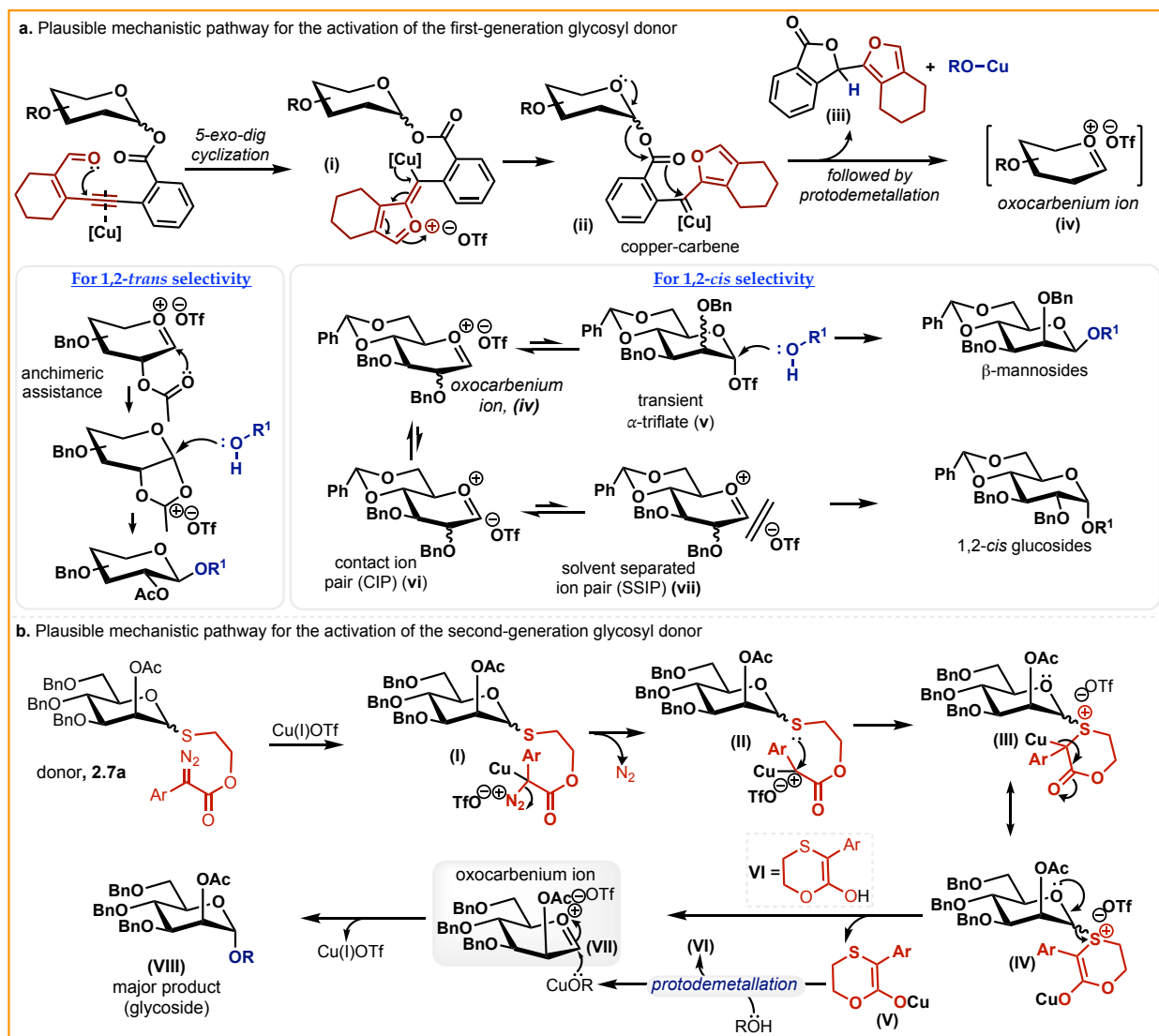


Figure 2.2.6: Plausible mechanistic pathways: (a) for the activation of first-generation donors; (b) for the activation of second-generation donors.

tautomerizes into the corresponding more stable metal-bound O-enolate **IV**, as described in our previous work.^[105] This intermediate releases ((3-argio-5,6-dihydro-1,4-oxathiin-2-yl)oxy)copper as the possible byproduct **V** to generate the oxocarbenium ion **VII**, a reactive intermediate in glycosylation chemistry. Simultaneously, the byproduct **V** undergoes Protodemetalation to generate copper-bound activated glycosyl acceptor (O-nucleophiles) and 3-argio-5,6-dihydro-1,4-oxathiin-2-ol as a plausible by-product **VI** as

described in our related work on copper-carbene mediated 1,2-cis-furanosylations^[106]. Finally, the oxocarbenium ion reacts with the activated copper nucleophile to generate the major glycoside product **VIII**. The findings from all our studies support this proposed reaction pathway.

2.3. Conclusion

In this chapter, two new classes of glycosyl donors were developed that enable efficient glycosylation under catalytic copper conditions. The first-generation donors utilized an enynal framework, combining olefin, alkyne, and aldehyde functionalities to generate copper–carbene intermediates responsible for donor activation. In the second generation, robust thioglycoside scaffolds were functionalized with donor–acceptor diazo groups to enable intramolecular copper-carbene formation. Both donor classes are bench-stable, readily synthesized, and operationally straightforward. Upon copper activation, they demonstrated broad compatibility with various glycosyl acceptors, including structurally complex substrates, affording the corresponding glycosides in good efficiency. Importantly, these donors exhibited orthogonal reactivity relative to traditional thioglycoside and alkyne-based donors, which enabled their incorporation into iterative glycosylation sequences and the synthesis of trisaccharide assemblies. Mechanistic investigations further clarified the distinct roles of the enynal and diazo functionalities in carbene generation and donor activation, providing insight into the underlying activation pathway. Overall, this work establishes copper–carbene-mediated glycosylation as a practical and sustainable alternative to precious-metal-based systems

2.4. Experimental Section

Reagents: Reagents and solvents were obtained from Sigma-Aldrich (www.sigma-aldrich.com), Chem-Impex (www.chemimpex.com), or Acros Organics (www.fishersci.com), AmBeed, and used without further purification unless otherwise indicated. Dry solvents (acetonitrile) were obtained from Acros Organics (www.fishersci.com), and dichloromethane was distilled over CaH_2 under N_2 unless stated otherwise. THF purchased from Sigma-Aldrich was distilled over Na metal with a benzophenone indicator. Toluene was obtained from Sigma-Aldrich.

Reactions: All reactions were performed in flame-dried glassware under positive N_2 pressure with magnetic stirring unless otherwise noted. Liquid reagents and solutions were transferred through rubber septa via syringes flushed with N_2 before use. Cold baths were generated as follows: 0 °C with wet ice/water and -78 °C with a Julabo chiller.

Chromatography: TLC was performed on 0.25 mm E. Merck silica gel 60 F254 plates and visualized under UV light (254 nm) or by staining with potassium permanganate (KMnO_4), cerium ammonium molybdate (CAM), phosphomolybdic acid (PMA), and ninhydrin. Silica flash chromatography was performed on Sorbtech 230–400 mesh silica gel 60.

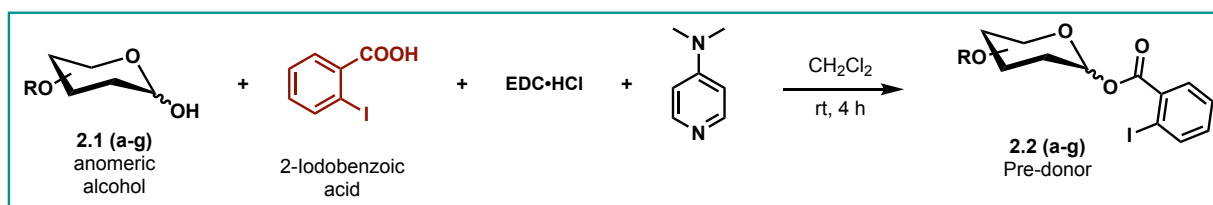
Analytical Instrumentation: NMR spectra were recorded on a Varian VNMRs 300, 400, 500, and 600 MHz, and Jeol 400, 500 NMR spectrometer in CDCl_3 unless otherwise indicated. Chemical shifts are expressed in ppm relative to solvent signals: CDCl_3 (^1H , 7.26 ppm, ^{13}C , 77.0 ppm); coupling constants are expressed in Hz. NMR spectra were processed using Mnova (www.mestrelab.com/software/mnova-nmr). Mass spectra were obtained at the OU Analytical Core Facility on an Agilent 6538 High-Mass-Resolution QTOF Mass Spectrometer and an Agilent 1290 UPLC.

2.4.1 Synthesis of Glycosyl Donor

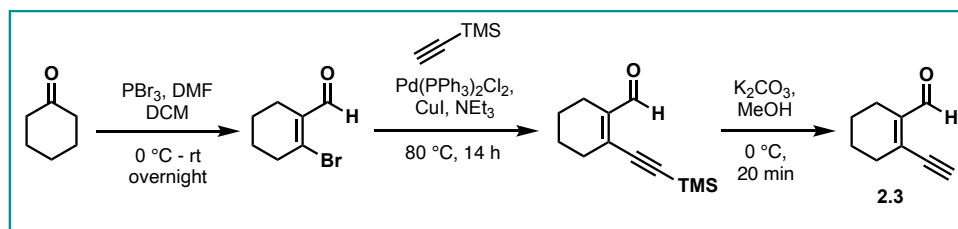
2.4.1.1 Synthesis of first-generation glycosyl donors

General procedure A for the synthesis of pre-donor 2.2(a-g):

To an oven-dried round-bottom flask was added anomeric sugar alcohol^[107] (1 equiv.) and commercially available 2-iodobenzoic acid (1.5 equiv.), EDCI (1.5 equiv.), DMAP (0.2 equiv.) and CH₂Cl₂ (10 mL/mmol). The reaction mixture was stirred at room temperature for 4 h. After completion, it was diluted with CH₂Cl₂ and washed with water and brine. The organic layer was dried over sodium sulfate, concentrated in vacuo, and purified by silica gel flash chromatography (ethyl acetate/hexane: 10% → 15%) to give the desired product.



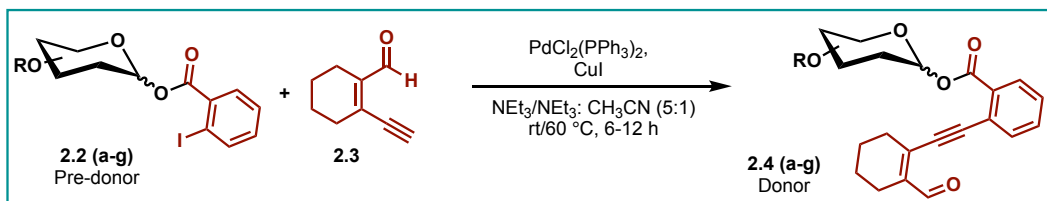
Synthesis of enynal precursor (2.3):



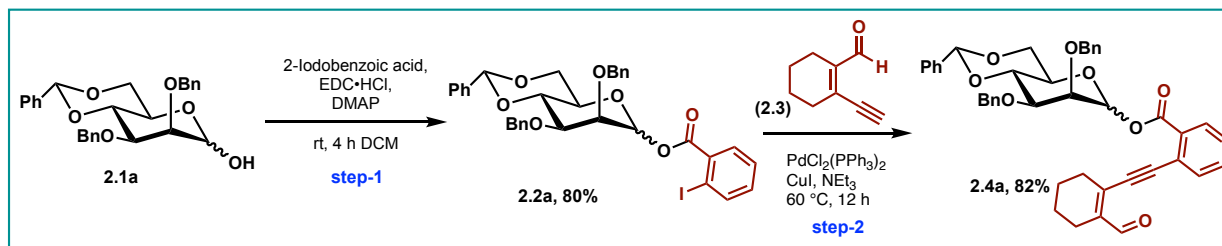
Note: 2.3 was synthesized according to the literature, and the characterized data were consistent.^[108-110]

General procedure B (Sonogashira coupling) for the synthesis of donor 2.4 (a-g):

To an oven-dried Schlenk flask were added the pre-donor (1.0 equiv.), alkyne (1.2 equiv.), Pd(PPh₃)₂Cl₂ (15 mol %) and CuI (10 mol %). The flask was vacuumed and filled with Argon three times before adding degassed Et₃N [if pre-donor is not dissolved, then the mixture of CH₃CN: NEt₃ (5:1) (~0.05 M)]. The mixture was stirred at rt for 6-12 h or heated to 60 °C for 12 h. After completion, it was diluted with EtOAc, filtered through celite, and washed with saturated NaHCO₃ aqueous solution, H₂O, and brine. The organic layer was dried over sodium sulfate, concentrated in vacuo, and purified by silica gel flash chromatography (ethyl acetate/hexane: 10% → 15%) to give pure donor.



Synthesis of 2,3-di-*O*-benzyl-4,6-*O*-benzylidene-*D*-mannopyranoside enynal donor (2.4a):



Step-1: Synthesized according to the general procedure A, using benzylidene mannose alcohol **2.1a**^[107] (1.2 g, 2.68 mmol), 2-iodobenzoic acid (0.996 g, 4.01 mmol, 1.5 equiv.), EDCI (0.77 g, 4.01 mmol, 1.5 equiv.), DMAP (66 mg, 0.535 mmol, 0.2 equiv.). Pre-donor **2.2a**, White paste^[111], 1.45 g, 80% yield, $R_f = 0.5$ in 85:15 hexane: ethyl acetate.

Pre-donor 2.2a:

^1H NMR (400 MHz, CDCl_3) δ 8.05 – 8.01 (m, 0.2H), 7.99 (dd, $J = 8.0, 1.3$ Hz, 1H), 7.80 (dd, $J = 7.8, 1.7$ Hz, 0.2H), 7.72 (dd, $J = 7.8, 1.8$ Hz, 1H), 7.53 (dd, $J = 7.8, 1.9$ Hz, 2H), 7.48 (dd, $J = 8.1, 1.6$ Hz, 2H), 7.18 (td, $J = 7.7, 1.8$ Hz, 1H), 6.72 (d, $J = 2.3$ Hz, 0.2H), 6.41 (d, $J = 1.9$ Hz, 1H), 6.15 (s, 0.2H), 5.69 (s, 1H), 4.88 (s, 2H), 4.84 (d, $J = 12.5$ Hz, 1H), 4.70 (d, $J = 12.5$ Hz, 1H), 4.59 (d, $J = 11.9$ Hz, 0.2H), 4.39 (t, $J = 9.7$ Hz, 1H), 4.32 (td, $J = 9.6, 5.0$ Hz, 1H), 4.14 (dd, $J = 10.1, 3.4$ Hz, 1H), 4.02 – 3.95 (m, 2H), 3.89 (t, $J = 10.1$ Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 164.37, 141.58, 141.54, 138.37, 137.51, 137.40, 134.00, 133.33, 131.63, 128.95, 128.56, 128.54, 128.44, 128.41, 128.32, 128.26, 128.21, 128.08, 128.05, 127.96, 127.78, 127.76, 126.28, 126.25, 126.03, 103.22, 101.49, 94.10, 93.76, 92.57, 78.51, 77.28, 75.24, 75.03, 74.53, 73.63, 73.35, 72.93, 71.76, 71.46, 68.47, 66.87.

HRMS (ESI): calc. for $\text{C}_{34}\text{H}_{31}\text{IO}_7\text{Na}$ ($\text{M}+\text{Na}$): 701.1012; found: 701.1016.

Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2a** (1.45 g, 2.14 mmol, 1.0 equiv.), alkyne **2.3** (0.35 g, 2.56 mmol, 1.2 equiv.), Pd(PPh₃)₂Cl₂ (0.22 g, 0.32 mmol, 15 mol %) and CuI (41 mg, 0.21 mmol, 10 mol %). Donor **2.4a**, yellow fluffy solid, R_f = 0.4 in 85:15 hexane: ethyl acetate, 1.21 g, 82% yield, (α:β 10:1).

Donor 2.4a:

¹H NMR (400 MHz, CDCl₃) δ 10.38 (s, 1H), 7.83 (d, *J* = 8.0 Hz, 1H), 7.63 – 7.59 (m, 1H), 7.58 – 7.55 (m, 1H), 7.54 – 7.49 (m, 2H), 7.45 (t, *J* = 7.1 Hz, 2H), 7.42 – 7.27 (m, 12H), 6.41 (s, 1H), 5.69 (s, 1H), 4.84 (d, *J* = 11.1 Hz, 3H), 4.66 (d, *J* = 12.1 Hz, 1H), 4.40 (t, *J* = 9.7 Hz, 1H), 4.29 (dd, *J* = 9.9, 4.4 Hz, 1H), 4.05 (dd, *J* = 10.1, 3.2 Hz, 1H), 3.98 (td, *J* = 9.6, 4.4 Hz, 1H), 3.94 – 3.91 (m, 1H), 3.88 (d, *J* = 10.1 Hz, 1H), 2.58 – 2.52 (m, 2H), 2.29 (t, *J* = 5.7 Hz, 2H), 1.70 – 1.61 (m, 4H).

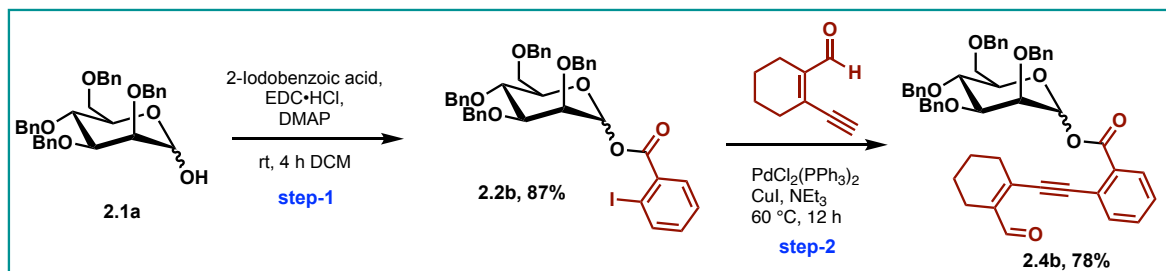
¹³C NMR (100 MHz, CDCl₃) δ 193.14, 162.70, 143.46, 139.38, 137.98, 137.35, 137.14, 134.36, 132.49, 130.51, 129.80, 128.68, 128.52, 128.26, 128.14, 128.00, 127.98, 127.74, 127.49, 127.46, 125.74, 123.53, 101.15, 96.38, 92.91, 91.74, 78.29, 75.29, 75.22, 73.27, 72.94, 68.29, 66.68, 31.79, 21.94, 21.62, 20.73.

HRMS (ESI): calc. for C₄₃H₄₀O₈Na (M+Na): 707.2621; found: 707.2589.

The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3,4,6-tetra-O-benzyl-D-Mannopyranoside enynal donor (2.4b):

Step-1: Synthesized according to the general procedure A and using tetra benzyl-O-mannose alcohol **2.1b** (0.75 g, 1.39 mmol), 2-iodobenzoic acid (0.517 g, 2.08 mmol, 1.5 equiv.), EDCI (0.325 g, 2.08 mmol, 1.5 equiv.), DMAP (45.37 mg, 0.347 mmol, 0.2 equiv.). Pre-donor **2.2b**, White paste, 1.45 g, 87% yield, R_f = 0.5 in 85:15 hexane: ethyl acetate, NMR spectra were consistent with the reported literature.^[112]



Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2b** (0.450 g, 0.584 mmol, 1.0 equiv.), alkyne (94.0 mg, 0.7 mmol, 1.2 equiv.), Pd(PPh₃)₂Cl₂ (62 mg, 0.088 mmol, 15 mol %) and CuI (12 mg, 0.059 mmol, 10 mol %). Donor **2.4b**, dark yellow paste, R_f = 0.4 in 85:15 hexane: ethyl acetate, 0.355 g, 78% yield, (α: β = 4:1)

Donor 2.4b:

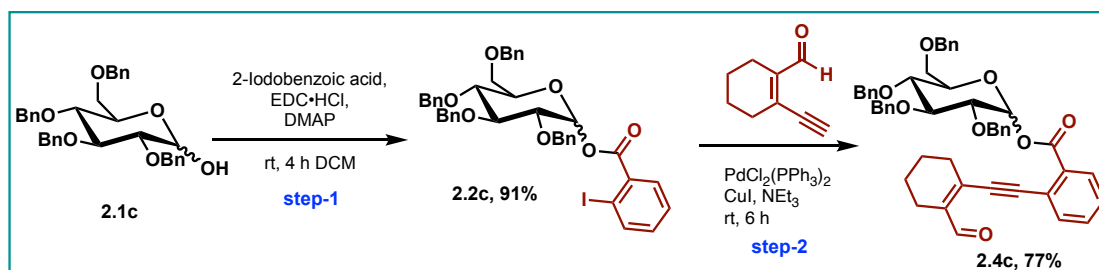
¹H NMR (400 MHz, CDCl₃) δ 10.37 (s, 1H), 10.03 (s, 0.25H), 7.90 (dd, *J* = 8.2, 1.4 Hz, 1H), 7.79 (d, *J* = 9.4 Hz, 1H), 7.67 – 7.62 (m, 1H), 7.60 (dd, *J* = 7.7, 1.5 Hz, 1H), 7.57 – 7.51 (m, 2H), 7.48 – 7.43 (m, 3H), 7.40 – 7.26 (m, 22H), 7.19 (dd, *J* = 7.1, 2.4 Hz, 3H), 6.50 (d, *J* = 2.2 Hz, 1H), 4.91 (d, *J* = 10.6 Hz, 1H), 4.89 – 4.77 (m, 3H), 4.69 (d, *J* = 12.1 Hz, 2H), 4.60 – 4.53 (m, 5H), 4.18 (t, *J* = 9.6 Hz, 1H), 3.94 (dd, *J* = 9.4, 3.1 Hz, 3H), 3.89 – 3.87 (m, 1H), 3.83 (d, *J* = 4.5 Hz, 1H), 3.80 (d, *J* = 4.4 Hz, 1H), 3.74 (d, *J* = 2.0 Hz, 1H), 3.71 (d, *J* = 1.8 Hz, 1H), 2.58 – 2.51 (m, 3H), 2.29 (t, *J* = 6.1 Hz, 3H), 1.72 – 1.60 (m, 5H).

¹³C NMR (100 MHz, CDCl₃) δ 193.43, 163.08, 143.55, 139.74, 138.21, 138.13, 137.97, 137.80, 134.44, 132.50, 130.69, 130.42, 128.66, 128.43, 128.41, 128.39, 128.33, 128.31, 128.07, 127.92, 127.86, 127.84, 127.79, 127.75, 127.55, 123.61, 96.72, 92.64, 91.79, 78.98, 77.27, 75.53, 74.93, 74.19, 73.56, 72.50, 72.03, 68.78, 36.63, 32.02, 24.70, 22.14, 21.85, 20.99.

HRMS (ESI): calc. for C₅₀H₄₈O₈Na (M+Na): 799.3247; found: 799.3208. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3,4,6-tetra-O-benzyl-D-glucopyranoside enynal donor (2.4c):

Step-1: Synthesized according to the general procedure A, and using tetrabenzyl glucose alcohol **2.1c** (0.52 g, 0.971 mmol), 2-iodobenzoic acid (0.36 g, 1.46 mmol, 1.5 equiv.), EDCI (0.28 g, 1.46 mmol, 1.5 equiv.), DMAP (24 mg, 0.194 mmol, 0.2 equiv.). Pre-donor **2.2c**, White solid, 0.68 g, 91% yield, R_f = 0.5 in 85:15 hexane: ethyl acetate, NMR spectra were consistent with the reported literature.^[112]



Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2c** (0.35 g, 0.45 mmol, 1.0 equiv.), alkyne (77 mg, 0.567 mmol, 1.2 equiv.), Pd(PPh₃)₂Cl₂ (64 mg, 0.091 mmol, 15 mol %) and CuI (9 mg, 0.045 mmol, 10 mol %). Donor **2.4c**, brown sticky paste, *R_f* = 0.4 in 85:15 hexane: ethyl acetate, 0.274 g, 77% yield, Isolated as an inseparable mixture of diastereomers (α : β 1:0.6), δ = 6.65 (d, *J* = 3.7 Hz, 1H _{α}), 5.89 (d, *J* = 7.8 Hz, 0.6H _{β}), ppm.

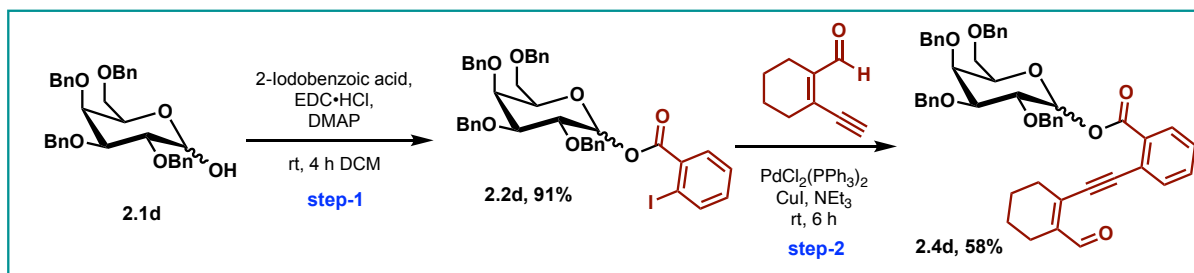
Donor **2.4c**:

¹H NMR (400 MHz, CDCl₃) δ 10.39 (s, 1H), 10.37 (s, 0.6H), 8.00 (t, *J* = 8.9 Hz, 2H), 7.72 – 7.66 (m, 1H), 7.64 – 7.59 (m, 2H), 7.54 (t, *J* = 7.5 Hz, 2H), 7.45 – 7.39 (m, 2H), 7.36 – 7.24 (m, 26H), 7.18 – 7.12 (m, 4H), 6.65 (d, *J* = 3.7 Hz, 1H), 5.89 (d, *J* = 7.8 Hz, 0.6H), 4.97 (d, *J* = 10.9 Hz, 1H), 4.91 (d, *J* = 11.0 Hz, 1H), 4.86 (d, *J* = 8.9 Hz, 3H), 4.81 (d, *J* = 8.0 Hz, 1H), 4.77 (s, 2H), 4.69 – 4.60 (m, 3H), 4.60 – 4.46 (m, 4H), 4.05 – 3.95 (m, 3H), 3.85 – 3.73 (m, 6H), 3.66 (dd, *J* = 10.8, 1.9 Hz, 2H), 2.58 – 2.51 (m, 3H), 2.34 – 2.25 (m, 4H), 1.72 – 1.61 (m, 7H).

¹³C NMR (100 MHz, CDCl₃) δ 193.54, 193.50, 163.48, 163.40, 143.43, 143.39, 139.85, 139.76, 138.55, 138.35, 137.89, 137.80, 137.75, 137.61, 134.35, 134.32, 132.42, 132.32, 130.93, 130.81, 128.69, 128.61, 128.56, 128.47, 128.42, 128.40, 128.33, 128.20, 128.01, 127.98, 127.94, 127.92, 127.88, 127.84, 127.78, 127.75, 127.73, 127.71, 127.65, 123.74, 123.62, 96.80, 94.60, 91.63, 90.82, 84.90, 81.76, 80.89, 78.96, 75.73, 75.66, 75.59, 75.50, 75.01, 75.00, 73.46, 73.06, 68.04, 68.00, 32.06, 32.01, 22.15, 22.11, 21.87, 21.85, 21.03, 20.99.

HRMS (ESI): calc. for C₅₀H₄₈O₈Na (*M*+Na): 799.3247; found: 799.3205. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3,4,6-tetra-O-benzyl-D-galactopyranoside enynal donor (**2.4d**):



Step-1: Synthesized according to the general procedure A and using tetra benzyl galactose alcohol **2.1d** (0.7 g, 1.29 mmol), 2-iodobenzoic acid (0.482 g, 1.94 mmol, 1.5 equiv.), EDCI (0.372 g, 1.94 mmol, 1.5 equiv.), DMAP (32 mg, 0.258 mmol, 0.2 equiv.). Pre-donor **2.2d**, White solid, 0.92 g, 92% yield, $R_f = 0.5$ in 85:15 hexane: ethyl acetate. Isolated as an inseparable diastereomeric mixture.

Pre-donor **2.2d**:

^1H NMR (400 MHz, CDCl_3) δ 8.03 (dd, $J = 7.9, 1.3$ Hz, 1H), 8.00 (dd, $J = 7.9, 1.3$ Hz, 1H), 7.86 (dd, $J = 7.8, 1.7$ Hz, 1H), 7.75 (dd, $J = 7.7, 1.7$ Hz, 1H), 7.40 – 7.21 (m, 39H), 7.16 (td, $J = 7.7, 1.7$ Hz, 2H), 6.66 (d, $J = 3.7$ Hz, 1H), 5.84 (d, $J = 8.0$ Hz, 1H), 5.00 (d, $J = 6.5$ Hz, 1H), 4.97 (d, $J = 6.6$ Hz, 1H), 4.85 (t, $J = 10.5$ Hz, 2H), 4.80 (d, $J = 6.9$ Hz, 3H), 4.76 (d, $J = 2.0$ Hz, 3H), 4.66 (d, $J = 11.5$ Hz, 1H), 4.62 (d, $J = 11.2$ Hz, 1H), 4.48 (dd, $J = 11.7, 2.4$ Hz, 2H), 4.42 (dd, $J = 11.7, 4.1$ Hz, 2H), 4.28 (dd, $J = 10.1, 3.6$ Hz, 1H), 4.18 (t, $J = 7.1$ Hz, 1H), 4.13 – 4.08 (m, 2H), 4.05 – 3.99 (m, 2H), 3.80 (t, $J = 6.5$ Hz, 1H), 3.71 (dd, $J = 9.7, 2.9$ Hz, 1H), 3.67 – 3.61 (m, 2H), 3.57 (dt, $J = 9.2, 5.1$ Hz, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 164.90, 164.08, 142.22, 141.80, 141.46, 138.48, 138.46, 138.41, 138.12, 138.06, 137.73, 137.71, 134.68, 133.24, 132.89, 132.81, 131.70, 131.48, 128.45, 128.37, 128.31, 128.27, 128.25, 128.05, 127.99, 127.97, 127.95, 127.89, 127.87, 127.84, 127.74, 127.71, 127.68, 127.65, 127.63, 127.60, 127.58, 127.56, 95.16, 94.30, 92.27, 82.56, 78.19, 77.86, 75.46, 75.33, 74.97, 74.77, 74.33, 74.30, 73.57, 73.53, 73.29, 73.11, 72.89, 72.74, 72.43, 68.29, 67.90.

HRMS (ESI): calc. for $\text{C}_{41}\text{H}_{39}\text{IO}_7\text{Na}$ ($\text{M}+\text{Na}$): 793.1638; found: 793.1598.

Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2d** (0.31 g, 0.403 mmol, 1.0 equiv.), alkyne **2.3** (68 mg, 0.503 mmol, 1.2 equiv.), $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (43 mg, 0.061 mmol, 15 mol %) and CuI (8 mg, 0.041 mmol, 10 mol %).

Donor **2.4d**, brown sticky paste, $R_f = 0.4$ in 85:15 hexane: ethyl acetate, 0.180 g, 58% yield, Isolated as an inseparable mixture of diastereomers ($\alpha:\beta$ 0.6:1.0), $\delta = 6.65$ (d, $J = 3.3$ Hz, 0.6H_a), 5.86 (d, $J = 8.0$ Hz, 1H_b) ppm.

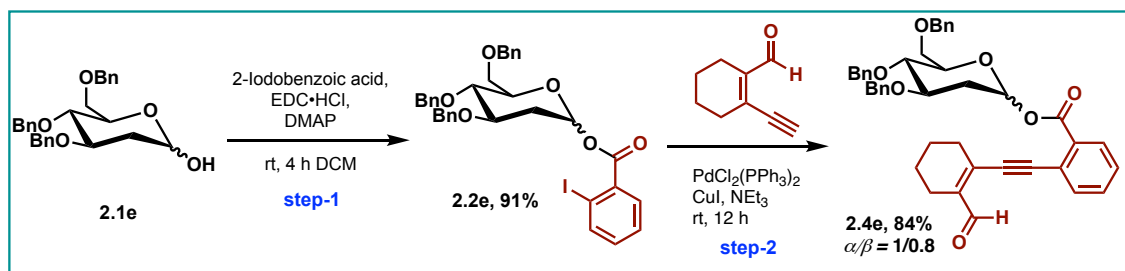
Donor **2.4d**:

¹H NMR (400 MHz, CDCl₃) δ 10.38 (s, 0.6H), 10.36 (s, 1H), 7.98 (d, $J = 7.9$ Hz, 1H), 7.90 (d, $J = 8.1$ Hz, 1H), 7.73 – 7.65 (m, 2H), 7.60 (t, $J = 7.9$ Hz, 2H), 7.56 – 7.49 (m, 3H), 7.48 – 7.42 (m, 1H), 7.32 (dt, $J = 16.8, 10.2$ Hz, 31H), 7.19 (s, 6H), 6.65 (d, $J = 3.3$ Hz, 0.6H), 5.86 (d, $J = 8.0$ Hz, 1H), 4.97 (t, $J = 11.0$ Hz, 2H), 4.83 (dd, $J = 11.5, 5.3$ Hz, 3H), 4.79 – 4.73 (m, 5H), 4.63 (dd, $J = 18.5, 11.6$ Hz, 3H), 4.44 (p, $J = 11.2$ Hz, 5H), 4.28 (dd, $J = 9.9, 3.3$ Hz, 1H), 4.16 – 3.97 (m, 6H), 3.84 – 3.79 (m, 2H), 3.73 – 3.67 (m, 2H), 3.67 – 3.60 (m, 3H), 3.60 – 3.52 (m, 2H), 2.53 (d, $J = 5.0$ Hz, 3H), 2.30 (d, $J = 7.2$ Hz, 3H), 1.69 – 1.60 (m, 6H).

¹³C NMR (100 MHz, CDCl₃) δ 193.57, 193.45, 163.57, 163.44, 143.36, 143.30, 139.98, 139.84, 138.51, 138.45, 138.42, 138.16, 138.09, 138.05, 137.73, 137.66, 134.30, 134.22, 132.35, 132.16, 132.04, 131.27, 131.03, 130.65, 130.46, 128.58, 128.43, 128.35, 128.28, 128.27, 128.24, 128.18, 128.01, 127.99, 127.83, 127.70, 127.67, 127.65, 127.59, 127.55, 127.50, 123.67, 123.59, 96.86, 96.82, 94.86, 91.68, 91.67, 91.55, 82.50, 78.32, 77.93, 75.49, 75.24, 74.94, 74.82, 74.35, 74.17, 73.62, 73.50, 73.20, 73.16, 72.88, 72.85, 72.23, 68.29, 67.83, 32.01, 22.14, 21.86, 21.83, 21.03.

HRMS (ESI): calc. for C₅₀H₄₈O₈Na (M+Na): 799.3247; found: 799.3206. The spectral images for this compound are published in our research article.^[107]

Synthesis of 3,4,6-tri-*O*-benzyl-2-deoxyglucopyranoside enynal donor (**3f**):



Step-1: Synthesized according to the general procedure **A**, and using tri-*O*-benzyl-2-deoxy glucose alcohol **2.1e** (0.7 g, 1.61 mmol), 2-iodobenzoic acid (0.600 g, 2.42 mmol,

1.5 equiv.), EDCI (0.556 g, 2.42 mmol, 1.5 equiv.), DMAP (40 mg, 0.322 mmol, 0.2 equiv.). Pre-donor **2.2e**, colorless syrup, 0.970 g, 91% yield, $R_f = 0.5$ in 85:15 hexane: ethyl acetate. Isolated as an inseparable mixture of diastereomers

Pre-donor **2.2e**:

^1H NMR (400 MHz, CDCl_3) δ 8.02 (d, $J = 7.9$ Hz, 1H), 7.98 (d, $J = 7.9$ Hz, 1H), 7.95 (dd, $J = 7.8, 1.8$ Hz, 1H), 7.73 (dd, $J = 7.8, 1.8$ Hz, 1H), 7.43 – 7.37 (m, 3H), 7.37 – 7.27 (m, 22H), 7.22 – 7.13 (m, 6H), 6.53 (d, $J = 3.1$ Hz, 1H), 5.94 (dd, $J = 9.9, 2.3$ Hz, 1H), 4.95 – 4.89 (m, 2H), 4.74 – 4.69 (m, 3H), 4.65 (d, $J = 11.8$ Hz, 3H), 4.60 – 4.49 (m, 4H), 4.16 – 4.07 (m, 1H), 3.99 – 3.94 (m, 1H), 3.84 – 3.75 (m, 5H), 3.75 – 3.67 (m, 2H), 3.64 – 3.58 (m, 1H), 2.56 – 2.45 (m, 2H), 2.00 – 1.89 (m, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 164.56, 163.98, 141.46, 141.19, 138.11, 137.98, 137.88, 137.81, 137.72, 134.50, 133.05, 133.04, 132.74, 131.56, 131.13, 128.29, 128.28, 128.21, 128.20, 128.16, 127.88, 127.81, 127.78, 127.77, 127.75, 127.72, 127.59, 127.56, 127.53, 127.51, 127.45, 94.60, 93.77, 93.54, 93.01, 78.67, 77.36, 76.99, 76.41, 75.74, 75.07, 74.81, 73.74, 73.36, 73.30, 71.66, 71.57, 68.27, 68.11, 35.04, 34.20.

HRMS (ESI): calc. for $\text{C}_{34}\text{H}_{33}\text{IO}_6\text{Na}$ ($\text{M}+\text{Na}$): 687.1220; found: 687.1183.

Step-2: Synthesized according to the general procedure **B**, and using pre-donor **2.2e** (0.400 g, 0.602 mmol, 1.0 equiv.), alkyne (97 mg, 0.722 mmol, 1.2 equiv.), $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (64 mg, 0.091 mmol, 15 mol %) and CuI (12 mg, 0.040 mmol, 10 mol %). Donor **2.4e**, brown sticky paste, $R_f = 0.4$ in 85:15 hexane: ethyl acetate, 0.338 g, 84% yield, Isolated as an inseparable mixture of diastereomers ($\alpha:\beta$ 0.8:1), $\delta = 6.53$ (s, 0.8H_α), 5.96 (dd, $J = 10.0, 2.3$ Hz, 1H_β) ppm.

Donor **3f**:

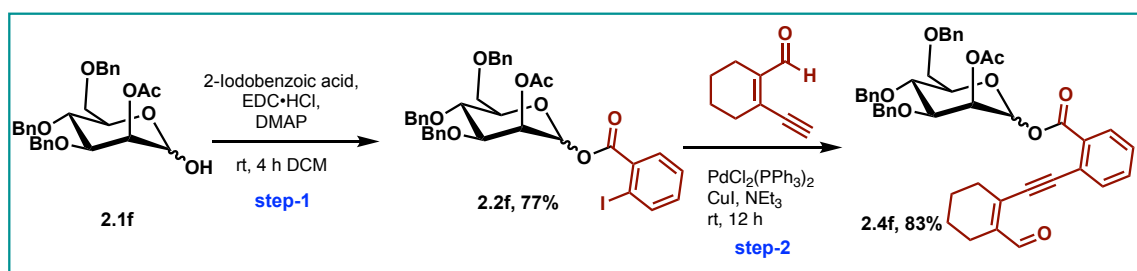
^1H NMR (400 MHz, CDCl_3) δ 10.37 (s, 0.8H), 10.36 (s, 1H), 8.08 (d, $J = 9.3$ Hz, 1H), 7.90 (d, $J = 9.2$ Hz, 1H), 7.68 (dd, $J = 12.0, 6.9$ Hz, 1H), 7.60 (d, $J = 7.5$ Hz, 2H), 7.53 (t, $J = 7.5$ Hz, 2H), 7.46 (d, $J = 7.8$ Hz, 1H), 7.44 – 7.39 (m, 2H), 7.38 – 7.27 (m, 20H), 7.20 (dt, $J = 4.8, 2.2$ Hz, 3H), 6.53 (s, 1H), 5.96 (dd, $J = 10.0, 2.3$ Hz, 1H), 4.91 (dd, $J = 10.7, 2.5$ Hz, 2H), 4.71 (dd, $J = 11.5, 4.7$ Hz, 2H), 4.68 – 4.60 (m, 4H), 4.57 (d, $J = 10.7$ Hz, 2H), 4.52 (dd, $J = 12.2, 2.8$ Hz, 2H), 4.08 – 4.00 (m, 1H), 3.96 (d, $J = 9.1$ Hz, 1H), 3.80 (dq, J

= 8.5, 4.1 Hz, 4H), 3.74 – 3.59 (m, 3H), 2.59 – 2.52 (m, 4H), 2.50 – 2.40 (m, 2H), 2.34 – 2.25 (m, 4H), 2.00 – 1.88 (m, 2H), 1.73 – 1.62 (m, 7H).

¹³C NMR (100 MHz, CDCl₃) δ 193.38, 193.21, 163.27, 163.19, 143.25, 143.16, 139.64, 139.55, 138.04, 137.99, 137.92, 137.91, 137.82, 137.74, 134.18, 134.05, 132.17, 132.09, 130.92, 130.74, 130.44, 130.39, 128.42, 128.27, 128.25, 128.22, 128.17, 128.13, 128.01, 127.76, 127.63, 127.57, 127.52, 127.49, 127.42, 123.28, 123.25, 96.61, 93.01, 92.66, 91.41, 91.36, 78.67, 76.67, 75.66, 75.18, 74.76, 73.73, 73.38, 73.24, 71.52, 68.32, 68.16, 35.19, 34.28, 31.86, 31.83, 21.94, 21.91, 21.67, 21.62, 20.83, 20.77.

HRMS (ESI): calc. for C₄₃H₄₂O₇Na (M+Na): 693.2828; found: 693.2793. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2-O-acetyl-3,4,6-tri-O-benzyl-D-mannopyranoside enynal donor (2.4f):



Step-1: Synthesized according to the general procedure A, and using 2-OAc-tri-O-benzyl mannose alcohol **2.1f** (0.59 g, 1.2 mmol), 2-iodobenzoic acid (0.445 g, 1.8 mmol, 1.5 equiv.), EDCI (0.345 g, 1.8 mmol, 1.5 equiv.), DMAP (30 mg, 0.194 mmol, 0.2 equiv.). Pre-donor **2.2f**, colorless syrup, 0.66 g, 77% yield, R_f = 0.3 in 85:15 hexane: ethyl acetate. Isolated as an inseparable mixture of diastereomers (α : β =5:1), δ = 6.39 (d, J = 2.1 Hz, 1H $_{\alpha}$), 5.97 (d, J = 1.2 Hz, 0.2H $_{\beta}$), 5.78 (d, J = 3.4 Hz, 0.2H, C₂-OAc), 5.59 – 5.56 (m, 1H, C₂-OAc) ppm.

Pre-donor **2.2f**:

¹H NMR (400 MHz, CDCl₃) δ 8.05 (d, J = 8.9 Hz, 0.2H), 8.03 (d, J = 6.7 Hz, 0.2H), 7.99 (d, J = 8.0 Hz, 1H), 7.72 (dd, J = 7.8, 1.8 Hz, 1H), 7.44 – 7.39 (m, 1H), 7.38 – 7.27 (m, 18H), 7.22 – 7.15 (m, 4H), 6.39 (d, J = 2.1 Hz, 1H $_{\alpha}$), 5.97 (d, J = 1.2 Hz, 0.2H $_{\beta}$), 5.78 (d, J = 3.4 Hz, 0.2H, C₂-OAc), 5.59 – 5.56 (m, 1H, C₂-OAc), 4.92 – 4.87 (m, 1H), 4.80 – 4.72 (m, 2H), 4.72 – 4.68 (m, 1H), 4.61 (d, J = 11.4 Hz, 1H), 4.53 (dd, J = 11.2, 6.1 Hz, 3H),

4.16 (dd, $J = 9.4, 3.3$ Hz, 1H), 4.07 (t, $J = 9.5$ Hz, 1H), 3.99 – 3.94 (m, 1H), 3.88 – 3.81 (m, 2H), 3.73 (dd, $J = 11.2, 2.0$ Hz, 1H), 2.24 (s, 0.6H), 2.22 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.58, 170.15, 163.91, 163.80, 141.86, 141.79, 141.57, 138.08, 138.06, 137.65, 137.32, 134.03, 133.44, 133.39, 133.27, 131.90, 131.82, 131.58, 128.54, 128.52, 128.42, 128.37, 128.35, 128.27, 128.21, 128.07, 128.03, 127.99, 127.97, 127.95, 127.90, 127.84, 127.73, 127.68, 127.65, 94.97, 94.14, 92.62, 92.13, 76.44, 75.48, 75.29, 74.35, 73.70, 73.66, 73.57, 73.53, 71.91, 71.79, 68.33, 67.52, 67.48, 21.19, 21.10.

HRMS (ESI): calc. for $\text{C}_{36}\text{H}_{35}\text{IO}_8\text{Na}$ ($\text{M}+\text{Na}$): 745.1274; found: 745.1232.

Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2f** (0.66 g, 0.914 mmol, 1.0 equiv.), alkyne (147 mg, 1.1 mmol, 1.2 equiv.), $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (96 mg, 0.137 mmol, 15 mol %) and CuI (17 mg, 0.092 mmol, 10 mol %). Donor **2.4f**, dark-brown paste, $R_f = 0.2$ in 85:15 hexane: ethyl acetate, 0.55 g, 83% yield, ($\alpha:\beta = 5:1$), $\delta = 6.40$ (d, $J = 2.2$ Hz, 1H_α), 6.00 (s, 0.2H_β), 5.76 (d, $J = 3.0$ Hz, 0.2H , $\text{C}_2\text{-OAc}$), 5.51 (t, $J = 2.4$ Hz, 1H , $\text{C}_2\text{-OAc}$).

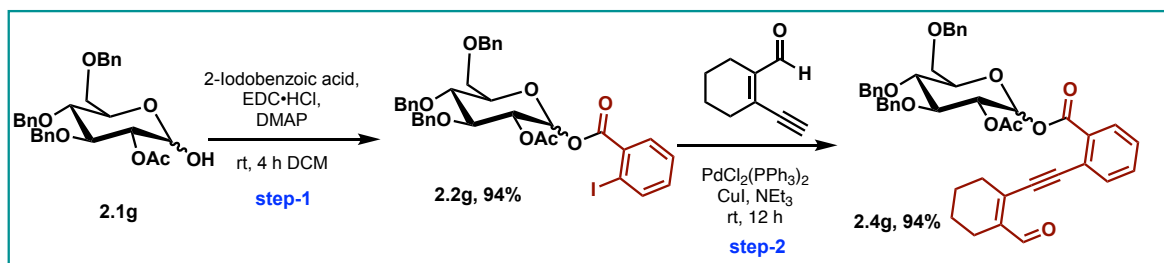
Donor 2.4f:

^1H NMR (400 MHz, CDCl_3) δ 10.38 (s, 0.2H), 10.36 (s, 1H), 7.83 (d, $J = 6.7$ Hz, 1H), 7.72 – 7.67 (m, 1H), 7.62 – 7.58 (m, 1H), 7.57 – 7.53 (m, 1H), 7.42 – 7.36 (m, 3H), 7.36 – 7.26 (m, 16H), 7.18 (dd, $J = 7.2, 2.2$ Hz, 3H), 6.40 (d, $J = 2.2$ Hz, 1H_α), 6.00 (s, 1H_β), 5.76 (d, $J = 3.0$ Hz, 0.2H , $\text{C}_2\text{-OAc}$), 5.51 (t, $J = 2.4$ Hz, 1H , $\text{C}_2\text{-OAc}$), 4.88 (dd, $J = 10.5, 4.8$ Hz, 1H), 4.77 (d, $J = 11.1$ Hz, 1H), 4.71 (d, $J = 12.1$ Hz, 1H), 4.58 (d, $J = 5.9$ Hz, 1H), 4.57 – 4.53 (m, 2H), 4.52 (d, $J = 7.0$ Hz, 1H), 4.08 – 4.05 (m, 2H), 3.96 – 3.92 (m, 1H), 3.84 (dd, $J = 11.2, 3.8$ Hz, 2H), 3.71 (dd, $J = 11.2, 2.1$ Hz, 1H), 2.55 (t, $J = 4.2$ Hz, 2H), 2.30 – 2.26 (m, 2H), 2.23 (s, 0.6H), 2.21 (s, 3H), 1.66 (ddt, $J = 12.1, 7.6, 4.3$ Hz, 5H).

^{13}C NMR (100 MHz, CDCl_3) δ 193.72, 193.32, 170.56, 170.12, 162.56, 143.61, 143.47, 139.77, 139.67, 138.12, 138.09, 138.01, 137.50, 137.36, 135.27, 135.21, 135.15, 134.46, 134.30, 132.63, 132.53, 130.61, 130.18, 128.67, 128.53, 128.50, 128.44, 128.38, 128.35, 128.32, 128.30, 128.20, 128.18, 127.97, 127.95, 127.89, 127.87, 127.65, 127.62, 123.76, 123.72, 96.53, 92.02, 91.93, 91.71, 77.64, 76.36, 75.60, 75.19, 74.34, 73.74, 73.71, 73.59, 73.44, 71.99, 71.74, 68.37, 67.59, 67.55, 32.01, 22.13, 21.89, 21.82, 21.07, 20.97.

HRMS (ESI): calc. for $C_{45}H_{44}O_9Na$ ($M+Na$): 751.2883; found: 751.2843. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2-O-acetyl-3,4,6-tri-O-benzyl-D-glucopyranoside enynal donor (2.4g):



Step-1: Synthesized according to the general procedure A and using 2-OAc-tri-O-benzyl glucose alcohol **2.1g** (0.2 g, 0.406 mmol), 2-iodobenzoic acid (0.151 g, 0.609 mmol, 1.5 equiv.), EDCI (0.117 g, 0.609 mmol, 1.5 equiv.), DMAP (10 mg, 0.082 mmol, 0.2 equiv.). Pre-donor **2.2g**, colorless syrup, 0.274 g, 94% yield, R_f = 0.3 in 80:20 hexane: ethyl acetate.

Pre-donor 2.2g:

^1H NMR (400 MHz, $CDCl_3$) δ 8.05 – 8.00 (m, 1.5H), 7.97 – 7.93 (m, 0.5H), 7.76 (dd, J = 7.9, 2.0 Hz, 1H), 7.42 (td, J = 7.5, 3.3 Hz, 1.5H), 7.33 (dd, J = 16.6, 6.2 Hz, 20H), 7.22 – 7.15 (m, 5H), 6.58 (d, J = 3.7 Hz, $1H_\alpha$), 5.85 (d, J = 8.2 Hz, $0.5H_\beta$), 5.29 (t, J = 8.8 Hz, 0.5H, C_2 -OAc), 5.17 (dd, J = 10.0, 3.6 Hz, 1H, C_2 -OAc), 4.88 – 4.82 (m, 3H), 4.79 (d, J = 6.3 Hz, 1H), 4.76 – 4.70 (m, 1H), 4.65 (d, J = 12.1 Hz, 2H), 4.60 – 4.54 (m, 2H), 4.53 – 4.49 (m, 1H), 4.14 – 4.02 (m, 2H), 3.94 – 3.86 (m, 2H), 3.81 (d, J = 8.3 Hz, 3H), 3.70 (t, J = 10.2 Hz, 2H), 2.00 (s, 3H), 1.92 (s, 1.5H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 169.98, 169.63, 164.51, 163.83, 141.96, 141.63, 138.25, 138.00, 137.81, 137.77, 137.73, 134.23, 133.62, 133.16, 132.18, 131.94, 131.26, 128.52, 128.49, 128.46, 128.41, 128.24, 128.16, 128.06, 128.03, 128.01, 127.95, 127.87, 127.81, 127.76, 127.73, 95.28, 94.31, 93.08, 91.37, 82.70, 79.60, 77.27, 77.12, 75.93, 75.47, 75.34, 75.23, 75.15, 73.76, 73.61, 73.57, 72.03, 71.93, 67.92, 67.88, 20.91, 20.88.

HRMS (ESI): calc. for $C_{36}H_{35}IO_8Na$ ($M+Na$): 745.1274; found: 745.1240.

Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2g** (0.265 g, 0.366 mmol, 1.0 equiv.), alkyne (60 mg, 0.44 mmol, 1.2 equiv.), $Pd(PPh_3)_2Cl_2$

(39 mg, 0.055 mmol, 15 mol %) and CuI (7 mg, 0.037 mmol, 10 mol %). Donor **2.4g**, brown paste, $R_f = 0.2$ in 80:20 hexane: ethyl acetate, 0.25 g, 94% yield, ($\alpha:\beta = 2:1$), $\delta = 6.58$ (d, $J = 3.7$ Hz, $1H_\alpha$), 5.86 (d, $J = 8.2$ Hz, $0.5H_\beta$), 5.31 (t, $J = 8.8$ Hz, $C_2\text{-OAc}$), 5.19 (dd, $J = 9.8, 3.8$ Hz, $1H, C_2\text{-OAc}$) ppm.

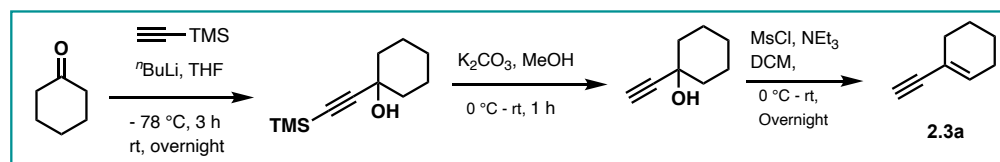
Donor **2.4g**:

^1H NMR (400 MHz, $CDCl_3$) δ 10.39 (s, 0.5H), 10.35 (s, 1H), 8.04 (d, $J = 8.0$ Hz, 1H), 7.96 (d, $J = 7.9$ Hz, 1H), 7.69 (s, 1H), 7.65 – 7.51 (m, 4H), 7.45 (t, $J = 8.6$ Hz, 2H), 7.32 (dd, $J = 11.8, 6.8$ Hz, 24H), 7.18 (d, $J = 4.0$ Hz, 4H), 6.58 (d, $J = 3.7$ Hz, $1H_\alpha$), 5.86 (d, $J = 8.2$ Hz, $0.5H_\beta$), 5.31 (t, $J = 8.8$ Hz, $C_2\text{-OAc}$), 5.19 (dd, $J = 9.8, 3.8$ Hz, $1H, C_2\text{-OAc}$), 4.86 (dd, $J = 12.9, 7.1$ Hz, 3H), 4.80 (d, $J = 6.2$ Hz, 1H), 4.77 – 4.70 (m, 1H), 4.65 (dd, $J = 12.1, 6.0$ Hz, 2H), 4.60 – 4.54 (m, 3H), 4.50 (d, $J = 12.5$ Hz, 1H), 4.06 (dt, $J = 16.9, 9.3$ Hz, 3H), 3.91 (t, $J = 9.4$ Hz, 2H), 3.84 – 3.77 (m, 3H), 3.69 (d, $J = 10.8$ Hz, 2H), 2.55 (q, $J = 6.7$ Hz, 4H), 2.34 – 2.26 (m, 4H), 1.95 (s, 3H), 1.89 (s, 1.5H), 1.74 – 1.61 (m, 6H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 193.77, 193.19, 169.91, 169.62, 163.20, 143.52, 143.48, 139.82, 139.74, 138.25, 138.06, 137.84, 137.82, 137.78, 137.70, 135.28, 135.22, 135.17, 134.49, 134.35, 132.69, 132.54, 131.33, 130.65, 130.52, 129.76, 128.92, 128.71, 128.54, 128.50, 128.47, 128.39, 128.30, 128.06, 128.01, 127.96, 127.94, 127.92, 127.88, 127.85, 127.80, 127.71, 127.64, 123.88, 123.75, 96.72, 96.68, 92.75, 91.84, 91.82, 90.83, 82.66, 79.90, 77.32, 77.28, 77.12, 75.82, 75.59, 75.37, 75.21, 75.10, 73.67, 73.63, 73.52, 72.12, 71.97, 67.93, 32.06, 31.99, 22.16, 22.13, 21.90, 21.83, 21.04, 20.98, 20.81, 20.72.

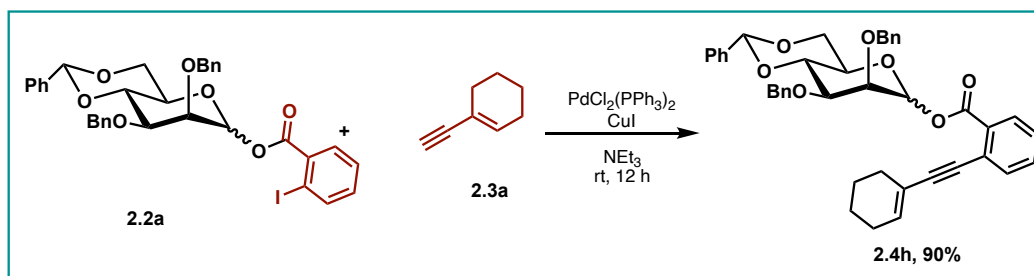
HRMS (ESI): calc. for $C_{45}H_{44}O_9Na$ ($M+Na$): 751.2883; found: 751.2851. The spectral images for this compound are published in our research article.^[107]

Synthesis of alkyne-alkene precursor (**2.3a**):



Note: **2.3a** was synthesized according to the literature, and the characterized data were consistent.^[113-114]

Synthesis of 2,3-di-O-benzyl-4,6-di-O-benzylidene-D-mannopyranoside en-yn donor (2.4h):



Synthesized according to the general procedure B, using pre-donor **2.2a** (0.1 g, 0.162 mmol, 1.0 equiv.), alkyne-alkene **2.3a** (20 mg, 0.195 mmol, 1.2 equiv.), $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (17 mg, 0.025 mmol, 15 mol %) and CuI (3.0 mg, 0.016 mmol, 10 mol %). Donor **2.4h**, colorless viscous syrup, $R_f = 0.3$ in 85:15 hexane: ethyl acetate, 96.0 mg, 90% yield, ($\alpha:\beta=1:5$).

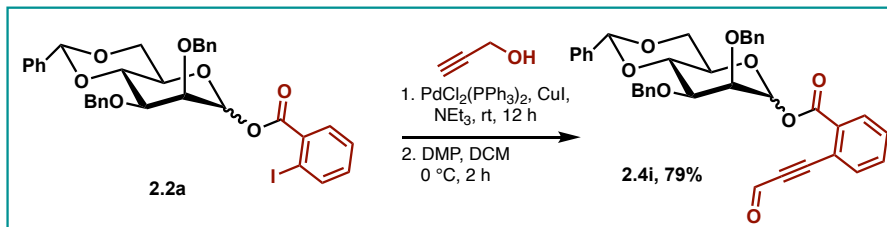
Donor 2.4h:

^1H NMR (400 MHz, CDCl_3) δ 7.82 (d, $J = 8.1$ Hz, 1H), 7.56 (d, $J = 7.8$ Hz, 1H), 7.47 (dt, $J = 20.2, 6.2$ Hz, 5H), 7.34 (dp, $J = 22.4, 7.2$ Hz, 12H), 6.43 (s, 1H, alkene), 6.27 (s, 1H_β), 5.68 (s, 1H, benzylidene), 4.86 – 4.83 (m, 2H), 4.64 (d, $J = 12.0$ Hz, 1H), 4.38 (t, $J = 9.6$ Hz, 1H), 4.30 (dd, $J = 10.1, 4.5$ Hz, 1H), 4.12 (dd, $J = 10.1, 3.0$ Hz, 1H), 4.05 – 3.96 (m, 2H), 3.88 (t, $J = 10.2$ Hz, 1H), 2.28 – 2.18 (m, 2H), 2.07 – 2.00 (m, 2H), 1.64 – 1.48 (m, 4H).

^{13}C NMR (100 MHz, CDCl_3) δ 164.05, 138.48, 137.76, 137.57, 136.55, 134.69, 132.46, 130.83, 130.01, 128.94, 128.44, 128.28, 128.02, 127.72, 127.70, 127.59, 126.09, 124.97, 120.81, 101.46, 97.42, 93.32, 85.78, 78.72, 75.94, 75.65, 73.55, 73.36, 68.66, 66.82, 29.06, 25.83, 22.29, 21.44.

HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{40}\text{O}_7\text{Na}$ ($\text{M}+\text{Na}$): 679.2672; found: 679.2666. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3-di-O-benzyl-4,6-di-O-benzylidene-D-mannopyranoside yn-al donor (2.4i):



Synthesized according to the general procedure B, pre-donor **2.2a** (0.135 g, 0.199 mmol, 1.0 equiv.), and using propargyl alcohol (23 mL, 0.398 mmol, 2 equiv.), Pd(PPh₃)₂Cl₂ (21 mg, 0.03 mmol, 15 mol %) and CuI (4.0 mg, 0.02 mmol, 10 mol %). Crude colorless viscous syrup (*R*_f = 0.3 in 85:15 hexane: ethyl acetate) was moved forward without any further purification. Dess-Martin periodinane **DMP** (0.186 mmol) was added to a magnetically stirred solution of the above crude product (0.187 mmol) in DCM (2 mL) maintained at 0°C. After 1-2 h, the starting material is completely consumed by TLC analysis. The reaction was quenched by adding Na₂S₂O₃ (10 mL of a saturated aqueous solution). The aqueous layer was extracted with DCM (3 × 5 mL), washed with NaHCO₃ (2 × 5 mL of a saturated aqueous solution), dried over Na₂SO₄, and concentrated under reduced pressure. The crude was purified by flash column chromatography to obtain the pure donor **2.4i** as light-yellow paste, *R*_f = 0.2 in 85:15 hexane: ethyl acetate. 93.0 mg, 79% yield, (α:β=1:5).

Donor **2.4i**:

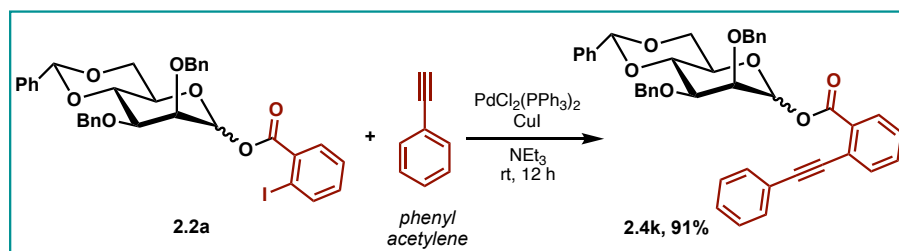
¹H NMR (400 MHz, CDCl₃) δ 9.41 (s, 1H), 9.41 (s, 0.3H), 7.92 (d, *J* = 7.4 Hz, 1H), 7.73 (d, *J* = 7.9 Hz, 1H), 7.62 (t, *J* = 7.5 Hz, 2H), 7.55 (t, *J* = 7.5 Hz, 2H), 7.50 (d, *J* = 8.5 Hz, 2H), 7.44 (d, *J* = 7.7 Hz, 3H), 7.39 – 7.28 (m, 17H), 6.49 (s, 0.3H_α), 6.41 (s, 1H_β), 5.67 (s, 1H_β, benzyldiene), 5.54 (s, 0.3H_α, benzyldiene), 4.96 (dd, *J* = 29.6, 12.4 Hz, 1H), 4.85 (d, *J* = 8.8 Hz, 2H), 4.82 – 4.71 (m, 2H), 4.69 – 4.62 (m, 2H), 4.39 (t, *J* = 9.5 Hz, 1H), 4.33 – 4.27 (m, 1H), 4.23 – 4.12 (m, 1H), 4.08 (dd, *J* = 10.2, 3.5 Hz, 1H), 3.99 (d, *J* = 19.4 Hz, 2H), 3.94 – 3.86 (m, 2H).

¹³C NMR (100 MHz, CDCl₃) δ 192.45, 177.25, 176.88, 168.32, 163.40, 163.04, 138.13, 137.49, 137.24, 136.56, 136.32, 136.08, 135.85, 134.49, 132.86, 131.57, 131.49, 131.24, 130.96, 130.78, 129.76, 129.35, 129.00, 128.95, 128.66, 128.55, 128.51, 128.49, 128.37, 128.34, 128.30, 128.25, 128.20, 128.07, 128.04, 128.00, 127.88, 127.77, 127.70, 125.96,

120.37, 119.98, 101.77, 101.57, 93.81, 93.48, 93.34, 92.53, 92.22, 81.58, 78.49, 78.08, 77.23, 76.05, 75.31, 73.63, 73.16, 72.81, 72.60, 72.42, 71.56, 68.47, 67.02, 66.81, 66.62.

HRMS (ESI): calc. for $C_{37}H_{32}O_8Na$ ($M+Na$): 627.1995; found: 627.1989. The spectral images for this compound are published in our research article.^[107]

Synthesis of alkyne donor (**2.4k**):



Synthesized according to the general procedure B, and using pre-donor **2.2a** (0.08 g, 0.117 mmol, 1.0 equiv.), alkyne (15 mg, 0.142 mmol, 1.2 equiv.), $Pd(PPh_3)_2Cl_2$ (13 mg, 0.018 mmol, 15 mol %) and CuI (2.5 mg, 0.012 mmol, 10 mol %). Donor **2.4k**, brown paste, $R_f = 0.3$ in 85:15 hexane: ethyl acetate, 70 mg, 91% yield, (α : β 3:1), $\delta = 6.46$ (d, $J = 1.9$ Hz, $1H_\alpha$), 6.41 (d, $J = 1.9$ Hz, $0.3H_\beta$) ppm.

Donor **2.4k**:

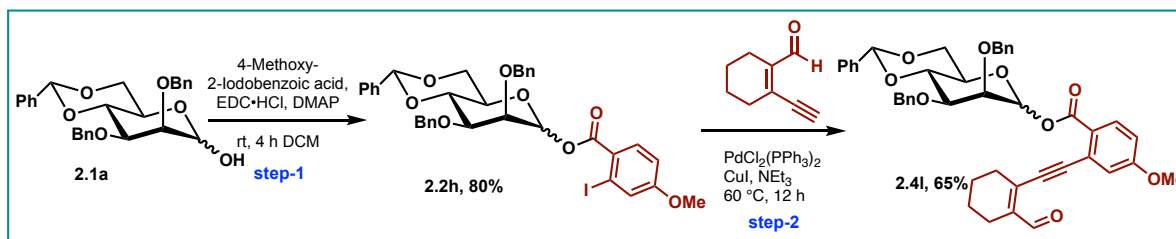
^1H NMR (400 MHz, $CDCl_3$) δ 7.98 (dd, $J = 8.0, 1.2$ Hz, 1H), 7.90 (dd, $J = 7.9, 1.4$ Hz, 1H), 7.69 (dd, $J = 7.8, 1.3$ Hz, 1H), 7.58 (t, $J = 1.6$ Hz, 1H), 7.57 (d, $J = 1.6$ Hz, 1H), 7.56 – 7.53 (m, 2H), 7.53 – 7.51 (m, 1H), 7.49 (dd, $J = 7.2, 2.1$ Hz, 2H), 7.46 (dd, $J = 5.4, 1.7$ Hz, 2H), 7.42 (dd, $J = 3.3, 1.4$ Hz, 2H), 7.41 – 7.35 (m, 12H), 7.34 – 7.30 (m, 5H), 7.28 (tt, $J = 5.0, 1.8$ Hz, 5H), 7.25 – 7.18 (m, 5H), 6.46 (d, $J = 1.9$ Hz, $1H_\alpha$), 6.41 (d, $J = 1.9$ Hz, $0.3H_\beta$), 5.69 (s, 0.3H benzylidene), 5.66 (s, 1H, benzylidene), 4.88 (s, 1H), 4.84 (s, 2H), 4.68 (d, $J = 3.0$ Hz, 1H), 4.64 (d, $J = 4.9$ Hz, 1H), 4.42 – 4.33 (m, 3H), 4.33 – 4.28 (m, 1H), 4.26 (dd, $J = 10.2, 4.7$ Hz, 1H), 4.16 – 4.12 (m, 1H), 4.09 (dd, $J = 10.1, 3.3$ Hz, 1H), 4.03 (dt, $J = 9.7, 4.9$ Hz, 1H), 4.00 – 3.95 (m, 2H), 3.93 – 3.80 (m, 2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 164.37, 163.99, 141.57, 138.36, 137.65, 137.51, 137.47, 137.40, 134.67, 133.31, 132.49, 131.91, 131.81, 131.62, 131.60, 130.90, 130.27, 128.94, 128.86, 128.76, 128.57, 128.53, 128.47, 128.43, 128.34, 128.32, 128.25, 128.23, 128.18, 128.07, 128.04, 127.93, 127.76, 127.65, 127.57, 127.53, 126.08, 126.03, 126.01, 124.19,

122.85, 101.57, 101.49, 101.33, 95.12, 94.09, 93.75, 93.39, 88.15, 78.60, 78.51, 75.80, 75.51, 75.24, 75.03, 73.63, 73.50, 73.11, 72.92, 68.51, 68.30, 66.86, 66.71.

HRMS (ESI): calc. for $C_{42}H_{36}O_7Na$ ($M+Na$): 675.2359; found: 675.2326. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3-di-O-benzyl-4,6-O-benzylidene-D-mannopyranoside 4-methoxy



enynal donor (2.4I):

Step-1: Synthesized according to the general procedure A, and using benzylidene mannose alcohol **2.1a** (0.1 g, 0.223 mmol), 4-methoxy-2-iodobenzoic acid (93 mg, 0.334 mmol, 1.5 equiv.), EDCI (64 mg, 0.334 mmol, 1.5 equiv.), DMAP (11 mg, 0.09 mmol, 0.2 equiv.). Pre-donor **2.2h**, White paste, 0.127 g, 80% yield, $R_f = 0.2$ in 85:15 hexane: ethyl acetate.

Pre-donor 2.2h:

^1H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, $J = 8.8$ Hz, 1H), 7.53 (dd, $J = 8.2, 2.4$ Hz, 3H), 7.48 – 7.43 (m, 2H), 7.42 – 7.27 (m, 10H), 6.90 (dd, $J = 8.8, 2.6$ Hz, 1H), 6.39 (d, $J = 1.7$ Hz, 1H), 5.68 (s, 1H), 4.84 (d, $J = 17.9$ Hz, 3H), 4.70 (d, $J = 12.4$ Hz, 1H), 4.39 (t, $J = 9.7$ Hz, 1H), 4.30 (dd, $J = 9.9, 4.4$ Hz, 1H), 4.14 (dd, $J = 10.1, 3.3$ Hz, 1H), 4.01 – 3.93 (m, 2H), 3.90 (d, $J = 10.0$ Hz, 1H), 3.84 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 163.41, 162.61, 138.46, 137.66, 137.51, 133.59, 129.03, 128.63, 128.60, 128.58, 128.52, 128.49, 128.41, 128.35, 128.33, 128.09, 127.89, 127.85, 127.34, 126.14, 126.11, 124.91, 113.96, 101.56, 96.04, 93.37, 78.65, 75.51, 75.17, 73.65, 72.97, 68.61, 66.87, 55.86.

HRMS (ESI): calc. for $C_{35}H_{33}IO_8Na$ ($M+Na$): 731.1118; found: 731.1103.

Step-2: According to the general procedure B, pre-donor **2.2h** (0.127 g, 0.180 mmol, 1.2 equiv.), alkyne (29 mg, 0.215 mmol, 1.2 equiv.), $Pd(PPh_3)_2Cl_2$ (19 mg, 0.027 mmol, 15

mol %) and CuI (4 mg, 0.018 mmol, 10 mol %). Donor **2.4I**, dark brown paste, R_f = 0.1 in 85:15 hexane: ethyl acetate, 83 mg, 65% yield, (α : β 1:17).

Donor 2.4I:

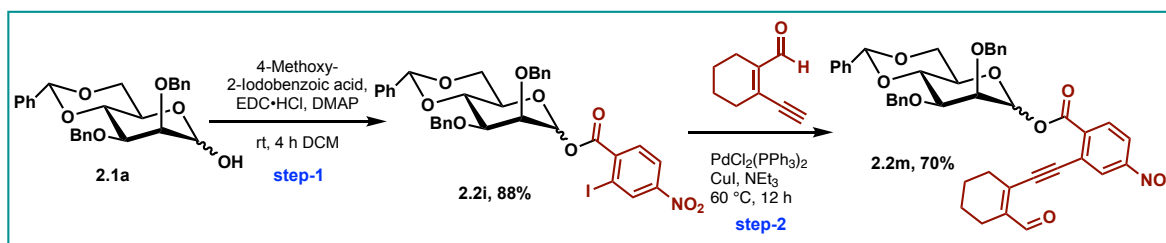
^1H NMR (400 MHz, CDCl_3) δ 10.39 (s, 1H), 7.80 (d, J = 8.9 Hz, 1H), 7.55 – 7.50 (m, 2H), 7.48 – 7.43 (m, 2H), 7.42 – 7.27 (m, 12H), 7.07 (d, J = 2.7 Hz, 1H), 6.90 (dd, J = 8.9, 2.7 Hz, 1H), 6.41 (d, J = 1.7 Hz, 1H_β), 5.69 (s, 1H_β -benzylidene), 4.89 – 4.82 (m, 3H), 4.67 (d, J = 12.1 Hz, 1H), 4.40 (t, J = 9.6 Hz, 1H), 4.29 (dd, J = 9.9, 4.4 Hz, 1H), 4.06 (dd, J = 10.0, 3.3 Hz, 1H), 4.01 – 3.91 (m, 3H), 3.89 (s, 3H), 3.86 (d, J = 2.6 Hz, 1H), 2.56 (tt, J = 3.8, 1.8 Hz, 2H), 2.33 – 2.25 (m, 2H), 1.72 – 1.60 (m, 4H).

^{13}C NMR (150 MHz, CDCl_3) δ 192.87, 192.75, 161.75, 149.87, 145.27, 145.25, 138.26, 138.24, 137.57, 137.37, 135.24, 131.91, 129.05, 129.03, 128.65, 128.60, 128.58, 128.57, 128.54, 128.47, 128.44, 128.41, 128.34, 128.32, 128.28, 128.16, 128.14, 128.12, 127.89, 127.83, 127.81, 127.53, 126.10, 126.05, 125.58, 122.99, 101.57, 94.69, 94.29, 94.10, 78.53, 75.52, 75.39, 73.80, 73.32, 68.50, 67.32, 31.87, 22.35, 21.85, 20.91.

HRMS (ESI): calc. for $\text{C}_{44}\text{H}_{42}\text{O}_9\text{Na}$ ($\text{M}+\text{Na}$): 737.2727; found: 737.2704. The spectral images for this compound are published in our research article.^[107]

Synthesis of 2,3-di-O-benzyl-4,6-O-benzylidene-D-mannopyranoside 4-nitro enynal donor (2.4m):

Step-1: Synthesized according to the general procedure A, and using benzylidene mannose alcohol **2.1a** (0.1 g, 0.223 mmol), 4-nitro-2-iodobenzoic acid (98 mg, 0.334 mmol, 1.5 equiv.), EDCI (64 mg, 0.334 mmol, 1.5 equiv.), DMAP (11 mg, 0.09 mmol, 0.2 equiv.). Pre-donor **2.2i**, White paste, 0.127 g, 88% yield, R_f = 0.3 in 85:15 hexane: ethyl acetate.



Pre-donor 2.2i:

¹H NMR (400 MHz, CDCl₃) δ 8.75 (s, 1H), 8.22 (d, *J* = 8.6 Hz, 1H), 7.77 (d, *J* = 9.8 Hz, 1H), 7.52 (d, *J* = 7.4 Hz, 2H), 7.48 (d, *J* = 7.6 Hz, 2H), 7.39 (p, *J* = 6.8 Hz, 7H), 7.32 (s, 5H), 6.72 (s, 0.13H_α), 6.40 (s, 1H_β), 6.15 (s, 0.13H_α-benzylidene), 5.69 (s, 1H_β-benzylidene), 4.90 (d, *J* = 3.8 Hz, 2H), 4.85 (d, *J* = 12.4 Hz, 1H), 4.72 (d, *J* = 12.5 Hz, 1H), 4.40 (t, *J* = 9.4 Hz, 1H), 4.30 (d, *J* = 6.3 Hz, 1H), 4.09 (dd, *J* = 10.1, 3.3 Hz, 1H), 4.01 – 3.98 (m, 1H), 3.95 – 3.86 (m, 2H).

¹³C NMR (100 MHz, CDCl₃) δ 163.48, 148.99, 140.22, 138.36, 137.34, 137.26, 135.85, 131.72, 129.02, 128.58, 128.51, 128.33, 128.28, 128.21, 128.16, 127.94, 127.90, 127.80, 125.99, 122.82, 101.55, 94.70, 93.29, 78.44, 75.06, 74.61, 73.78, 72.91, 68.33, 67.09.

HRMS (ESI): calc. for C₃₄H₃₀INO₉Na (M+Na): 746.0863; found: 745.0843.

Step-2: Synthesized according to the general procedure B, and using pre-donor **2.2i** (0.140 g, 0.194 mmol, 1.2 equiv.), alkyne (31 mg, 0.232 mmol, 1.2 equiv.), Pd(PPh₃)₂Cl₂ (21 mg, 0.029 mmol, 15 mol %) and CuI (4 mg, 0.019 mmol, 10 mol %). Donor **2.2m**, dark brown paste, R_f = 0.2 in 85:15 hexane: ethyl acetate, 98 mg, 70% yield, (α:β 1:10).

Donor 2.2m:

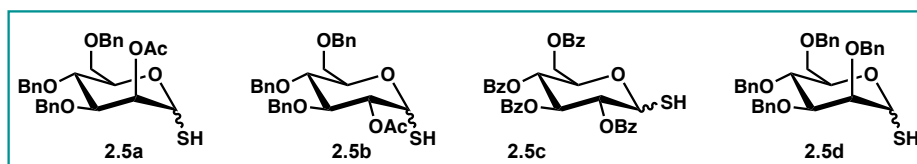
¹H NMR (400 MHz, CDCl₃) δ 10.34 (s, 1H), 8.41 (d, *J* = 2.2 Hz, 1H), 8.18 (dd, *J* = 8.7, 2.3 Hz, 1H), 7.92 (d, *J* = 8.7 Hz, 1H), 7.50 (dd, *J* = 7.5, 2.0 Hz, 2H), 7.45 (d, *J* = 6.8 Hz, 2H), 7.40 – 7.36 (m, 4H), 7.33 (dt, *J* = 8.6, 5.4 Hz, 6H), 6.40 (d, *J* = 1.8 Hz, 1H_β), 5.68 (s, 1H_β-benzylidene), 4.88 – 4.83 (m, 2H), 4.67 (d, *J* = 12.1 Hz, 1H), 4.40 (t, *J* = 9.4 Hz, 1H), 4.30 – 4.25 (m, 1H), 4.00 (dd, *J* = 10.1, 3.2 Hz, 1H), 3.94 – 3.89 (m, 2H), 2.59 – 2.49 (m, 2H), 2.35 – 2.26 (m, 2H), 1.71 – 1.62 (m, 5H).

¹³C NMR (100 MHz, CDCl₃) δ 192.82, 161.60, 149.73, 145.13, 138.25, 138.09, 137.40, 137.19, 131.82, 128.96, 128.51, 128.38, 128.24, 128.20, 128.04, 127.74, 127.71, 125.91, 125.50, 122.89, 101.43, 94.59, 94.05, 78.38, 75.28, 75.19, 73.64, 73.20, 68.37, 67.16, 31.76, 22.23, 21.73, 20.78.

HRMS (ESI): calc. for C₄₃H₃₉O₁₀NNa (M+Na): 752.2472; found: 752.2448. The spectral images for this compound are published in our research article.^[107]

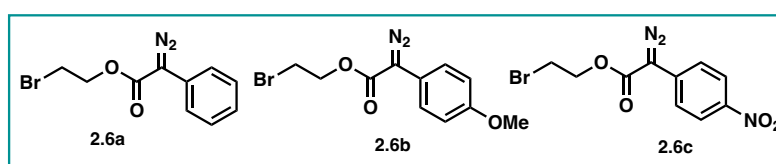
2.4.1.2 Synthesis of second-generation glycosyl donors

List of synthesized glycosyl anomeric thiols



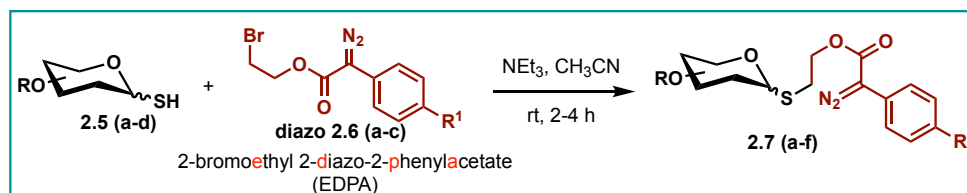
Note: The anomeric thiols were synthesized using literature-reported protocols (**2.5a**, **2.5b**, **2.5d**)^[115] and (**2.5c**)^[116].

List of synthesized diazo linkers



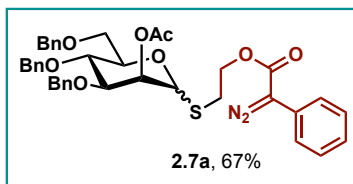
Note: The diazo linkers were synthesized using literature-reported protocols (diazo-1)^[117], (diazo-2)^[118].

General procedure C for the synthesis of diazo-based donor 2.7 (a-f):



To a solution of thiol, **2.5(a-d)** (1.0 equiv) and **diazo linker 2.6(a-c)** (1.15 equiv) in anhydrous CH₃CN (0.3 M) was added triethylamine (1.5 equiv). The mixture was stirred at room temperature for two hours before being concentrated in vacuo. The residue was purified by silica gel column chromatography (hexane: EtOAc = 5:1) to afford the desired EDPA thioglycoside donor **2.7 (a-f)**.

2-O-acetyl-3,4,6-tri-O-benzyl-α/β-D-mannopyranoside EDPA thioglycoside donor (**2.7a**):



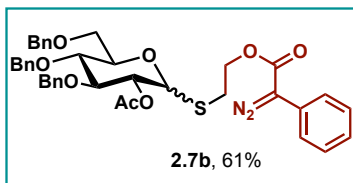
Prepared according to general procedure C: a solution of 2-O-acetyl-3,4,6-tri-O-benzyl-D-mannopyranosyl thiol **2.5a** ^[115] (1 g, 1.98 mmol, 1.0 equiv) was coupled with **diazo linker 2.6a** ^[117] (0.608 g, 2.26 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7a** (0.93 g, 67%, $\alpha:\beta=10:1$). $R_f=0.3$ (hexane: ethyl acetate = 80:20).

¹H NMR (400 MHz, CDCl₃) δ 7.48 (d, $J = 8.0$ Hz, 2H), 7.39 (t, $J = 7.8$ Hz, 2H), 7.31 (dq, $J = 11.5, 5.9$ Hz, 13H), 7.22 – 7.15 (m, 3H), 5.46 (s, 1H), 5.37 (s, 1H), 4.86 (d, $J = 10.7$ Hz, 1H), 4.69 (dd, $J = 11.6, 7.3$ Hz, 2H), 4.51 (dd, $J = 20.5, 11.3$ Hz, 4H), 4.38 (dt, $J = 11.4, 6.9$ Hz, 1H), 4.17 (dd, $J = 8.7, 3.2$ Hz, 1H), 3.97 – 3.88 (m, 2H), 3.84 (dd, $J = 10.5, 4.5$ Hz, 1H), 3.71 (d, $J = 10.7$ Hz, 1H), 2.99 (dt, $J = 13.8, 6.9$ Hz, 1H), 2.88 (dt, $J = 13.7, 6.5$ Hz, 1H), 2.17 (s, 3H).

¹³C NMR (101 MHz, CDCl₃) δ 170.44, 138.31, 138.18, 137.65, 129.07, 128.57, 128.46, 128.42, 128.30, 128.02, 127.99, 127.87, 127.80, 127.71, 126.01, 124.11, 83.31, 78.50, 75.35, 74.49, 73.52, 72.16, 72.05, 70.27, 68.77, 63.51, 30.37, 21.26.

HRMS (ESI): calc. for C₃₉H₄₀N₂NaO₈S (M+Na): 719.2403; found: 719.2420. The spectral images for this compound are published in our research article.^[119]

2-O-acetyl-3,4,6-tri-O-benzyl- α/β -D-glucopyranoside EDPA thioglycoside donor (2.7b):



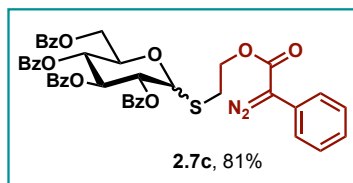
Prepared according to general procedure C: a solution of 2-O-acetyl-3,4,6-tri-O-benzyl-D-glucopyranosyl thiol **2.5b** ^[115] (0.5 g, 0.99 mmol, 1.0 equiv) was coupled with **diazo linker-2.6a** ^[117] (0.291 g, 1.13 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7b** (0.415 g, 61%, $\alpha:\beta=1:10$). $R_f=0.3$ (hexane: ethyl acetate = 80:20).

¹H NMR (400 MHz, CDCl₃) δ 7.47 (d, *J* = 7.8 Hz, 2H), 7.39 (t, *J* = 7.7 Hz, 2H), 7.33 – 7.27 (m, 13H), 7.21 – 7.18 (m, 3H), 5.04 (t, *J* = 9.4 Hz, 1H), 4.81 (dd, *J* = 11.1, 9.1 Hz, 2H), 4.69 (d, *J* = 11.5 Hz, 1H), 4.59 (t, *J* = 11.7 Hz, 2H), 4.54 (d, *J* = 12.1 Hz, 1H), 4.48 – 4.40 (m, 3H), 3.77 – 3.66 (m, 5H), 3.52 (dq, *J* = 7.4, 2.2 Hz, 1H), 3.05 (ddd, *J* = 14.0, 7.7, 6.3 Hz, 1H), 2.88 (ddd, *J* = 13.9, 7.7, 6.2 Hz, 1H), 1.96 (s, 3H).

¹³C NMR (101 MHz, CDCl₃) δ 169.64, 164.72, 138.13, 138.07, 137.86, 128.94, 128.43, 128.39, 128.34, 128.02, 127.88, 127.87, 127.80, 127.74, 127.70, 127.59, 125.87, 125.38, 124.02, 84.21, 83.54, 79.47, 77.74, 75.23, 75.11, 73.51, 73.49, 71.62, 68.81, 64.17, 28.59, 20.89.

HRMS (ESI): calc. for C₃₉H₄₀N₂NaO₈S (M+Na): 719.2403; found: 719.2421. The spectral images for this compound are published in our research article.^[119]

2,3,4,6-tetra-*O*-benzoyl- α/β -D-glucopyranoside EDPA thioglycoside donor (**2.7c**):



Prepared according to general procedure C: a solution of 2,3,4,6-tetra-*O*-benzoyl-D-glucopyranosyl thiol **2.5c**^[116] (0.25 g, 0.408 mmol, 1.0 equiv) was coupled with **diazo linker 2.6a**^[117] (0.132 g, 0.49 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7c** (0.265 g, 81%, $\alpha:\beta=1:8$). *R_f* = 0.2 (hexane: ethyl acetate = 80:20).

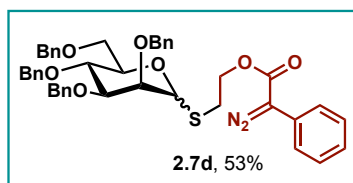
¹H NMR (400 MHz, CDCl₃) δ 8.02 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.98 – 7.90 (m, 5H), 7.82 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.44 (d, *J* = 1.4 Hz, 1H), 7.42 (d, *J* = 1.9 Hz, 2H), 7.40 (s, 1H), 7.39 – 7.35 (m, 8H), 7.29 (d, *J* = 8.2 Hz, 2H), 7.22 – 7.17 (m, 1H), 5.93 (t, *J* = 9.5 Hz, 1H), 5.68 (t, *J* = 9.8 Hz, 1H), 5.57 (t, *J* = 9.7 Hz, 1H), 4.92 (d, *J* = 10.1 Hz, 1H), 4.66 (dd, *J* = 12.2, 3.0 Hz, 1H), 4.52 – 4.46 (m, 2H), 4.44 – 4.35 (m, 1H), 4.19 (ddd, *J* = 9.0, 5.5, 2.9 Hz, 1H), 3.10 (ddd, *J* = 14.1, 8.0, 6.2 Hz, 1H), 2.94 (ddd, *J* = 14.0, 7.9, 6.1 Hz, 1H).

¹³C NMR (101 MHz, CDCl₃) δ 166.16, 165.84, 165.31, 165.29, 133.62, 133.51, 133.40, 133.22, 130.09, 130.03, 129.96, 129.84, 129.81, 129.79, 129.60, 129.07, 129.02, 128.81,

128.77, 128.55, 128.52, 128.46, 128.42, 126.05, 125.36, 124.16, 84.27, 76.56, 73.99, 70.57, 69.50, 64.01, 63.22, 29.23.

HRMS (ESI): calc. for $C_{44}H_{36}N_2NaO_{11}S$ ($M+Na$): 823.1938; found: 823.1956. The spectral images for this compound are published in our research article.^[119]

2,3,4,6-tetra-O-benzyl- α/β -D-mannopyranoside EDPA thioglycoside donor (2.7d):



Prepared according to general procedure C: a solution of 2,3,4,6-tetra-O-benzyl-D-mannopyranosyl thiol **2.5d**^[115] (0.25 g, 0.449 mmol, 1.0 equiv) was coupled with **diazo linker 2.6a**^[117] (0.139 g, 0.52 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7d** (0.177 g, 53%, $\alpha:\beta=10:1$). $R_f = 0.4$ (hexane: ethyl acetate = 80:20).

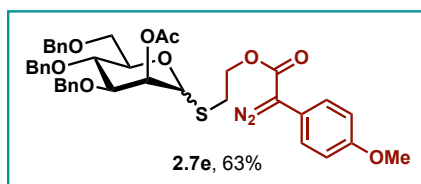
^1H NMR (400 MHz, $CDCl_3$) δ 7.47 (dd, $J = 8.6, 1.2$ Hz, 2H), 7.41 – 7.36 (m, 4H), 7.34 (t, $J = 2.0$ Hz, 1H), 7.31 (dd, $J = 6.9, 2.3$ Hz, 7H), 7.29 – 7.27 (m, 7H), 7.21 – 7.15 (m, 3H), 5.44 (s, 1H), 4.88 (d, $J = 10.7$ Hz, 1H), 4.73 (d, $J = 12.3$ Hz, 1H), 4.67 (s, 1H), 4.64 (s, 1H), 4.55 (d, $J = 4.3$ Hz, 2H), 4.51 (dd, $J = 12.1, 7.8$ Hz, 4H), 4.35 – 4.28 (m, 1H), 4.14 – 4.09 (m, 1H), 4.05 – 3.99 (m, 1H), 3.84 – 3.79 (m, 3H), 3.72 (dd, $J = 10.8, 2.0$ Hz, 1H), 2.99 – 2.91 (m, 1H), 2.82 (dt, $J = 13.7, 6.8$ Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 164.91, 138.46, 138.35, 138.23, 138.01, 129.08, 128.49, 128.43, 128.38, 128.07, 127.92, 127.84, 127.83, 127.79, 127.72, 127.59, 126.00, 125.46, 124.09, 82.42, 80.18, 76.07, 75.26, 74.98, 73.43, 72.31, 72.19, 72.04, 69.12, 63.23, 30.10.

HRMS (ESI): calc. for $C_{44}H_{44}N_2NaO_7S$ ($M+Na$): 767.2767; found: 767.2784. The spectral images for this compound are published in our research article.^[119]

2-O-acetyl-3,4,6-tri-O-benzyl- α/β -D-mannopyranoside 4-OMe-EDPA thioglycoside donor (2.7e): Prepared according to general procedure C: a solution of 2-O-acetyl-3,4,6-tri-O-benzyl-D-mannopyranosyl thiol **2.5a**^[115] (0.1 g, 0.197 mmol, 1.0 equiv) was coupled

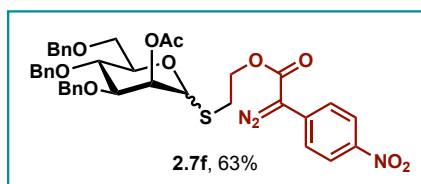
with **diazo linker 2.6b**^[118] (0.068 g, 0.226 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7e** (0.087 g, 61%, $\alpha:\beta=10:1$). $R_f = 0.3$ (hexane: ethyl acetate = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 7.38 – 7.35 (m, 3H), 7.33 – 7.27 (m, 17H), 7.16 (dd, $J = 7.2, 2.3$ Hz, 3H), 6.95 – 6.92 (m, 2H), 5.45 (dd, $J = 3.0, 1.7$ Hz, 1H), 5.35 (d, $J = 1.6$ Hz, 1H), 4.85 (d, $J = 10.7$ Hz, 1H), 4.68 (dd, $J = 11.6, 6.2$ Hz, 3H), 4.52 (d, $J = 11.1$ Hz, 1H), 4.50 – 4.45 (m, 4H), 4.35 (dt, $J = 11.3, 7.0$ Hz, 1H), 3.93 – 3.89 (m, 2H), 3.80 (s, 3H), 3.70 (dd, $J = 10.7, 2.1$ Hz, 1H), 2.97 (dt, $J = 13.8, 7.0$ Hz, 1H), 2.90 – 2.82 (m, 1H), 2.16 (s, 3H).

¹³C NMR (101 MHz, CDCl₃) δ 170.46, 158.21, 138.32, 138.19, 137.65, 128.57, 128.45, 128.42, 128.30, 128.28, 128.05, 128.01, 127.99, 127.96, 127.91, 127.88, 127.80, 127.72, 126.14, 116.78, 114.72, 114.37, 114.22, 114.16, 83.28, 78.49, 77.34, 75.34, 74.49, 73.57, 73.51, 72.14, 72.04, 70.27, 68.77, 63.48, 55.45, 55.41, 49.57, 30.35, 29.81, 21.23, 21.17, 14.30, 14.24. The spectral images for this compound are published in our research article.^[119]

2-O-acetyl-3,4,6-tri-O-benzyl- α/β -D-mannopyranoside 4-NO₂-EDPA thioglycoside donor (2.7f):



Prepared according to general procedure C: a solution of 2-O-acetyl-3,4,6-tri-O-benzyl-D-mannopyranosyl thiol **2.5a**^[115] (0.1 g, 0.196 mmol, 1.0 equiv) was coupled with **diazo linker 2.6c** (0.071 g, 0.226 mmol, 1.15 equiv) to afford EDPA thioglycoside donor **2.7f** (0.063 g, 43%, $\alpha:\beta=10:1$). $R_f = 0.2$ (hexane: ethyl acetate = 80:20).

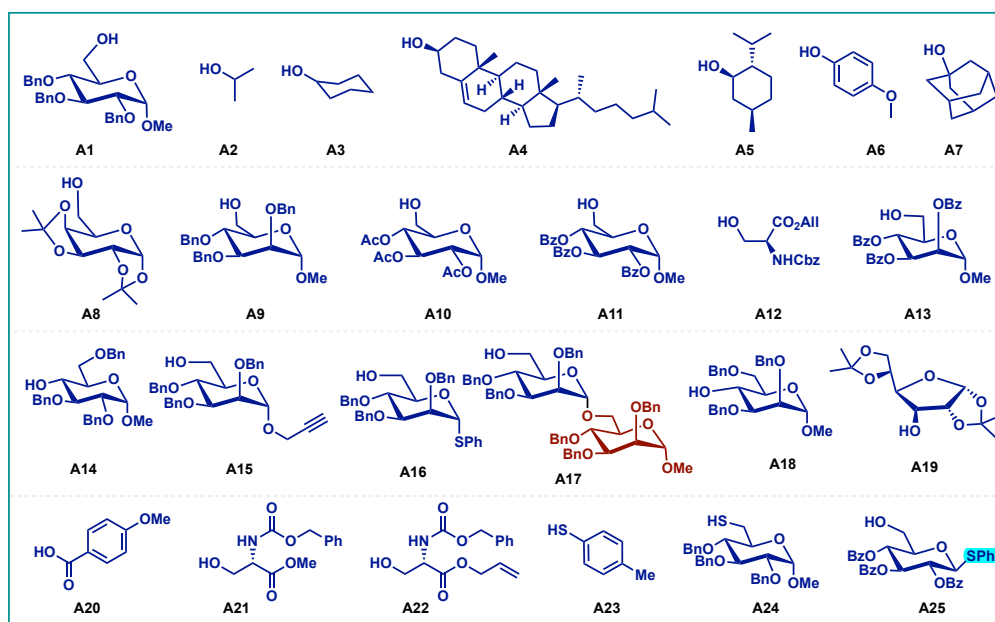
¹H NMR (400 MHz, CDCl₃) δ 8.22 (d, $J = 9.1$ Hz, 2H), 7.64 (d, $J = 9.1$ Hz, 2H), 7.31 (q, $J = 7.9$ Hz, 13H), 7.19 – 7.13 (m, 2H), 5.43 (s, 1H), 5.35 (s, 1H), 4.85 (d, $J = 10.7$ Hz, 1H),

4.70 – 4.62 (m, 2H), 4.53 (d, $J = 11.1$ Hz, 2H), 4.49 (d, $J = 4.7$ Hz, 1H), 4.46 (d, $J = 3.2$ Hz, 1H), 4.41 (dt, $J = 11.3, 6.8$ Hz, 1H), 4.15 (dd, $J = 7.6, 4.5$ Hz, 1H), 3.94 – 3.86 (m, 2H), 3.81 (dd, $J = 10.7, 4.6$ Hz, 1H), 3.72 – 3.68 (m, 1H), 2.99 (dt, $J = 13.7, 6.8$ Hz, 1H), 2.88 (dt, $J = 13.6, 6.4$ Hz, 1H), 2.17 (s, 3H).

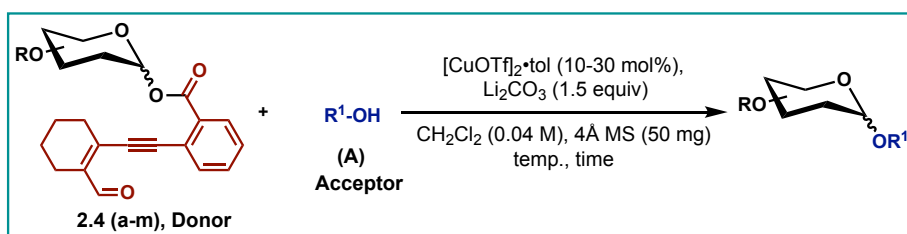
^{13}C NMR (101 MHz, CDCl_3) δ 170.28, 163.25, 145.09, 138.13, 138.05, 137.49, 133.64, 128.43, 128.33, 128.27, 128.10, 127.88, 127.86, 127.70, 127.64, 127.57, 124.27, 123.19, 83.15, 78.32, 75.23, 74.43, 73.38, 72.14, 71.93, 70.17, 68.79, 63.82, 30.17, 21.05.

HRMS (ESI): calc. for $\text{C}_{39}\text{H}_{39}\text{N}_3\text{NaO}_{10}\text{S}$ ($\text{M}+\text{Na}$): 764.2254; found: 764.2269. The spectral images for this compound are published in our research article.^[119]

List of acceptors used in this Thesis

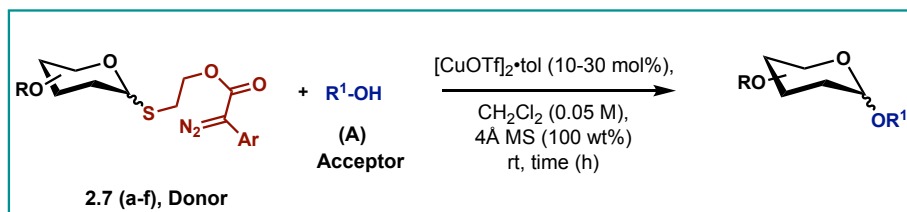


General procedure D for the Cu(I)-catalyzed activation of first-generation glycosyl donors:



A 5 mL dried Schlenk flask was charged with the corresponding acceptor **A** (0.05 mmol, 1.0 equiv), first-generation donor **2.4** (0.1 mmol, 2.0 equiv), [Cu(I)OTf]₂•tol (0.3 mmol, 30 mol%) with respect to the alcohol, Li₂CO₃ (0.06 mmol, 1.2 equiv.), 4Å molecular sieve and 2 mL CH₂Cl₂. The resulting solution was stirred at 0 °C or room temperature, and the progress was monitored by TLC (2-24 h). After completion, saturated NaHCO₃ solution was added, the aqueous phase was extracted with CH₂Cl₂ (3x), 1,3,5-trimethoxybenzene (0.05 mmol, 1.0 eq.) was added, and the organic phases were concentrated in vacuo. The product yield and anomeric ratio were determined by ¹H NMR.

General procedure E for the Cu(I)-catalyzed activation of second-generation glycosyl donors:

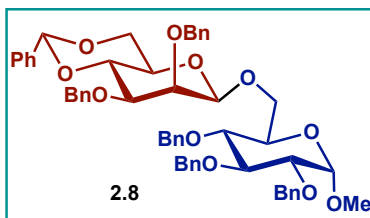


In an oven-dried vial equipped with a stir bar, acceptor **(A)** (0.050 mmol) was combined with EDPA thioglycoside donor **2.7(a-f)** (0.075 mmol, 1.5 equiv), 4Å molecular sieves (50 mg or 100 wt.%), and [Cu(OTf)₂].tol (0.002 mmol, 0.1 equiv) dissolved in CH₂Cl₂ (0.05 M). Upon complete addition, the reaction mixture was stirred at the ambient temperature, and the reaction progress was monitored by TLC and quenched with saturated aqueous NaHCO₃ upon completion. The layers were separated, and the aqueous layer was washed with ethyl acetate. The organic layers were combined, dried over Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl acetate and passed through a short silica pad to remove traces of iron (to check the crude material via ¹H-NMR). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.

Note: The donor was added in three portions initially, 0.8 equiv was charged, and TLC was used to monitor the reaction progress. Upon complete consumption of the donor, 0.35 equiv was added to the reaction mixture twice.

2.4.2 Substrate Scope of Activation of First- and Second-Generation Donors:

Methyl (2,3-di-O-benzyl-4,6-O-benzylidene- β -D-mannopyranosyl) -(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (2.8)



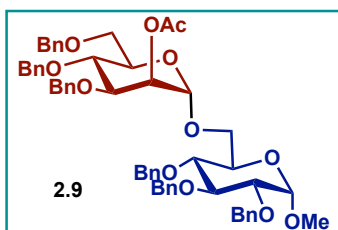
Prepared according to the General Procedure **D** at 0 °C in 24 h, yielding the product **2.8** as a white paste (40 mg, 90%, α : β = 1:8) or at rt in 2 h (81%, α : β = 1:5).

^1H NMR (600 MHz, CDCl_3) δ 7.53 – 7.48 (m, 2H), 7.45 – 7.10 (m, 28H), 5.60 (s, 1H), 5.03 (d, J = 10.9 Hz, 1H), 4.93 (d, J = 12.2 Hz, 1H), 4.87 – 4.75 (m, 4H), 4.72 (d, J = 12.4 Hz, 1H), 4.67 (d, J = 12.1 Hz, 1H), 4.62 (d, J = 12.5 Hz, 1H), 4.59 (d, J = 3.5 Hz, 1H), 4.51 (d, J = 11.6 Hz, 1H), 4.26 (dd, J = 10.5, 4.8 Hz, 1H), 4.19 (t, J = 9.6 Hz, 1H), 4.11 – 4.06 (m, 2H), 4.02 (t, J = 9.3 Hz, 1H), 3.91 (t, J = 10.3 Hz, 1H), 3.76 (ddd, J = 10.0, 5.0, 1.9 Hz, 1H), 3.70 (d, J = 3.0 Hz, 1H), 3.53 – 3.43 (m, 4H), 3.33 (s, 3H), 3.23 (td, J = 9.7, 4.8 Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.95, 138.52, 138.49, 138.47, 138.16, 137.72, 128.98, 128.69, 128.62, 128.54, 128.49, 128.47, 128.35, 128.32, 128.22, 128.11, 128.07, 127.82, 127.77, 127.70, 126.16, 102.10, 101.52, 97.95, 82.33, 79.91, 78.78, 77.95, 77.48, 75.72, 74.84, 74.66, 73.48, 72.65, 69.75, 68.67, 68.36, 67.67, 55.24.

LRMS (ESI): calc. for $\text{C}_{55}\text{H}_{62}\text{NO}_{11}$ ($\text{M}+\text{NH}_4^+$): 912.4; found: 912.5. The data were in accordance with the literature^[120-121], and the spectral images for this compound are published in our research article.^[107]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (2.9)



Prepared according to General Procedure **D** at rt in 5 h, yielding the product **2.9** as a white paste (40 mg, 78%, α -only).

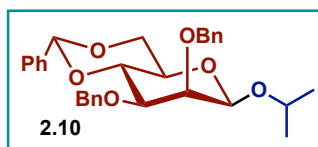
Following the general procedure **E**, glycosyl acceptor **A1** (24.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μ mol) to afford **2.9** (43.0 mg, 45.8 μ mol, 88% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

^1H NMR (600 MHz, CDCl_3) δ 7.38 – 7.35 (m, 2H), 7.34 – 7.30 (m, 10H), 7.29 – 7.26 (m, 10H), 7.25 – 7.23 (m, 3H), 7.20 (dd, J = 5.5, 2.1 Hz, 2H), 7.15 (dd, J = 7.5, 2.0 Hz, 1H), 7.13 (dd, J = 7.2, 2.1 Hz, 2H), 5.39 (td, J = 3.8, 1.9 Hz, 1H), 4.99 (d, J = 10.8 Hz, 1H), 4.90 (d, J = 1.9 Hz, 1H), 4.88 – 4.86 (m, 1H), 4.86 – 4.84 (m, 1H), 4.79 (d, J = 4.1 Hz, 1H), 4.78 (d, J = 5.3 Hz, 1H), 4.70 – 4.69 (m, 1H), 4.67 (s, 1H), 4.64 – 4.62 (m, 1H), 4.58 (d, J = 3.5 Hz, 1H), 4.53 (d, J = 6.0 Hz, 1H), 4.52 – 4.49 (m, 1H), 4.48 (s, 1H), 4.46 (d, J = 3.5 Hz, 1H), 4.43 (d, J = 8.6 Hz, 1H), 3.98 (t, J = 9.3 Hz, 1H), 3.91 (dd, J = 9.5, 3.2 Hz, 1H), 3.86 (t, J = 9.5 Hz, 1H), 3.81 – 3.78 (m, 1H), 3.73 – 3.70 (m, 3H), 3.66 (dd, J = 10.8, 4.2 Hz, 1H), 3.63 (dd, J = 11.4, 1.9 Hz, 1H), 3.54 (ddd, J = 13.3, 10.2, 2.8 Hz, 2H), 3.45 – 3.41 (m, 1H), 3.32 (s, 3H), 2.13 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.31, 138.67, 138.50, 138.27, 138.20, 138.16, 138.09, 137.76, 128.45, 128.38, 128.34, 128.31, 128.24, 128.21, 128.15, 128.09, 128.07, 128.00, 127.92, 127.89, 127.86, 127.75, 127.72, 127.66, 127.63, 127.61, 127.59, 127.52, 127.48, 97.99, 97.78, 82.07, 80.07, 77.61, 77.58, 75.75, 75.12, 75.03, 74.90, 74.48, 74.17, 73.48, 73.32, 71.79, 71.57, 71.45, 71.38, 69.62, 68.90, 68.67, 68.48, 66.07, 55.08, 21.12.

LRMS (ESI): calc. for $\text{C}_{57}\text{H}_{66}\text{NO}_{12}$ ($\text{M}+\text{NH}_4^+$): 956.5; found: 956.8. The data were in accordance with the literature^[122], and the spectral images for this compound are published in our research article.^[119]

Isopropyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene- β -D-mannopyranoside (**2.10**)



Prepared according to General Procedure **D** at 0 °C in 5 h, yielding the product **2.10** as a colorless oil (21.6 mg, 88%, α : β = 1:4) or at rt in 2 h (21.5 mg, 84%, α : β = 1:4).

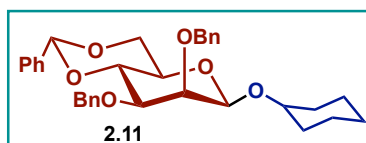
^1H NMR (600 MHz, CDCl_3) δ 7.50 (td, J = 8.2, 1.5 Hz, 4H), 7.40 – 7.24 (m, 11H), 5.62 (s, 1H), 5.00 (d, J = 12.4 Hz, 1H), 4.90 (d, J = 12.4 Hz, 1H), 4.67 (d, J = 12.5 Hz, 1H), 4.63

– 4.48 (m, 2H), 4.29 (dd, $J = 10.4, 4.9$ Hz, 1H), 4.22 (t, $J = 9.6$ Hz, 1H), 4.03 – 3.91 (m, 2H), 3.86 (dd, $J = 3.2, 1.0$ Hz, 1H), 3.58 (dd, $J = 9.9, 3.2$ Hz, 1H), 3.32 (td, $J = 9.8, 4.9$ Hz, 1H), 1.28 (d, $J = 6.2$ Hz, 3H), 1.16 (d, $J = 6.1$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.70, 138.56, 137.81, 128.96, 128.88, 128.43, 128.32, 128.19, 127.66, 127.64, 127.60, 126.20, 101.53, 100.31, 78.80, 78.23, 76.38, 74.78, 72.43, 71.56, 68.85, 67.72, 23.69, 21.81.

LRMS (ESI): calc. for $\text{C}_{30}\text{H}_{35}\text{O}_6$ ($\text{M}+\text{H}^+$): 491.2; found: 491.4. The data were in accordance with the literature^[120], and the spectral images for this compound are published in our research article.^[107]

Cyclohexyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene- β -D-mannopyranoside (**2.11**)



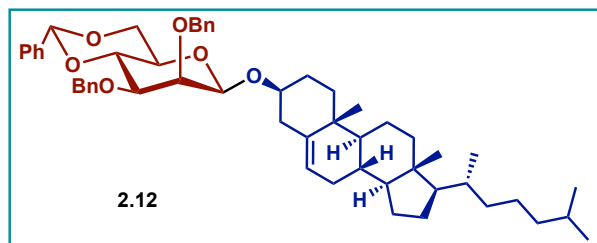
Prepared according to General Procedure d at 0 °C in 16 h, yielding the product **2.11** as a colorless oil (23 mg, 87%, $\alpha:\beta = 1:5.5$).

^1H NMR (400 MHz, CDCl_3) δ 7.54 – 7.45 (m, 4H), 7.41 – 7.23 (m, 11H), 5.62 (s, 1H), 5.02 (d, $J = 12.5$ Hz, 1H), 4.91 (d, $J = 12.5$ Hz, 1H), 4.67 (d, $J = 12.5$ Hz, 1H), 4.58 (dd, $J = 6.8, 5.8$ Hz, 2H), 4.30 (dd, $J = 10.4, 4.9$ Hz, 1H), 4.22 (t, $J = 9.6$ Hz, 1H), 3.94 (t, $J = 10.3$ Hz, 1H), 3.87 (dd, $J = 3.2, 0.9$ Hz, 1H), 3.70 (tt, $J = 8.5, 3.8$ Hz, 1H), 3.58 (dd, $J = 9.9, 3.2$ Hz, 1H), 3.31 (ddd, $J = 10.1, 9.2, 4.9$ Hz, 1H), 1.97 – 1.88 (m, 1H), 1.86 – 1.67 (m, 1H), 1.53 – 1.47 (m, 2H), 1.37 – 1.28 (m, 4H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.71, 138.56, 137.81, 128.95, 128.88, 128.42, 128.31, 128.22, 127.65, 127.63, 127.60, 126.20, 101.51, 100.14, 78.79, 78.27, 76.33, 74.73, 72.42, 68.86, 67.71, 33.52, 31.60, 25.81, 23.90, 23.76.

LRMS (ESI): calc. for $\text{C}_{33}\text{H}_{42}\text{NO}_6$ ($\text{M}+\text{NH}_4^+$): 548.3; found: 548.2. The data were in accordance with the literature^[120], and the spectral images for this compound are published in our research article.^[107]

Cholesteryl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene- β -D-mannopyranoside (**2.12**)



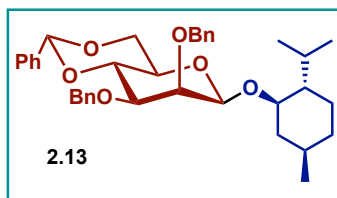
Prepared according to General Procedure **D** at 0 °C in 16 h, yielding the product **2.12** as an off-white paste (35.5 mg 90%, $\alpha:\beta$ = 1:6).

¹H NMR (600 MHz, CDCl₃) δ 7.50 (ddd, J = 7.7, 6.0, 1.6 Hz, 4H), 7.40 – 7.26 (m, 11H), 5.61 (s, 1H), 5.34 (dd, J = 5.1, 2.4 Hz, 1H), 4.99 (d, J = 12.4 Hz, 1H), 4.90 (d, J = 12.5 Hz, 1H), 4.69 (d, J = 12.5 Hz, 1H), 4.60 (d, J = 12.6 Hz, 2H), 4.29 (dd, J = 10.4, 4.9 Hz, 1H), 4.21 (t, J = 9.6 Hz, 1H), 3.93 (t, J = 10.3 Hz, 1H), 3.89 – 3.84 (m, 1H), 3.62 – 3.52 (m, 2H), 3.31 (td, J = 9.7, 4.8 Hz, 1H), 2.29 (ddd, J = 13.4, 5.1, 2.4 Hz, 1H), 2.25 – 2.18 (m, 1H), 2.04 – 1.94 (m, 4H), 1.90 – 1.80 (m, 3H), 1.65 – 1.42 (m, 7H), 1.40 – 1.32 (m, 4H), 1.29 – 1.23 (m, 2H), 1.20 – 1.05 (m, 10H), 1.04 – 0.96 (m, 7H), 0.92 (dd, J = 6.6, 2.2 Hz, 5H), 0.87 (dd, J = 6.6, 2.6 Hz, 10H), 0.68 (d, J = 6.5 Hz, 4H).

¹³C NMR (100 MHz, CDCl₃) δ 140.65, 138.67, 138.55, 137.80, 128.93, 128.44, 128.40, 128.31, 128.22, 128.19, 127.66, 127.63, 127.56, 126.20, 122.15, 101.53, 100.18, 78.79, 78.21, 76.36, 74.81, 72.46, 68.84, 67.68, 56.90, 56.29, 50.33, 42.48, 39.91, 39.67, 38.94, 37.36, 36.92, 36.34, 35.94, 32.11, 32.04, 29.76, 28.39, 28.17, 24.45, 23.98, 22.98, 22.72, 21.21, 19.56, 19.50, 18.88, 12.02.

LRMS (ESI): calc. for C₅₄H₇₆NO₆ (M+NH₄⁺): 834.6; found: 834.6. The data were in accordance with the literature^[123-124], and the spectral images for this compound are published in our research article.^[107]

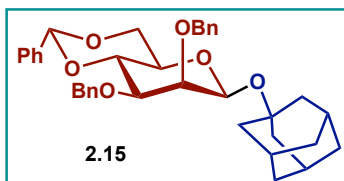
***l*-Menthyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene- β -D-mannopyranoside (**2.13**)**



Prepared according to General Procedure **D** at 0 °C in 5 h (28 mg 95%, $\alpha:\beta$ = 1:4) or at rt in 2 h (88%, $\alpha:\beta$ = 1:4), yielding the product **2.13** as a colorless oil.

LRMS (ESI): calc. for $C_{34}H_{35}O_7$ ($M+H^+$): 555.2; found: 555.1. The data were in accordance with the literature^[125], and the spectral images for this compound are published in our research article.^[107]

Adamantanyl 2,3-di-O-benzyl-4,6-O-benzylidene- β -D-mannopyranoside (2.15)



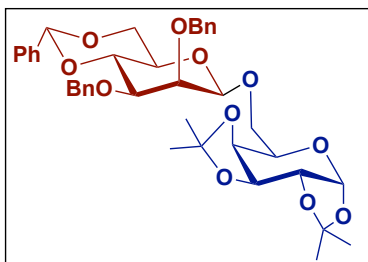
Prepared according to General Procedure **D** at rt in 10 h yielding the product **2.15** as a white paste (25 mg, 87%, $\alpha:\beta = 1:5$).

^1H NMR (600 MHz, $CDCl_3$) δ 7.52 – 7.47 (m, 4H), 7.39 – 7.25 (m, 11H), 5.61 (s, 1H), 5.02 (d, $J = 12.5$ Hz, 1H), 4.93 (d, $J = 12.5$ Hz, 1H), 4.75 (d, $J = 1.1$ Hz, 1H), 4.68 (d, $J = 12.5$ Hz, 1H), 4.58 (d, $J = 12.4$ Hz, 1H), 4.25 (dd, $J = 10.4, 4.9$ Hz, 1H), 4.20 (t, $J = 9.6$ Hz, 1H), 3.93 (t, $J = 10.3$ Hz, 1H), 3.77 (dd, $J = 3.2, 1.0$ Hz, 1H), 3.59 (dd, $J = 9.9, 3.2$ Hz, 1H), 3.31 (td, $J = 9.7, 4.9$ Hz, 1H), 2.18 – 2.13 (m, 4H), 1.88 – 1.82 (m, 3H), 1.79 – 1.74 (m, 3H), 1.71 (d, $J = 2.9$ Hz, 2H), 1.68 – 1.58 (m, 9H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.75, 138.62, 137.88, 128.98, 128.93, 128.40, 128.30, 128.18, 127.62, 127.59, 127.57, 126.22, 101.53, 95.02, 78.76, 78.56, 75.35, 74.76, 72.45, 69.00, 67.46, 45.51, 42.56, 36.38, 36.23, 30.88, 30.77.

LRMS (ESI): calc. for $C_{37}H_{46}NO_6$ ($M+NH_4^+$): 600.3; found: 600.3. The data were in accordance with the literature^[123,126], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3-di-O-benzyl-4,6-O-benzylidene- β -D-mannopyranosyl) -(1 $\rightarrow$ 6)-1,2:3,4-di-O-isopropylidene- α -D-galactopyranoside (2.16)



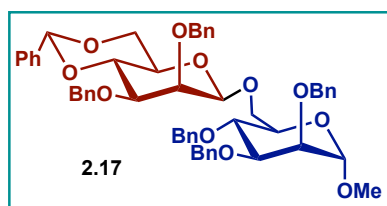
Prepared according to General Procedure **D** at 0 °C in 12 h, yielding the product **2.16** as a colorless oil (32.8 mg, 95%, $\alpha:\beta = 1:3$).

¹H NMR (600 MHz, CDCl₃) δ 7.53 – 7.47 (m, 4H), 7.42 – 7.21 (m, 11H), 5.62 (s, 1H), 5.59 (d, J = 5.0 Hz, 1H), 5.02 (d, J = 12.2 Hz, 1H), 4.91 (d, J = 12.3 Hz, 1H), 4.65 – 4.54 (m, 4H), 4.37 – 4.27 (m, 2H), 4.25 – 4.15 (m, 3H), 4.13 – 4.07 (m, 1H), 4.03 (dd, J = 3.2, 0.9 Hz, 1H), 3.93 (t, J = 10.3 Hz, 1H), 3.64 (dd, J = 10.8, 8.3 Hz, 1H), 3.55 (dd, J = 9.9, 3.2 Hz, 1H), 3.32 (td, J = 9.8, 4.9 Hz, 1H), 1.51 (s, 3H), 1.45 (s, 3H), 1.35 (s, 3H), 1.33 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 138.48, 138.37, 137.74, 128.97, 128.42, 128.40, 128.34, 128.31, 127.68, 127.66, 126.20, 109.69, 108.92, 103.06, 101.56, 96.55, 78.64, 75.04, 74.71, 72.24, 71.76, 70.93, 70.62, 70.25, 68.75, 68.13, 67.72, 26.21, 26.13, 25.22, 24.55.

LRMS (ESI): calc. for C₃₉H₅₀NO₁₁ (M+NH₄⁺): 708.3; found: 708.3. The data were in accordance with the literature^[126-127], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3-di-O-benzyl-4,6-O-benzylidene-β-D-mannopyranosyl) -(1→6)-2,3,4-tri-O-benzyl-α-D-mannopyranoside (2.17)



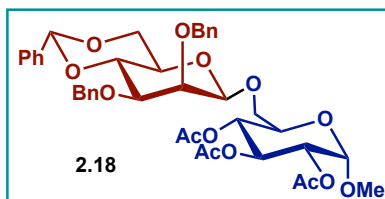
Prepared according to General Procedure **D** at rt in 14 h yielding the product **2.17** as a colorless oil (36 mg, 81%, α:β = 1:5).

¹H NMR (600 MHz, CDCl₃) δ 7.53 – 7.49 (m, 2H), 7.49 – 7.45 (m, 2H), 7.41 – 7.21 (m, 26H), 5.61 (s, 1H), 4.96 (d, J = 12.3 Hz, 1H), 4.89 (d, J = 11.5 Hz, 1H), 4.83 (d, J = 12.2 Hz, 1H), 4.73 – 4.61 (m, 7H), 4.56 (dd, J = 12.0, 6.0 Hz, 2H), 4.28 (dd, J = 10.4, 4.8 Hz, 1H), 4.24 (d, J = 0.9 Hz, 1H), 4.20 – 4.15 (m, 2H), 3.96 – 3.83 (m, 4H), 3.81 – 3.75 (m, 3H), 3.56 (dd, J = 10.5, 6.2 Hz, 1H), 3.48 (dd, J = 9.9, 3.2 Hz, 1H), 3.26 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 138.62, 138.53, 138.29, 137.79, 128.96, 128.91, 128.52, 128.46, 128.43, 128.32, 128.27, 128.06, 127.82, 127.75, 127.71, 127.56, 126.19, 102.75, 101.52, 98.98, 80.50, 78.74, 75.34, 75.02, 74.73, 74.54, 72.87, 72.47, 72.12, 71.36, 69.13, 68.76, 67.66, 54.80.

LRMS (ESI): calc. for $C_{55}H_{62}NO_{11}$ ($M+NH_4^+$): 912.4; found: 912.5. The data were in accordance with the literature^[121,128], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3-di-O-benzyl-4,6-O-benzylidene- β -D-mannopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-acetyl- α -D-glucopyranoside (2.18)



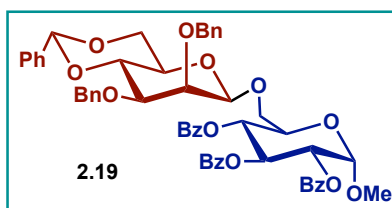
Prepared according to General Procedure **D** at rt in 24 h yielding the product **2.18** as a colorless oil (18.8 mg, 50%, $\alpha:\beta = 1:5$).

^1H NMR (600 MHz, $CDCl_3$) δ 7.48 (ddd, $J = 18.0, 8.1, 1.6$ Hz, 4H), 7.40 – 7.25 (m, 11H), 5.61 (s, 1H), 5.50 (dd, $J = 10.2, 9.3$ Hz, 1H), 5.01 – 4.93 (m, 3H), 4.88 – 4.83 (m, 2H), 4.68 (d, $J = 12.5$ Hz, 1H), 4.58 (d, $J = 12.5$ Hz, 1H), 4.48 (d, $J = 0.9$ Hz, 1H), 4.30 (dd, $J = 10.4, 4.9$ Hz, 1H), 4.20 (t, $J = 9.6$ Hz, 1H), 4.05 – 3.98 (m, 3H), 3.92 (t, $J = 10.3$ Hz, 1H), 3.60 (dd, $J = 9.9, 3.1$ Hz, 1H), 3.52 – 3.48 (m, 1H), 3.37 (s, 3H), 3.35 – 3.29 (m, 1H), 2.08 (s, 3H), 2.03 (s, 3H), 2.02 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 170.31, 170.15, 170.00, 138.50, 138.41, 137.66, 129.00, 128.61, 128.53, 128.47, 128.43, 128.42, 128.34, 128.32, 128.19, 127.87, 127.73, 127.67, 126.25, 126.18, 126.14, 102.66, 101.57, 96.61, 78.63, 77.89, 76.24, 75.25, 72.49, 71.08, 70.25, 69.21, 68.73, 68.66, 68.44, 67.77, 55.40, 20.90, 20.88, 20.84.

LRMS (ESI): calc. for $C_{40}H_{50}NO_{14}$ ($M+NH_4^+$): 768.3; found: 768.6. The data were in accordance with the literature^[126], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3-di-O-benzyl-4,6-O-benzylidene- β -D-mannopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (2.19)



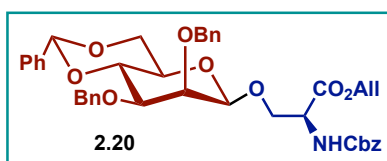
Prepared according to General Procedure **D** at 0 °C in 36 h, yielding the product as a colorless oil (43.5 mg, 93%, $\alpha:\beta = 1:6$).

¹H NMR (600 MHz, CDCl₃) δ 8.00 – 7.97 (m, 2H), 7.95 – 7.92 (m, 2H), 7.86 (dd, $J = 8.4$, 1.3 Hz, 2H), 7.54 – 7.47 (m, 6H), 7.44 – 7.41 (m, 1H), 7.41 – 7.33 (m, 10H), 7.32 – 7.27 (m, 8H), 6.19 – 6.11 (m, 1H), 5.59 (s, 1H), 5.53 – 5.45 (m, 1H), 5.28 – 5.23 (m, 2H), 5.02 (d, $J = 12.1$ Hz, 1H), 4.92 (d, $J = 12.1$ Hz, 1H), 4.69 (d, $J = 12.4$ Hz, 1H), 4.59 (d, $J = 12.5$ Hz, 1H), 4.49 (d, $J = 1.0$ Hz, 1H), 4.29 (ddd, $J = 10.3$, 6.5, 1.9 Hz, 1H), 4.23 – 4.12 (m, 3H), 4.07 (dd, $J = 3.1$, 0.9 Hz, 1H), 3.86 (t, $J = 10.3$ Hz, 1H), 3.66 (dd, $J = 11.0$, 6.6 Hz, 1H), 3.59 (dd, $J = 9.9$, 3.1 Hz, 1H), 3.44 (s, 3H), 3.28 (td, $J = 9.8$, 4.9 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 165.98, 165.88, 165.64, 138.62, 138.45, 137.69, 133.68, 133.52, 133.24, 130.08, 129.99, 129.80, 129.37, 129.20, 128.98, 128.95, 128.65, 128.62, 128.57, 128.44, 128.42, 128.36, 128.31, 127.74, 127.69, 126.19, 102.78, 101.54, 96.98, 78.61, 77.90, 76.18, 75.24, 72.46, 72.28, 70.58, 69.56, 68.98, 68.83, 68.63, 67.74, 55.64.

LRMS (ESI): calc. for C₅₅H₅₆NO₁₄ (M+NH₄⁺): 954.4; found: 954.4. The data were in accordance with the literature^[127], and the spectral images for this compound are published in our research article.^[107]

Allyl ***N*-(benzyloxycarbonyl)-*O*-(2,3-di-*O*-benzyl-4,6-*O*-benzylidene- β -D-mannopyranosyl)-*L*-serinate (2.20)**

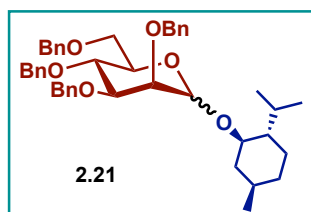


Prepared according to General Procedure **D** at 0 °C in 10 h, yielding the product **2.20** as a colorless oil (24 mg, 68%, $\alpha:\beta = 1:3$).

¹H NMR (600 MHz, CDCl₃) δ 7.51 – 7.48 (m, 2H), 7.43 – 7.23 (m, 18H), 5.89 (ddt, $J = 16.4$, 10.9, 5.7 Hz, 1H), 5.61 (s, 1H), 5.56 (d, $J = 8.3$ Hz, 1H), 5.33 (dd, $J = 17.3$, 1.5 Hz, 1H), 5.24 (dd, $J = 10.4$, 1.3 Hz, 1H), 5.13 (d, $J = 2.3$ Hz, 2H), 4.87 (d, $J = 12.3$ Hz, 1H), 4.76 (d, $J = 12.3$ Hz, 1H), 4.73 – 4.67 (m, 2H), 4.66 – 4.61 (m, 2H), 4.60 – 4.55 (m, 2H), 4.40 (s, 1H), 4.36 (dd, $J = 10.1$, 3.4 Hz, 1H), 4.29 (dd, $J = 10.4$, 4.8 Hz, 1H), 4.19 (t, $J = 9.6$ Hz, 1H), 3.89 (dd, $J = 6.7$, 3.6 Hz, 2H), 3.78 (dd, $J = 10.2$, 3.4 Hz, 1H), 3.55 (dd, $J = 9.9$, 3.1 Hz, 1H), 3.28 (td, $J = 9.7$, 4.8 Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.98, 165.88, 165.64, 138.62, 138.45, 137.69, 133.68, 133.52, 133.24, 130.08, 129.99, 129.80, 129.37, 129.20, 128.98, 128.95, 128.65, 128.62, 128.57, 128.44, 128.42, 128.36, 128.31, 127.74, 127.69, 126.19, 102.78, 101.54, 96.98, 78.61, 77.90, 76.18, 75.24, 72.46, 72.28, 70.58, 69.56, 68.98, 68.83, 68.63, 67.74, 55.64. **LRMS (ESI)**: calc. for $\text{C}_{41}\text{H}_{43}\text{NNaO}_4$ ($\text{M}+\text{Na}^+$): 732.3; found: 732.2. The data were in accordance with the literature^[123], and the spectral images for this compound are published in our research article.^[107]

***l*-Menthyl 2,3,4,6-tetra-*O*-benzyl-*D*-mannopyranoside (2.21)**



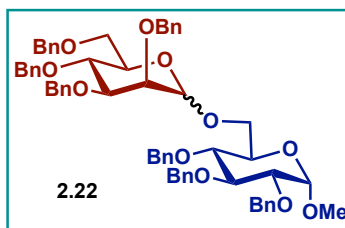
Prepared according to General Procedure **D** at rt in 4 h, yielding the product **2.21** as a white paste and an inseparable mixture of two diastereomers (27 mg, 77%, $\alpha:\beta = 1:1.5$).

^1H NMR (400 MHz, CDCl_3) δ 7.38 (dd, $J = 8.1, 1.7$ Hz, 6H), 7.35 – 7.26 (m, 10H), 7.20 (dd, $J = 7.3, 2.2$ Hz, 2H), 4.94 – 4.88 (m, 2H), 4.78 – 4.61 (m, 5H), 4.58 – 4.51 (m, 2H), 3.27 (td, $J = 10.6, 4.3$ Hz, 1H), 2.21 – 2.14 (m, 1H), 1.80 (pd, $J = 7.0, 2.7$ Hz, 1H), 1.65 – 1.55 (m, 2H), 1.39 – 1.30 (m, 1H), 1.13 (ddt, $J = 12.5, 10.4, 3.0$ Hz, 1H), 1.01 – 0.90 (m, 3H), 0.89 – 0.77 (m, 7H), 0.67 (d, $J = 6.9$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.60, 138.56, 138.53, 138.27, 128.32, 128.22, 128.07, 128.00, 127.78, 127.68, 127.64, 127.56, 127.54, 127.37, 99.86, 81.08, 80.11, 75.29, 75.16, 74.45, 73.29, 72.39, 72.26, 71.81, 69.53, 48.68, 42.87, 34.30, 31.61, 25.75, 23.26, 22.19, 21.04, 16.30.

LRMS (ESI): calc. for $\text{C}_{44}\text{H}_{58}\text{NO}_6$ ($\text{M}+\text{NH}_4^+$): 696.4; found: 696.8. The data were in accordance with the literature^[129], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3,4,6-tetra-*O*-benzyl-*D*-mannopyranosyl)-(1 $\rightarrow$ 6) 2,3,4-tri-*O*-benzyl- α -*D*-glucopyranoside (2.22)



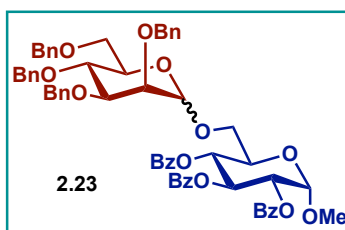
Prepared according to General Procedure **D** at rt in 8 h, yielding the product as a white paste (29 mg, 59%, $\alpha:\beta = 1:1$).

^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.20 (m, 37H), 7.17 – 7.13 (m, 2H), 4.99 (d, $J = 10.9$ Hz, 2H), 4.87 (dd, $J = 10.9, 7.8$ Hz, 2H), 4.82 – 4.75 (m, 3H), 4.73 – 4.65 (m, 4H), 4.64 – 4.59 (m, 3H), 4.57 (d, $J = 3.5$ Hz, 1H), 4.52 – 4.42 (m, 4H), 3.99 (q, $J = 9.4$ Hz, 3H), 3.88 – 3.81 (m, 2H), 3.79 (s, 1H), 3.73 – 3.57 (m, 6H), 3.46 (dd, $J = 9.7, 3.4$ Hz, 1H), 3.43 – 3.37 (m, 1H), 3.31 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.66, 138.63, 138.46, 138.42, 138.36, 138.18, 138.13, 128.48, 128.40, 128.35, 128.26, 128.21, 128.01, 127.99, 127.93, 127.84, 127.75, 127.70, 127.64, 127.60, 127.59, 127.55, 127.48, 127.44, 127.37, 98.24, 97.81, 82.13, 79.98, 79.56, 77.62, 75.80, 75.01, 74.92, 74.86, 73.25, 72.42, 71.98, 71.93, 69.80, 69.11, 65.79, 55.07.

LRMS (ESI): calc. for $\text{C}_{62}\text{H}_{70}\text{NO}_{11}$ ($\text{M}+\text{NH}_4^+$): 1004.3; found: 1003.9. The data were in accordance with the literature^[130], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3,4,6-tetra-O-benzyl-D-mannopyranosyl)-(1→6) 2,3,4-tri-O-benzoyl- α -D-glucopyranoside (2.23)



Prepared according to General Procedure **D** at 0 °C in 24 h, yielding the product **2.23** as a white paste (36 mg, 71%, $\alpha:\beta = 1.9:1$).

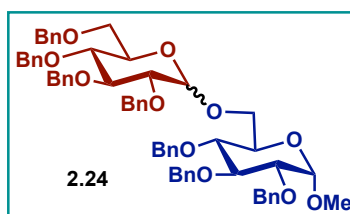
^1H NMR (400 MHz, CDCl_3) δ 8.01 – 7.97 (m, 2H), 7.93 – 7.86 (m, 4H), 7.52 (t, $J = 7.4$ Hz, 1H), 7.47 – 7.33 (m, 10H), 7.29 (dt, $J = 9.8, 5.1$ Hz, 16H), 7.20 – 7.16 (m, 2H), 6.13 (t, $J = 9.9$ Hz, 1H), 5.57 (t, $J = 9.9$ Hz, 1H), 5.24 (dd, $J = 10.1, 3.6$ Hz, 1H), 5.18 (d, $J = 3.6$ Hz,

1H), 4.93 – 4.91 (m, 1H), 4.88 (d, $J = 10.9$ Hz, 1H), 4.75 – 4.66 (m, 2H), 4.59 – 4.52 (m, 1H), 4.47 (dd, $J = 11.2, 7.8$ Hz, 3H), 4.40 (d, $J = 12.1$ Hz, 1H), 3.99 – 3.85 (m, 3H), 3.70 (s, 1H), 3.68 – 3.60 (m, 3H), 3.55 (d, $J = 9.0$ Hz, 1H), 3.39 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.83, 165.80, 165.06, 138.69, 138.59, 138.47, 138.40, 133.34, 133.23, 133.04, 129.92, 129.89, 129.65, 129.10, 129.08, 128.40, 128.37, 128.29, 128.26, 128.21, 127.91, 127.75, 127.66, 127.65, 127.49, 127.43, 127.35, 98.19, 96.91, 79.87, 74.99, 74.75, 73.20, 72.55, 72.10, 72.05, 71.92, 70.51, 69.83, 69.03, 68.07, 66.16, 55.53.

LRMS (ESI): calc. for $\text{C}_{62}\text{H}_{64}\text{NO}_{14}$ ($\text{M}+\text{NH}_4^+$): 1046.4; found: 1046.9. The data were in accordance with the literature^[131], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3,4,6-tetra-*O*-benzyl- α -D-glucopyranosyl)-(1 $\rightarrow$ 6) 2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (2.24)



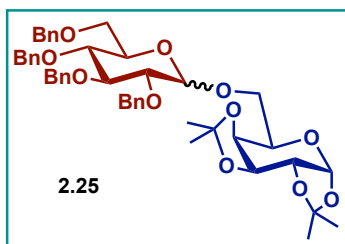
Prepared according to General Procedure **D** at rt in 8 h, yielding the product as a white paste as an inseparable mixture of diastereomers **2.24** (17 mg, 35%, $\alpha:\beta = 1.4:1$).

^1H NMR (600 MHz, CDCl_3) δ 7.34 – 7.22 (m, 50H), 7.21 – 7.15 (m, 4H), 7.12 (dd, $J = 7.4, 2.1$ Hz, 2H), 4.99 – 4.88 (m, 6H), 4.84 – 4.69 (m, 8H), 4.65 (dd, $J = 12.1, 2.3$ Hz, 4H), 4.62 – 4.50 (m, 6H), 4.44 (dd, $J = 21.3, 11.5$ Hz, 2H), 4.01 – 3.94 (m, 3H), 3.84 – 3.76 (m, 4H), 3.73 – 3.70 (m, 2H), 3.69 – 3.60 (m, 5H), 3.58 – 3.47 (m, 5H), 3.44 (dd, $J = 9.7, 3.5$ Hz, 1H), 3.35 (s, 3H), 3.33 (s, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.81, 138.44, 138.41, 138.17, 137.97, 128.43, 128.39, 128.37, 128.34, 128.31, 128.29, 128.25, 128.12, 128.00, 127.98, 127.96, 127.94, 127.92, 127.89, 127.86, 127.84, 127.82, 127.73, 127.69, 127.64, 127.63, 127.61, 127.59, 127.56, 127.53, 127.51, 127.47, 103.80, 97.94, 97.24, 84.78, 82.12, 82.06, 81.97, 81.67, 80.13, 79.98, 79.76, 77.99, 77.77, 77.60, 77.20, 75.70, 75.47, 74.96, 74.87, 73.39, 73.36, 72.33, 70.35, 70.22, 69.83, 69.00, 68.46, 66.03, 55.18, 55.13, 29.69.

LRMS (ESI): calc. for $C_{62}H_{70}NO_{11}$ ($M+NH_4^+$): 1004.3; found: 1004.9. The data were in accordance with the literature^[132-133], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3,4,6-tetra-O-benzyl-D-glucopyranosyl)-(1→6)-1,2:3,4-di-O-isopropylidene- α -D-galactopyranoside (2.25)



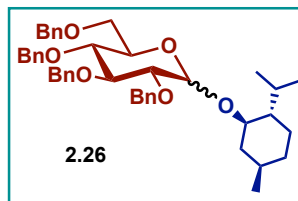
Prepared according to General Procedure **D** at 0 °C in 12 h, yielding the product as a colorless oil as an inseparable mixture of diastereomers **2.25** (33 mg, 74%, $\alpha:\beta = 1.1:1$).

^1H NMR (600 MHz, $CDCl_3$) δ 7.42 (d, $J = 2.0$ Hz, 2H), 7.38 – 7.35 (m, 2H), 7.35 – 7.29 (m, 17H), 7.30 – 7.26 (m, 13H), 7.14 (d, $J = 11.1$ Hz, 4H), 5.57 (d, $J = 5.0$ Hz, 1H), 5.53 (d, $J = 5.0$ Hz, 1H), 5.06 – 4.94 (m, 4H), 4.84 – 4.78 (m, 4H), 4.77 – 4.68 (m, 4H), 4.63 – 4.57 (m, 4H), 4.54 – 4.45 (m, 5H), 4.35 (dd, $J = 7.9, 2.0$ Hz, 1H), 4.32 (dt, $J = 5.3, 2.8$ Hz, 2H), 4.25 (dd, $J = 7.9, 1.9$ Hz, 1H), 4.16 (dd, $J = 10.7, 3.7$ Hz, 1H), 4.09 (ddt, $J = 5.7, 3.8, 2.0$ Hz, 1H), 4.06 – 4.02 (m, 1H), 3.98 (t, $J = 9.3$ Hz, 1H), 3.83 (dt, $J = 10.0, 2.7$ Hz, 1H), 3.80 – 3.71 (m, 5H), 3.71 – 3.57 (m, 7H), 3.48 – 3.43 (m, 2H), 1.53 (s, 3H), 1.50 (s, 3H), 1.45 (s, 6H), 1.34 – 1.31 (m, 12H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.90, 138.67, 138.64, 138.33, 138.30, 138.13, 138.09, 137.94, 128.63, 128.34, 128.32, 128.19, 127.93, 127.91, 127.86, 127.82, 127.69, 127.65, 127.62, 127.60, 127.53, 127.50, 127.48, 109.37, 109.21, 108.58, 104.37, 96.97, 96.36, 96.29, 84.52, 81.93, 81.61, 79.79, 77.70, 77.55, 75.64, 75.61, 74.97, 74.72, 74.36, 73.49, 73.45, 72.35, 71.42, 70.82, 70.76, 70.65, 70.63, 70.47, 70.21, 69.72, 68.73, 68.35, 67.36, 66.18, 65.67, 26.17, 26.06, 26.03, 25.99, 25.02, 24.92, 24.63, 24.44

LRMS (ESI): calc. for $C_{46}H_{58}NO_{11}$ ($M+NH_4^+$): 800.4; found: 800.8. The data were in accordance with the literature^[111,131,134], and the spectral images for this compound are published in our research article.^[107]

***l*-Menthyl 2,3,4,6-tetra-O-benzyl-D-glucopyranoside (2.26)**



Prepared according to General Procedure **D** at rt in 4 h, yielding the product **2.26** as a colorless oil (68%, $\alpha:\beta = 1:1$).

α -anomer: $^1\text{H NMR}$ (600 MHz, CDCl_3) δ 7.37 – 7.27 (m, 18H), 7.15 (dd, $J = 7.5, 2.0$ Hz, 2H), 5.04 (d, $J = 3.7$ Hz, 1H), 4.99 (d, $J = 11.0$ Hz, 1H), 4.87 – 4.82 (m, 2H), 4.74 – 4.68 (m, 2H), 4.65 (d, $J = 12.1$ Hz, 1H), 4.48 (dd, $J = 11.4, 5.1$ Hz, 2H), 4.03 (t, $J = 9.3$ Hz, 1H), 3.99 (ddd, $J = 10.1, 4.0, 2.2$ Hz, 1H), 3.77 (dd, $J = 10.5, 4.0$ Hz, 1H), 3.67 – 3.63 (m, 2H), 3.56 (dd, $J = 9.8, 3.7$ Hz, 1H), 3.37 (dd, $J = 10.6, 4.5$ Hz, 1H), 2.43 (pd, $J = 7.1, 2.6$ Hz, 1H), 2.17 – 2.13 (m, 1H), 1.62 (dp, $J = 13.2, 3.3$ Hz, 2H), 1.41 – 1.30 (m, 2H), 1.08 – 1.02 (m, 1H), 0.96 – 0.92 (m, 1H), 0.86 (dd, $J = 6.7, 3.2$ Hz, 7H), 0.72 (d, $J = 6.9$ Hz, 3H).

$^{13}\text{C NMR}$ (100 MHz, CDCl_3) δ 138.91, 138.38, 138.30, 138.05, 128.34, 128.32, 128.30, 128.23, 127.89, 127.87, 127.63, 127.62, 127.61, 127.48, 127.46, 98.62, 81.97, 80.99, 80.54, 75.47, 75.03, 73.44, 73.18, 70.29, 68.66, 48.75, 43.04, 34.26, 31.73, 24.57, 22.95, 22.28, 21.10, 16.05.

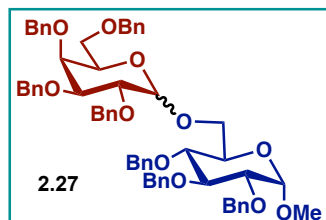
LRMS (ESI): calc. for $\text{C}_{44}\text{H}_{58}\text{NO}_6$ ($\text{M}+\text{NH}_4^+$): 696.4; found: 696.8.

β -anomer: $^1\text{H NMR}$ (600 MHz, CDCl_3) δ 7.36 – 7.32 (m, 5H), 7.31 – 7.26 (m, 9H), 7.20 (dd, $J = 7.8, 1.8$ Hz, 1H), 4.94 (dd, $J = 15.9, 11.1$ Hz, 2H), 4.80 (dd, $J = 16.7, 11.0$ Hz, 2H), 4.69 (d, $J = 10.8$ Hz, 1H), 4.63 – 4.53 (m, 3H), 4.48 (d, $J = 7.9$ Hz, 1H), 3.70 (d, $J = 3.4$ Hz, 2H), 3.65 – 3.58 (m, 2H), 3.51 (td, $J = 10.8, 4.3$ Hz, 1H), 3.43 – 3.39 (m, 2H), 2.35 (pd, $J = 6.8, 2.5$ Hz, 1H), 2.16 – 2.12 (m, 1H), 1.69 – 1.64 (m, 2H), 1.39 – 1.32 (m, 1H), 1.30 – 1.27 (m, 1H), 1.04 – 0.94 (m, 2H), 0.92 (dd, $J = 12.2, 6.8$ Hz, 6H), 0.89 – 0.84 (m, 1H), 0.83 (d, $J = 6.9$ Hz, 3H).

$^{13}\text{C NMR}$ (100 MHz, CDCl_3) δ 138.82, 138.56, 138.38, 138.22, 128.36, 128.30, 128.27, 128.06, 127.76, 127.70, 127.61, 127.57, 127.48, 127.46, 100.75, 84.96, 82.21, 77.96, 77.74, 75.57, 74.97, 74.80, 73.66, 69.33, 48.12, 40.96, 34.45, 31.46, 25.27, 23.21, 22.23, 21.07, 15.95.

LRMS (ESI): calc. for $C_{44}H_{58}NO_6$ ($M+NH_4^+$): 696.4; found: 696.8. The data were in accordance with the literature^[134], and the spectral images for this compound are published in our research article.^[107]

Methyl (2,3,4,6-tetra-O-benzyl-D-galactopyranosyl)-(1→6) 2,3,4-tri-O-benzyl- α -D-glucopyranoside (2.27)



Prepared according to General Procedure **D** at rt in 8 h yielding the product **2.27** as a yellow paste (32 mg, 61%, $\alpha:\beta = 2:1$).

α -anomer: ^1H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.33 (m, 7H), 7.32 – 7.21 (m, 28H), 5.01 – 4.92 (m, 3H), 4.86 – 4.77 (m, 3H), 4.75 – 4.66 (m, 4H), 4.60 – 4.52 (m, 4H), 4.45 – 4.34 (m, 2H), 4.04 – 3.88 (m, 5H), 3.74 (dd, $J = 15.3, 10.2$ Hz, 3H), 3.59 (t, $J = 8.9$ Hz, 1H), 3.54 – 3.46 (m, 2H), 3.41 (dd, $J = 9.6, 3.6$ Hz, 1H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.88, 138.86, 138.75, 138.71, 138.41, 138.20, 138.04, 128.38, 128.35, 128.33, 128.27, 128.22, 128.19, 128.17, 127.96, 127.94, 127.79, 127.68, 127.63, 127.61, 127.52, 127.49, 127.48, 127.40, 127.33, 97.86, 82.07, 80.17, 78.25, 77.99, 76.53, 75.68, 75.09, 74.98, 74.73, 73.34, 73.32, 72.80, 72.51, 70.30, 69.37, 68.92, 66.40, 55.02.

LRMS (ESI): calc. for $C_{62}H_{70}NO_{11}$ ($M+NH_4^+$): 1004.3; found: 1004.8.

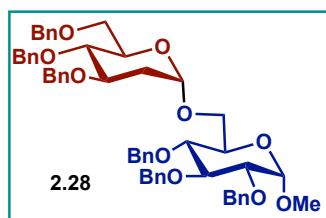
$\alpha+\beta = 1:2$ – anomer: ^1H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.21 (m, 52H), 5.00 – 4.91 (m, 5H), 4.86 – 4.75 (m, 5H), 4.73 – 4.63 (m, 7H), 4.56 (ddd, $J = 19.0, 7.1, 3.9$ Hz, 6H), 4.45 – 4.29 (m, 5H), 4.05 – 3.88 (m, 7H), 3.87 – 3.79 (m, 2H), 3.78 – 3.70 (m, 3H), 3.58 (dt, $J = 16.8, 8.4$ Hz, 4H), 3.52 – 3.45 (m, 4H), 3.42 (d, $J = 3.5$ Hz, 1H), 3.39 (d, $J = 3.7$ Hz, 1H), 3.35 – 3.32 (m, 1H), 3.29 (s, 1H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.87, 138.71, 138.40, 138.20, 138.04, 128.40, 128.38, 128.34, 128.32, 128.29, 128.27, 128.22, 128.19, 128.17, 128.11, 128.08, 127.97, 127.94, 127.92, 127.85, 127.79, 127.67, 127.65, 127.62, 127.49, 127.40, 127.32, 97.86,

82.07, 80.16, 78.24, 77.99, 77.20, 76.53, 75.67, 75.09, 74.98, 74.73, 73.50, 73.31, 72.80, 72.51, 70.29, 69.37, 68.92, 66.40, 55.02.

LRMS (ESI): calc. for $C_{62}H_{70}NO_{11}$ ($M+NH_4^+$): 1004.3; found: 1004.8. The data were in accordance with the literature^[135], and the spectral images for this compound are published in our research article.^[107]

Methyl (3,4,6-tri-O-benzyl-2-deoxy-D-arabino-hexopyranosyl)-(1→6) 2,3,4-tri-O-benzyl - α -D-glucopyranoside (2.28)



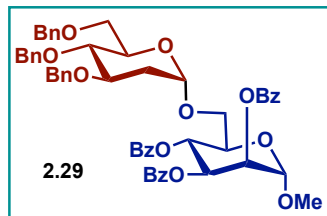
Prepared according to General Procedure **D** at rt in 8 h yielding the product **2.28** as a pale-yellow paste (28 mg, 61%, $\alpha:\beta = 2:1$).

^1H NMR (600 MHz, $CDCl_3$) δ 7.37 (dd, $J = 6.8, 1.8$ Hz, 2H), 7.34 – 7.31 (m, 8H), 7.30 – 7.26 (m, 10H), 7.23 (d, $J = 3.5$ Hz, 8H), 7.14 (dd, $J = 7.6, 2.0$ Hz, 2H), 5.00 – 4.97 (m, 2H), 4.91 (d, $J = 11.1$ Hz, 1H), 4.87 (d, $J = 11.1$ Hz, 1H), 4.79 (dd, $J = 11.5, 9.3$ Hz, 2H), 4.68 (d, $J = 12.1$ Hz, 1H), 4.65 (d, $J = 11.6$ Hz, 1H), 4.61 (dd, $J = 7.6, 4.0$ Hz, 2H), 4.56 (dd, $J = 11.7, 10.4$ Hz, 2H), 4.48 (d, $J = 11.0$ Hz, 1H), 4.40 (d, $J = 12.2$ Hz, 1H), 3.99 (t, $J = 9.3$ Hz, 1H), 3.93 (ddd, $J = 11.5, 8.7, 5.0$ Hz, 1H), 3.81 (dd, $J = 11.4, 4.4$ Hz, 1H), 3.73 (ddd, $J = 10.3, 4.5, 1.8$ Hz, 1H), 3.68 – 3.65 (m, 1H), 3.62 – 3.55 (m, 3H), 3.53 – 3.47 (m, 3H), 3.34 (s, 3H), 2.29 (dd, $J = 11.6, 5.2$ Hz, 1H), 1.71 – 1.65 (m, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.67, 138.65, 138.55, 138.30, 138.14, 138.09, 128.45, 128.39, 128.34, 128.31, 128.26, 128.20, 128.03, 128.00, 127.89, 127.84, 127.74, 127.70, 127.62, 127.53, 127.51, 127.42, 127.40, 97.89, 97.78, 82.20, 79.99, 78.11, 77.72, 77.20, 75.77, 74.85, 74.80, 73.37, 73.25, 71.68, 70.85, 69.72, 68.65, 55.08, 35.25, 29.69.

LRMS (ESI): calc. for $C_{55}H_{64}NO_{10}$ ($M+NH_4^+$): 898.5; found: 899.0. The data were consistent with the literature^[130], and the spectral images for this compound are published in our research article.^[107]

Methyl (3,4,6-tri-O-benzyl-2-deoxy-D-arabino-hexopyranosyl)-(1→6) 2,3,4-tri-O-benzyl - α -D-mannopyranoside (2.29)



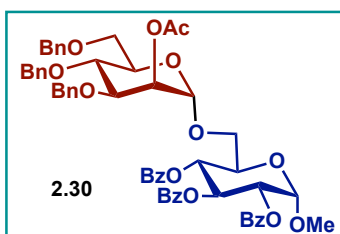
Prepared according to General Procedure **D** at rt in 10 h yielding the product **2.29** as a thick yellow syrup (39 mg, 90%, α : β = 4:1).

^1H NMR (600 MHz, CDCl_3) δ 8.11 – 8.08 (m, 2H), 7.98 – 7.95 (m, 2H), 7.85 – 7.82 (m, 2H), 7.55 (t, J = 7.5 Hz, 1H), 7.44 (tt, J = 14.9, 7.3 Hz, 4H), 7.33 – 7.25 (m, 17H), 7.19 – 7.16 (m, 2H), 5.96 (t, J = 10.0 Hz, 1H), 5.86 (dd, J = 10.2, 3.2 Hz, 1H), 5.65 (dd, J = 3.5, 1.9 Hz, 1H), 5.01 (d, J = 3.5 Hz, 1H), 4.96 (d, J = 1.9 Hz, 1H), 4.87 (d, J = 11.0 Hz, 1H), 4.53 (d, J = 12.1 Hz, 1H), 4.49 (d, J = 11.0 Hz, 1H), 4.44 (s, 2H), 4.38 (d, J = 12.2 Hz, 1H), 4.21 (dt, J = 9.1, 4.2 Hz, 1H), 3.91 (ddd, J = 15.5, 8.4, 4.2 Hz, 2H), 3.71 – 3.62 (m, 3H), 3.57 (t, J = 9.3 Hz, 1H), 3.49 (s, 1H), 3.48 (s, 3H), 2.19 (dd, J = 13.0, 5.1 Hz, 1H), 1.68 – 1.62 (m, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.49, 165.47, 165.34, 138.70, 138.67, 138.07, 133.45, 133.25, 133.07, 129.84, 129.81, 129.73, 129.43, 129.29, 129.17, 128.55, 128.40, 128.31, 128.26, 128.24, 128.21, 127.81, 127.80, 127.53, 127.46, 127.45, 98.52, 97.62, 78.09, 77.44, 77.21, 74.80, 73.34, 71.55, 70.83, 70.60, 70.09, 69.24, 68.62, 67.77, 66.38, 55.41, 35.13, 29.69.

LRMS (ESI): calc. for $\text{C}_{55}\text{H}_{58}\text{NO}_{13}$ ($\text{M}+\text{NH}_4^+$): 940.4; found: 940.6. The data were consistent with the literature^[131], and the spectral images for this compound are published in our research article.^[107]

Methyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (**2.30**)



Prepared according to General Procedure **D** at rt in 6 h yielding the product **2.30** as a white paste (35 mg, 70%, α -only).

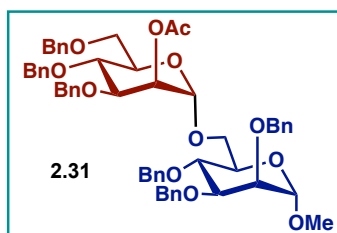
Following the general procedure **E**, glycosyl acceptor **A11** (25.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7a** (52.0 mg, 75.0 μmol) to afford **2.30** (34.0 mg, 34.7 μmol , 70% yield) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.98 (dd, $J = 8.5, 1.3$ Hz, 2H), 7.94 (dd, $J = 8.5, 1.3$ Hz, 2H), 7.87 (dd, $J = 8.4, 1.4$ Hz, 2H), 7.50 (ddt, $J = 14.1, 7.1, 1.3$ Hz, 2H), 7.46 – 7.41 (m, 2H), 7.41 – 7.35 (m, 3H), 7.33 – 7.27 (m, 15H), 7.16 (dd, $J = 7.4, 2.1$ Hz, 2H), 6.13 (t, $J = 9.9$ Hz, 1H), 5.56 (t, $J = 9.9$ Hz, 1H), 5.33 (dd, $J = 3.3, 1.8$ Hz, 1H), 5.26 (dd, $J = 10.2, 3.7$ Hz, 1H), 5.19 (d, $J = 3.7$ Hz, 1H), 4.87 – 4.83 (m, 2H), 4.60 (d, $J = 2.2$ Hz, 1H), 4.57 (s, 1H), 4.46 (d, $J = 7.3$ Hz, 1H), 4.43 (d, $J = 7.7$ Hz, 1H), 4.38 (d, $J = 12.0$ Hz, 1H), 4.20 (ddd, $J = 10.2, 5.4, 3.2$ Hz, 1H), 3.94 (dd, $J = 9.3, 3.4$ Hz, 1H), 3.91 – 3.86 (m, 1H), 3.84 (d, $J = 9.5$ Hz, 1H), 3.74 – 3.69 (m, 1H), 3.69 – 3.65 (m, 1H), 3.63 (dd, $J = 11.6, 3.7$ Hz, 1H), 3.53 (dd, $J = 10.7, 1.9$ Hz, 1H), 3.39 (s, 3H), 2.13 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.30, 165.79, 165.15, 138.56, 138.18, 137.97, 133.31, 133.03, 129.92, 129.67, 129.24, 129.07, 128.94, 128.40, 128.38, 128.32, 128.25, 128.22, 128.12, 127.79, 127.71, 127.66, 127.50, 127.48, 97.88, 77.84, 77.21, 75.01, 74.15, 73.30, 72.09, 71.73, 71.45, 70.48, 69.64, 68.65, 68.60, 68.05, 66.30, 55.49, 21.09.

LRMS (ESI): calc. for $\text{C}_{57}\text{H}_{60}\text{NO}_{15}$ ($\text{M}+\text{NH}_4^+$): 998.4; found: 998.8. The data were in accordance with the literature^[131], and the spectral images for this compound are published in our research article.^[107]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (**2.31**)



Prepared according to General Procedure **D** at rt in 5 h yielding the product **2.31** as a yellow viscous oil (36 mg, 71%, α -only).

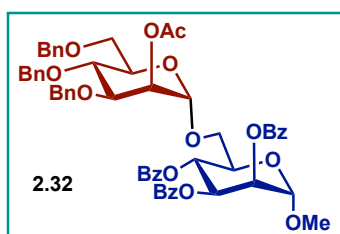
Following the general procedure **E**, glycosyl acceptor **A9** (24.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μmol) to afford **2.31** (39.0 mg, 41.5 μmol , 81% yield) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).

¹H NMR (400 MHz, CDCl₃) δ 7.39 – 7.36 (m, 2H), 7.34 – 7.27 (m, 21H), 7.24 – 7.22 (m, 4H), 7.16 – 7.11 (m, 3H), 5.48 – 5.45 (m, 1H), 4.96 (d, *J* = 2.1 Hz, 1H), 4.91 (d, *J* = 11.2 Hz, 1H), 4.86 (dd, *J* = 10.9, 3.4 Hz, 1H), 4.73 – 4.70 (m, 3H), 4.67 – 4.65 (m, 1H), 4.64 (d, *J* = 3.9 Hz, 1H), 4.59 (d, *J* = 1.2 Hz, 2H), 4.55 (d, *J* = 6.9 Hz, 1H), 4.50 (d, *J* = 3.6 Hz, 1H), 4.48 – 4.46 (m, 2H), 4.44 (d, *J* = 4.3 Hz, 1H), 3.96 (dd, *J* = 9.2, 3.2 Hz, 1H), 3.91 (d, *J* = 9.4 Hz, 1H), 3.87 (t, *J* = 2.3 Hz, 2H), 3.80 – 3.77 (m, 2H), 3.72 (d, *J* = 5.2 Hz, 1H), 3.70 (t, *J* = 3.3 Hz, 1H), 3.67 (s, 1H), 3.59 (dd, *J* = 10.8, 1.9 Hz, 1H), 3.25 (s, 3H), 2.14 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 170.28, 138.59, 138.45, 138.42, 138.30, 138.28, 137.82, 128.38, 128.35, 128.32, 128.30, 128.28, 128.23, 128.19, 128.06, 127.92, 127.86, 127.81, 127.76, 127.72, 127.62, 127.60, 127.53, 127.48, 127.43, 98.69, 97.94, 80.25, 77.56, 75.12, 74.99, 74.94, 74.59, 74.53, 74.47, 74.18, 73.48, 73.32, 72.58, 71.97, 71.79, 71.39, 71.35, 71.31, 70.90, 69.18, 68.90, 68.72, 68.52, 66.70, 54.64, 21.12.

LRMS (ESI): calc. for C₅₇H₆₆NO₁₂ (M+NH₄⁺): 956.5; found: 956.8. The data were in accordance with the literature^[136], and the spectral images for this compound are published in our research article.^[107]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl-α-D-mannopyranosyl-(1→6)-2,3,4-tri-O-benzoyl-α-D-mannopyranoside (2.32)



Prepared according to General Procedure **D** at rt in 5 h, yielding the product **2.32** as a colorless oil (40 mg, 79%, α-only).

Following the general procedure **E**, glycosyl acceptor **A13** (25.0 mg, 50.0 μmol) was coupled with EDPAT donor 2.7a (52.0 mg, 75.0 μmol) to afford **2.32** (36.0 mg, 36.7 μmol, 73% yield) as a colorless viscous oil. *R_f* = 0.2 (hexane: EtOAc = 70:30).

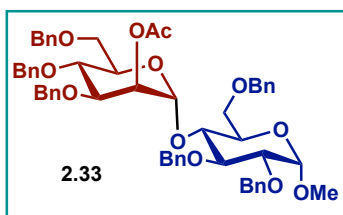
¹H NMR (400 MHz, CDCl₃) δ 8.08 (d, *J* = 7.7 Hz, 2H), 7.96 (d, *J* = 7.9 Hz, 2H), 7.82 (d, *J* = 7.6 Hz, 2H), 7.62 – 7.51 (m, 1H), 7.44 (dt, *J* = 15.1, 7.8 Hz, 4H), 7.30 (dd, *J* = 19.6, 5.3 Hz, 17H), 7.19 – 7.09 (m, 2H), 5.97 – 5.76 (m, 2H), 5.65 (s, 1H), 5.34 (s, 1H), 4.91 (d, *J*

= 16.7 Hz, 2H), 4.83 (d, J = 11.1 Hz, 1H), 4.65 – 4.29 (m, 6H), 4.27 – 4.17 (m, 1H), 4.00 – 3.81 (m, 3H), 3.71 (dd, J = 23.6, 11.8 Hz, 3H), 3.54 (d, J = 11.2 Hz, 1H), 3.45 (s, 3H), 2.12 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.47, 165.66, 165.60, 165.53, 138.64, 138.24, 138.03, 133.64, 133.50, 133.25, 130.02, 129.99, 129.87, 129.48, 129.23, 129.14, 128.75, 128.59, 128.55, 128.48, 128.40, 128.38, 128.24, 128.18, 128.11, 128.03, 127.96, 127.92, 127.89, 127.82, 127.67, 98.63, 98.02, 78.25, 75.21, 74.21, 73.44, 71.76, 71.58, 70.63, 70.13, 69.18, 68.65, 68.60, 67.60, 66.83, 55.54, 21.27.

HRMS (ESI): calc. for $\text{C}_{57}\text{H}_{56}\text{O}_{15}\text{Na}$ ($\text{M}+\text{Na}$): 1003.3517; found: 1003.3524. The spectral images for this compound are published in our research article.^[107]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzyl- α -D-glucopyranoside (2.33)



Prepared according to General Procedure **D** at rt in 6 h yielding the product **2.33** as a white paste (41mg, 81%, α -only).

Following the general procedure **E**, glycosyl acceptor **A14** (24.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μmol) to afford **2.33** (33.0 mg, 35.1 μmol , 67% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

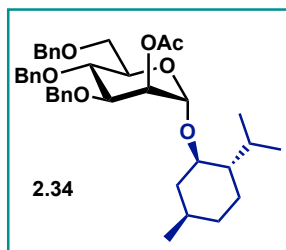
^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.34 (m, 1H), 7.33 (d, J = 1.9 Hz, 3H), 7.31 – 7.26 (m, 21H), 7.25 – 7.19 (m, 3H), 7.16 – 7.13 (m, 2H), 5.48 – 5.44 (m, 1H), 5.42 (d, J = 2.2 Hz, 1H), 5.04 (d, J = 11.2 Hz, 1H), 4.81 (d, J = 10.8 Hz, 1H), 4.76 – 4.72 (m, 1H), 4.67 (d, J = 18.7 Hz, 1H), 4.62 (d, J = 2.8 Hz, 1H), 4.59 (d, J = 2.3 Hz, 2H), 4.54 (d, J = 11.8 Hz, 2H), 4.48 – 4.41 (m, 3H), 4.41 – 4.34 (m, 2H), 3.93 (t, J = 9.1 Hz, 1H), 3.88 – 3.85 (m, 1H), 3.85 – 3.80 (m, 2H), 3.72 (s, 1H), 3.69 (t, J = 4.2 Hz, 2H), 3.67 – 3.63 (m, 1H), 3.54 (dd, J = 9.5, 3.5 Hz, 1H), 3.50 (dd, J = 10.8, 1.9 Hz, 1H), 3.38 (s, 3H), 1.98 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.85, 138.52, 138.45, 138.20, 137.97, 137.92, 128.44, 128.30, 128.24, 128.20, 128.14, 128.05, 127.93, 127.88, 127.82, 127.61, 127.56, 127.53,

127.40, 127.27, 127.25, 99.30, 97.76, 81.74, 80.05, 78.20, 77.22, 75.71, 75.13, 75.09, 74.02, 73.44, 73.27, 72.41, 71.67, 69.57, 69.20, 68.72, 55.28, 20.95.

LRMS (ESI): calc. for $C_{57}H_{66}NO_{12}$ ($M+NH_4^+$): 956.5; found: 956.9. The data were in accordance with the literature^[131], and the spectral images for this compound are published in our research article.^[107]

***l*-Menthyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- α -D-mannopyranoside (2.34)**

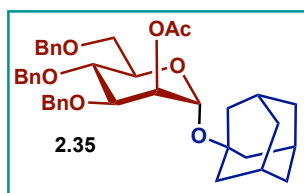


Following the general procedure **E**, glycosyl acceptor **A5** (8.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μ mol) to afford **2.34** (22.0 mg, 36.8 μ mol, 74% yield) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.26 (m, 13H), 7.18 (dd, J = 7.4, 2.1 Hz, 2H), 5.26 (dd, J = 3.3, 1.9 Hz, 1H), 4.94 – 4.86 (m, 2H), 4.71 (dd, J = 11.7, 6.6 Hz, 2H), 4.58 (d, J = 11.3 Hz, 1H), 4.50 (dd, J = 11.4, 10.0 Hz, 2H), 4.02 – 3.95 (m, 2H), 3.91 – 3.80 (m, 2H), 3.71 (dd, J = 10.6, 1.9 Hz, 1H), 3.35 (td, J = 10.6, 4.3 Hz, 1H), 2.16 (s, 3H), 2.05 (pd, J = 7.0, 2.5 Hz, 1H), 1.66 – 1.57 (m, 2H), 1.41 – 1.31 (m, 1H), 1.24 – 1.15 (m, 1H), 1.03 – 0.90 (m, 5H), 0.85 (d, J = 6.5 Hz, 3H), 0.78 (d, J = 7.0 Hz, 4H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 170.58, 138.40, 138.31, 137.98, 128.37, 128.32, 128.25, 128.08, 127.92, 127.72, 127.70, 127.62, 127.50, 99.27, 81.63, 77.97, 75.19, 74.62, 73.36, 71.76, 71.41, 69.34, 69.05, 48.55, 42.71, 34.26, 31.58, 25.84, 23.30, 22.20, 21.20, 21.02, 16.31. The data are identical to the literature report^[137], and the spectral images for this compound are published in our research article.^[119]

Adamantanyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- α -D-mannopyranoside (2.35)



Prepared according to General Procedure **D** at rt in 5 h, yielding the product **2.35** as a colorless paste (27 mg, 82%, α -only).

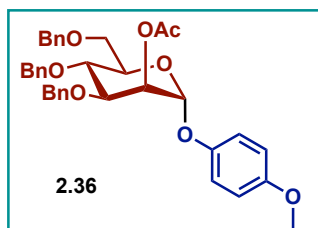
Following the general procedure **E**, glycosyl acceptor **A7** (8.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μ mol) to afford **2.35** (28.0 mg, 44.8 μ mol, 84% yield) as a colorless viscous oil. R_f = 0.7 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.26 (m, 13H), 7.17 (dd, J = 7.4, 2.1 Hz, 2H), 5.27 (d, J = 2.1 Hz, 1H), 5.18 (dd, J = 3.3, 2.0 Hz, 1H), 4.86 (d, J = 10.6 Hz, 1H), 4.73 – 4.68 (m, 2H), 4.55 (d, J = 11.1 Hz, 1H), 4.48 (dd, J = 11.3, 4.4 Hz, 2H), 4.08 – 3.99 (m, 2H), 3.90 (t, J = 9.6 Hz, 1H), 3.83 (dd, J = 10.6, 4.2 Hz, 1H), 3.68 (dd, J = 10.6, 2.0 Hz, 1H), 2.15 (s, 3H), 2.14 – 2.10 (m, 3H), 1.79 (d, J = 2.0 Hz, 6H), 1.64 – 1.55 (m, 6H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.75, 138.46, 138.35, 138.11, 128.35, 128.30, 128.22, 128.06, 127.94, 127.69, 127.65, 127.59, 127.46, 90.95, 78.24, 75.20, 75.03, 74.68, 73.36, 71.71, 70.91, 70.44, 69.07, 42.28, 36.20, 30.59, 21.24.

LRMS (ESI): calc. for $\text{C}_{39}\text{H}_{50}\text{NO}_7$ ($\text{M}+\text{NH}_4^+$): 644.4; found: 644.6. The data are identical to the literature report^[138-139], and the spectral images for this compound are published in our research article.^[119]

***p*-Methoxyphenyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- α -D-mannopyranoside (**2.36**)**



Prepared according to General Procedure **D** at rt in 14 h yielding the product **2.36** as a colorless paste (29 mg, 84%, α -only).

Following the general procedure **E**, glycosyl acceptor **A6** (6.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μ mol) to afford **2.36** (22.0 mg, 36.8 μ mol, 76% yield) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).

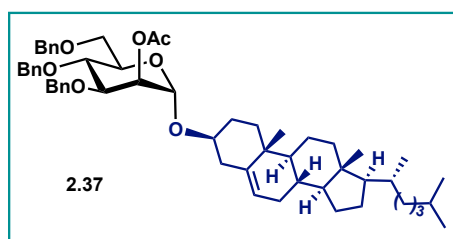
^1H NMR (600 MHz, CDCl_3) δ 7.38 – 7.27 (m, 13H), 7.18 (dd, J = 7.8, 1.7 Hz, 2H), 7.01 – 6.97 (m, 2H), 6.81 – 6.78 (m, 2H), 5.55 (dd, J = 3.4, 2.0 Hz, 1H), 5.46 (d, J = 2.0 Hz, 1H), 4.89 (d, J = 10.7 Hz, 1H), 4.77 (d, J = 11.1 Hz, 1H), 4.66 (d, J = 12.0 Hz, 1H), 4.62 (d, J = 11.1 Hz, 1H), 4.52 (d, J = 10.7 Hz, 1H), 4.46 (d, J = 12.0 Hz, 1H), 4.19 (dd, J = 9.0, 3.4

Hz, 1H), 4.00 (t, $J = 9.5$ Hz, 1H), 3.96 (ddd, $J = 9.8, 4.1, 1.8$ Hz, 1H), 3.82 (dd, $J = 10.8, 4.1$ Hz, 1H), 3.76 (s, 3H), 3.68 (dd, $J = 10.8, 1.9$ Hz, 1H), 2.18 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.44, 155.10, 149.95, 138.31, 138.13, 137.87, 128.43, 128.32, 128.27, 128.09, 127.84, 127.80, 127.78, 127.65, 127.57, 117.81, 114.57, 96.86, 78.02, 75.22, 74.16, 73.35, 71.97, 71.86, 68.68, 68.65, 55.60, 21.12.

LRMS (ESI): calc. for $\text{C}_{36}\text{H}_{42}\text{NO}_8$ ($\text{M}+\text{NH}_4^+$): 616.3; found: 616.5. The data are identical to the literature report^[140], and the spectral images for this compound are published in our research article.^[119]

Cholesteryl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- α -D-mannopyranoside (2.37**):**

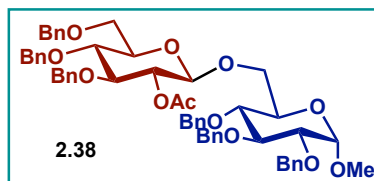


Following the general procedure B, glycosyl acceptor **A4** (19.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7a** (54.0 mg, 75.0 μmol) to afford **2.37** (34.0 mg, 40.8 μmol , 83% yield) as a colorless viscous oil. $R_f = 0.7$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.27 (m, 12H), 7.19 – 7.15 (m, 2H), 5.34 (dd, $J = 3.4, 1.8$ Hz, 1H), 5.29 (dd, $J = 4.8, 2.7$ Hz, 1H), 5.01 (d, $J = 1.8$ Hz, 1H), 4.86 (d, $J = 10.6$ Hz, 1H), 4.71 (dd, $J = 11.5, 9.0$ Hz, 2H), 4.55 (d, $J = 11.1$ Hz, 1H), 4.50 (d, $J = 9.3$ Hz, 1H), 4.48 (d, $J = 8.0$ Hz, 1H), 4.03 (dt, $J = 6.1, 3.3$ Hz, 1H), 3.92 – 3.89 (m, 2H), 3.85 – 3.81 (m, 1H), 3.72 (dd, $J = 10.6, 1.3$ Hz, 1H), 3.49 (dq, $J = 10.9, 5.6$ Hz, 1H), 2.35 – 2.27 (m, 2H), 2.15 (s, 3H), 2.05 – 1.97 (m, 2H), 1.95 – 1.81 (m, 4H), 1.61 – 1.42 (m, 8H), 1.41 – 1.30 (m, 4H), 1.29 – 1.24 (m, 2H), 1.13 (ddt, $J = 15.7, 9.9, 5.6$ Hz, 6H), 1.00 (s, 4H), 0.92 (d, $J = 6.5$ Hz, 3H), 0.88 (dd, $J = 6.6, 1.8$ Hz, 6H), 0.68 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 170.58, 140.54, 138.37, 138.25, 138.06, 128.36, 128.32, 128.26, 128.03, 127.95, 127.78, 127.67, 127.63, 127.52, 121.92, 109.99, 95.81, 78.35, 77.22, 75.24, 74.49, 73.38, 71.76, 71.32, 69.31, 68.93, 56.75, 56.14, 50.07, 42.31, 39.84, 39.75, 39.52, 36.96, 36.67, 36.19, 35.78, 31.93, 31.87, 28.23, 28.01, 27.68, 24.29, 23.82, 22.82, 22.57, 21.18, 21.04, 19.33, 18.72, 11.86. The data are identical to the literature report^[137], and the spectral images for this compound are published in our research article.^[119]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl-β-D-glucopyranosyl-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (2.38)



Prepared according to General Procedure **D** at rt in 6 h, yielding the product **2.38** as a pale-yellow paste (61%, β-only).

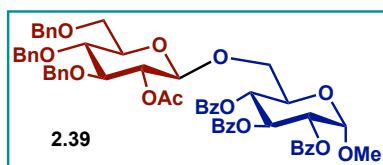
Following the general procedure **E**, glycosyl acceptor **A1** (24.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7b** (54.0 mg, 75.0 μmol) to afford **2.38** (33.0 mg, 35.2 μmol, 68% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (600 MHz, CDCl₃) δ 7.35 (dd, J = 8.2, 1.6 Hz, 2H), 7.33 – 7.29 (m, 16H), 7.29 – 7.25 (m, 9H), 7.24 (s, 1H), 7.18 (dd, J = 7.4, 2.1 Hz, 2H), 5.05 (t, J = 8.6 Hz, 1H), 4.97 (d, J = 11.1 Hz, 1H), 4.83 (d, J = 10.8 Hz, 1H), 4.80 – 4.76 (m, 4H), 4.65 (dd, J = 11.8, 5.1 Hz, 2H), 4.59 – 4.55 (m, 3H), 4.55 – 4.51 (m, 2H), 4.39 (d, J = 8.1 Hz, 1H), 4.09 (dd, J = 10.8, 2.0 Hz, 1H), 3.97 (t, J = 9.3 Hz, 1H), 3.78 – 3.74 (m, 1H), 3.73 (dd, J = 11.1, 2.1 Hz, 1H), 3.69 – 3.61 (m, 4H), 3.52 (dd, J = 9.6, 3.6 Hz, 1H), 3.50 – 3.47 (m, 1H), 3.44 (t, J = 9.5 Hz, 1H), 3.35 (s, 3H), 1.87 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 169.17, 138.83, 138.25, 138.14, 138.09, 137.81, 128.44, 128.42, 128.33, 128.15, 128.01, 127.89, 127.86, 127.83, 127.73, 127.72, 127.65, 127.56, 127.51, 100.95, 98.00, 79.82, 78.03, 77.74, 75.66, 75.36, 75.04, 75.00, 74.86, 73.43, 73.41, 72.93, 69.70, 68.81, 67.90, 55.06, 20.93.

LRMS (ESI): calc. for C₅₇H₆₆NO₁₂ (M+NH₄⁺): 956.5; found: 956.9. The data are identical to the literature report^[141], and the spectral images for this compound are published in our research article.^[119]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl-β-D-glucopyranosyl-(1→6)-2,3,4-tri-O-benzoyl-α-D-glucopyranoside (2.39)



Prepared according to General Procedure **D** at rt for 10 h, yielding the product **2.39** as a white paste (32 mg, 67%, β -only).

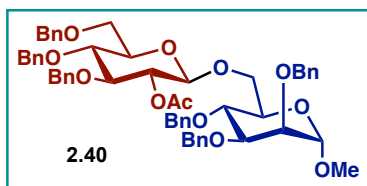
Following the general procedure **E**, glycosyl acceptor **A11** (25.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7b** (52.0 mg, 75.0 μ mol) to afford **2.39** (36.0 mg, 36.7 μ mol, 74% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

^1H NMR (600 MHz, CDCl_3) δ 7.99 – 7.97 (m, 2H), 7.94 – 7.92 (m, 2H), 7.85 (dd, J = 8.5, 1.3 Hz, 2H), 7.51 (td, J = 7.3, 1.4 Hz, 2H), 7.42 (tt, J = 7.2, 1.4 Hz, 1H), 7.38 (d, J = 8.5 Hz, 2H), 7.37 – 7.35 (m, 2H), 7.33 (dt, J = 8.5, 1.4 Hz, 1H), 7.30 (dd, J = 10.7, 1.2 Hz, 3H), 7.29 – 7.26 (m, 10H), 7.24 (dd, J = 4.9, 3.7 Hz, 1H), 7.18 – 7.16 (m, 2H), 6.14 (t, J = 9.7 Hz, 1H), 5.42 (t, J = 9.9 Hz, 1H), 5.23 (dd, J = 10.1, 3.7 Hz, 1H), 5.20 (d, J = 3.7 Hz, 1H), 5.06 – 5.03 (m, 1H), 4.79 (dd, J = 11.1, 7.2 Hz, 2H), 4.69 (d, J = 11.4 Hz, 1H), 4.55 – 4.53 (m, 2H), 4.47 – 4.42 (m, 2H), 4.27 (ddd, J = 9.2, 7.2, 1.9 Hz, 1H), 4.07 (dd, J = 10.9, 2.0 Hz, 1H), 3.70 – 3.67 (m, 4H), 3.66 – 3.64 (m, 1H), 3.45 (s, 3H), 2.02 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.50, 165.81, 165.69, 165.37, 138.17, 138.01, 137.87, 133.40, 133.31, 133.01, 129.91, 129.85, 129.63, 129.26, 129.08, 128.87, 128.41, 128.38, 128.31, 128.22, 127.98, 127.83, 127.80, 127.71, 127.69, 127.55, 101.35, 96.64, 82.86, 77.81, 75.20, 75.03, 75.01, 73.41, 73.07, 72.14, 70.56, 69.53, 68.70, 68.39, 55.33, 20.95.

LRMS (ESI): calc. for $\text{C}_{57}\text{H}_{60}\text{NO}_{15}$ ($\text{M}+\text{NH}_4^+$): 998.4; found: 998.8. The data are identical to the literature report^[142], and the spectral images for this compound are published in our research article.^[119]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (**2.40**)



Prepared according to General Procedure **D** at rt in 6 h yielding the product **2.40** as a white paste (44 mg, 87%, β -only).

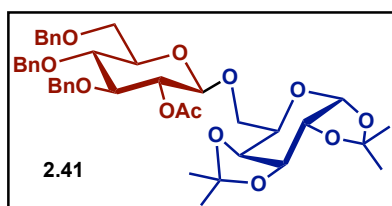
Following the general procedure **B**, glycosyl acceptor **A9** (24.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7b** (54.0 mg, 75.0 μ mol) to afford **2.40** (39.0 mg, 41.6 μ mol, 81% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (400 MHz, CDCl₃) δ 7.36 (dd, *J* = 8.3, 1.9 Hz, 2H), 7.34 – 7.27 (m, 26H), 7.18 (dd, *J* = 7.3, 2.2 Hz, 2H), 5.04 (dd, *J* = 9.5, 7.9 Hz, 1H), 4.91 (d, *J* = 11.2 Hz, 1H), 4.78 (d, *J* = 11.7 Hz, 2H), 4.72 (s, 2H), 4.68 (s, 2H), 4.65 – 4.63 (m, 1H), 4.61 (s, 1H), 4.58 (s, 3H), 4.55 (s, 1H), 4.51 (d, *J* = 7.3 Hz, 1H), 4.44 (t, *J* = 8.6 Hz, 2H), 4.18 – 4.14 (m, 1H), 3.88 – 3.85 (m, 1H), 3.77 (dd, *J* = 3.1, 1.9 Hz, 1H), 3.75 – 3.71 (m, 3H), 3.68 (d, *J* = 3.8 Hz, 1H), 3.66 (t, *J* = 2.2 Hz, 1H), 3.63 (s, 1H), 3.29 (s, 3H), 1.92 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 169.31, 138.43, 138.25, 138.17, 137.97, 128.39, 128.38, 128.34, 128.32, 127.97, 127.89, 127.82, 127.79, 127.75, 127.69, 127.67, 127.64, 127.57, 127.53, 101.31, 98.83, 82.95, 80.29, 78.00, 77.21, 75.21, 75.04, 74.98, 74.94, 74.81, 74.45, 73.49, 73.10, 72.72, 72.07, 71.51, 68.91, 68.69, 54.58, 20.91.

LRMS (ESI): calc. for C₅₇H₆₆NO₁₂ (M+NH₄⁺): 956.5; found: 956.9. The data are identical to the literature report^[143], and the spectral images for this compound are published in our research article.^[119]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl-β-D-glucopyranosyl-(1→6)-1,2:3,4-di-O-isopropylidene-α-D-galactopyranoside (2.41)



Prepared according to General Procedure **D** at rt in 2 h, yielding the product **2.41** as a colorless paste (88%, β-only).

Following the general procedure **E**, glycosyl acceptor **A8** (13.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7b** (53.0 mg, 75.0 μmol) to afford **2.41** (29.0 mg, 39.5 μmol, 79% yield) as a colorless viscous oil. *R_f* = 0.4 (hexane: EtOAc = 70:30).

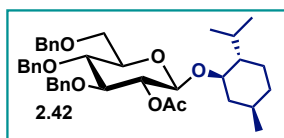
¹H NMR (600 MHz, CDCl₃) δ 7.35 – 7.31 (m, 4H), 7.31 (d, *J* = 2.3 Hz, 1H), 7.29 (d, *J* = 2.8 Hz, 2H), 7.27 (d, *J* = 12.1 Hz, 6H), 7.18 (dd, *J* = 7.7, 2.0 Hz, 2H), 5.49 (d, *J* = 5.0 Hz, 1H), 5.02 – 4.98 (m, 1H), 4.78 (dd, *J* = 11.1, 8.1 Hz, 2H), 4.68 (d, *J* = 11.4 Hz, 1H), 4.63 (d, *J* = 12.1 Hz, 1H), 4.58 – 4.55 (m, 2H), 4.54 (d, *J* = 6.4 Hz, 1H), 4.44 (d, *J* = 8.1 Hz, 1H), 4.27 (dd, *J* = 4.9, 2.4 Hz, 1H), 4.18 (dd, *J* = 8.1, 1.9 Hz, 1H), 4.06 (dd, *J* = 11.3, 3.5 Hz, 1H), 3.92 (ddt, *J* = 5.4, 3.5, 1.9 Hz, 1H), 3.73 (d, *J* = 2.9 Hz, 2H), 3.71 – 3.65 (m, 2H),

3.62 (dd, $J = 11.3, 7.4$ Hz, 1H), 3.47 (dt, $J = 9.4, 3.2$ Hz, 1H), 2.01 (s, 3H), 1.50 (s, 3H), 1.42 (s, 3H), 1.31 (s, 3H), 1.30 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.75, 138.23, 138.16, 137.96, 128.39, 128.38, 128.33, 127.99, 127.83, 127.79, 127.76, 127.67, 127.55, 109.29, 108.65, 101.83, 96.20, 82.79, 77.94, 75.17, 75.03, 74.96, 73.51, 73.05, 71.30, 70.62, 70.53, 69.48, 68.60, 67.84, 26.06, 25.94, 25.10, 24.30, 20.95.

LRMS (ESI): calc. for $\text{C}_{41}\text{H}_{54}\text{NO}_{12}$ ($\text{M}+\text{NH}_4^+$): 752.4; found: 752.9. The data are identical to the literature report^[144], and the spectral images for this compound are published in our research article.^[119]

***l*-Menthyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl- β -D-glucopyranoside (**2.42**):**

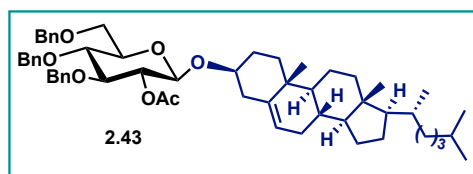


Following the general procedure **E**, glycosyl acceptor **A5** (8.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7b** (54.0 mg, 75.0 μmol) to afford **2.42** (30.0 mg, 47.6 μmol , 94% yield) as a colorless viscous oil. $R_f = 0.6$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.34 – 7.30 (m, 7H), 7.30 – 7.26 (m, 6H), 7.23 (dd, $J = 7.8, 1.8$ Hz, 2H), 4.94 (dd, $J = 9.0, 8.0$ Hz, 1H), 4.80 (dd, $J = 11.2, 4.3$ Hz, 2H), 4.67 (d, $J = 11.5$ Hz, 1H), 4.64 – 4.60 (m, 2H), 4.55 (d, $J = 12.1$ Hz, 1H), 4.40 (d, $J = 8.0$ Hz, 1H), 3.73 – 3.64 (m, 4H), 3.44 (ddd, $J = 9.3, 4.5, 2.1$ Hz, 1H), 3.39 (td, $J = 10.7, 4.3$ Hz, 1H), 2.31 (td, $J = 7.0, 2.7$ Hz, 1H), 1.96 (s, 3H), 1.93 (d, $J = 3.2$ Hz, 1H), 1.63 (ddt, $J = 13.0, 6.3, 3.3$ Hz, 2H), 1.33 (dtd, $J = 12.0, 6.0, 3.2$ Hz, 1H), 1.23 – 1.18 (m, 1H), 0.95 – 0.93 (m, 1H), 0.90 (d, $J = 6.5$ Hz, 3H), 0.88 (d, $J = 7.1$ Hz, 3H), 0.83 – 0.80 (m, 1H), 0.78 (d, $J = 6.9$ Hz, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 169.41, 138.33, 138.30, 137.98, 128.42, 128.37, 128.33, 128.11, 127.83, 127.81, 127.63, 127.60, 127.51, 98.96, 83.14, 78.33, 78.10, 75.10, 75.02, 74.83, 73.71, 73.42, 69.14, 47.50, 40.89, 34.30, 31.38, 24.99, 23.00, 22.29, 21.00, 20.97, 15.76. The data are identical to the literature report^[137], and the spectral images for this compound are published in our research article.^[119]

Cholesteryl 2-O-acetyl-3,4,6-tri-O-benzyl- β -D-glucopyranoside (**2.43**)

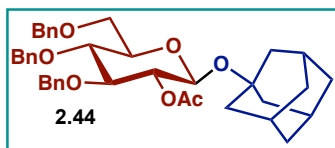


Following the general procedure **E**, glycosyl acceptor **A4** (19.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7b** (54.0 mg, 75.0 μ mol) to afford **2.43** (32.0 mg, 38.4 μ mol, 78% yield) as a colorless viscous oil. R_f = 0.7 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.34 – 7.29 (m, 7H), 7.28 (ddd, J = 8.8, 3.6, 1.4 Hz, 6H), 7.21 – 7.19 (m, 2H), 5.34 – 5.32 (m, 1H), 4.96 (dd, J = 9.3, 8.0 Hz, 1H), 4.79 (dd, J = 11.1, 4.3 Hz, 2H), 4.67 (d, J = 11.4 Hz, 1H), 4.62 (d, J = 12.2 Hz, 1H), 4.56 (dd, J = 11.5, 3.9 Hz, 2H), 4.43 (d, J = 8.0 Hz, 1H), 3.76 – 3.73 (m, 1H), 3.70 – 3.64 (m, 3H), 3.50 – 3.45 (m, 2H), 2.24 – 2.18 (m, 1H), 1.97 (s, 6H), 1.83 (dt, J = 13.4, 3.0 Hz, 2H), 1.62 – 1.44 (m, 8H), 1.36 – 1.33 (m, 2H), 1.26 (td, J = 6.3, 3.3 Hz, 2H), 1.17 – 1.02 (m, 7H), 0.99 (s, 5H), 0.92 (d, J = 6.5 Hz, 4H), 0.87 (dd, J = 6.6, 2.6 Hz, 6H), 0.68 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 169.42, 140.63, 138.21, 137.89, 128.41, 128.39, 128.31, 128.03, 127.86, 127.83, 127.68, 127.67, 127.53, 121.83, 99.95, 83.02, 79.54, 78.13, 77.20, 75.11, 75.02, 74.94, 73.42, 73.36, 68.90, 56.75, 56.14, 50.18, 42.31, 39.76, 39.51, 39.05, 37.26, 36.71, 36.18, 35.77, 31.94, 31.86, 29.61, 28.22, 28.01, 24.28, 23.80, 22.81, 22.55, 21.04, 20.96, 19.37, 18.71, 11.84. The data are identical to the literature report^[137], and the spectral images for this compound are published in our research article.^[119]

Adamantanyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-glucopyranoside (**2.44**)



Prepared according to General Procedure **D** at rt in 24 h, yielding the product **2.44** as a pale-yellow paste (21 mg, 56%, β -only).

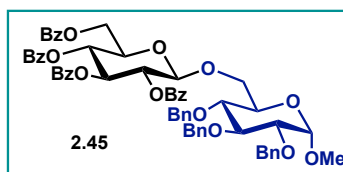
Following the general procedure **E**, glycosyl acceptor **A7** (8.0 mg, 50.0 μ mol) was coupled with EDPAT donor **2.7b** (54.0 mg, 75.0 μ mol) to afford **2.44** (29.0 mg, 46.3 μ mol, 87% yield) as a colorless viscous oil. R_f = 0.7 (hexane: EtOAc = 70:30).

¹H NMR (600 MHz, CDCl₃) δ 7.34 (d, *J* = 7.3 Hz, 2H), 7.32 (d, *J* = 6.0 Hz, 6H), 7.28 (d, *J* = 8.2 Hz, 5H), 7.16 (dd, *J* = 7.5, 1.9 Hz, 2H), 5.46 (d, *J* = 3.8 Hz, 1H), 4.81 (d, *J* = 2.5 Hz, 1H), 4.80 (s, 1H), 4.78 – 4.74 (m, 1H), 4.66 (d, *J* = 12.1 Hz, 1H), 4.52 – 4.48 (m, 2H), 4.04 (t, *J* = 9.5 Hz, 2H), 3.78 (dd, *J* = 10.8, 3.9 Hz, 1H), 3.70 (t, *J* = 9.4 Hz, 1H), 3.65 (dd, *J* = 10.7, 2.2 Hz, 1H), 2.13 – 2.09 (m, 3H), 2.02 (s, 3H), 1.78 (dd, *J* = 10.8, 1.8 Hz, 3H), 1.73 – 1.69 (m, 3H), 1.62 (d, *J* = 11.9 Hz, 3H), 1.59 – 1.55 (m, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 170.42, 138.86, 138.19, 138.14, 128.37, 128.34, 128.30, 127.99, 127.78, 127.72, 127.56, 127.49, 127.44, 88.80, 80.41, 78.04, 75.28, 75.14, 74.43, 74.17, 73.43, 69.90, 68.68, 42.30, 36.20, 30.54, 21.02.

LRMS (ESI): calc. for C₃₉H₅₀NO₇ (M+NH₄⁺): 644.4; found: 644.7. The data are identical to the literature report^[138-139], and the spectral images for this compound are published in our research article.^[119]

Methyl (2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (2.45)

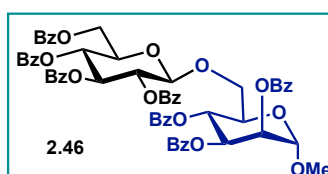


Following the general procedure **E**, glycosyl acceptor **A1** (24.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7c** (62.0 mg, 75.0 μmol) to afford **2.45** (47.0 mg, 45.2 μmol, 88% yield) as a colorless viscous oil. *R_f* = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (400 MHz, CDCl₃) δ 7.98 – 7.96 (m, 2H), 7.87 (ddd, *J* = 8.3, 3.2, 1.3 Hz, 5H), 7.80 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.53 – 7.45 (m, 3H), 7.38 (dd, *J* = 15.1, 7.8 Hz, 6H), 7.33 – 7.29 (m, 6H), 7.29 – 7.25 (m, 7H), 7.24 – 7.17 (m, 6H), 7.04 – 7.01 (m, 2H), 5.87 (t, *J* = 9.7 Hz, 1H), 5.65 (t, *J* = 9.7 Hz, 1H), 5.58 (dd, *J* = 9.8, 7.8 Hz, 1H), 4.87 (d, *J* = 10.9 Hz, 1H), 4.80 (d, *J* = 7.8 Hz, 1H), 4.72 (d, *J* = 12.1 Hz, 1H), 4.66 (d, *J* = 11.0 Hz, 1H), 4.61 – 4.56 (m, 2H), 4.52 – 4.45 (m, 3H), 4.26 (d, *J* = 11.0 Hz, 1H), 4.13 (d, *J* = 8.7 Hz, 1H), 4.11 – 4.05 (m, 1H), 3.86 (t, *J* = 9.3 Hz, 1H), 3.75 – 3.68 (m, 2H), 3.41 (dd, *J* = 9.7, 3.6 Hz, 1H), 3.36 (t, *J* = 9.3 Hz, 1H), 3.19 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 166.23, 165.95, 165.27, 165.03, 138.87, 138.26, 138.22, 133.55, 133.37, 133.25, 133.23, 129.92, 129.86, 129.85, 129.82, 129.80, 129.62, 129.23, 128.85, 128.80, 128.54, 128.52, 128.46, 128.44, 128.41, 128.38, 128.24, 128.01, 127.99, 127.71, 127.59, 127.57, 101.41, 98.04, 81.97, 79.79, 75.65, 74.81, 73.49, 72.91, 72.27, 71.86, 69.84, 69.52, 68.38, 63.32, 55.11. The data are identical to the literature report^[145], and the spectral images for this compound are published in our research article.^[119]

Methyl (2,3,4,6-tetra-O-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (2.46):

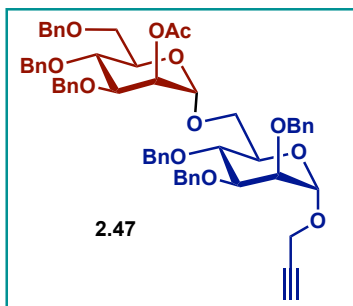


Following the general procedure **E**, glycosyl acceptor **A13** (25.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7c** (59.0 mg, 75.0 μmol) to afford **2.46** (49.0 mg, 45.2 μmol , 91% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 8.08 – 8.04 (m, 2H), 8.00 – 7.97 (m, 2H), 7.93 (dd, J = 8.3, 1.4 Hz, 2H), 7.89 – 7.85 (m, 4H), 7.82 (dd, J = 8.5, 1.4 Hz, 2H), 7.76 (dd, J = 8.3, 1.3 Hz, 2H), 7.64 – 7.59 (m, 1H), 7.56 – 7.45 (m, 6H), 7.44 – 7.37 (m, 5H), 7.33 (td, J = 8.1, 3.9 Hz, 6H), 7.30 – 7.27 (m, 2H), 7.22 (d, J = 7.5 Hz, 2H), 5.90 (t, J = 9.7 Hz, 1H), 5.78 (dd, J = 9.9, 3.4 Hz, 1H), 5.69 – 5.62 (m, 2H), 5.60 – 5.56 (m, 1H), 5.54 (dd, J = 3.5, 1.8 Hz, 1H), 4.97 (d, J = 7.9 Hz, 1H), 4.64 – 4.59 (m, 2H), 4.43 (dd, J = 12.1, 5.1 Hz, 1H), 4.25 (t, J = 8.5 Hz, 1H), 4.15 (d, J = 14.9 Hz, 2H), 3.85 (dd, J = 11.1, 8.4 Hz, 1H), 3.11 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 166.21, 165.90, 165.77, 165.58, 165.39, 165.26, 165.24, 133.57, 133.54, 133.35, 133.29, 133.24, 130.02, 129.92, 129.90, 129.86, 129.83, 129.77, 129.42, 128.90, 128.85, 128.83, 128.70, 128.54, 128.49, 128.40, 128.33, 102.02, 98.05, 72.90, 72.29, 71.91, 70.51, 69.91, 69.80, 69.71, 67.41, 63.08, 54.96, 29.81. The data are identical to the literature report^[146], and the spectral images for this compound are published in our research article.^[119]

Propargyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6) 2,3,4-tri-O-benzyl- α -D-mannopyranoside (2.47)



Prepared according to General Procedure **D** at rt in 12 h, yielding the product **2.47** as a colorless oil (24 mg, 67%, α -only).

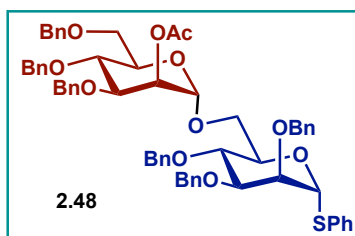
Following the general procedure **E**, glycosyl acceptor **A15** (25.0 mg, 51.0 μ mol) was coupled with EDPAT donor **2.7a** (54.0 mg, 77.5 μ mol) to afford **2.47** (38.0 mg, 39.5 μ mol, 77% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.42 – 7.18 (m, 28H), 7.17 – 7.09 (m, 2H), 5.46 (dd, J = 3.2, 1.9 Hz, 1H), 4.99 (dd, J = 27.0, 1.8 Hz, 2H), 4.88 (dd, J = 21.7, 11.0 Hz, 2H), 4.73 (s, 2H), 4.69 – 4.62 (m, 2H), 4.59 (d, J = 1.5 Hz, 2H), 4.45 (ddd, J = 13.8, 11.6, 4.9 Hz, 4H), 4.13 (dd, J = 4.0, 2.4 Hz, 2H), 3.98 – 3.81 (m, 6H), 3.80 – 3.76 (m, 1H), 3.69 (td, J = 10.9, 10.1, 2.6 Hz, 3H), 3.59 (dd, J = 10.9, 1.9 Hz, 1H), 2.38 (t, J = 2.4 Hz, 1H), 2.15 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.49, 138.69, 138.47, 138.35, 138.25, 137.91, 128.56, 128.52, 128.50, 128.46, 128.40, 128.34, 128.05, 127.95, 127.89, 127.85, 127.80, 127.77, 127.73, 127.67, 127.59, 98.10, 96.38, 80.14, 78.93, 75.16, 74.94, 74.56, 74.43, 74.24, 73.46, 72.80, 72.11, 71.64, 71.53, 71.47, 68.78, 68.61, 66.66, 54.30, 29.86, 21.34.

HRMS (ESI): calc. for $\text{C}_{59}\text{H}_{62}\text{O}_{12}\text{Na}$ ($M+\text{Na}$): 985.4139; found: 985.4137. The spectral images for this compound are published in our research article.^[119]

Phenyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6) 2,3,4-tri-O-benzyl-1-deoxy-1-thio- α -D-mannopyranoside (2.48**):**



Prepared according to General Procedure **D** at rt in 24 h, yielding the product **2.48** as a yellowish semisolid (60%, α -only).

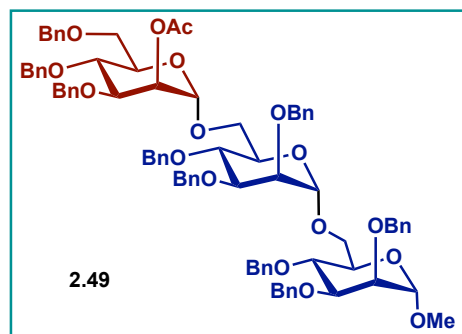
Following the general procedure E, glycosyl acceptor **A16** (27.0 mg, 50.0 μmol) was coupled with EDPAT donor **2.7a** (54.0 mg, 77.5 μmol) to afford **2.48** (43.0 mg, 42.5 μmol , 84% yield) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.32 (qd, $J = 24.1, 4.6$ Hz, 32H), 7.18 – 7.09 (m, 3H), 5.57 (s, 1H), 5.45 (s, 1H), 4.94 (d, $J = 7.8$ Hz, 2H), 4.86 (d, $J = 10.8$ Hz, 1H), 4.74 (d, $J = 13.3$ Hz, 1H), 4.71 – 4.57 (m, 6H), 4.50 (d, $J = 10.9$ Hz, 1H), 4.47 – 4.36 (m, 2H), 4.23 (dd, $J = 10.7, 6.2$ Hz, 1H), 4.01 (s, 1H), 3.97 – 3.89 (m, 3H), 3.89 – 3.76 (m, 3H), 3.70 (dd, $J = 17.7, 12.6$ Hz, 2H), 3.59 (d, $J = 10.9$ Hz, 1H), 2.14 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.45, 138.70, 138.42, 138.32, 138.16, 137.97, 137.94, 134.79, 131.97, 131.01, 129.27, 128.60, 128.57, 128.54, 128.50, 128.41, 128.33, 128.09, 128.00, 127.91, 127.86, 127.82, 127.74, 127.68, 127.61, 127.34, 98.20, 86.11, 85.52, 80.38, 77.95, 76.19, 75.25, 74.71, 74.20, 73.44, 72.24, 72.08, 71.96, 71.62, 71.43, 68.71, 68.56, 66.87, 21.34.

HRMS (ESI): calc. for $\text{C}_{62}\text{H}_{64}\text{O}_{11}\text{SNa}$ ($\text{M}+\text{Na}$): 1039.4067; found: 1039.4059. The spectral images for this compound are published in our research article.^[119]

Methyl 6-O-(6-O-(2-O-Acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl)-2,3,4-tri-O-benzyl- α -D-mannopyranosyl)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (2.49)



Prepared according to General Procedure D at rt in 10 h (36 mg, 56%, α -only).

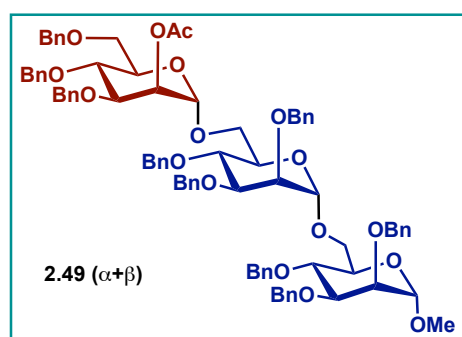
^1H NMR (600 MHz, CDCl_3) δ 7.39 – 7.09 (m, 45H), 5.48 (dd, $J = 3.2, 1.9$ Hz, 1H), 5.08 (d, $J = 1.8$ Hz, 1H), 4.95 – 4.79 (m, 4H), 4.72 – 4.55 (m, 11H), 4.50 – 4.34 (m, 7H), 3.97 – 3.74 (m, 11H), 3.73 – 3.55 (m, 7H), 3.52 (dd, $J = 10.8, 1.9$ Hz, 1H), 3.21 (s, 3H), 2.12 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.32, 138.89, 138.81, 138.66, 138.62, 138.47, 138.42, 138.39, 138.00, 128.50, 128.46, 128.40, 128.38, 128.32, 128.30, 128.04, 127.99, 127.91,

127.87, 127.84, 127.80, 127.77, 127.72, 127.67, 127.61, 127.58, 127.52, 127.42, 124.30, 99.06, 98.24, 98.03, 80.46, 79.46, 77.85, 75.13, 74.98, 74.95, 74.85, 74.66, 74.50, 74.27, 73.66, 73.54, 73.47, 72.96, 72.49, 72.25, 71.64, 71.59, 71.51, 71.44, 71.20, 68.81, 68.72, 68.55, 66.61, 66.13, 54.81, 21.30.

HRMS (ESI): calc. for $C_{84}H_{94}NO_{17}Na$ ($M+NH_4^+$): 1388.7; found: 1388.7. The data are identical to the literature report ^[147], and the spectral images for this compound are published in our research article.^[119]

Methyl 6-O-(6-O-(2-O-Acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl)-2,3,4-tri-O-benzyl- α -D-mannopyranosyl)-2,3,4-tri-O-benzyl- α -D-mannopyranoside [2.49($\alpha+\beta$)]



Procedure 1: Prepared according to the literature Procedure^[147] using donor **16** (20 μ mol), mannose acceptor (1.1 equiv.) NIS (1.75 equiv.)/TMSOTf(10 mol%) in DCM at 0 $^{\circ}$ C in 3 h (52%, $\alpha:\beta$ = 2:1). The ^1H NMR of the compound **13 (a-anomer)** matches the literature report.^[147]

Procedure 2: Prepared according to the literature Procedure^[148] using donor **17** (7 μ mol), mannose acceptor (1.2 equiv.) $AuCl_3$ (1 mol%) in acetonitrile at 60 $^{\circ}$ C in 3 h (76%, $\alpha:\beta$ = 2:1). The ^1H NMR of the compound **13 (a-anomer)** matches with the literature report.^[148] The spectroscopic data for the compound **13 ($\alpha:\beta$ = 2:1)** is given below.

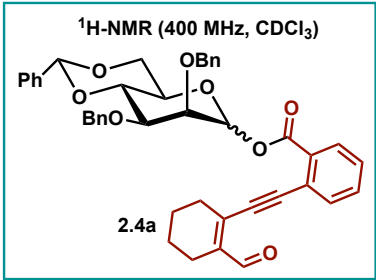
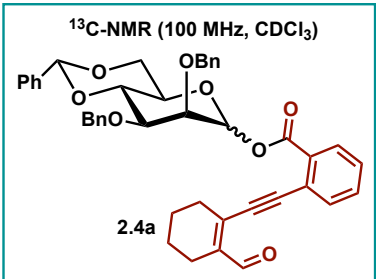
^1H NMR (400 MHz, $CDCl_3$) δ 7.47 – 7.44 (m, 1H), 7.40 – 7.37 (m, 2H), 7.34 (dt, J = 4.3, 2.4 Hz, 9H), 7.32 – 7.26 (m, 20H), 7.26 – 7.15 (m, 39H), 7.09 (dd, J = 6.6, 3.0 Hz, 4H), 5.49 (q, J = 3.2 Hz, 2H), 5.09 (d, J = 1.7 Hz, 1H), 5.00 – 4.87 (m, 7H), 4.85 – 4.80 (m, 3H), 4.73 – 4.52 (m, 19H), 4.50 – 4.35 (m, 12H), 4.20 (d, J = 16.7 Hz, 2H), 3.98 – 3.82 (m, 15H), 3.82 – 3.74 (m, 5H), 3.72 – 3.59 (m, 9H), 3.53 (ddd, J = 21.6, 10.8, 1.9 Hz, 4H), 3.40 (dd, J = 9.4, 3.0 Hz, 1H), 3.22 (s, 3H_a), 3.18 (s, 1.5H_b), 2.13 (s, 3H_a), 2.11 (s, 11.5H_b).

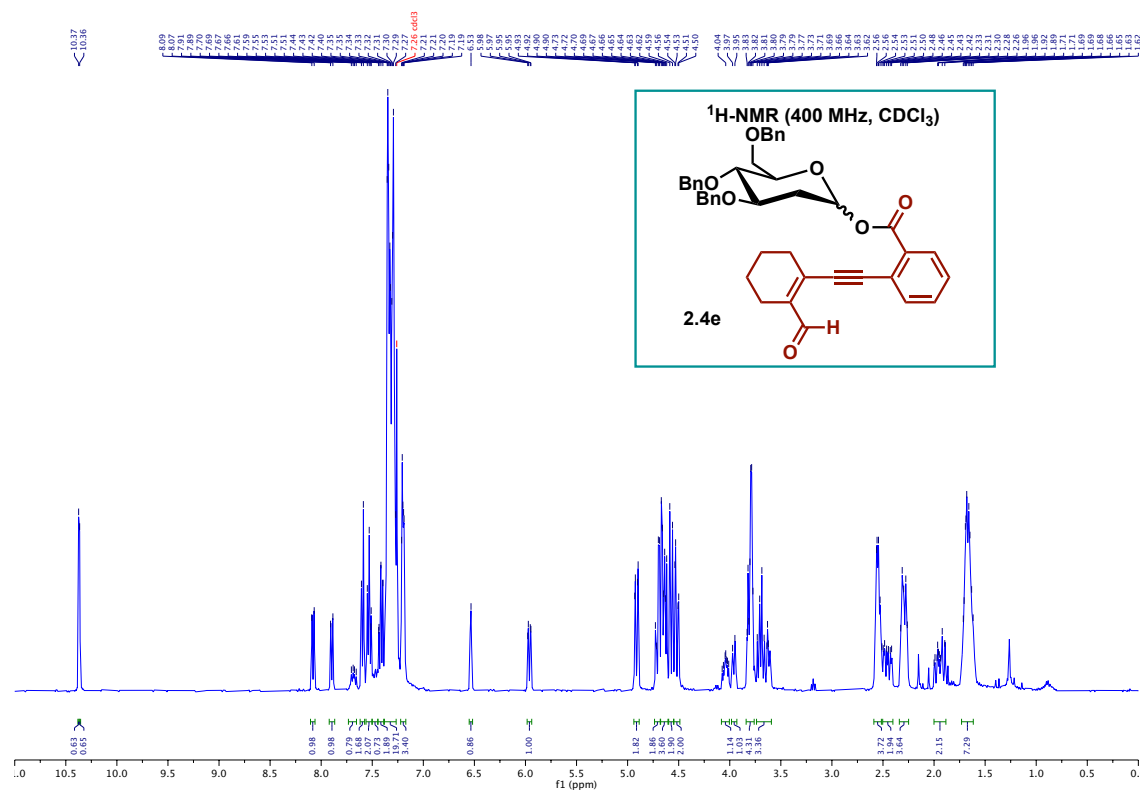
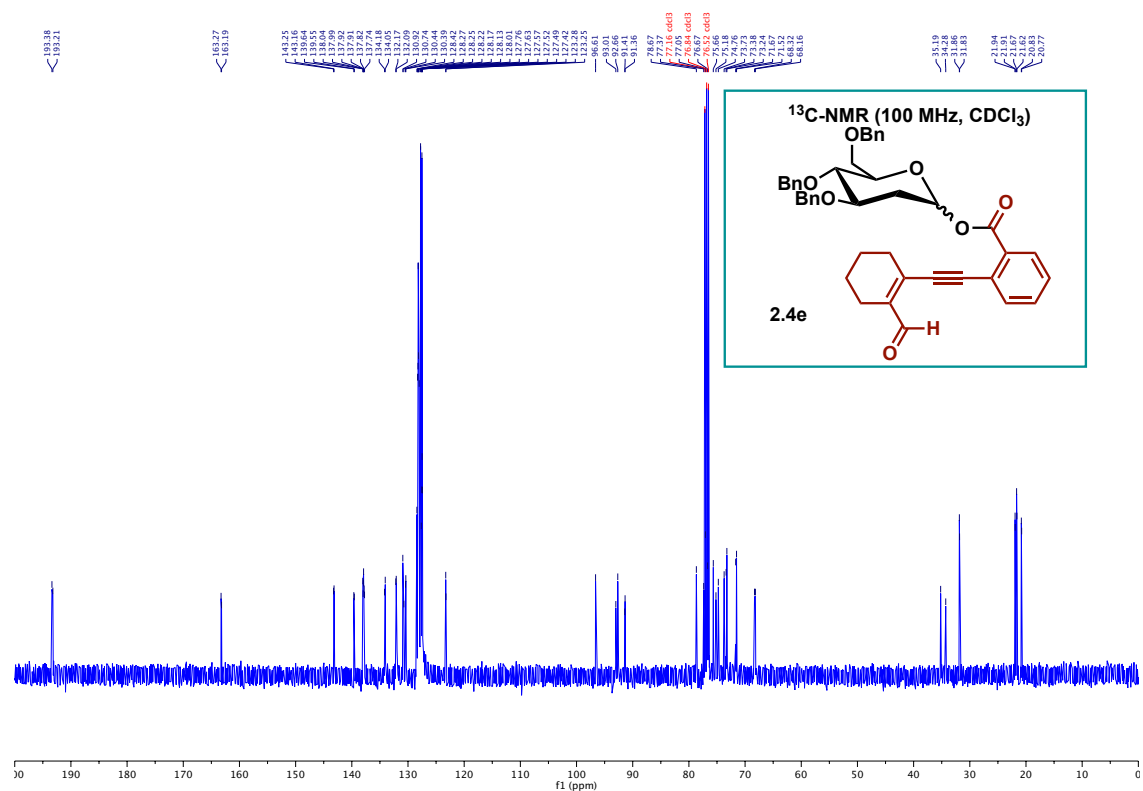
^{13}C NMR (100 MHz, $CDCl_3$) δ 170.22, 138.71, 138.69, 138.64, 138.62, 138.60, 138.46, 138.41, 138.24, 138.21, 138.17, 138.06, 137.84, 137.80, 128.61, 128.36, 128.33, 128.31,

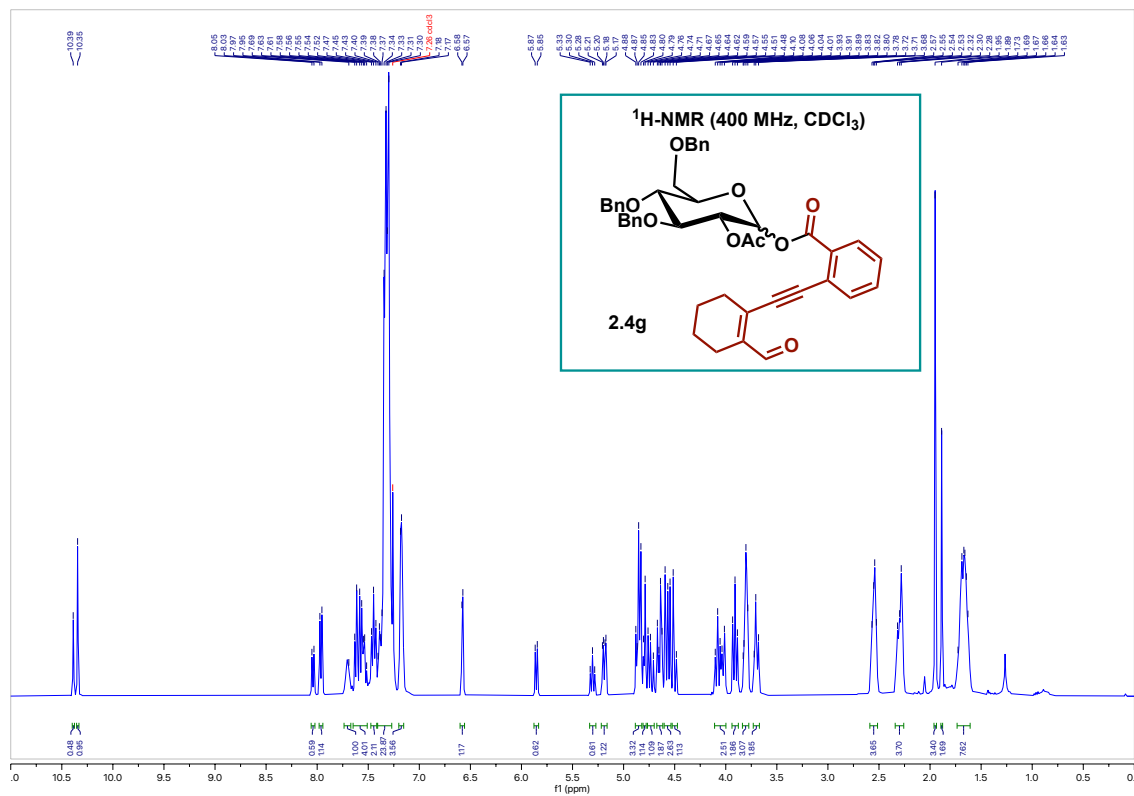
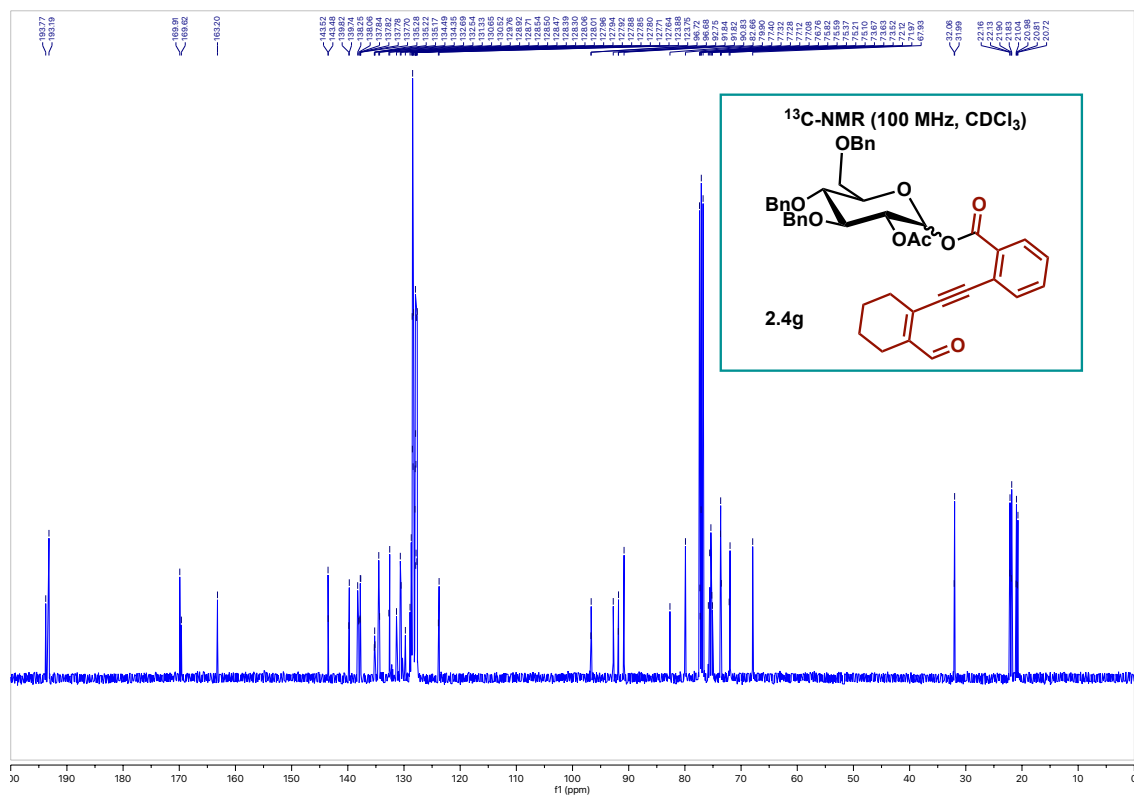
128.26, 128.23, 128.17, 128.16, 128.14, 128.09, 127.92, 127.89, 127.86, 127.79, 127.78, 127.73, 127.71, 127.67, 127.64, 127.62, 127.60, 127.58, 127.53, 127.48, 127.44, 127.41, 127.39, 127.32, 127.27, 102.22, 98.85, 98.74, 98.16, 98.06, 97.81, 82.15, 80.27, 79.25, 77.80, 77.67, 77.22, 74.98, 74.85, 74.67, 74.56, 74.44, 74.27, 74.04, 73.52, 73.30, 72.88, 72.77, 72.62, 72.30, 72.05, 71.89, 71.41, 71.29, 71.23, 70.99, 68.55, 68.34, 66.40, 65.93, 54.67, 54.58, 21.18, 21.16.

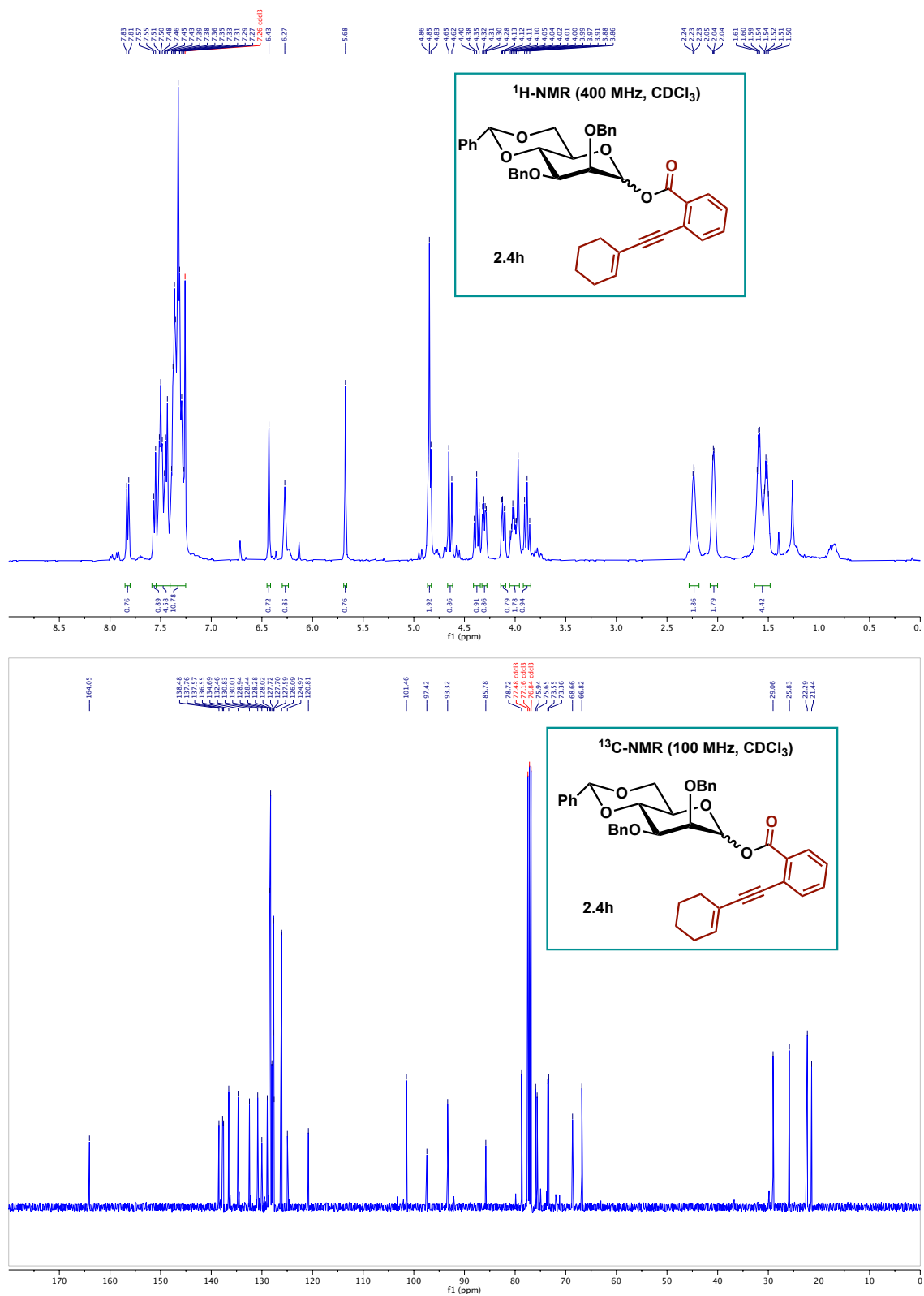
HRMS (ESI): calc. for $C_{84}H_{90}O_{17}Na$ (M+Na): 1393.6076; found: 1393.6072.

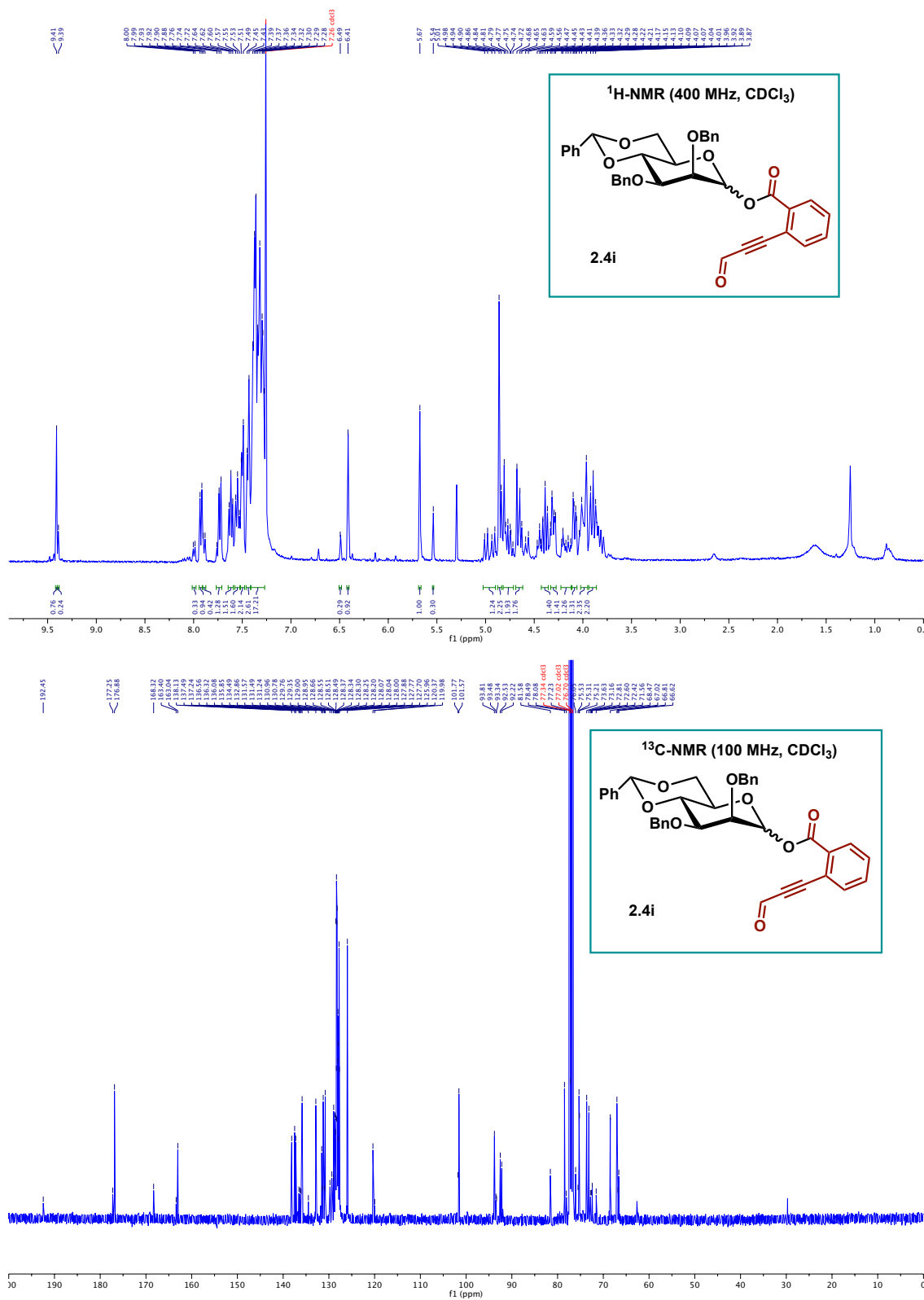
Work discussed in this chapter was published in *Adv. Synth. Catal.* **2024**, 366(8), 1847–1856 and *Molecules*, **2024**, 29 (22), 5367. The thesis author primarily performed the work reported in Results and Discussion.

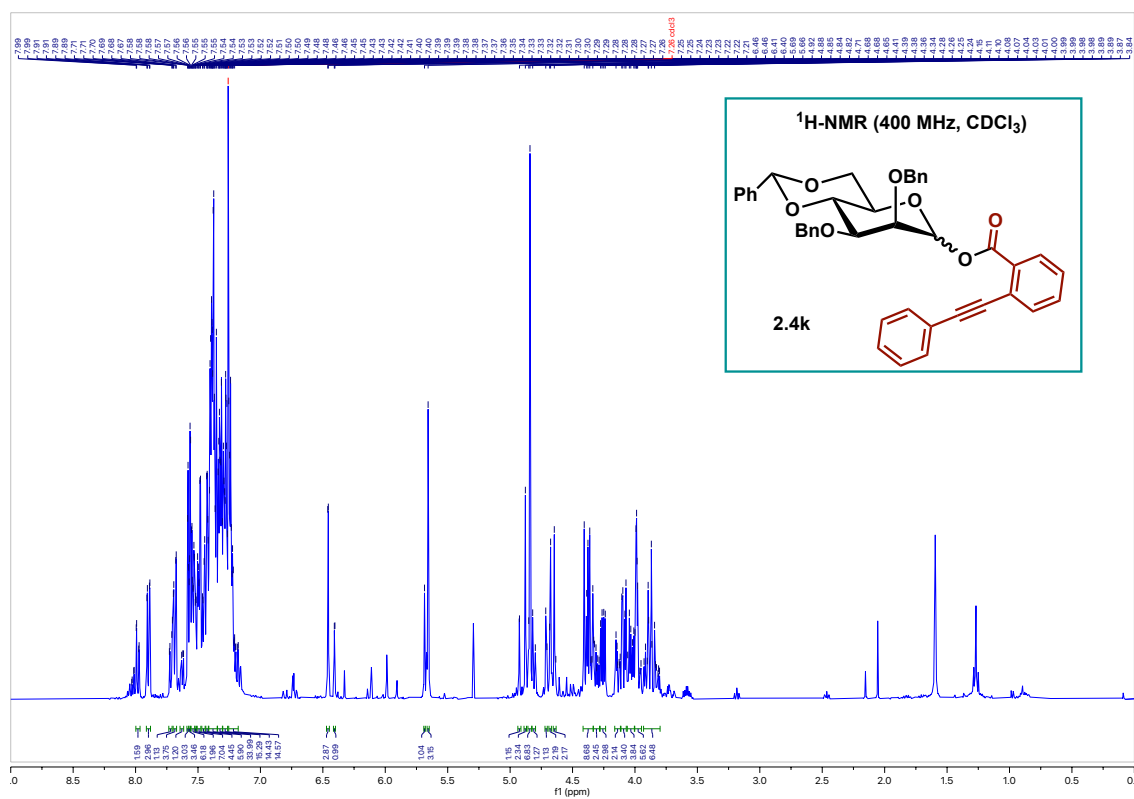
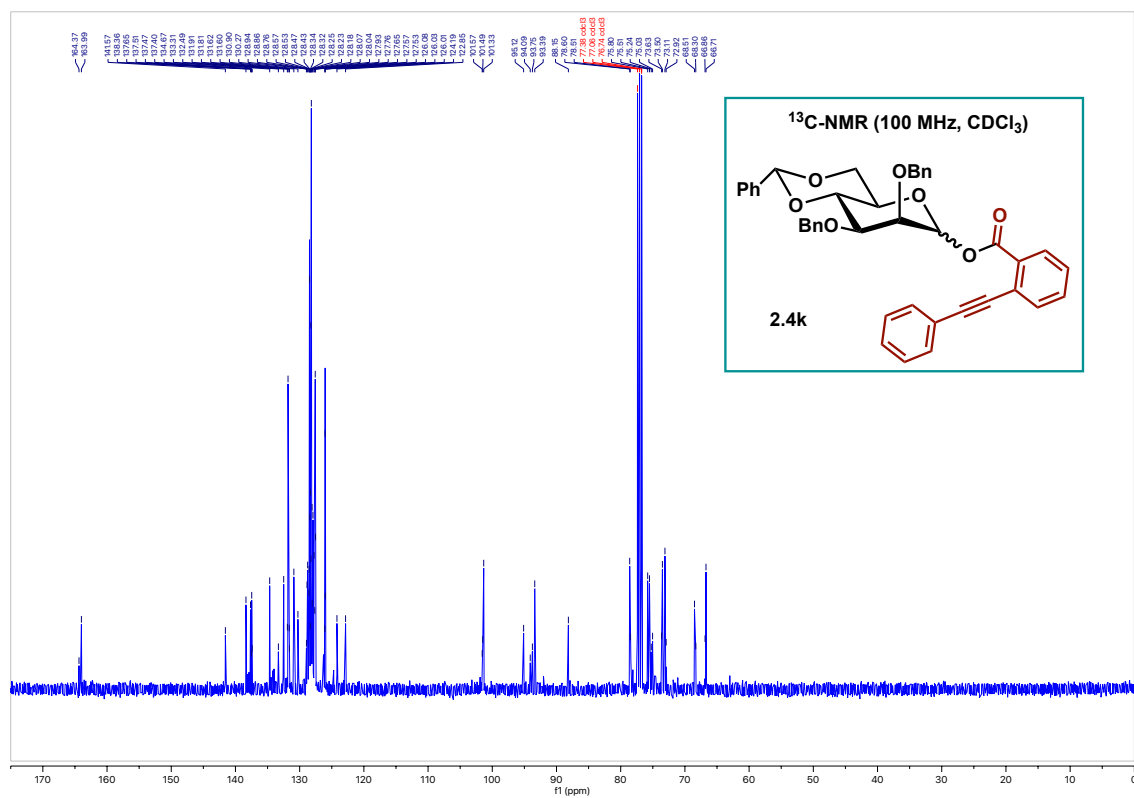


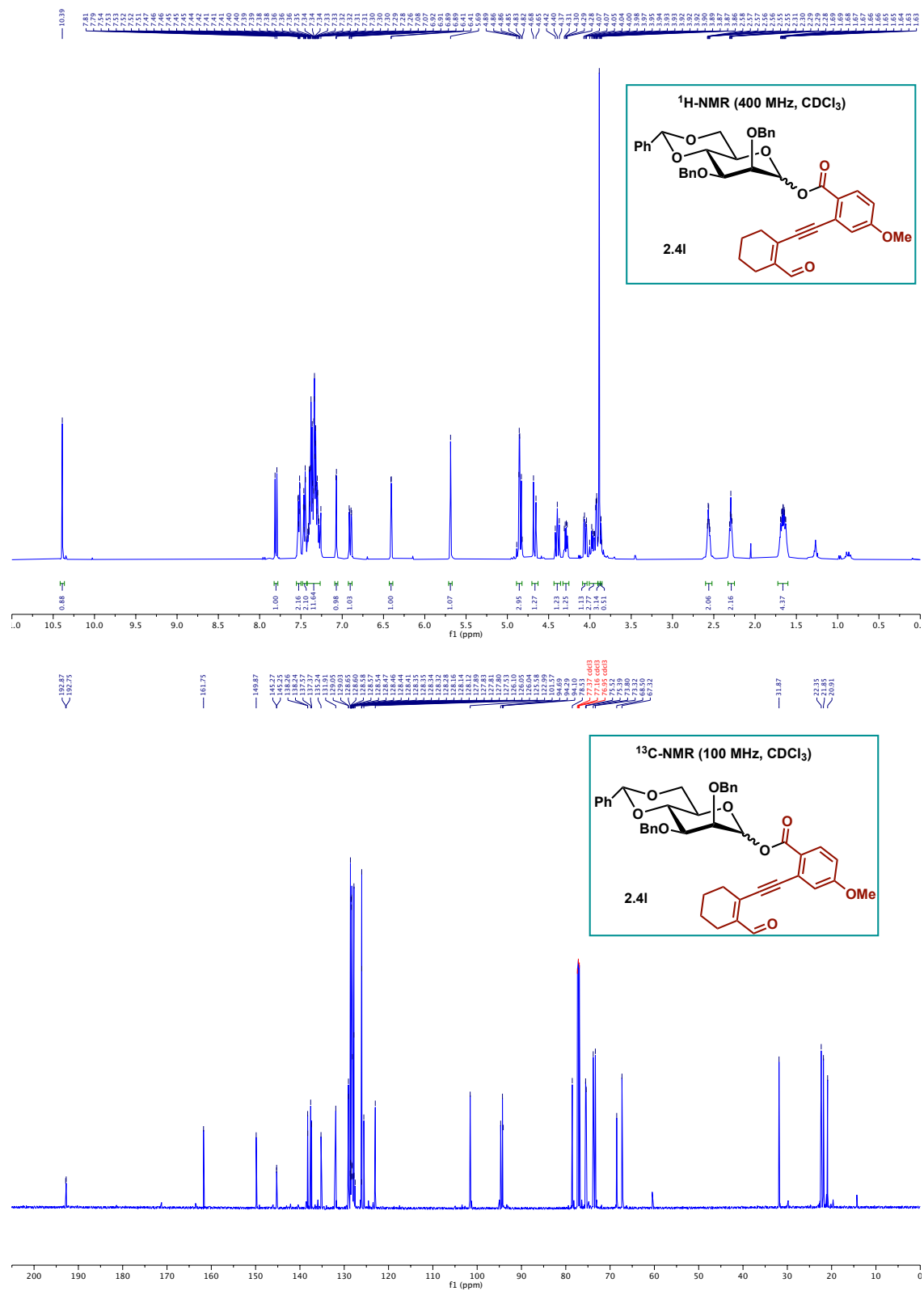


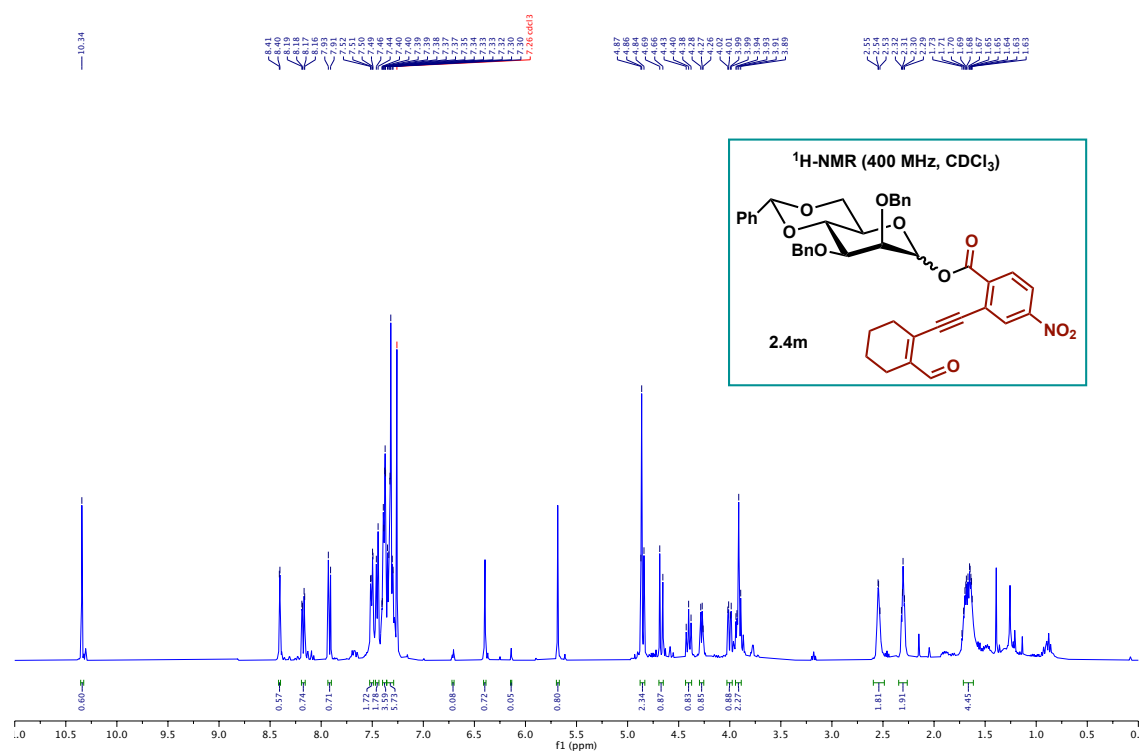
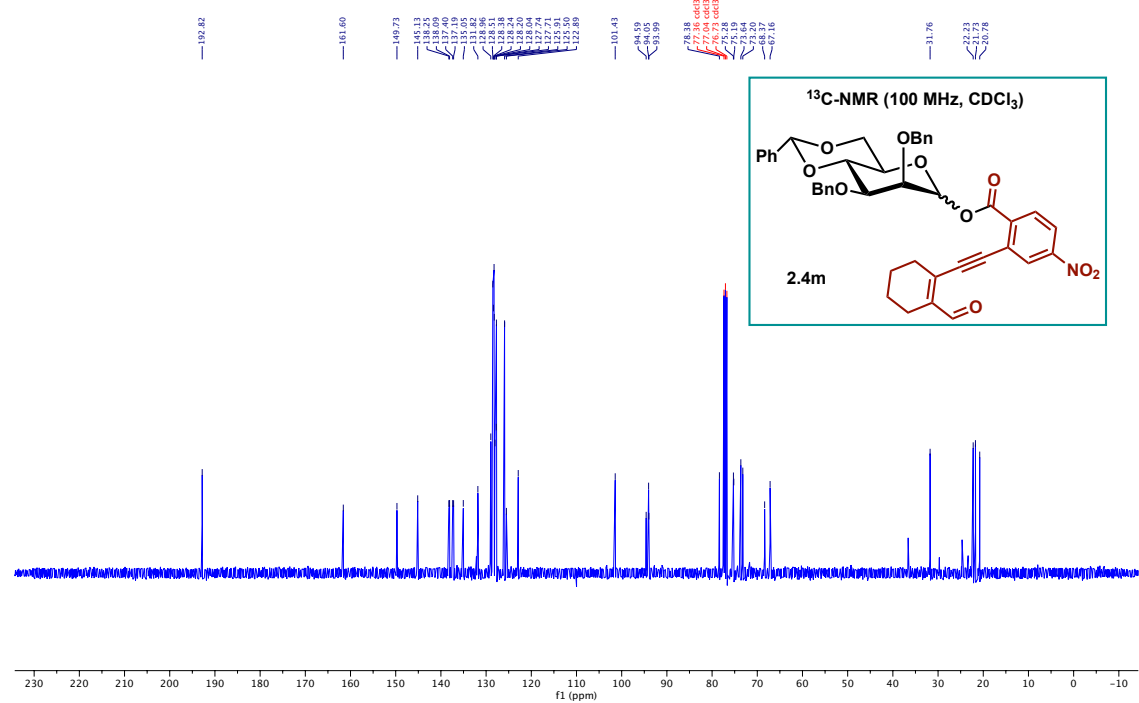


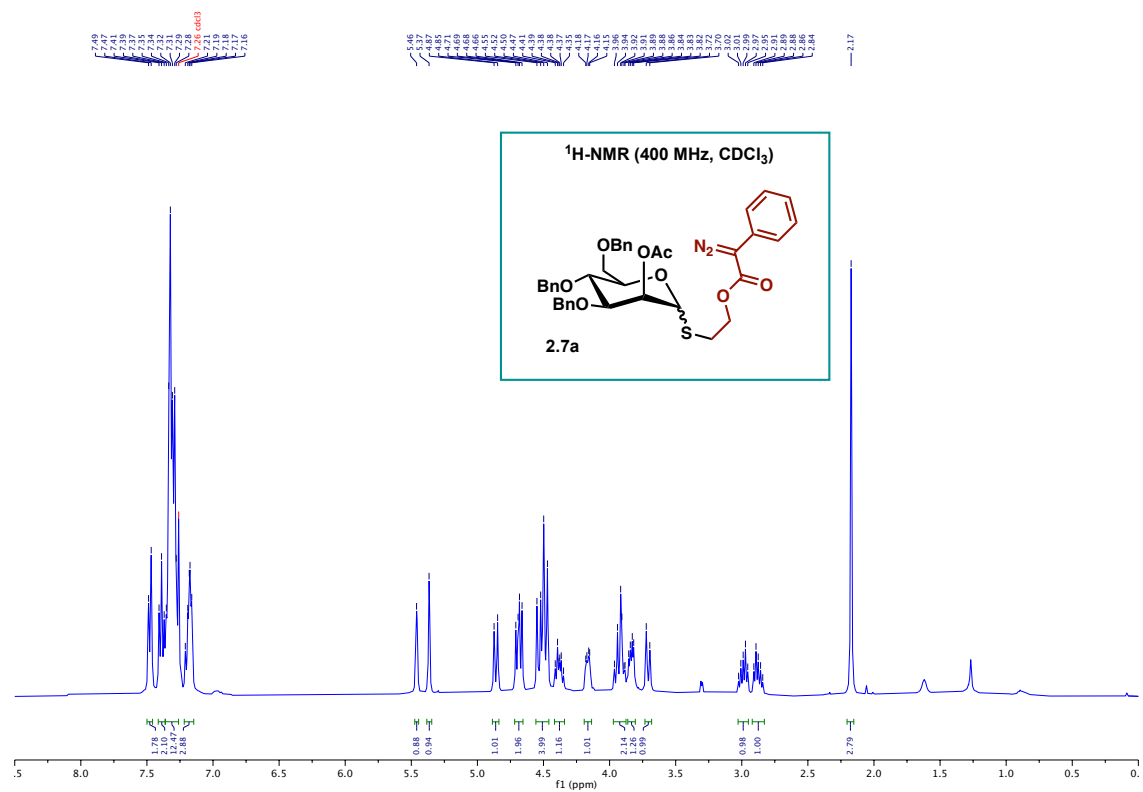
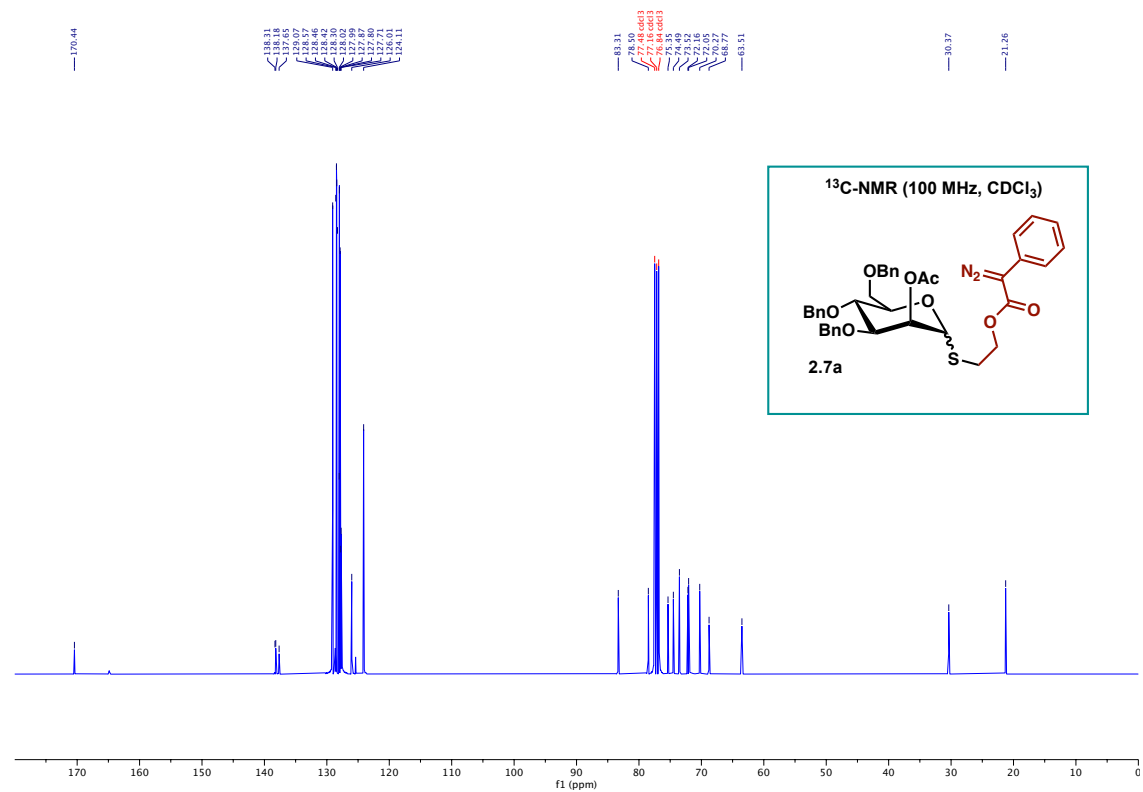


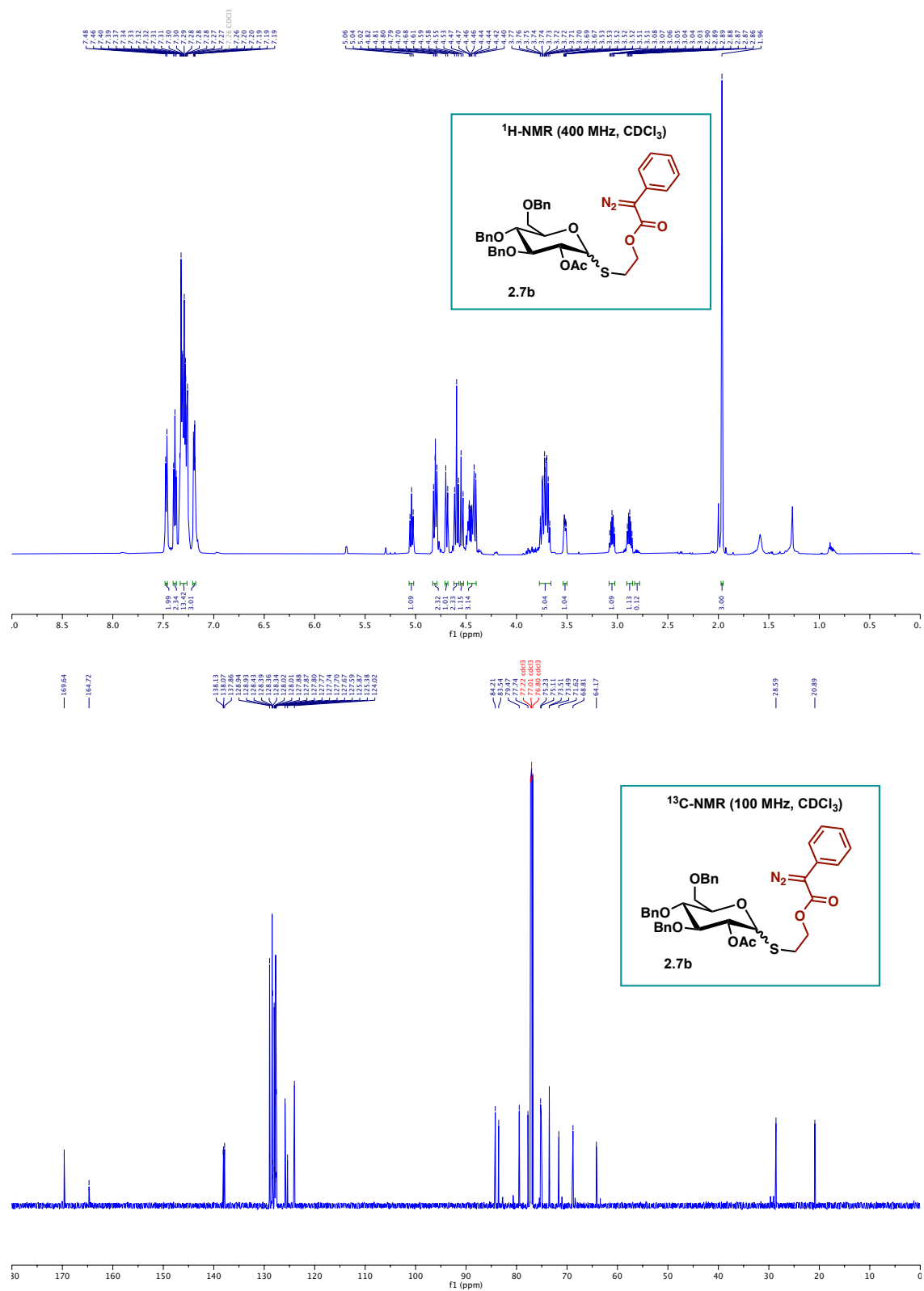


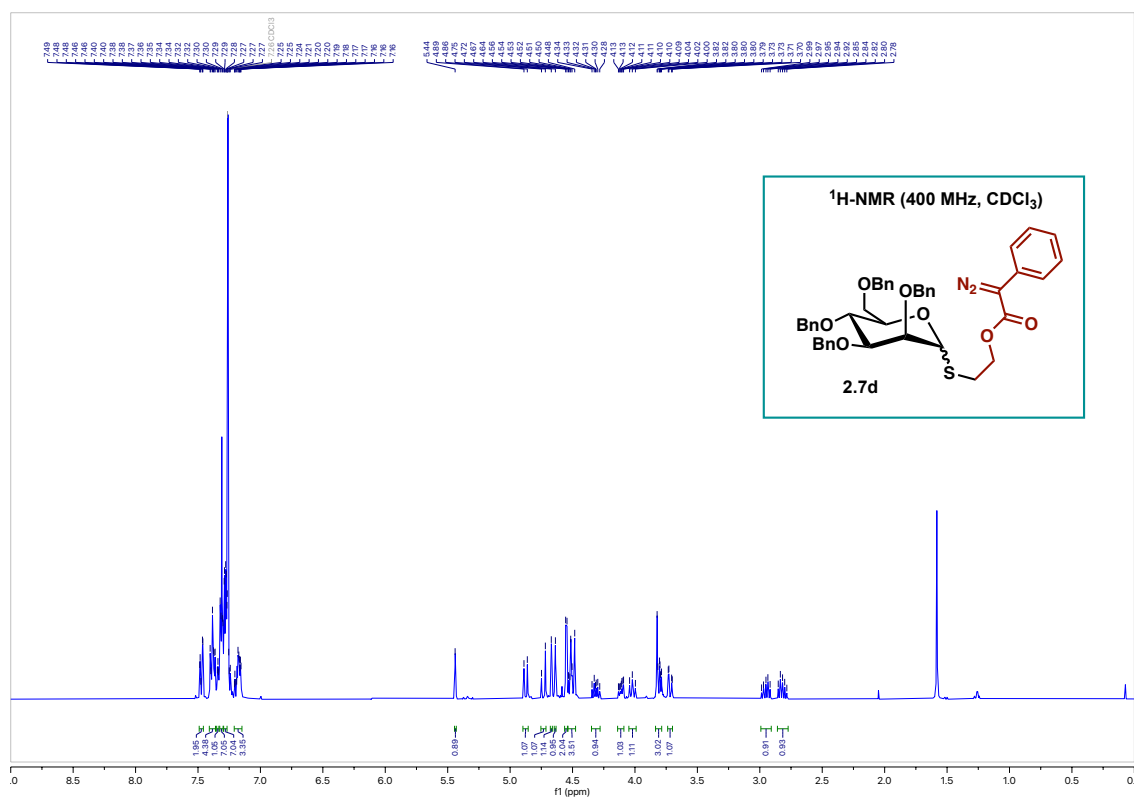
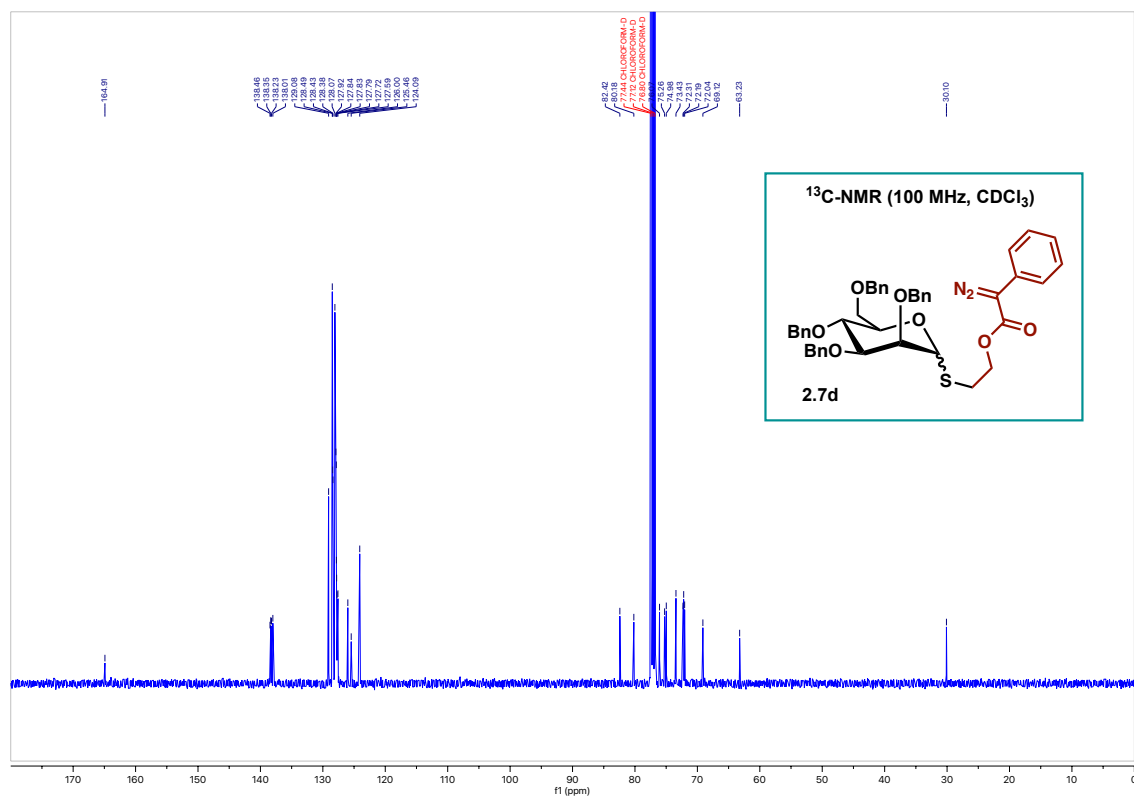


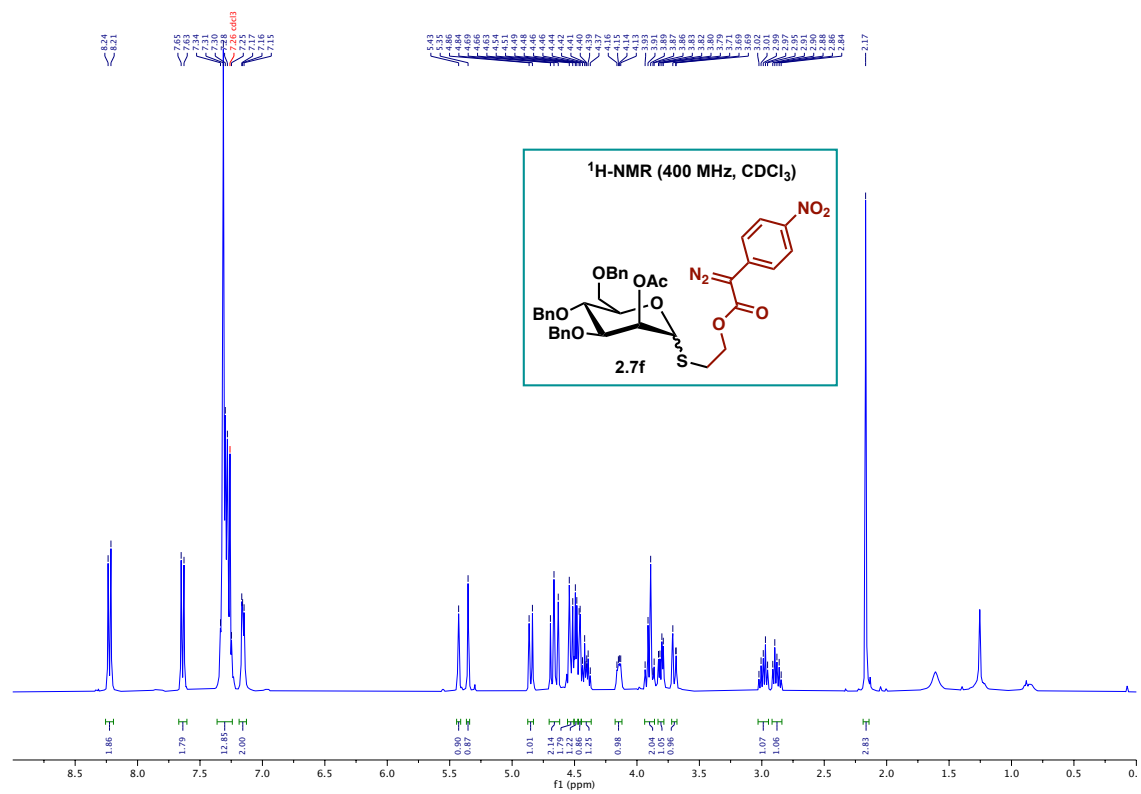
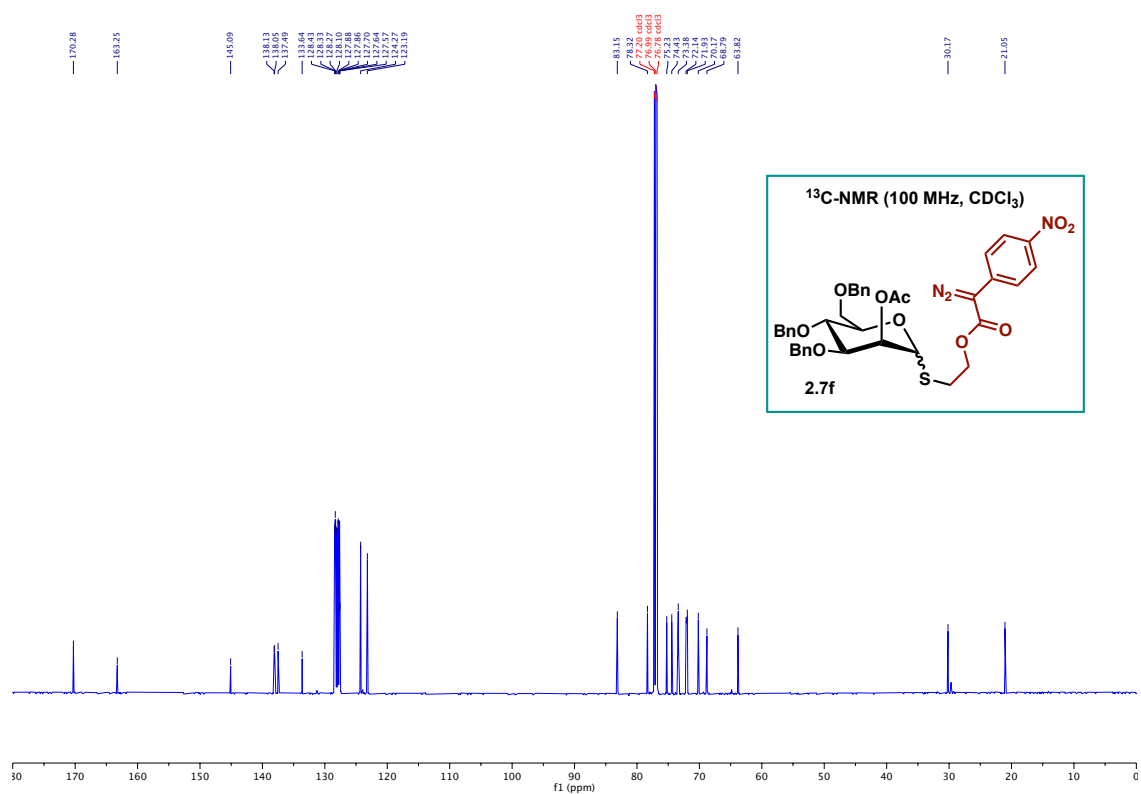


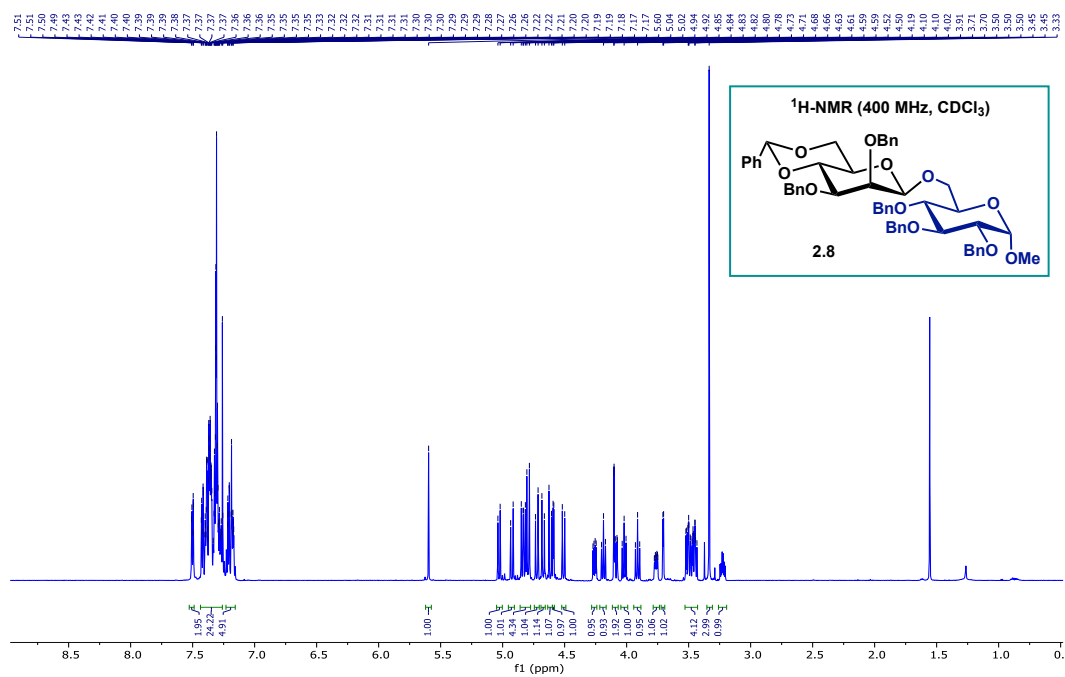
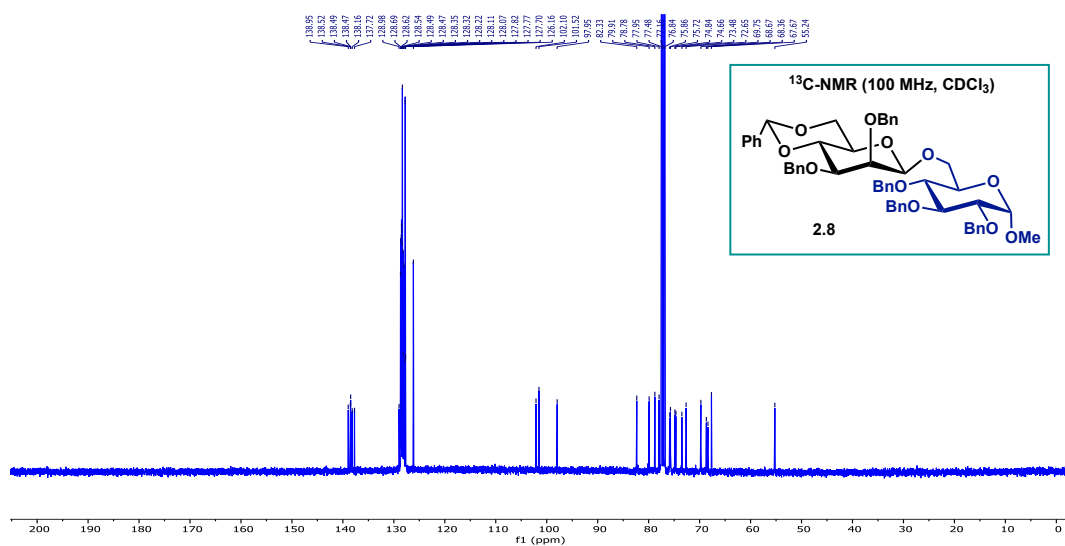












2.6. References

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CHAPTER 3

Fe(OTf)₃ or Photosensitizer-Free Blue Light Mediated Carbenes for Stereocontrolled Glycosylations

3.1 Introduction

As described in Chapter 2, carbenes are versatile reactive intermediates in organic synthesis, widely employed in various transformations such as cyclopropanations, cycloadditions, X-H, X-R (X = O, N, S) insertions, and cascade reactions.^[1-5] Traditionally, diazo compounds have been the most common carbene precursors, but their activation typically required harsh thermal conditions, often resulting in limited selectivity.^{[6-11], [12-13]} The introduction of transition metal catalysis, specifically rhodium^[14-15] (Rh) and gold^[16-17] (Au), has dramatically improved the efficiency of carbene-based transformations.^{[14], [18-21]} However, the reliance on these precious and platinum group metals [PGMs] presents environmental and human health concerns^[22], posing substantial challenges in developing sustainable synthetic methods.

Iron (Fe) is the second most abundant metal (5%) in the Earth's crust, after aluminum (8%)^[19], and offers a cost-effective and non-toxic alternative to these precious and platinum group metals [PGMs] in catalytic processes (**Figure 3.1.1a**).^[23-26] Significantly less expensive than precious metals (Rh, Au) frequently used in carbene chemistry, making it a more sustainable choice for large-scale applications. For instance, mining 1 kg of rhodium and gold produces 35,100 and 12,500 kilograms of CO₂, respectively, while mining the same amount of iron emits only 1.5 kilograms of CO₂.^[27] Moreover, all these PGMs are primarily responsible for global terrestrial acidification, freshwater eutrophication, and human toxicity, compared to earth-abundant metals like iron^[27], underscoring the importance of developing iron-catalyzed organic transformations. Iron catalysts also operate under milder conditions, exhibit lower toxicity, and are environmentally benign, making them attractive in both industrial and academic fields. By utilizing iron in catalytic transformations, chemists can adopt greener, more cost-effective methodologies without compromising efficiency or selectivity. Moreover, using blue light to generate carbenes offers an eco-friendly approach, further boosting the sustainability of these transformations (**Figure 3.1.1a**).^[2,28-30] The iron and blue light-initiated carbene generation provides a promising platform for developing synthetic methods that are both cost-effective and environmentally sustainable.

In this context, our group and others have developed carbene-based transformations using iron catalysis^[26,31] or blue light.^[2,32] Focusing on applying carbenes in carbohydrate chemistry,^[33-36] we turned our attention to thioglycoside activations. Due to their prolonged stability, thioglycosides are the most widely used glycosyl donors in automated glycan assembly (AGA). However, the inherent stability of thioglycosides often

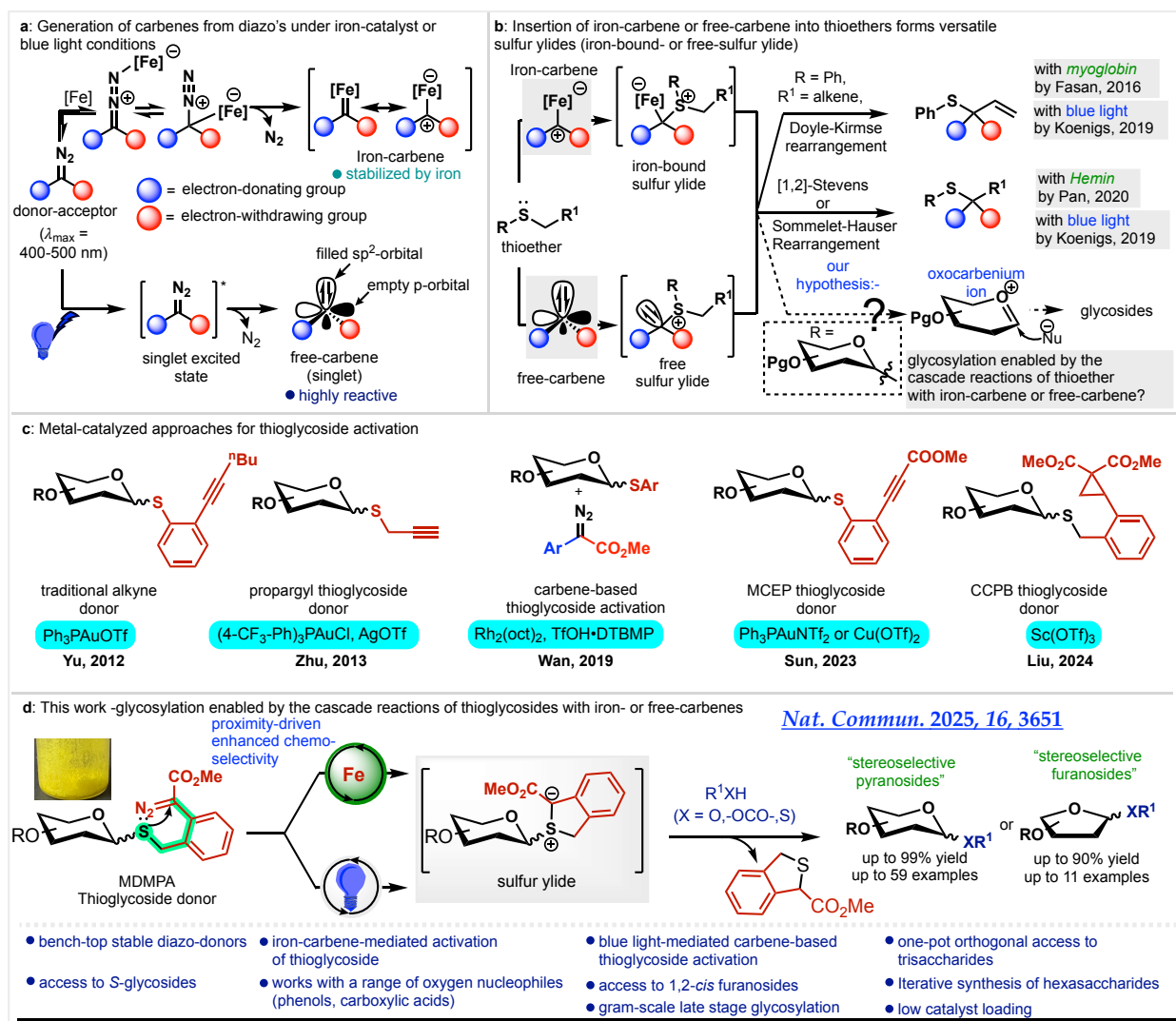


Figure 3.1.1: Iron-, or Free-carbenes in Organic Transformations by Activating Thioethers. **(a)** generation of iron- or free-carbenes from donor-acceptor diazo's, **(b)** application of thioethers with carbenes, and our hypothesis, **(c)** metal-catalyzed activation of various thioglycoside donors, **(d) This work:** iron- or free-carbene-mediated proximity-driven glycosylations. Pg, protecting group; MDMPA, methyl 2-diazo-2-(2-((methyl)phenyl)acetate; Me, methyl; Tf, trifluoromethanesulfonate; Ph, phenyl; oct, octanoate.

necessitates the use of stoichiometric amounts of promoters or harsh reaction conditions for activation, limiting their applicability and compatibility with various functional groups.^{[37-}

^{39]} Over the past decade, several catalytic strategies have been developed to overcome the limitations of traditional thioglycoside activation (**Figure 3.1.1c**).^[40-43] Notably, Wan and coworkers introduced an innovative method in 2019 utilizing rhodium carbenes.^[44] In

their report, once rhodium carbene reacts with the thioglycoside functionality, it transforms into a sulfur ylide. Then, the sulfur ylide gets eliminated to form the oxocarbenium ion, eventually leading to access to the glycosidic linkages. While these methods represent significant advancements, their reliance on PGMs and precious metals such as Au^[40,43], Ag^[41], Rh^[44], and Sc^[42], along with the requirement of harsh reaction conditions, continues to present challenges for the synthetic community and calls for more sustainable and environmentally benign alternatives.

The thioaryl group in thioglycoside donors is a valuable functionality in organic synthesis, inspiring the development of numerous synthetic transformations. A literature survey revealed that substituted thioether derivatives can react with iron-carbenoids or free carbenes to form unique sulfur ylides. These ylides are crucial intermediates in significant transformations such as the Doyle-Kirmse reaction^[45], [1,2]-Stevens rearrangement^[46], and Sommelet-Hauser rearrangement.^[2,26] Fasan and coworkers reported the iron carbene-mediated sulfur-ylide reaction in 2016, utilizing an iron-biocatalyst, *myoglobin* (*Mb*), to produce allylic or allenyl sulfides (**Figure 3.1.1b**).^[47] Following Fasan's pioneering work, only a few other reports have emerged, notably from Koenigs and colleagues^[48-49], Bi and coworkers^[50-51], and the Pan group^[52]. They further investigated these iron-bound sulfur-ylides in various transformations.

The reaction between blue light-initiated free carbenes and thioethers was reported by Koenigs and coworkers in 2019, where they demonstrated free sulfur ylide-derived Doyle-Kirmse rearrangement to produce allylic sulfides.^[53] Since then, only a few groups have utilized these free sulfur ylides.^[54-57] While these iron-bound or free sulfur ylides have been primarily used to access benzylic or allylic sulfides and allenes, their

potential remains largely untapped. Expanding sulfur-ylides, mainly through activating thioglycosides (a class of thioethers) using iron or blue light to synthesize glycosides, represents a significant advancement in this area.

In this Chapter, we propose an approach to meet the synthetic community's urgent need for more sustainable methods in catalytic stereoselective glycosylations. We hypothesize that environmentally friendly, iron- or photosensitizer-free blue-light-promoted carbenes can activate thioglycosides via intramolecular pathways, enabling the development of orthogonal and stereoselective glycosylation strategies under mild conditions. These approaches offer a milder, more cost-effective alternative to expensive and environmentally harmful PGMs (**Figure 3.1.1d**). These carbene intermediates can fragment to generate an oxocarbenium ion, a key intermediate, and easily removable thioether byproducts. The mild, carbene-based activation provides orthogonal reactivity compared to traditional glycosyl donors. The proximity-driven, intramolecular design will accommodate a range of nucleophiles, including primary, secondary, and tertiary alcohols, carboxylic acids, phenols, and sulfur-based nucleophiles. Ultimately, this methodology will offer a new platform for thioglycoside activation, enhancing automated glycan assembly (AGA) for synthesizing oligosaccharides.

3.2 Results and Discussion

3.2.1 Reaction Development

3.2.1.1 Initial Studies

In our initial studies, we synthesized perbenzoylated thioglucopyranoside (**3.1a**) as a donor, methyl 6-OH tri-O-benzyl glucopyranoside (**A1**) as an acceptor, and methyl 2-diazo-2-phenylacetate (**3.2a**) as a carbene precursor. We utilized our previously

developed diazo-activation method using $\text{Fe}(\text{BF}_4)_2 \cdot 6\text{H}_2\text{O}$ as a catalyst and NaBAR^{F} as an additive.^[31] As expected, the diazo decomposed and generated iron-carbene. However, we observed a direct insertion of the acceptor O–H into the diazo-derived iron carbene, producing product **5** as a major product and only a minimal amount of the desired product **3.3** (see optimization table S-3.1 from experimental section). After screening multiple iron salts and additives, we found that $\text{Fe}(\text{OTf})_3$ was the most optimized catalyst, and

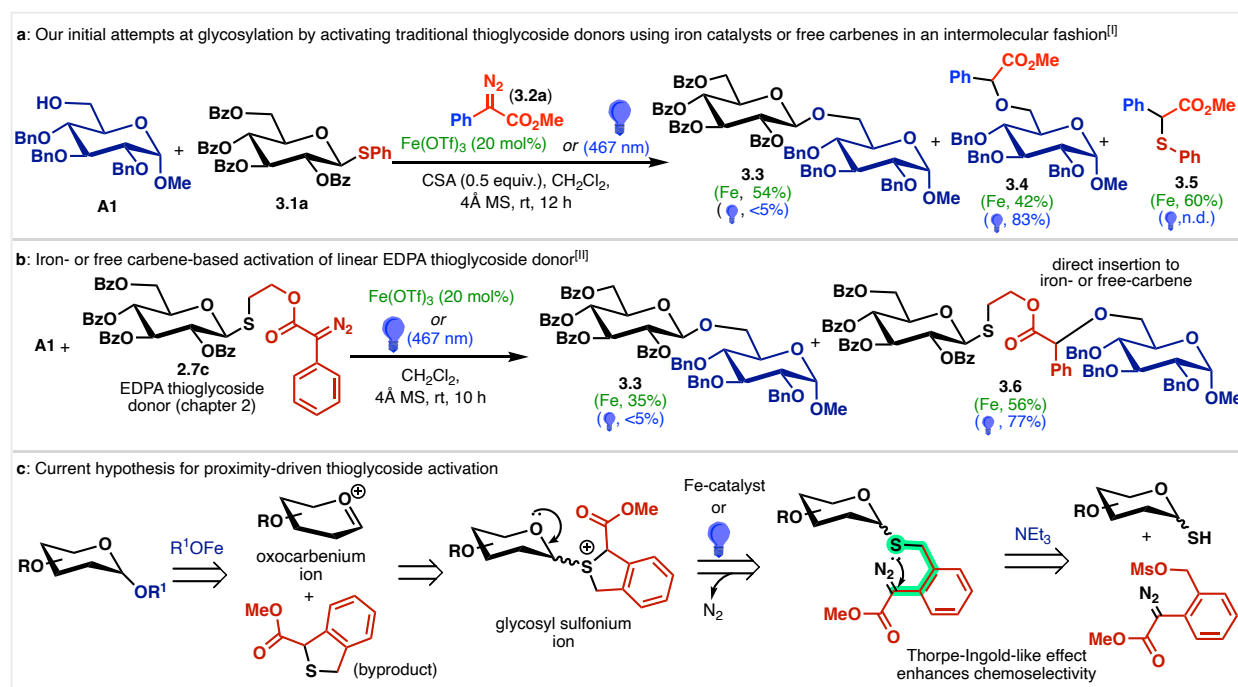


Figure 3.2.1.1: Initial reaction development. **(a)** carbene-based iron-catalyzed or blue-light-initiated intermolecular activation of traditional thioglycosides for glycosylation, **(b)** iron-catalyzed or blue-light-initiated intramolecular diazo-based thioglycoside activations for glycosylation, **(c)** retrosynthetic analysis for the proximity-driven diazo-based thioglycoside activation. [I] acceptor (0.025 mmol), donor (0.037 mmol), $\text{Fe}(\text{OTf})_3$ (0.05 mmol, 20 mol%) or Blue-light (467 nm, 50% intensity), CSA (0.012 mmol), CH_2Cl_2 (0.05 M), and diazo-1 (0.063 mmol). [II] acceptor (0.025 mmol), donor (0.050 mmol), $\text{Fe}(\text{OTf})_3$ (0.05 mmol, 20 mol%) or Blue-light (467 nm, 50% intensity), and CH_2Cl_2 (0.05 M). Yields in green are for $\text{Fe}(\text{OTf})_3$, and those in blue are for blue light. CSA, camphorsulfonic acid; n.d., not detected; Bn, benzyl; Bz, benzoyl; Ph, phenyl; Me, methyl; Tf, trifluoromethanesulfonate; EDPA, ethyl 2-diazo-2-phenylacetate; rt, room temperature; MS, molecular sieves.

camphorsulfonic acid (CSA) was the best additive, yielding 54% of the desired product.

However, there was still a significant amount of insertion byproduct (**Figure 3.2.1a**).

Our exploration of photosensitizer-free blue-light-mediated diazo activation successfully generated free carbenes. However, the primary outcome was the insertion of the carbene into the acceptor O–H bond, yielding product **3.4** as the major product, with only a minor amount of the desired glycoside **3.3**. The direct insertion of a free carbene into the O–H bond can be explained by the work of Koenigs and coworkers.^[58] They demonstrated that free carbenes interact significantly with the hydroxyl group through hydrogen bonding, which prefers the formation of O–H insertion products. These preliminary findings with both reaction conditions (Fe-catalyst and photochemical) highlighted a competitive interaction between two nucleophilic systems within the same reaction vessel. Based on the observed byproducts and the reduced yield of the target glycoside, we proposed a plausible reaction pathway for the intermolecular activation of thioglycosides (see **Figure 3.4.2.1** in the experimental section for more details). In this pathway, diazo compounds react with Fe(OTf)₃ to form an iron-carbene intermediate, which then interacts with nucleophiles present in the reaction mixture, namely the thioglycoside and glycosyl acceptor. This competition leads to relatively low yields of the desired product alongside significant byproduct formation. Nevertheless, these findings validate and strengthen our hypothesis of developing a carbene-based methodology for thioglycoside activation. To avoid the direct O–H insertion of acceptor alcohols into carbenes to achieve chemoselective thioglycoside activation, we designed an intramolecular thioglycoside donor featuring a diazo functionality **2.7c** (**Figure 3.2.1b**).

This donor was synthesized using a readily available, literature-known glycosyl thiol as the glycosyl donor^[59], which reacted with 2-bromomethyl 2-diazo-2-phenylacetate (EDPA) via an S_N2 mechanism with triethylamine as the base and acetonitrile as the

solvent, as discussed in Chapter 2. We anticipated that this donor would undergo an intramolecular reaction with the carbene to form a six-membered sulfonium ylide (either iron-bound or free), which would then transform into a glycosyl sulfonium ion, ultimately leading to the formation of an oxocarbenium ion and a glycosidic bond upon coupling with a glycosyl acceptor (see **Figure 3.4.2.2** in the experimental section for mechanistic details). Upon introducing donor **2.7c** and acceptor **A1** to the catalytic conditions of $\text{Fe}(\text{OTf})_3$ without any additives, we observed the insertion of acceptor **A1** into the iron carbene, producing a major byproduct (**3.6**) and yielding only a small amount of the desired glycoside (**3.3**). Similarly, irradiation of donor **2.7c** under blue light in the presence of acceptor **A1** exclusively produced byproduct **3.6**. These results suggest that, despite the intramolecular design, the sulfur and diazo groups may not be in close enough proximity to achieve the desired reaction.

We hypothesize that the linearity of the linker in this donor could be responsible for the unproductive pathways leading to byproducts and the low chemoselectivity favoring alcohol over sulfur for carbene insertion. While preliminary results demonstrated successful glycoside formation using iron- or blue-light-promoted carbenes, the key challenge remained the chemoselective activation of the thioglycoside in the presence of acceptor alcohol.

To enhance chemoselectivity, we propose leveraging the Thorpe-Ingold-like effect^[60] to bring the sulfur atom of the thioglycoside and the carbene closer together (**Figure 3.2.1c**). We hypothesize that introducing a phenyl ring with thioether and diazo groups at the *ortho* position will address this issue, promoting chemoselective activation due to the improved spatial alignment of the reactive centers.

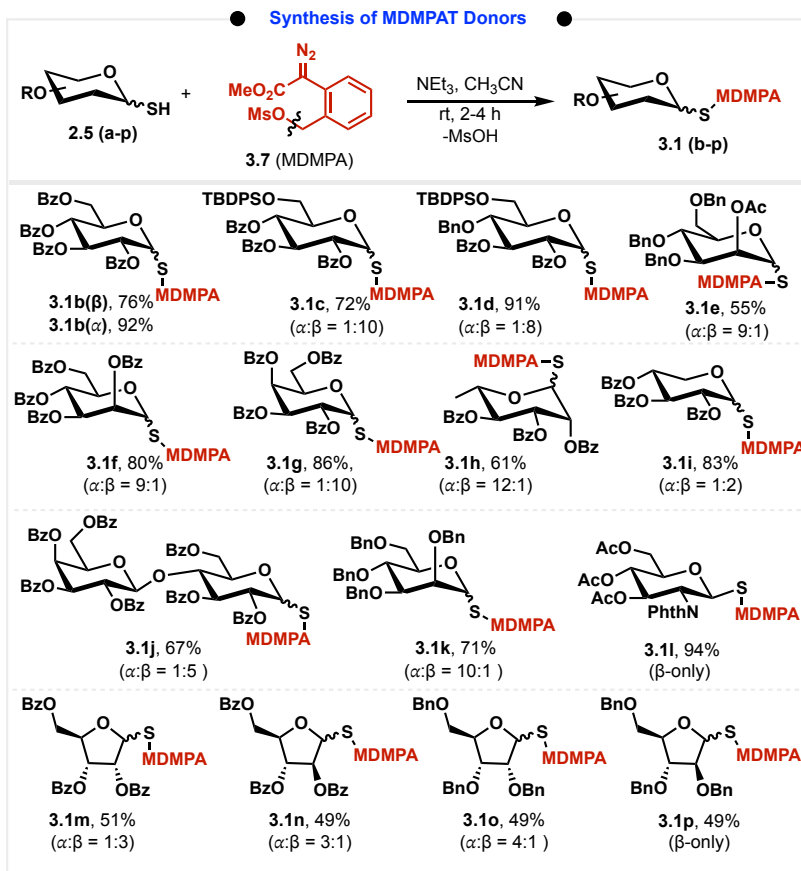


Figure 3.2.1.2: Synthesis of MDMPA thioglycoside donors. Reactions were performed with glycosyl thiol (1 equiv.), MDMPA linker (3.6) (1.15-1.2 equiv.), triethylamine (1.5 equiv.), and CH_3CN (0.3 M). MDMPA, methyl 2-diazo-2-((2-((methylsulfonyloxy)methyl)phenyl)acetate; Me, methyl; Ms, methanesulfonate; Bz, benzoyl; TBDPS, *tert*-butyldiphenylsilyl; Bn, benzyl; Ac, acetyl.

3.2.1.2 Synthesis of MDMPA thioglycoside donors

After a better understanding of reactivity, we resumed our studies by synthesizing designed thioglycoside donors. These donors were easily synthesized using readily accessible glycosyl thiols, which could be synthesized in two steps from the perbenzoylated glycosyl bromide to form glycosyl thiourea salt or thioacetate, and their hydrolysis. The crude thiols^[59] were light brown solids and significantly pure to use in the last step of donor synthesis, where they were coupled with methyl 2-diazo-2-(((methylsulfonyloxy)methyl)phenyl)acetate^[61] (MDMPA) in an $\text{S}_{\text{N}}2$ fashion (**Figure 3.2.1.2**).^[42] These donors were yellow, solid, and benchtop stable. Overall, the synthesis

of these donors required mainly four main steps, starting from perbenzoylated sugars, but the purification was needed only in the last step, producing overall high yields. We synthesize various classes of glycosyl donors, including D-glucose, D-mannose, D-galactose, L-rhamnose, D-xylose, lactose, 2-deoxyamino glucose, D-ribose, and D-arabinose, in good to excellent yields.

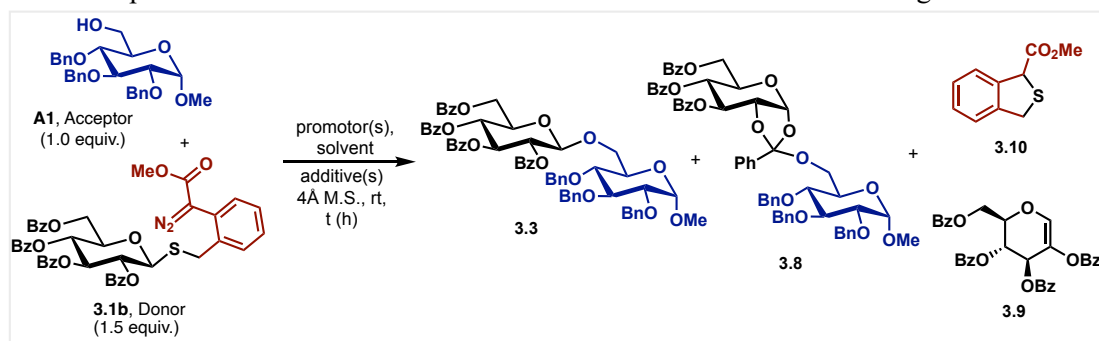
3.2.1.3 Optimization of reaction conditions

After successfully synthesizing the MDMPA thioglycoside donors, we optimized the reaction conditions. In our initial studies, we selected perbenzoylated (disarmed) MDMPAT **3.1b** as the model glycosyl donor and **A1** as the model glycosyl acceptor. Based on previous optimizations (see **Table S-3.1** from the experimental section), we used $\text{Fe}(\text{OTf})_3$ as a catalyst at 20 mol%, CH_2Cl_2 as a solvent, and 4Å molecular sieves for the initial trial. After stirring the reaction at ambient temperature for 4 hours, we were delighted to see an excellent yield of the desired product (entry 1, **Table 3.2.1.1**). To our delight, the major byproduct (**3.10**) and other byproducts were easily separated from the desired glycoside **3.3** by a small plug of column chromatography (see **filtration setup image** in the experimental section). To understand and determine the exact stereochemistry at the anomeric position of the product, we performed the 2D-NMR studies. More specifically, the coupled $^1\text{H},^{13}\text{C}$ -HSQC (Heteronuclear Single Quantum Coherence) provides the $^1J_{\text{C1-H1}}$ values for the anomeric carbon and hydrogen. In this case, we found that the $^1J_{\text{C1-H1}}$ value at the newly formed glycosidic bond was 161 Hz, and at the acceptor, the $^1J_{\text{C1-H1}}$ value was recorded 169 Hz. These values were consistent with the standard known values.^[62] We also screened other iron salts as catalysts, such as $\text{Fe}(\text{OTf})_2$ (entry 2) and FeCl_2 (entry 3), but after stirring the reaction mixture for 24

hours, no product formation was observed, and the starting thioglycoside donor remained unreactive. In the case of FeCl_3 (entries 4 and 5) and $\text{Fe}(\text{BF}_4)_2 \cdot 6\text{H}_2\text{O}$ (entry 6), the donor decomposed into unproductive pathways to produce significant endo glycal (**3.9**) as the major outcome, highlighting the importance of triflate counter anion in glycosylation reactions.^[63] We also screened $\text{Rh}_2(\text{esp})_2$ (entry 7) as a catalyst; the reaction was completed in just 2 hours, producing the major byproducts with no product formation. Superacids such as trifluoromethanesulfonic acid (TfOH) can also decompose the donor-acceptor diazo and generate carbene, so we performed two experiments with and without molecular sieves (entries 8 and 9). Molecular sieves quenched the TfOH , and the starting material remained unreactive, but without sieves, the starting donor decomposed into undesired products. This experiment was crucial for understanding the role of iron (III) and the triflate counterion in forming disaccharide **3.3**. We then screened various solvents, including THF (entry 10), CH_3CN (entry 11), toluene (entry 12), acetone (entry 13), and ethyl acetate (entry 14). Among these solvents, toluene was found to produce the desired compound, but dichloromethane remained the optimal solvent. We also examined the effect of temperature on the reaction conditions. We observed that lower temperatures, such as $-20\text{ }^\circ\text{C}$ and $-10\text{ }^\circ\text{C}$, did not produce a product, but at $0\text{ }^\circ\text{C}$, the product was observed after a prolonged time of 36 hours with slightly lower yields. We varied the amount of donor and catalyst loading and found that 1.5 equivalents of donor and 20 mol% of catalyst were optimal for the reaction.

Then, we also examined the different sizes of molecular sieves (MS) $3\text{ \AA}$ (entry 15) and $5\text{ \AA}$ (entry 16). $3\text{ \AA}$ molecular sieves work as efficiently as $4\text{ \AA}$ MS, while $5\text{ \AA}$ MS

Table 3.2.1.1. Optimization of the reaction conditions for the activation of the first-generation donor.^[a]



Entry	Promotor (s) [mol%]	Solvent (s)	Additive (s) [equiv.]	t (h)	Yields (%) ^[b]
1.	Fe(OTf) ₃ [20]	CH ₂ Cl ₂	-	4	3.3 (91) ^[c] , 3.10 (76) ^[c]
2.	Fe(OTf) ₂ [20]	CH ₂ Cl ₂	-	24	n.r.
3.	FeCl ₂ [20]	CH ₂ Cl ₂	-	24	n.r.
4.	FeCl ₃ [20]	CH ₂ Cl ₂	-	8	3.3 (<5), 3.9 (81)
5. ^[d]	FeCl ₃ [20]	CH ₂ Cl ₂	-	22	3.3 (<5), 3.9 (83)
6.	Fe(BF ₄) ₂ •6H ₂ O [20]	CH ₂ Cl ₂	-	24	3.3 (<5), 3.9 (72)
7.	Rh ₂ esp ₂ [20]	CH ₂ Cl ₂	-	4	3.8 (34) ^[c] , 3.9 (70) ^[c] , 3.10 (74) ^[c]
8.	TfOH [100]	CH ₂ Cl ₂	-	24	n.r.
9. ^[e]	TfOH [100]	CH ₂ Cl ₂	-	2	3.3 (<10), 3.8 (28)
10.	Fe(OTf) ₃ [20]	THF	-	24	n.r.
11.	Fe(OTf) ₃ [20]	CH ₃ CN	-	12	3.3 (11)
12.	Fe(OTf) ₃ [20]	toluene	-	18	3.3 (83), 3.10 (92)
13.	Fe(OTf) ₃ [20]	acetone	-	24	n.r.
14.	Fe(OTf) ₃ [20]	EA	-	24	n.r.
15. ^[f]	Fe(OTf) ₃ [20]	CH ₂ Cl ₂	-	4	3.3 (90) ^[c] , 3.10 (73) ^[c]
16. ^[g]	Fe(OTf) ₃ [20]	CH ₂ Cl ₂	-	4	3.3 (82) ^[c] , 3.10 (73) ^[c]
17. ^[e]	Fe(OTf) ₃ [20]	CH ₂ Cl ₂	-	4	3.3 (79) ^[c] , 3.10 (73) ^[c]
18.	Blue LED (456 nm)	CH ₂ Cl ₂	-	2	3.3 (<5), 3.9 (91)
19.	Blue LED (456 nm)	CH ₂ Cl ₂	LiOTf [1.0]	3	3.3 (29), 3.9 (91), 3.10 (82)
20.	Blue LED (456 nm)	CH ₂ Cl ₂	LiOTf [1.0] + CSA [0.5]	3	3.3 (49), 3.10 (80)
21. ^[h]	Blue LED (456 nm)	CH ₂ Cl ₂	LiOTf [1.0] + CSA [0.5]	3	3.3 (65), 3.10 (73)
22. ^[i]	Blue LED (456 nm)	CH ₂ Cl ₂	LiOTf [1.0] + CSA [0.5]	4	3.3 (72), 3.10 (86)
23.	Blue LED (456 nm)	CH ₂ Cl ₂	CSA [0.5]	4	3.3 (<5)
24.	none	CH ₂ Cl ₂	LiOTf [1.0] + CSA [0.5]	24	n.r.

^[a]Unless otherwise specified, all reactions were conducted with acceptor **2a** (0.025 mmol), donor **3c** (0.037 mmol), promoters (0.005 mmol, 20 mol%) or blue-light (456 nm), and CH₂Cl₂ (0.05 M). ^[b]Yield was determined by ¹H NMR using 1,3,5-trimethoxybenzene as the internal standard. ^[c]Isolated yields, **note**: The yield of byproduct **10** was calculated based on the initial amount of the donor. ^[d]reactions were performed at 0 °C temperature. ^[e]Molecular sieves (MS) were not added. ^[f]3Å MS were added. ^[g]5Å MS were added. ^[h]2.0 equiv. of a donor was added. ^[i]2.5 equiv. of a donor was added. n.r., no reaction; n.d., not detected; Bz, benzoyl; Bn, benzyl; Tf, trifluoromethanesulfonate; CSA, camphorsulfonic acid; THF, tetrahydrofuran; rt, room temperature; esp, ethylsorbate propionate, M.S., molecular sieves; t, time; EA, ethyl acetate.

produces slightly less yield. Finally, we experimented in the absence of molecular sieves (entry 17), which also led to a slight decrease in yields, further highlighting the importance of molecular sieves.

Simultaneously, we optimized the reaction conditions for blue-light-promoted activation of thioglycosides, using superarmed MDMPAT **3.1e** as a model glycosyl donor. During these studies, we primarily screened three wavelengths of blue light (467, 456, and 440 nm) known to decompose donor/acceptor diazo under photosensitizer-free conditions.^[32] We also tested various additives to improve the efficiency of the glycoside formation. Ultimately, for donor **3.1e**, we found that the 456 nm wavelength combined with LiOTf as an additive produced the best results, highlighting the importance of triflate counteranion in glycosylation^[63] (refer to **Table S-3.2** in the experimental section). We then applied the same optimized conditions to the disarmed donor **3.1b**, and to our great satisfaction, we observed the desired product, though with significantly low yields (entry 19). The ambiphilic nature of this free carbene^[2] and the electron-withdrawing nature of the disarmed^[64] donor **3.1b** resulted in the elimination product (**3.9**) as the major outcome. This issue was addressed by introducing a Brønsted acid, which significantly increased the yields, presumably protonating the free carbene to enhance its electrophilicity (entry 20, see **Figure S-3.4.4.3** in the experimental section for a plausible mechanism). By increasing the donor equivalents and adding them in portions to the ongoing reaction, we further optimized the conditions for disarmed donor **3.1b** (entries 21 and 22). Finally, we conducted experiments without LiOTf (entry 23) and without blue light irradiation (entry 24). We concluded that Fe(OTf)₃ or blue light (456 nm) works equally well as an efficient promoter for activating MDMPA thioglycoside donors.

3.2.1.4 Effect of protecting groups on the reactivity of MDMPA donors

In our continued investigation into the effects of protecting groups on MDMPA thioglycoside donors under optimized conditions, we selected a range of donors with varying levels of moderately armed (**3.1d**) and superarmed (**3.1e**). Fe(OTf)₃ works protection at each position: fully disarmed (**3.1b**), disarmed (**3.1c**), equally efficiently across all donor classes, although electronic variations influence reaction time. Under blue-light-mediated activation, however, we noted changes in reactivity (**Figure 3.2.1.4a**). Specifically, electronically rich MDMPAT donors (**3.1d**, **3.1c**) exhibited similar reactivity, requiring only LiOTf as an additive.

Conversely, electronically deficient MDMPAT donors (**3.1b** and **3.1c**) reacted slightly differently, necessitating a combination of CSA and LiOTf as additives. To explain these reactivity differences under blue light, we propose a plausible mechanism (refer to **Figure S-3.4.4.3** in the experimental section). It is well known that carbenes, generated from diazo compounds under blue light, are less electrophilic than metal carbenes. Once free carbene is formed, it reacts quickly with the most acidic site nearby. In the case of disarmed donors, it reacts with the C2 proton, producing endo-glycal **3.9**. A proton source is introduced into the reaction, and it first protonates the carbene, generating a carbocation intermediate, which is then captured by the sulfur atom of thioglycoside to form an oxocarbenium ion. Notably, in the case of superarmed donors, only LiOTf sufficiently stabilizes the carbene and facilitates efficient glycosylation.

To further investigate the impact of electronic effects at the anomeric position, we conducted experiments with anomERICALLY pure donors. Specifically, we synthesized anomERICALLY pure donors **3.1b(α)** and **3.1b(β)**. Upon treatment with acceptor **A1** under

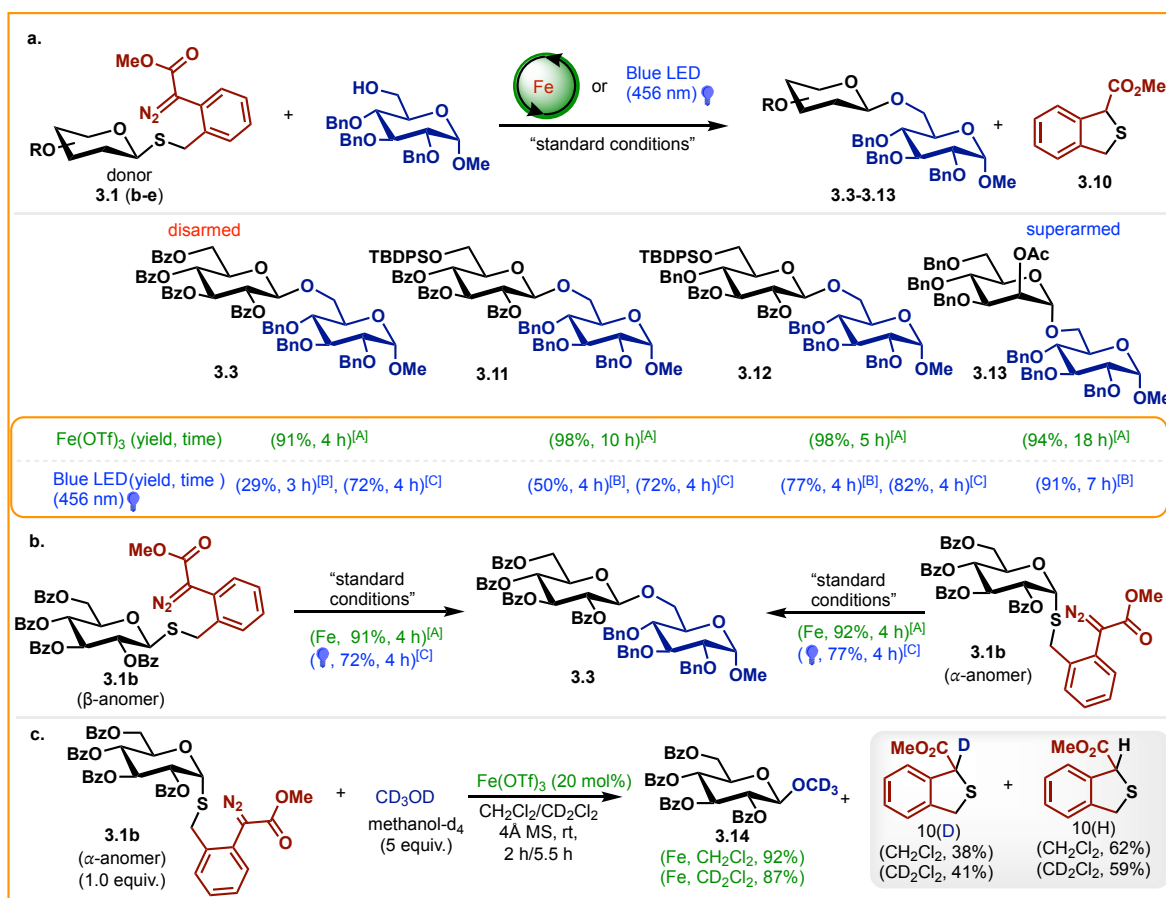


Figure 3.2.1.4: Effect of electronics on the reactivity of MDMPAT donors under iron- and blue-light activation conditions. **(a)** Effect of protecting groups (disarmed, armed, and superarmed) on the reactivity of MDMPAT donors under standard conditions. **(b)** Effect of anomeric stereochemistry of the MDMPAT donor (**3c**) under standard conditions. **(c)** A deuterium labeling experiment was conducted to elucidate the reaction pathway. [A] acceptor (0.025 mmol), donor (0.037 mmol), Fe(OTf)₃ (0.005 mmol, 20 mol%), and CH₂Cl₂ (0.05 M). [B] acceptor (0.025 mmol), donor (0.050 mmol), LiOTf (0.025 mmol), Blue-light (456 nm, 50% intensity), and CH₂Cl₂ (0.05 M). [C] acceptor (0.025 mmol), donor (0.062 mmol), CSA (0.012 mmol), LiOTf (0.025 mmol), blue-light (456 nm, 50% intensity), and CH₂Cl₂ (0.05 M). Yields in green are for Fe(OTf)₃, and those in blue are for blue light. CSA, camphorsulfonic acid; Bz, benzoyl; Bn, benzyl; Tf, trifluoromethanesulfonate; TBDPS, *tert*-butyldiphenylsilyl; rt, room temperature; MS, molecular sieves; Ac, acetyl.

standard reaction conditions, both donors exhibited identical reactivity patterns (**Figure 3.2.1.4b**), yielding the desired disaccharide **3.3** in excellent yield. These results indicate that the stereochemistry at the anomeric position does not influence the reactivity of MDMPA thiofuranoside donors, and the reaction proceeds through the common oxocarbenium intermediate.

To gain further insight into the reaction pathway, we performed deuterium-labeling experiments. Using donor **3.1b(a)** as a model and methanol- d_4 as the glycosyl acceptor, we observed excellent yields of the desired glucoside **3.14**, accompanied by a 38–41% yield of the deuterated byproduct (**3.10**) (**Figure 3.2.1.4c**). These findings suggest that the protonation of the glycosyl sulfonium ylide can occur via two pathways: (1) proton donation from the glycosyl acceptor or (2) protonation from residual moisture in the reaction solvent (see **Figure 3.4.4.4** in the experimental section). This series of experiments not only elucidated the mechanistic pathways but also enhanced our understanding of MDMPA donor reactivity. Encouraged by these insights, we extended our investigation to screen various substrates, aiming to develop a comprehensive library of glycosylated molecules.

3.2.2 Substrate Scope of MDMPA-Based Thioglycoside Donors

3.2.2.1 Scope of acceptors

After optimizing the reaction conditions, we investigated various nucleophiles, including O-nucleophiles (alcohols, phenols, carboxylic acids) and S-nucleophiles, as glycosyl acceptors to demonstrate the effectiveness of this methodology. We chose the perbenzoylated (disarmed) MDMPA thioglycoside **3.1b** to investigate the glycosyl acceptors as a model donor. Initially, we utilized primary sugar alcohols with different protecting groups, such as benzyl mannopyranoside **A9**, benzoyl glucopyranoside **A11**, mannopyranoside **A13**, galactose acetonide **A8**, and acetyl glucopyranoside **A10**. We were pleased to observe excellent yields of the disaccharides (**3.15-3.19**) (**Figure 3.2.2.1**). Subsequently, we examined sterically hindered secondary sugar alcohols (**A14**, **A18**, and **A19**), producing pyranosides (**3.20**, **3.21**) and furanosides (**3.22**) in excellent yields with expedited reaction times. The chiral secondary alcohol menthol provided an

excellent yield of the desired product **3.23**. Additionally, the highly sterically bulky alcohol 1-adamantanol **3.24** yielded excellent results under standard reaction conditions.

After successfully screening various alcohols, we then investigated other O-nucleophiles. Specifically, we used 4-methoxyphenol as a phenol, which produced an excellent yield of **3.25** despite being less nucleophilic. Typically, synthesizing glycosyl esters requires stoichiometric amounts of coupling reagents^[65-66], but our methodology efficiently formed glycosyl ester **3.26** quantitatively from its corresponding carboxylic acid. Glycopeptides, often found in pharmaceutically active compounds^[67], pose a significant challenge for carbohydrate chemists due to their complex synthesis. We attempted OH-Z-ser-OMe (**A21**) and OH-Z-ser-OAllyl (**A22**) as acceptors, successfully obtaining their corresponding glycopeptides **3.27** and **3.28** in excellent yields. This suggests our methodology could be useful for the synthesis of late-stage glycopeptides. Following the successful screening of the oxygen nucleophiles, we turned our attention to sulfur nucleophiles as glycosyl acceptors. Fortunately, we obtained the corresponding thioglycosides (**3.29-3.30**) in moderate to good yields. To further test the robustness of our methodology, we synthesized glycosyl acceptors with thioglycoside and alkyne functionalities at the activated anomeric position. Upon treatment with MDMPA thioglycoside donor **3.1b**, both functionalities remained unreactive under our reaction conditions (**Figure 3.2.2.1**). We were delighted to observe excellent yields of the desired disaccharides **3.31-3.33**. We then focused on the reactivity of superarmed donors **3.2e**^[64] with various nucleophiles. Using primary sugar alcohols with different protecting groups,

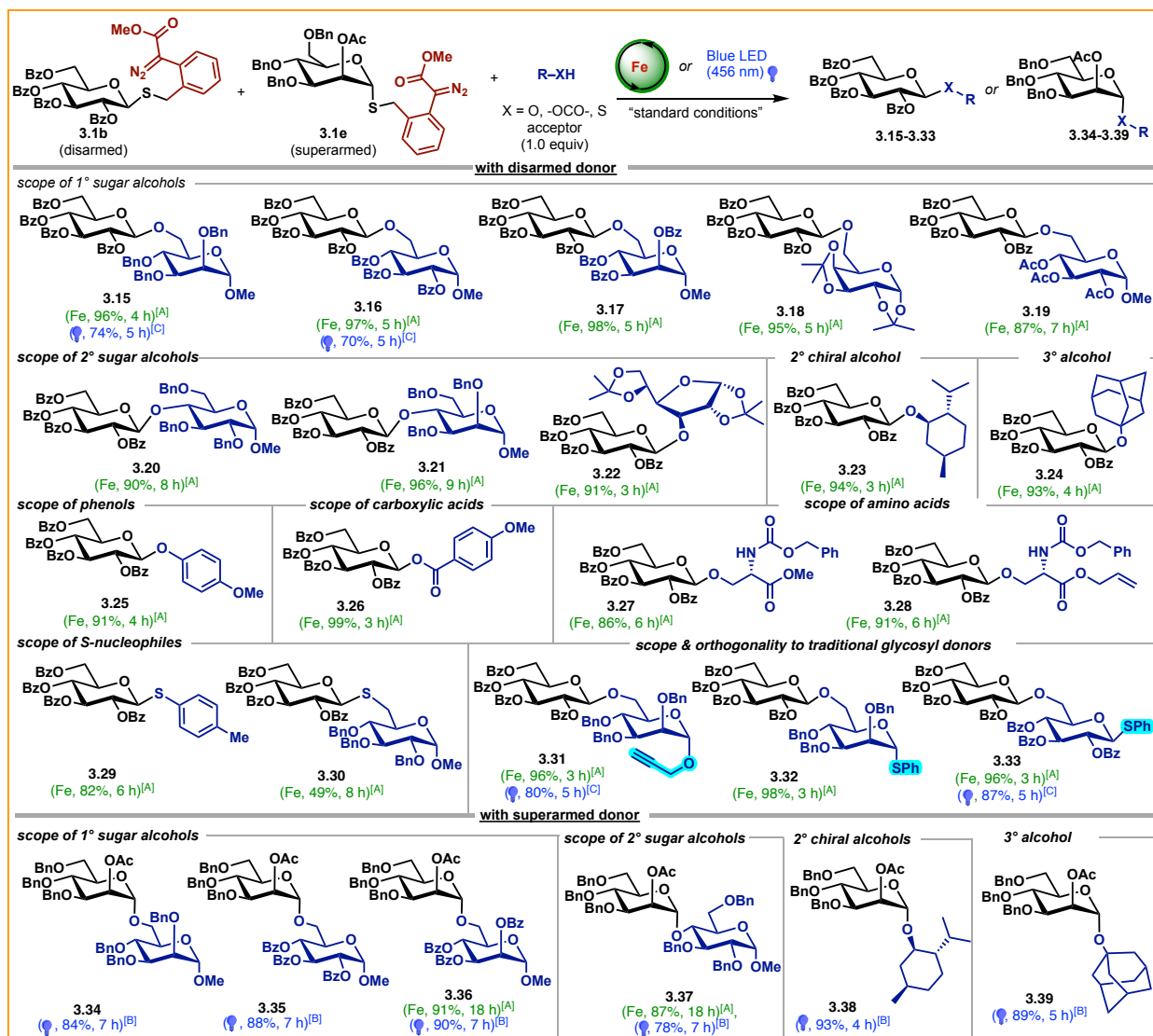


Figure 3.2.2.1: Scope of glycosyl acceptors. [A] acceptor (0.025 mmol), donor (0.037 mmol), Fe(OTf)₃ (0.005 mmol), and CH₂Cl₂ (0.05 M). [B] acceptor (0.025 mmol), donor (0.050 mmol), LiOTf (0.025 mmol), Blue LED (456 nm, 50% intensity), and CH₂Cl₂ (0.05 M). [C] acceptor (0.025 mmol), donor (0.062 mmol), CSA (0.012 mmol), LiOTf (0.025 mmol), and Blue LED (456 nm, 50% intensity), CH₂Cl₂ (0.05 M). Yields in green are for Fe(OTf)₃, and those in blue are for blue light. **Note:** In the product numbering system, the first number and letter (e.g., 4c) represent the donor's identity, while the second (e.g., d in 4cd) indicates the product's identity. Bz, benzoyl; Bn, benzyl; Ac, acetyl.

such as benzyl mannopyranoside **A9**, benzoyl glucopyranoside **A11**, and mannopyranoside **A13**, we observed excellent yields of disaccharides **3.34-3.36**. Similarly, sterically hindered secondary sugar alcohols **A14** produced pyranosides **3.37** in excellent yield. The chiral secondary alcohol menthol **A5** yielded the desired product

3.38 with high efficiency. The sterically bulky alcohol 1-adamantanol **A7** was tolerated well, yielding the desired product **3.39** in excellent yield under standard reaction conditions. Overall, our methodology is robust and cost-effective for all classes of glycosyl acceptors. Given its robustness, this approach can more efficiently synthesize various complex molecules, such as glycosyl esters and glycopeptides, and complement other known methods.

3.2.2.2 Scope of MDMPA donors

After successfully investigating glycosyl acceptors, we expanded our studies to include MDMPA thioglycoside donors. We resumed testing different protecting groups from **Figure 3.2.1.4**, using the MDMPA thioglucopyranoside donor **3.1c** with a tert-butyldiphenylsilyl (TBDPS) group protecting the C6 oxygen. Under standard conditions, this donor produced excellent yields with a benzoylated mannopyranoside acceptor **A13** and a sterically hindered glucosyl acceptor **A14**, yielding **3.40** and **3.41** (**Figure 3.2.2.2**). We then used an MDMPAT mannosyl donor **3.1f** with various acceptors, including primary sugar alcohols, thiols, and phenols. Sugar alcohols were successfully transformed into disaccharides (**3.42-3.44**) with excellent yields. While sugar thiols **A24** produced the desired product **3.45** in moderate yields, phenols yielded product **3.46** in excellent quantities. We then activated our MDMPAT galactose donor (**3.1g**) with primary glycosyl acceptors (**A1**, **A13**) and secondary glycosyl acceptor (**A14**) to produce excellent yields of the desired disaccharides (**3.47-3.49**). It is well known that the protecting group at the C6 position of sugars affects the reactivity at the anomeric position. To further investigate the effect of C6 protection, we used our synthesized MDMPAT rhamnose donor **3.1h**. We were pleased to find that this donor worked well with various primary and

secondary sugar alcohols, yielding rhamnose disaccharides (**3.50-3.52**) in excellent quantities. Next, we explored the effect of C5 substitution on the reactivity at the anomeric position. We used our xylose donor **3.1i**, which has no substitution at the C5 position. We found it worked well with both primary (**A1**, **A13**) and secondary (**A14**) sugar acceptors without affecting the reactivity of the thioglycoside donor, producing excellent yields of the xylose disaccharides (**3.53-3.55**). After testing monosaccharide donors, we examined the effect of disaccharide donors on the reactivity at the anomeric position. We used our synthesized lactose donor **3.1k** and exposed it to glycosyl (1°, 2°) acceptors under our standard conditions. We were pleased to find it produced the respective trisaccharides (**3.56-3.58**) in excellent yields. So far, we only used benzoyl protection, which worked excellently with our standard conditions. However, we aimed to test our methodology with various protection groups to increase its applicability. In the realm of this, we synthesized a perbenzylated mannose donor **3.1k** and found it worked with sugar alcohol to produce the desired disaccharide **3.59** in good yield and with a mixture of diastereomers. Furthermore, we activated our MDMPAT 2-deoxyamino glucose donor **3.1l** with secondary glycosyl alcohol (**A1**) under standard conditions. We also found this to work well, producing the desired 2-deoxy amino disaccharide (**3.60**) in excellent yields. After successfully exploring the scope of pyranose donors, we shifted our focus to a different class of carbohydrates, the five-membered furanosides.

Furanosides are crucial components of many oligosaccharides of biological importance, and interest in the stereoselective synthesis of furanose-containing glycans has gained significant attention from the carbohydrate community.^[68-73] Furanosides often feature 1,2-*trans* and 1,2-*cis* linkages, essential for their biological function.^[74-76] We

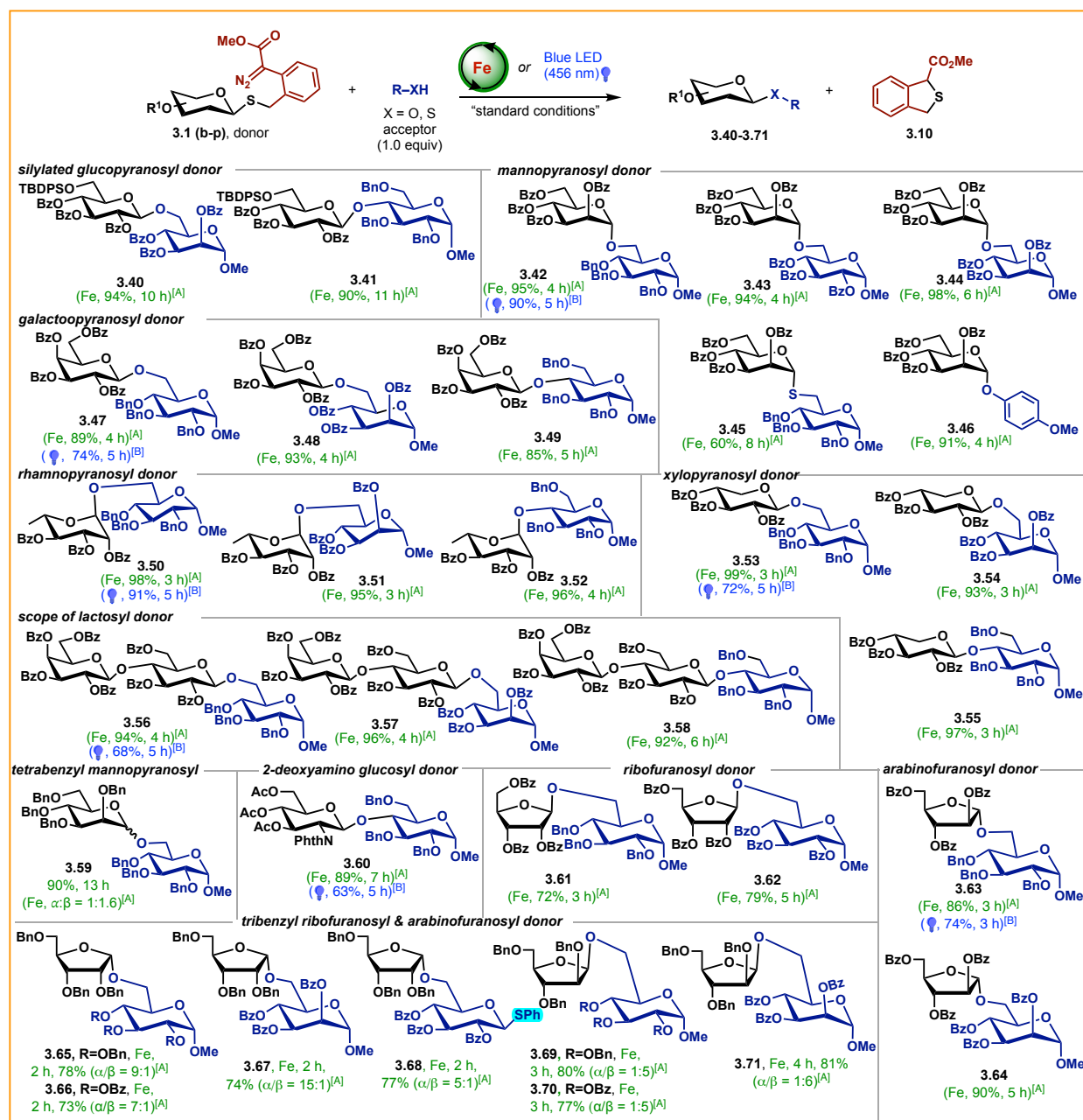


Figure 3.2.2.2 | Scope of MDMPA thioglycoside donors. [A] Acceptor (0.025 mmol), donor (0.037 mmol), Fe(OTf)₃ (0.005 mmol), and CH₂Cl₂ (0.05 M). [B] Acceptor (0.025 mmol), donor (0.062 mmol), CSA (0.012 mmol), LiOTf (0.025 mmol), and Blue LED (456 nm, 50% intensity), CH₂Cl₂ (0.05 M). Yields in green are for Fe(OTf)₃, and those in blue are for blue light. Bz, benzoyl; Bn, benzyl; Ac, acetyl; Ph, phenyl; Phth, phthalimido; TBDPS, tert-butyldiphenylsilyl; Me, methyl.

envision the synthesis of these linkages using MDMPA thiofuranoside donors. The reactivity of pyranose and furanose differs due to their conformational stability and rigidity; applying the same methodology to thiofuranosides is challenging. Following our strategy,

we synthesized a perbenzoylated ribose MDMPA thiofuranoside donor **3.1m** and reacted it under standard conditions using primary sugar alcohols having benzyl (**A1**, activated) and benzoyl (**A11**, deactivated) protecting groups. We were ecstatic to find the formation of the desired products (**3.61**, **3.62**) in excellent yields. Building on these results, we also synthesized an arabinose MDMPA thiofuranoside donor **3.1n** and reacted it under standard reaction conditions using glucose (**A1**) and mannose (**A13**) glycosyl acceptors. Expectedly, we observed similar results and produced excellent yields of desired products (**3.63**, **3.64**). After successfully achieving the *trans* linkage, we considered applying our methodology to access the *cis* linkages. The synthesis of 1,2-*cis* linkage in furanosides is challenging due to the higher oxocarbenium ion stability. It is well known that the activation of furanose donors proceeds via an oxocarbenium ion, which favors the S_N1 pathway, making 1,2-*cis*-selectivity challenging to access.^[77-78] Few literature reports have achieved 1,2-*cis* furanosides by utilizing chelation either by metal- or organo-catalysts.^[35,79-81] We could also leverage C2-O coordination with iron in this design to help deliver upcoming acceptors from the same face (see **Figure 3.4.5.4** in the experimental section for mechanistic pathways). We started investigating our synthesized tri-O-benzyl ribose MDMPA thiofuranoside donor **3.1o** to probe our hypothesis. In our initial studies, we introduced donor **3.1o** under the optimized conditions along with glycosyl acceptor **A1**; upon completion, we were ecstatic to observe the good yield of the desired product **3.65** (68%, $\alpha/\beta = 9/1$), but with the high 1,2-*cis* selectivity (**Figure 3.2.2.2**). The exact stereochemistry of the 1,2-*cis* furanosides was confirmed through NMR analysis, particularly using ¹H,¹³C-HSQC studies.^[62] After this encouraging result, attention was directed towards other glycosyl alcohol acceptors with different protecting groups.

Encouragingly, reaction yields and selectivity were unaffected by the influence of protecting groups for benzyl- and benzoyl-protected glycosyl acceptors (**3.66**, **3.67**). Specifically, the thioglycoside moiety at the anomeric position of the acceptor **3.68** was also found to work efficiently and orthogonal to our conditions. Building on the success observed with the ribose MDMPAT donor, we explored the range of substrates using an arabinose MDMPAT donor **3.1P**. Like our investigation with ribose, we began with primary sugar alcohols; encouragingly, benzyl- and benzoyl-protected glucose acceptors (**A1** and **A11**) demonstrated easy reactivity in our system, yielding products **3.69** and **3.70** with high yields and good β -1,2-*cis*-selectivity. Notably, acceptors derived from mannose were unreactive with the well-established furanosylation protocols. Our method achieved the intended product with high yields and selectivity when employing the mannosyl acceptor (**A14**). Overall, this extensive exploration of donors and acceptors further supports our methodology as one of the best for activating thioglycoside donors.

3.2.3 Applications of MDMPA-Based Thioglycoside Donor

Late-stage modification of pharmaceuticals has been an exciting topic for developing a chemical library of biologically active compounds.^[82] Similarly, we successfully performed late-stage glycosylation of biologically relevant compounds such as simvastatin^[83] **3.72** and cholesterol^[84] **3.73** in excellent yields with perbenzoylated MDMPA glucosyl donor **3.1b**. Often, methods developed in academic labs are found difficult to scale up. To test the robustness of our methodology, we did a gram-scale late-stage glycosylation of simvastatin **13** with rhamnosyl donor **3.1h**. Specifically, in this transformation, we only used 3 mol% of the $\text{Fe}(\text{OTf})_3$, highlighting the efficiency of the catalytic cycle. Furthermore, we performed the one-pot access to trisaccharide using other traditional thioglycoside donors to demonstrate the orthogonal nature of our

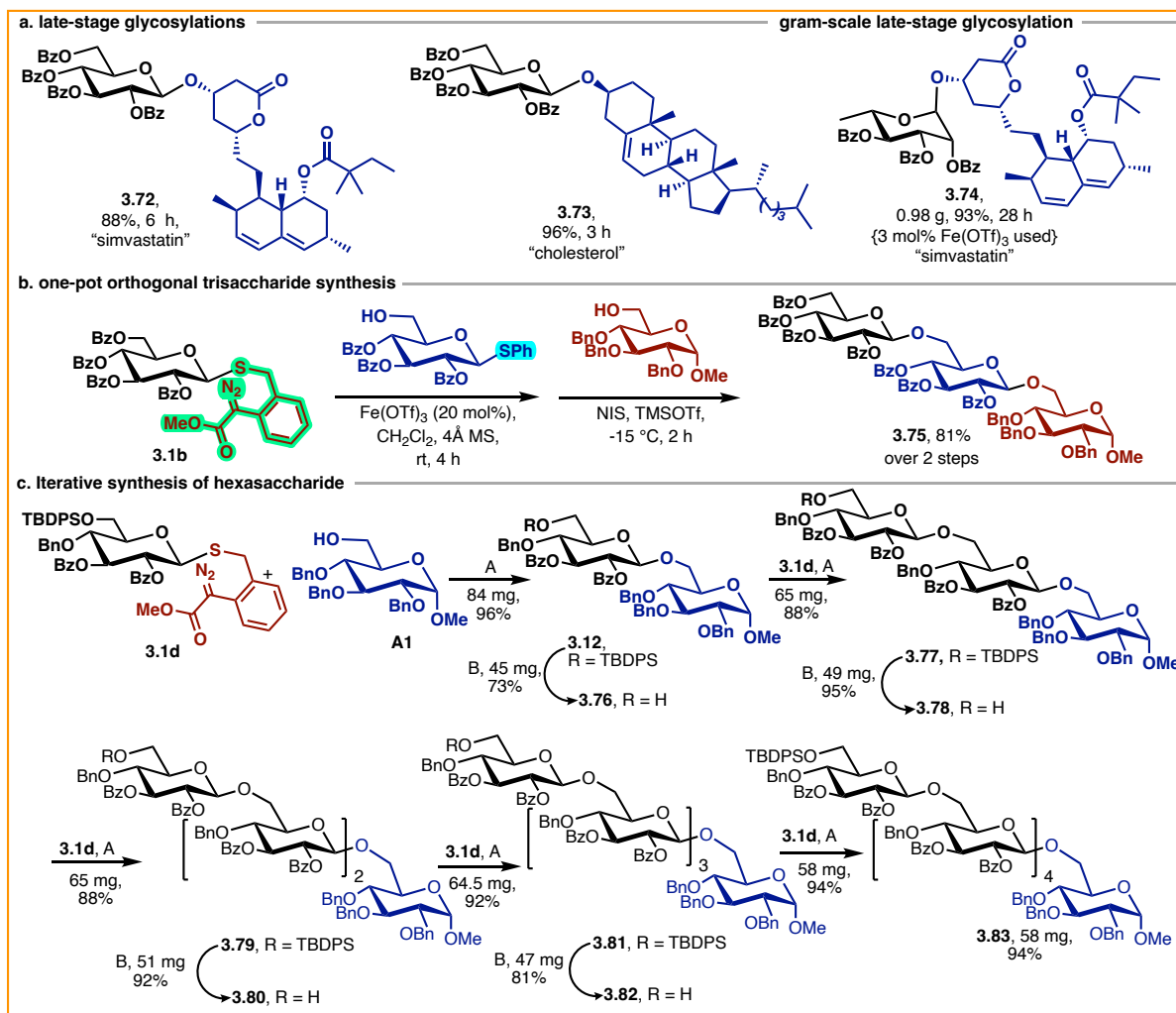


Figure 3.2.3: Applications of this methodology. **(a)** Late-stage glycosylations and gram-scale synthesis **(b)** One-pot orthogonal access to trisaccharides. **(c)** Iterative synthesis of hexasaccharides (A) acceptor (1.0 equiv.), donor (1.5 equiv.) $\text{Fe}(\text{OTf})_3$ (20 mol%), CH_2Cl_2 , time = 5 h, (B) TBAF in THF (1 mol/L, 1.5 equiv.), THF (2.0mL). Bz, benzoyl; Bn, benzyl; Ac, acetyl; TBDPS, tert-butyldiphenylsilyl; THF, tetrahydrofuran; Tf, trifluoromethanesulfonate; Me, methyl; NIS, N-Iodosuccinimide; TBAF, tetrabutylammonium fluoride.

activation conditions (**Figure 3.2.3b**). We first activated our MDMPAT donor **3.1b** under optimized conditions in the presence of an acceptor bearing a traditional thioglycoside, followed by the activation of in situ formed disaccharide thioglycoside under established literature conditions^[85] to achieve trisaccharide (**3.75**) in 81% yield over two steps.

Despite the numerous glycosylation strategies available, only a few methods can effectively accommodate the synthesis of oligosaccharides.^[86] To address this challenge, we synthesized donor **3.1d** for hexasaccharide synthesis. We were pleased to observe

the formation of the hexasaccharide using our strategy, achieving a 31% yield after 9 steps (**Figure 3.2.3c**). Our experience synthesizing hexasaccharides indicates that this methodology could be readily adapted for synthesizing larger oligosaccharide assemblies.

3.3 Conclusion

In the conclusion of this chapter, this study presents a catalytic glycosylation method that leverages diazo-thioglycoside donors activated by earth-abundant iron or photosensitizer-free blue light conditions, offering a sustainable alternative to traditional activation methods, which typically use precious and platinum-group metals (PGMs). The orthogonal reactivity provided by this approach opens new pathways for glycosylation reactions, distinct from widely used thioglycosides and alkyne-based donors. By capitalizing on a Thorpe-Ingold-like effect, this system facilitates proximity-induced S-insertion into carbenes, ensuring high chemoselectivity and efficiency. The versatility of carbene-based thioglycoside donors is demonstrated through their compatibility with a wide range of protecting groups, nucleophiles, and glycosyl donors, including mannose, galactose, rhamnose, xylose, 2-deoxyamino glucose, lactose, and furanose derivatives. This broad applicability highlights the potential of this method for diverse glycan syntheses. Additionally, the robustness of the approach is underscored by successful late-stage modifications of biomolecules, such as cholesterol and the drug simvastatin, even at the gram-scale. Furthermore, the methodology has been validated through the iterative synthesis of complex hexasaccharides, showcasing its utility in constructing intricate glycan structures. Overall, this work not only advances the field of glycosylation

by providing an iron- and light-driven catalytic strategy but also sets the stage for further development of sustainable and chemoselective approaches in carbohydrate chemistry. The broad applicability and potential for late-stage functionalization render this method a valuable tool for both fundamental research and practical applications in the synthesis of complex glycoconjugates.

3.4 Experimental Section

Reagents: Reagents and solvents were obtained from Sigma-Aldrich (www.sigma-aldrich.com), Chem-Impex (www.chemimpex.com), or Acros Organics (www.fishersci.com), AmBeed, and used without further purification unless otherwise indicated. Dry solvents (acetonitrile) were obtained from Acros Organics (www.fishersci.com), and dichloromethane was distilled over CaH_2 under N_2 unless stated otherwise. THF purchased from Sigma-Aldrich was distilled over Na metal with a benzophenone indicator. Toluene was obtained from Sigma-Aldrich.

Reactions: All reactions were performed in flame-dried glassware under positive N_2 pressure with magnetic stirring unless otherwise noted. Liquid reagents and solutions were transferred through rubber septa via syringes flushed with N_2 before use. Cold baths were generated as follows: 0 °C with wet ice/water and -78 °C with a Julabo chiller.

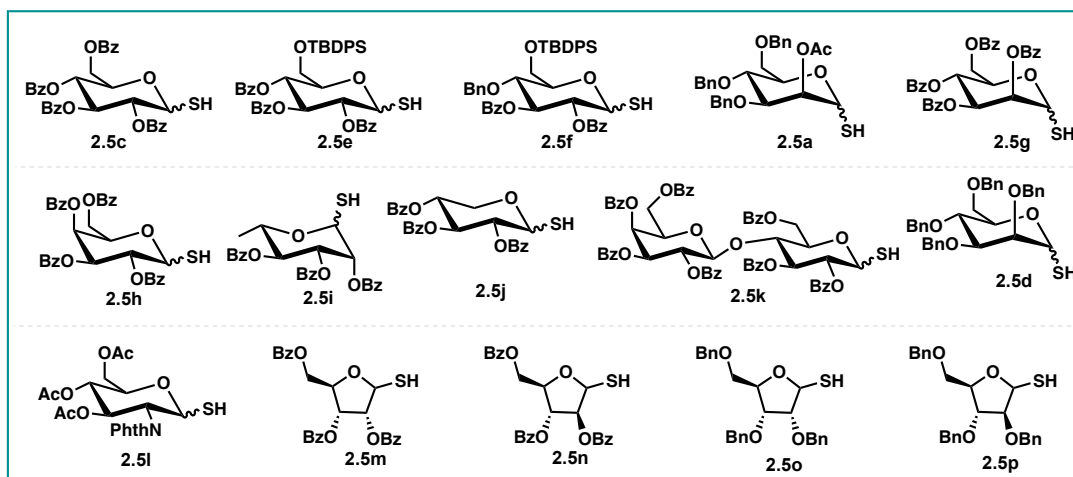
Chromatography: TLC was performed on 0.25 mm E. Merck silica gel 60 F254 plates and visualized under UV light (254 nm) or by staining with potassium permanganate (KMnO_4), cerium ammonium molybdate (CAM), phosphomolybdic acid (PMA), and ninhydrin. Silica flash chromatography was performed on Sorbtech 230–400 mesh silica gel 60.

Analytical Instrumentation: NMR spectra were recorded on a Varian VNMR 300, 400, 500, and 600 MHz, and Jeol 400, 500 NMR spectrometer in CDCl_3 unless otherwise indicated. Chemical shifts are expressed in ppm relative to solvent signals: CDCl_3 (^1H , 7.26 ppm, ^{13}C , 77.0 ppm); coupling constants are expressed in Hz. NMR spectra were processed using Mnova (www.mestrelab.com/software/mnova-nmr). Mass spectra were obtained at the OU Analytical Core Facility on an Agilent 6538 High-Mass-

Resolution QTOF Mass Spectrometer and an Agilent 1290 UPLC. We utilized Kessil blue light lamps at four distinct wavelengths (nm) – PR160-390, PR160-440, PR160-456, and PR160-467 – as the blue light source, accompanied by a cooling fan to regulate the ambient reaction temperature.

3.4.1 Synthetic Procedures for the Synthesis of Starting Materials

List of synthesized glycosyl anomeric thiols:



Note:- Anomeric thiols **[2.5c, 2.5g, 2.5h, 2.5i, 2.5j, 2.5k]**^[59], **[2.5e, 2.5l]**^[87], **[2.5a]**^[88], **[2.5d]**^[89] were synthesized following the literature protocols, and the synthetic procedures are provided below.

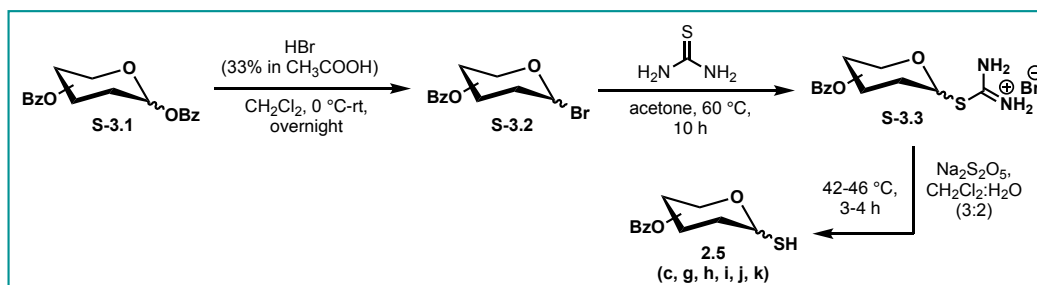
General procedure for the synthesis of perbenzoylated anomeric thiols **2.5 (c, g, h, i, j, k)**

Perbenzoylated pyranoses **S-3.1** (1.0 equiv.) was dissolved in CH₂Cl₂ (0.5 M) and cooled to 0 °C. To this stirring solution was added HBr (33% in AcOH, 12.5 equiv.). The reaction was allowed to attain room temperature overnight, while being stirred. The reaction mixture was then poured onto iced water, stirred for 15 minutes, and the layers were separated. The aq. layer was extracted with CH₂Cl₂. The combined organic portions were washed with saturated aqueous. NaHCO₃, brine, dried over Na₂SO₄. The solvent was removed under reduced pressure to give the tetrabenzoylated pyranosyl bromide **S-3.2** as pale white foam, which was used in the next step without further purification.

Tetrabenzoylated pyranosyl bromide **S-3.2** (1.0 equiv.) was dissolved in acetone (0.5 M), and to this solution was added thiourea (1.7 equiv.). The reaction was heated to reflux (60 °C) and stirred for the next 10 hours at the same temperature. The clear solution

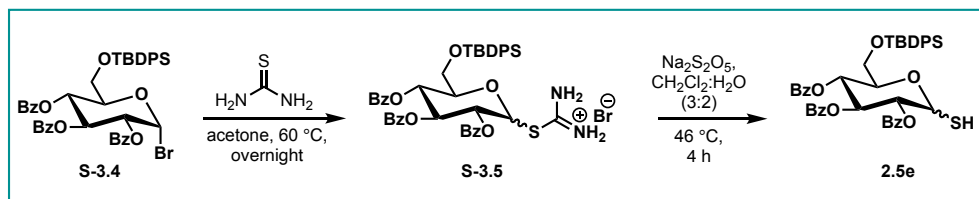
was cooled to room temperature, and the solvent was removed under reduced pressure. The salt **S-3.3** obtained was used in the next step without any further purification.

Tetrabenzoylated pyranosyl thiourea salt **S-3.3** (1 equiv.) was suspended in a 3:2 CH₂Cl₂-H₂O mixture (0.5 M) to which sodium metabisulfite (1.3 equiv.) was added. The reaction mixture was heated to reflux (42 °C) and stirred for 4 hours. The solution was cooled to room temperature, and the layers were separated. The aqueous layer was extracted with CH₂Cl₂. The combined organic portions were washed with H₂O, dried over Na₂SO₄, and the solvent was removed under reduced pressure to afford the crude glycosyl thiols **2.5** (**c, g, h, i, j, k**). This crude thiol was used in the final step of synthesizing MDMPA thioglycoside donors without further purification.



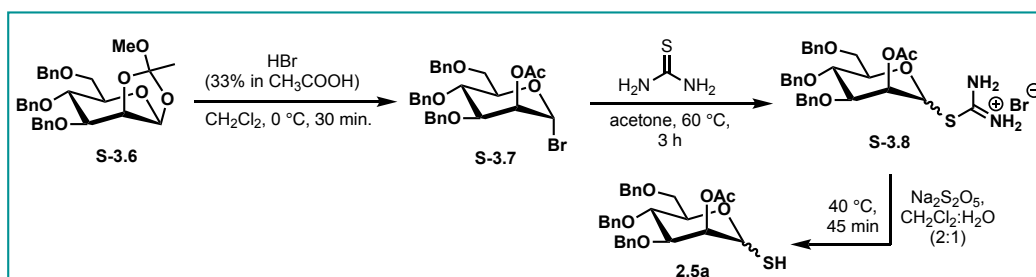
Procedure for the synthesis of **2.5e**

To a solution of bromide **S-3.4**^[90] (1.08 g, 1.36 mmol, 1.0 equiv.) in anhydrous acetone (27 mL, 0.5 M) was added thiourea (211 mg, 2.72 mmol, 2.0 equiv.). The reaction mixture was refluxed overnight, cooled to room temperature, and concentrated under vacuum to yield **S-3.5**. The obtained compound **S-3.5** was then suspended in a mixture of CH₂Cl₂ and H₂O (3:2 v/v, 50 mL). Sodium metabisulfite (Na₂S₂O₅, 3.88 mg, 2.04 mmol) was added to the suspension, and the mixture was refluxed at 46 °C for 4 hours. After cooling to room temperature, the reaction mixture was diluted with CH₂Cl₂, and the two phases were separated. The aqueous phase was extracted with CH₂Cl₂, and the combined organic layers were dried over Na₂SO₄, filtered, and concentrated under vacuum to yield crude compound **2.5e** as a pale brown foam. This crude thiol **2.5e** was used in the final step of the synthesis of MDMPA thioglycoside donor **3.1c** without any further purification.



Procedure for the synthesis of 2.5a

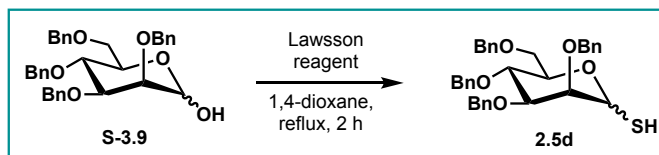
A solution of 3,4,6-tri-O-benzyl- β -D-mannopyranose 1,2-(methyl orthoacetate) **S-3.6**^[91] (1.0 g, 1.97 mmol) in CH_2Cl_2 (20 mL, 0.1 M) was stirred in an ice bath while HBr/HOAc (1.2 mL, 33 wt %, 6.91 mmol, 3.5 equiv.) was added dropwise. The reaction mixture was stirred at the same temperature for 30 minutes, then washed sequentially with ice water and cold-saturated NaHCO_3 solution. The organic layer was dried over Na_2SO_4 and concentrated to afford the unstable mannosyl bromide (**S-3.7**) as a pale-yellow oil (1.08 g). The resulting oil was dissolved in dry acetone (10 mL, 0.2 M) and added to freshly activated 4 Å molecular sieves (1.0 g) along with



thiourea (296 mg, 3.88 mmol, 2.0 equiv.). The reaction mixture was refluxed under a dry nitrogen atmosphere for 2.5 hours, cooled to room temperature, and filtered through Celite. The solvent was removed, and the syrupy residue was triturated with hexanes to yield a colorless amorphous powder (**S-3.8**, 1.2 g). The crude product (**S-3.8**) was dissolved in CH_2Cl_2 (20 mL), and an aqueous solution of $\text{Na}_2\text{S}_2\text{O}_5$ (1.08 g, 5.7 mmol, 3.0 equiv.) in water (10 mL) was added. The mixture was heated at 40 °C for 45 minutes, then cooled to room temperature. The CH_2Cl_2 layer was separated, washed with water and brine solution, dried over anhydrous Na_2SO_4 , filtered, and concentrated to yield the thiol (**2.5a**) as a colorless syrup. The crude material was purified by column chromatography, and the characterization data followed the literature.^[88]

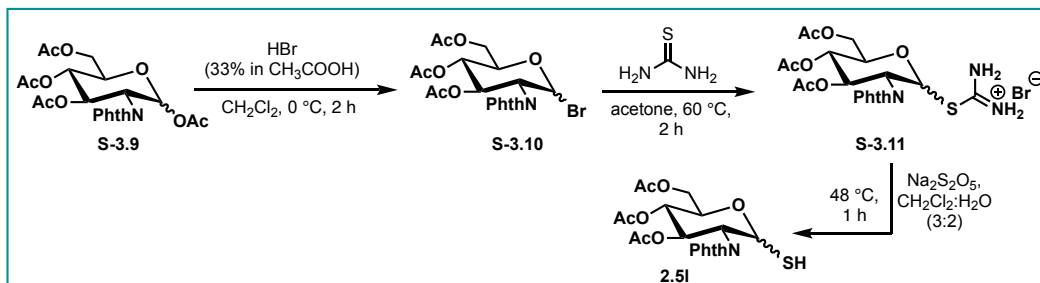
Procedure for the synthesis of 2.5d

2,3,4,6-Tetrabenzyl mannosyl alcohol (**S-3.9**, 1.0 g, 1.85 mmol) was dissolved in anhydrous dioxane (19 mL, 0.1 M), and Lawesson's reagent (898 mg, 2.22 mmol, 1.2 equiv.) was added. The reaction mixture was heated to reflux under an argon atmosphere. Upon completion, as confirmed by TLC analysis (hexane: ethyl acetate = 80:20), which showed the formation of a major product and consumption of the starting material, the reaction mixture was cooled to room temperature, filtered through a Celite® pad, and concentrated under reduced pressure. The residue was purified by flash column chromatography (hexane: ethyl acetate = 85:15) to yield a viscous, colorless syrup identified as 2,3,4,6-tetrabenzyl mannosyl thiol **2.5d**. The characterization data matched the values reported in the literature.^[89]



Procedure for the synthesis of **2.5l**

1,3,4,6-Tetra-O-acetyl-2-deoxy-2-phthalimido-glucopyranose **S-3.9**^[92] (0.8 g, 2.41 mmol, 1.0 equiv.) was dissolved in CH_2Cl_2 (12.0 mL, 0.2 M) and cooled to 0 °C. HBr (1.2 mL, 33% in AcOH, 3.0 equiv.) was added dropwise to the stirring solution. The reaction mixture was stirred at 0 °C for 2 hours, with progress monitored by TLC. Upon completion, the reaction mixture was poured



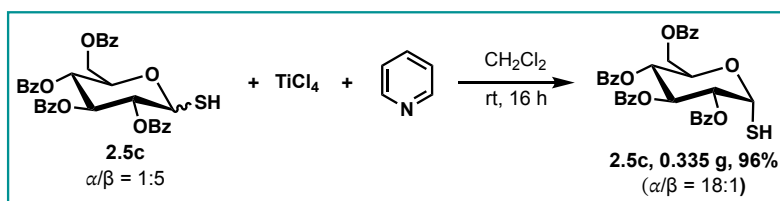
into ice-cold water, stirred for 5 minutes while maintaining the cold conditions, and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 , and the combined organic layers were washed sequentially with saturated aqueous NaHCO_3 and brine, then dried over Na_2SO_4 . The solvent was removed under reduced pressure to yield 3,4,6-tri-O-acetyl-2-deoxy-2-phthalimido-D-glucopyranosyl bromide (**S-3.10**) as a white foam, which was used directly in the next step without further purification. 3,4,6-Tri-O-acetyl-2-

deoxy-2-phthalimido-D-glucopyranosyl bromide (**S-3.10**, 0.85 g, 2.41 mmol, 1.0 equiv.) was dissolved in acetone (12 mL, 0.2 M), and thiourea (0.368 g, 2.0 equiv.) was added. The reaction mixture was refluxed at 60 °C for 2 hours. After cooling to room temperature, the solvent was removed under reduced pressure, yielding the thiourea salt (**S-3.11**, 1.0 g), which was used directly in the next step without further purification.

The thiourea salt (**S-3.11**, 1.0 g, 2.33 mmol, 1.0 equiv.) was suspended in a 3:2 mixture of CH₂Cl₂ and H₂O (12 mL, 0.2 M), and sodium metabisulfite (622 mg, 1.4 equiv.) was added. The reaction mixture was refluxed at 42 °C for 1 hour, then cooled to room temperature. The layers were separated, and the aqueous phase was extracted with CH₂Cl₂. The combined organic layers were washed with water, dried over Na₂SO₄, and concentrated under reduced pressure to yield the crude 3,4,6-tri-O-acetyl-2-deoxy-2-phthalimido-D-glucopyranosyl thiol (**2.5I**). This crude product was used directly in the final step to synthesize MDMPA thioglycoside donors without additional purification.

Synthesis of anomerically pure glucosyl thiol (**2.5c α**)

The glucosyl thiol **2.5c**^[59] (350 mg, 0.571 mmol, 1.0 equiv.) was dissolved in CH₂Cl₂ (0.1 M) under an inert nitrogen or argon atmosphere. Then pyridine (0.286 mL, 0.5 equiv., 1.0 M in CH₂Cl₂) and TiCl₄ (1.71 mL, 3.0 equiv., 1.0 M in anhydrous CH₂Cl₂) were added, and the reaction mixture was stirred at room temperature for 16 hours. Over time, the initially deep-colored solution gradually lightened. The reaction mixture was diluted with CH₂Cl₂ and washed sequentially with saturated aqueous NH₄Cl. The organic layer was separated, and the aqueous layer was extracted with additional CH₂Cl₂. The combined organic extracts were washed with saturated aqueous NaHCO₃ and brine, dried over Na₂SO₄, and concentrated under reduced pressure. The crude product was



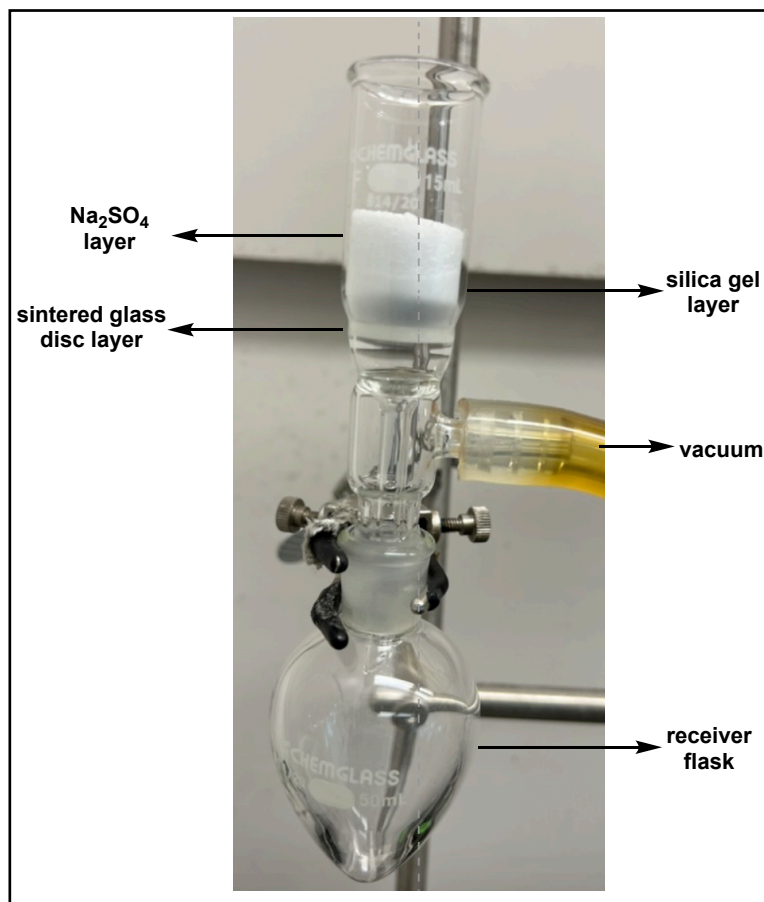
purified by flash column chromatography to afford the glucosyl thiol **2.5c(α)** (0.335 g, 96%). The characterization data were consistent with the literature.^[59]

3.4.2 Procedures for the Reaction Development

General protocols for the activation of thioglycosides by utilizing iron-carbenes via an intermolecular fashion.

General procedure A: In an oven-dried vial equipped with a stir bar, acceptor **A1** (0.025 mmol) was combined with thioglycoside donors [**3.1a** (1-5)]^[93-97] (0.032 mmol, 1.25 equiv.), 4Å molecular sieves (50 mg or 100 wt.%), and iron salts (0.005 mmol, 0.2 equiv.) dissolved in solvent (0.05 M). The mixture was stirred at room temperature for 15 minutes, after which methyl 2-diazo-2-phenylacetate (**3.2a**)^[98] (0.063 mmol, 2.5 equiv.) was added to the suspension. Upon addition of the diazo compound, immediate bubbling was observed, indicating nitrogen gas evolution and the progress of the reaction. The reaction was monitored by TLC and quenched with saturated aqueous NaHCO₃ upon completion. The layers were separated, and the aqueous layer was washed with ethyl acetate. The organic layers were combined, dried over Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl acetate and passed through a short silica pad to remove traces of iron (to check the crude material via ¹H-NMR). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.

General procedure B: In an oven-dried vial equipped with a stir bar, acceptor **A1** (0.025 mmol) was combined with thioglycoside donors [**3.1a** (1-5)]^[93-97] (0.032 mmol, 1.25 equiv.), additive (0.012 mmol, 0.5 equiv.), 4Å molecular sieves (50 mg or 100 wt.%), and iron salts (0.005 mmol, 0.2 equiv.) or irradiated under blue light (467 nm), and dissolved in solvent (0.05M). The mixture was stirred at room temperature for 15 minutes before adding methyl 2-diazo-2-phenylacetate (**3.2a**)^[98] (0.063 mmol, 2.5 equiv.) to the stirred suspension. Upon addition of the diazo compound, bubbles appeared immediately, indicating the evolution of nitrogen gas and the progress of the reaction. The reaction was monitored by TLC and quenched with saturated aqueous NaHCO₃ upon completion. The layers were then separated, with the aqueous layer washed with ethyl acetate. The organic layers were combined, dried over Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl acetate and passed through a short silica pad to remove traces of iron (for crude material analysis via ¹H-NMR). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.



Filtration Setup

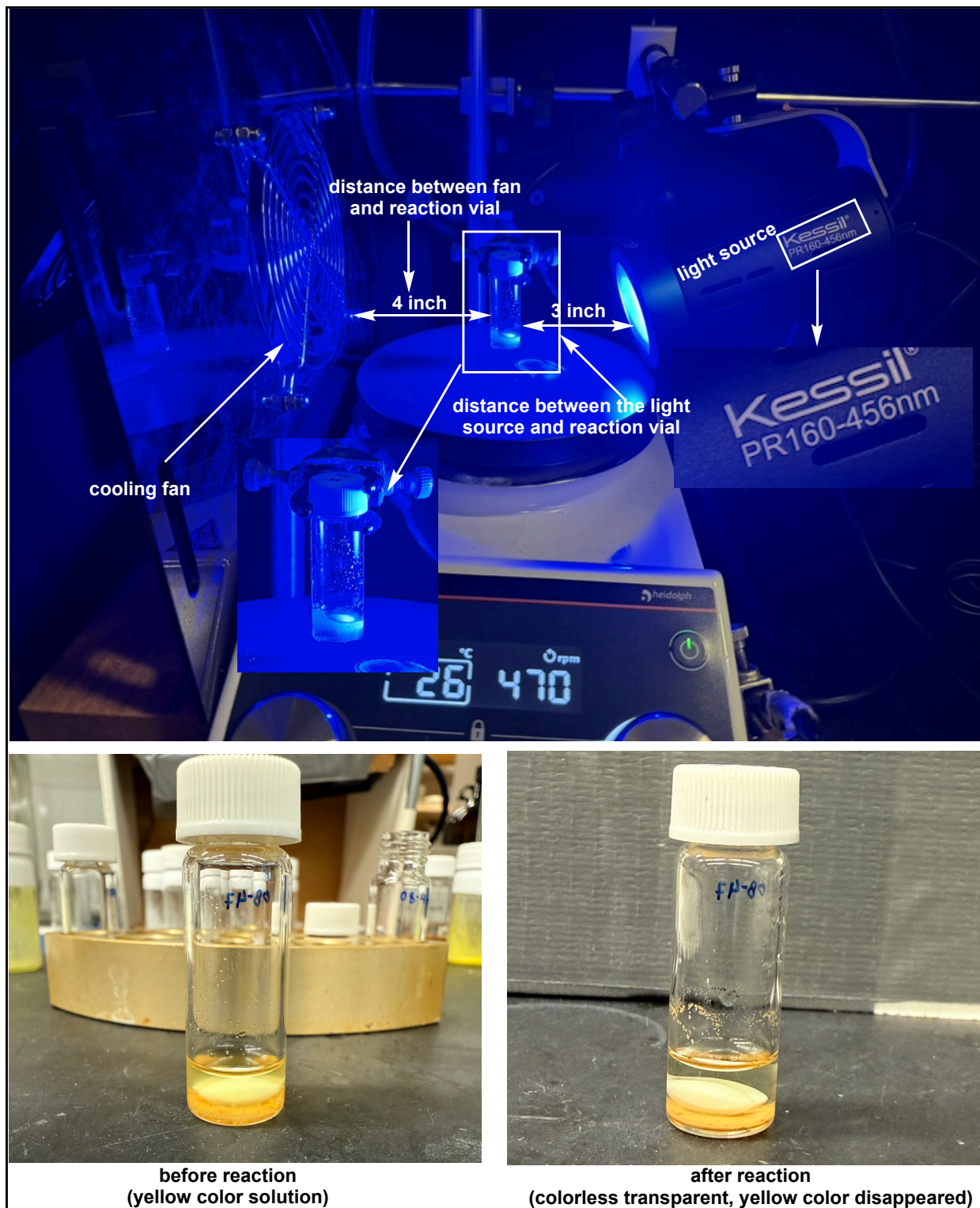


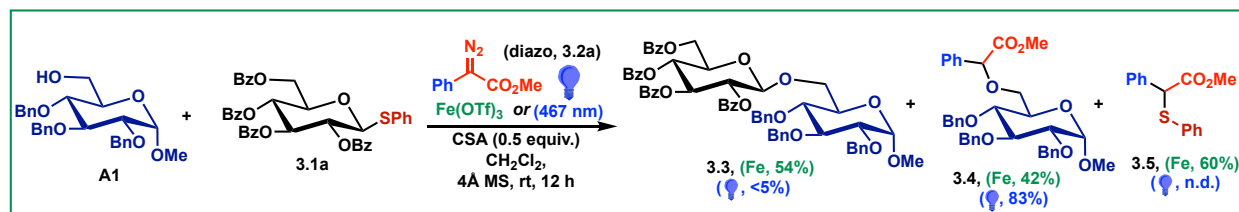
Figure 3.4.2. Reaction setup for the blue light-mediated glycosylation reactions. One lamp of 456 nm (Kessil, 50% intensity, 10 volts) was used [right top], a reaction vial [middle top], and an external cooling fan [left top]. Reaction vial before the reaction starts [left bottom], a reaction vial after the reaction is complete [right bottom].

Table S-3.1. Optimization for the intermolecular activation of thioglycosides using iron- or free-carbenes.^a

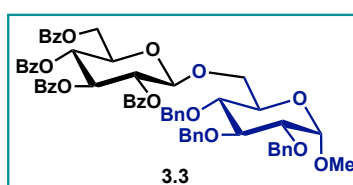
entry	donors	procedure(s)	Iron catalyst/additive	time (h)	yields (%) ^b
1.	3.1a.1	B	Fe(BF ₄) ₂ ·6H ₂ O (20 mol%)/NaBar ^F (20 mol%)	12 h	3.3a1 (11%) ^c , 3.4 (77%) ^c , 3.5 (14%)
2.	3.1a.1	B	FeCl ₂ (20 mol%)/NaBar ^F (20 mol%)	24 h	n.r.
3.	3.1a.1	B	FeCl ₃ (20 mol%)/NaBar ^F (20 mol%)	24 h	3.3a1 (21%), 3.4 (62%)
4.	3.1a.1	A	FeCl ₃ (20 mol%)/no additive	24 h	4aa (21%), 3.4 (62%)
5.	3.1a.1	A	Fe(OTf) ₂ (20 mol%)/no additive	24 h	n.r.
6.	3.1a.1	B	Fe(OTf) ₂ (20 mol%)/NaBar ^F (20 mol%)	24 h	3.3a1 (<5%), 3.4 (23%), 3.5 (8%)
7.	3.1a.1	B	Fe(OTf) ₃ (20 mol%)/NaBar ^F (20 mol%)	8 h	3.3a1 (23%), 3.4 (71%), 3.5 (30%)
8.	3.1a.1	A	Fe(OTf) ₃ (20 mol%)/no additive	12 h	3.3a1 (33%), 3.4 (58%), 3.5 (40%)
9.	3.1a.2	A	Fe(OTf) ₃ (20 mol%)/no additive	18 h	3.3a2 (34%), 3.4 (61%), 3.5 (40%)
10.	3.1a.3	A	Fe(OTf) ₃ (20 mol%)/no additive	12 h	3.3a3 (17%), 3.4 (78%), 3.5 (28%)
11.	3.1a.4	A	Fe(OTf) ₃ (20 mol%)/no additive	24 h	3.3a4 (27%), 3.4 (71%), 3.5 (36%)
12.	3.1a.5	A	Fe(OTf) ₃ (20 mol%)/no additive	12 h	3.3a5 (10%), 3.4 (80%), 3.5 (16%)
13.	3.1a.1	B	Fe(OTf) ₃ (20 mol%)/TfOH·DTBMP (50 mol%)	12 h	3.3a1 (40%), 3.4 (53%), 3.5 (50%)
14.	3.1a.1	B	Fe(OTf) ₃ (20 mol%)/TsOH·H ₂ O (50 mol%)	12 h	3.3a1 (13%), 3.4 (78%), 3.5 (22%)
15.	3.1a.1	B	Fe(OTf)₃ (20 mol%)/CSA (50 mol%)	12 h	3.3a1 (54%)^c, 3.4 (42%)^c, 3.5 (58%)^c
16.	3.1a.1	B	Fe(OTf) ₃ (20 mol%)/CSA (100 mol%)	12 h	3.3a1 (55%), 3.4 (42%), 3.5 (60%)
17.	3.1a.1	B	Fe(OTf) ₃ (20 mol%)/CSA (130 mol%)	12 h	3.3a1 (55%), 3.4 (43%), 3.5 (60%)
18.	3.1a.1	B	Blue LED (467 nm, 50% intensity)/CSA (50 mol%)	12 h	3.3a1 (<5%), 3.4 (83%)^c, 3.5 (n.d.)

^aReactions were conducted with an acceptor (0.025 mmol), donor (0.032 mmol, 1.25 equiv), Fe(OTf)₃ (0.05 mmol, 20 mol%) or blue light (467 nm), and additives (20-130 mol%), diazo-1 (2.5 equiv), CH₂Cl₂ (0.05 M). ^bYield was determined by ¹H NMR using 1,3,5-trimethoxybenzene as the internal standard. ^cisolated yields, n.r. = no reaction, CSA = camphorsulfonic acid, NaBar^F = Sodium tetrakis[(3,5-trifluoromethyl)phenyl]borate, n.d. = not detected. Note: entries in bold are the optimized conditions.

Optimized reaction conditions for the intermolecular activation of conventional thioglycosides



Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.3).

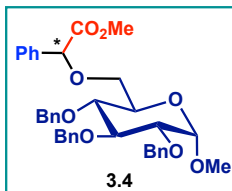


Following the general procedure **B**, **A1** (20 mg, 43.0 μ mol) was coupled with **3.1a** (37 mg, 54.0 μ mol) to afford **3.3** (24 mg, 23.0 μ mol, 54% yield) as a white viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (399 MHz, CDCl₃) δ 7.98 – 7.96 (m, 2H), 7.87 (ddd, J = 8.3, 3.2, 1.3 Hz, 4H), 7.80 (dd, J = 8.4, 1.3 Hz, 2H), 7.53 – 7.45 (m, 3H), 7.38 (dd, J = 15.1, 7.8 Hz, 5H), 7.34 – 7.29 (m, 6H), 7.29 – 7.25 (m, 6H), 7.24 – 7.17 (m, 5H), 7.04 – 7.01 (m, 2H), 5.87 (t, J = 9.7 Hz, 1H), 5.65 (t, J = 9.7 Hz, 1H), 5.58 (dd, J = 9.8, 7.8 Hz, 1H), 4.87 (d, J = 10.9 Hz, 1H), 4.80 (d, J = 7.8 Hz, 1H), 4.72 (d, J = 12.1 Hz, 1H), 4.66 (d, J = 11.0 Hz, 1H), 4.61 – 4.56 (m, 2H), 4.52 – 4.45 (m, 3H), 4.26 (d, J = 11.0 Hz, 1H), 4.13 (d, J = 8.7 Hz, 1H), 4.11 – 4.05 (m, 1H), 3.86 (t, J = 9.3 Hz, 1H), 3.75 – 3.68 (m, 2H), 3.41 (dd, J = 9.7, 3.6 Hz, 1H), 3.36 (t, J = 9.3 Hz, 1H), 3.19 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 166.23, 165.95, 165.27, 165.03, 138.87, 138.26, 138.22, 133.55, 133.37, 133.25, 133.23, 129.92, 129.86, 129.85, 129.82, 129.80, 129.62, 129.23, 128.85, 128.80, 128.54, 128.52, 128.46, 128.44, 128.41, 128.38, 128.24, 128.01, 127.99, 127.71, 127.59, 127.57, 101.41, 98.04, 81.97, 79.79, 75.65, 74.81, 73.49, 72.91, 72.27, 71.86, 69.84, 69.52, 68.38, 63.32, 55.11. The data are identical to the literature report.^[99]

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2-phenyl carboxymethyl)- α -D-glucopyranoside (3.4).



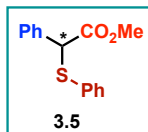
Following the general procedures, **A** and **B**, **3.4** was isolated as a byproduct of white viscous oil, $R_f = 0.5$ (hexane: EtOAc = 70:30). A ratio of unidentified diastereomers 2:1.

^1H NMR (399 MHz, CDCl_3) δ 7.41 (td, $J = 7.0, 2.4$ Hz, 3H), 7.38 – 7.27 (m, 25H), 7.15 (dd, $J = 7.2, 2.4$ Hz, 1H), 4.99 – 4.94 (m, 2H), 4.88 (q, $J = 5.6$ Hz, 2H), 4.84 – 4.75 (m, 4H), 4.68 – 4.58 (m, 3H), 4.50 (d, $J = 11.0$ Hz, 1H), 3.98 (t, $J = 9.3$ Hz, 2H), 3.88 (dd, $J = 10.8, 4.1$ Hz, 1H), 3.79 – 3.74 (m, 2H), 3.66 (s, 2H), 3.64 (s, 3H), 3.63 – 3.59 (m, 1H), 3.52 (ddd, $J = 19.6, 9.6, 3.4$ Hz, 2H), 3.35 (s, 5H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.28, 171.25, 138.78, 138.51, 138.26, 136.43, 128.72, 128.68, 128.65, 128.56, 128.53, 128.50, 128.47, 128.25, 128.20, 128.17, 128.13, 128.03, 128.01, 127.83, 127.76, 127.27, 98.16, 82.24, 82.19, 81.72, 81.50, 79.95, 79.80, 73.52, 70.32, 70.26, 68.73, 68.39, 55.27, 52.34.

HRMS (ESI): calc. for $\text{C}_{45}\text{H}_{44}\text{O}_9\text{Na}$ ($\text{M}+\text{Na}$): 635.2621; found: 635.2640.

methyl 2-phenyl-2-(phenylthio)acetate (**3.5**)



Following the general procedures, **A** and **B**, **3.5** was isolated as a byproduct of colorless viscous oil, $R_f = 0.9$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.45 – 7.42 (m, 2H), 7.38 – 7.32 (m, 3H), 7.32 – 7.29 (m, 2H), 7.28 – 7.26 (m, 2H), 7.26 (s, 1H), 4.91 (s, 1H), 3.68 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.03, 135.65, 133.74, 132.76, 129.10, 128.81, 128.60, 128.46, 128.14, 56.42, 52.87.

HRMS (ESI): calc. for $\text{C}_{15}\text{H}_{14}\text{NaO}_2\text{S}$ ($\text{M}+\text{Na}$): 281.061; found: 281.0614.

Plausible reaction pathway for the intermolecular activation of Conventional thioglycosides

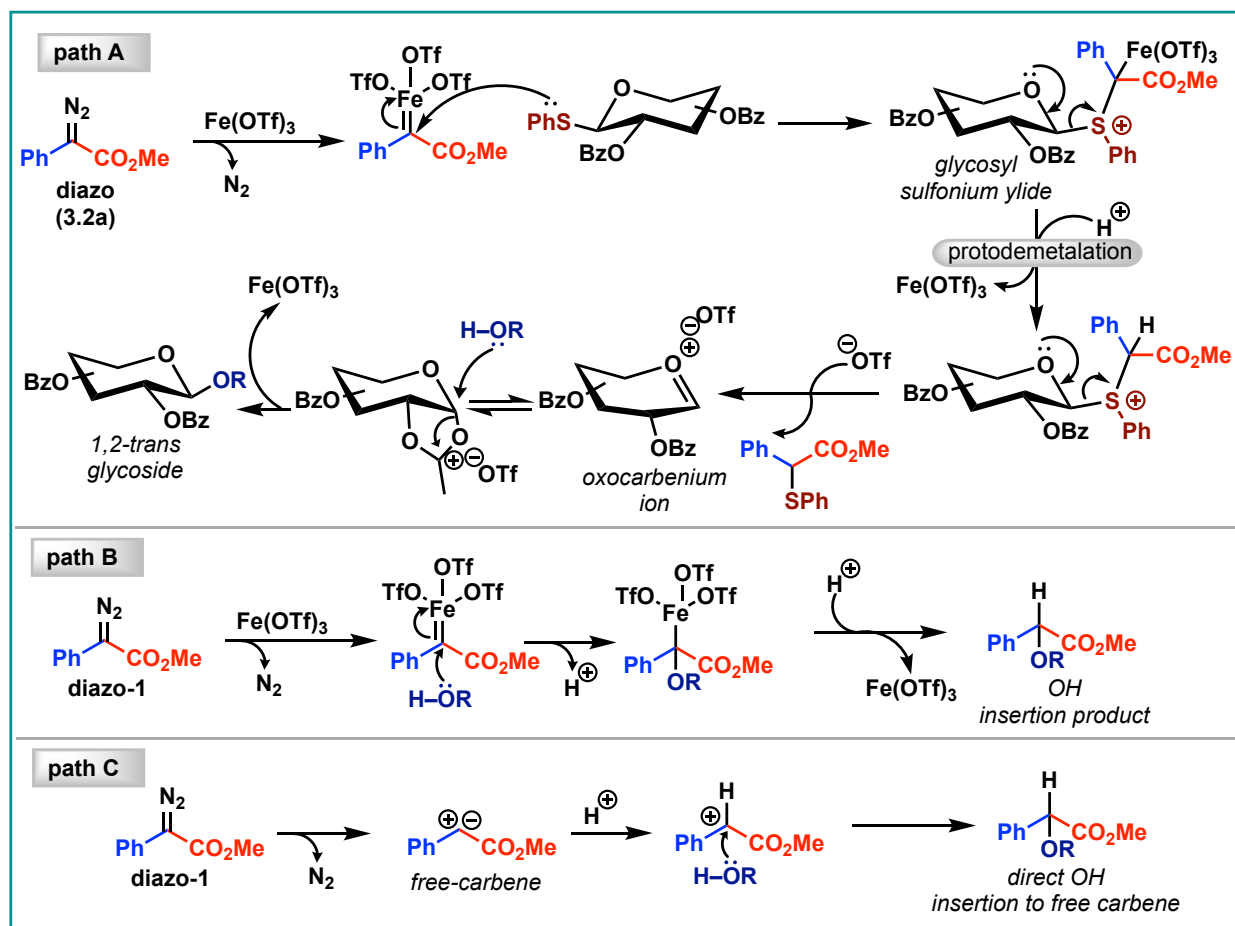
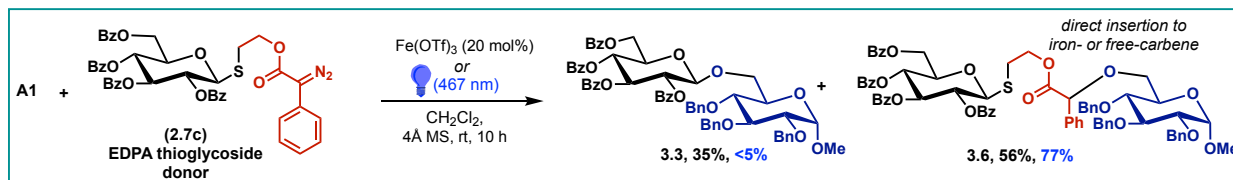


Figure 3.4.2.1: Plausible reaction pathways for the intermolecular thioglycoside activation. (A) Reaction pathway for the catalytic iron-carbene-based activation of thioglycoside for glycosylation. (B) Reaction pathway for the direct insertion of the O–H bond to the iron-carbene. (C) Reaction pathway for the direct insertion of the O–H bond to free-carbene.

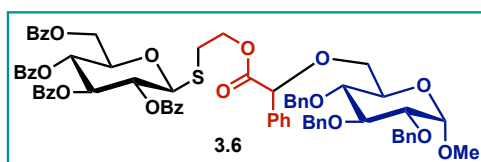
Procedure for the activation of linear EDPA thioglycoside donor by utilizing iron- or free-carbenes via an intramolecular fashion.

In an oven-dried vial equipped with a stir bar, acceptor **A1** (0.025 mmol) was combined with linear EDPA thioglycoside donor **2.7c** (0.037 mmol, 1.5 equiv.), 4Å molecular sieves (50 mg or 100 wt.%), and $\text{Fe}(\text{OTf})_3$ (0.005 mmol, 0.2 equiv.) or irradiated under blue light (467 nm), dissolved in CH_2Cl_2 (0.05M). Upon complete addition, the reaction mixture was stirred at the ambient temperature, and the reaction progress was monitored by TLC and quenched with saturated aqueous NaHCO_3 upon completion. The layers were separated, and the aqueous layer was washed with ethyl acetate. The organic layers were combined, dried over Na_2SO_4 , filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl

acetate and passed through a short silica pad to remove traces of iron (to check the crude material via $^1\text{H-NMR}$). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.



Methyl 6-O-(2-(2,3,4,6-tetra-O-benzoyl- β -D-thioglycopyranose) ethyl 2-phenylacetate)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.6).



Following the procedure for the activation of an EDPA thioglycoside donor (2.7c), 3.6 was isolated as a major byproduct of yellow viscous oil, $R_f = 0.5$ (hexane: EtOAc = 70:30).

$^1\text{H NMR}$ (399 MHz, CDCl_3) δ 7.99 (d, $J = 7.1$ Hz, 2H), 7.92 (dd, $J = 14.6, 6.9$ Hz, 4H), 7.80 (d, $J = 8.0$ Hz, 2H), 7.53 – 7.48 (m, 3H), 7.45 – 7.26 (m, 28H), 7.15 – 7.12 (m, 1H), 5.86 (dt, $J = 14.4, 9.5$ Hz, 1H), 5.63 (td, $J = 9.8, 5.2$ Hz, 1H), 5.48 (td, $J = 9.7, 2.3$ Hz, 1H), 4.96 (dd, $J = 10.7, 4.1$ Hz, 1H), 4.91 – 4.79 (m, 3H), 4.78 – 4.71 (m, 2H), 4.68 – 4.55 (m, 3H), 4.49 – 4.38 (m, 2H), 4.35 – 4.16 (m, 2H), 4.09 – 3.94 (m, 2H), 3.88 – 3.72 (m, 2H), 3.65 – 3.46 (m, 3H), 3.34 (s, 3H), 2.91 (ddt, $J = 29.3, 14.1, 7.0$ Hz, 1H), 2.78 – 2.69 (m, 1H).

$^{13}\text{C NMR}$ (100 MHz, CDCl_3) δ 166.16, 165.87, 165.84, 165.26, 165.24, 138.80, 136.12, 133.62, 133.56, 133.41, 133.28, 129.96, 129.93, 129.82, 129.57, 128.97, 128.80, 128.72, 128.56, 128.51, 128.47, 128.43, 128.23, 128.19, 128.16, 128.12, 128.05, 128.02, 127.80, 127.75, 127.42, 127.34, 98.12, 83.89, 82.23, 81.43, 81.28, 79.82, 76.32, 75.96, 75.04, 73.92, 73.45, 70.65, 70.35, 70.17, 69.52, 68.70, 63.24, 55.27.

HRMS (ESI): calc. for $\text{C}_{72}\text{H}_{68}\text{O}_{17}\text{S}$ ($\text{M}+\text{Na}$): 1259.4075; found: 1259.4125.

A plausible mechanism for the activation of linear EDPA thioglycoside donor

When donor 2.7C is treated with $\text{Fe}(\text{OTf})_3$, it releases dinitrogen gas and forms iron-carbene intermediate **A**, which can proceed through two reaction pathways (**A** and **B**). In pathway **A**, the iron-carbene is intramolecularly captured by a sulfur atom, forming glycosyl sulfonium ylide **B**. This ylide can undergo protodemetalation with an alcohol nucleophile to generate glycosyl

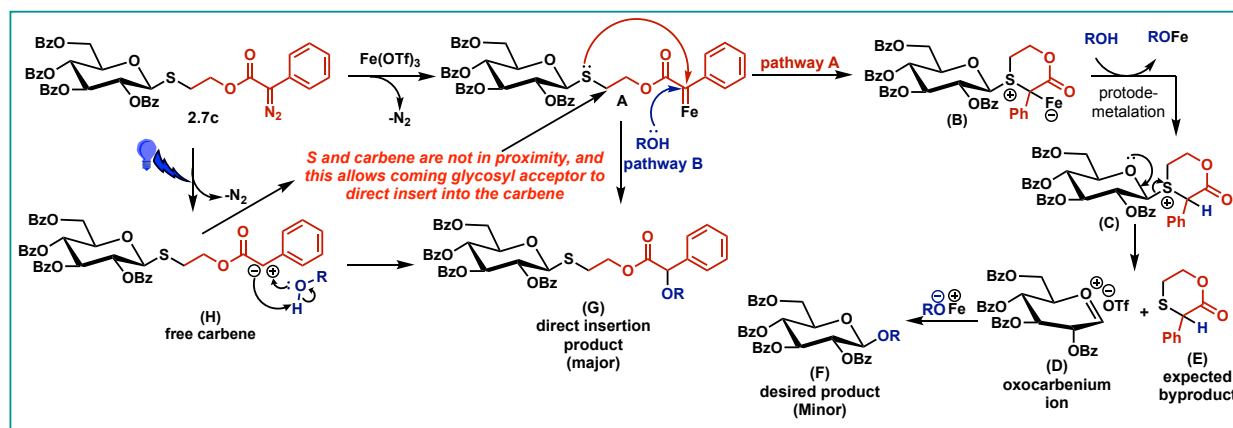


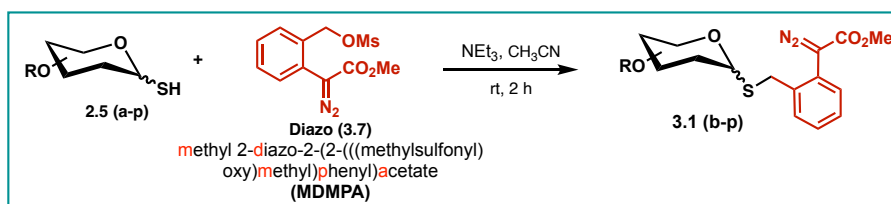
Figure 3.4.2.2: Plausible mechanistic pathways for activating linear EDPA thioglycoside donor by catalytic iron-carbene or free-carbene.

sulfonium ion **C**. Ion **C** then fragments to produce oxocarbenium ion **D** and byproduct **E**. The oxocarbenium ion is subsequently attacked by a metalated oxygen nucleophile, leading to the formation of the desired disaccharide product **F**.

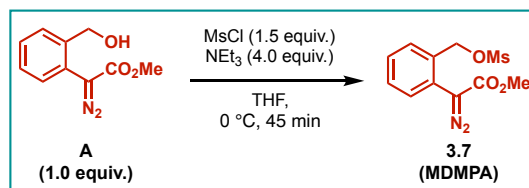
In pathway **B**, however, the glycosyl iron-carbene is directly captured by the alcohol nucleophile, resulting in the insertion product **G**. Experimental evidence suggests that pathway **B** is the dominant mechanism. The reduced occurrence of pathway **A** is attributed to the distance between the sulfur nucleophile and the iron-carbene, which limits their reactivity, thus favoring direct insertion by the incoming glycosyl acceptor. Additionally, under blue light irradiation, the formation of a free carbene allows for easier capture by the glycosyl acceptor, further promoting the insertion product as the major outcome.

General procedure for the synthesis of novel methyl 2-diazo-2-(2-((methyl)phenyl)acetate (MDMPA) thioglycoside donors.

General procedure C: To a solution of glycosyl anomeric thiols, **2.5 (a-p)** (1.0 equiv.) and diazo (**3.7**, 1.15 equiv.) in anhydrous CH_3CN (0.3 M), triethylamine (1.5 equiv.) at 0 °C. The resulting mixture was slowly warmed up to room temperature for two hours before being concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 92:8) to afford the desired novel MDMPA thioglycoside donor(s) **3.1b-3.1p**.



Synthesis of methyl 2-diazo-2-(2-(((methylsulfonyl)oxy)methyl)phenyl)acetate [3.7].



In a flask, combine the alcohol **A**^[61] (10 mmol) and triethylamine (40 mmol) in 25 mL of THF, and cool the mixture to 0 °C. Gradually, added mesyl chloride (15 mmol) in 50 mL of THF over 30 minutes while maintaining the temperature. Allowed the reaction mixture to stir at 0 °C for 20-30 minutes, then added cold water to the mixture. Extracted the mixture with 125 mL of diethyl ether, then introduced triethylamine (5 mmol) into the crude product solution to remove any unreacted mesyl chloride. Washed the solution sequentially with 10 mL of saturated aqueous NaHCO₃, 25 mL of cold water, and 25 mL of brine. Dried the solution over anhydrous Na₂SO₄, and finally, removed the solvent under reduced pressure to afford the crude material. The crude product was pure enough to be used in the next step without any further purification. ¹H NMR (400 MHz, CDCl₃) δ 7.58 – 7.54 (m, 1H), 7.44 (d, *J* = 6.0 Hz, 3H), 5.28 (s, 2H), 3.83 (s, 3H), 2.96 (d, *J* = 1.2 Hz, 3H).

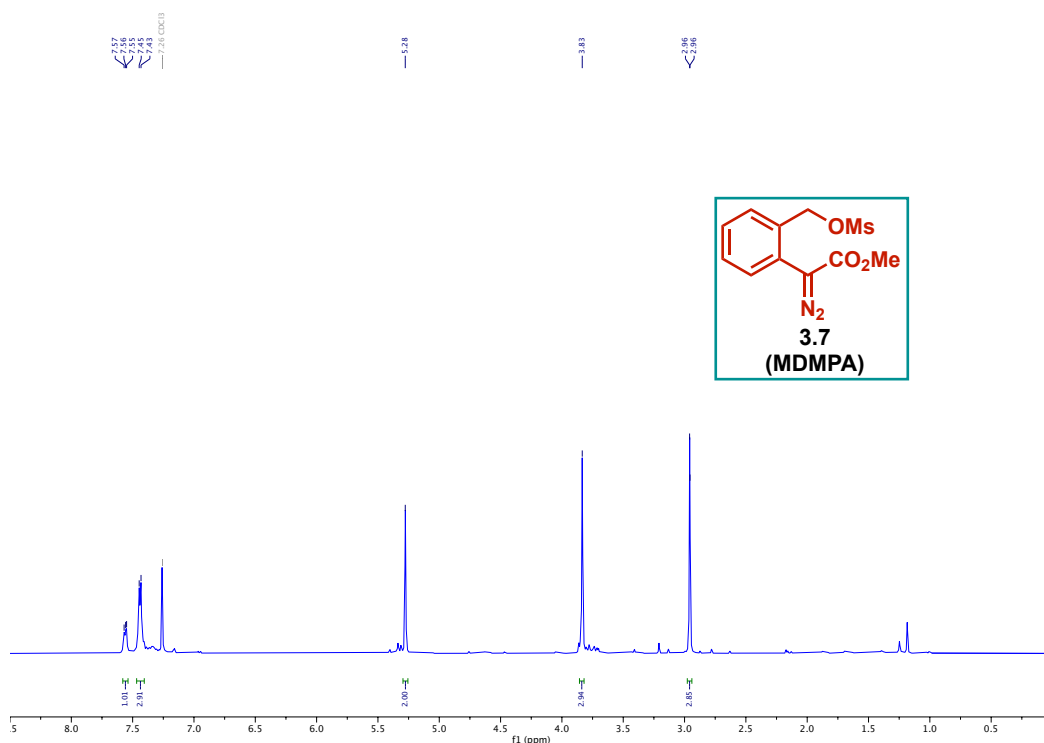
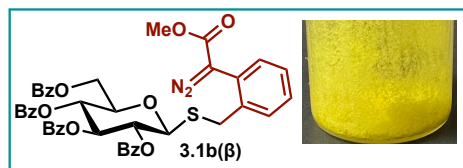


Figure 3.4.2.3: ¹H-NMR spectra of the crude sample of MDMPA **3.7**.

MDMPA thioglycoside donor **3.1b**(β).



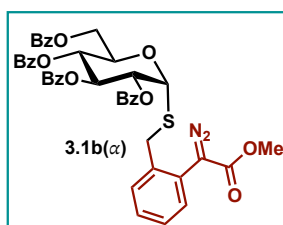
The MDMPAT donor compound **3.1b** was synthesized following general procedure **C**. Glycosyl thiol **2.5c**^[59] (430 mg, 702.0 μ mol), **3.7** (230 mg, 807.0 μ mol), and triethylamine (147 μ L, 1.05 mmol) were used to obtain donor **3.1b** (76%, 370 mg, 462.0 μ mol, α : β = 1:15) as a bright yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

^1H NMR (399 MHz, CDCl_3) δ 8.07 – 8.04 (m, 2H), 7.91 – 7.87 (m, 4H), 7.81 – 7.78 (m, 2H), 7.57 – 7.47 (m, 4H), 7.44 – 7.41 (m, 3H), 7.41 – 7.37 (m, 4H), 7.34 (dd, J = 8.3, 1.9 Hz, 4H), 7.32 (d, J = 1.5 Hz, 1H), 7.29 (d, J = 5.7 Hz, 1H), 7.25 – 7.22 (m, 1H), 5.83 (t, J = 9.5 Hz, 1H), 5.67 (t, J = 9.7 Hz, 1H), 5.56 (t, J = 9.7 Hz, 1H), 4.65 – 4.58 (m, 2H), 4.46 (dd, J = 12.2, 5.2 Hz, 1H), 4.09 – 4.03 (m, 2H), 3.93 (d, J = 13.3 Hz, 1H), 3.70 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.27, 165.85, 165.29, 165.26, 137.61, 133.57, 133.45, 133.37, 133.32, 132.21, 131.01, 130.03, 129.93, 129.84, 129.82, 129.64, 129.54, 129.03, 128.82, 128.80, 128.55, 128.52, 128.44, 128.40, 128.32, 125.11, 82.64, 74.07, 70.55, 69.56, 63.35, 52.24, 32.34.

HRMS (ESI): calc. for $\text{C}_{44}\text{H}_{36}\text{N}_2\text{NaO}_{11}\text{S}$ ($\text{M}+\text{Na}$): 823.1938; found:823.196.

MDMPA thioglycoside donor **3.1b**(α).



The MDMPAT donor compound **3.1b**(α) was synthesized following general procedure **C**. Glycosyl thiol **2.5c**^[59] (335 mg, 547.0 μ mol), **3.7** (187 mg, 656.0 μ mol), and triethylamine (115 μ L, 0.820 mmol) were used to obtain donor **3.1b**(α) (92%, 403 mg, 504.0 μ mol, α -only) as a bright yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

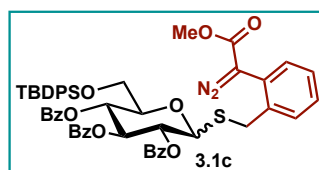
^1H NMR (399 MHz, CDCl_3) δ 8.08 – 8.04 (m, 2H), 7.93 (td, J = 8.6, 1.4 Hz, 4H), 7.87 – 7.84 (m, 2H), 7.52 (ddd, J = 14.8, 7.4, 5.8 Hz, 3H), 7.43 – 7.35 (m, 8H), 7.31 – 7.27 (m, 5H), 6.04 (t, J =

9.9 Hz, 1H), 5.76 (d, J = 5.8 Hz, 1H), 5.69 (t, J = 9.8 Hz, 1H), 5.47 (dd, J = 10.2, 5.8 Hz, 1H), 4.43 – 4.41 (m, 2H), 3.84 (s, 2H), 3.73 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.03, 165.49, 165.11, 165.09, 137.62, 133.40, 133.36, 133.10, 133.07, 130.74, 130.06, 129.88, 129.78, 129.61, 129.59, 129.48, 129.43, 128.86, 128.66, 128.56, 128.38, 128.35, 128.32, 128.19, 128.06, 124.57, 81.96, 71.20, 70.82, 69.20, 68.28, 62.63, 52.10, 32.40.

HRMS (ESI): calc. for $\text{C}_{44}\text{H}_{36}\text{N}_2\text{NaO}_{11}\text{S}$ ($\text{M}+\text{Na}$): 823.1938; found: 823.1952.

MDMPA thioglycoside donor **3.1c**.



The MDMPAT donor compound **3.1c** was synthesized following general procedure **C**. Glycosyl thiol **1b**^[87] (1.0 g, 1.34 mmol), **3.7** (457 mg, 1.61 mmol), and triethylamine (280 μL , 2.01 mmol) were used to obtain donor **3.1c** (72%, 900 mg, 963.0 μmol , $\alpha:\beta$ = 1:10) as a dark yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

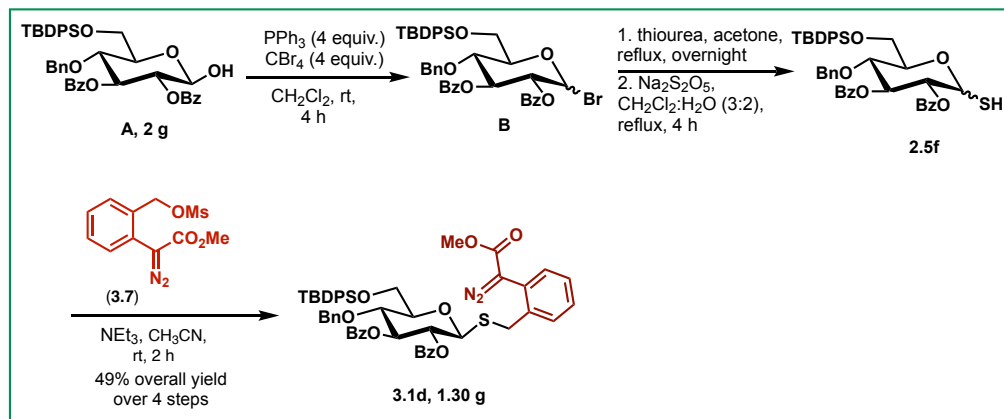
^1H NMR (399 MHz, CDCl_3) δ 7.89 – 7.84 (m, 4H), 7.81 (dd, J = 8.5, 1.4 Hz, 2H), 7.75 – 7.72 (m, 2H), 7.61 (dd, J = 7.7, 1.8 Hz, 2H), 7.51 (td, J = 7.5, 1.3 Hz, 2H), 7.42 – 7.32 (m, 13H), 7.28 (d, J = 8.2 Hz, 2H), 7.22 (t, J = 7.6 Hz, 2H), 5.77 (t, J = 9.4 Hz, 1H), 5.68 (t, J = 9.7 Hz, 1H), 5.54 (t, J = 10.1 Hz, 1H), 4.57 (d, J = 10.0 Hz, 1H), 4.09 – 3.97 (m, 2H), 3.86 (d, J = 4.6 Hz, 2H), 3.65 (s, 3H), 1.06 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.99, 165.31, 165.04, 137.66, 135.77, 135.62, 133.34, 133.25, 132.29, 131.19, 130.02, 129.86, 129.84, 129.77, 129.52, 129.24, 129.06, 128.99, 128.51, 128.47, 128.40, 128.36, 128.25, 127.81, 127.76, 125.39, 125.08, 124.76, 82.16, 79.25, 74.52, 70.78, 69.04, 62.91, 59.35, 52.16, 26.75, 19.27.

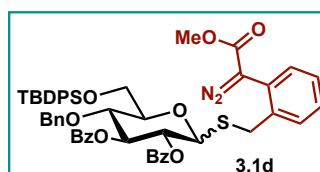
MDMPA thioglycoside donor **3e**.

To a solution of glycosyl anomeric alcohol, **A**^[99] (2 g, 2.74 mmol), triphenylphosphine (2.87 g, 10.95 mmol), carbon tetrabromide (3.63 g, 10.95 mmol) in dichloromethane (45.0 ml) was stirred at room temperature for 4h. The organic solution was diluted with ethyl acetate and then washed with saturated sodium bicarbonate twice and brine in sequence, dried with anhydrous Na_2SO_4 ,

and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether-EtOAc, 20:1) to obtain **4** (1.7 g, 78%) colorless syrup. To a



solution of bromide **B** (1.7 g, 2.14 mmol) in anhydrous acetone (22 mL), thiourea (326 mg, 4.28 mmol) was added. The mixture was refluxed overnight before being cooled to room temperature, and the solvent was evaporated to afford the thiourea salt. The above salt was suspended in a mixed solvent of CH₂Cl₂/H₂O (v/v = 3:2, 25 mL), and Na₂S₂O₅ (640 mg, 3.36 mmol) was added to this mixture. The mixture was refluxed for four hours before it was cooled to room temperature and diluted with CH₂Cl₂. Two phases were separated, and the aqueous phase was extracted by CH₂Cl₂; the organic phases were combined, dried over Na₂SO₄, filtered, and concentrated in a vacuum to afford compound **2.5f**. The compound **2.5f** (1.16 g, 1.55 mmol) obtained from the last step was coupled with diazo-3 (530 mg, 1.86 mmol 1.2 equiv.) in anhydrous CH₃CN (0.3 M). Triethylamine (0.325 mL, 2.33 mmol, 1.5 equiv.) at the 0 °C. The resulting mixture was slowly warmed up to room temperature and stirred at room temperature for two hours before it was then concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 92:8) to afford the MDMPA thioglycoside donor **3.1d** (1.30 g, 1.41 mmol, 91% $\alpha:\beta$ = 1:8)(overall 49% yield over four steps) as a yellow foam. *R_f* = 0.3 (hexane: EtOAc = 85:15).



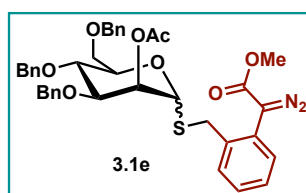
¹H NMR (500 MHz, CDCl₃) δ 7.92 (dd, *J* = 8.6, 1.3 Hz, 2H), 7.88 – 7.82 (m, 4H), 7.77 – 7.75 (m, 2H), 7.51 – 7.47 (m, 3H), 7.46 – 7.43 (m, 3H), 7.42 – 7.41 (m, 2H), 7.40 – 7.38 (m, 2H), 7.38 – 7.33 (m, 6H), 7.32 – 7.28 (m, 2H), 7.26 – 7.22 (m, 1H), 7.14 – 7.11 (m, 3H), 7.02 (dd, *J* = 7.8,

1.8 Hz, 2H), 5.65 (t, J = 9.5 Hz, 1H), 5.42 (t, J = 9.7 Hz, 1H), 4.61 – 4.59 (m, 2H), 4.44 (d, J = 10.0 Hz, 1H), 4.09 – 3.99 (m, 4H), 3.95 (s, 1H), 3.64 (s, 3H), 3.53 (ddd, J = 9.7, 3.4, 2.2 Hz, 1H), 1.15 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.81, 165.58, 137.67, 137.40, 136.03, 135.71, 133.51, 133.26, 132.93, 132.27, 131.13, 130.03, 129.95, 129.91, 129.82, 129.51, 129.47, 129.24, 128.47, 128.40, 128.36, 128.20, 128.05, 127.93, 127.90, 127.86, 125.01, 81.81, 80.08, 76.44, 75.92, 75.10, 71.04, 62.74, 52.14, 27.01, 19.46.

HRMS (ESI): calc. for $\text{C}_{53}\text{H}_{52}\text{N}_2\text{NaO}_9\text{SSi}$ ($\text{M}+\text{Na}$): 943.3060; found: 943.3085.

MDMPA thioglycoside donor **3.1e**.



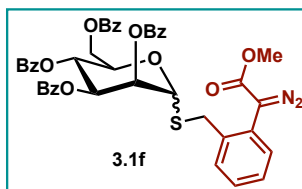
The MDMPAT donor compound **3.1e** was synthesized following general procedure **C**. Glycosyl thiol **2.5a**^[88] (0.625 g, 1.23 mmol), **3.7** (385 mg, 1.35 mmol), and triethylamine (257 μL , 1.84 mmol) were used to obtain donor **3.1e** (55%, 470 mg, 675.0 μmol , $\alpha:\beta$ = 9:1) as a dark yellow viscous oil after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

^1H NMR (399 MHz, CDCl_3) δ 7.43 – 7.39 (m, 1H), 7.37 (t, J = 2.9 Hz, 1H), 7.35 (s, 2H), 7.33 (d, J = 1.5 Hz, 1H), 7.33 – 7.31 (m, 4H), 7.29 (d, J = 2.3 Hz, 8H), 7.27 (q, J = 1.6 Hz, 3H), 7.15 (dd, J = 7.1, 2.3 Hz, 2H), 5.38 (dd, J = 3.0, 1.6 Hz, 1H), 5.16 (d, J = 1.7 Hz, 1H), 4.83 (d, J = 10.6 Hz, 1H), 4.70 – 4.64 (m, 2H), 4.50 (d, J = 3.8 Hz, 1H), 4.48 – 4.45 (m, 2H), 4.11 (dd, J = 9.1, 2.4 Hz, 1H), 3.93 (d, J = 9.3 Hz, 1H), 3.89 (d, J = 4.6 Hz, 1H), 3.87 – 3.84 (m, 1H), 3.82 (d, J = 2.9 Hz, 1H), 3.79 (s, 3H), 3.78 (s, 1H), 3.59 (dd, J = 10.7, 1.9 Hz, 1H), 2.12 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.35, 138.41, 138.21, 138.01, 137.69, 132.06, 131.03, 129.68, 128.54, 128.44, 128.41, 128.29, 128.14, 127.97, 127.95, 127.75, 124.62, 81.93, 78.85, 75.27, 74.45, 73.56, 72.08, 72.01, 70.03, 68.70, 52.39, 33.07, 21.24.

HRMS (ESI): calc. for $\text{C}_{39}\text{H}_{40}\text{N}_2\text{NaO}_8\text{S}$ ($\text{M}+\text{Na}$): 719.2403; found: 719.2421.

MDMPA thioglycoside donor **3.1f**.



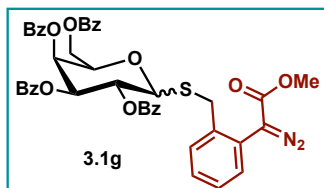
The MDMPAT donor compound **3.1f** was synthesized following general procedure **C**. Glycosyl thiol **2.5g**^[59] (0.450 g, 0.735 mmol), **diazo 3.7** (241 mg, 0.845 mmol), and triethylamine (154 μ L, 1.1 mmol) were used to obtain donor **3.1f** (80%, 470 mg, 587.0 μ mol, α : β = 9:1) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

¹H NMR (399 MHz, CDCl₃) δ 8.10 (dd, J = 8.1, 1.6 Hz, 2H), 8.02 (dd, J = 8.4, 1.3 Hz, 2H), 7.96 – 7.93 (m, 2H), 7.82 – 7.78 (m, 2H), 7.60 – 7.54 (m, 2H), 7.52 – 7.48 (m, 1H), 7.45 (dt, J = 7.2, 2.9 Hz, 1H), 7.42 – 7.37 (m, 7H), 7.36 – 7.32 (m, 4H), 7.22 (s, 1H), 6.14 (t, J = 9.9 Hz, 1H), 5.80 – 5.75 (m, 2H), 5.41 (s, 1H), 4.71 (dt, J = 9.9, 3.1 Hz, 1H), 4.51 (dd, J = 12.3, 2.6 Hz, 1H), 4.43 (dd, J = 12.3, 3.9 Hz, 1H), 3.94 (d, J = 4.7 Hz, 2H), 3.82 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 166.22, 165.50, 165.48, 165.28, 137.72, 133.61, 133.36, 133.21, 132.11, 131.01, 129.95, 129.93, 129.83, 129.34, 128.98, 128.96, 128.69, 128.60, 128.57, 128.42, 124.77, 82.21, 71.60, 70.73, 69.48, 66.95, 62.74, 52.46, 33.48.

HRMS (ESI): calc. for C₄₄H₃₆N₂NaO₁₁S (M+Na): 823.1938; found:823.196.

MDMPA thioglycoside donor **3.1g**.



The MDMPAT donor compound **3.1g** was synthesized following general procedure **C**. Glycosyl thiol **2.5h**^[59] (0.410 g, 0.670 mmol), **diazo 3.7** (229 mg, 0.803 mmol), and triethylamine (140 μ L, 1.0 mmol) were used to obtain donor **3.1g** (86%, 460 mg, 575.0 μ mol, α : β = 1:12) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). R_f = 0.3 (hexane: EtOAc = 85:15).

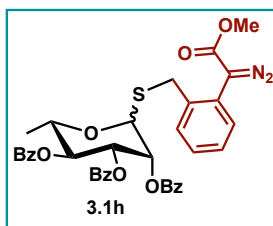
¹H NMR (399 MHz, CDCl₃) δ 8.09 – 8.03 (m, 4H), 7.90 – 7.86 (m, 2H), 7.75 (d, J = 7.3 Hz, 2H), 7.63 (t, J = 7.3 Hz, 1H), 7.50 (td, J = 6.6, 3.2 Hz, 4H), 7.44 (t, J = 7.8 Hz, 4H), 7.40 – 7.34 (m, 5H), 7.22 (d, J = 7.8 Hz, 2H), 6.05 – 5.99 (m, 1H), 5.83 (t, J = 10.0 Hz, 1H), 5.57 (dd, J = 9.9,

3.4 Hz, 1H), 4.67 – 4.61 (m, 2H), 4.42 (dd, $J = 11.4, 6.4$ Hz, 1H), 4.28 (t, $J = 6.6$ Hz, 1H), 4.11 (d, $J = 13.1$ Hz, 1H), 4.00 (d, $J = 13.1$ Hz, 1H), 3.71 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.16, 165.61, 165.56, 137.63, 133.77, 133.48, 133.46, 133.41, 132.27, 131.03, 130.09, 130.05, 130.03, 129.98, 129.95, 129.90, 129.87, 129.85, 129.82, 129.80, 129.60, 129.45, 129.09, 129.06, 128.81, 128.80, 128.75, 128.63, 128.61, 128.58, 128.53, 128.46, 128.39, 128.34, 82.94, 75.08, 72.62, 68.44, 68.14, 62.34, 52.27, 32.21.

HRMS (ESI): calc. for $\text{C}_{44}\text{H}_{36}\text{N}_2\text{NaO}_{11}\text{S}$ ($\text{M}+\text{Na}$): 823.1938; found: 823.196.

MDMPA thioglycoside donor **3.1h**.



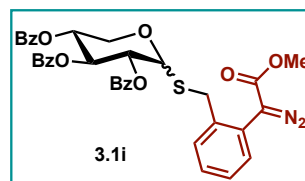
The MDMPAT donor compound **3.1h** was synthesized following general procedure **C**. Glycosyl thiol **2.5i**^[59] (0.450 g, 0.914 mmol), **diazo 3.7** (299 mg, 1.05 mmol), and triethylamine (139 μL , 1.37 mmol) were used to obtain donor **3.1h** (61%, 380 mg, 0.558 mmol, $\alpha:\beta = 12:1$) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 90:10). $R_f = 0.3$ (hexane: EtOAc = 85:15).

^1H NMR (399 MHz, CDCl_3) δ 8.08 – 8.04 (m, 2H), 7.99 – 7.96 (m, 2H), 7.81 – 7.77 (m, 2H), 7.60 (t, $J = 7.4$ Hz, 1H), 7.53 – 7.46 (m, 4H), 7.42 – 7.37 (m, 5H), 7.35 (d, $J = 1.8$ Hz, 1H), 7.26 – 7.22 (m, 2H), 5.70 (q, $J = 8.9$ Hz, 3H), 5.37 – 5.31 (m, 1H), 4.47 (dd, $J = 9.2, 6.3$ Hz, 1H), 3.97 – 3.87 (m, 2H), 3.84 (s, 3H), 1.30 (d, $J = 6.3$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.85, 165.51, 165.48, 138.03, 133.61, 133.49, 133.27, 130.94, 130.01, 129.86, 129.81, 129.78, 129.42, 129.27, 129.09, 128.68, 128.56, 128.38, 128.28, 124.75, 81.84, 72.03, 71.99, 70.57, 67.55, 52.43, 33.31, 17.61.

HRMS (ESI): calc. for $\text{C}_{37}\text{H}_{32}\text{N}_2\text{NaO}_9\text{S}$ ($\text{M}+\text{Na}$): 703.1726; found: 703.1744.

MDMPA thioglycoside donor **3.1i**.



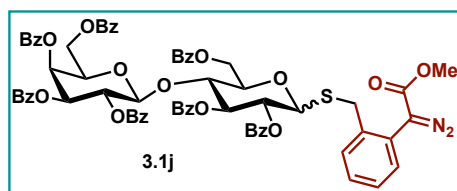
The MDMPAT donor compound **3.1i** was synthesized following general procedure **C**. Glycosyl thiol **2.5j**^[59] (0.500 g, 1.04 mmol), **diazo 3.7** (342 mg, 1.20 mmol), and triethylamine (219 μ L, 1.57 mmol) were used to obtain donor **3.1i** (83%, 580 mg, 0.870 mmol, $\alpha:\beta = 1:2$) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 93:7). $R_f = 0.4$ (hexane: EtOAc = 85:15).

¹H NMR (399 MHz, CDCl₃) δ 7.99 (d, $J = 1.8$ Hz, 2H), 7.97 (s, 3H), 7.94 (d, $J = 4.2$ Hz, 2H), 7.91 (dd, $J = 10.3, 1.8$ Hz, 2H), 7.56 – 7.50 (m, 4H), 7.49 – 7.44 (m, 2H), 7.41 – 7.29 (m, 15H), 5.95 (t, $J = 9.1$ Hz, 0.5H), 5.72 (t, $J = 7.1$ Hz, 1H), 5.59 (d, $J = 5.3$ Hz, 0.5H), 5.41 (t, $J = 7.0$ Hz, 1H), 5.39 – 5.26 (m, 2H), 4.83 (d, $J = 7.0$ Hz, 1H), 4.56 (dd, $J = 12.1, 4.3$ Hz, 1H), 4.26 – 4.12 (m, 0.5H), 4.09 – 3.82 (m, 4H), 3.77 (s, 3H), 3.75 (s, 1H), 3.66 (dd, $J = 12.1, 7.3$ Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 165.68, 165.61, 165.50, 165.41, 165.37, 165.25, 137.91, 137.88, 133.58, 133.53, 133.47, 130.98, 130.88, 130.11, 130.07, 130.03, 129.98, 129.96, 129.83, 129.69, 129.21, 128.97, 128.54, 128.47, 128.45, 128.23, 124.97, 124.81, 82.80, 82.12, 71.15, 70.95, 70.04, 69.75, 69.07, 64.04, 53.83, 52.35, 32.92, 32.47, 29.35.

HRMS (ESI): calc. for C₃₇H₃₂N₂NaO₉S (M+Na): 703.1726; found: 703.1744.

MDMPA thioglycoside donor **3.1j**.



The MDMPAT donor compound **3.1j** was synthesized following general procedure **C**. Glycosyl thiol **2.5k**^[59] (0.500 g, 0.560 mmol), **diazo 3.7** (151 mg, 0.529 mmol), and triethylamine (97 μ L, 0.690 mmol) were used to obtain donor **3.1j** (67%, 390 mg, 0.310 mmol, $\alpha:\beta = 1:5$) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 80:20). $R_f = 0.3$ (hexane: EtOAc = 75:25).

¹H NMR (399 MHz, CDCl₃) δ 8.02 – 7.95 (m, 11H), 7.88 (ddd, $J = 8.3, 2.6, 1.4$ Hz, 5H), 7.73 – 7.71 (m, 2H), 7.64 – 7.59 (m, 2H), 7.58 – 7.54 (m, 2H), 7.51 – 7.48 (m, 3H), 7.47 – 7.42 (m, 6H), 7.41 – 7.36 (m, 6H), 7.34 – 7.31 (m, 3H), 7.30 (t, $J = 1.5$ Hz, 1H), 7.29 – 7.26 (m, 2H), 7.23 – 7.19 (m, 4H), 7.16 – 7.11 (m, 3H), 5.75 – 5.65 (m, 4H), 5.48 (t, $J = 9.8$ Hz, 1H), 5.35 (dd, $J =$

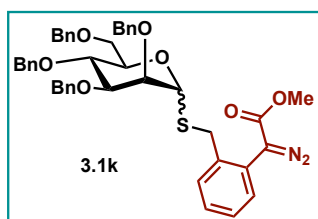
10.3, 3.4 Hz, 1H), 4.85 (d, $J = 7.9$ Hz, 1H), 4.52 (dd, $J = 10.3, 5.8$ Hz, 2H), 4.45 (dd, $J = 12.3, 4.6$ Hz, 1H), 4.25 – 4.19 (m, 1H), 3.94 (d, $J = 13.1$ Hz, 1H), 3.86 (d, $J = 13.4$ Hz, 2H), 3.76 – 3.69 (m, 4H), 3.69 (s, 1H), 3.62 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.95, 165.67, 165.51, 165.41, 165.39, 165.31, 164.86, 137.69, 133.65, 133.55, 133.49, 133.40, 133.31, 132.11, 130.86, 130.09, 130.03, 129.96, 129.88, 129.85, 129.75, 129.68, 129.63, 129.56, 129.53, 129.47, 129.08, 128.90, 128.76, 128.73, 128.71, 128.68, 128.62, 128.54, 128.44, 128.36, 128.24, 125.03, 101.07, 82.63, 75.95, 73.99, 71.85, 71.42, 70.44, 69.93, 67.53, 62.67, 61.07, 53.55, 52.14, 32.34..

HRMS (ESI): calc. for $\text{C}_{71}\text{H}_{58}\text{N}_2\text{NaO}_{19}\text{S}$ ($\text{M}+\text{Na}$): 1297.3292; found: 1297.3287.

MDMPA thioglycoside donor 3.1k.

The MDMPAT donor compound **3.1k** was synthesized following general procedure **C**. Glycosyl thiol **2.5d**^[89] (0.100 g, 0.180 mmol), **diazo 3.7** (59 mg, 0.207 mmol), and triethylamine (38 μL , 0.270 mmol) were used to obtain donor **3.1k** (67%, 90 mg, 0.121 mmol, $\alpha:\beta = 10:1$) as a light-yellow viscous oil purification by column chromatography (hexane: EtOAc = 93:07). $R_f = 0.5$ (hexane: EtOAc = 75:25).

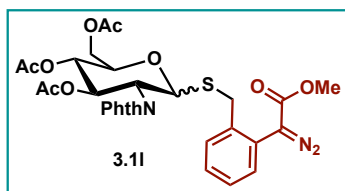


^1H NMR (399 MHz, CDCl_3) δ 7.37 (dd, $J = 5.9, 2.7$ Hz, 5H), 7.34 – 7.28 (m, 11H), 7.28 – 7.26 (m, 6H), 7.20 – 7.16 (m, 2H), 5.24 (d, $J = 1.5$ Hz, 1H), 4.88 (d, $J = 10.9$ Hz, 1H), 4.66 (dd, $J = 13.8, 12.2$ Hz, 2H), 4.57 – 4.49 (m, 5H), 4.11 – 4.01 (m, 2H), 3.84 – 3.80 (m, 2H), 3.79 (s, 3H), 3.77 – 3.71 (m, 3H), 3.65 (dd, $J = 10.9, 1.6$ Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.57, 138.47, 138.43, 138.24, 137.93, 132.11, 131.08, 129.63, 129.06, 128.53, 128.51, 128.48, 128.42, 128.07, 128.02, 127.96, 127.91, 127.89, 127.85, 127.77, 127.70, 127.60, 125.39, 124.77, 124.63, 81.27, 80.46, 75.75, 75.25, 74.99, 73.46, 72.44, 72.12, 71.86, 69.28, 69.11, 59.35, 52.40, 33.02.

LRMS (ESI): calc. for $\text{C}_{44}\text{H}_{45}\text{N}_2\text{O}_7\text{S}$ ($\text{M}+\text{H}$): 745.3; found: 745.4.

MDMPA thioglycoside donor 3.1l.



The MDMPAT donor compound **3.1I** was synthesized following general procedure **C**. Glycosyl thiol **2.5I**^[87] (0.350 g, 0.712 mmol), **diazo 3.7** (243 mg, 0.855 mmol), and triethylamine (149 μ L, 1.07 mmol) were used to obtain donor **3.1I** (94%, 450 mg, 671.0 μ mol, β -only) as a light-yellow foam after purification by column chromatography (hexane: EtOAc = 70:30). R_f = 0.2 (hexane: EtOAc = 60:40).

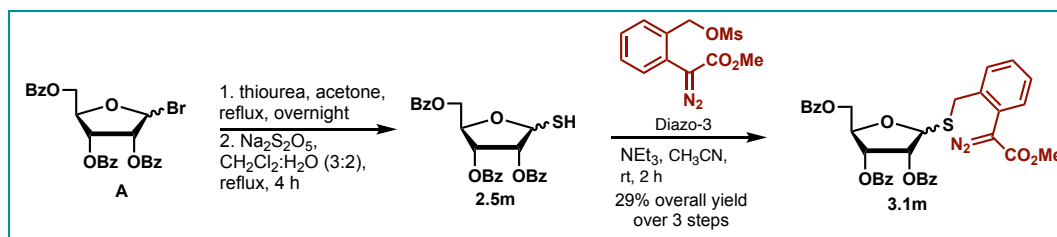
¹H NMR (399 MHz, CDCl₃) δ 7.85 – 7.78 (m, 2H), 7.73 (dd, J = 5.6, 3.0 Hz, 2H), 7.36 – 7.33 (m, 1H), 7.32 – 7.27 (m, 3H), 5.74 (dd, J = 10.2, 9.1 Hz, 1H), 5.26 (d, J = 10.6 Hz, 1H), 5.15 (dd, J = 10.2, 9.1 Hz, 1H), 4.39 (t, J = 10.4 Hz, 1H), 4.27 (dd, J = 12.3, 4.9 Hz, 1H), 4.13 – 4.09 (m, 1H), 3.95 (d, J = 13.1 Hz, 1H), 3.88 (d, J = 13.1 Hz, 1H), 3.79 – 3.76 (m, 1H), 3.75 (s, 3H), 2.13 (s, 3H), 2.02 (s, 3H), 1.84 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 170.88, 170.22, 169.60, 167.55, 167.23, 137.60, 134.52, 134.40, 132.04, 131.63, 131.24, 131.01, 129.57, 128.38, 125.09, 123.86, 80.29, 75.90, 71.55, 68.91, 62.37, 53.57, 52.33, 32.64, 20.93, 20.77, 20.58.

LRMS (ESI): calc. for C₄₂H₂₆N₂O₉S (M+H): 494.1; found: 494.1.

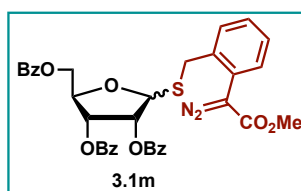
MDMPA thioglycoside donor **3.1m**.

2,3,5-tri-O-benzoyl-ribose bromide **A**^[100] (0.5 g, 0.952 mmol) was dissolved in acetone (20 mL), and to this solution was added thiourea (131 mg, 1.71 mmol). The reaction was heated to reflux (60 °C) and stirred at this temperature overnight. The clear solution was cooled to room temp and the solvent was removed under reduced pressure. The salt obtained was used without any further purification. The above salt (0.570 g, 0.948 mmol) was suspended in a mixed solvent of



CH₂Cl₂/H₂O (v/v = 3:2, 25 mL), and to this mixture was added Na₂S₂O₅ (253 mg, 1.33 mmol). The mixture was refluxed for four hours before it was cooled to room temperature and diluted with CH₂Cl₂. The two phases were separated, and the aqueous phase was extracted by CH₂Cl₂.

The organic phases were combined, dried over Na₂SO₄, filtered, and concentrated in a vacuum to afford tri-O-benzoyl ribosyl thiol **2.5m**, which was directly used in the next step without any further purification. The ribosyl thiol **2.5m** (0.420 g, 0.878 mmol) obtained from the last step was coupled with diazo-3 (287 mg, 1.01 mmol, 1.15 equiv) in anhydrous CH₃CN (0.3 M). Triethylamine (0.184 mL, 1.32 mmol, 1.5 equiv.) at the 0 °C. The resulting mixture was slowly warmed up to room temperature and stirred at room temperature for two hours before it was then concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 91:9) to afford the MDMPA thioglycoside donor **3.1m** (0.176 g, 29% yield over three steps, α : β = 1:3) as a yellow viscous oil. R_f = 0.3 (hexane: EtOAc = 85:15).



¹H NMR (399 MHz, CDCl₃) δ 8.10 (dd, J = 8.2, 1.4 Hz, 2H), 7.98 – 7.94 (m, 2H), 7.90 – 7.86 (m, 2H), 7.59 – 7.51 (m, 4H), 7.46 (d, J = 6.8 Hz, 2H), 7.40 (td, J = 7.6, 4.3 Hz, 6H), 7.35 – 7.28 (m, 7H), 5.91 (dd, J = 6.5, 5.0 Hz, 1H), 5.71 (dd, J = 5.1, 3.0 Hz, 1H), 5.32 (t, J = 3.2 Hz, 2H), 4.76 – 4.74 (m, 1H), 4.73 – 4.66 (m, 2H), 4.59 – 4.54 (m, 1H), 4.03 (d, J = 13.7 Hz, 1H), 3.92 – 3.85 (m, 2H), 3.78 (s, 3H), 3.74 (d, J = 2.2 Hz, 1H).

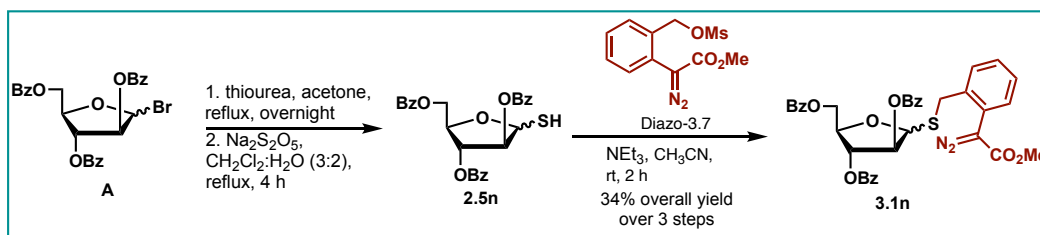
¹³C NMR (100 MHz, CDCl₃) δ 166.34, 165.38, 165.18, 140.57, 137.94, 135.45, 133.63, 133.59, 133.32, 131.98, 130.88, 130.37, 130.23, 130.09, 130.01, 129.97, 129.91, 129.87, 129.84, 129.68, 129.64, 129.11, 129.06, 128.92, 128.89, 128.76, 128.69, 128.64, 128.56, 128.53, 128.50, 128.34, 128.13, 128.10, 125.37, 124.81, 124.76, 124.01, 123.59, 122.61, 121.33, 85.44, 79.95, 73.26, 72.73, 70.24, 69.28, 64.31, 59.35, 53.40, 52.36, 32.79.

HRMS (ESI): calc. for C₃₆H₃₀N₂NaO₉S (M+Na): 689.1570; found: 689.1583.

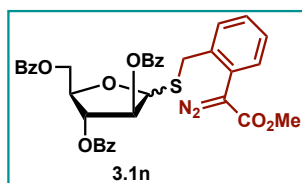
MDMPA thioglycoside donor **3.1n**.

2,3,5-tri-O-benzoyl-arabinosyl bromide **A**^[101] (0.5 g, 0.952 mmol) was dissolved in acetone (20 mL) and to this solution was added thiourea (131 mg, 1.71 mmol). The reaction was heated to reflux (60 °C) and stirred at this temperature overnight. The clear solution was cooled to room temperature and the solvent was removed under reduced pressure. The salt obtained was used without any further purification. The above salt (0.550 g, 0.915 mmol) was suspended in a mixed

solvent of CH₂Cl₂/H₂O (v/v = 3:2, 25 mL), and to this mixture was added Na₂S₂O₅ (243 mg, 1.28 mmol). The mixture was refluxed for four hours before it was cooled to room temperature and



diluted with CH₂Cl₂. Two phases were separated, and the aqueous phase was extracted by CH₂Cl₂. The organic phases were combined, dried over Na₂SO₄, filtered, and concentrated in a vacuum to afford tri-O-benzoyl arabinosyl thiol **2.5n**, which was directly used in the next step without any further purification. The arabinosyl thiol **2.5n** (0.4 g, 0.836 mmol) obtained from the last step was coupled with diazo-3 (273 mg, 0.962 mmol, 1.15 equiv.) in anhydrous CH₃CN (0.3 M). Triethylamine (0.127 mL, 1.25 mmol, 1.5 equiv.) at the 0 °C. The resulting mixture was slowly warmed up to room temperature and stirred at room temperature for two hours before it was then concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 91:9) to afford the MDMPA thioglycoside donor **3.1n** (0.185 g, 34% yield over three steps, α : β = 3:1) as a yellow viscous oil. R_f = 0.3 (hexane: EtOAc = 85:15).



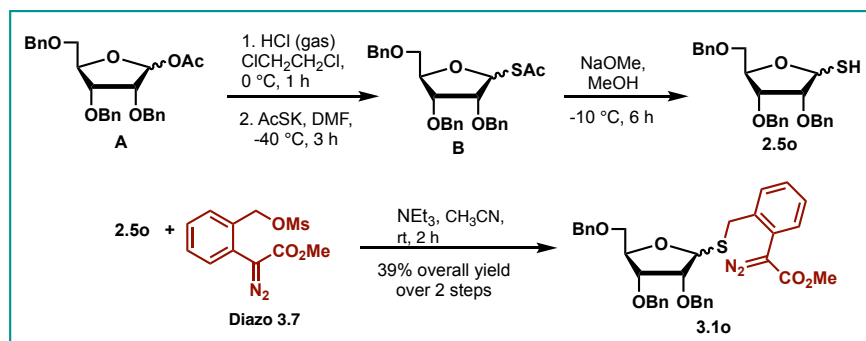
¹H NMR (399 MHz, CDCl₃) δ 8.08 (dd, J = 8.3, 1.4 Hz, 3H), 8.04 (dd, J = 8.3, 1.4 Hz, 3H), 7.98 (dd, J = 8.4, 1.3 Hz, 3H), 7.62 – 7.55 (m, 4H), 7.53 – 7.45 (m, 6H), 7.41 – 7.36 (m, 5H), 7.34 – 7.29 (m, 5H), 5.61 (dt, J = 4.6, 1.1 Hz, 1H), 5.53 – 5.49 (m, 2H), 5.43 – 5.28 (m, 1H), 4.83 – 4.68 (m, 4H), 4.04 – 3.86 (m, 3H), 3.78 (s, 3H), 3.74 (s, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 166.29, 165.73, 165.43, 138.08, 133.75, 133.69, 133.22, 130.97, 130.12, 130.01, 129.90, 129.87, 129.76, 129.72, 129.02, 128.98, 128.75, 128.66, 128.64, 128.50, 128.45, 128.14, 87.75, 82.71, 81.14, 69.27, 63.55, 60.52, 52.39, 33.23.

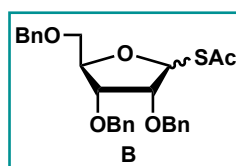
HRMS (ESI): calc. for C₃₆H₃₀N₂NaO₉S (M+Na): 689.1570; found: 689.1596.

MDMPA thioglycoside donor **3.1o**.

Dissolved 500 mg (1.08 mmol) of 1-O-acetyl-2,3,5-tris-O-(benzyl)- α , β -D-ribofuranose (**A**)^[102] in 10 mL of anhydrous dichloroethane and treated the solution with anhydrous HCl by bubbling the gas through it for 20 minutes at 0 °C. After stirring the reaction mixture at room temperature for 30 minutes, concentrating it, and then adding the resulting product dissolved in 5 mL of dry dimethylformamide to a solution of 1.23 g (0.018 mol) of potassium thioacetate in 10 mL of dry dimethylformamide at -40 °C via cannulation. After 3 hours, concentrated the reaction mixture, dissolved it in 20 mL of dichloromethane, and filtered the solution through a celite pad. Finally, concentrated the filtrate and purified the product by chromatography on silica gel using a 10:1 hexane/ethyl acetate eluent to afford pure 1-O-thioacetyl-2,3,5-tris-O-(benzyl)- α , β -D-ribofuranose **B** (342 mg, 0.715 mmol, 66% yield over two steps).



1-O-thioacetyl-2,3,5-tris-O-(benzyl)- α , β -D-ribofuranose (**B**)

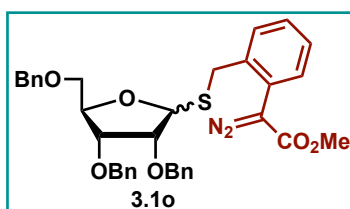


¹H NMR (400 MHz, CDCl₃) δ 7.38 (d, J = 1.6 Hz, 2H), 7.36 – 7.27 (m, 13H), 5.95 (d, J = 2.2 Hz, 1H), 4.80 (d, J = 12.2 Hz, 1H), 4.67 (s, 1H), 4.59 (d, J = 12.2 Hz, 1H), 4.53 – 4.46 (m, 2H), 4.40 (d, J = 11.8 Hz, 1H), 4.31 – 4.27 (m, 1H), 4.08 (dd, J = 7.2, 4.5 Hz, 1H), 4.01 (dd, J = 4.6, 2.3 Hz, 1H), 3.64 (dd, J = 11.0, 3.1 Hz, 1H), 3.55 – 3.48 (m, 1H), 2.33 (s, 3H).

¹³C NMR (101 MHz, CDCl₃) δ 194.57, 138.16, 137.55, 128.39, 128.37, 128.29, 128.18, 127.87, 127.85, 127.55, 127.52, 84.52, 81.44, 80.99, 73.35, 72.23, 71.68, 69.22, 31.08.

HRMS (ESI): calc. for C₂₈H₃₀NaO₅S (M+Na): 501.1712; found: 501.1727.

1-O-thioacetyl-2,3,5-tris-O-(benzyl)- α , β -D-ribofuranose **B** (0.258 g, 0.539 mmol) was dissolved in anhydrous MeOH (5 mL) and the solution was cooled to -10 °C, into the cooled solution NaOMe (32 mg, 0.593 mmol, 1.1 equiv) was added to the cooled solution, and reaction mixture was stirred at the same temperature for the next 6 hours. Upon complete consumption of the starting material, the reaction was filtered through the short celite pad, and the filtrate was evaporated under reduced pressure to afford ribosyl thiol **2.5o** which was then directly used in the next step without further purification. The ribosyl thiol **1l** (0.22 g, .504 mmol) obtained from the last step was coupled with **diazo 3.7** (165 mg, 0.580 mmol 1.2 equiv) in anhydrous CH₃CN (0.3 M). Triethylamine (0.106 mL, 0.773 mmol, 1.5 equiv.) at the 0 °C. The resulting mixture was slowly warmed up to room temperature and stirred at room temperature for 2 h before it was then concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 92:8) to afford the MDMPA thioglycoside donor **3.1o** (0.130, 39% yield over 2 steps, α : β = 4:1) as a yellow viscous oil. R_f = 0.3 (hexane: EtOAc = 85:15).



¹H NMR (399 MHz, CDCl₃) δ 7.56 (d, J = 7.5 Hz, 1H), 7.45 – 7.35 (m, 7H), 7.33 – 7.26 (m, 32H), 5.38 (d, J = 13.7 Hz, 1H), 5.32 (s, 1H), 5.11 (d, J = 3.4 Hz, 2H), 4.76 (s, 1H), 4.57 (d, J = 4.1 Hz, 2H), 4.54 – 4.53 (m, 4H), 4.50 (d, J = 8.8 Hz, 2H), 4.47 – 4.43 (m, 3H), 4.29 (ddd, J = 6.3, 5.1, 3.8 Hz, 2H), 4.03 (dd, J = 6.3, 4.9 Hz, 2H), 3.92 (d, J = 13.5 Hz, 2H), 3.85 – 3.81 (m, 3H), 3.78 (s, 4H), 3.74 (s, 3H), 3.62 (dd, J = 10.7, 3.9 Hz, 2H), 3.56 (dd, J = 10.6, 5.1 Hz, 2H).

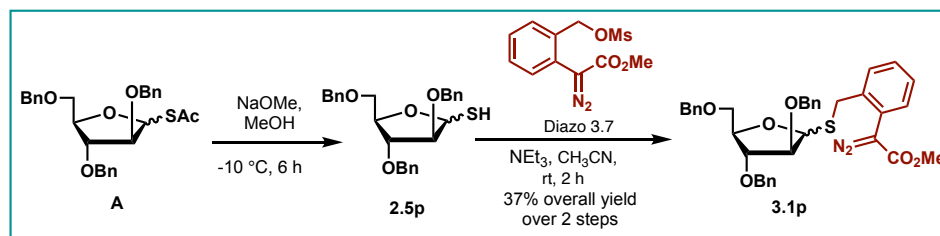
¹³C NMR (100 MHz, CDCl₃) δ 138.29, 137.71, 137.52, 130.96, 129.61, 129.06, 128.51, 128.49, 128.45, 128.16, 128.09, 127.98, 127.95, 127.73, 127.68, 125.39, 124.76, 124.60, 85.27, 59.35, 52.35, 32.93, 24.77.

HRMS (ESI): calc. for C₃₆H₃₆N₂NaO₆S (M+Na): 647.2192; found: 647.2206.

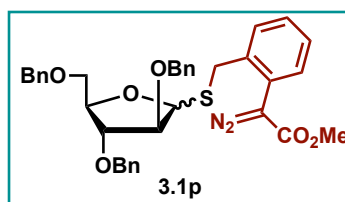
MDMPA thioglycoside donor **3.1p**.

1-O-thioacetyl-2,3,5-tris-O-(benzyl)- α , β -D-arabinofuranose **A**^[103] (0.250 g, 0.522 mmol) was dissolved in anhydrous MeOH (5 mL) and the solution was cooled to -10 °C, into the cooled solution NaOMe (31 mg, 0.575 mmol, 1.1 equiv.) was added and reaction mixture was stirred at the same temperature for next 6 hours. Upon complete consumption of the starting material, the

reaction was filtered through a short celite pad, and the filtrate was evaporated under reduced pressure to afford ribosyl thiol **2.5p**, which was then used directly in the next step without further purification. The ribosyl thiol **3.1p** (0.21 g, 0.481 mmol) obtained from the last step was coupled with **diazo-3** (157 mg, 0.553 mmol 1.2 equiv.) in anhydrous CH₃CN (0.3 M). Triethylamine (0.101



mL, 0.722 mmol, 1.5 equiv.) at the 0 °C. The resulting mixture was slowly warmed to room temperature and stirred at room temperature for 2 h, then concentrated in vacuo. The crude material was purified by silica gel column chromatography (hexane: EtOAc = 92:8) to afford the MDMPA thioglycoside donor **3.1p** (0.120, 37% yield over 2 steps, α -only) as a yellow viscous oil. R_f = 0.3 (hexane: EtOAc = 85:15).



¹H NMR (399 MHz, CDCl₃) δ 7.47 – 7.44 (m, 1H), 7.40 – 7.37 (m, 1H), 7.34 – 7.28 (m, 14H), 7.24 – 7.21 (m, 3H), 5.21 (d, J = 2.4 Hz, 1H), 4.62 – 4.43 (m, 5H), 4.35 – 4.28 (m, 2H), 3.99 – 3.91 (m, 3H), 3.83 (d, J = 13.6 Hz, 1H), 3.79 (s, 3H), 3.66 (qd, J = 10.9, 4.2 Hz, 2H).

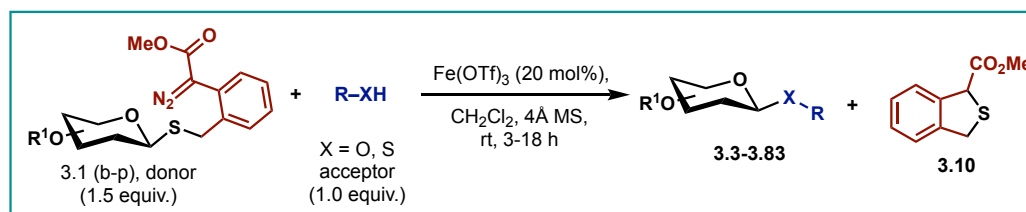
¹³C NMR (100 MHz, CDCl₃) δ 138.51, 138.19, 137.78, 137.30, 132.14, 130.99, 129.56, 128.52, 128.47, 128.12, 128.02, 127.93, 127.87, 127.73, 124.64, 88.46, 86.81, 83.65, 72.32, 71.97, 69.04, 52.37, 33.42.

HRMS (ESI): calc. for C₃₆H₃₆N₂NaO₆S (M+Na): 647.2192; found: 647.2215.

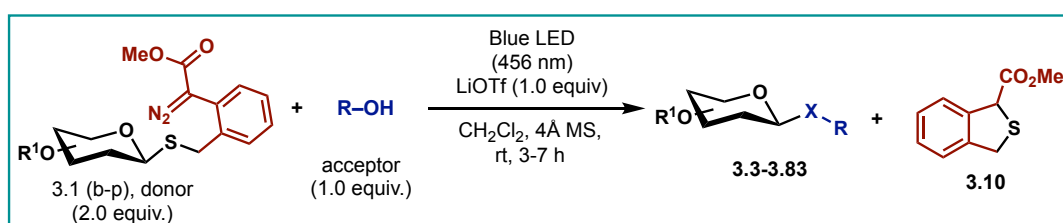
3.4.3 Procedures for the Activation of MDMPA-based Thioglycoside Donors

General procedure D: In an oven-dried vial equipped with a stir bar, a glycosyl acceptor (0.025 mmol) was combined with MDMPA thioglycoside donors **3.1 (b-p)** (0.037 mmol, 1.5 equiv.), 4Å molecular sieves (50 mg or 100 wt.%), and Fe(OTf)₃ (0.005 mmol, 0.2 equiv.) dissolved in CH₂Cl₂ (0.05M). Upon complete addition, the reaction mixture was stirred at the ambient temperature, and the reaction progress was monitored by TLC and quenched with saturated

aqueous NaHCO_3 upon completion. The layers were separated, and the aqueous layer was washed with ethyl acetate. The organic layers were combined, dried over Na_2SO_4 , filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl acetate and passed through a short silica pad to remove traces of iron (to check the crude material via ^1H -NMR). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.



General procedure E: In an oven-dried vial equipped with a stir bar, a glycosyl acceptor (0.025 mmol) was mixed with thioglycoside donors **3.1 (b-p)** (0.025 mmol, 2 equiv.), LiOTf (0.025 mmol, 1.0 equiv.), and 4Å molecular sieves (50 mg or 100 wt.%), all dissolved in a solvent (0.05M). The

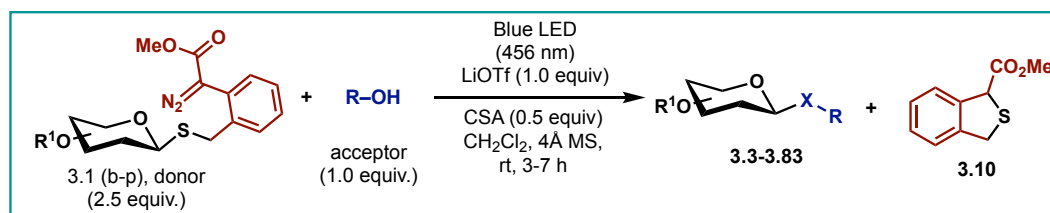


reaction mixture was then irradiated under blue LED light (456 nm) for 1 hour at the same temperature. Progress was monitored by TLC, and once the starting donor was fully consumed, an additional portion of donor **3.1 (b-p)** (0.0125 mmol, 0.5 equiv.) was added, followed by another 1 hour of irradiation under blue LED light (456 nm). This step was repeated with another addition of donor **3.1 (b-p)** (0.0125 mmol, 0.5 equiv.) and subsequent irradiation until the starting glycosyl acceptor was completely consumed. The reaction mixture was then filtered through a celite pad, with no additional workup required. The filtrate was evaporated, and the resulting crude product was purified by column chromatography.

Note: For a more detailed blue light experimental setup, see **Figure 3.4.2**.

General procedure F: In an oven-dried vial equipped with a stir bar, a glycosyl acceptor (0.025 mmol) was mixed with thioglycoside donors **3.1 (b-p)** (0.025 mmol, 2 equiv.), LiOTf (0.025 mmol, 1.0 equiv.), camphorsulfonic acid (0.0125 mmol, 0.5 equiv.) and 4Å molecular sieves (50 mg or 100 wt.%), all dissolved in a solvent (0.05M). The reaction mixture was then irradiated under

blue LED light (456 nm) for 1 hour at the same temperature. Progress was monitored by TLC, and once the starting donor was fully consumed, an additional portion of donor **3.1 (b-p)** (0.0125 mmol, 0.5 equiv.) was added, followed by another 1 hour of irradiation under blue LED light (456 nm). This step was repeated with another addition of donor **3.1 (b-p)** (0.0125 mmol, 0.5 equiv) and subsequent irradiation until the starting glycosyl acceptor was completely consumed. The reaction mixture was then filtered through a celite pad, with no additional workup required. The filtrate was evaporated, and the resulting crude product was purified by column chromatography.



Note: For a more detailed blue light experimental setup, see **Figure S-9**.

Table S-3.2. Optimization for the activation of MDMPA superarmed thioglycoside donor **3.1e** under blue light promoted carbenes conditions.^a

entry	donors (equiv.)	wavelength (nm)	light intensity	additives	time	yields (%) ^b
1.	1.5	467 nm	25%	-	6 h	3.13 (<5%), 10 (80%) ^c
2.	1.5	467 nm	25%	LiOTf (1.0 equiv.)	8 h	3.13 (54%) ^c , 10 (100%) ^c
3.	1.5	467 nm	50%	LiOTf (1.0 equiv.)	6 h	3.13 (56%), 10 (100%)
4.	1.5	467 nm	100%	LiOTf (1.0 equiv.)	6 h	3.13 (56%), 10 (100%)
5.	1.5	456 nm	50%	LiOTf (1.0 equiv.)	6 h	3.13 (60%), 10 (100%)
6.	1.5	440 nm	50%	LiOTf (1.0 equiv.)	5 h	3.13 (50%), 10 (100%)
7.	1.5	456 nm	50%	LiCl (1.0 equiv.)	8 h	3.13 (<5%), 10 (90%) ^c
8.	1.5	456 nm	50%	LiClO ₄ ·3H ₂ O (1.0 equiv.)	8 h	3.13 (56%), 10 (100%)
9.	1.5	456 nm	50%	LiPF ₆ (1.0 equiv.)	8 h	3.13 (<5%), 10 (90%) ^c
10 ^d .	1.5	456 nm	50%	LiOTf (1.0 equiv.)	6 h	3.13 (71%), 10 (100%)
11 ^d .	1.8	456 nm	50%	LiOTf (1.0 equiv.)	6 h	3.13 (81%), 10 (100%)
12^d.	2.0	456 nm	50%	LiOTf (1.0 equiv.)	7 h	3.13 (91%), 10 (100%)
13.	1.5	-	-	LiOTf (1.0 equiv.)	24 h	n.r.

^aReactions were conducted with an acceptor (0.025 mmol), CH₂Cl₂ (0.05 M). ^bYield was determined by ¹H NMR using 1,3,5-trimethoxybenzene as the internal standard. ^cIsolated yields. ^dReaction was performed using the general procedure E. n.r. = no reaction. Note: The entry in bold represents the optimized condition.

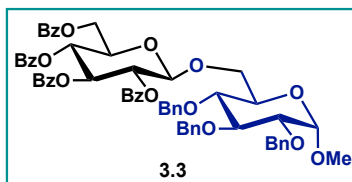
Note: Please check **Figure S-9** for the detailed experimental setup.

3.4.4. Procedures for the Activation of MDMPA-based Thioglycoside Donors

3.4.4.1 Effect of Protecting Groups on the Reactivity of MDMPAT Donors Under Standard Conditions.

Methyl (2,3,4,6-tetra-O-benzoyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (**3.3**).

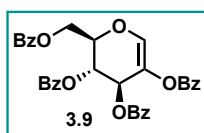
- Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31 mg, 38.0 μmol) to afford **3.3** (25.0 mg, 24.0 μmol, 91% yield) as a white viscous oil. *R_f* = 0.3 (hexane: EtOAc = 70:30).
- Following the general procedure **E**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (41.0 mg, 50.0 μmol) to afford **3.3** (8.0 mg, 8.0 μmol, 29% yield) as a white viscous oil. *R_f* = 0.3 (hexane: EtOAc = 70:30).
- Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (52.0 mg, 63.0 μmol) to afford **3.3** (20.0 mg, 19.0 μmol, 72% yield) as a white viscous oil. *R_f* = 0.3 (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 7.98 – 7.96 (m, 2H), 7.87 (ddd, J = 8.3, 3.2, 1.3 Hz, 5H), 7.80 (dd, J = 8.4, 1.3 Hz, 2H), 7.53 – 7.45 (m, 3H), 7.38 (dd, J = 15.1, 7.8 Hz, 6H), 7.33 – 7.29 (m, 6H), 7.29 – 7.25 (m, 7H), 7.24 – 7.17 (m, 6H), 7.04 – 7.01 (m, 2H), 5.87 (t, J = 9.7 Hz, 1H), 5.65 (t, J = 9.7 Hz, 1H), 5.58 (dd, J = 9.8, 7.8 Hz, 1H), 4.87 (d, J = 10.9 Hz, 1H), 4.80 (d, J = 7.8 Hz, 1H), 4.72 (d, J = 12.1 Hz, 1H), 4.66 (d, J = 11.0 Hz, 1H), 4.61 – 4.56 (m, 2H), 4.52 – 4.45 (m, 3H), 4.26 (d, J = 11.0 Hz, 1H), 4.13 (d, J = 8.7 Hz, 1H), 4.11 – 4.05 (m, 1H), 3.86 (t, J = 9.3 Hz, 1H), 3.75 – 3.68 (m, 2H), 3.41 (dd, J = 9.7, 3.6 Hz, 1H), 3.36 (t, J = 9.3 Hz, 1H), 3.19 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.23, 165.95, 165.27, 165.03, 138.87, 138.26, 138.22, 133.55, 133.37, 133.25, 133.23, 129.92, 129.86, 129.85, 129.82, 129.80, 129.62, 129.23, 128.85, 128.80, 128.54, 128.52, 128.46, 128.44, 128.41, 128.38, 128.24, 128.01, 127.99, 127.71, 127.59, 127.57, 101.41, 98.04, 81.97, 79.79, 75.65, 74.81, 73.49, 72.91, 72.27, 71.86, 69.84, 69.52, 68.38, 63.32, 55.11. The data are identical to the literature report.^[99]

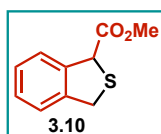
2,3,4,6-Tetra-*O*-benzoyl-1,5-anhydro-D-arabino-hex-1-enitol (3.9)



^1H NMR (399 MHz, CDCl_3) δ 8.13 – 8.09 (m, 2H), 8.02 (ddd, J = 8.5, 3.2, 1.3 Hz, 5H), 7.98 – 7.94 (m, 2H), 7.62 – 7.50 (m, 5H), 7.47 (dd, J = 8.3, 7.2 Hz, 3H), 7.44 – 7.36 (m, 8H), 6.96 (d, J = 0.6 Hz, 1H), 6.09 (d, J = 3.8 Hz, 1H), 5.84 – 5.81 (m, 1H), 4.93 – 4.84 (m, 2H), 4.73 – 4.69 (m, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.21, 165.61, 165.50, 165.14, 139.86, 133.77, 133.68, 133.53, 133.37, 130.20, 130.18, 129.93, 129.84, 129.13, 129.06, 128.68, 128.59, 128.53, 127.47, 68.25, 66.61, 61.59. The data are identical to the literature report.^[104]

methyl 1,3-dihydrobenzo[*c*]thiophene-1-carboxylate (3.10)



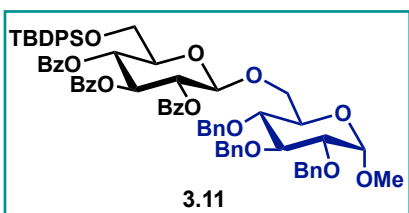
¹H NMR (399 MHz, CDCl₃) δ 7.35 – 7.26 (m, 4H), 5.17 (d, *J* = 2.6 Hz, 1H), 4.51 (dd, *J* = 13.6, 2.6 Hz, 1H), 4.21 (d, *J* = 13.7 Hz, 1H), 3.74 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 172.69, 141.26, 138.29, 128.15, 127.22, 125.23, 125.00, 54.53, 52.97, 38.15.

HRMS (ESI): calc. for C₁₀H₁₀NaO₂S (M+Na): 217.0299; found: 217.0299.

Methyl (2,3,4-tri-*O*-benzoyl-6-*O*-tert-butyldiphenylsilyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (3.11).

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1c** (36.0 mg, 39.0 μmol) to afford **3.11** (30.0 mg, 25.5 μmol, 98% yield) as a colorless viscous oil. *R_f* = 0.5 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **E**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1c** (48.0 mg, 51.0 μmol) to afford **3.11** (15.0 mg, 13.0 μmol, 50% yield) as a colorless viscous oil. *R_f* = 0.5 (hexane: EtOAc = 70:30).
- 3) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1c** (60.0 mg, 63.0 μmol) to afford **3.11** (22.0 mg, 19.0 μmol, 72% yield) as a colorless viscous oil. *R_f* = 0.5 (hexane: EtOAc = 70:30).



¹H NMR (400 MHz, CDCl₃) δ 7.89 (d, *J* = 1.3 Hz, 1H), 7.87 (d, *J* = 1.4 Hz, 1H), 7.86 (d, *J* = 1.3 Hz, 1H), 7.84 (d, *J* = 1.4 Hz, 1H), 7.82 (d, *J* = 1.3 Hz, 1H), 7.80 (d, *J* = 1.4 Hz, 1H), 7.69 – 7.67 (m, 2H), 7.59 (t, *J* = 1.4 Hz, 1H), 7.57 (d, *J* = 1.5 Hz, 1H), 7.54 – 7.49 (m, 1H), 7.43 – 7.36 (m, 4H), 7.35 – 7.31 (m, 5H), 7.31 – 7.27 (m, 9H), 7.25 – 7.18 (m, 10H), 7.05 – 7.02 (m, 2H), 5.81 (t, *J* = 9.6 Hz, 1H), 5.59 – 5.53 (m, 2H), 4.89 (d, *J* = 10.9 Hz, 1H), 4.76 – 4.72 (m, 2H), 4.68 (d, *J* = 11.1 Hz, 1H), 4.60 (d, *J* = 12.0 Hz, 1H), 4.53 (d, *J* = 3.5 Hz, 1H), 4.48 (d, *J* = 11.2 Hz, 1H), 4.28 (d, *J* = 11.0 Hz, 1H), 4.20 – 4.15 (m, 1H), 3.92 – 3.85 (m, 2H), 3.84 – 3.79 (m, 2H), 3.74 – 3.69 (m, 2H), 3.44 (dd, *J* = 9.7, 3.5 Hz, 1H), 3.39 (t, *J* = 9.4 Hz, 1H), 3.21 (s, 3H), 1.00 (s, 9H).

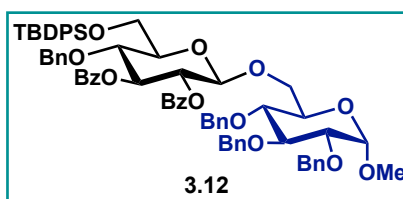
¹³C NMR (100 MHz, CDCl₃) δ 166.10, 165.16, 165.10, 138.92, 138.35, 138.29, 135.77, 135.64, 133.39, 133.30, 133.20, 133.11, 129.90, 129.87, 129.77, 129.74, 128.59, 128.50, 128.45,

128.41, 128.30, 128.04, 127.79, 127.75, 127.67, 127.54, 101.38, 98.14, 82.03, 79.86, 75.69, 75.48, 74.79, 73.56, 73.40, 72.16, 69.65, 69.43, 68.07, 63.02, 55.12, 26.72, 25.77, 19.26, 18.12.

HRMS (ESI): calc. for $C_{71}H_{72}NaO_{14}Si$ ($M+Na$): 1199.4589; found: 1199.4688.

Methyl (2,3-di-O-benzoyl-4-O-benzyl-6-O-tert-butyldiphenylsilyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.12)

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1d** (36.0 mg, 39.0 μ mol) to afford **3.12** (29.5 mg, 25.3 μ mol, 98% yield) as a white solid. R_f = 0.5 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **E**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1d** (48.0 mg, 50.0 μ mol) to afford **3.12** (23.0 mg, 19.8 μ mol, 77% yield) as a white solid. R_f = 0.5 (hexane: EtOAc = 70:30).
- 3) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1d** (59.0 mg, 63.0 μ mol) to afford **3.12** (24.5 mg, 21.5 μ mol, 82% yield) as a white solid. R_f = 0.5 (hexane: EtOAc = 70:30).



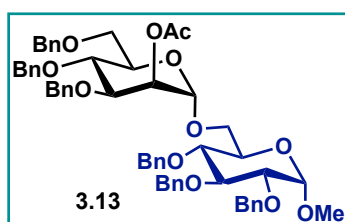
^1H NMR (399 MHz, $CDCl_3$) δ 7.94 (dd, J = 8.5, 1.4 Hz, 2H), 7.87 (dd, J = 8.4, 1.3 Hz, 2H), 7.77 (dd, J = 7.5, 1.9 Hz, 2H), 7.73 – 7.70 (m, 2H), 7.52 – 7.47 (m, 1H), 7.42 – 7.34 (m, 10H), 7.32 (dd, J = 3.3, 1.4 Hz, 3H), 7.31 – 7.27 (m, 4H), 7.25 – 7.16 (m, 7H), 7.14 – 7.10 (m, 3H), 7.05 – 6.99 (m, 4H), 5.71 (t, J = 9.6 Hz, 1H), 5.46 (dd, J = 9.9, 7.9 Hz, 1H), 4.87 (d, J = 11.0 Hz, 1H), 4.73 (d, J = 12.0 Hz, 1H), 4.67 (d, J = 11.0 Hz, 1H), 4.63 (d, J = 7.9 Hz, 1H), 4.61 – 4.59 (m, 2H), 4.52 (d, J = 3.4 Hz, 1H), 4.44 (d, J = 11.2 Hz, 1H), 4.25 (d, J = 11.2 Hz, 1H), 4.19 (d, J = 9.9 Hz, 1H), 4.01 (t, J = 9.5 Hz, 1H), 3.95 (d, J = 2.3 Hz, 2H), 3.88 (t, J = 9.3 Hz, 1H), 3.68 (td, J = 11.1, 5.0 Hz, 2H), 3.54 (dt, J = 9.5, 2.9 Hz, 1H), 3.43 (dd, J = 9.7, 3.5 Hz, 1H), 3.37 (t, J = 9.3 Hz, 1H), 3.22 (s, 3H), 1.08 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 165.91, 165.31, 138.88, 138.29, 138.26, 137.45, 136.00, 135.69, 133.49, 133.25, 132.98, 129.84, 129.72, 129.51, 128.54, 128.48, 128.40, 128.35, 128.23, 128.05, 127.99, 127.90, 127.87, 127.75, 127.61, 127.56, 127.45, 101.38, 98.08, 81.99, 79.80,

76.11, 75.63, 75.28, 75.06, 74.71, 73.49, 72.34, 69.69, 55.07, 26.94, 19.37. The data are identical to the literature report.^[99]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.13)

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1e** (27.0 mg, 38.0 μ mol) to afford **3.13** (23.0 mg, 24.5 μ mol, 94% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **E**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1e** (36.0 mg, 50.0 μ mol) to afford **3.13** (22.0 mg, 23.4 μ mol, 91% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



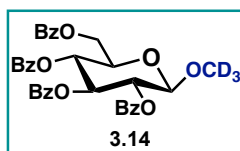
^1H NMR (600 MHz, CDCl_3) δ 7.38 – 7.35 (m, 2H), 7.34 – 7.30 (m, 10H), 7.29 – 7.26 (m, 10H), 7.25 – 7.23 (m, 3H), 7.20 (dd, J = 5.5, 2.1 Hz, 2H), 7.15 (dd, J = 7.5, 2.0 Hz, 1H), 7.13 (dd, J = 7.2, 2.1 Hz, 2H), 5.39 (td, J = 3.8, 1.9 Hz, 1H), 4.99 (d, J = 10.8 Hz, 1H), 4.90 (d, J = 1.9 Hz, 1H), 4.88 – 4.86 (m, 1H), 4.86 – 4.84 (m, 1H), 4.79 (d, J = 4.1 Hz, 1H), 4.78 (d, J = 5.3 Hz, 1H), 4.70 – 4.69 (m, 1H), 4.67 (s, 1H), 4.64 – 4.62 (m, 1H), 4.58 (d, J = 3.5 Hz, 1H), 4.53 (d, J = 6.0 Hz, 1H), 4.52 – 4.49 (m, 1H), 4.48 (s, 1H), 4.46 (d, J = 3.5 Hz, 1H), 4.43 (d, J = 8.6 Hz, 1H), 3.98 (t, J = 9.3 Hz, 1H), 3.91 (dd, J = 9.5, 3.2 Hz, 1H), 3.86 (t, J = 9.5 Hz, 1H), 3.81 – 3.78 (m, 1H), 3.73 – 3.70 (m, 3H), 3.66 (dd, J = 10.8, 4.2 Hz, 1H), 3.63 (dd, J = 11.4, 1.9 Hz, 1H), 3.54 (ddd, J = 13.3, 10.2, 2.8 Hz, 2H), 3.45 – 3.41 (m, 1H), 3.32 (s, 3H), 2.13 (s, 3H)

^{13}C NMR (101 MHz, CDCl_3) δ 170.31, 138.67, 138.50, 138.27, 138.20, 138.16, 138.09, 137.76, 128.45, 128.38, 128.34, 128.31, 128.24, 128.21, 128.15, 128.09, 128.07, 128.00, 127.92, 127.89, 127.86, 127.75, 127.72, 127.66, 127.63, 127.61, 127.59, 127.52, 127.48, 97.99, 97.78, 82.07, 80.07, 77.61, 77.58, 75.75, 75.12, 75.03, 74.90, 74.48, 74.17, 73.48, 73.32, 71.79, 71.57, 71.45, 71.38, 69.62, 68.90, 68.67, 68.48, 66.07, 55.08, 21.12. The data are identical to the literature report.^[105]

3.4.4.2. A deuterium labeling experiment was conducted to elucidate the reaction pathway

Methyl (d_3) 2,3,4,6-tetra-O-benzoyl- β -D-glucopyranoside (3.14)

- 1) Following the general procedure **D**, glycosyl acceptor **MeOH-d₄** (4.5 mg, 125.0 μ mol) was coupled with MDMPAT donor **3.1b** (20.0 mg, 25.0 μ mol) in CH₂Cl₂ to afford **3.14** (14.0 mg, 23.0 μ mol, 92% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).
- 2) Following the general procedure **D**, glycosyl acceptor **MeOH-d₄** (4.5 mg, 125.0 μ mol) was coupled with MDMPAT donor **3.1b** (20.0 mg, 25.0 μ mol) CD₂Cl₂ to afford **3.14** (13.4 mg, 22.0 μ mol, 87% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).



¹H NMR (500 MHz, CDCl₃) δ 8.03 – 8.00 (m, 2H), 7.97 – 7.94 (m, 2H), 7.91 – 7.88 (m, 2H), 7.83 – 7.80 (m, 2H), 7.55 – 7.47 (m, 3H), 7.43 – 7.32 (m, 7H), 7.27 (d, J = 7.9 Hz, 2H), 5.90 (t, J = 9.7 Hz, 1H), 5.67 (t, J = 9.7 Hz, 1H), 5.51 (dd, J = 9.8, 7.8 Hz, 1H), 4.76 (d, J = 7.8 Hz, 1H), 4.64 (dd, J = 12.1, 3.2 Hz, 1H), 4.50 (dd, J = 12.1, 5.2 Hz, 1H), 4.15 (ddd, J = 10.0, 5.2, 3.2 Hz, 1H).

¹³C NMR (126 MHz, CDCl₃) δ 166.33, 165.99, 165.35, 165.32, 133.60, 133.39, 133.29, 130.01, 129.99, 129.91, 129.89, 129.73, 129.41, 128.92, 128.56, 128.53, 128.50, 128.45, 102.17, 73.03, 72.35, 71.95, 69.89, 63.29.

LRMS (ESI): calc. for C₃₅H₂₈D₃O₁₀ (M+H): 614.2; found: 614.2.

3.4.4.3 Plausible reaction pathways for the reactivity of disarmed MDMPAT donors with or without Brønsted acid under blue-light activation.

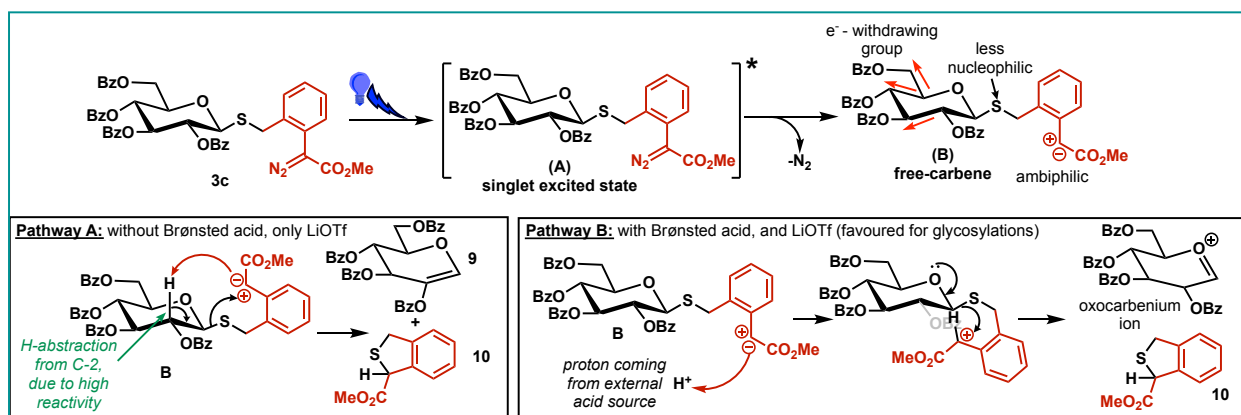


Figure 3.4.4.3: A plausible pathway for the reactivity of disarmed donors with or without Brønsted acid present along with LiOTf.

3.4.4.4. Plausible reaction pathways for activating MDMPAT donors under catalytic $\text{Fe}(\text{OTf})_3$ reaction conditions.

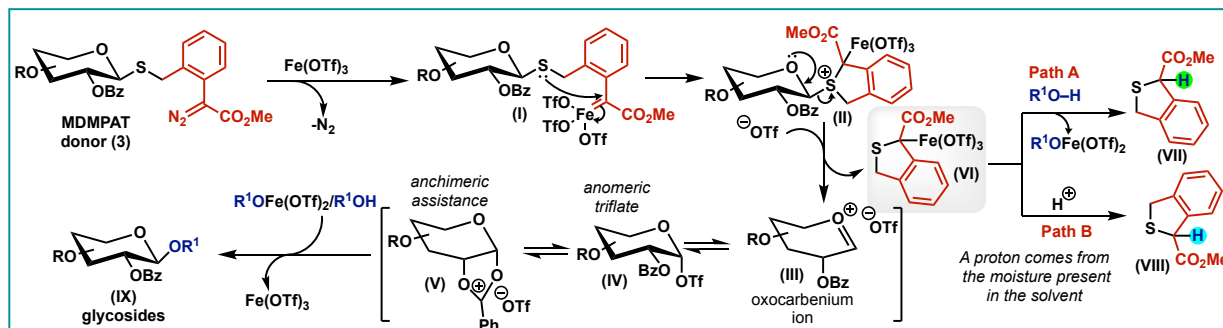


Figure 3.4.4.4: A plausible pathway for the activation of MDMPA thioglycoside donors.

3.4.4.5. Evidence for the formation of a glycosyl triflate intermediate.

The triflate ion is known to stabilize oxocarbenium ions, facilitating the formation of α - and β -transient glycosyl triflates, which can subsequently lead to glycoside formation. This concept was first introduced by Professor David Crich, who has published extensively on the mechanistic understanding of glycosylation reactions. In several of his studies, he emphasized the role of triflate ions and successfully characterized transient glycosyl triflate intermediates using NMR spectroscopy, albeit at low temperature. By following the same studies, we attempted to detect anomeric triflate transient intermediate. During the experiment, we encountered a few issues: 1) at lower temperatures ($-60\text{ }^{\circ}\text{C}$), the MDMPAT donor 3.1b was completely stable under our $\text{Fe}(\text{OTf})_3$, 2) $\text{Fe}(\text{III})$ has a significant paramagnetism to affect the peak splitting in the ^1H -NMR spectrum. We performed our experiment at room temperature using

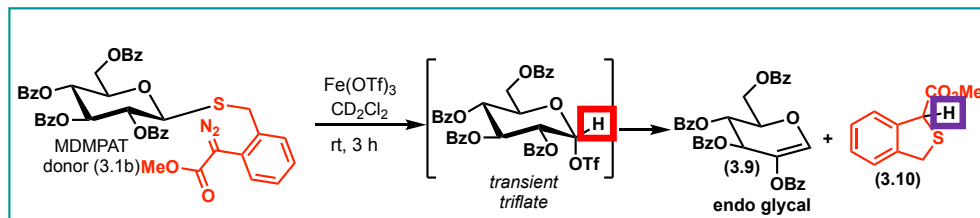


Figure 3.4.4.5. Scheme for the capture of the transient triflate intermediate.

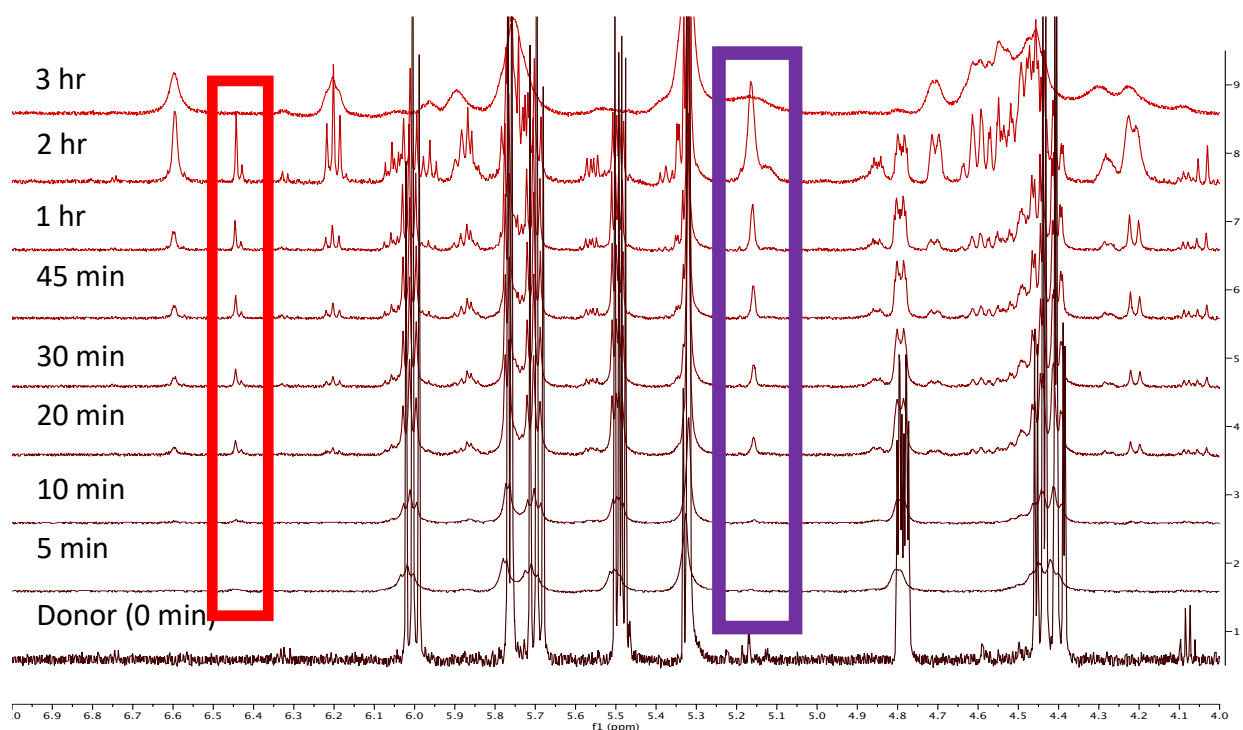


Figure 3.4.4.5: ^1H -NMR-spectrum at the given time for the above reaction.

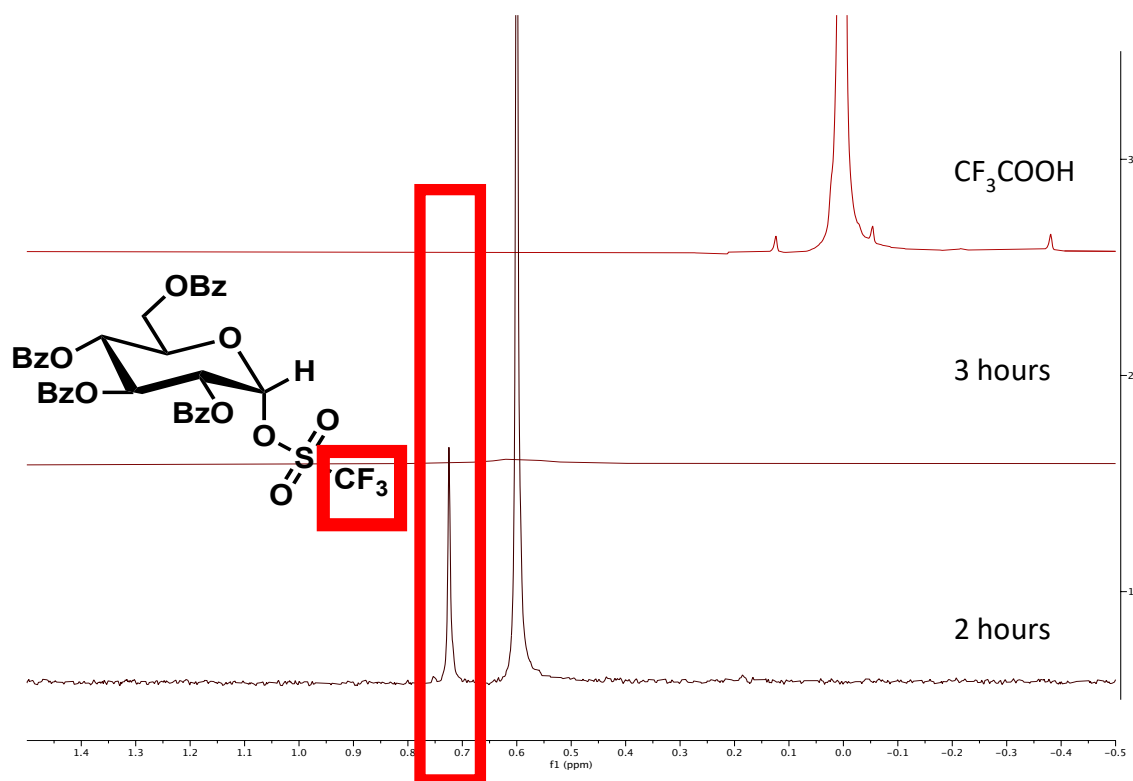


Figure 3.4.4.5: ^{19}F -NMR-spectrum of the reaction mixture in CD_2Cl_2

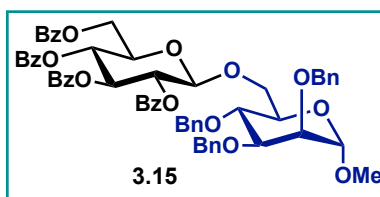
MDMPAT donor **3.1b** with Fe(OTf)₃ in CD₂Cl₂ as a solvent and recorded the ¹H-NMR and ¹⁹F-NMR at regular intervals of time. During the ¹H-NMR experiment, we found a new peak appearing at 6.45 ppm (highlighted in red box). More specifically, we started observing the same peak after 20 minutes, and we could see it till 2 hours of the reaction at room temperature, then it disappeared after 2 hours. In 1997, Crich and coworkers performed low-temperature NMR studies to capture the transient anomeric triflate intermediate.^[106] In their studies, they activated tetra-*O*-acetyl thioglucoside at -78 °C, and they observed the α-triflate (β-proton) at 6.3 ppm. We assumed that this shift in anomeric proton values could be the electronic effect of the benzoyl vs acetyl protecting groups. However, it is a clear indication that the appearance of a new peak supports our hypothesis. In our ¹⁹F-NMR analysis, we observed a new peak that appeared at 0.7 ppm (highlighted in red), but after 2 hours, during our studies at 3 hours, it disappeared. In the same report, Crich and coworkers reported the fluorine NMR spectra for this transient triflate intermediate with tetra-*O*-acetyl glucose. In their report, they found that the new triflate resonates around 0.6-0.7 ppm in ¹⁹F-NMR spectra. After the comparison to the previous report, we strongly believe that this transformation is also proceeding through the transient triflate intermediate. Because this transformation works at ambient reaction conditions, we do not have isolated and characterized data for the transient intermediate.

3.4.5. Substrate scope of MDMPA thioglycoside donors

3.4.5.1. Scope of glycosyl acceptors with disarmed glucosyl MDMPA thioglycoside donor under Fe(OTf)₃ or Blue LED conditions

Methyl (2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-mannopyranoside (**3.15**)

- 1) Following the general procedure **D**, glycosyl acceptor **A9** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.15** (26.0 mg, 25.3 μmol, 96% yield) as a colorless viscous oil. *R*_f = 0.3 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A9** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (51.0 mg, 63.0 μmol) to afford **3.15** (20.0 mg, 19.0 μmol, 74% yield) as a colorless viscous oil. *R*_f = 0.3 (hexane: EtOAc = 70:30).

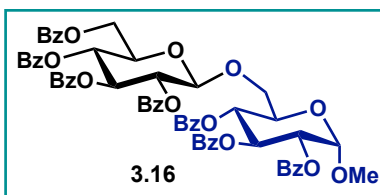


^1H NMR (399 MHz, CDCl_3) δ 8.03 – 7.98 (m, 3H), 7.91 – 7.88 (m, 4H), 7.82 (dd, J = 8.4, 1.4 Hz, 2H), 7.51 – 7.48 (m, 2H), 7.46 (dd, J = 8.8, 1.5 Hz, 1H), 7.44 – 7.41 (m, 2H), 7.40 – 7.37 (m, 2H), 7.35 (d, J = 8.3 Hz, 4H), 7.33 – 7.31 (m, 3H), 7.31 – 7.28 (m, 5H), 7.28 – 7.26 (m, 6H), 7.25 (s, 2H), 7.20 (dd, J = 7.9, 1.8 Hz, 2H), 5.90 (t, J = 9.6 Hz, 1H), 5.69 (t, J = 9.7 Hz, 1H), 5.58 (dd, J = 9.8, 7.8 Hz, 1H), 4.96 (d, J = 7.9 Hz, 1H), 4.74 (d, J = 11.0 Hz, 1H), 4.66 (s, 2H), 4.61 (dd, J = 12.1, 3.3 Hz, 1H), 4.54 – 4.49 (m, 4H), 4.42 (d, J = 11.1 Hz, 1H), 4.21 (d, J = 9.4 Hz, 1H), 4.16 – 4.11 (m, 1H), 3.79 – 3.62 (m, 6H), 2.96 (s, 3H)

^{13}C NMR (100 MHz, CDCl_3) δ 166.28, 165.99, 165.26, 165.12, 138.49, 138.40, 138.33, 133.51, 133.32, 133.19, 133.11, 130.03, 129.97, 129.93, 129.91, 129.85, 129.81, 129.66, 129.53, 128.92, 128.89, 128.53, 128.51, 128.44, 128.41, 128.39, 128.33, 127.98, 127.83, 127.75, 127.71, 127.63, 127.61, 101.82, 98.69, 80.30, 75.08, 75.00, 74.27, 73.05, 72.71, 72.16, 72.09, 72.00, 71.41, 69.84, 69.66, 63.24, 54.37. The data are identical to the literature report.^[107]

Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (3.16)

- 1) Following the general procedure **D**, glycosyl acceptor **A11** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.16** (26.5 mg, 25.3 μmol , 97% yield) as a white solid. R_f = 0.2 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A11** (12 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (51.0 mg, 63.0 μmol) to afford **3.16** (19.5 mg, 18.0 μmol , 70% yield) as a white solid. R_f = 0.2 (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 7.97 (td, J = 8.7, 1.4 Hz, 4H), 7.92 (dd, J = 8.4, 1.3 Hz, 2H), 7.88 (dd, J = 8.4, 1.3 Hz, 2H), 7.85 (dd, J = 8.4, 1.3 Hz, 2H), 7.81 (dd, J = 8.4, 1.4 Hz, 2H), 7.78 (dd, J = 8.5, 1.4 Hz, 2H), 7.56 – 7.51 (m, 1H), 7.51 – 7.46 (m, 4H), 7.43 – 7.37 (m, 5H), 7.36 – 7.31 (m, 7H), 7.30 (d, J = 1.9 Hz, 1H), 7.29 – 7.26 (m, 2H), 7.23 (s, 1H), 6.05 (t, J = 9.8 Hz, 1H), 5.91

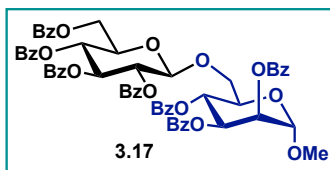
(t, $J = 9.7$ Hz, 1H), 5.65 (t, $J = 9.7$ Hz, 1H), 5.55 (dd, $J = 9.8, 7.9$ Hz, 1H), 5.33 – 5.27 (m, 1H), 5.07 (dd, $J = 10.2, 3.6$ Hz, 1H), 4.96 (d, $J = 7.9$ Hz, 1H), 4.92 (d, $J = 3.7$ Hz, 1H), 4.59 (dd, $J = 12.1, 3.1$ Hz, 1H), 4.43 (dd, $J = 12.2, 5.1$ Hz, 1H), 4.23 – 4.18 (m, 1H), 4.15 – 4.07 (m, 2H), 3.77 (dd, $J = 11.5, 7.7$ Hz, 1H), 3.08 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.22, 165.91, 165.81, 165.75, 165.53, 165.27, 165.26, 133.55, 133.42, 133.35, 133.23, 133.15, 129.99, 129.95, 129.94, 129.87, 129.84, 129.72, 129.62, 129.41, 129.28, 129.12, 128.87, 128.84, 128.81, 128.53, 128.51, 128.48, 128.43, 128.40, 128.32, 101.85, 96.49, 72.87, 72.34, 72.07, 71.91, 70.36, 69.68, 68.80, 63.07, 55.10, 29.81.

The data are identical to the literature report.^[87]

Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-mannopyranoside (3.17)

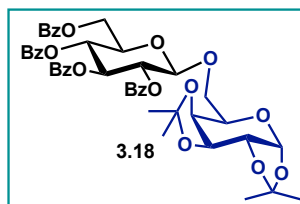
Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.17** (27.0 mg, 26.0 μmol , 98% yield) as a white solid. $R_f = 0.2$ (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 8.08 – 8.04 (m, 2H), 8.00 – 7.97 (m, 2H), 7.93 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.89 – 7.85 (m, 4H), 7.82 (dd, $J = 8.5, 1.4$ Hz, 2H), 7.76 (dd, $J = 8.3, 1.3$ Hz, 2H), 7.64 – 7.59 (m, 1H), 7.56 – 7.45 (m, 6H), 7.44 – 7.37 (m, 5H), 7.33 (td, $J = 8.1, 3.9$ Hz, 6H), 7.30 – 7.27 (m, 2H), 7.22 (d, $J = 7.5$ Hz, 2H), 5.90 (t, $J = 9.7$ Hz, 1H), 5.78 (dd, $J = 9.9, 3.4$ Hz, 1H), 5.69 – 5.62 (m, 2H), 5.60 – 5.56 (m, 1H), 5.54 (dd, $J = 3.5, 1.8$ Hz, 1H), 4.97 (d, $J = 7.9$ Hz, 1H), 4.64 – 4.59 (m, 2H), 4.43 (dd, $J = 12.1, 5.1$ Hz, 1H), 4.25 (t, $J = 8.5$ Hz, 1H), 4.15 (d, $J = 14.9$ Hz, 2H), 3.85 (dd, $J = 11.1, 8.4$ Hz, 1H), 3.11 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.21, 165.90, 165.77, 165.58, 165.39, 165.26, 165.24, 133.57, 133.54, 133.35, 133.29, 133.24, 130.02, 129.92, 129.90, 129.86, 129.83, 129.77, 129.42, 128.90, 128.85, 128.83, 128.70, 128.54, 128.49, 128.40, 128.33, 102.02, 98.05, 72.90, 72.29, 71.91, 70.51, 69.91, 69.80, 69.71, 67.41, 63.08, 54.96, 29.81. The data are identical to the literature report.^[108]

2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-1,2:3,4-di-*O*-isopropylidene- α -D-galactopyranose (3.18)



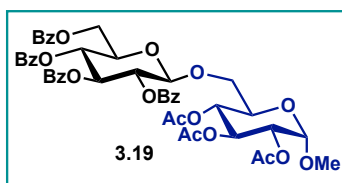
Following the general procedure **D**, glycosyl acceptor **A8** (7.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μ mol) to afford **3.18** (21.0 mg, 25.0 μ mol, 95% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.03 (dd, J = 8.4, 1.3 Hz, 2H), 7.97 (dd, J = 8.4, 1.3 Hz, 2H), 7.89 (dd, J = 8.4, 1.3 Hz, 2H), 7.83 (dd, J = 8.5, 1.4 Hz, 2H), 7.53 (dd, J = 7.5, 1.9 Hz, 1H), 7.50 – 7.47 (m, 2H), 7.42 – 7.37 (m, 4H), 7.36 (s, 2H), 7.34 – 7.34 (m, 1H), 7.29 (d, J = 8.2 Hz, 2H), 5.90 (t, J = 9.6 Hz, 1H), 5.68 (t, J = 9.7 Hz, 1H), 5.53 (dd, J = 9.7, 7.8 Hz, 1H), 5.42 (d, J = 5.0 Hz, 1H), 5.04 (d, J = 7.9 Hz, 1H), 4.64 (dd, J = 12.1, 3.2 Hz, 1H), 4.48 (dd, J = 12.1, 5.3 Hz, 1H), 4.43 (dd, J = 7.9, 2.5 Hz, 1H), 4.21 (dd, J = 5.0, 2.4 Hz, 1H), 4.20 – 4.14 (m, 1H), 4.13 – 4.08 (m, 1H), 4.01 (dd, J = 10.2, 3.3 Hz, 1H), 3.90 – 3.83 (m, 2H), 1.37 (s, 3H), 1.24 (s, 3H), 1.20 (s, 3H), 1.19 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.33, 165.95, 165.34, 165.30, 133.56, 133.34, 133.22, 130.16, 129.98, 129.91, 129.75, 129.47, 128.97, 128.93, 128.54, 128.50, 128.42, 128.35, 109.40, 108.62, 101.36, 96.29, 73.12, 72.28, 71.91, 71.10, 70.64, 70.45, 69.91, 68.40, 67.66, 63.37, 26.01, 25.80, 24.99, 24.36. The data are identical to the literature report.^[87]

Methyl (2,3,4,6-tetra-O-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-acetyl- α -D-glucopyranoside (3.19)

Following the general procedure **D**, glycosyl acceptor **A10** (8.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μ mol) to afford **3.19** (19.5 mg, 22.0 μ mol, 87% yield) as a colorless viscous oil. R_f = 0.1 (hexane: EtOAc = 70:30).

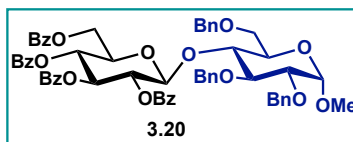


^1H NMR (399 MHz, CDCl_3) δ 8.02 (dd, J = 8.2, 1.7 Hz, 2H), 7.94 (dd, J = 8.3, 1.7 Hz, 2H), 7.91 – 7.88 (m, 2H), 7.84 – 7.81 (m, 2H), 7.58 – 7.48 (m, 3H), 7.45 – 7.39 (m, 4H), 7.38 – 7.34 (m, 3H), 7.29 (d, J = 7.9 Hz, 2H), 5.91 (t, J = 9.7 Hz, 1H), 5.68 (t, J = 9.7 Hz, 1H), 5.54 (dd, J = 9.9, 7.8 Hz, 1H), 5.38 (t, J = 9.7 Hz, 1H), 4.92 (d, J = 7.9 Hz, 1H), 4.82 – 4.76 (m, 1H), 4.71 (dd, J =

10.2, 3.7 Hz, 1H), 4.64 (dd, $J = 13.3, 3.5$ Hz, 2H), 4.48 (dd, $J = 12.3, 5.1$ Hz, 1H), 4.18 – 4.11 (m, 1H), 3.97 – 3.88 (m, 2H), 3.61 (dd, $J = 10.6, 7.4$ Hz, 1H), 3.02 (s, 3H), 2.02 (s, 3H), 1.95 (s, 6H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.22, 170.05, 169.95, 166.25, 165.90, 165.27, 165.23, 133.59, 133.37, 133.30, 129.94, 129.91, 129.86, 129.83, 129.61, 129.33, 128.83, 128.80, 128.55, 128.53, 128.43, 128.41, 116.10, 114.88, 101.72, 96.12, 72.79, 72.39, 71.81, 70.92, 70.04, 69.69, 69.28, 68.91, 68.28, 63.08, 54.88, 20.70. The data are identical to the literature report.^[87]

Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 4)-2,3,6-tri-*O*-benzyl- α -D-glucopyranoside (3.20)

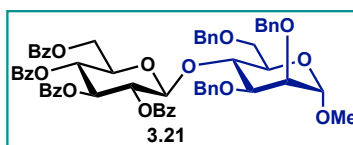


Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.20** (24.5 mg, 23.5 μmol , 90% yield) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.08 – 8.05 (m, 1H), 8.01 – 7.93 (m, 4H), 7.89 – 7.86 (m, 5H), 7.79 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.53 – 7.48 (m, 5H), 7.47 – 7.40 (m, 7H), 7.39 – 7.35 (m, 8H), 7.34 – 7.28 (m, 4H), 7.19 – 7.17 (m, 2H), 5.61 (t, $J = 9.5$ Hz, 1H), 5.54 (t, $J = 9.5$ Hz, 1H), 5.46 (dd, $J = 9.6, 8.0$ Hz, 1H), 5.07 (d, $J = 11.2$ Hz, 1H), 4.79 (d, $J = 11.1$ Hz, 1H), 4.77 – 4.72 (m, 3H), 4.58 (d, $J = 12.2$ Hz, 1H), 4.54 (d, $J = 3.7$ Hz, 1H), 4.39 (dd, $J = 12.1, 3.5$ Hz, 1H), 4.34 (d, $J = 12.0$ Hz, 1H), 4.25 (dd, $J = 12.1, 5.0$ Hz, 1H), 3.98 – 3.93 (m, 1H), 3.87 (t, $J = 9.1$ Hz, 1H), 3.70 (ddd, $J = 10.9, 7.7, 3.8$ Hz, 2H), 3.51 – 3.39 (m, 3H), 3.27 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.15, 165.83, 165.19, 164.92, 139.36, 138.43, 137.96, 133.47, 133.44, 133.27, 133.07, 130.03, 129.97, 129.91, 129.84, 129.81, 129.78, 129.70, 129.18, 129.00, 128.98, 128.94, 128.58, 128.55, 128.52, 128.50, 128.45, 128.39, 128.17, 128.14, 127.86, 127.49, 127.24, 100.50, 98.59, 80.05, 78.80, 75.47, 73.71, 73.68, 73.23, 72.31, 71.90, 69.91, 69.52, 67.95, 67.61, 63.22, 62.91, 55.46. The data are identical to the literature report.^[87]

Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 4)-2,3,6-tri-*O*-benzyl- α -D-mannopyranoside (3.21)



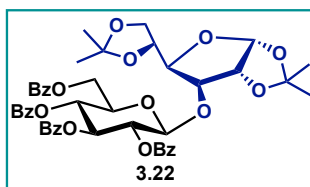
Following the general procedure **D**, glycosyl acceptor **A18** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.21** (19.5 mg, 19.0 μmol , 96% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.95 (dd, J = 8.4, 1.3 Hz, 2H), 7.90 (dd, J = 8.4, 1.3 Hz, 2H), 7.86 (dd, J = 8.5, 1.4 Hz, 2H), 7.79 (dd, J = 8.4, 1.3 Hz, 2H), 7.53 – 7.45 (m, 3H), 7.44 – 7.40 (m, 2H), 7.40 – 7.35 (m, 7H), 7.35 – 7.32 (m, 4H), 7.31 – 7.26 (m, 9H), 7.25 – 7.20 (m, 4H), 5.70 (t, J = 9.6 Hz, 1H), 5.59 (t, J = 9.7 Hz, 1H), 5.47 (dd, J = 9.8, 8.0 Hz, 1H), 4.97 (d, J = 8.0 Hz, 1H), 4.85 (d, J = 12.2 Hz, 1H), 4.67 (d, J = 2.6 Hz, 3H), 4.61 (d, J = 8.3 Hz, 1H), 4.58 (d, J = 8.2 Hz, 1H), 4.43 (dd, J = 12.1, 3.3 Hz, 1H), 4.33 – 4.25 (m, 2H), 4.21 (dd, J = 12.2, 4.4 Hz, 1H), 3.85 (dd, J = 9.0, 3.2 Hz, 1H), 3.76 – 3.70 (m, 2H), 3.64 – 3.54 (m, 2H), 3.53 – 3.49 (m, 1H), 3.23 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.92, 165.59, 164.90, 164.85, 138.93, 138.28, 138.22, 133.15, 132.97, 132.76, 129.62, 129.58, 129.53, 129.39, 128.92, 128.73, 128.68, 128.29, 128.26, 128.20, 128.08, 128.06, 128.04, 127.66, 127.60, 127.55, 127.30, 127.02, 126.69, 100.69, 99.10, 77.96, 75.65, 74.77, 73.08, 72.97, 72.53, 72.28, 72.22, 71.73, 70.68, 69.41, 68.39, 62.76, 54.61.

HRMS (ESI): calc. for $\text{C}_{62}\text{H}_{58}\text{NaO}_{15}$ ($\text{M}+\text{Na}$): 1065.3673; found: 1065.3707.

2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 3)-1,2:5,6-di-*O*-isopropylidene- α -D-galactopyranose (3.22**)**



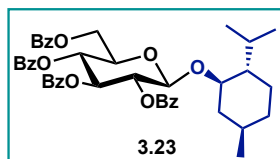
Following the general procedure **D**, glycosyl acceptor **A19** (7.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.22** (20.5 mg, 24.5 μmol , 91% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.03 (dd, J = 8.5, 1.4 Hz, 2H), 7.95 (t, J = 1.5 Hz, 1H), 7.93 (d, J = 1.5 Hz, 1H), 7.91 (d, J = 1.4 Hz, 1H), 7.89 (t, J = 1.7 Hz, 1H), 7.82 (dd, J = 8.4, 1.3 Hz, 2H), 7.55 – 7.49 (m, 4H), 7.43 (d, J = 2.7 Hz, 1H), 7.41 (d, J = 1.5 Hz, 2H), 7.39 (d, J = 1.7 Hz, 1H), 7.36 (d, J = 2.4 Hz, 2H), 7.34 (d, J = 3.3 Hz, 2H), 7.29 (d, J = 8.1 Hz, 2H), 5.92 – 5.86 (m, 2H), 5.67 (t, J = 9.7 Hz, 1H), 5.54 (dd, J = 9.8, 7.8 Hz, 1H), 4.95 (d, J = 7.8 Hz, 1H), 4.67 – 4.62 (m, 1H), 4.51 – 4.46 (m, 2H), 4.18 – 4.07 (m, 4H), 3.74 – 3.69 (m, 2H), 1.37 (s, 3H), 1.28 (s, 3H), 1.16 (s, 3H), 1.09 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.29, 165.94, 165.28, 165.08, 133.54, 133.35, 133.26, 133.23, 129.97, 129.94, 129.90, 129.87, 129.81, 129.66, 129.42, 128.87, 128.51, 128.47, 128.42, 112.26, 106.42, 101.82, 101.01, 84.00, 79.23, 74.93, 72.91, 72.26, 71.91, 71.75, 70.38, 69.78, 63.19, 27.18, 26.59, 23.80, 23.65. The data are identical to the literature report.^[43]

HRMS (ESI): calc. for $\text{C}_{46}\text{H}_{46}\text{NaO}_{15}$ ($\text{M}+\text{Na}$): 861.2734; found: 861.2768.

D-Menthyl 2,3,4,6-tetra-O-benzoyl- β -D-glucopyranoside (3.23)

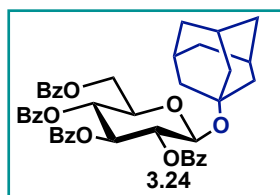


Following the general procedure **D**, glycosyl acceptor **A5** (4.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 38.0 μmol) to afford **3.23** (17.5 mg, 24.0 μmol , 94% yield) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.98 (ddd, J = 13.8, 8.5, 1.4 Hz, 4H), 7.92 – 7.89 (m, 2H), 7.85 – 7.81 (m, 2H), 7.56 – 7.47 (m, 3H), 7.43 (s, 1H), 7.40 (s, 1H), 7.38 (t, J = 0.8 Hz, 2H), 7.36 (s, 1H), 7.35 – 7.34 (m, 1H), 7.32 (d, J = 6.5 Hz, 1H), 7.28 (d, J = 7.6 Hz, 1H), 5.88 (t, J = 9.7 Hz, 1H), 5.63 (t, J = 9.7 Hz, 1H), 5.48 (dd, J = 9.8, 7.9 Hz, 1H), 4.92 (d, J = 7.9 Hz, 1H), 4.62 (dd, J = 11.9, 3.4 Hz, 1H), 4.48 (dd, J = 12.0, 5.7 Hz, 1H), 4.16 – 4.09 (m, 1H), 3.47 (td, J = 10.6, 4.3 Hz, 1H), 2.28 – 2.20 (m, 1H), 1.93 (d, J = 12.1 Hz, 1H), 1.55 (s, 2H), 1.24 – 1.13 (m, 2H), 0.97 – 0.84 (m, 2H), 0.81 (d, J = 7.1 Hz, 3H), 0.75 (d, J = 6.5 Hz, 3H), 0.70 (d, J = 6.9 Hz, 4H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.25, 165.96, 165.41, 165.17, 133.50, 133.29, 133.21, 133.18, 129.94, 129.87, 129.82, 129.69, 129.60, 129.00, 128.93, 128.51, 128.40, 128.37, 99.11, 79.20, 73.26, 72.19, 72.07, 70.25, 63.55, 47.36, 40.85, 34.15, 31.45, 29.81, 25.18, 23.06, 22.12, 20.89, 15.66. The data are identical to the literature report.^[109]

1-Adamantyl 2,3,4,6-tetra-O-benzoyl- β -D-glucopyranoside (3.24)

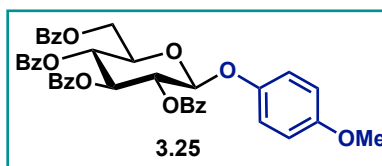


Following the general procedure **D**, glycosyl acceptor **A7** (4.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.24** (31.0 mg, 38.0 μmol) to afford **3.24** (17.0 mg, 24.0 μmol , 93% yield) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.01 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.95 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.91 (dd, $J = 8.5, 1.4$ Hz, 2H), 7.83 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.56 – 7.44 (m, 4H), 7.43 – 7.40 (m, 2H), 7.39 – 7.36 (m, 4H), 7.34 – 7.28 (m, 2H), 5.92 (t, $J = 9.6$ Hz, 1H), 5.58 – 5.46 (m, 2H), 5.12 (d, $J = 8.0$ Hz, 1H), 4.58 (dd, $J = 11.9, 3.2$ Hz, 1H), 4.48 (dd, $J = 11.9, 7.1$ Hz, 1H), 4.18 (ddd, $J = 10.2, 7.2, 3.2$ Hz, 1H), 2.03 (d, $J = 8.0$ Hz, 3H), 1.82 (d, $J = 11.4$ Hz, 3H), 1.65 (d, $J = 10.4$ Hz, 3H), 1.54 (s, 3H), 1.48 (d, $J = 11.7$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.18, 165.97, 165.45, 165.02, 133.56, 133.29, 133.20, 129.95, 129.88, 129.82, 129.76, 129.60, 128.99, 128.89, 128.53, 128.45, 128.42, 128.39, 94.40, 75.97, 73.32, 72.14, 72.01, 70.39, 63.79, 42.42, 36.10, 30.62. The data are identical to the literature report.^[109]

4-Methoxyphenyl 2',3',4',6'-tetra-*O*-benzoyl- β -D-glucopyranoside (**3.25**)



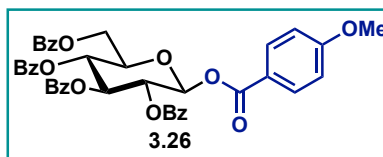
Following the general procedure **D**, glycosyl acceptor **A6** (5.0 mg, 40.0 μmol) was coupled with MDMPAT donor **3.1b** (42.0 mg, 52.0 μmol) to afford **3.25** (25.0 mg, 36.0 μmol , 90% yield) as a colorless viscous oil. $R_f = 0.6$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.04 (dd, $J = 8.5, 1.4$ Hz, 2H), 7.98 (dd, $J = 8.5, 1.3$ Hz, 2H), 7.93 (dd, $J = 8.5, 1.4$ Hz, 2H), 7.86 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.60 – 7.55 (m, 1H), 7.54 – 7.49 (m, 2H), 7.45 (d, $J = 1.9$ Hz, 1H), 7.44 – 7.40 (m, 3H), 7.39 – 7.36 (m, 3H), 7.34 (d, $J = 9.4$ Hz, 1H), 7.30 (d, $J = 1.4$ Hz, 1H), 6.97 – 6.92 (m, 2H), 6.69 – 6.64 (m, 2H), 5.97 (t, $J = 9.5$ Hz, 1H), 5.77 (dd, $J = 9.7, 7.8$ Hz, 1H), 5.70 (t, $J = 9.7$ Hz, 1H), 5.26 (d, $J = 7.8$ Hz, 1H), 4.67 (dd, $J = 12.1, 3.0$ Hz, 1H), 4.54 (dd, $J = 12.1, 6.6$ Hz, 1H), 4.28 (ddd, $J = 9.7, 6.6, 3.1$ Hz, 1H), 3.71 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.15, 165.89, 165.38, 165.21, 133.68, 133.46, 133.44, 133.33, 129.99, 129.93, 129.91, 129.89, 129.67, 129.23, 128.81, 128.58, 128.54, 128.51, 128.45, 119.09, 114.52, 100.96, 72.91, 72.58, 71.83, 69.79, 63.31, 55.66. The data are identical to the literature report.^[87]

4-Methoxybenzoyl 2',3',4',6'-tetra-*O*-benzoyl- β -D-glucopyranoside (**3.26**)

Following the general procedure **D**, glycosyl acceptor **A20** (4.0 mg, 27.0 μ mol) was coupled with MDMPAT donor **3.1b** (32.0 mg, 39.0 μ mol) to afford **3.26** (19.0 mg, 26 μ mol, 99% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).



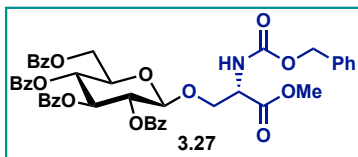
^1H NMR (399 MHz, CDCl_3) δ 8.06 – 8.02 (m, 2H), 7.99 (d, J = 9.0 Hz, 2H), 7.91 (dd, J = 8.4, 1.3 Hz, 4H), 7.86 (d, J = 8.6 Hz, 2H), 7.55 – 7.47 (m, 3H), 7.44 – 7.38 (m, 4H), 7.35 (d, J = 7.9 Hz, 3H), 7.31 (d, J = 8.1 Hz, 2H), 6.88 (d, J = 8.9 Hz, 2H), 6.27 (d, J = 8.0 Hz, 1H), 6.03 (t, J = 9.5 Hz, 1H), 5.84 (q, J = 8.7 Hz, 2H), 4.65 (dd, J = 12.5, 3.0 Hz, 1H), 4.51 (dd, J = 12.3, 4.7 Hz, 1H), 4.40 (ddd, J = 9.9, 4.6, 2.9 Hz, 1H), 3.83 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.24, 165.79, 165.27, 165.22, 164.37, 164.17, 133.64, 133.55, 133.46, 133.21, 132.49, 130.03, 129.96, 129.93, 129.90, 129.85, 129.81, 129.61, 128.85, 128.79, 128.75, 128.59, 128.56, 128.52, 128.46, 128.41, 120.79, 113.91, 92.60, 73.18, 72.91, 70.93, 69.14, 62.78, 55.57.

HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{34}\text{NaO}_{12}$ ($\text{M}+\text{Na}$): 753.1948; found: 753.1966.

N-Benzyloxycarbonyl-O-(2,3,4,6-tetra-O-benzoyl- β -D-glucopyranosyl)-L-serine methyl ester (3.27)

Following the general procedure **D**, glycosyl acceptor **A21** (7.0 mg, 28.0 μ mol) was coupled with MDMPAT donor **3.1b** (33.0 mg, 43.0 μ mol) to afford **3.27** (20.0 mg, 24 μ mol, 86% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

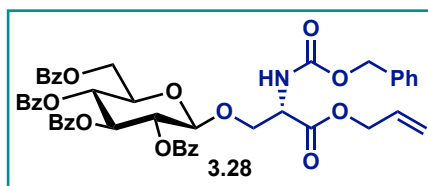


^1H NMR (399 MHz, CDCl_3) δ 8.02 (dd, J = 8.5, 1.4 Hz, 2H), 7.94 (dd, J = 8.3, 1.4 Hz, 2H), 7.89 (dd, J = 8.5, 1.4 Hz, 2H), 7.82 (dd, J = 8.5, 1.4 Hz, 2H), 7.58 – 7.53 (m, 1H), 7.52 – 7.48 (m, 1H), 7.46 – 7.42 (m, 2H), 7.40 (dd, J = 8.4, 1.3 Hz, 2H), 7.37 – 7.32 (m, 5H), 7.32 – 7.27 (m, 6H), 5.87 (t, J = 9.6 Hz, 1H), 5.66 (t, J = 9.7 Hz, 1H), 5.48 (td, J = 9.9, 7.9 Hz, 2H), 5.06 – 4.94 (m, 2H), 4.81 (d, J = 7.8 Hz, 1H), 4.63 (dd, J = 12.2, 3.2 Hz, 1H), 4.49 – 4.43 (m, 2H), 4.33 (dd, J = 10.2, 3.0 Hz, 1H), 4.09 (dd, J = 7.7, 3.3 Hz, 1H), 3.90 (dd, J = 10.3, 3.4 Hz, 1H), 3.66 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.96, 166.23, 165.85, 165.23, 165.18, 155.92, 136.29, 133.61, 133.41, 133.31, 129.93, 129.89, 129.86, 129.57, 129.08, 128.79, 128.78, 128.62, 128.54, 128.53, 128.43, 128.26, 128.23, 101.47, 72.66, 72.40, 71.72, 69.48, 67.07, 62.97, 54.26, 52.83. The data are identical to the literature report.^[110]

N-Benzyloxycarbonyl-O-(2,3,4,6-tetra-O-benzoyl- β -D-glucopyranosyl)-L-serine allyl ester (3.28)

Following the general procedure **D**, glycosyl acceptor **A22** (7.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 37.0 μmol) to afford **3.28** (19.5 mg, 23.0 μmol , 91% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

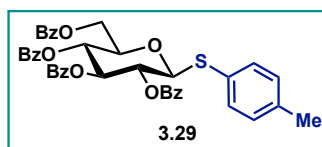


^1H NMR (399 MHz, CDCl_3) δ 8.02 (dd, J = 8.5, 1.4 Hz, 2H), 7.95 – 7.92 (m, 2H), 7.89 (dd, J = 8.5, 1.4 Hz, 2H), 7.82 (dd, J = 8.5, 1.4 Hz, 2H), 7.57 – 7.53 (m, 1H), 7.52 – 7.48 (m, 1H), 7.46 – 7.42 (m, 2H), 7.42 – 7.38 (m, 2H), 7.37 – 7.32 (m, 5H), 7.31 – 7.26 (m, 6H), 5.91 – 5.76 (m, 2H), 5.65 (t, J = 9.7 Hz, 1H), 5.54 – 5.44 (m, 2H), 5.26 (dd, J = 17.3, 1.6 Hz, 1H), 5.17 (dd, J = 10.3, 1.3 Hz, 1H), 5.03 (d, J = 12.2 Hz, 1H), 4.95 (d, J = 12.1 Hz, 1H), 4.81 (d, J = 7.9 Hz, 1H), 4.64 – 4.56 (m, 3H), 4.50 – 4.42 (m, 2H), 4.37 (dd, J = 10.2, 3.0 Hz, 1H), 4.12 – 4.06 (m, 1H), 3.91 (dd, J = 10.0, 3.4 Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.14, 166.23, 165.85, 165.23, 165.19, 155.94, 136.31, 133.61, 133.41, 133.30, 131.45, 129.93, 129.89, 129.86, 129.57, 129.09, 128.78, 128.61, 128.52, 128.50, 128.43, 128.25, 128.21, 118.72, 101.48, 72.67, 72.39, 71.77, 69.48, 67.05, 66.37, 63.01, 54.32.

HRMS (ESI): calc. for $\text{C}_{48}\text{H}_{43}\text{NNaO}_{14}$ ($M+\text{Na}$): 880.2581; found: 880.2603.

p-Tolyl 2,3,4,6-tetra-O-benzoyl-1-thio- β -D-glucopyranoside (3.29)

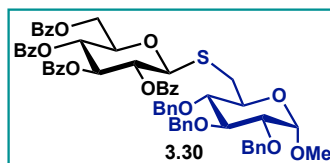


Following the general procedure **D**, glycosyl acceptor **A23** (5.0 mg, 40.0 μmol) was coupled with MDMPAT donor **3.1b** (42.0 mg, 53.0 μmol) to afford **3.29** (24.5 mg, 35.0 μmol , 86% yield) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).

¹H NMR (399 MHz, CDCl₃) δ 8.06 – 8.02 (m, 2H), 7.98 (dd, *J* = 8.3, 1.4 Hz, 2H), 7.91 – 7.87 (m, 2H), 7.79 (dd, *J* = 8.3, 1.4 Hz, 2H), 7.59 (d, *J* = 7.4 Hz, 1H), 7.56 – 7.46 (m, 3H), 7.45 (s, 1H), 7.44 – 7.38 (m, 4H), 7.37 – 7.32 (m, 3H), 6.93 (d, *J* = 7.8 Hz, 2H), 5.89 (t, *J* = 9.5 Hz, 1H), 5.59 (t, *J* = 9.8 Hz, 1H), 5.45 (t, *J* = 9.7 Hz, 1H), 4.98 (d, *J* = 10.0 Hz, 1H), 4.68 (dd, *J* = 12.1, 2.8 Hz, 1H), 4.47 (dd, *J* = 12.2, 5.7 Hz, 1H), 4.18 (td, *J* = 5.9, 2.8 Hz, 1H), 2.28 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 166.18, 165.90, 165.29, 165.15, 138.77, 134.01, 133.60, 133.45, 133.35, 133.28, 129.99, 129.96, 129.85, 129.75, 129.31, 128.83, 128.77, 128.53, 128.51, 128.38, 127.60, 86.30, 74.28, 70.50, 69.40, 63.19, 21.30. The data are identical to the literature report.^[87]

Methyl 2,3,4,6-tetra-*O*-benzoyl-β-D-mannopyranosyl-(1→6)-2,3,4-tri-*O*-benzyl-6-thio-α-D-glucopyranoside (3.30)



Following the general procedure **D**, glycosyl acceptor **A24** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 37.0 μmol) to afford **3.30** (13.0 mg, 12.5 μmol, 49% yield) as a colorless viscous oil. *R*_f = 0.4 (hexane: EtOAc = 70:30).

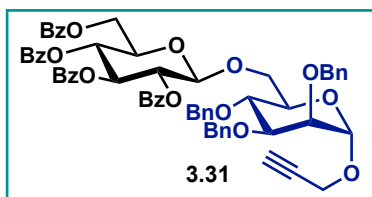
¹H NMR (399 MHz, CDCl₃) δ 7.97 (dd, *J* = 8.3, 1.4 Hz, 2H), 7.91 – 7.86 (m, 4H), 7.80 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.52 – 7.46 (m, 3H), 7.43 – 7.38 (m, 2H), 7.37 – 7.34 (m, 3H), 7.34 – 7.27 (m, 18H), 7.22 (s, 1H), 5.87 (t, *J* = 9.5 Hz, 1H), 5.62 (t, *J* = 9.8 Hz, 1H), 5.46 (t, *J* = 9.8 Hz, 1H), 4.98 (d, *J* = 10.1 Hz, 1H), 4.93 (d, *J* = 10.9 Hz, 1H), 4.84 (d, *J* = 11.2 Hz, 1H), 4.75 (d, *J* = 5.7 Hz, 1H), 4.72 (d, *J* = 7.0 Hz, 1H), 4.61 (d, *J* = 12.2 Hz, 1H), 4.55 – 4.50 (m, 3H), 4.42 (dd, *J* = 12.2, 5.5 Hz, 1H), 4.01 (ddd, *J* = 9.2, 5.4, 3.2 Hz, 1H), 3.89 (t, *J* = 9.2 Hz, 1H), 3.77 (t, *J* = 8.2 Hz, 1H), 3.39 (dd, *J* = 9.6, 3.5 Hz, 1H), 3.18 (s, 3H), 3.02 (dd, *J* = 13.8, 2.6 Hz, 1H), 2.77 (dd, *J* = 13.8, 8.6 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 166.16, 165.97, 165.25, 165.18, 138.78, 138.16, 133.57, 133.26, 129.91, 129.88, 129.82, 129.80, 129.65, 129.13, 128.83, 128.64, 128.59, 128.53, 128.51, 128.46, 128.42, 128.16, 128.06, 128.01, 127.92, 127.74, 97.76, 84.46, 80.97, 79.92, 76.08, 75.73, 75.19, 73.35, 71.13, 69.75, 55.09.

HRMS (ESI): calc. for C₆₂H₅₈NaO₁₄S (*M*+Na): 1081.3445; found: 1081.3469.

Propargyl (2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-mannopyranoside (3.31)

- 1) Following the general procedure **D**, glycosyl acceptor **A15** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1b** (30.0 mg, 37.0 μ mol) to afford **3.31** (25.0 mg, 26.0 μ mol, 96% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A15** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1b** (50.0 mg, 63.0 μ mol) to afford **3.31** (22.0 mg, 19.7 μ mol, 80% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



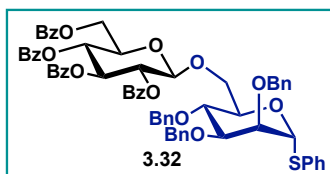
^1H NMR (399 MHz, CDCl_3) δ 8.00 (td, J = 7.8, 1.3 Hz, 3H), 7.93 (d, J = 1.1 Hz, 1H), 7.91 (d, J = 1.4 Hz, 2H), 7.89 (t, J = 1.7 Hz, 1H), 7.82 (dd, J = 8.3, 1.3 Hz, 2H), 7.59 – 7.50 (m, 3H), 7.49 (d, J = 2.1 Hz, 1H), 7.44 (dd, J = 7.2, 1.6 Hz, 2H), 7.41 (s, 1H), 7.41 – 7.39 (m, 1H), 7.37 (dd, J = 8.4, 2.0 Hz, 4H), 7.34 (s, 2H), 7.32 (d, J = 2.4 Hz, 3H), 7.30 (s, 3H), 7.29 – 7.28 (m, 4H), 7.18 (dd, J = 7.8, 1.8 Hz, 2H), 5.91 (t, J = 9.7 Hz, 1H), 5.68 (t, J = 9.7 Hz, 1H), 5.58 (dd, J = 9.8, 7.9 Hz, 1H), 4.93 (d, J = 7.9 Hz, 1H), 4.88 (d, J = 1.8 Hz, 1H), 4.72 (d, J = 11.1 Hz, 1H), 4.66 (s, 2H), 4.61 (dd, J = 12.1, 3.4 Hz, 1H), 4.52 (d, J = 11.9 Hz, 3H), 4.40 (d, J = 11.1 Hz, 1H), 4.21 – 4.12 (m, 2H), 3.89 (t, J = 2.2 Hz, 2H), 3.79 (dd, J = 9.0, 3.2 Hz, 2H), 3.75 (s, 2H), 3.70 – 3.66 (m, 1H), 2.32 (t, J = 2.4 Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.28, 165.97, 165.27, 165.15, 138.43, 138.32, 138.17, 133.53, 133.33, 133.20, 133.18, 129.97, 129.93, 129.86, 129.65, 129.41, 128.90, 128.87, 128.51, 128.46, 128.41, 128.02, 127.84, 127.80, 127.62, 127.60, 101.74, 96.06, 80.06, 78.87, 75.03, 74.89, 74.68, 74.13, 72.97, 72.77, 72.20, 72.06, 71.98, 71.91, 69.82, 69.43, 67.95, 63.23, 53.86.

HRMS (ESI): calc. for $\text{C}_{64}\text{H}_{58}\text{NaO}_{15}$ ($\text{M}+\text{Na}$): 1089.3673; found: 1089.3702.

Phenyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl-1-thio- α -D-mannopyranoside (3.32**)**

Following the general procedure **D**, glycosyl acceptor **A16** (14.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 37.0 μ mol) to afford **3.32** (28.0 mg, 25 μ mol, 98% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).

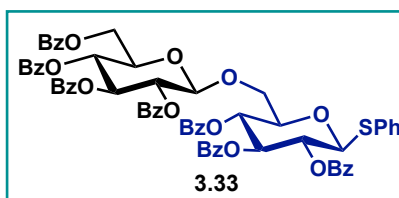


^1H NMR (399 MHz, CDCl_3) δ 7.99 (dd, J = 8.4, 1.3 Hz, 2H), 7.88 (td, J = 8.0, 1.3 Hz, 4H), 7.83 (dd, J = 8.4, 1.3 Hz, 2H), 7.52 – 7.47 (m, 2H), 7.44 – 7.39 (m, 4H), 7.35 (d, J = 8.0 Hz, 4H), 7.33 – 7.26 (m, 16H), 7.25 – 7.22 (m, 4H), 7.21 – 7.16 (m, 2H), 5.84 (t, J = 9.6 Hz, 1H), 5.65 – 5.57 (m, 3H), 4.87 (d, J = 7.8 Hz, 1H), 4.69 (d, J = 12.5 Hz, 1H), 4.61 (d, J = 10.9 Hz, 1H), 4.58 – 4.51 (m, 2H), 4.46 (s, 2H), 4.43 (dd, J = 12.0, 5.3 Hz, 1H), 4.38 (d, J = 11.2 Hz, 1H), 4.24 (dd, J = 9.4, 3.6 Hz, 1H), 4.16 – 4.11 (m, 1H), 4.05 – 4.00 (m, 1H), 3.96 – 3.90 (m, 2H), 3.84 (t, J = 9.5 Hz, 1H), 3.75 – 3.70 (m, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.25, 165.97, 165.23, 165.12, 138.45, 138.22, 137.99, 134.73, 133.14, 131.03, 129.95, 129.91, 129.88, 129.86, 129.50, 129.22, 128.94, 128.92, 128.50, 128.48, 128.46, 128.44, 128.42, 128.39, 128.35, 128.01, 127.77, 127.74, 127.69, 127.39, 101.30, 85.67, 75.92, 74.61, 73.09, 72.77, 72.22, 71.87, 71.76, 69.82, 63.32.

HRMS (ESI): calc. for $\text{C}_{67}\text{H}_{60}\text{NaO}_{14}\text{S}$ ($\text{M}+\text{Na}$): 1143.3601; found: 1143.3624.

Phenyl (2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl-1-thio- β -D-glucopyranoside (3.33)



- 1) Following the general procedure **D**, glycosyl acceptor **A25** (15.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (31.0 mg, 37.0 μmol) to afford **3.33** (27.0 mg, 24 μmol , 96% yield) as a white foam. R_f = 0.3 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A25** (15.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1b** (52.0 mg, 63.0 μmol) to afford **3.33** (26.0 mg, 22.4 μmol , 87% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.06 – 8.03 (m, 2H), 7.94 (s, 1H), 7.93 (d, J = 1.5 Hz, 2H), 7.92 – 7.89 (m, 3H), 7.83 (s, 2H), 7.82 (d, J = 1.6 Hz, 2H), 7.76 – 7.73 (m, 2H), 7.55 (d, J = 7.3 Hz, 1H), 7.53 (s, 1H), 7.50 (s, 1H), 7.48 (s, 2H), 7.47 (d, J = 3.8 Hz, 2H), 7.43 (d, J = 1.6 Hz, 2H), 7.41 (s, 2H), 7.39 – 7.35 (m, 8H), 7.34 (s, 2H), 7.33 – 7.30 (m, 3H), 7.29 (s, 1H), 7.27 (s, 2H),

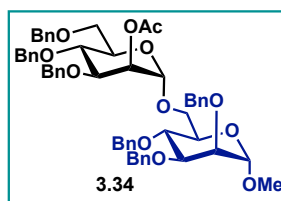
5.81 (dt, $J = 12.6, 9.5$ Hz, 2H), 5.60 (t, $J = 9.7$ Hz, 1H), 5.49 (dd, $J = 9.6, 8.0$ Hz, 1H), 5.35 (t, $J = 9.7$ Hz, 1H), 5.25 (t, $J = 9.8$ Hz, 1H), 4.93 (dd, $J = 20.6, 8.9$ Hz, 2H), 4.59 (dd, $J = 12.3, 2.9$ Hz, 1H), 4.39 (dd, $J = 12.2, 5.2$ Hz, 1H), 4.06 – 4.00 (m, 2H), 3.95 (d, $J = 6.7$ Hz, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.20, 165.89, 165.74, 165.43, 165.30, 165.27, 165.11, 133.60, 133.42, 133.29, 133.09, 131.84, 129.98, 129.95, 129.93, 129.91, 129.86, 129.81, 129.61, 129.32, 129.28, 129.26, 128.92, 128.87, 128.70, 128.62, 128.58, 128.54, 128.49, 128.44, 128.41, 128.35, 101.09, 85.94, 78.59, 74.10, 72.99, 72.34, 71.92, 70.56, 69.68, 69.60, 62.94. The data are identical to the literature report.^[87]

3.4.5.2. Scope of glycosyl acceptors with superarmed MDMPA thioglycoside donor under $\text{Fe}(\text{OTf})_3$ or Blue LED conditions.

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (3.34)

Following the general procedure **E**, glycosyl acceptor **A9** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1e** (36.0 mg, 50.0 μmol) to afford **3.34** (20.5 mg, 22.0 μmol , 84% yield) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).

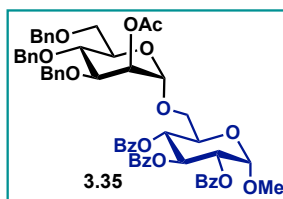


^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.36 (m, 2H), 7.34 – 7.27 (m, 24H), 7.24 – 7.22 (m, 5H), 7.16 – 7.11 (m, 4H), 5.48 – 5.45 (m, 1H), 4.96 (d, $J = 2.1$ Hz, 1H), 4.91 (d, $J = 11.2$ Hz, 1H), 4.86 (dd, $J = 10.9, 3.4$ Hz, 2H), 4.73 – 4.70 (m, 4H), 4.67 – 4.65 (m, 1H), 4.64 (d, $J = 3.9$ Hz, 2H), 4.59 (d, $J = 1.2$ Hz, 2H), 4.55 (d, $J = 6.9$ Hz, 1H), 4.50 (d, $J = 3.6$ Hz, 1H), 4.48 – 4.46 (m, 2H), 4.44 (d, $J = 4.3$ Hz, 2H), 3.96 (dd, $J = 9.2, 3.2$ Hz, 1H), 3.91 (d, $J = 9.4$ Hz, 1H), 3.87 (t, $J = 2.3$ Hz, 2H), 3.80 – 3.77 (m, 3H), 3.72 (d, $J = 5.2$ Hz, 1H), 3.70 (t, $J = 3.3$ Hz, 2H), 3.67 (s, 1H), 3.59 (dd, $J = 10.8, 1.9$ Hz, 1H), 3.25 (s, 3H), 2.14 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 170.28, 138.59, 138.45, 138.42, 138.30, 138.28, 137.82, 128.38, 128.35, 128.32, 128.30, 128.28, 128.23, 128.19, 128.06, 127.92, 127.86, 127.81, 127.76, 127.72, 127.62, 127.60, 127.53, 127.48, 127.43, 98.69, 97.94, 80.25, 77.56, 75.12, 74.99, 74.94, 74.59, 74.53, 74.47, 74.18, 73.48, 73.32, 72.58, 71.97, 71.79, 71.39, 71.35, 71.31, 70.90, 69.18, 68.90, 68.72, 68.52, 66.70, 54.64, 21.12. The data are identical to the literature report.^[105]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.35)

Following the general procedure **E**, glycosyl acceptor **A11** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1e** (36.0 mg, 50.0 μ mol) to afford **3.35** (22.0 mg, 22.0 μ mol, 88% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

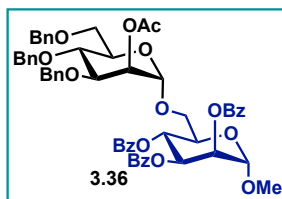


^1H NMR (400 MHz, CDCl_3) δ 7.98 (dd, J = 8.5, 1.3 Hz, 2H), 7.94 (dd, J = 8.5, 1.3 Hz, 2H), 7.87 (dd, J = 8.4, 1.4 Hz, 2H), 7.50 (ddt, J = 14.1, 7.1, 1.3 Hz, 2H), 7.46 – 7.41 (m, 2H), 7.41 – 7.35 (m, 3H), 7.33 – 7.27 (m, 15H), 7.16 (dd, J = 7.4, 2.1 Hz, 2H), 6.13 (t, J = 9.9 Hz, 1H), 5.56 (t, J = 9.9 Hz, 1H), 5.33 (dd, J = 3.3, 1.8 Hz, 1H), 5.26 (dd, J = 10.2, 3.7 Hz, 1H), 5.19 (d, J = 3.7 Hz, 1H), 4.87 – 4.83 (m, 2H), 4.60 (d, J = 2.2 Hz, 1H), 4.57 (s, 1H), 4.46 (d, J = 7.3 Hz, 1H), 4.43 (d, J = 7.7 Hz, 1H), 4.38 (d, J = 12.0 Hz, 1H), 4.20 (ddd, J = 10.2, 5.4, 3.2 Hz, 1H), 3.94 (dd, J = 9.3, 3.4 Hz, 1H), 3.91 – 3.86 (m, 1H), 3.84 (d, J = 9.5 Hz, 1H), 3.74 – 3.69 (m, 1H), 3.69 – 3.65 (m, 1H), 3.63 (dd, J = 11.6, 3.7 Hz, 1H), 3.53 (dd, J = 10.7, 1.9 Hz, 1H), 3.39 (s, 3H), 2.13 (s, 3H)

^{13}C NMR (101 MHz, CDCl_3) δ 170.30, 165.79, 165.15, 138.56, 138.18, 137.97, 133.31, 133.03, 129.92, 129.67, 129.24, 129.07, 128.94, 128.40, 128.38, 128.32, 128.25, 128.22, 128.12, 127.79, 127.71, 127.66, 127.50, 127.48, 97.88, 77.84, 77.21, 75.01, 74.15, 73.30, 72.09, 71.73, 71.45, 70.48, 69.64, 68.65, 68.60, 68.05, 66.30, 55.49, 21.09. The data are identical to the literature report.^[105]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.36)

- 1) Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1e** (27.0 mg, 37.0 μ mol) to afford **3.36** (23.0 mg, 22.0 μ mol, 91% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **E**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1e** (36.0 mg, 50.0 μ mol) to afford **3.36** (22.5 mg, 22.0 μ mol, 90% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

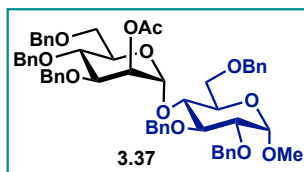


^1H NMR (400 MHz, CDCl_3) δ 8.08 (d, J = 7.7 Hz, 2H), 7.96 (d, J = 7.9 Hz, 2H), 7.82 (d, J = 7.6 Hz, 2H), 7.57 – 7.52 (m, 1H), 7.44 (dt, J = 15.1, 7.8 Hz, 4H), 7.30 (dd, J = 19.6, 5.3 Hz, 18H), 7.17 – 7.11 (m, 2H), 5.91 – 5.83 (m, 2H), 5.65 (s, 1H), 5.34 (s, 1H), 4.91 (d, J = 16.7 Hz, 2H), 4.83 (d, J = 11.1 Hz, 1H), 4.58 (d, J = 12.2 Hz, 1H), 4.49 (d, J = 11.2 Hz, 1H), 4.43 (d, J = 11.0 Hz, 1H), 4.35 (dd, J = 17.8, 11.8 Hz, 2H), 4.24 – 4.17 (m, 1H), 3.93 (dd, J = 10.6, 2.4 Hz, 2H), 3.86 (t, J = 9.5 Hz, 1H), 3.74 (d, J = 12.8 Hz, 1H), 3.68 (d, J = 10.7 Hz, 2H), 3.54 (d, J = 11.2 Hz, 1H), 3.45 (s, 3H), 2.12 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 170.33, 165.51, 165.45, 165.39, 138.49, 138.09, 137.89, 133.50, 133.35, 133.11, 129.88, 129.85, 129.72, 129.34, 129.08, 129.00, 128.61, 128.45, 128.41, 128.34, 128.26, 128.23, 128.10, 128.04, 127.96, 127.89, 127.82, 127.78, 127.75, 127.67, 127.53, 98.49, 97.87, 78.11, 75.07, 74.07, 73.29, 71.62, 71.43, 70.49, 69.98, 68.51, 68.46, 67.46, 66.69, 55.40, 21.12. The data are identical to the literature report.^[105]

Methyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzyl- α -D-glucopyranoside (3.37)

- 1) Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1e** (26.0 mg, 37.0 μmol) to afford **3.37** (21.0 mg, 22.0 μmol , 87% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **E**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1e** (36.0 mg, 50.0 μmol) to afford **3.37** (19.0 mg, 20.0 μmol , 78% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



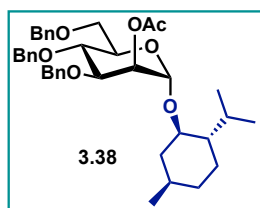
^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.34 (m, 1H), 7.33 (d, J = 1.9 Hz, 3H), 7.31 – 7.26 (m, 21H), 7.25 – 7.19 (m, 3H), 7.16 – 7.13 (m, 2H), 5.48 – 5.44 (m, 1H), 5.42 (d, J = 2.2 Hz, 1H), 5.04 (d, J = 11.2 Hz, 1H), 4.81 (d, J = 10.8 Hz, 1H), 4.76 – 4.72 (m, 1H), 4.67 (d, J = 18.7 Hz, 1H), 4.62 (d, J = 2.8 Hz, 1H), 4.59 (d, J = 2.3 Hz, 2H), 4.54 (d, J = 11.8 Hz, 2H), 4.48 – 4.41 (m, 3H), 4.41

– 4.34 (m, 2H), 3.93 (t, $J = 9.1$ Hz, 1H), 3.88 – 3.85 (m, 1H), 3.85 – 3.80 (m, 2H), 3.72 (s, 1H), 3.69 (t, $J = 4.2$ Hz, 2H), 3.67 – 3.63 (m, 1H), 3.54 (dd, $J = 9.5, 3.5$ Hz, 1H), 3.50 (dd, $J = 10.8, 1.9$ Hz, 1H), 3.38 (s, 3H), 1.98 (s, 3H).

^{13}C NMR (101 MHz, CDCl_3) δ 169.85, 138.52, 138.45, 138.20, 137.97, 137.92, 128.44, 128.30, 128.24, 128.20, 128.14, 128.05, 127.93, 127.88, 127.82, 127.61, 127.56, 127.53, 127.40, 127.27, 127.25, 99.30, 97.76, 81.74, 80.05, 78.20, 77.22, 75.71, 75.13, 75.09, 74.02, 73.44, 73.27, 72.41, 71.67, 69.57, 69.20, 68.72, 55.28, 20.95. The data are identical to the literature report.^[105]

D-Menthyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranoside (3.38)

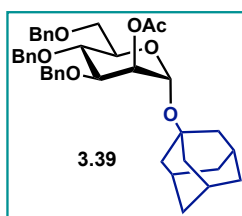
Following the general procedure **E**, glycosyl acceptor **A5** (6.0 mg, 38.0 μmol) was coupled with MDMPAT donor **3.1e** (40.0 mg, 58.0 μmol) to afford **3.38** (22.5 mg, 36.0 μmol , 93% yield) as a colorless viscous oil. $R_f = 0.6$ (hexane: EtOAc = 70:30).



^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.26 (m, 13H), 7.18 (dd, $J = 7.4, 2.1$ Hz, 2H), 5.26 (dd, $J = 3.3, 1.9$ Hz, 1H), 4.94 – 4.86 (m, 2H), 4.71 (dd, $J = 11.7, 6.6$ Hz, 2H), 4.58 (d, $J = 11.3$ Hz, 1H), 4.50 (dd, $J = 11.4, 10.0$ Hz, 2H), 4.02 – 3.95 (m, 2H), 3.91 – 3.80 (m, 2H), 3.71 (dd, $J = 10.6, 1.9$ Hz, 1H), 3.35 (td, $J = 10.6, 4.3$ Hz, 1H), 2.16 (s, 3H), 2.05 (pd, $J = 7.0, 2.5$ Hz, 1H), 1.66 – 1.57 (m, 2H), 1.41 – 1.31 (m, 1H), 1.24 – 1.15 (m, 1H), 1.03 – 0.90 (m, 5H), 0.85 (d, $J = 6.5$ Hz, 3H), 0.78 (d, $J = 7.0$ Hz, 4H).

^{13}C NMR (101 MHz, CDCl_3) δ 170.58, 138.40, 138.31, 137.98, 128.37, 128.32, 128.25, 128.08, 127.92, 127.72, 127.70, 127.62, 127.50, 99.27, 81.63, 77.97, 75.19, 74.62, 73.36, 71.76, 71.41, 69.34, 69.05, 48.55, 42.71, 34.26, 31.58, 25.84, 23.30, 22.20, 21.20, 21.02, 16.31. The data are identical to the literature report.^[111]

Adamantanyl 2-O-acetyl-3,4,6-tri-O-benzyl- α -D-mannopyranoside (3.39)



Following the general procedure **E**, glycosyl acceptor **A7** (6.0 mg, 39.0 μmol) was coupled with MDMPAT donor **3.1e** (41.0 mg, 59.0 μmol) to afford **3.39** (22.0 mg, 35.0 μmol , 89% yield) as a colorless viscous oil. R_f = 0.7 (hexane: EtOAc = 70:30).

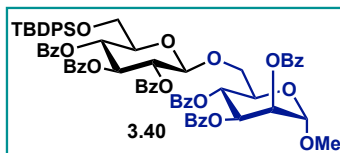
^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.26 (m, 12H), 7.17 (dd, J = 7.4, 2.1 Hz, 2H), 5.27 (d, J = 2.1 Hz, 1H), 5.18 (dd, J = 3.3, 2.0 Hz, 1H), 4.86 (d, J = 10.6 Hz, 1H), 4.73 – 4.68 (m, 2H), 4.55 (d, J = 11.1 Hz, 1H), 4.48 (dd, J = 11.3, 4.4 Hz, 2H), 4.08 – 3.99 (m, 2H), 3.90 (t, J = 9.6 Hz, 1H), 3.83 (dd, J = 10.6, 4.2 Hz, 1H), 3.68 (dd, J = 10.6, 2.0 Hz, 1H), 2.15 (s, 3H), 2.14 – 2.10 (m, 3H), 1.79 (d, J = 2.0 Hz, 6H), 1.64 – 1.55 (m, 6H).

^{13}C NMR (101 MHz, CDCl_3) δ 170.75, 138.46, 138.35, 138.11, 128.35, 128.30, 128.22, 128.06, 127.94, 127.69, 127.65, 127.59, 127.46, 90.95, 78.24, 75.20, 75.03, 74.68, 73.36, 71.71, 70.91, 70.44, 69.07, 42.28, 36.20, 30.59, 21.24. The data are identical to the literature report.^[105]

3.4.5.3. Scope of MDMPA thioglycoside donor under $\text{Fe}(\text{OTf})_3$ or Blue LED conditions.

Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-tert-butyldiphenylsilyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-mannopyranoside (**3.40**).

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1c** (36.0 mg, 39.0 μmol) to afford **3.40** (29.5 mg, 24.0 μmol , 94% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

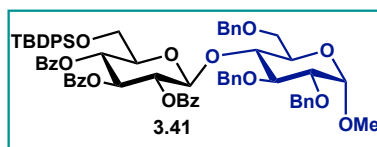


^1H NMR (399 MHz, CDCl_3) δ 8.07 (dd, J = 7.8, 1.4 Hz, 2H), 7.95 – 7.91 (m, 4H), 7.84 (td, J = 8.5, 1.1 Hz, 4H), 7.79 – 7.76 (m, 2H), 7.65 – 7.59 (m, 3H), 7.54 – 7.46 (m, 7H), 7.45 – 7.40 (m, 2H), 7.39 – 7.33 (m, 5H), 7.31 (s, 1H), 7.30 (s, 1H), 7.27 (s, 1H), 7.26 – 7.18 (m, 6H), 7.14 (t, J = 7.6 Hz, 2H), 5.86 – 5.77 (m, 2H), 5.66 (td, J = 9.5, 5.0 Hz, 2H), 5.57 – 5.51 (m, 2H), 4.93 (dd, J = 7.9, 0.9 Hz, 1H), 4.62 (s, 1H), 4.28 (t, J = 9.4 Hz, 1H), 4.19 (d, J = 11.0 Hz, 1H), 3.82 (d, J = 8.9 Hz, 4H), 3.05 (s, 3H), 0.97 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.04, 165.70, 165.62, 165.42, 165.31, 165.05, 135.65, 135.56, 133.60, 133.32, 133.23, 133.20, 133.01, 130.02, 129.98, 129.93, 129.89, 129.86, 129.78, 129.69, 129.66, 129.56, 129.45, 129.28, 129.18, 129.03, 128.92, 128.71, 128.58, 128.46, 128.37, 128.34, 128.32, 127.66, 101.93, 97.99, 75.19, 73.34, 72.11, 70.60, 70.04, 69.84, 69.43, 69.15, 67.36, 62.52, 54.85, 26.60, 19.15.

HRMS (ESI): calc. for $\text{C}_{71}\text{H}_{66}\text{NaO}_{17}\text{Si}$ ($\text{M}+\text{Na}$): 1241.3967; found: 1241.3996.

Methyl 2,3,4-tri-O-benzoyl-6-O-tert-butyldiphenylsilyl- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzyl- α -D-glucopyranoside (3.41)



Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1c** (36.0 mg, 38.0 μ mol) to afford **3.41** (27.5 mg, 23.0 μ mol, 90% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

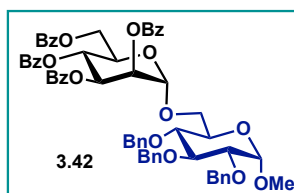
^1H NMR (399 MHz, CDCl_3) δ 7.87 – 7.83 (m, 4H), 7.82 – 7.78 (m, 2H), 7.69 (dd, J = 7.4, 1.8 Hz, 2H), 7.56 – 7.49 (m, 5H), 7.47 – 7.43 (m, 3H), 7.41 (t, J = 1.5 Hz, 1H), 7.40 – 7.31 (m, 13H), 7.28 (d, J = 8.2 Hz, 3H), 7.25 – 7.17 (m, 5H), 7.14 (t, J = 7.3 Hz, 2H), 5.56 – 5.48 (m, 2H), 5.39 (t, J = 8.9 Hz, 1H), 5.01 (d, J = 12.1 Hz, 1H), 4.85 (d, J = 12.0 Hz, 1H), 4.78 – 4.66 (m, 3H), 4.61 (d, J = 12.3 Hz, 1H), 4.55 (d, J = 3.7 Hz, 1H), 4.30 (d, J = 12.0 Hz, 1H), 3.98 (t, J = 9.4 Hz, 1H), 3.88 (t, J = 9.2 Hz, 1H), 3.69 (t, J = 3.8 Hz, 2H), 3.64 (dd, J = 10.5, 3.0 Hz, 1H), 3.54 (d, J = 9.9 Hz, 1H), 3.49 – 3.42 (m, 3H), 3.29 (s, 3H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.93, 165.12, 164.91, 139.57, 138.42, 137.82, 135.73, 135.60, 133.31, 133.28, 133.17, 133.15, 133.06, 129.86, 129.82, 129.73, 129.65, 129.14, 128.86, 128.54, 128.48, 128.45, 128.35, 128.26, 128.09, 127.88, 127.84, 127.72, 127.65, 127.06, 100.14, 98.66, 79.89, 78.62, 69.72, 69.55, 67.88, 62.87, 55.39, 26.75, 19.19.

HRMS (ESI): calc. for $\text{C}_{71}\text{H}_{72}\text{NaO}_{14}\text{Si}$ ($\text{M}+\text{Na}$): 1199.4589; found: 1199.4623.

Methyl 2,3,4,6-tetra-O-benzoyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.42).

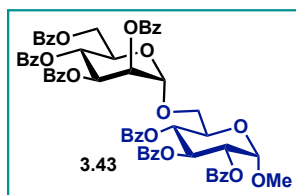
- Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1f** (31.0 mg, 38.0 μ mol) to afford **3.42** (25.5 mg, 25.0 μ mol, 95% yield) as a white viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).
- Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1f** (52.0 mg, 63.0 μ mol) to afford **3.42** (24.0 mg, 23.0 μ mol, 90% yield) as a white viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 8.08 (dd, $J = 8.3, 1.4$ Hz, 2H), 8.04 (dd, $J = 8.4, 1.4$ Hz, 2H), 7.90 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.82 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.61 – 7.55 (m, 2H), 7.51 (t, $J = 7.4$ Hz, 1H), 7.44 (d, $J = 7.4$ Hz, 1H), 7.42 – 7.35 (m, 11H), 7.34 (s, 2H), 7.33 – 7.29 (m, 7H), 7.28 (d, $J = 1.8$ Hz, 1H), 7.27 (s, 1H), 6.07 (t, $J = 10.1$ Hz, 1H), 5.87 (dd, $J = 10.1, 3.3$ Hz, 1H), 5.73 (dd, $J = 3.4, 1.8$ Hz, 1H), 5.15 (d, $J = 1.8$ Hz, 1H), 5.02 (dd, $J = 11.1, 2.4$ Hz, 2H), 4.84 – 4.78 (m, 2H), 4.69 (dd, $J = 11.7, 3.2$ Hz, 2H), 4.65 – 4.60 (m, 2H), 4.39 (dd, $J = 10.0, 2.3$ Hz, 1H), 4.33 (dd, $J = 12.1, 4.3$ Hz, 1H), 4.03 (t, $J = 9.2$ Hz, 1H), 3.94 (dd, $J = 11.0, 5.0$ Hz, 1H), 3.86 (dd, $J = 10.3, 5.1$ Hz, 1H), 3.80 (dd, $J = 10.9, 1.7$ Hz, 1H), 3.60 – 3.49 (m, 2H), 3.45 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.22, 165.54, 165.36, 138.81, 138.28, 138.25, 133.55, 133.27, 133.17, 130.01, 129.95, 129.84, 129.82, 129.42, 129.18, 129.06, 128.67, 128.61, 128.56, 128.52, 128.42, 128.23, 128.08, 128.00, 127.89, 127.73, 127.71, 98.00, 97.83, 82.22, 80.28, 77.79, 77.33, 75.84, 75.14, 73.57, 70.32, 70.05, 69.94, 68.96, 66.92, 66.72, 62.76, 55.34. The data are identical to the literature report.^[99]

Methyl 2,3,4,6-tetra-*O*-benzoyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (3.43)



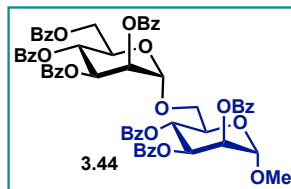
Following the general procedure **D**, glycosyl acceptor **A11** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1f** (31.0 mg, 38.0 μmol) to afford **3.43** (26.0 mg, 24.0 μmol , 94% yield) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.10 – 7.95 (m, 10H), 7.93 – 7.89 (m, 2H), 7.86 – 7.82 (m, 2H), 7.59 (d, $J = 2.7$ Hz, 2H), 7.51 (d, $J = 7.4$ Hz, 2H), 7.48 – 7.36 (m, 12H), 7.31 (td, $J = 7.7, 3.0$ Hz, 5H), 6.18 (t, $J = 9.8$ Hz, 1H), 6.06 (t, $J = 10.0$ Hz, 1H), 5.96 (dd, $J = 10.1, 3.3$ Hz, 1H), 5.74 (dd, $J = 3.3, 1.8$ Hz, 1H), 5.55 (t, $J = 9.9$ Hz, 1H), 5.31 (d, $J = 3.7$ Hz, 1H), 5.23 (dd, $J = 10.2, 3.7$ Hz, 1H), 5.12 (d, $J = 1.7$ Hz, 1H), 4.59 (dd, $J = 12.2, 2.2$ Hz, 1H), 4.50 (ddd, $J = 10.3, 5.0, 2.3$ Hz, 1H), 4.34 (dt, $J = 9.8, 6.0$ Hz, 2H), 4.06 (dd, $J = 10.8, 6.2$ Hz, 1H), 3.75 (dd, $J = 10.6, 2.1$ Hz, 1H), 3.59 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.17, 165.91, 165.85, 165.63, 165.51, 165.49, 165.42, 133.65, 133.57, 133.46, 133.26, 133.22, 133.15, 130.07, 129.99, 129.96, 129.94, 129.86, 129.84, 129.35, 129.31, 129.20, 129.11, 128.82, 128.68, 128.61, 128.59, 128.53, 128.41, 97.51, 96.99,

72.20, 70.58, 70.38, 70.06, 69.37, 69.02, 68.34, 66.86, 66.49, 62.75, 55.75. The data are identical to the literature report.^[112]

Methyl 2,3,4,6-tetra-O-benzoyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.44)



Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1f** (31.0 mg, 38.0 μ mol) to afford **3.44** (27.0 mg, 25.0 μ mol, 98% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

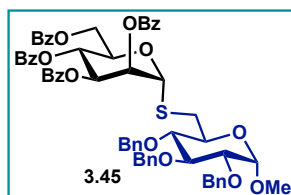
^1H NMR (399 MHz, CDCl_3) δ 8.15 (dd, J = 8.2, 1.6 Hz, 2H), 8.03 – 7.95 (m, 8H), 7.85 (ddd, J = 8.5, 4.9, 1.3 Hz, 4H), 7.58 – 7.48 (m, 6H), 7.45 – 7.33 (m, 10H), 7.30 – 7.26 (m, 5H), 6.08 (dt, J = 20.0, 10.1 Hz, 2H), 6.00 (dd, J = 10.1, 3.3 Hz, 1H), 5.92 (dd, J = 10.1, 3.4 Hz, 1H), 5.78 (dd, J = 3.3, 1.8 Hz, 1H), 5.74 (dd, J = 3.4, 1.7 Hz, 1H), 5.15 (d, J = 1.8 Hz, 1H), 5.02 (d, J = 1.7 Hz, 1H), 4.50 (dd, J = 12.2, 2.4 Hz, 1H), 4.44 – 4.35 (m, 2H), 4.29 (dd, J = 12.2, 4.2 Hz, 1H), 4.13 (dd, J = 10.8, 5.4 Hz, 1H), 3.78 (dd, J = 10.8, 2.1 Hz, 1H), 3.62 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.16, 165.80, 165.65, 165.63, 165.57, 165.37, 165.35, 133.63, 133.56, 133.25, 133.22, 133.12, 130.13, 129.97, 129.94, 129.86, 129.82, 129.79, 129.36, 129.32, 129.20, 129.13, 128.98, 128.87, 128.66, 128.61, 128.56, 128.53, 128.43, 128.40, 98.93, 97.78, 70.56, 70.32, 70.24, 70.13, 69.52, 68.97, 67.01, 66.78, 66.68, 62.64, 55.69.

HRMS (ESI): calc. for $\text{C}_{62}\text{H}_{52}\text{NaO}_{18}$ ($\text{M}+\text{Na}$): 1107.3051; found: 1107.3098.

Methyl 2,3,4,6-tetra-O-benzoyl- α -D-mannopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl-6-thio- α -D-glucopyranoside (3.45)

Following the general procedure **D**, glycosyl acceptor **A24** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1f** (30.0 mg, 37.0 μ mol) to afford **3.45** (26.0 mg, 15.0 μ mol, 60% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).

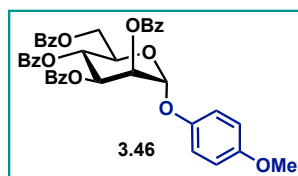


¹H NMR (399 MHz, CDCl₃) δ 8.07 (dd, *J* = 9.1, 7.5 Hz, 4H), 7.95 (d, *J* = 7.3 Hz, 2H), 7.83 (d, *J* = 7.3 Hz, 2H), 7.63 – 7.49 (m, 4H), 7.43 (dd, *J* = 8.9, 7.0 Hz, 4H), 7.40 – 7.34 (m, 9H), 7.34 – 7.28 (m, 8H), 7.25 (s, 2H), 6.14 (t, *J* = 9.7 Hz, 1H), 5.83 (d, *J* = 8.6 Hz, 2H), 5.64 (s, 1H), 5.00 (d, *J* = 10.9 Hz, 1H), 4.91 (d, *J* = 11.0 Hz, 1H), 4.78 (ddd, *J* = 14.7, 10.5, 4.3 Hz, 3H), 4.67 (d, *J* = 12.1 Hz, 1H), 4.63 – 4.56 (m, 3H), 4.48 (dd, *J* = 12.3, 4.2 Hz, 1H), 4.00 (t, *J* = 9.2 Hz, 1H), 3.89 (ddd, *J* = 9.9, 6.9, 2.8 Hz, 1H), 3.59 (dd, *J* = 9.6, 3.5 Hz, 1H), 3.55 – 3.48 (m, 1H), 3.38 (s, 3H), 3.10 (dd, *J* = 13.8, 2.7 Hz, 1H), 2.83 (dd, *J* = 13.8, 6.8 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 166.21, 165.57, 165.54, 165.33, 138.85, 138.26, 138.11, 130.01, 129.98, 129.96, 129.89, 129.85, 129.51, 129.06, 129.03, 128.74, 128.65, 128.61, 128.55, 128.48, 128.29, 128.07, 128.05, 128.03, 127.75, 98.03, 83.00, 81.97, 80.31, 80.10, 75.81, 75.41, 73.60, 71.99, 70.53, 69.96, 69.52, 67.08, 62.93, 55.48.

HRMS (ESI): calc. for C₆₂H₅₈NaO₁₄S (*M*+Na): 1081.3445; found: 1081.3466.

4-Methoxyphenyl 2',3',4',6'-tetra-*O*-benzoyl- α -D-mannopyranoside (3.46)



Following the general procedure **D**, glycosyl acceptor **A6** (5.0 mg, 40.0 μmol) was coupled with MDMPAT donor **3.1f** (42.0 mg, 52.0 μmol) to afford **3.46** (25.5 mg, 36.5 μmol, 91% yield) as a colorless viscous oil. *R*_f = 0.6 (hexane: EtOAc = 70:30).

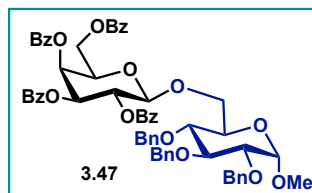
¹H NMR (399 MHz, CDCl₃) δ 8.11 – 8.07 (m, 2H), 8.05 – 8.00 (m, 2H), 8.00 – 7.95 (m, 2H), 7.90 – 7.85 (m, 2H), 7.65 – 7.56 (m, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.48 – 7.35 (m, 8H), 7.29 (t, *J* = 7.9 Hz, 2H), 7.15 (d, *J* = 9.1 Hz, 2H), 6.81 (d, *J* = 9.0 Hz, 2H), 6.14 (d, *J* = 8.2 Hz, 2H), 5.90 (t, *J* = 1.5 Hz, 1H), 5.70 (d, *J* = 2.3 Hz, 1H), 4.67 – 4.58 (m, 2H), 4.49 (dd, *J* = 11.8, 5.0 Hz, 1H), 3.77 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 166.21, 165.66, 165.60, 165.51, 155.50, 149.88, 133.73, 133.65, 133.40, 133.19, 129.95, 129.89, 129.25, 128.76, 128.59, 128.50, 128.47, 117.99, 114.77, 96.69, 70.45, 70.01, 69.46, 66.90, 62.97, 55.71.

HRMS (ESI): calc. for C₄₁H₃₄NaO₁₁ (*M*+Na): 725.1999; found: 725.2011.

Methyl (2,3,4,6-tetra-*O*-benzoyl- β -D-galactopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.47).

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1j** (31 mg, 38.0 μmol) to afford **3.47** (24.0 mg, 23.0 μmol , 89% yield) as a white viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1j** (52.0 mg, 63.0 μmol) to afford **3.47** (20.0 mg, 19.0 μmol , 74% yield) as a white viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).



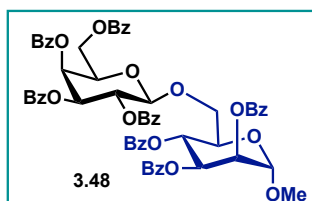
^1H NMR (500 MHz, CDCl_3) δ 8.09 – 8.07 (m, 2H), 8.03 – 8.00 (m, 2H), 7.88 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.76 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.64 – 7.60 (m, 1H), 7.57 – 7.53 (m, 1H), 7.48 (dd, $J = 8.2, 7.4$ Hz, 2H), 7.44 – 7.38 (m, 4H), 7.33 – 7.26 (m, 11H), 7.25 – 7.20 (m, 6H), 7.11 (dd, $J = 7.8, 1.8$ Hz, 2H), 5.96 (dd, $J = 3.6, 1.2$ Hz, 1H), 5.84 (dd, $J = 10.4, 8.0$ Hz, 1H), 5.58 (dd, $J = 10.4, 3.5$ Hz, 1H), 4.89 (d, $J = 10.9$ Hz, 1H), 4.76 – 4.64 (m, 4H), 4.56 (dd, $J = 13.6, 11.6$ Hz, 2H), 4.49 (d, $J = 3.5$ Hz, 1H), 4.41 – 4.35 (m, 2H), 4.26 – 4.19 (m, 2H), 3.89 (dd, $J = 9.6, 8.9$ Hz, 1H), 3.77 – 3.73 (m, 2H), 3.41 – 3.34 (m, 2H), 3.20 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3) δ 166.13, 165.73, 165.68, 165.23, 138.86, 138.29, 138.23, 133.70, 133.41, 133.26, 130.16, 129.87, 129.79, 129.48, 129.33, 129.09, 128.78, 128.71, 128.58, 128.54, 128.51, 128.47, 128.39, 128.20, 128.00, 127.98, 127.81, 127.65, 127.60, 102.10, 97.97, 82.00, 79.89, 77.52, 75.63, 74.81, 73.46, 71.70, 71.42, 69.78, 69.66, 68.76, 68.15, 61.94, 55.10.

The data are identical to the literature report.^[87]

Methyl (2,3,4,6-tetra-O-benzoyl- β -D-galactopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.48)

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1g** (31.0 mg, 38.0 μmol) to afford **3.48** (24.0 mg, 22.2 μmol , 93% yield) as a viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).



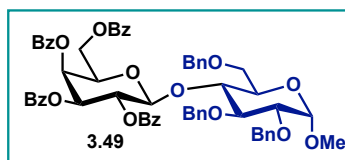
¹H NMR (500 MHz, CDCl₃) δ 8.08 – 8.04 (m, 4H), 8.00 (dd, *J* = 8.3, 1.5 Hz, 2H), 7.92 (ddd, *J* = 18.2, 8.3, 1.4 Hz, 4H), 7.80 – 7.75 (m, 4H), 7.64 – 7.58 (m, 2H), 7.52 – 7.49 (m, 3H), 7.48 (d, *J* = 5.6 Hz, 1H), 7.46 – 7.39 (m, 8H), 7.36 (t, *J* = 7.9 Hz, 2H), 7.30 (t, *J* = 7.8 Hz, 2H), 7.25 – 7.22 (m, 3H), 5.98 (dd, *J* = 3.5, 1.3 Hz, 1H), 5.86 – 5.80 (m, 2H), 5.68 – 5.63 (m, 1H), 5.62 – 5.59 (m, 1H), 5.53 (dd, *J* = 3.5, 1.8 Hz, 1H), 4.95 (d, *J* = 8.0 Hz, 1H), 4.62 (dd, *J* = 11.2, 6.3 Hz, 1H), 4.58 (d, *J* = 1.8 Hz, 1H), 4.38 (dd, *J* = 11.2, 7.0 Hz, 1H), 4.34 – 4.30 (m, 1H), 4.21 (dd, *J* = 11.1, 1.8 Hz, 1H), 3.90 – 3.83 (m, 1H), 3.52 (s, 1H), 3.10 (s, 3H).

¹³C NMR (126 MHz, CDCl₃) δ 166.11, 165.82, 165.67, 165.60, 165.57, 165.45, 165.41, 133.68, 133.62, 133.42, 133.31, 133.23, 130.11, 130.03, 130.02, 130.00, 129.92, 129.88, 129.81, 129.78, 129.49, 129.42, 129.17, 129.07, 128.90, 128.81, 128.75, 128.71, 128.63, 128.61, 128.57, 128.39, 128.35, 102.54, 98.01, 68.05, 67.45, 67.35, 61.81, 55.62, 54.92.

LRMS (ESI): calc. for C₆₂H₅₃NaO₁₈ (M+H): 1085.3; found: 1085.3.

Methyl (2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (3.49)

Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1g** (31.0 mg, 38.0 μmol) to afford **3.49** (23.0 mg, 22.0 μmol, 85% yield) as a colorless viscous oil. *R*_f = 0.4 (hexane: EtOAc = 70:30).



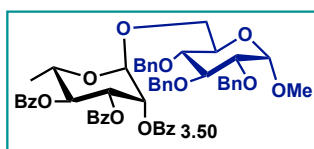
¹H NMR (399 MHz, CDCl₃) δ 8.03 – 8.00 (m, 2H), 7.95 – 7.92 (m, 2H), 7.86 – 7.82 (m, 2H), 7.77 – 7.74 (m, 2H), 7.57 – 7.51 (m, 3H), 7.48 – 7.44 (m, 5H), 7.42 (s, 1H), 7.40 (d, *J* = 3.1 Hz, 2H), 7.38 (dd, *J* = 5.4, 2.6 Hz, 4H), 7.37 (s, 2H), 7.31 – 7.27 (m, 4H), 7.26 – 7.20 (m, 5H), 7.17 (d, *J* = 7.2 Hz, 1H), 5.84 (d, *J* = 3.5 Hz, 1H), 5.69 (dd, *J* = 10.4, 8.0 Hz, 1H), 5.29 (dd, *J* = 10.4, 3.5 Hz, 1H), 5.17 (d, *J* = 11.1 Hz, 1H), 4.90 (d, *J* = 11.1 Hz, 1H), 4.81 – 4.74 (m, 3H), 4.64 (d, *J* = 12.4 Hz, 1H), 4.57 (d, *J* = 3.7 Hz, 1H), 4.39 (dd, *J* = 11.2, 6.2 Hz, 1H), 4.31 (d, *J* = 12.2 Hz, 1H), 4.17 (dd, *J* = 11.2, 7.6 Hz, 1H), 4.02 (t, *J* = 9.5 Hz, 1H), 3.93 – 3.89 (m, 2H), 3.69 (dd, *J* = 10.7, 2.9 Hz, 1H), 3.52 (ddd, *J* = 13.5, 7.2, 3.0 Hz, 2H), 3.43 (dd, *J* = 10.8, 2.0 Hz, 1H), 3.30 (s, 3H).

¹³C NMR (126 MHz, CDCl₃) δ 166.00, 165.61, 165.59, 165.04, 139.52, 138.48, 137.93, 133.59, 133.47, 133.35, 129.99, 129.95, 129.87, 129.82, 129.64, 129.19, 128.95, 128.72, 128.61, 128.60, 128.52, 128.48, 128.42, 128.25, 128.24, 127.93, 127.36, 127.33, 100.53, 98.71, 79.98,

78.71, 75.40, 73.79, 73.76, 71.99, 71.07, 70.41, 69.61, 67.94, 67.65, 61.53, 55.54. The data are identical to the literature report.^[87]

Methyl 2,3,4-tri-O-benzoyl- α -L-rhamnopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (3.50).

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1h** (36.0 mg, 38.0 μ mol) to afford **3.50** (23.0 mg, 25.0 μ mol, 98% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1h** (44.0 mg, 63.0 μ mol) to afford **3.50** (21.5 mg, 23.29 μ mol, 91% yield) as a white viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

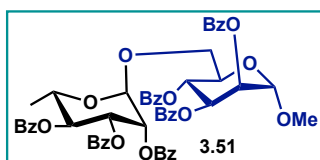


¹H NMR (399 MHz, CDCl₃) δ 8.08 (dd, J = 8.2, 1.7 Hz, 2H), 7.97 (dd, J = 8.2, 1.7 Hz, 2H), 7.81 (dd, J = 8.2, 1.6 Hz, 2H), 7.64 – 7.59 (m, 1H), 7.55 – 7.47 (m, 3H), 7.43 – 7.36 (m, 8H), 7.35 – 7.29 (m, 10H), 7.27 (s, 1H), 7.24 (d, J = 2.4 Hz, 1H), 5.80 (dd, J = 10.1, 3.6 Hz, 1H), 5.67 – 5.60 (m, 2H), 5.03 (d, J = 10.9 Hz, 1H), 4.97 (d, J = 11.2 Hz, 1H), 4.93 (d, J = 1.7 Hz, 1H), 4.88 – 4.81 (m, 2H), 4.70 (d, J = 12.1 Hz, 1H), 4.66 – 4.61 (m, 2H), 4.19 – 4.13 (m, 1H), 4.05 (t, J = 9.2 Hz, 1H), 3.96 (dd, J = 11.1, 1.9 Hz, 1H), 3.87 (dd, J = 10.5, 5.1 Hz, 1H), 3.65 – 3.58 (m, 2H), 3.55 – 3.49 (m, 1H), 3.46 (s, 3H), 1.31 (d, J = 6.2 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.91, 165.55, 165.54, 138.79, 138.24, 133.55, 133.43, 133.17, 130.01, 129.86, 129.78, 129.37, 129.32, 128.68, 128.60, 128.58, 128.53, 128.36, 128.25, 128.09, 128.04, 127.92, 127.74, 98.09, 98.01, 82.29, 80.21, 77.89, 75.91, 75.26, 73.58, 71.86, 70.78, 70.19, 69.98, 67.12, 66.76, 55.42, 17.69. The data are identical to the literature report.^[87]

Methyl 2,3,4-tri-O-benzoyl- α -L-rhamnopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.51).

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1h** (26.0 mg, 38.0 μ mol) to afford **3.51** (23.0 mg, 24.4 μ mol, 95% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).



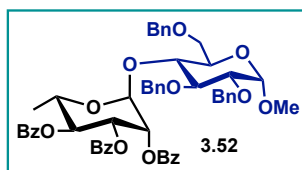
¹H NMR (399 MHz, CDCl₃) δ 8.13 – 8.07 (m, 4H), 8.01 (dd, *J* = 8.3, 1.4 Hz, 2H), 7.92 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.82 (td, *J* = 8.4, 1.3 Hz, 4H), 7.62 – 7.55 (m, 2H), 7.53 – 7.47 (m, 6H), 7.45 (dd, *J* = 6.8, 1.5 Hz, 1H), 7.43 – 7.42 (m, 1H), 7.41 – 7.33 (m, 5H), 7.28 (s, 2H), 7.24 (s, 1H), 5.93 (dd, *J* = 10.1, 3.4 Hz, 1H), 5.86 – 5.79 (m, 2H), 5.74 (dd, *J* = 3.5, 1.8 Hz, 1H), 5.71 (dd, *J* = 3.4, 1.8 Hz, 1H), 5.64 (t, *J* = 9.9 Hz, 1H), 5.19 (d, *J* = 1.8 Hz, 1H), 5.01 (d, *J* = 1.8 Hz, 1H), 4.40 (ddd, *J* = 9.6, 6.9, 2.5 Hz, 1H), 4.19 – 4.15 (m, 1H), 3.98 (dd, *J* = 11.7, 2.5 Hz, 1H), 3.91 (dd, *J* = 11.7, 7.0 Hz, 1H), 3.64 (s, 3H), 1.28 (d, *J* = 6.3 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.85, 165.76, 165.68, 165.54, 165.48, 165.43, 133.62, 133.61, 133.53, 133.40, 133.24, 133.16, 130.04, 130.01, 129.96, 129.85, 129.82, 129.79, 129.52, 129.39, 129.34, 129.20, 129.01, 128.77, 128.66, 128.60, 128.51, 128.38, 128.36, 98.63, 98.33, 71.84, 70.73, 70.69, 70.53, 70.01, 69.90, 69.27, 67.49, 67.00, 60.52, 17.68.

HRMS (ESI): calc. for C₅₅H₄₈NaO₁₆ (M+Na): 987.2840; found: 987.2864.

Methyl 2,3,4-tri-*O*-benzoyl-α-L-rhamnopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (3.52)

Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1h** (36.0 mg, 38.0 μmol) to afford **3.52** (23.0 mg, 24.5 μmol, 96% yield) as a colorless viscous oil. *R*_f = 0.4 (hexane: EtOAc = 70:30).

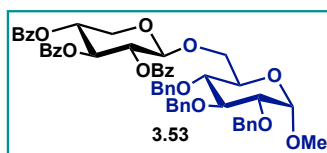


¹H NMR (399 MHz, CDCl₃) δ 8.06 (dd, *J* = 8.5, 1.3 Hz, 2H), 7.92 – 7.84 (m, 4H), 7.62 – 7.57 (m, 1H), 7.56 – 7.52 (m, 1H), 7.49 – 7.43 (m, 3H), 7.43 – 7.37 (m, 5H), 7.35 – 7.27 (m, 8H), 7.21 – 7.09 (m, 6H), 5.78 (dd, *J* = 10.2, 3.4 Hz, 1H), 5.63 – 5.55 (m, 2H), 5.24 – 5.19 (m, 2H), 4.84 (d, *J* = 10.9 Hz, 1H), 4.77 (d, *J* = 12.0 Hz, 1H), 4.66 – 4.60 (m, 2H), 4.59 – 4.51 (m, 2H), 4.40 – 4.32 (m, 1H), 4.00 (p, *J* = 9.1 Hz, 2H), 3.91 – 3.82 (m, 2H), 3.75 – 3.71 (m, 1H), 3.65 (dd, *J* = 9.0, 3.4 Hz, 1H), 3.41 (s, 3H), 0.87 (d, *J* = 6.2 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.86, 165.18, 165.79, 138.79, 138.03, 137.81, 133.57, 133.36, 133.28, 129.99, 129.81, 129.77, 129.49, 129.29, 128.66, 128.60, 128.50, 128.43, 128.38, 128.30, 128.26, 128.12, 128.00, 127.59, 127.53, 127.40, 98.10, 97.10, 80.37, 79.83, 75.65, 74.85, 73.47, 73.35, 71.79, 71.35, 70.14, 70.04, 68.32, 67.11, 55.42, 17.23. The data are identical to the literature report.^[87]

Methyl 2,3,4-tri-O-benzoyl- β -D-xylopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.53)

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1i** (26.0 mg, 38.0 μ mol) to afford **3.53** (23.3 mg, 25.6 μ mol, 99% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).
- 2) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1i** (43.0 mg, 63.0 μ mol) to afford **3.53** (17 mg, 19.0 μ mol, 72% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



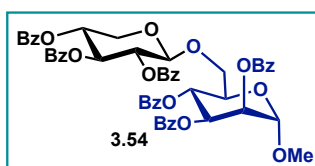
^1H NMR (399 MHz, CDCl_3) δ 8.00 – 7.95 (m, 3H), 7.95 – 7.90 (m, 3H), 7.56 – 7.51 (m, 1H), 7.47 – 7.41 (m, 2H), 7.40 – 7.35 (m, 3H), 7.35 – 7.31 (m, 6H), 7.30 (dd, J = 4.9, 2.7 Hz, 6H), 7.25 – 7.21 (m, 4H), 7.08 (dd, J = 7.5, 2.2 Hz, 2H), 5.76 (t, J = 7.7 Hz, 1H), 5.43 (dd, J = 7.7, 5.8 Hz, 1H), 4.92 (d, J = 10.9 Hz, 1H), 4.79 – 4.72 (m, 3H), 4.63 (d, J = 3.5 Hz, 1H), 4.60 (d, J = 2.5 Hz, 1H), 4.57 (d, J = 3.7 Hz, 1H), 4.43 (dd, J = 11.9, 4.5 Hz, 1H), 4.37 (d, J = 11.1 Hz, 1H), 4.10 – 4.05 (m, 1H), 3.93 (t, J = 9.3 Hz, 1H), 3.77 – 3.71 (m, 2H), 3.63 (dd, J = 11.8, 7.9 Hz, 1H), 3.51 – 3.42 (m, 2H), 3.26 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.63, 165.60, 165.08, 138.85, 138.26, 133.51, 133.46, 133.30, 129.96, 129.92, 129.26, 129.12, 128.57, 128.54, 128.50, 128.43, 128.18, 128.04, 128.01, 127.71, 127.64, 100.43, 98.16, 82.09, 79.93, 75.75, 74.95, 73.52, 70.72, 70.47, 69.64, 69.31, 67.83, 55.20.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{52}\text{NaO}_{13}$ ($\text{M}+\text{Na}$): 931.3306; found: 931.3328.

Methyl 2,3,4-tri-O-benzoyl- β -D-xylopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.54)

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1i** (26.0 mg, 38.0 μ mol) to afford **3.54** (23.8 mg, 24.0 μ mol, 93% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).



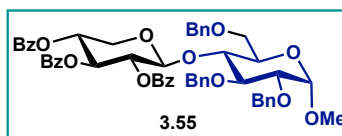
¹H NMR (399 MHz, CDCl₃) δ 8.00 – 7.95 (m, 3H), 7.95 – 7.90 (m, 3H), 7.56 – 7.51 (m, 1H), 7.47 – 7.41 (m, 2H), 7.40 – 7.35 (m, 3H), 7.35 – 7.31 (m, 6H), 7.30 (dd, *J* = 4.9, 2.7 Hz, 6H), 7.25 – 7.21 (m, 4H), 7.08 (dd, *J* = 7.5, 2.2 Hz, 2H), 5.76 (t, *J* = 7.7 Hz, 1H), 5.43 (dd, *J* = 7.7, 5.8 Hz, 1H), 4.92 (d, *J* = 10.9 Hz, 1H), 4.79 – 4.72 (m, 3H), 4.63 (d, *J* = 3.5 Hz, 1H), 4.60 (d, *J* = 2.5 Hz, 1H), 4.57 (d, *J* = 3.7 Hz, 1H), 4.43 (dd, *J* = 11.9, 4.5 Hz, 1H), 4.37 (d, *J* = 11.1 Hz, 1H), 4.10 – 4.05 (m, 1H), 3.93 (t, *J* = 9.3 Hz, 1H), 3.77 – 3.71 (m, 2H), 3.63 (dd, *J* = 11.8, 7.9 Hz, 1H), 3.51 – 3.42 (m, 2H), 3.26 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.66, 165.57, 165.04, 138.79, 137.93, 133.51, 133.44, 133.39, 129.96, 129.88, 129.86, 129.29, 129.21, 129.19, 128.78, 128.59, 128.52, 128.49, 128.45, 128.29, 128.23, 127.96, 127.72, 100.35, 98.56, 80.05, 79.32, 76.70, 76.07, 73.78, 73.57, 71.78, 71.54, 69.79, 67.66, 62.02, 55.49.

HRMS (ESI): calc. for C₅₄H₄₆NaO₁₆ (M+Na): 973.2684; found: 973.2717.

Methyl 2,3,4-tri-*O*-benzoyl-β-D-xylopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (3.55)

Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1i** (26.0 mg, 38.0 μmol) to afford **3.55** (22.8 mg, 24.3 μmol, 97% yield) as a colorless viscous oil. *R_f* = 0.4 (hexane: EtOAc = 70:30).

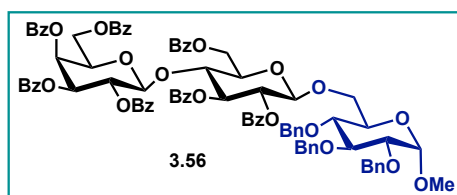


¹H NMR (399 MHz, CDCl₃) δ 8.01 (dd, *J* = 7.8, 1.3 Hz, 2H), 7.92 (dd, *J* = 7.8, 1.4 Hz, 2H), 7.88 (dd, *J* = 7.8, 1.4 Hz, 2H), 7.58 – 7.49 (m, 3H), 7.45 (dd, *J* = 6.6, 1.7 Hz, 4H), 7.42 (d, *J* = 2.3 Hz, 2H), 7.41 – 7.34 (m, 10H), 7.32 – 7.27 (m, 5H), 5.60 (t, *J* = 8.5 Hz, 1H), 5.40 – 5.35 (m, 1H), 5.29 – 5.23 (m, 1H), 4.95 (d, *J* = 10.4 Hz, 1H), 4.88 (d, *J* = 10.5 Hz, 1H), 4.82 (d, *J* = 12.2 Hz, 1H), 4.71 – 4.61 (m, 3H), 4.53 (d, *J* = 3.7 Hz, 1H), 4.33 (d, *J* = 12.0 Hz, 1H), 4.28 (dd, *J* = 12.1, 5.2 Hz, 1H), 3.96 (t, *J* = 9.4 Hz, 1H), 3.88 (t, *J* = 9.2 Hz, 1H), 3.69 (dd, *J* = 10.5, 2.8 Hz, 1H), 3.55 – 3.48 (m, 2H), 3.41 (dd, *J* = 12.6, 10.7 Hz, 1H), 3.30 (s, 3H), 3.26 (dd, *J* = 11.9, 8.9 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 165.66, 165.57, 165.04, 138.79, 137.93, 133.51, 133.44, 133.39, 129.96, 129.88, 129.86, 129.29, 129.21, 129.19, 128.78, 128.59, 128.52, 128.49, 128.45, 128.29, 128.23, 127.96, 127.72, 100.35, 98.56, 80.05, 79.32, 76.70, 76.07, 73.78, 73.57, 71.78, 71.54, 69.79, 67.66, 62.02, 55.49. The data are identical to the literature report.^[99]

Methyl 2,3,4,6-tetra-O-benzoyl- β -D-galactopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (3.56)

- 1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1j** (49.0 mg, 38.0 μ mol) to afford **3.56** (37.0 mg, 24.4 μ mol, 94% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 60:40).
- 2) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1j** (82.0 mg, 64.0 μ mol) to afford **3.56** (27 mg, 18.0 μ mol, 68% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 60:40).



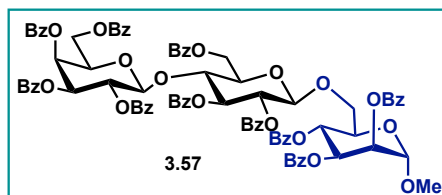
^1H NMR (399 MHz, CDCl_3) δ 8.01 – 7.95 (m, 9H), 7.91 – 7.86 (m, 4H), 7.65 – 7.60 (m, 1H), 7.60 – 7.53 (m, 2H), 7.52 – 7.49 (m, 2H), 7.49 – 7.46 (m, 2H), 7.39 (ddd, J = 7.9, 4.6, 3.0 Hz, 5H), 7.34 – 7.27 (m, 12H), 7.24 – 7.21 (m, 6H), 7.21 – 7.18 (m, 3H), 7.13 (t, J = 7.8 Hz, 2H), 7.03 (dd, J = 6.7, 1.8 Hz, 2H), 5.78 (t, J = 9.5 Hz, 1H), 5.74 – 5.69 (m, 2H), 5.52 (dd, J = 10.1, 7.9 Hz, 1H), 5.35 (dd, J = 10.3, 3.4 Hz, 1H), 4.89 – 4.83 (m, 2H), 4.72 – 4.63 (m, 3H), 4.55 (d, J = 12.1 Hz, 2H), 4.46 (dd, J = 13.0, 3.9 Hz, 3H), 4.22 (t, J = 10.4 Hz, 2H), 4.06 – 4.01 (m, 1H), 3.89 – 3.81 (m, 2H), 3.72 (dd, J = 11.5, 6.3 Hz, 2H), 3.68 – 3.61 (m, 3H), 3.38 – 3.34 (m, 1H), 3.30 (t, J = 9.3 Hz, 1H), 3.15 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.94, 165.68, 165.53, 165.51, 165.30, 165.14, 164.87, 138.84, 138.20, 133.66, 133.53, 133.38, 133.30, 133.20, 130.10, 129.88, 129.85, 129.76, 129.72, 129.63, 129.57, 129.47, 129.31, 128.92, 128.78, 128.74, 128.69, 128.64, 128.61, 128.53, 128.46, 128.38, 128.34, 128.21, 128.00, 127.96, 127.73, 127.59, 127.55, 101.45, 101.03, 97.96, 81.93, 79.78, 76.03, 75.61, 74.82, 73.46, 73.10, 72.96, 71.83, 71.70, 71.46, 69.93, 69.58, 68.37, 67.59, 62.45, 61.20, 55.06.

HRMS (ESI): calc. for $\text{C}_{89}\text{H}_{80}\text{NaO}_{23}$ ($\text{M}+\text{Na}$): 1529.4988; found: 1529.5025.

Methyl 2,3,4,6-tetra-O-benzoyl- β -D-galactopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.57)

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1j** (49.0 mg, 38.0 μ mol) to afford **3.57** (38.5 mg, 24.7 μ mol, 96% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 60:40).



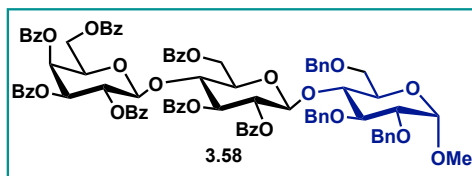
^1H NMR (399 MHz, CDCl_3) δ 8.04 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.97 (dq, $J = 10.4, 1.8$ Hz, 7H), 7.92 (dd, $J = 8.3, 1.5$ Hz, 2H), 7.90 – 7.87 (m, 2H), 7.85 – 7.82 (m, 2H), 7.73 (ddd, $J = 10.3, 8.3, 1.5$ Hz, 4H), 7.65 – 7.60 (m, 2H), 7.58 (td, $J = 2.9, 1.2$ Hz, 1H), 7.57 – 7.53 (m, 1H), 7.51 – 7.45 (m, 7H), 7.43 – 7.38 (m, 6H), 7.36 – 7.27 (m, 8H), 7.24 – 7.19 (m, 4H), 7.14 (d, $J = 8.3$ Hz, 2H), 5.80 (t, $J = 9.6$ Hz, 1H), 5.75 (dd, $J = 10.2, 3.3$ Hz, 1H), 5.72 – 5.67 (m, 2H), 5.56 (t, $J = 10.2$ Hz, 1H), 5.53 – 5.47 (m, 2H), 5.33 (dd, $J = 10.3, 3.4$ Hz, 1H), 4.83 (t, $J = 7.7$ Hz, 2H), 4.61 – 4.54 (m, 2H), 4.44 (dd, $J = 12.3, 4.3$ Hz, 1H), 4.24 (t, $J = 9.4$ Hz, 1H), 4.21 – 4.16 (m, 1H), 4.05 – 4.01 (m, 1H), 3.86 – 3.73 (m, 3H), 3.68 (dd, $J = 6.6, 4.8$ Hz, 2H), 3.06 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.89, 165.72, 165.66, 165.56, 165.51, 165.49, 165.39, 165.37, 165.31, 164.85, 133.66, 133.58, 133.52, 133.38, 133.25, 130.09, 130.01, 129.93, 129.90, 129.86, 129.77, 129.74, 129.68, 129.48, 129.41, 129.15, 128.86, 128.75, 128.72, 128.69, 128.64, 128.50, 128.36, 128.33, 101.84, 101.01, 98.00, 75.94, 73.05, 72.86, 71.87, 71.81, 71.43, 70.50, 69.92, 69.84, 67.55, 67.33, 62.35, 61.09, 54.89.

HRMS (ESI): calc. for $\text{C}_{89}\text{H}_{74}\text{NaO}_{26}$ ($\text{M}+\text{Na}$): 1581.4366; found: 1581.4398.

Methyl 2,3,4,6-tetra-*O*-benzoyl- β -D-galactopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-*O*-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-*O*-benzyl- α -D-glucopyranoside (3.58)

Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1j** (49.0 mg, 38.0 μmol) to afford **3.58** (36.0 mg, 24.0 μmol , 92% yield) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 60:40).



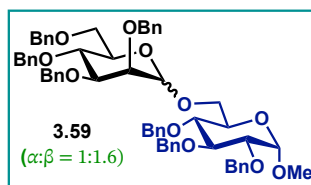
^1H NMR (399 MHz, CDCl_3) δ 8.07 (dd, $J = 8.5, 1.4$ Hz, 2H), 8.00 (dd, $J = 7.0, 1.7$ Hz, 3H), 7.96 (dd, $J = 6.7, 1.5$ Hz, 4H), 7.91 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.87 (dd, $J = 8.3, 1.3$ Hz, 2H), 7.74 (dd, $J = 8.3, 1.4$ Hz, 2H), 7.65 – 7.60 (m, 1H), 7.57 – 7.52 (m, 3H), 7.51 – 7.48 (m, 5H), 7.44 – 7.38 (m, 6H), 7.38 – 7.34 (m, 6H), 7.24 – 7.17 (m, 9H), 7.11 (t, $J = 7.9$ Hz, 2H), 6.99 – 6.95 (m, 3H), 5.74 – 5.67 (m, 2H), 5.50 – 5.44 (m, 1H), 5.38 (dd, $J = 10.0, 7.9$ Hz, 1H), 5.29 – 5.26 (m, 1H), 5.00 (d, $J = 11.3$ Hz, 1H), 4.74 – 4.65 (m, 4H), 4.55 – 4.48 (m, 3H), 4.29 – 4.22 (m, 3H), 4.16 –

4.10 (m, 1H), 3.85 – 3.79 (m, 2H), 3.74 (t, $J = 6.9$ Hz, 1H), 3.67 – 3.57 (m, 3H), 3.46 – 3.42 (m, 1H), 3.37 (s, 2H), 3.25 (s, 3H), 3.22 (d, $J = 9.9$ Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.87, 165.64, 165.47, 165.41, 165.32, 165.06, 164.94, 139.28, 138.36, 137.72, 133.63, 133.53, 133.45, 133.16, 130.10, 130.02, 129.85, 129.83, 129.75, 129.71, 129.63, 129.51, 129.30, 129.01, 128.86, 128.77, 128.70, 128.58, 128.45, 128.41, 128.37, 128.27, 128.17, 127.99, 127.82, 127.09, 127.02, 100.77, 100.41, 98.52, 80.12, 78.56, 75.47, 75.24, 73.65, 73.61, 73.09, 72.65, 72.23, 71.85, 71.35, 69.85, 69.49, 67.54, 55.41. The data are identical to the literature report.^[87]

Methyl 2,3,4,6-tetra-O-benzyl- α/β -D-mannopyranosyl-(1 $\rightarrow$ 6)2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.59).

Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1k** (28.0 mg, 38.0 μmol) to afford **3.59** (23.0 mg, 23.3 μmol , 90% yield, α : β = 1:1.6) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



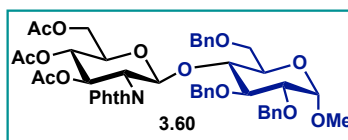
^1H NMR (399 MHz, CDCl_3) δ 7.43 – 7.27 (m, 40H), 7.25 – 7.12 (m, 23H), 5.03 – 4.94 (m, 3H), 4.92 – 4.76 (m, 9H), 4.72 – 4.64 (m, 5H), 4.63 – 4.41 (m, 15H), 4.18 – 4.10 (m, 1H), 3.98 (q, $J = 9.6$ Hz, 3H), 3.87 – 3.75 (m, 7H), 3.68 (ddd, $J = 14.7, 7.8, 3.6$ Hz, 6H), 3.63 – 3.56 (m, 3H), 3.53 – 3.36 (m, 6H), 3.32 (s, 2H), 3.30 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.90, 138.77, 138.69, 138.51, 138.46, 138.43, 138.25, 138.20, 138.13, 128.60, 128.58, 128.54, 128.47, 128.40, 128.38, 128.34, 128.28, 128.21, 128.19, 128.15, 128.06, 127.86, 127.85, 127.77, 127.74, 127.67, 127.62, 127.58, 127.52, 101.54, 98.30, 97.89, 82.23, 80.02, 79.64, 77.67, 75.92, 75.14, 75.03, 74.89, 74.62, 73.74, 73.58, 73.35, 72.50, 72.07, 71.95, 71.62, 69.85, 69.11, 65.85, 55.18, 55.14. The data are identical to the literature report.^[105]

Methyl 3,4,6-tri-O-acetyl-2-deoxy-2-phthalimido- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-2,3,6-tri-O-benzyl- α -D-glucopyranoside (3.60)

1) Following the general procedure **D**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1l** (25.0 mg, 38.9 μmol) to afford **3.60** (23.8 mg, 24.5 μmol , 89% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 60:40).

- 2) Following the general procedure **F**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1l** (42.0 mg, 63.0 μmol) to afford **3.60** (18 mg, 17.0 μmol , 65% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 60:40).

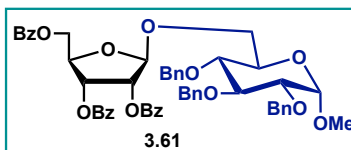


^1H NMR (500 MHz, CDCl_3) δ 7.84 – 7.79 (m, 2H), 7.68 (dd, J = 5.5, 3.0 Hz, 2H), 7.44 – 7.41 (m, 2H), 7.37 (t, J = 7.6 Hz, 2H), 7.33 – 7.26 (m, 4H), 7.26 – 7.21 (m, 7H), 5.68 (dd, J = 10.7, 9.1 Hz, 1H), 5.63 (d, J = 8.4 Hz, 1H), 5.11 (dd, J = 10.2, 9.1 Hz, 1H), 4.99 (d, J = 11.8 Hz, 1H), 4.92 (d, J = 11.7 Hz, 1H), 4.69 (d, J = 12.2 Hz, 1H), 4.55 (d, J = 12.2 Hz, 1H), 4.49 (d, J = 3.7 Hz, 1H), 4.37 – 4.31 (m, 2H), 4.25 (dd, J = 10.7, 8.4 Hz, 1H), 4.07 (dd, J = 12.4, 3.8 Hz, 1H), 3.97 (dd, J = 10.0, 8.8 Hz, 1H), 3.87 (t, J = 9.1 Hz, 1H), 3.80 (dd, J = 12.4, 2.3 Hz, 1H), 3.55 (dt, J = 10.0, 2.6 Hz, 1H), 3.47 – 3.42 (m, 3H), 3.34 (ddd, J = 10.2, 3.8, 2.3 Hz, 1H), 3.26 (s, 3H), 1.98 (s, 3H), 1.97 (s, 3H), 1.82 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3) δ 170.83, 170.29, 169.54, 139.55, 138.35, 138.25, 134.39, 131.49, 128.45, 128.35, 128.32, 128.16, 127.89, 127.50, 127.37, 127.20, 126.92, 123.69, 98.18, 97.40, 80.29, 79.43, 75.60, 74.75, 73.50, 72.87, 71.66, 70.86, 69.37, 68.62, 68.24, 61.59, 55.42, 55.34, 20.81, 20.72, 20.52. The data are identical to the literature report.^[87]

Methyl (2,3,5-tri-*O*-benzoyl- β -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.61)

Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1m** (26.0 mg, 38.0 μmol) to afford **3.61** (17.0 mg, 18.70 μmol , 72% yield) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).



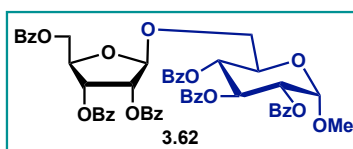
^1H NMR (399 MHz, CDCl_3) δ 8.01 (ddd, J = 12.1, 8.4, 1.3 Hz, 4H), 7.86 (dd, J = 8.4, 1.4 Hz, 2H), 7.60 – 7.55 (m, 1H), 7.53 – 7.46 (m, 2H), 7.44 – 7.41 (m, 2H), 7.40 – 7.36 (m, 3H), 7.35 – 7.34 (m, 3H), 7.33 (q, J = 1.1 Hz, 3H), 7.31 (q, J = 1.4 Hz, 3H), 7.30 – 7.26 (m, 2H), 7.25 (d, J = 2.0 Hz, 3H), 5.82 (dd, J = 6.7, 4.9 Hz, 1H), 5.63 (d, J = 4.9 Hz, 1H), 5.14 (s, 1H), 4.99 (d, J = 10.9 Hz, 1H), 4.87 (d, J = 11.2 Hz, 1H), 4.83 – 4.77 (m, 2H), 4.71 – 4.66 (m, 2H), 4.64 – 4.57

(m, 3H), 4.54 (dd, $J = 11.5, 6.0$ Hz, 1H), 4.00 – 3.93 (m, 2H), 3.74 – 3.70 (m, 1H), 3.61 (dd, $J = 10.9, 4.7$ Hz, 1H), 3.57 – 3.53 (m, 1H), 3.51 – 3.48 (m, 1H), 3.32 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.28, 165.46, 165.24, 138.87, 138.34, 138.27, 133.72, 133.59, 133.48, 133.17, 129.97, 129.90, 129.85, 129.82, 129.79, 129.29, 129.01, 128.67, 128.59, 128.57, 128.53, 128.48, 128.45, 128.43, 128.25, 128.02, 127.99, 127.77, 127.65, 105.84, 97.93, 82.24, 80.13, 79.12, 73.50, 72.75, 69.80, 66.64, 65.44, 55.28. The data are identical to the literature report.^[113]

Methyl (2,3,5-tri-*O*-benzoyl- β -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (3.62)

Following the general procedure **D**, glycosyl acceptor **A11** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1m** (26.0 mg, 38.0 μmol) to afford **3.62** (19.0 mg, 20.28 μmol , 79% yield) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 8.00 (ddd, $J = 11.9, 8.4, 1.4$ Hz, 6H), 7.86 (tt, $J = 6.9, 1.2$ Hz, 6H), 7.58 (ddt, $J = 7.9, 7.0, 1.4$ Hz, 1H), 7.54 – 7.46 (m, 4H), 7.45 – 7.34 (m, 8H), 7.33 (d, $J = 2.2$ Hz, 2H), 7.31 – 7.27 (m, 4H), 6.12 (t, $J = 9.7$ Hz, 1H), 5.86 (s, 1H), 5.74 (d, $J = 4.8$ Hz, 1H), 5.50 (t, $J = 9.9$ Hz, 1H), 5.36 (s, 1H), 5.26 – 5.20 (m, 2H), 4.70 – 4.64 (m, 2H), 4.56 – 4.48 (m, 1H), 4.23 (ddd, $J = 9.6, 6.7, 2.2$ Hz, 1H), 3.96 (dd, $J = 11.6, 2.2$ Hz, 1H), 3.76 – 3.70 (m, 1H), 3.46 (s, 3H).

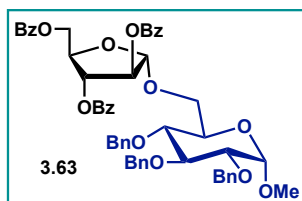
^{13}C NMR (100 MHz, CDCl_3) δ 166.20, 165.89, 165.87, 165.42, 165.21, 133.56, 133.47, 133.43, 133.25, 133.16, 130.05, 129.94, 129.83, 129.78, 129.70, 129.32, 129.19, 129.01, 128.92, 128.58, 128.51, 128.45, 128.43, 128.36, 106.23, 96.86, 79.25, 75.50, 72.34, 72.21, 70.52, 69.58, 69.02, 67.04, 64.88, 55.74.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{46}\text{NaO}_{16}$ ($\text{M}+\text{Na}$): 973.2684; found: 973.2710.

Methyl (2,3,5-tri-*O*-benzoyl- α -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (3.63)

1) Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1n** (26.0 mg, 38.0 μmol) to afford **3.63** (20.2 mg, 22.22 μmol , 86% yield) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).

- 2) Following the general procedure **F**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1n** (43.0 mg, 64.0 μ mol) to afford **3.63** (17.5 mg, 19.2 μ mol, 74% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 80:20).

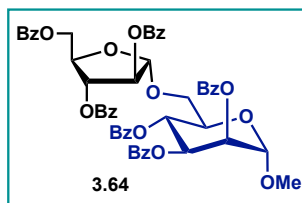


^1H NMR (399 MHz, CDCl_3) δ 8.05 – 8.02 (m, 2H), 7.97 (ddd, J = 8.4, 4.9, 1.3 Hz, 4H), 7.57 (s, 1H), 7.51 – 7.44 (m, 3H), 7.41 – 7.33 (m, 5H), 7.32 – 7.28 (m, 10H), 7.25 (s, 4H), 7.22 (dd, J = 5.0, 2.8 Hz, 4H), 7.18 – 7.15 (m, 2H), 5.59 (d, J = 1.0 Hz, 1H), 5.53 – 5.50 (m, 1H), 5.40 (s, 1H), 4.98 (d, J = 10.8 Hz, 1H), 4.84 – 4.79 (m, 2H), 4.77 (d, J = 1.2 Hz, 1H), 4.71 (d, J = 3.4 Hz, 1H), 4.66 (d, J = 12.1 Hz, 1H), 4.63 – 4.55 (m, 3H), 4.46 (s, 1H), 4.12 – 4.06 (m, 1H), 3.97 (d, J = 9.3 Hz, 1H), 3.78 (s, 2H), 3.68 (d, J = 9.2 Hz, 1H), 3.57 (dd, J = 9.6, 3.5 Hz, 1H), 3.33 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.31, 165.78, 165.33, 138.91, 138.29, 138.26, 133.67, 133.62, 133.14, 130.02, 129.97, 129.84, 129.74, 129.10, 129.03, 128.64, 128.57, 128.55, 128.45, 128.38, 128.20, 128.06, 128.00, 127.81, 127.66, 127.55, 106.20, 98.15, 82.05, 81.88, 80.16, 77.96, 77.87, 75.76, 75.13, 73.50, 69.92, 66.07, 63.86, 55.26. The data are identical to the literature report.^[114]

Methyl (2,3,5-tri-*O*-benzoyl- α -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-mannopyranoside (3.64)

Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1n** (26.0 mg, 38.0 μ mol) to afford **3.64** (21.7 mg, 23.16 μ mol, 90% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



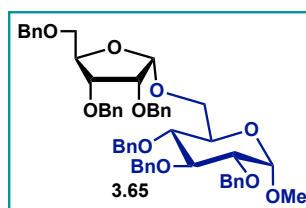
^1H NMR (399 MHz, CDCl_3) δ 8.10 (dt, J = 8.5, 1.4 Hz, 4H), 7.96 – 7.89 (m, 6H), 7.79 – 7.76 (m, 2H), 7.58 – 7.53 (m, 1H), 7.50 – 7.26 (m, 13H), 7.24 – 7.14 (m, 5H), 6.09 (t, J = 10.1 Hz, 1H), 5.84 (dd, J = 10.1, 3.3 Hz, 1H), 5.71 (dd, J = 3.4, 1.9 Hz, 1H), 5.63 (d, J = 1.0 Hz, 1H), 5.55 (d, J = 4.7 Hz, 1H), 5.39 (s, 1H), 4.96 (d, J = 1.9 Hz, 1H), 4.76 – 4.71 (m, 1H), 4.64 – 4.58 (m, 2H),

4.29 (ddd, $J = 10.1, 4.5, 2.2$ Hz, 1H), 4.09 (dd, $J = 10.9, 4.4$ Hz, 1H), 3.75 (dd, $J = 10.9, 2.3$ Hz, 1H), 3.48 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.29, 166.21, 165.67, 165.63, 165.39, 133.67, 133.58, 133.50, 133.30, 133.21, 133.05, 130.12, 129.96, 129.88, 129.78, 129.32, 129.30, 128.70, 128.61, 128.58, 128.35, 128.32, 105.62, 98.79, 82.45, 81.45, 78.11, 70.46, 70.30, 69.56, 66.79, 65.59, 63.66.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{46}\text{NaO}_{16}$ ($\text{M}+\text{Na}$): 973.2684; found: 973.2705.

Methyl (2,3,5-tri-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.65)



Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1o** (24.2 mg, 38.7 μmol) to afford **3.65** (17.5 mg, 20 μmol , 78% yield, $\alpha:\beta=9:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.38 – 7.35 (m, 2H), 7.34 – 7.17 (m, 28H), 5.15 – 5.13 (m, 1H), 4.94 (d, $J = 11.0$ Hz, 1H), 4.81 (d, $J = 11.0$ Hz, 1H), 4.77 – 4.72 (m, 3H), 4.70 (d, $J = 15.9$ Hz, 1H), 4.66 – 4.56 (m, 3H), 4.50 (d, $J = 12.2$ Hz, 1H), 4.42 (dd, $J = 12.0, 5.3$ Hz, 2H), 4.23 – 4.12 (m, 2H), 3.97 – 3.92 (m, 1H), 3.90 – 3.85 (m, 2H), 3.78 – 3.72 (m, 2H), 3.66 (dd, $J = 11.2, 1.6$ Hz, 1H), 3.46 (dt, $J = 9.6, 3.4$ Hz, 2H), 3.39 (dd, $J = 10.6, 4.0$ Hz, 1H), 3.33 (s, 3H).

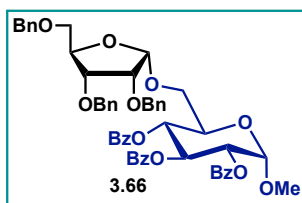
^1H NMR (500 MHz, $\text{BENZENE-}D_6$) δ 7.41 – 7.39 (m, 2H), 7.36 – 7.33 (m, 2H), 7.32 – 7.30 (m, 2H), 7.29 – 7.27 (m, 2H), 7.26 – 7.24 (m, 2H), 7.13 (dt, $J = 6.3, 3.1$ Hz, 9H), 7.07 (s, 2H), 7.03 (td, $J = 13.3, 6.2$ Hz, 9H), **5.17 (d, $J = 4.2$ Hz, 1H)**, 4.99 (d, $J = 11.4$ Hz, 1H), 4.95 – 4.91 (m, 2H), 4.81 (d, $J = 11.3$ Hz, 1H), 4.74 (d, $J = 11.6$ Hz, 1H), 4.62 (d, $J = 11.5$ Hz, 1H), **4.60 (d, $J = 3.4$ Hz, 1H)**, 4.40 – 4.36 (m, 4H), 4.34 (dd, $J = 11.4, 2.8$ Hz, 2H), 4.24 – 4.14 (m, 4H), 4.07 (t, $J = 9.5$ Hz, 1H), 3.92 (dd, $J = 6.2, 3.5$ Hz, 1H), 3.82 – 3.77 (m, 2H), 3.63 (dd, $J = 11.3, 1.7$ Hz, 1H), 3.48 (dd, $J = 9.5, 3.5$ Hz, 1H), 3.30 (dd, $J = 10.5, 3.9$ Hz, 1H), 3.26 (dd, $J = 10.5, 3.7$ Hz, 1H), 3.05 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.16, 138.75, 138.39, 138.34, 138.28, 138.07, 128.51, 128.46, 128.42, 128.39, 128.31, 128.15, 128.05, 127.93, 127.91, 127.74, 127.71, 127.61, 127.51,

102.16, 98.26, 82.11, 81.49, 80.07, 77.89, 77.87, 76.17, 75.65, 75.15, 73.53, 73.47, 72.53, 72.48, 70.26, 69.85, 66.72, 55.22. The data are identical to the literature report.^[115-116]

Methyl (2,3,5-tri-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (3.66)

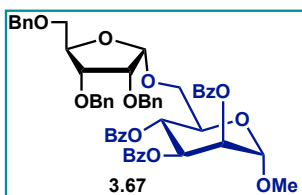
Following the general procedure **D**, glycosyl acceptor **A11** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1o** (24.0 mg, 38.5 μ mol) to afford **3.66** (19.6 mg, 21.5 μ mol, 73% yield, α : β =7:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



¹H NMR (399 MHz, CDCl₃) δ 7.98 – 7.90 (m, 4H), 7.84 (d, J = 7.2 Hz, 2H), 7.52 – 7.46 (m, 2H), 7.35 (td, J = 8.1, 5.5 Hz, 8H), 7.31 – 7.26 (m, 12H), 7.21 – 7.17 (m, 2H), 6.11 (t, J = 10.0 Hz, 1H), 5.49 (t, J = 9.9 Hz, 1H), 5.21 – 5.16 (m, 2H), 4.99 (d, J = 4.1 Hz, 1H), 4.66 – 4.59 (m, 4H), 4.54 – 4.45 (m, 3H), 4.41 (s, 1H), 4.31 (t, J = 3.9 Hz, 2H), 3.93 (dd, J = 11.3, 6.7 Hz, 1H), 3.84 (dd, J = 6.6, 3.8 Hz, 1H), 3.80 – 3.72 (m, 2H), 3.40 (t, J = 3.3 Hz, 1H), 3.35 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.91, 165.38, 138.43, 138.08, 138.05, 133.38, 133.09, 130.03, 129.95, 129.80, 129.43, 129.25, 128.59, 128.48, 128.46, 128.44, 128.33, 128.14, 128.08, 127.85, 127.73, 127.68, 127.65, 101.55, 96.68, 81.75, 73.49, 72.63, 72.31, 70.82, 69.90, 69.83, 68.89, 66.76, 55.55. The data are identical to the literature report.^[116]

Methyl (2,3,5-tri-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (3.67)



Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with MDMPAT donor **3.1o** (24.0 mg, 38.5 μ mol) to afford **3.67** (20.0 mg, 22.0 μ mol, 74% yield, α : β =15:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

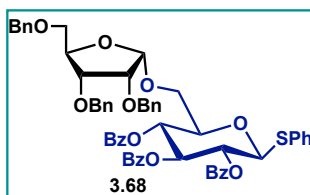
¹H NMR (399 MHz, CDCl₃) δ 8.07 (dd, J = 8.3, 1.4 Hz, 2H), 7.96 (dd, J = 8.4, 1.3 Hz, 2H), 7.82 (dd, J = 8.3, 1.4 Hz, 2H), 7.58 – 7.48 (m, 2H), 7.45 – 7.38 (m, 4H), 7.36 (d, J = 7.3 Hz, 2H), 7.32 – 7.26 (m, 9H), 7.25 – 7.22 (m, 5H), 7.20 (dd, J = 7.5, 2.1 Hz, 2H), 5.84 (dd, J = 10.1, 3.3 Hz,

1H), 5.77 (t, $J = 10.1$ Hz, 1H), 5.63 (dd, $J = 3.4, 1.7$ Hz, 1H), 5.01 (d, $J = 4.1$ Hz, 1H), 4.93 (d, $J = 1.8$ Hz, 1H), 4.60 (d, $J = 9.6$ Hz, 3H), 4.50 – 4.45 (m, 2H), 4.42 (s, 1H), 4.37 (d, $J = 11.9$ Hz, 1H), 4.32 (q, $J = 3.8$ Hz, 1H), 4.04 – 3.98 (m, 1H), 3.85 (dd, $J = 6.9, 3.9$ Hz, 1H), 3.81 – 3.75 (m, 2H), 3.45 (d, $J = 11.7$ Hz, 1H), 3.40 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.76, 165.70, 165.54, 133.49, 133.17, 130.03, 129.94, 129.82, 128.64, 128.51, 128.45, 128.40, 128.35, 128.32, 128.10, 127.74, 127.72, 101.67, 98.32, 73.48, 72.62, 72.30, 70.78, 70.07, 69.88, 67.67, 55.41.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{52}\text{NaO}_{13}$ ($\text{M}+\text{Na}$): 931.3306; found: 931.3339.

Phenyl (2,3,5-tri-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl-1-thio- β -D-glucopyranoside (3.68)



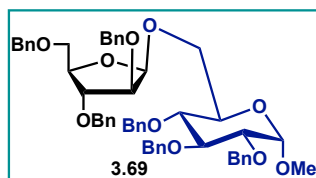
Following the general procedure **D**, glycosyl acceptor **A25** (15.0 mg, 25.6 μmol) was coupled with MDMPAT donor **3.1o** (24.0 mg, 38.5 μmol) to afford **3.68** (19.5 mg, 19.8 μmol , 77% yield, $\alpha:\beta=5:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.97 – 7.94 (m, 2H), 7.92 – 7.88 (m, 2H), 7.78 – 7.74 (m, 2H), 7.55 – 7.47 (m, 4H), 7.44 – 7.36 (m, 4H), 7.36 – 7.27 (m, 15H), 7.24 – 7.15 (m, 6H), 5.84 (t, $J = 9.4$ Hz, 1H), 5.41 (dt, $J = 12.9, 9.7$ Hz, 2H), 5.02 – 4.95 (m, 2H), 4.68 – 4.59 (m, 3H), 4.54 (d, $J = 12.7$ Hz, 1H), 4.46 (d, $J = 12.1$ Hz, 1H), 4.40 – 4.35 (m, 2H), 4.19 – 4.12 (m, 1H), 3.98 (dd, $J = 11.4, 6.4$ Hz, 1H), 3.87 – 3.74 (m, 3H), 3.41 (dd, $J = 10.7, 3.8$ Hz, 1H), 3.34 (dd, $J = 10.6, 3.9$ Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.87, 165.29, 165.09, 138.45, 138.08, 137.97, 133.46, 133.35, 133.21, 131.82, 129.98, 129.93, 129.86, 129.41, 129.07, 128.98, 128.49, 128.46, 128.43, 128.37, 128.32, 128.29, 128.26, 128.18, 127.86, 127.72, 127.70, 127.67, 101.56, 85.93, 81.66, 77.99, 77.68, 74.99, 74.58, 73.44, 72.70, 72.19, 70.62, 69.84, 69.79, 67.14.

HRMS (ESI): calc. for $\text{C}_{59}\text{H}_{54}\text{NaO}_{12}\text{S}$ ($\text{M}+\text{Na}$): 1009.3234; found: 1009.3266.

Methyl (2,3,5-tri-*O*-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.69)

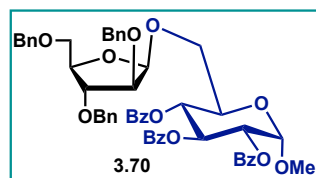


Following the general procedure **D**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1p** (24.2 mg, 38.7 μmol) to afford **3.69** (18.0 mg, 20.76 μmol , 80% yield, $\alpha:\beta=1:5$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.43 (tt, $J = 5.3, 3.1$ Hz, 2H), 7.38 – 7.26 (m, 33H), 7.23 – 7.18 (m, 3H), 5.03 – 4.95 (m, 3H), 4.85 – 4.76 (m, 4H), 4.67 (s, 1H), 4.64 (d, $J = 2.8$ Hz, 1H), 4.62 – 4.59 (m, 3H), 4.55 – 4.51 (m, 4H), 4.45 (d, $J = 12.0$ Hz, 2H), 4.13 – 4.06 (m, 4H), 4.00 – 3.92 (m, 2H), 3.71 (d, $J = 10.1$ Hz, 2H), 3.63 – 3.47 (m, 7H), 3.36 (s, 1H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.87, 138.43, 138.30, 138.25, 138.23, 137.84, 129.13, 128.84, 128.56, 128.49, 128.44, 128.41, 128.18, 128.07, 128.02, 128.00, 127.95, 127.88, 127.85, 127.83, 127.79, 127.77, 127.75, 127.73, 127.71, 127.68, 127.61, 106.84, 101.06, 98.23, 97.99, 87.97, 84.28, 83.67, 83.37, 82.17, 81.26, 80.79, 80.06, 79.96, 78.96, 78.78, 78.06, 73.47, 73.38, 72.75, 72.33, 72.14, 70.20, 66.47, 55.20, 53.55, 52.89, 52.53. The data are identical to the literature report.^[117]

Methyl (2,3,5-tri-O-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (3.70)

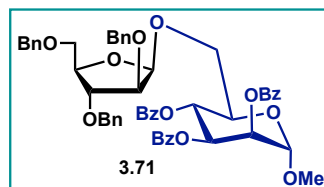


Following the general procedure **D**, glycosyl acceptor **A11** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1p** (24.0 mg, 38.5 μmol) to afford **3.70** (19.6 mg, 22.9 μmol , 77% yield, $\alpha:\beta=1:5$) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.98 (d, $J = 7.1$ Hz, 2H), 7.93 (d, $J = 7.1$ Hz, 2H), 7.85 – 7.81 (m, 2H), 7.54 – 7.47 (m, 3H), 7.44 – 7.40 (m, 4H), 7.39 – 7.34 (m, 5H), 7.33 (s, 2H), 7.31 – 7.27 (m, 11H), 6.12 (t, $J = 9.7$ Hz, 1H), 5.54 (t, $J = 9.9$ Hz, 1H), 5.24 – 5.17 (m, 2H), 5.06 (t, $J = 3.7$ Hz, 1H), 4.82 (d, $J = 11.8$ Hz, 1H), 4.67 – 4.55 (m, 3H), 4.50 – 4.41 (m, 3H), 4.22 – 4.17 (m, 1H), 4.13 – 4.09 (m, 3H), 3.89 (dd, $J = 11.6, 2.2$ Hz, 1H), 3.61 (dd, $J = 11.7, 5.9$ Hz, 1H), 3.52 (d, $J = 5.4$ Hz, 2H), 3.36 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.91, 165.88, 165.38, 138.27, 138.15, 138.09, 133.51, 133.45, 133.16, 130.04, 129.96, 129.82, 129.77, 129.35, 129.19, 129.06, 128.54, 128.52, 128.47, 128.43, 128.41, 128.36, 127.97, 127.94, 127.91, 127.84, 127.79, 127.71, 101.42, 96.85, 84.29, 83.28, 80.60, 73.34, 72.46, 72.35, 72.21, 72.17, 70.68, 69.55, 69.05, 66.03, 55.58. The data are identical to the literature report.^[117]

Methyl (2,3,5-tri-*O*-benzyl-β-D-arabinofuranosyl)-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-mannopyranoside (3.71)



Following the general procedure **D**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with MDMPAT donor **3.1p** (24.0 mg, 38.5 μmol) to afford **3.71** (21.8 mg, 24.0 μmol, 81% yield, α:β=1:6) as a colorless viscous oil. *R*_f = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (399 MHz, CDCl₃) δ 8.10 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.95 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.83 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.55 – 7.48 (m, 2H), 7.43 – 7.39 (m, 4H), 7.39 – 7.33 (m, 4H), 7.32 – 7.26 (m, 8H), 7.25 – 7.19 (m, 7H), 5.96 – 5.89 (m, 1H), 5.85 (dd, *J* = 10.0, 3.3 Hz, 1H), 5.12 (d, *J* = 4.0 Hz, 1H), 4.90 (d, *J* = 1.9 Hz, 1H), 4.82 (d, *J* = 11.7 Hz, 1H), 4.62 – 4.57 (m, 2H), 4.52 (d, *J* = 11.8 Hz, 1H), 4.44 (d, *J* = 12.0 Hz, 1H), 4.36 (d, *J* = 12.0 Hz, 1H), 4.26 – 4.20 (m, 1H), 4.11 – 4.05 (m, 3H), 3.93 (dd, *J* = 11.5, 2.1 Hz, 1H), 3.68 (dd, *J* = 11.3, 6.1 Hz, 1H), 3.50 (dd, *J* = 5.9, 3.1 Hz, 2H), 3.40 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.71, 165.58, 165.54, 138.26, 138.12, 138.01, 133.53, 133.50, 133.23, 130.10, 129.91, 129.83, 129.34, 129.27, 129.19, 128.67, 128.55, 128.43, 128.41, 128.38, 128.20, 127.84, 127.78, 127.72, 127.68, 101.22, 98.38, 84.24, 83.51, 80.62, 73.30, 72.51, 72.31, 72.18, 70.42, 70.29, 70.24, 67.31, 66.17, 55.48. The data are identical to the literature report.^[117]

3.4.5.4. Plausible reaction pathway for the 1,2-*cis*-furanosylations with MDMPA thioglycoside donors.

Following a series of experiments investigating chelation-controlled selectivity induction, we proposed a detailed reaction mechanism for the transformation (**Figure 3.4.2.2**). The process begins with the decomposition of the diazo compound with Fe(OTf)₃, generating the iron-

carbene intermediate **A**. Subsequent nucleophilic attack by the anomeric sulfur atom on the carbene center forms the five-membered iron-bound substituted dihydrobenzo[*c*]thiophene sulfur ylide **B**. Intermediate **B** then undergoes protodemetalation with the coming acceptor to form sulfonium ion intermediate **C**, and the iron forms a complex with the acceptor while remaining in the +III oxidation state. Glycosyl sulfonium ion **C** then eliminates the methyl 1,3-dihydrobenzo[*c*]thiophene-1-carboxylate as a byproduct and forms oxocarbenium ion **D** through

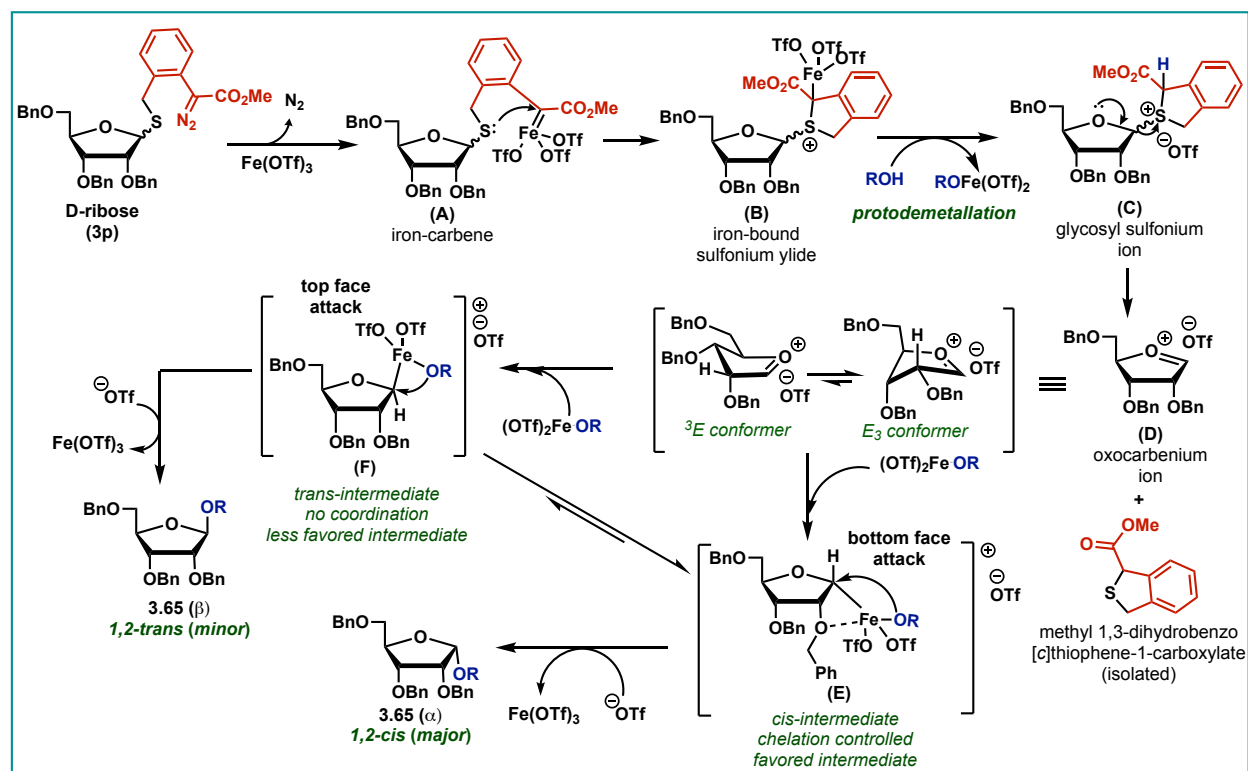


Figure 3.4.5.4. The plausible reaction pathway for the 1,2-*cis* furanosylation using chelation-controlled stereoselective induction.

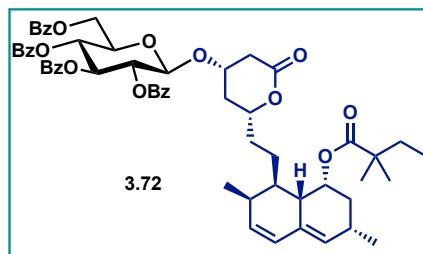
the push of the oxygen lone pair of the thioacetal. The resulting oxocarbenium ion **D** can adopt two conformations, *E*₃ and ³*E*, with *E*₃ as the more stable conformation favored for nucleophilic attack. The activated iron-acceptor species then reacts with the intermediate, which subsequently engages with the oxocarbenium ion in two different ways. In the case of the *cis* transition state **E**, stabilization is achieved through chelation between the C2-oxygen and iron. In contrast, no such stabilization is observed in the *trans*-transition state **F**. As a result, transition state **E** is determined to be more stable than transition state **F**. The release of Fe(III)OTf from transition state **E** yields the corresponding contra-thermodynamic α-1,2-*cis*-furanosylation

product **3.65**(α). Conversely, non-coordinated transition state **F** can lead to the corresponding β -1,2-*trans*-product **3.65**(β).

3.4.5.5. Applications of MDMPA thioglycoside donors.

Simvastatinyl 2,3,4,6-tetra-O-benzoyl- β -D-glucopyranoside (**3.72**)

Following the general procedure **D**, glycosyl acceptor simvastatin (**11.0** mg, **26.0** μ mol) was coupled with MDMPAT donor **3.1b** (**31.0** mg, **39.0** μ mol) to afford **3.72** (**23.0** mg, **23.0** μ mol, **88%** yield) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).



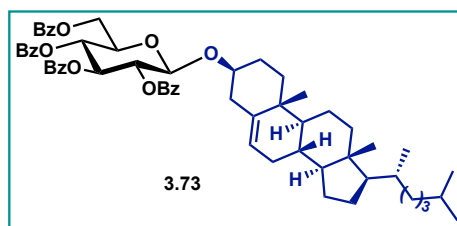
^1H NMR (399 MHz, CDCl_3) δ 8.03 (d, J = 8.6 Hz, 2H), 7.96 (d, J = 7.0 Hz, 2H), 7.91 (d, J = 8.2 Hz, 2H), 7.82 (d, J = 8.6 Hz, 2H), 7.56 (t, J = 7.4 Hz, 1H), 7.52 – 7.48 (m, 2H), 7.44 (s, 1H), 7.44 – 7.40 (m, 3H), 7.38 (s, 1H), 7.34 (d, J = 7.7 Hz, 2H), 7.29 (d, J = 8.0 Hz, 2H), 5.98 – 5.90 (m, 2H), 5.75 – 5.64 (m, 2H), 5.53 – 5.48 (m, 2H), 5.20 (d, J = 3.3 Hz, 1H), 4.97 (d, J = 7.8 Hz, 1H), 4.67 (dd, J = 12.2, 3.2 Hz, 1H), 4.49 (dd, J = 12.2, 5.3 Hz, 1H), 4.33 – 4.28 (m, 1H), 4.21 – 4.16 (m, 1H), 2.87 (dd, J = 17.3, 3.1 Hz, 1H), 2.73 (dd, J = 17.9, 5.5 Hz, 1H), 2.45 (s, 1H), 2.22 (q, J = 6.3 Hz, 1H), 2.01 (s, 1H), 1.98 – 1.93 (m, 2H), 1.68 (td, J = 13.1, 6.6 Hz, 1H), 1.50 (dt, J = 13.5, 7.3 Hz, 4H), 1.08 (d, J = 5.9 Hz, 11H), 0.79 (t, J = 7.5 Hz, 5H), 0.68 (d, J = 7.1 Hz, 4H).

^{13}C NMR (100 MHz, CDCl_3) δ 177.82, 169.45, 166.22, 165.86, 165.26, 164.87, 133.61, 133.44, 133.35, 132.94, 131.50, 129.95, 129.86, 129.81, 129.56, 129.23, 128.78, 128.60, 128.57, 128.54, 128.44, 128.40, 100.14, 72.69, 72.47, 71.88, 70.53, 69.62, 67.69, 63.02, 53.55, 43.05, 37.37, 37.05, 36.50, 33.18, 33.05, 32.59, 30.53, 29.81, 27.36, 24.89, 23.22, 23.11, 13.96, 9.46.

HRMS (ESI): calc. for $\text{C}_{59}\text{H}_{64}\text{NaO}_{14}$ ($\text{M}+\text{Na}$): 1019.4194; found: 1019.4227.

Cholesteryl 2,3,4,6-tetra-O-benzoyl- β -D-glucopyranoside (**3.73**)

Following the general procedure **D**, glycosyl acceptor cholesterol **A4** (**12.0** mg, **31.0** μ mol) was coupled with MDMPAT donor **3.1b** (**37.0** mg, **46.0** μ mol) to afford **3.73** (**28.8** mg, **29.8** μ mol, **96%** yield) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 70:30).

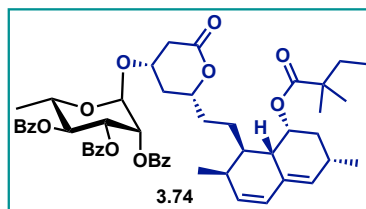


^1H NMR (399 MHz, CDCl_3) δ 7.99 (dd, J = 8.4, 1.3 Hz, 2H), 7.94 (dd, J = 8.4, 1.4 Hz, 2H), 7.89 (dd, J = 8.4, 1.3 Hz, 2H), 7.82 (dd, J = 8.4, 1.3 Hz, 2H), 7.55 – 7.52 (m, 1H), 7.51 (dd, J = 2.7, 1.4 Hz, 1H), 7.49 (d, J = 0.9 Hz, 1H), 7.47 – 7.43 (m, 1H), 7.42 – 7.39 (m, 2H), 7.37 (d, J = 1.1 Hz, 2H), 7.36 (d, J = 1.8 Hz, 1H), 7.33 (s, 1H), 7.30 (d, J = 3.9 Hz, 1H), 7.27 (s, 1H), 5.88 (t, J = 9.7 Hz, 1H), 5.61 (t, J = 9.7 Hz, 1H), 5.48 (dd, J = 9.8, 7.9 Hz, 1H), 5.21 (d, J = 5.4 Hz, 1H), 4.92 (d, J = 7.9 Hz, 1H), 4.59 (dd, J = 12.1, 3.4 Hz, 1H), 4.50 (dd, J = 11.9, 5.8 Hz, 1H), 4.19 – 4.10 (m, 1H), 3.51 (dt, J = 9.8, 5.3 Hz, 1H), 2.17 – 1.96 (m, 3H), 1.90 (d, J = 16.5 Hz, 2H), 1.70 (d, J = 13.0 Hz, 1H), 1.51 – 1.46 (m, 2H), 1.43 – 1.35 (m, 4H), 1.32 (d, J = 7.5 Hz, 3H), 1.15 – 1.04 (m, 5H), 0.91 – 0.81 (m, 15H), 0.63 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.21, 165.96, 165.35, 165.21, 140.43, 133.54, 133.19, 129.94, 129.88, 129.85, 129.83, 128.94, 128.52, 128.47, 128.45, 128.39, 126.44, 124.57, 122.07, 100.25, 80.58, 72.15, 70.14, 56.82, 56.21, 50.18, 42.38, 39.60, 38.89, 36.71, 36.26, 35.86, 31.88, 28.31, 28.11, 24.36, 23.89, 22.92, 22.66, 19.36, 18.80, 11.92. The data are identical to the literature report.^[99]

Simvastatinyl 2,3,4-tri-*O*-benzoyl- α -L-rhamnopyranoside (**3.74**)

Following the general procedure **D**, glycosyl acceptor simvastatin (500.0 mg, 1.19 mmol) was coupled with MDMPAT donor **3.1g** (1.02 g, 1.49 mmol, 1.25 equiv.) using $\text{Fe}(\text{OTf})_3$ as a catalyst (18 mg, 36.0 μmol , 3 mol%) to afford **3.74** (0.980 g, 1.12 mmol, 93% yield) as a white solid. R_f = 0.5 (hexane: EtOAc = 70:30).

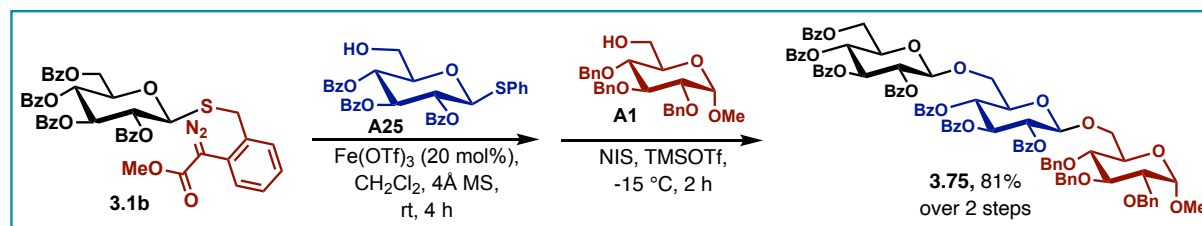


^1H NMR (399 MHz, CDCl_3) δ 8.11 – 8.06 (m, 2H), 8.02 – 7.98 (m, 2H), 7.85 – 7.80 (m, 2H), 7.64 – 7.59 (m, 1H), 7.55 – 7.47 (m, 3H), 7.45 – 7.38 (m, 3H), 7.26 (s, 2H), 6.00 (d, J = 9.6 Hz, 1H), 5.80 (dd, J = 9.6, 6.1 Hz, 1H), 5.75 – 5.66 (m, 2H), 5.60 (dd, J = 3.1, 1.7 Hz, 1H), 5.51 (t, J = 3.2 Hz, 1H), 5.41 (q, J = 3.2 Hz, 1H), 5.16 (d, J = 1.7 Hz, 1H), 4.71 – 4.63 (m, 1H), 4.35 (t, J = 4.3

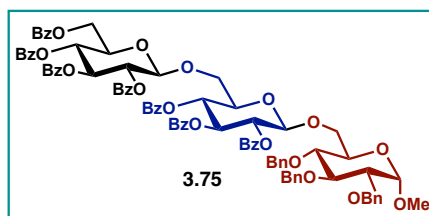
Hz, 1H), 4.17 (dd, $J = 8.9, 6.2$ Hz, 1H), 2.97 – 2.90 (m, 1H), 2.81 (dd, $J = 17.4, 5.1$ Hz, 1H), 2.48 – 2.37 (m, 2H), 2.32 – 2.18 (m, 2H), 1.99 – 1.87 (m, 3H), 1.72 (dq, $J = 9.9, 4.9$ Hz, 3H), 1.61 – 1.51 (m, 3H), 1.38 (dd, $J = 13.6, 7.2$ Hz, 5H), 1.13 (s, 6H), 1.08 (d, $J = 7.4$ Hz, 3H), 0.92 (d, $J = 7.0$ Hz, 3H), 0.83 (t, $J = 7.4$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.63, 165.76, 165.50, 133.73, 133.55, 133.29, 133.01, 131.67, 130.03, 129.95, 129.87, 129.82, 129.34, 129.19, 128.75, 128.60, 128.53, 128.42, 97.18, 71.46, 71.07, 70.31, 69.87, 68.02, 67.63, 43.12, 37.62, 36.96, 36.77, 33.67, 33.15, 33.07, 32.92, 30.76, 27.42, 24.92, 24.10, 23.14, 17.68, 14.09, 9.50. The data are identical to the literature report.^[99]

One-pot orthogonal synthesis of Methyl 2,3,4,6-tetra-*O*-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.75**).**



In an oven-dried vial equipped with a stir bar, acceptor **A25** (15.0 mg, 25.66 μmol) was combined with MDMPA thioglycoside donor **3.1b** (31.0 mg, 31.49 μmol , 1.5 equiv.), 4Å molecular sieves (50 mg or 100 wt.%), and $\text{Fe}(\text{OTf})_3$ (2.6 mg, 5.13 μmol , 20 mol%) dissolved in CH_2Cl_2 (0.05M). Upon complete addition, the reaction mixture was stirred at the ambient temperature. TLC monitored the reaction progress upon complete consumption of acceptor **A25**. The reaction mixture was cooled to -15°C and acceptor **A1** (12.0 mg, 25.66 μmol) was added, followed by **NIS** (8.66 mg, 38.49 μmol) into the stirred reaction mixture. The reaction mixture was stirred at the same temperature for 10 minutes before the addition of **TMSOTf** (52.0 μL , 0.1 M, 5.13 μmol , 20 mol%). Then, the reaction was stirred at the same temperature for the next 2 hours and quenched by the addition of saturated aqueous NaHCO_3 upon complete consumption of **A1**. The layers were separated, and the aqueous layer was washed with ethyl acetate. The organic layers were combined, dried over Na_2SO_4 , filtered, and evaporated under reduced pressure. The resulting crude material was purified by column chromatography to afford the desired trisaccharide **3.75** (31.5 mg, 20.76 μmol , 81% overall yield over two steps) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).



^1H NMR (399 MHz, CDCl_3) δ 8.02 – 7.98 (m, 3H), 7.94 – 7.89 (m, 2H), 7.86 – 7.73 (m, 12H), 7.56 – 7.46 (m, 4H), 7.44 – 7.37 (m, 6H), 7.36 – 7.26 (m, 20H), 7.22 (dd, J = 7.5, 4.7 Hz, 5H), 7.13 (t, J = 7.9 Hz, 2H), 6.95 – 6.92 (m, 2H), 5.82 (t, J = 9.7 Hz, 1H), 5.74 (t, J = 9.7 Hz, 1H), 5.58 (t, J = 9.7 Hz, 1H), 5.45 (td, J = 9.6, 7.9 Hz, 2H), 5.31 – 5.25 (m, 1H), 4.97 (d, J = 7.7 Hz, 1H), 4.86 (d, J = 11.0 Hz, 1H), 4.72 (d, J = 12.1 Hz, 1H), 4.65 (d, J = 10.9 Hz, 1H), 4.58 (d, J = 3.5 Hz, 1H), 4.55 (d, J = 3.5 Hz, 2H), 4.47 (d, J = 7.8 Hz, 1H), 4.38 (dd, J = 12.2, 5.3 Hz, 1H), 4.33 (d, J = 11.2 Hz, 1H), 4.12 (d, J = 11.3 Hz, 1H), 4.07 – 4.02 (m, 1H), 4.00 (d, J = 9.6 Hz, 1H), 3.85 (dd, J = 21.1, 9.5 Hz, 4H), 3.47 (d, J = 9.9 Hz, 1H), 3.41 – 3.35 (m, 2H), 3.32 (s, 3H).

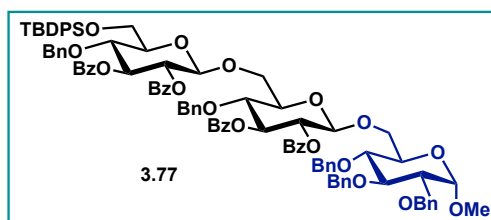
^{13}C NMR (100 MHz, CDCl_3) δ 166.20, 165.82, 165.44, 165.23, 165.19, 164.94, 138.96, 138.43, 138.27, 133.60, 133.47, 133.30, 129.94, 129.87, 129.81, 129.76, 129.61, 129.35, 128.80, 128.73, 128.59, 128.55, 128.52, 128.45, 128.40, 128.37, 128.34, 128.26, 128.01, 127.94, 127.60, 127.41, 101.49, 100.78, 98.27, 81.94, 79.72, 75.55, 74.56, 74.43, 73.55, 72.73, 72.35, 72.06, 71.79, 69.68, 69.53, 69.39, 68.56, 67.55, 63.03, 55.45.

HRMS (ESI): calc. for $\text{C}_{89}\text{H}_{80}\text{NaO}_{23}$ ($\text{M}+\text{Na}$): 1539.4988; found: 1539.5024.

3.4.5.6. Iterative synthesis of hexasaccharides

Methyl (2,3-di-*O*-benzoyl-4-*O*-benzyl-6-*O*-tert-butyldiphenylsilyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.77)

Following the general procedure **D**, glycosyl acceptor **3.76**^[99] (45.0 mg, 48.65 μmol) was coupled with MDMPAT donor **3.1d** (80.66 mg, 87.56 μmol) to afford **3.77** (65.0 mg, 39.41 μmol , 88% yield) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

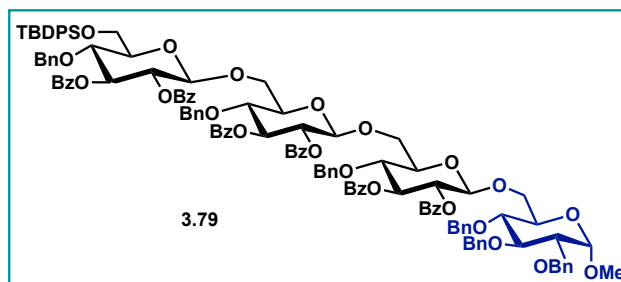


¹H NMR (399 MHz, CDCl₃) δ 7.96 – 7.89 (m, 4H), 7.82 – 7.78 (m, 6H), 7.73 (dd, *J* = 7.9, 1.5 Hz, 2H), 7.52 – 7.45 (m, 2H), 7.45 – 7.34 (m, 11H), 7.33 – 7.29 (m, 6H), 7.28 (d, *J* = 4.7 Hz, 3H), 7.26 – 7.19 (m, 8H), 7.15 – 7.10 (m, 8H), 7.03 (dd, *J* = 7.4, 2.1 Hz, 2H), 6.97 – 6.94 (m, 2H), 6.93 – 6.89 (m, 2H), 5.71 (t, *J* = 9.6 Hz, 1H), 5.63 – 5.57 (m, 1H), 5.43 (dd, *J* = 9.9, 7.8 Hz, 1H), 5.34 (dd, *J* = 9.9, 7.9 Hz, 1H), 4.87 – 4.80 (m, 2H), 4.73 – 4.61 (m, 4H), 4.57 (d, *J* = 12.2 Hz, 1H), 4.51 (d, *J* = 3.5 Hz, 1H), 4.46 (d, *J* = 7.9 Hz, 1H), 4.33 – 4.22 (m, 4H), 4.13 – 4.05 (m, 2H), 4.02 – 3.97 (m, 3H), 3.84 (t, *J* = 9.4 Hz, 1H), 3.77 – 3.71 (m, 1H), 3.63 – 3.49 (m, 5H), 3.40 – 3.31 (m, 2H), 3.22 (s, 3H), 1.11 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 166.47, 165.86, 165.82, 165.35, 138.95, 138.34, 137.10, 136.03, 135.69, 133.28, 133.03, 129.84, 129.79, 129.70, 129.33, 128.52, 128.41, 128.37, 128.33, 128.22, 128.03, 127.96, 127.89, 127.81, 127.78, 127.53, 127.40, 101.36, 100.92, 98.13, 81.96, 79.71, 76.09, 75.11, 74.63, 73.46, 72.57, 71.97, 55.38, 53.54, 26.99, 19.44. The data are identical to the literature report.^[99]

Methyl (2,3-di-*O*-benzoyl-4-*O*-benzyl-6-*O*-tert-butyldiphenylsilyl-β-D-glucopyranosyl)-(1→6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl-β-D-glucopyranosyl)-(1→6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (3.79)

Following the general procedure **D**, glycosyl acceptor **3.78**^[99] (49.0 mg, 35.37 μmol) was coupled with MDMPAT donor **3.1d** (58.64 mg, 87.56 μmol) to afford **3.79** (65.0 mg, 31.18 μmol, 88% yield) as a colorless viscous oil. *R*_f = 0.3 (hexane: EtOAc = 70:30).



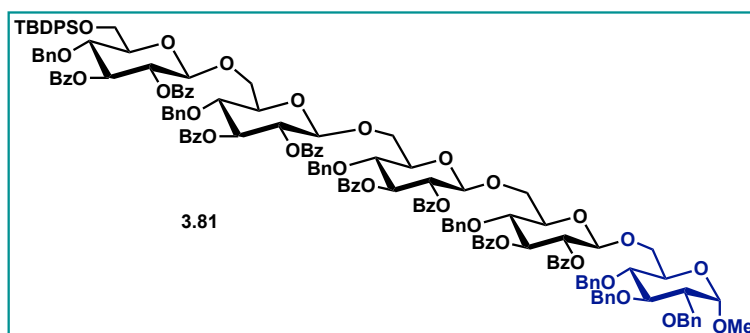
¹H NMR (400 MHz, CDCl₃) δ 7.95 (td, *J* = 8.3, 1.4 Hz, 4H), 7.88 (dd, *J* = 8.5, 1.3 Hz, 2H), 7.83 – 7.77 (m, 8H), 7.73 (dd, *J* = 8.0, 1.5 Hz, 2H), 7.53 – 7.44 (m, 3H), 7.44 – 7.27 (m, 23H), 7.25 (t, *J* = 1.4 Hz, 2H), 7.23 – 7.19 (m, 7H), 7.15 – 7.07 (m, 11H), 7.02 (dd, *J* = 7.7, 1.9 Hz, 2H), 6.96 – 6.91 (m, 4H), 6.89 – 6.86 (m, 2H), 5.75 (t, *J* = 9.6 Hz, 1H), 5.58 (ddd, *J* = 18.7, 9.9, 8.9 Hz, 2H), 5.48 (dd, *J* = 9.9, 7.9 Hz, 1H), 5.31 (ddd, *J* = 9.8, 7.8, 4.7 Hz, 2H), 4.85 (d, *J* = 11.0 Hz, 1H), 4.76 (d, *J* = 7.8 Hz, 1H), 4.73 – 4.69 (m, 2H), 4.65 (d, *J* = 11.0 Hz, 1H), 4.62 – 4.54 (m, 4H), 4.44 (d, *J* = 7.9 Hz, 1H), 4.32 – 4.26 (m, 3H), 4.26 – 4.19 (m, 2H), 4.16 (d, *J* = 2.3 Hz, 1H), 4.12 (d, *J* = 7.1 Hz, 1H), 4.09 (d, *J* = 1.5 Hz, 1H), 4.06 (d, *J* = 9.6 Hz, 1H), 3.98 (d, *J* = 2.6 Hz,

2H), 3.84 (t, $J = 9.3$ Hz, 1H), 3.76 – 3.50 (m, 9H), 3.47 (dd, $J = 9.9, 4.0$ Hz, 1H), 3.43 – 3.34 (m, 2H), 3.21 (s, 3H), 1.12 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.96, 165.66, 165.61, 165.35, 165.14, 139.01, 138.30, 137.43, 137.21, 137.16, 136.05, 135.69, 133.55, 133.20, 132.98, 129.88, 129.78, 129.68, 129.62, 129.48, 129.36, 129.33, 128.56, 128.51, 128.44, 128.42, 128.38, 128.35, 128.31, 128.23, 128.05, 127.94, 127.91, 127.83, 127.75, 127.74, 127.49, 101.48, 101.27, 100.98, 98.16, 81.93, 79.68, 76.24, 76.12, 76.01, 75.54, 75.37, 75.21, 75.13, 74.67, 73.44, 72.45, 71.93, 69.48, 55.34, 27.02, 19.43. The data are identical to the literature report.^[99]

Methyl (2,3-di-*O*-benzoyl-4-*O*-benzyl-6-*O*-tert-butyldiphenylsilyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-*O*-benzoyl-4-*O*-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (3.81)

Following the general procedure **D**, glycosyl acceptor **3.80**^[99] (51.0 mg, 27.63 μmol) was coupled with MDMPAT donor **3.1d** (43.2 mg, 47.0 μmol) to afford **3.81** (64.5 mg, 25.34 μmol , 92% yield) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).

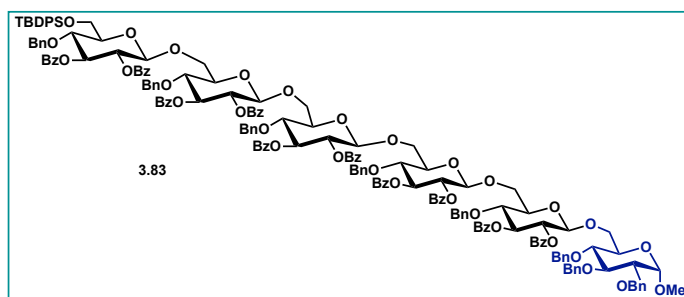


^1H NMR (399 MHz, CDCl_3) δ 7.98 (t, $J = 8.8$ Hz, 4H), 7.89 (t, $J = 8.8$ Hz, 6H), 7.83 (d, $J = 7.8$ Hz, 6H), 7.74 (t, $J = 8.2$ Hz, 4H), 7.51 – 7.39 (m, 7H), 7.38 – 7.28 (m, 20H), 7.24 – 7.15 (m, 11H), 7.13 – 6.90 (m, 23H), 6.86 (d, $J = 7.3$ Hz, 2H), 6.81 (d, $J = 8.7$ Hz, 2H), 5.77 (t, $J = 9.6$ Hz, 1H), 5.72 – 5.62 (m, 3H), 5.55 – 5.33 (m, 4H), 4.89 – 4.83 (m, 2H), 4.77 – 4.69 (m, 3H), 4.65 (d, $J = 11.0$ Hz, 1H), 4.57 (dd, $J = 16.0, 11.8$ Hz, 4H), 4.42 (d, $J = 10.9$ Hz, 1H), 4.36 – 4.28 (m, 3H), 4.27 – 4.18 (m, 5H), 4.15 – 4.02 (m, 5H), 3.98 – 3.75 (m, 9H), 3.61 (ddd, $J = 23.3, 9.4, 5.0$ Hz, 6H), 3.47 – 3.38 (m, 2H), 3.26 (s, 3H), 1.14 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.95, 165.72, 165.68, 165.32, 165.28, 165.23, 164.96, 139.04, 138.57, 138.36, 137.53, 137.48, 137.22, 137.13, 135.97, 135.69, 133.59, 133.37, 133.19, 132.91, 129.95, 129.90, 129.79, 129.64, 129.55, 129.50, 129.46, 129.42, 128.62, 128.51, 128.44, 128.37, 128.34, 128.30, 128.26, 128.23, 128.14, 128.06, 127.95, 127.92, 127.89,

127.85, 127.80, 127.73, 127.48, 127.36, 102.24, 101.81, 101.54, 100.82, 98.06, 82.01, 79.81, 75.59, 75.40, 75.17, 74.94, 74.71, 74.59, 73.41, 72.80, 72.52, 72.20, 69.51, 55.37, 27.05, 19.38. The data are identical to the literature report.^[99]

Methyl (2,3-di-O-benzoyl-4-O-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-O-benzoyl-4-O-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-(2,3-di-O-benzoyl-4-O-benzyl- β -D-glucopyranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (3.83)



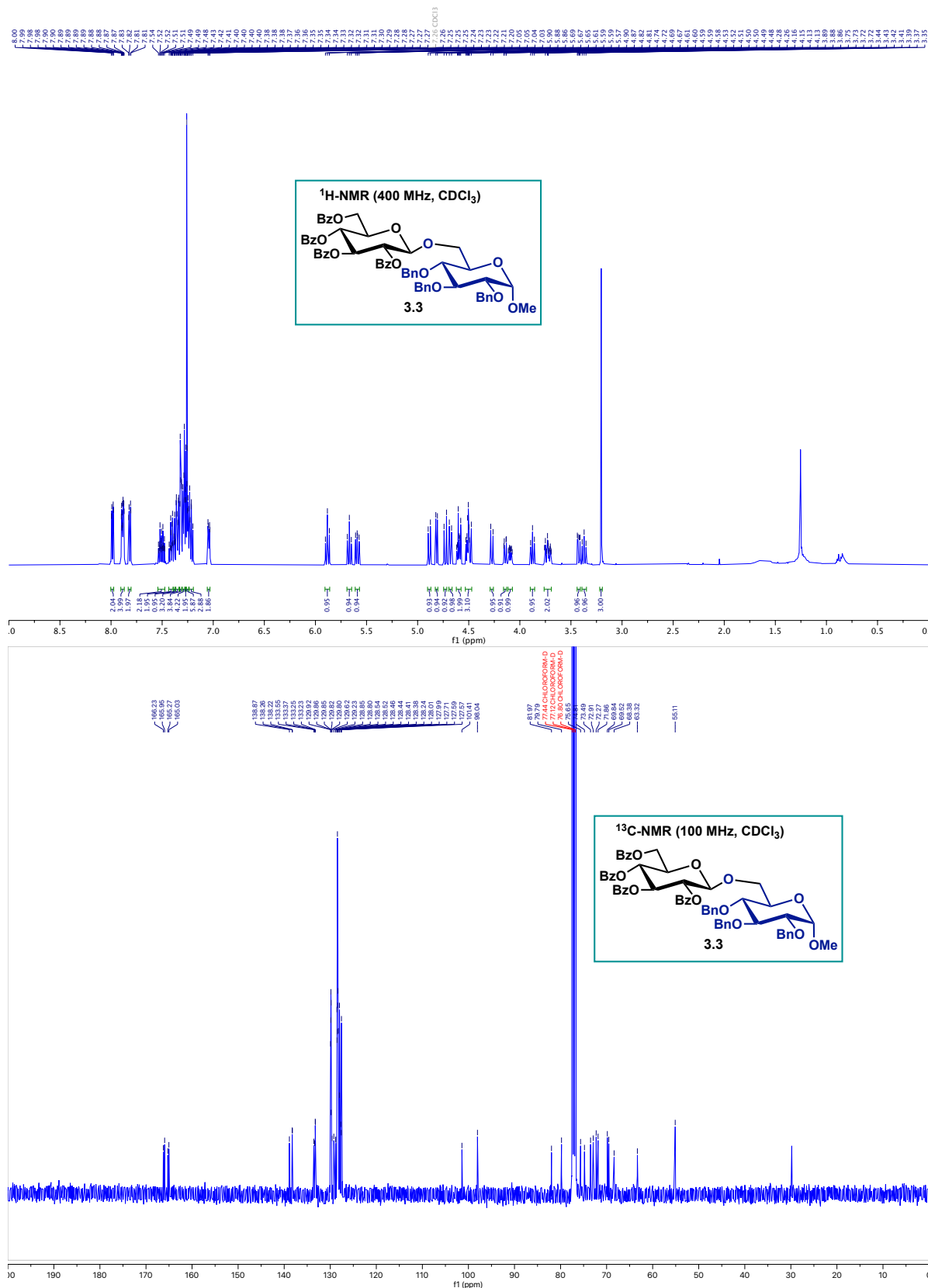
Following the general procedure **D**, glycosyl acceptor **3.82**^[99] (47.0 mg, 20.38 μ mol) was coupled with MDMPAT donor **3.1d** (32.0 mg, 34.64 μ mol) to afford **3.83** (58.0 mg, 19.30 μ mol, 94% yield) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 8.25 (d, J = 7.7 Hz, 2H), 8.13 (d, J = 7.8 Hz, 2H), 8.09 (d, J = 7.8 Hz, 2H), 8.04 (d, J = 7.7 Hz, 2H), 8.01 – 7.96 (m, 10H), 7.67 – 7.62 (m, 2H), 7.61 – 7.42 (m, 9H), 7.42 – 7.27 (m, 20H), 7.25 – 7.18 (m, 8H), 7.14 (dt, J = 6.4, 4.0 Hz, 6H), 7.10 (d, J = 7.3 Hz, 2H), 7.08 – 7.05 (m, 2H), 7.03 (d, J = 1.8 Hz, 2H), 7.02 – 6.98 (m, 7H), 6.95 (d, J = 7.8 Hz, 3H), 6.91 (dd, J = 7.8, 2.9 Hz, 3H), 6.85 (d, J = 7.4 Hz, 1H), 6.74 (t, J = 6.8 Hz, 6H), 6.67 (s, 1H), 6.66 – 6.61 (m, 5H), 6.58 – 6.52 (m, 5H), 6.31 (t, J = 7.8 Hz, 2H), 6.06 (t, J = 9.7 Hz, 1H), 5.98 – 5.92 (m, 2H), 5.78 (td, J = 9.3, 4.1 Hz, 2H), 5.73 – 5.63 (m, 3H), 5.58 (t, J = 8.9 Hz, 2H), 5.45 (d, J = 8.0 Hz, 1H), 5.35 (d, J = 8.0 Hz, 1H), 4.84 (t, J = 9.0 Hz, 2H), 4.72 (d, J = 8.3 Hz, 2H), 4.69 – 4.63 (m, 3H), 4.60 (s, 1H), 4.56 (d, J = 8.5 Hz, 1H), 4.52 (d, J = 2.6 Hz, 1H), 4.41 (dd, J = 10.4, 4.2 Hz, 4H), 4.34 (dd, J = 9.2, 3.4 Hz, 4H), 4.32 – 4.16 (m, 6H), 4.05 (d, J = 11.0 Hz, 2H), 4.03 – 3.96 (m, 2H), 3.87 (dd, J = 12.9, 9.8 Hz, 2H), 3.81 – 3.74 (m, 3H), 3.62 (td, J = 9.8, 5.9 Hz, 3H), 3.53 (dq, J = 8.9, 5.3 Hz, 4H), 3.47 (d, J = 9.4 Hz, 1H), 3.40 (s, 3H), 1.16 (s, 9H).

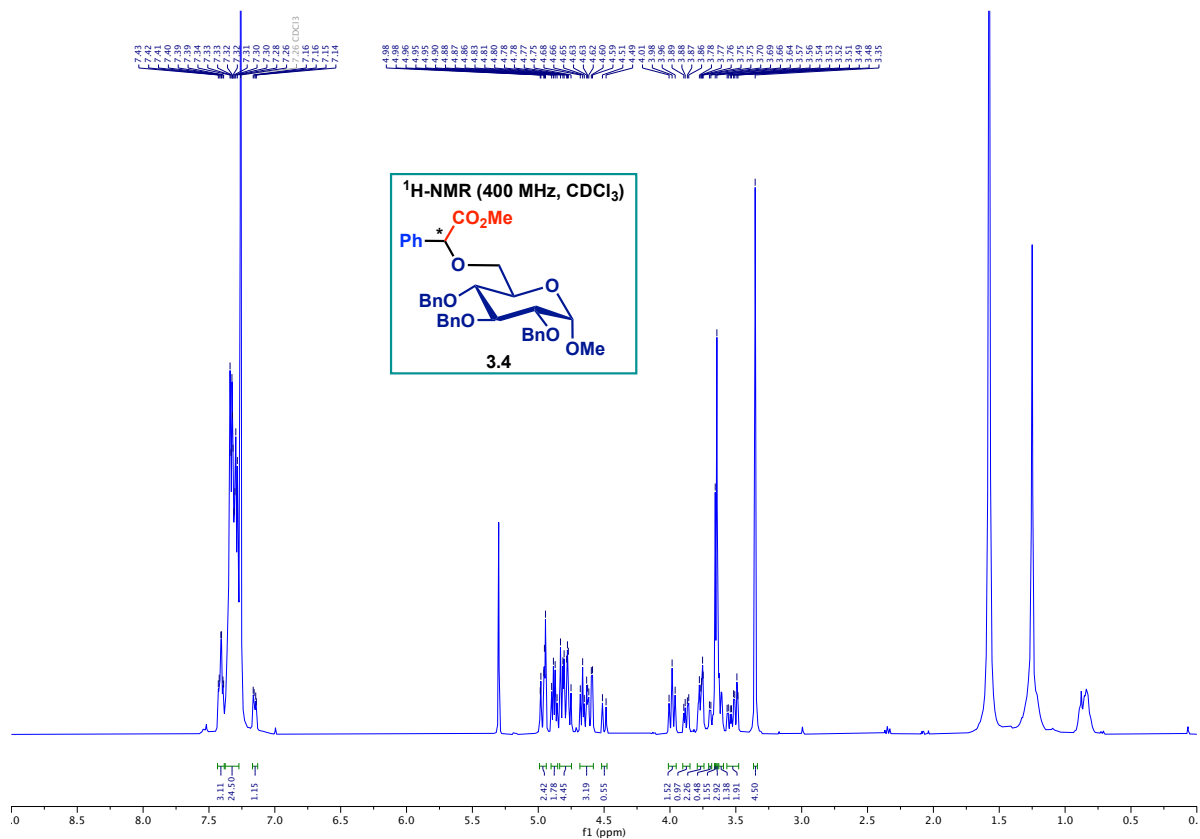
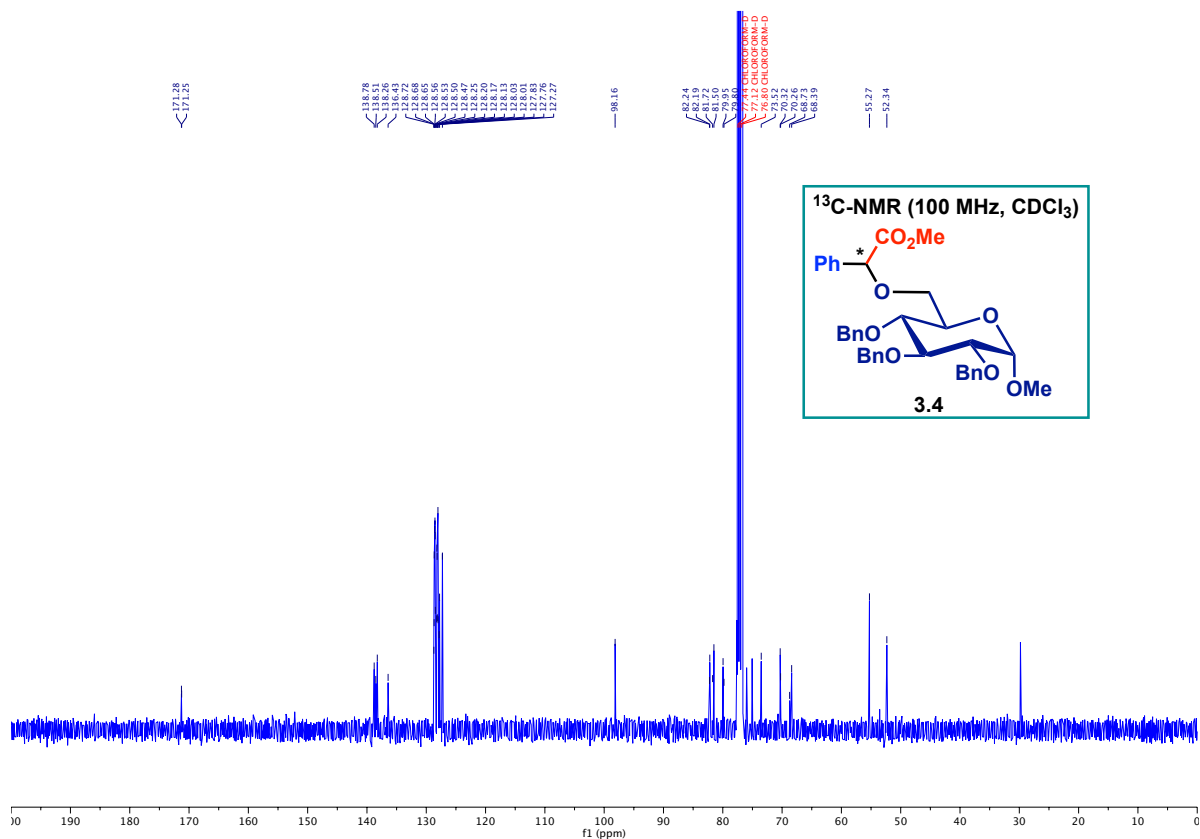
^{13}C NMR (100 MHz, CDCl_3) δ 165.92, 165.89, 165.83, 165.79, 165.52, 164.72, 164.63, 139.11, 138.67, 138.46, 137.82, 137.47, 136.99, 136.73, 135.82, 135.72, 133.69, 133.17, 132.79, 132.51, 131.77, 130.67, 130.33, 130.21, 130.15, 130.07, 129.92, 129.86, 129.79, 129.67, 129.64, 129.57, 128.88, 128.72, 128.61, 128.51, 128.48, 128.39, 128.26, 128.24, 128.18,

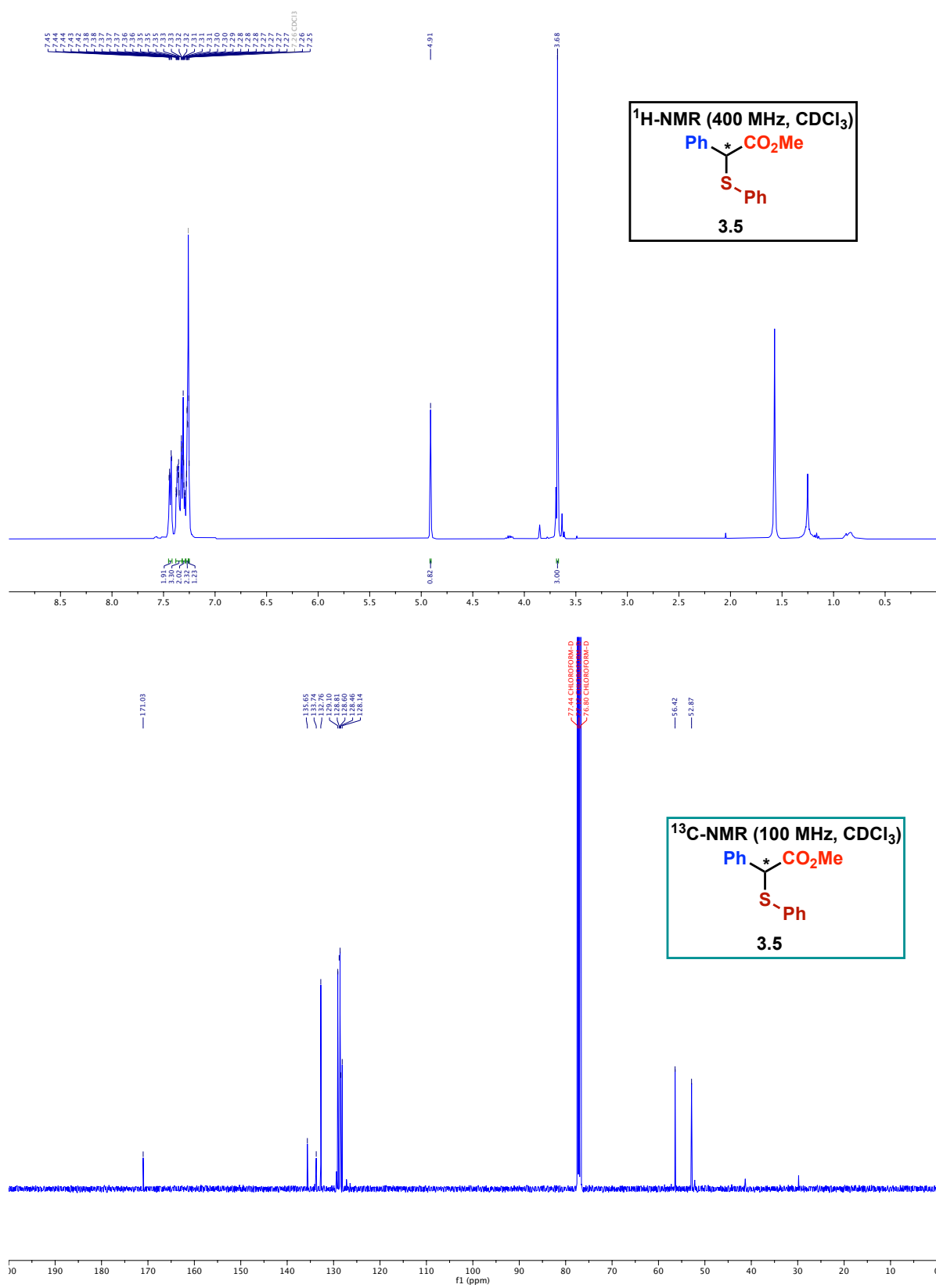
128.14, 128.09, 128.05, 128.02, 127.96, 127.87, 127.83, 127.77, 127.54, 127.47, 127.42, 127.36, 126.97, 104.27, 101.97, 100.20, 97.91, 82.10, 79.90, 78.75, 78.39, 78.03, 76.06, 75.93, 75.64, 75.26, 75.13, 74.99, 74.42, 72.78, 72.51, 69.72, 55.40, 27.08, 19.20. The data are identical to the literature report.^[99]

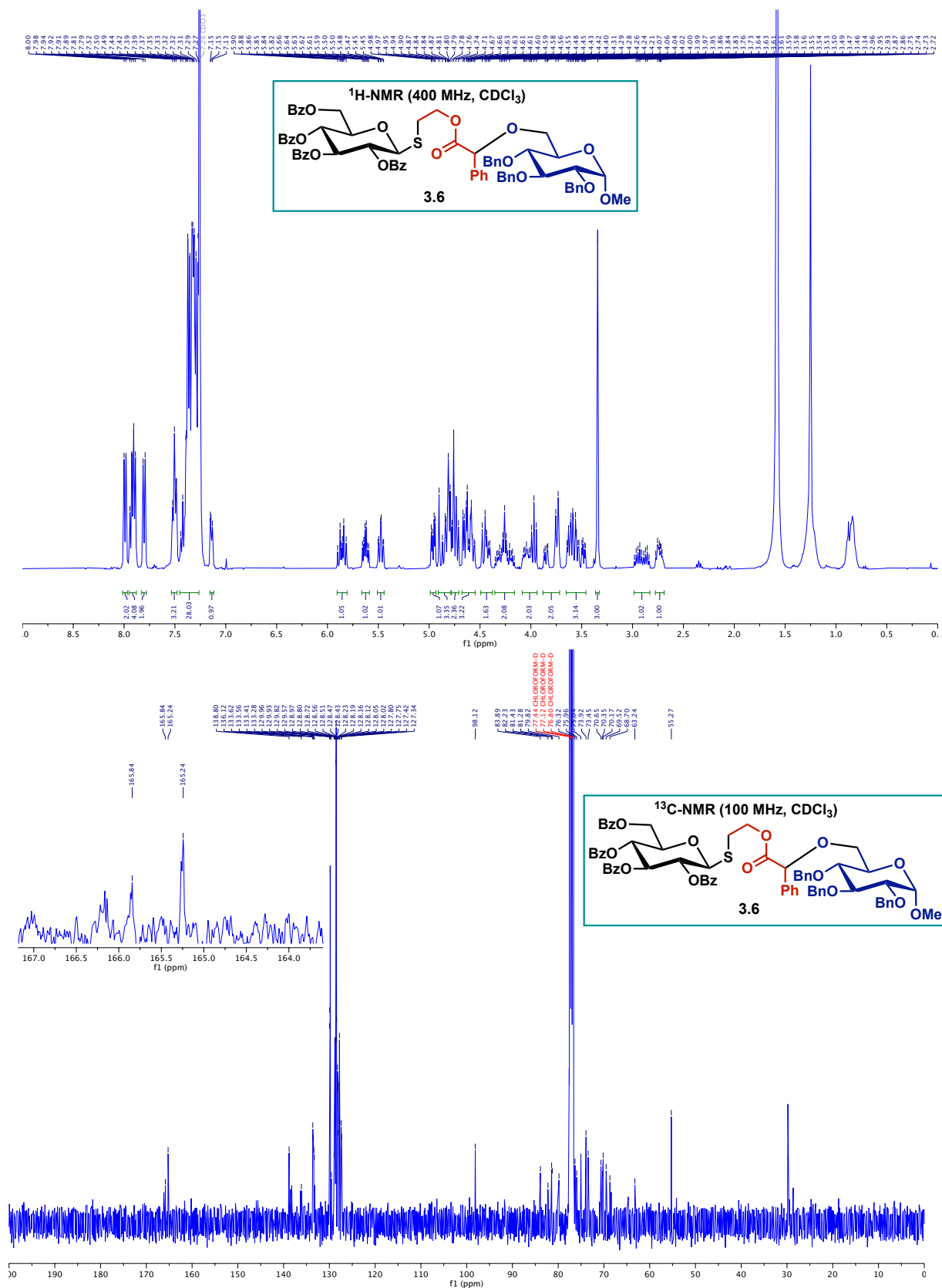
3.5. **Copy of NMR Spectra for Newly Synthesized Compounds** (All the spectra for this chapter are reported in our published article *Nat. Commun.* **2025**)^[118]

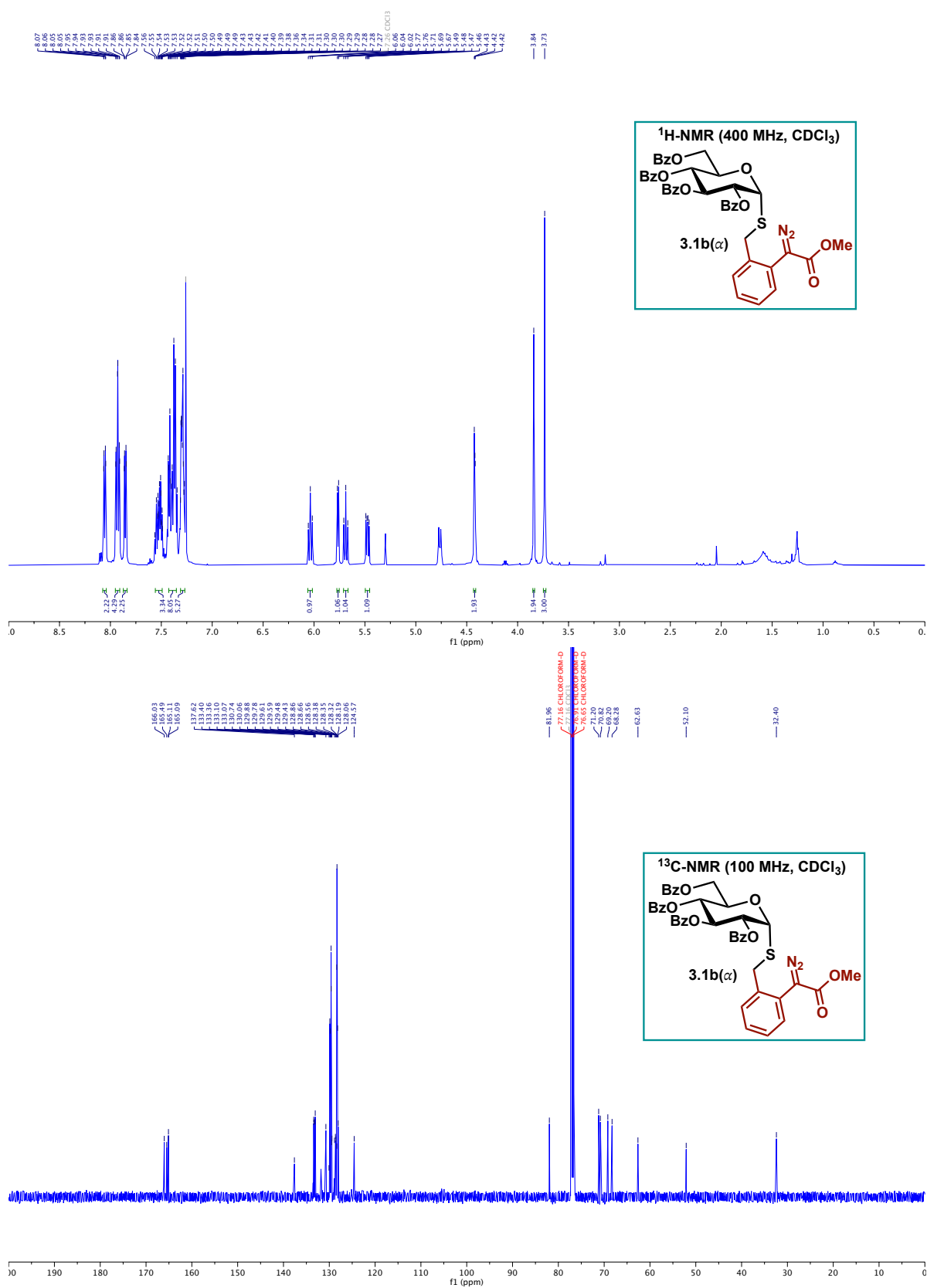


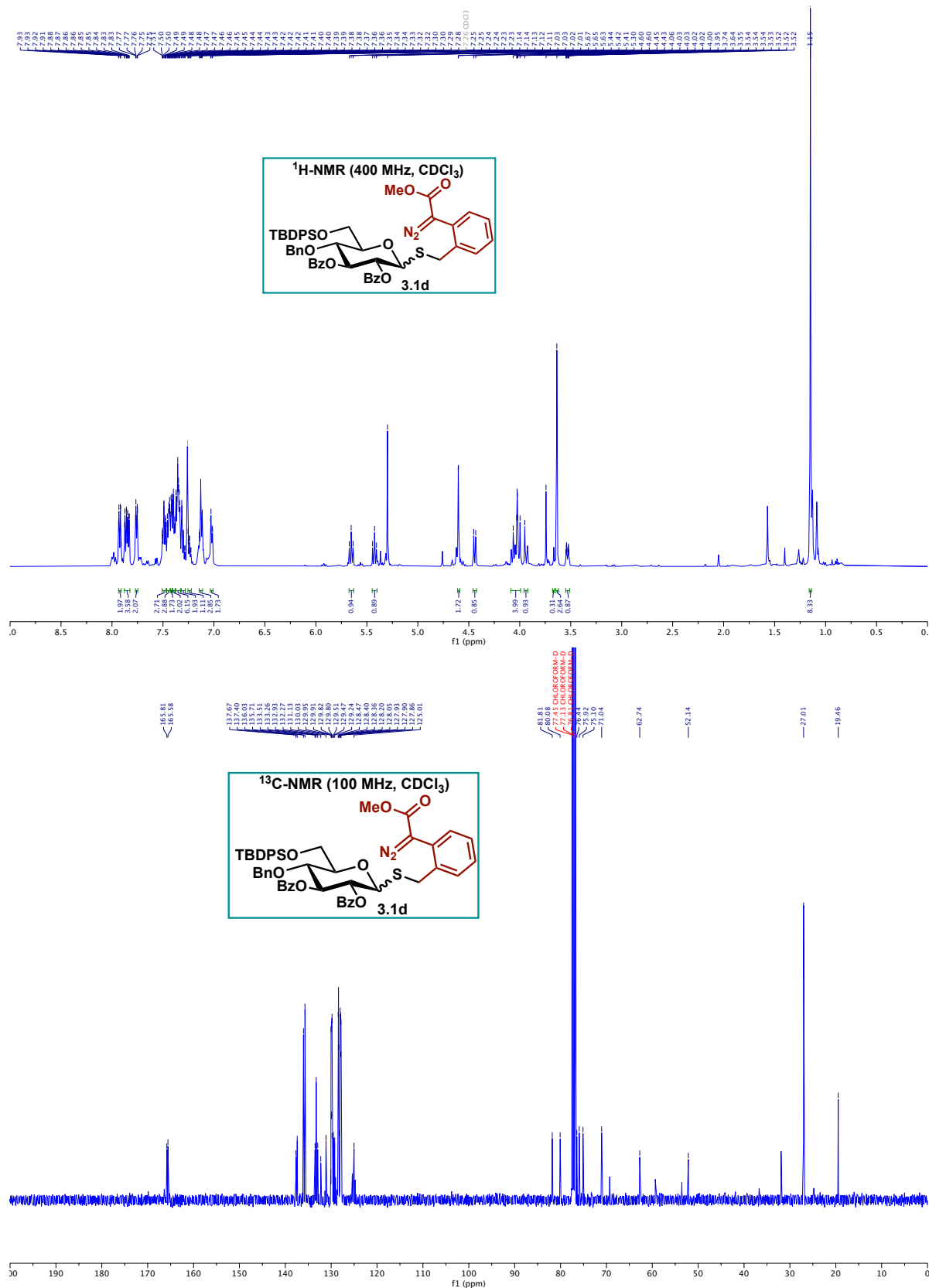
Work discussed in this chapter was published in *Nat. Commun.* **2025**, 16 (1), 3651. The thesis author primarily performed the work reported in the Results and Discussion.

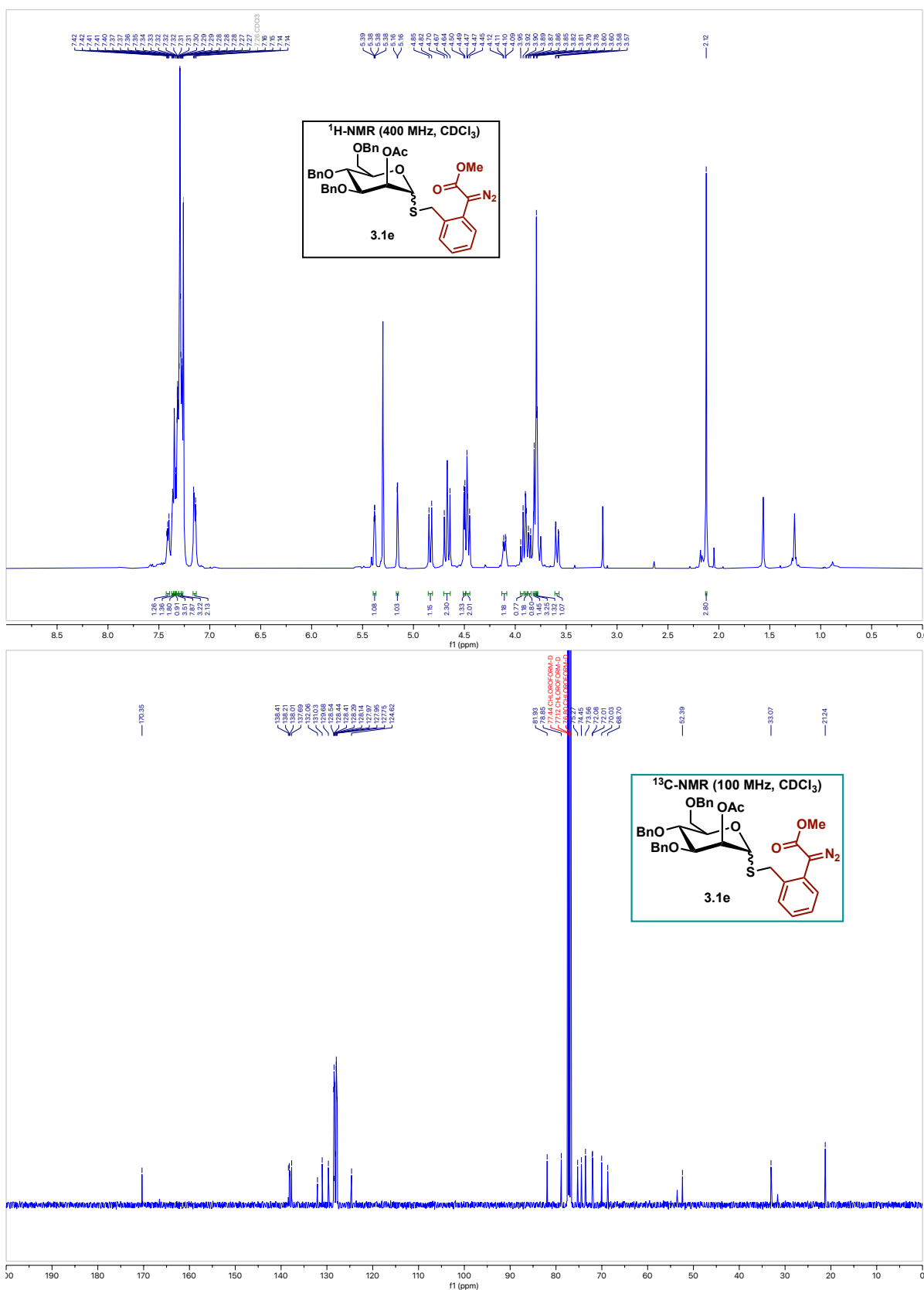


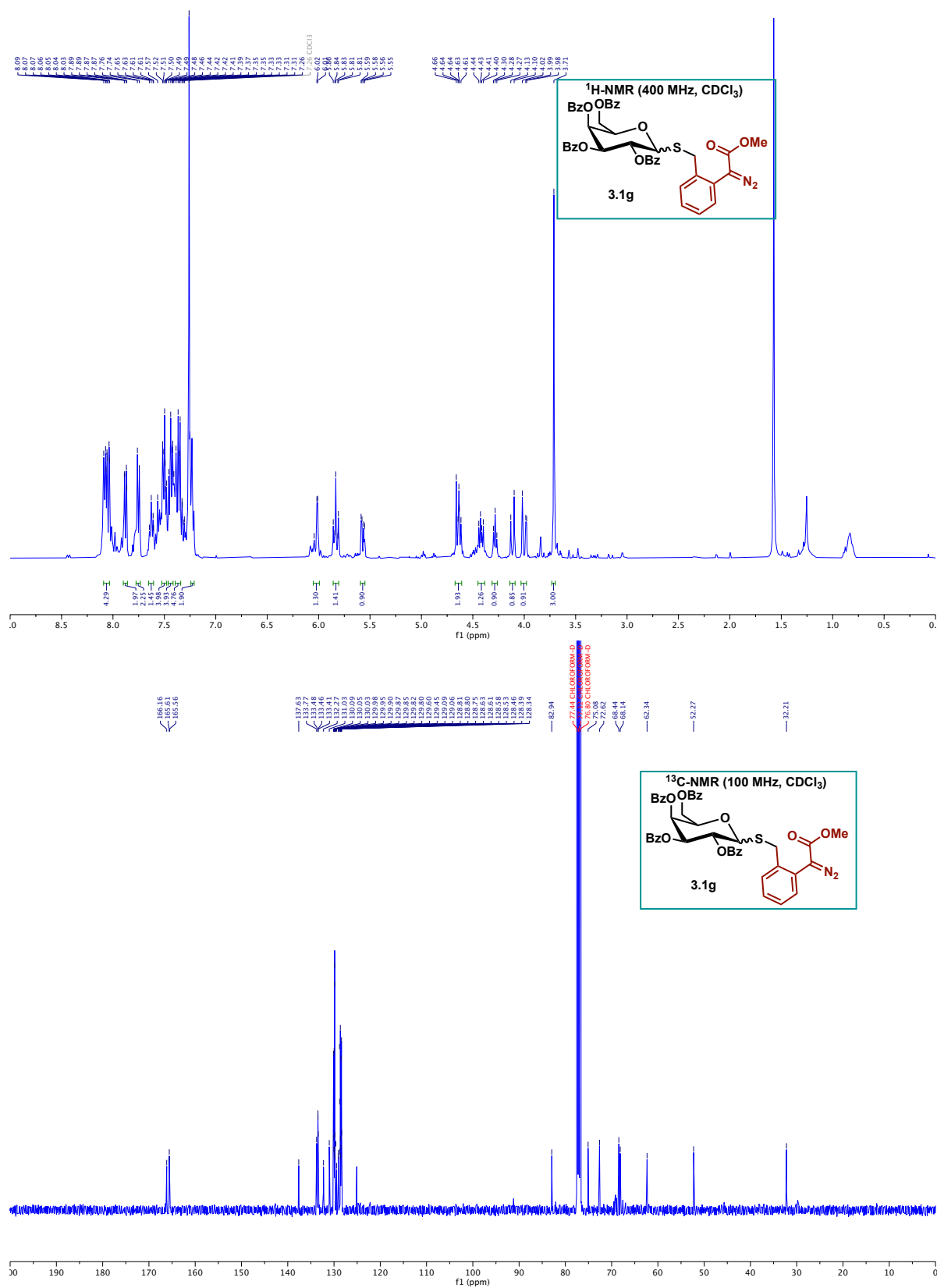


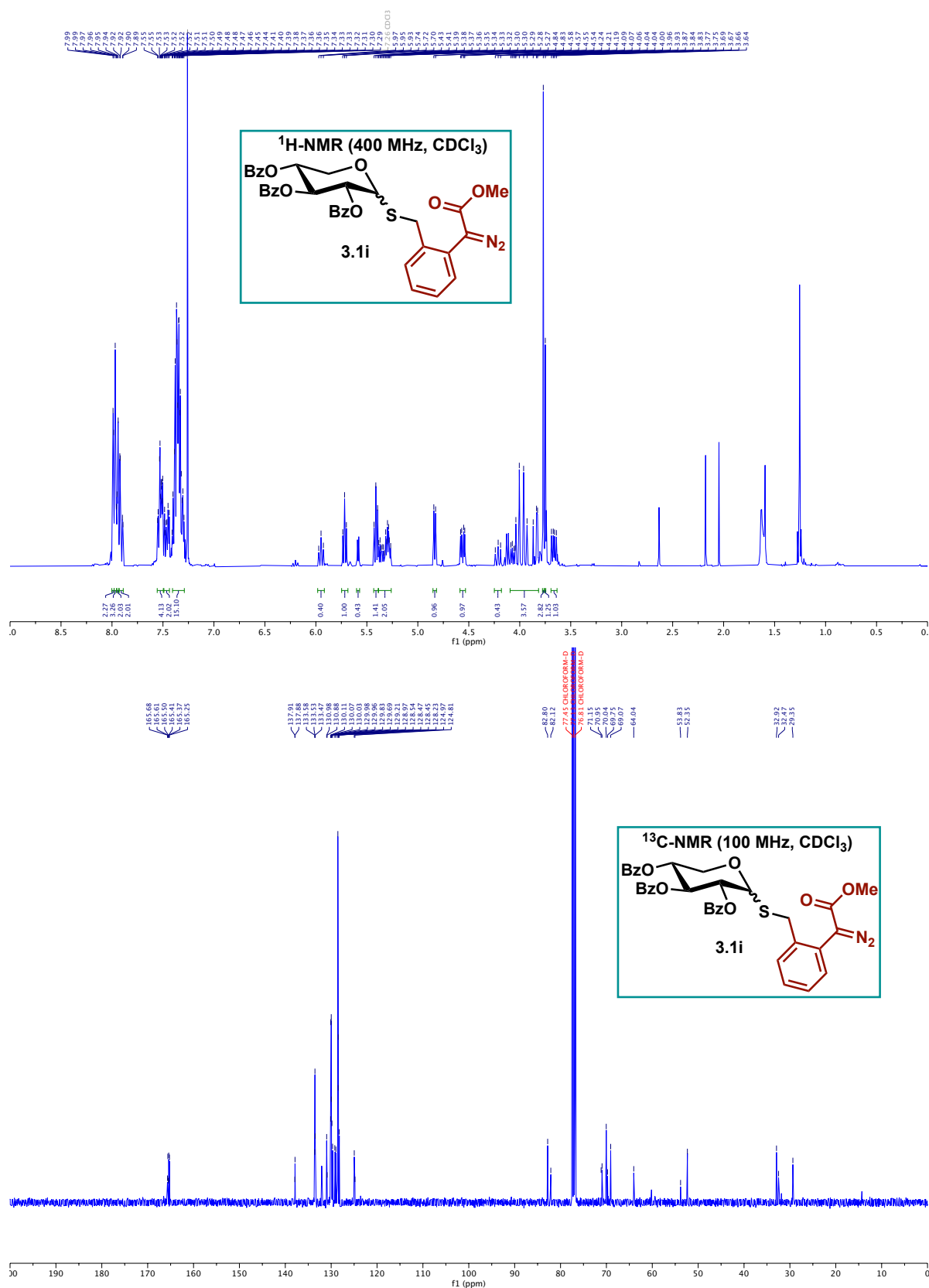


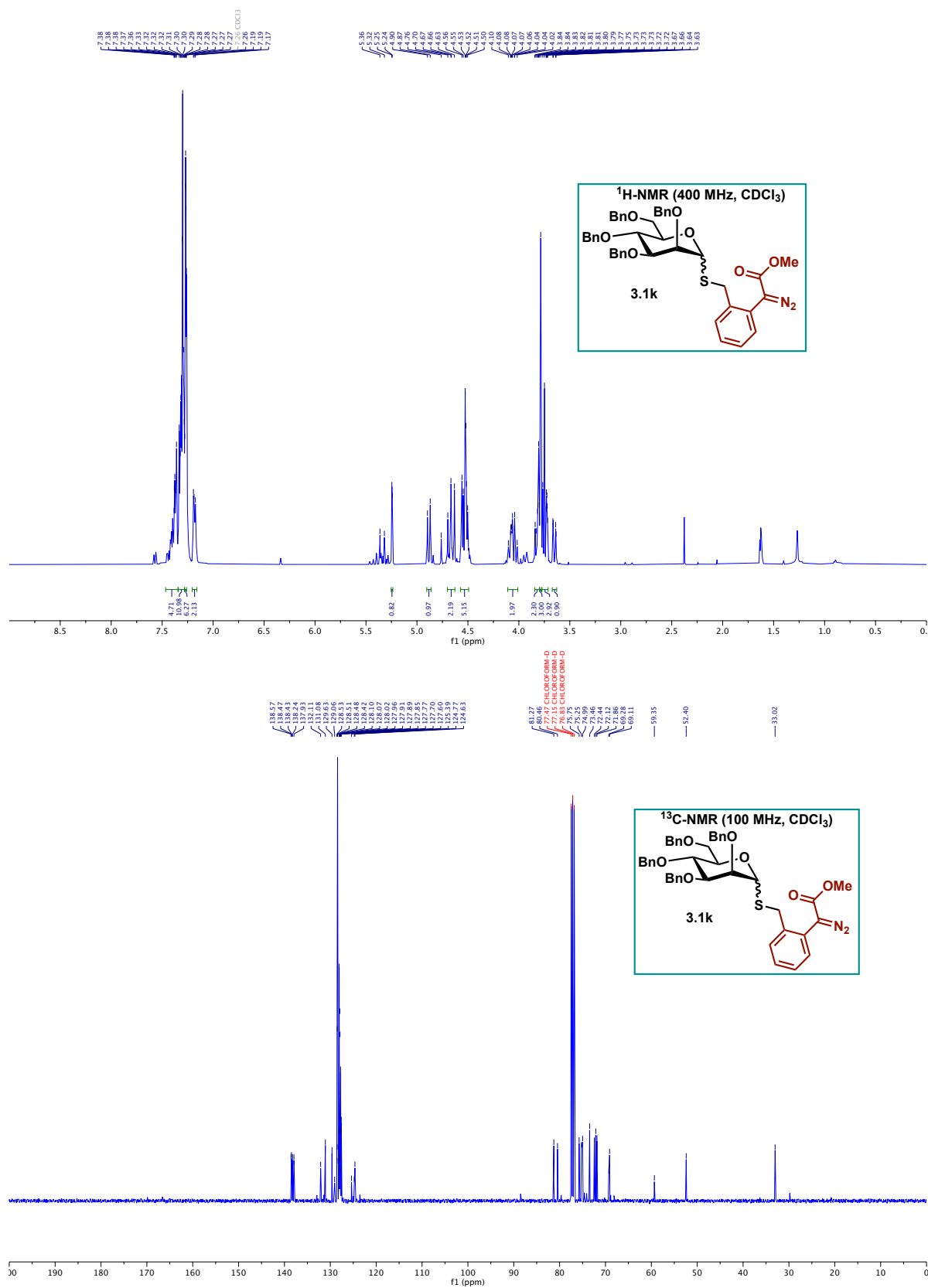


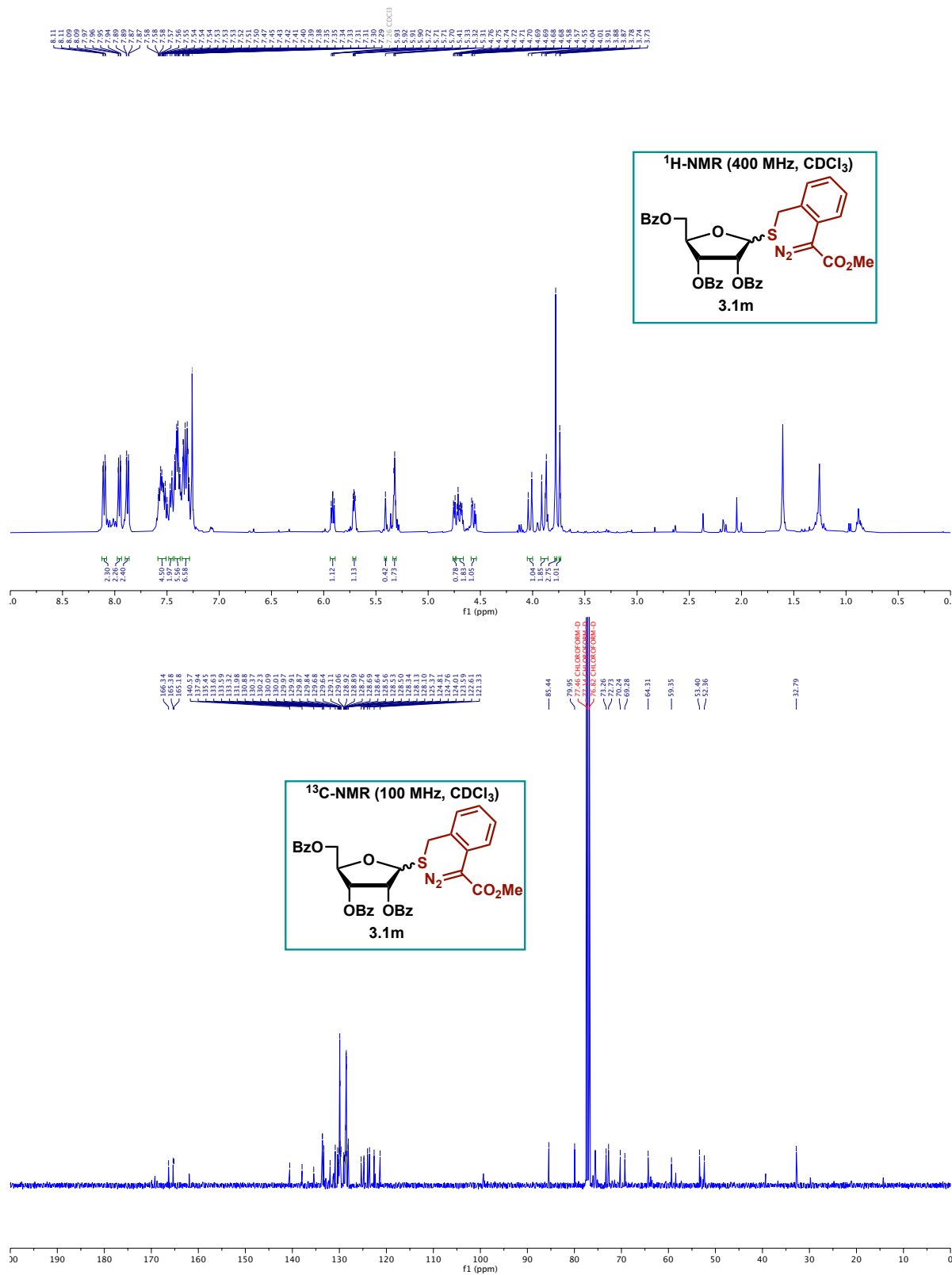


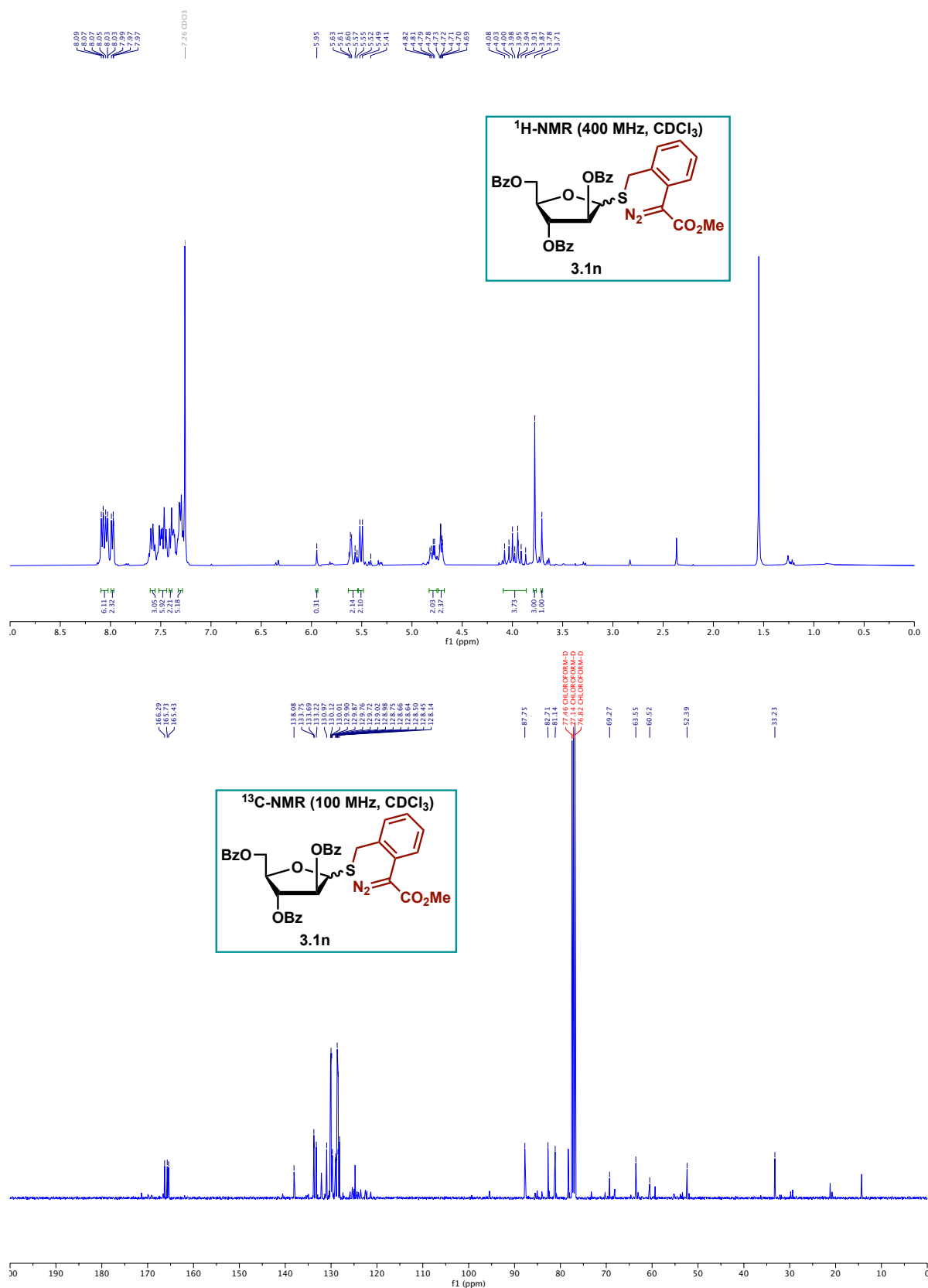


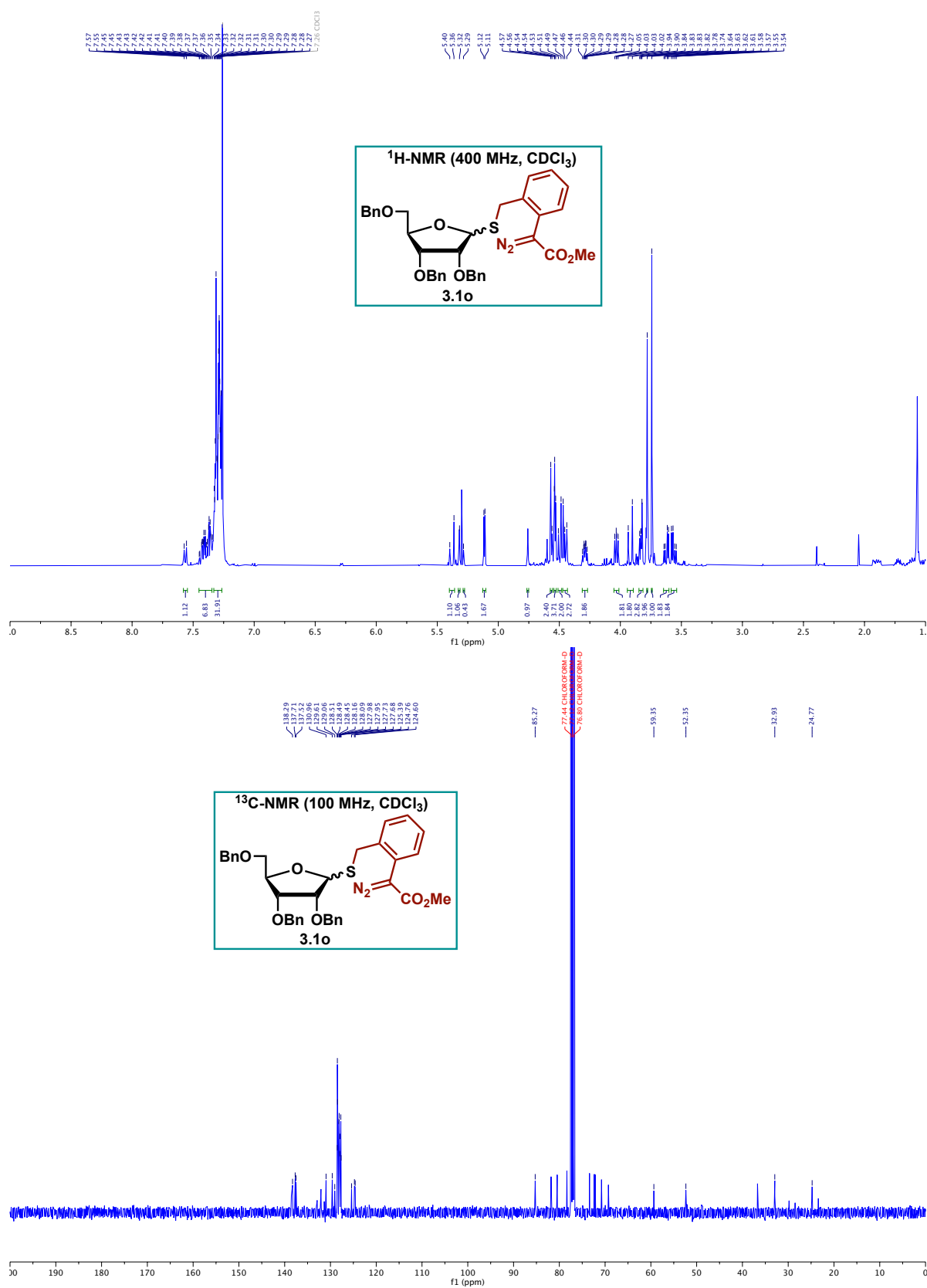


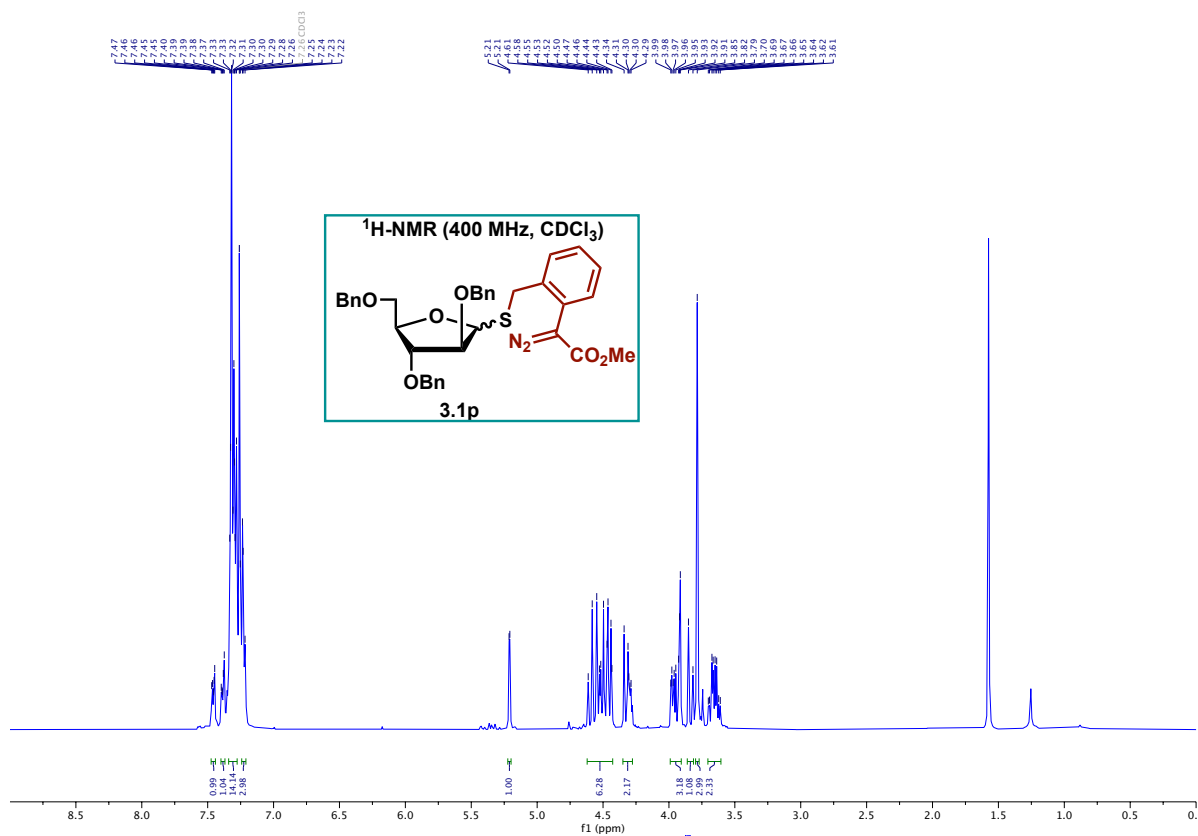
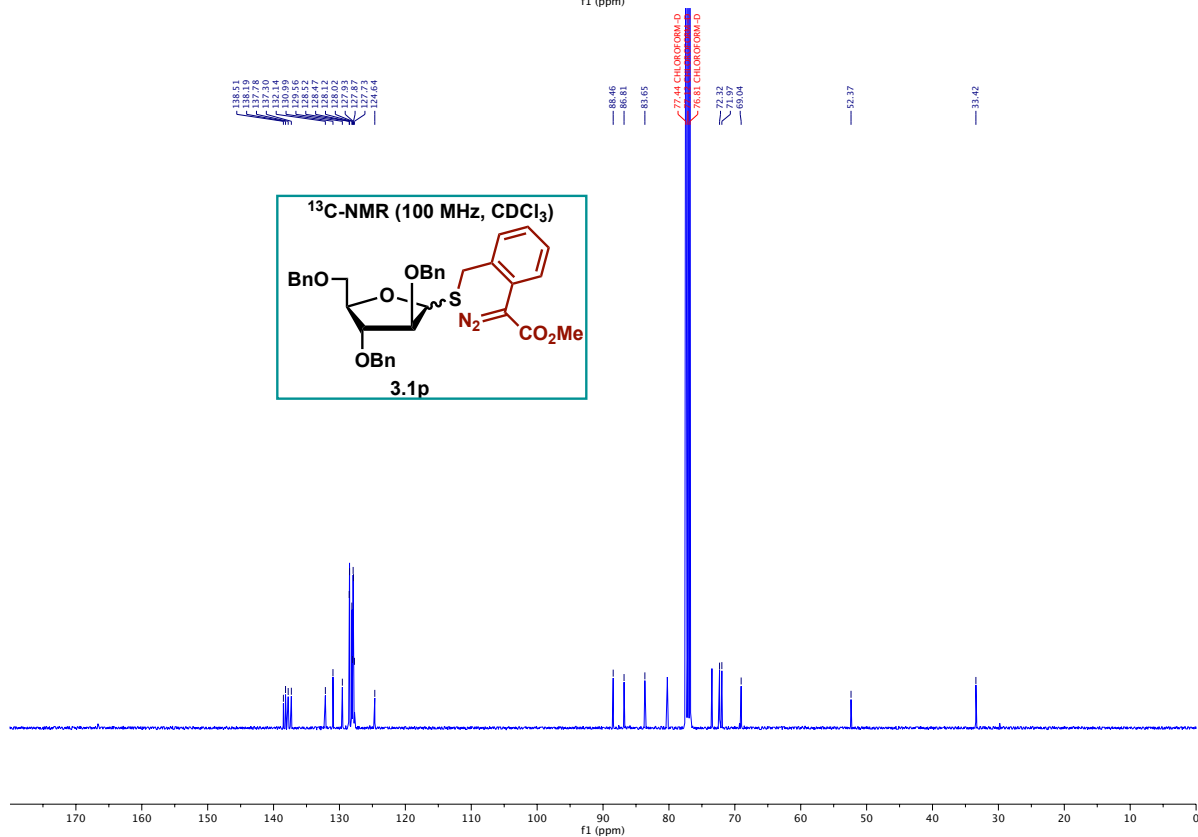












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CHAPTER 4

Iron-Carbene Mediated Intermolecular Activation of Conventional Thioglycosides for 1,2-Cis Furanosylations

4.1. Introduction

Earth-abundant metal complexes are fundamental to many biological processes, including oxygen transport, electron transfer, enzymatic catalysis, oxidative stress response, DNA/RNA stabilization, cell signaling, and photosynthesis.^[1-2] These complexes mainly consist of iron (37%), zinc (26%), calcium (11%), magnesium (11%), and copper (10%) (**Figure 4.1.1a**).^[3-6] Iron is the most abundant metal in the Earth's crust, making it a promising candidate for sustainable industrial catalytic applications (**Figure 4.1.1b**).^[7-8] Despite their critical role in biological systems and natural abundance, the synthetic community predominantly relies on precious and platinum group metals (PGMs) for catalysis.^[7,9] However, extracting and mining these metals can seriously harm the environment, leading to soil acidification, water pollution, and health risks for humans.^[10]

More importantly, these processes contribute to greenhouse gas emissions, particularly CO₂ (**Figure 4.1.1b**).^[7,10] In contrast, earth-abundant metals are more sustainable, environmentally friendly, and less toxic.^[11] Iron is permitted at concentrations of up to 1300 ppm in pharmaceuticals, whereas PGMs are highly toxic and restricted to levels below 1 ppm.^[12] These advantages highlight the potential of earth-abundant metals, with iron emerging as the most effective catalyst for sustainable industrial processes.

As discussed in very detail in chapters 1-3, carbenes are highly versatile intermediates in organic transformations,^[13-17] with diazo compounds being the most common and widely used carbene precursors. The efficient generation of carbenes has traditionally relied on coinage and precious metals such as copper (Cu), rhodium (Rh), and palladium (Pd).^[18-24] However, earth-abundant, metal-based carbenes have gained significant attention in the organic community in recent decades.^[7] Among these, iron carbenes have emerged as particularly efficient and versatile intermediates for organic transformations.^[25-29] Specifically, Srour and coworkers demonstrated the insertion of iron carbenes into N–H bonds,^[30] providing valuable feedstock chemicals (**Figure 4.1.1c**). Building on this work, several other research groups have reported iron carbene insertions into Si–H, B–H, and S–C bonds.^[31-35] Iron carbenes are well established, but their application in cascade reactions remains challenging due to the mild reactivity of iron catalysts.^[36] Our group recently developed a cascade approach for synthesizing versatile tetrahydrofurans using iron carbenes.^[37] As part of our ongoing efforts to advance sustainable carbene-based transformations,^[38-42] we are now exploring the synthesis of challenging 1,2-*cis* furanosidic linkages through iron carbene-mediated intermolecular glycosylation

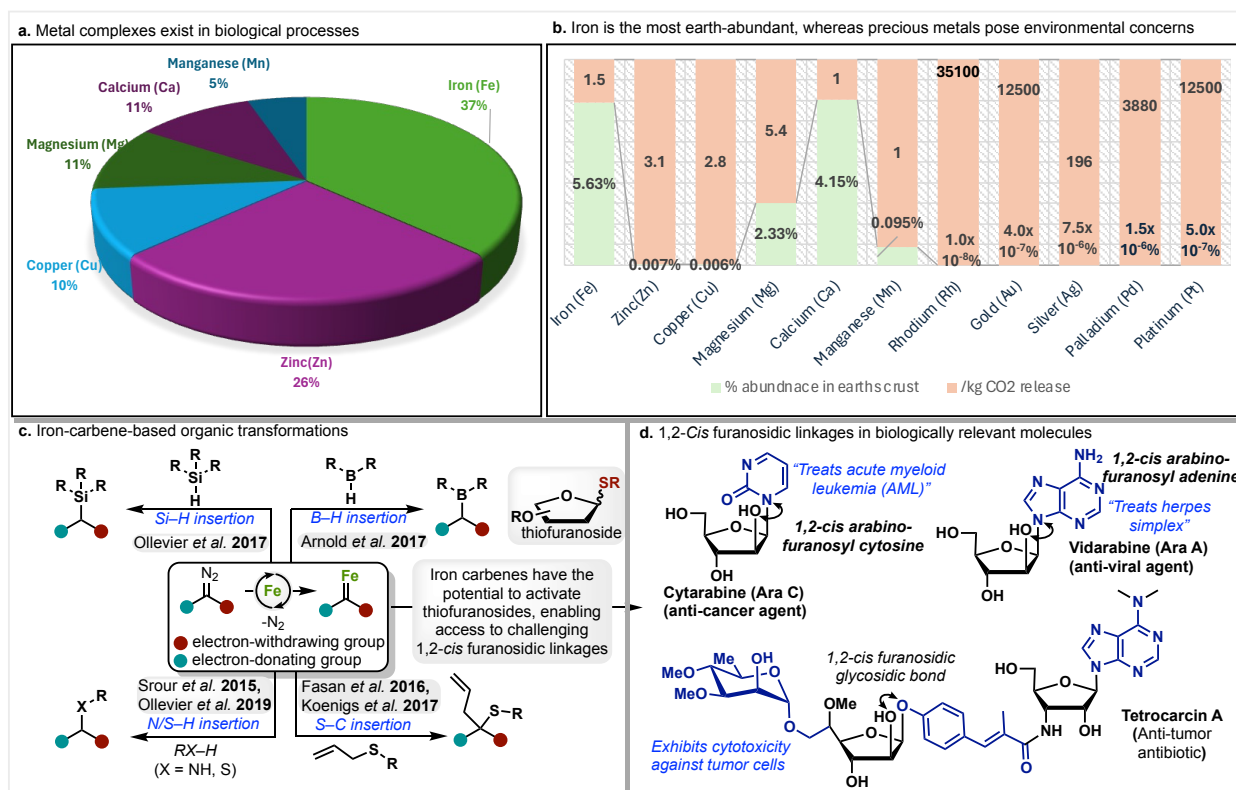


Figure 4.1.1. (a) Metal complexes in biological processes. (b) The abundance of biologically relevant metals in Earth's crust and comparison of CO₂ emissions in mining earth-abundant metals (EAMs) and precious platinum group metals (PGMs). (c) Iron carbene-based organic transformations. (d) 1,2-*cis* furanosidic linkages in biologically relevant molecules.

Furanosides are essential components of many biologically relevant carbohydrates,^[43] though they are less common than their pyranoside counterparts.^[44-46] These oligo- and polyfuranosides are widely distributed across mammals, plants, bacteria, and parasites, making their stereoselective synthesis a topic of significant interest (**Figure 4.1.1d**).^[46-47] The stereochemistry of furanosidic linkages, particularly the challenging 1,2-*cis* configuration, plays a crucial role in their biological function.^[48-51] While 1,2-*trans* linkages can be readily achieved through anchimeric assistance, furanosides inherently favor the S_N1 mechanism due to the stability of their oxocarbenium ion, complicating selective 1,2-*cis* glycosylation.^[52] As a result, the most efficient catalytic methods for stereoselective pyranosylations often fail to achieve high selectivity in

furanosylation, frequently yielding a mixture of anomers. In the past decade, several strategies have been explored to address this challenge, including hydrogen-bond-mediated aglycone transport using chiral bis-thiourea catalysts, anomeric bromide/fluoride-derived phenanthroline-catalyzed methods, anomeric ester-alkyne-based gold catalysis, and enynal-derived copper-carbene approaches (**Figure 4.1.2a**).^[38,52-54] We recently reported an intramolecular carbene-based activation of thioglycosides as a complementary strategy.^[40] However, these approaches often suffer from drawbacks such as complex synthesis of catalysts and side-linkers, unstable furanosyl donors, and reliance on expensive catalysts, limiting their broad applicability. Conventional thioglycosides have long been valued as glycosyl donors due to their stability, tunable reactivity, and ease of synthesis.^[55-57] Their activation in pyranosylations typically requires stoichiometric moisture-sensitive reagents or a catalytic amount of precious metals like rhodium and gold, which can lead to side reactions, especially in reactive functionalities.^[58-59] Despite extensive efforts, catalytic strategies for synthesizing 1,2-*cis*-furanosides from traditional thioglycosides remain scarce.^[40,60] Wan and coworkers reported the activation of traditional thioglycosides using rhodium carbenes, primarily for pyranosylations. While their study included a single example of a furanosidic linkage (**Figure 4.1.2b**), it exclusively resulted in the 1,2-*trans* configuration facilitated by anchimeric assistance.^[60] Additionally, the reliance on expensive rhodium catalysts further limits the practical application of this approach. To address these challenges, we propose an innovative, one-pot, multicomponent strategy that leverages iron carbenes for the intermolecular activation of traditional thiofuranosides. This method will work in high chemoselectivity towards S-insertion over O-insertion to the carbene, resulting in

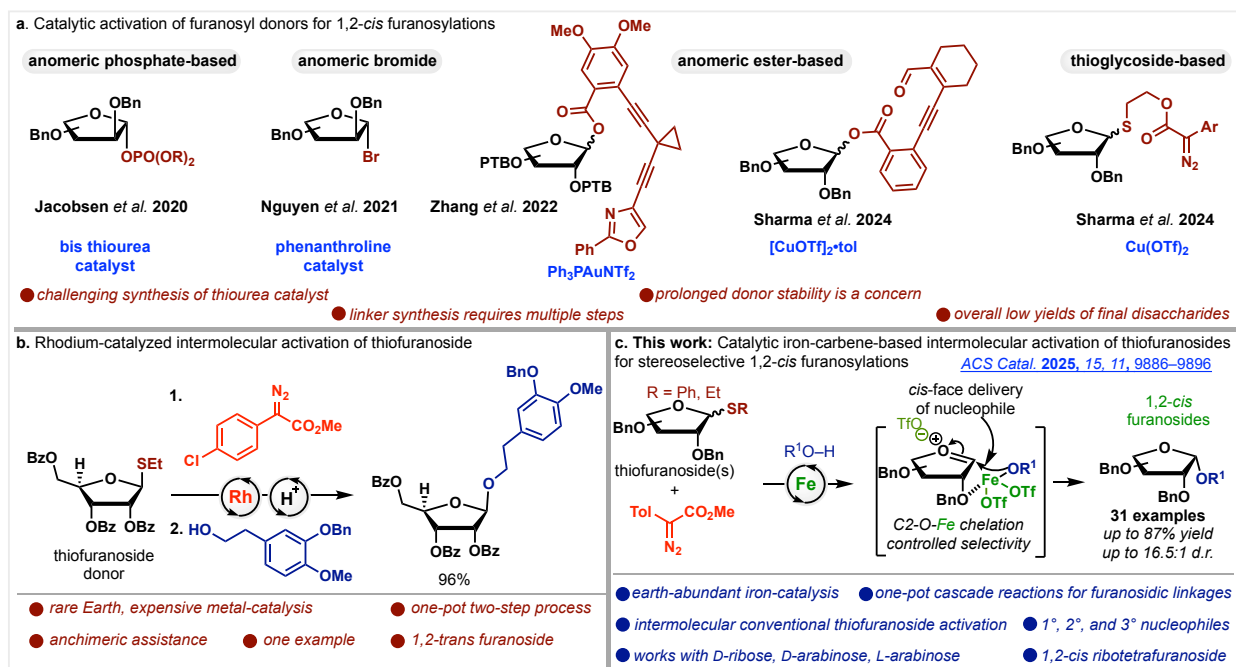


Figure 4.1.2. (a) Metal-catalyzed intermolecular activation of furanosyl donors for 1,2-*cis* furanosylations. (b) Rhodium catalyzed the intermolecular activation of thiofuranoside. (c) This work: Catalytic iron carbene-based intermolecular activation of thiofuranosides for stereoselective 1,2-*cis* furanosylations.

glycosyl sulfonium ion, which will fragment to provide oxocarbenium ion, eventually leading to the furanosidic linkages (**Figure 4.2.4c**). This will leverage our previously discovered C2-O metal coordination to induce the 1,2-*cis* selectivity. Hence, this method provides a stable, catalytic, and cost-effective route to access challenging 1,2-*cis* furanosides, overcoming the limitations of existing methodologies.

4.2. Results and Discussion

4.2.1. Preliminary results and optimization of reaction conditions

In our initial studies, we selected phenyl 2,3,5-tri-O-benzyl-1-thio-D-ribofuranoside (4.1a) as a model furanosyl donor, methyl 6-OH-2,3,4-tri-O-benzyl- α -D-glucopyranoside (A1) as a model glycosyl acceptor, and methyl phenyl diazoacetate (**3.2a**) as the carbene

precursor. Using our previously developed iron-catalyzed donor-acceptor activation strategy^[37], we activated diazo **3.2a** via the anticipated thioaryl insertion into the iron carbene (**Figure 4.2.1a**). The reaction showed good selectivity, yielding the desired furanoside **4.2** with high 1,2-*cis* selectivity ($\alpha/\beta = 6/1$). However, the overall yield of the desired disaccharide remained low (11%), with the predominant outcome being the insertion of glycosyl acceptor into the iron-carbene rather than the desired furanosylation (**Figure 4.2.1a**). While this initial study demonstrated feasibility, it highlighted the need for yield improvement. Specifically, it revealed that O-insertion^[61] (80%) is significantly favored over S-insertion (20%), posing a significant challenge to reaction selectivity. A couple of reports by Zhou and colleagues and the Koenigs group reported O–H nucleophile insertion into the carbene facilitated by the hydrogen bonding between O–H nucleophiles and metal carbene.^[62–63] Based on this insight, we hypothesize that weakening this interaction by introducing an external proton donor could shift the selectivity toward S-insertion. Additionally, fine-tuning carbene reactivity and modulating the nucleophilicity of thioglycosides may further enhance the desired transformation (**Figure 4.2.1a**).

We resumed our optimization studies to address these challenges, initially focusing on slow carbene generation in the reaction mixture. In our first experiment, we performed without an additive, only with Fe(BF₄)₂·6H₂O as a catalyst (entry 1, **Figure 4.2.1b**). However, it resulted in no reaction, presumably due to the low electrophilicity of Fe(II), and the starting diazo remained unreactive. Then, we screened FeCl₃ as an iron salt with and without NaBARF as an additive, producing similar results showing no yield

improvement (entries 2 and 3). Literature reports have revealed that triflate (OTf) as a counteranion plays a pivotal role in glycosylation reactions.^[64] Then we screened

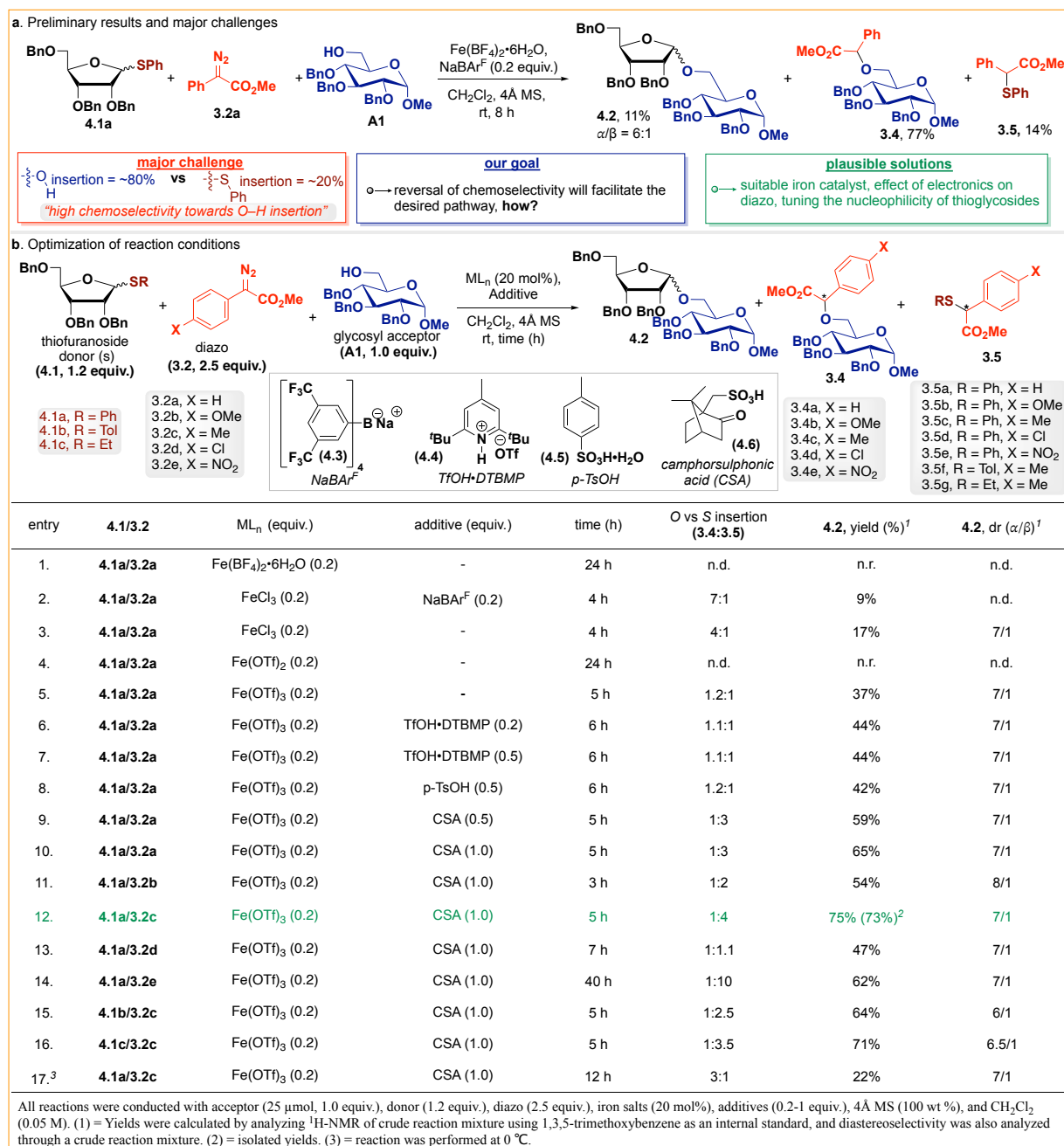


Figure 4.2.1 (a) Preliminary results for iron-catalyzed 1,2-*cis* furanosylation and major challenges for the desired outcome. (b) Optimization of reaction conditions.

Fe(OTf)₂ and Fe(OTf)₃ as iron salts; curiously, Fe(II) did not provide any desired outcome (entry 4). However, Fe(III) catalysis significantly increased the desired yield (entry 5) and

enhanced S-insertion from 20% to 46%. After successfully finding suitable iron catalysts, we screened different proton sources. In this realm, we used TfOH•DTBMP salt as a proton source in catalytic amounts (entries 6, 7), which produces the desired product with a slight increase in yield. Using p-TsOH was also found to produce the product without yield enhancement (entry 8). The introduction of camphorsulfonic acid (CSA) produced high chemoselectivity of S-insertion over O-insertion, with a significant increment in the yield (entry 9). The stoichiometric addition of CSA further increased the yield and remained highly chemoselective. This exploration of the Brønsted acid source led us to CSA as the optimum additive. Then, we started tuning the reactivity of diazo compounds by incorporating different functional groups at the *para* position of the aryl ring of methyl phenyl diazoacetate. In the next experiment, we used methyl 2-diazo-2-(4-methoxyphenyl)acetate (**3.2b**) as the carbene precursor, which produces the desired outcome with decreased chemoselectivity (entry 11). Methyl 2-diazo-2-(tolyl)acetate (**3.2c**) produces high chemoselectivity along with high yields (entry 12). Yields did not increase significantly with 4-Cl (**3.2d**, entry 13) and 4-NO₂ (**3.2e**, entry 14). However, the chemoselectivity was very high with 4-NO₂ (entry 14), but with prolonged reaction time, leaving the starting materials unreactive. These studies show that methyl 2-diazo-2-(tolyl)acetate (**3.2c**) is the best carbene precursor. Then, we studied the nucleophilicity of the thiofuranosides (entries 15, 16). Ethyl 2,3,5-tri-*O*-benzyl-1-thio-D-ribofuranoside (**4.1c**) was also found to react similarly to the model donor **1a** with a slight decrease in chemo- and stereoselectivity. The reduction in reaction temperature to 0 °C significantly declines chemo- and stereo-selectivity (entry 17). Finally, in the conclusion of the optimization studies, we found that the thioglycoside donors **4.1a** and **4.1c** are the

optimized donors, with **4.1a** being slightly better and **3.2c** being the best carbene precursor. Fe(OTf)₃ (20 mol%), along with CSA, were the best activating conditions, and like our previous studies^[39,41], anhydrous CH₂Cl₂ with 4Å molecular sieves was the best solvent system.

4.2.2. Substrate scope of the intermolecular activation

After optimizing the reaction conditions, we explored the substrate scope for 1,2-*cis*(α)-furanosylation using D-ribosyl donors and various glycosyl acceptors (**Figure 4.2.2**). We first examined methyl 6-OH-2,3,4-tri-O-benzyl- α -D-mannopyranoside (**A9**) as an acceptor. While literature reports suggest poor reactivity due to its C2 stereochemistry^[52-53], our methodology proved effective, yielding the desired furanoside **4.7** with high efficiency and 1,2-*cis* selectivity. Next, we investigated electronically deficient glycosyl acceptors, such as methyl 6-OH-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (**A11**) and methyl 6-OH-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (**A13**). Both acceptors performed well, affording furanosides **4.8** and **4.9** in good yields with high selectivity. Since primary nucleophiles reacted efficiently with donor **4.1a**, we extended the study to secondary nucleophiles, which are generally less reactive due to their lower nucleophilicity. Using methyl 4-OH-2,3,6-tri-O-benzoyl- α -D-glucopyranoside (**A14**) as a secondary glycosyl acceptor, we achieved high yield and 1,2-*cis* selectivity for furanoside **4.10** despite its reported lack of reactivity in previous studies.^[38] To further evaluate the scope, we tested the isopropanol and a complex natural bioactive compound, L-menthol, both of which exhibited high reactivity and selectivity, yielding **4.11**

and 4.12. Finally, we screened tertiary alcohol, 1-adamantanol, which coupled efficiently with the ribosyl donor, affording **4.13** with high yield and selectivity.

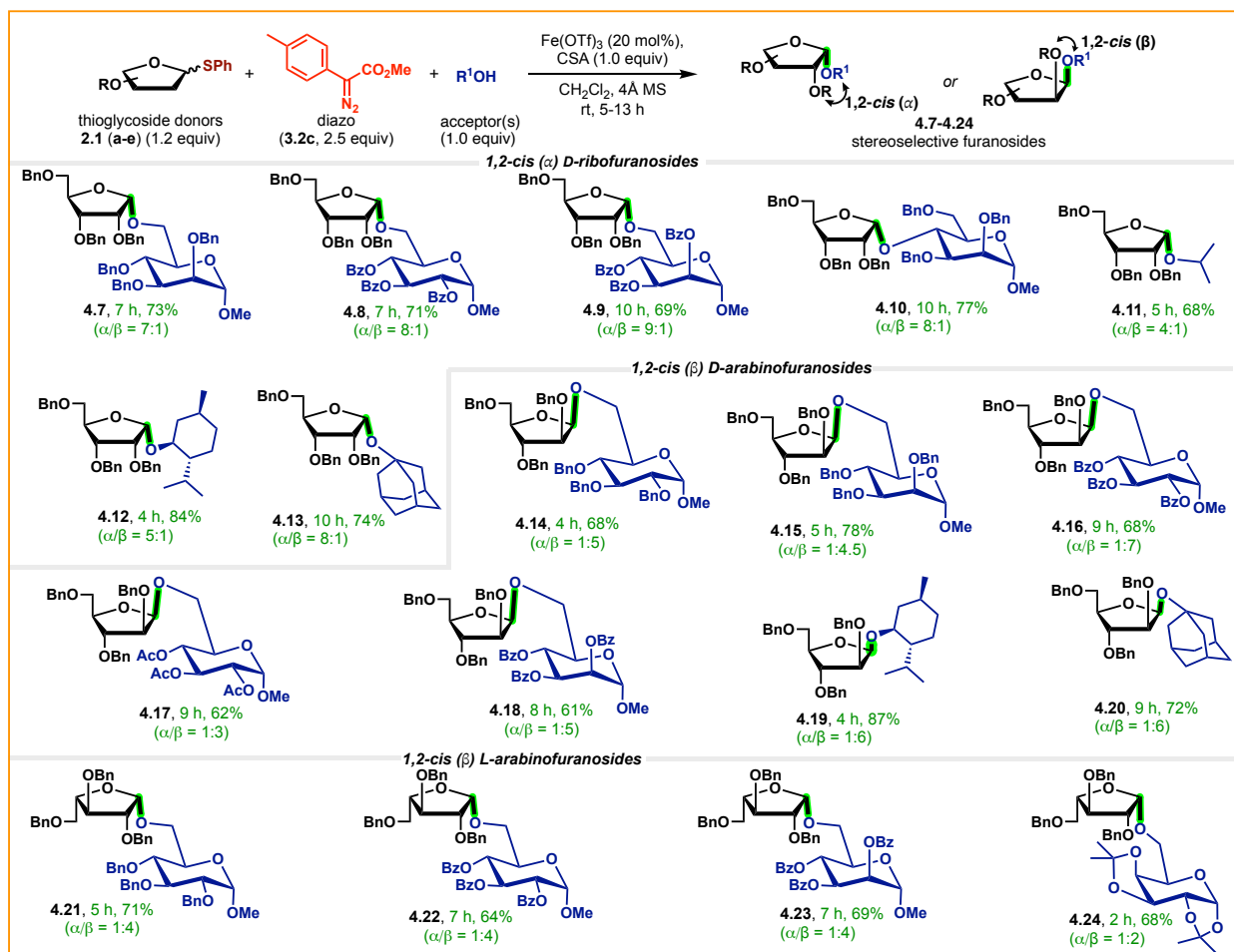


Figure 4.2.2. Substrate scope of the 1,2-*cis* furanosylations. All reactions were conducted with acceptor (25 μmol , 1.0 equiv.), donor (1.2 equiv.), diazo (2.5 equiv.), $\text{Fe}(\text{OTf})_3$ (20 mol%), CSA (1.0 equiv.) 4 $\text{\AA}$ MS (100 wt%), and CH_2Cl_2 (0.05 M). ^1H -NMR of the crude reaction mixture was analyzed to determine the diastereoselectivity. Highlighted bonds indicate the newly formed glycosidic linkages.

Having successfully established 1,2-*cis*(α)-furanosylation, we shifted our focus to achieving 1,2-*cis*(β)-selectivity using D- and L-arabinose thioglycoside donors (**4.1d**, **4.1e**). Like our approach with D-ribose, we began with the model glycosyl acceptor **A1**, which coupled with D-arabinose donor **4.1d** to produce disaccharide **4.14** in good yield and selectivity. Methyl 6-OH-2,3,4-tri-O-benzyl- α -D-mannopyranoside (**A9**) also performed well, yielding furanoside **4.15** with high selectivity. Electronically deficient, low-

nucleophilicity glycosyl acceptors, including methyl 6-OH-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (**A11**), methyl 6-OH-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (**A13**), and methyl 6-OH-2,3,4-tri-O-acetyl- α -D-glucopyranoside (**A10**), also yielded their respective furanosides **4.16-4.18** with good efficiency and selectivity. The secondary nucleophile *l*-menthol once again proved effective, delivering furanoside **4.19** in high yield and selectivity. Similarly, tertiary alcohol 1-adamantanol coupled successfully, affording **4.20** with high efficiency. Encouragingly, our methodology with L-arabinose was also successful. The parent glycosyl acceptor **A1** provided the desired product **4.21**, in good yield and selectivity, while electronically deficient acceptors **A11** and **A13** afforded furanosides **4.22** and **4.23** with similarly high efficiency. We also examined galactose acetonide acceptor **A8**, which yielded product **4.24** in good yield, albeit with slightly lower stereoselectivity. Overall, this methodology demonstrates broad applicability across different furanosyl donors and a wide range of acceptors, including primary, secondary, and tertiary alcohols, highlighting its robustness and versatility.

4.2.3. Applications of the intermolecular activation

Late-stage modification of bioactive and pharmaceutically relevant molecules remains a significant challenge in synthetic chemistry, making these transformations highly valuable.^[65] In this context, we successfully achieved late-stage 1,2-*cis* furanosylation of cholesterol, a lipid essential for cell membrane structure, hormone production, and bile acid synthesis,^[66] yielding the desired product **4.25** in good yield with high 1,2-*cis* selectivity (**Figure 4.2.3a**). Encouraged by this success, we extended our strategy to oleanolic acid, a pentacyclic triterpenoid known for its antioxidant, anti-

inflammatory, and hepatoprotective properties.^[67] Remarkably, the reaction proceeded efficiently, affording the desired product **4.26** in excellent yield and selectivity.

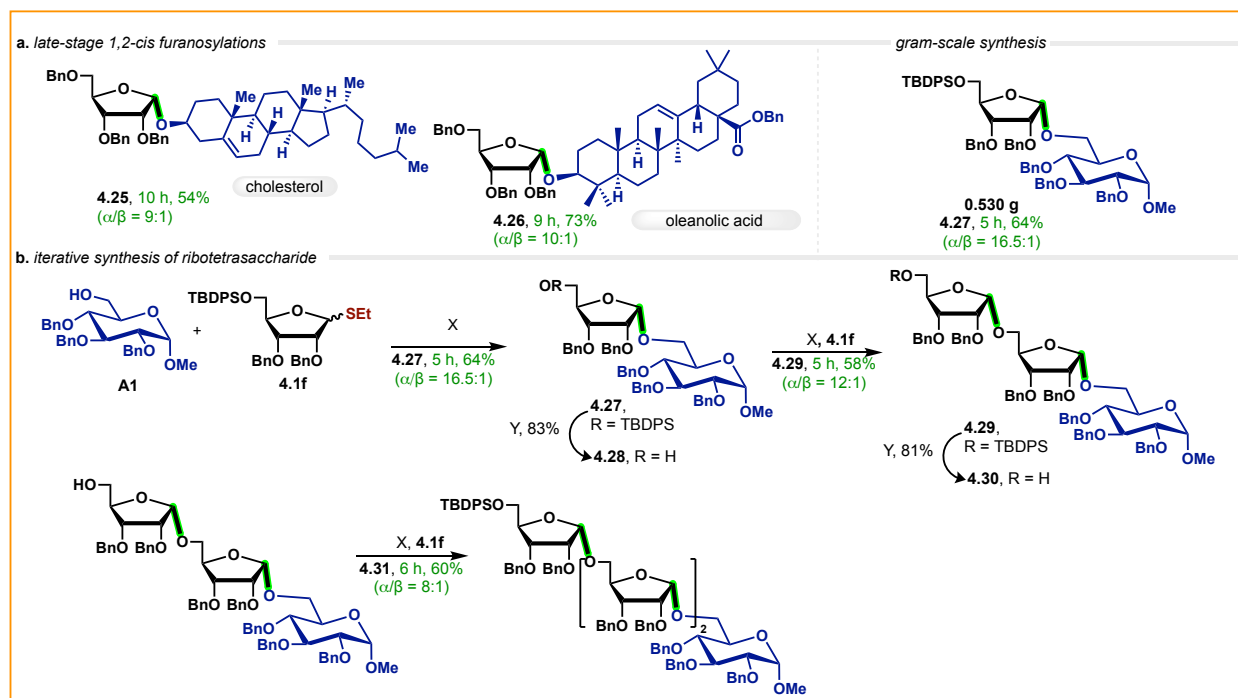


Figure 4.2.3: Application of this methodology. (a) late-stage 1,2-*cis* furanosylations, and gram-scale synthesis. (b) Iterative synthesis of ribotetrasaccharide. (X) acceptor (1.0 equiv.), donor (1.2 equiv.), diazo (2.5 equiv.), Fe(OTf)₃ (20 mol%), CSA (1.0 equiv.) 4 Å MS (100 wt %), and CH₂Cl₂ (0.05 M)., (Y) TBAF in THF (1mol/L, 1.5 equiv.), THF (2.0 M). Highlighted bonds indicate the newly formed glycosidic linkages.

Methodologies developed in research laboratories often fail to translate to industrial-scale applications.^[68] To demonstrate the robustness of our approach, we conducted gram-scale experiments (**Figure 4.2.3a**) using our designed ribosyl donor, ethyl 2,3-bis-O-benzyl-5-tert-butyldiphenylsilyl-1-thio-D-ribofuranoside (**4.1f**), with the model glycosyl acceptor **A1**. Encouragingly, the transformation proceeded efficiently, delivering the desired disaccharide in good yield with high 1,2-*cis* selectivity, highlighting our methodology's scalability and practical utility.

Oligosaccharides are complex biomolecules that play essential roles in living organisms but are challenging to synthesize.^[69-70] Over the years, carbohydrate chemists

have developed elegant strategies for constructing pyranose-based stereoselective oligosaccharides.^[71] However, the synthesis of 1,2-*cis* oligosaccharides remains particularly difficult due to steric hindrance at the C2 position, and efficient methods for assembling furanose-based oligosaccharides are scarce.^[72] To address this challenge, we leveraged our specially designed donor **4.1f** for the iterative synthesis of a ribotetrasaccharide **4.31**. Our approach delivered the desired tetrasaccharide in good yield with high 1,2-*cis* selectivity over five steps. This achievement underscores the significance of our strategy in enabling the efficient construction of complex 1,2-*cis* oligosaccharides.

4.2.4. Mechanistic studies

After thoroughly evaluating the substrate scope and synthetic applications of this strategy, we turned our attention to understanding the underlying reaction pathway responsible for the observed 1,2-*cis* selectivity. To probe the influence of anomeric configuration on reactivity and selectivity, we subjected our model donor **4.1a**, used both as a mixture of α/β (1:4) and as a pure β -anomer, to glycosylation with the model acceptor **A1** under the optimized reaction conditions. In both cases, the reaction furnished the disaccharide **4.2** in comparable yields and with identical 1,2-*cis* selectivity (**Figure 4.2.4a**). This noteworthy result suggests that the transformation proceeds through a common reactive intermediate, likely an oxocarbenium ion (**D**, **Figure 4.2.4c**), which is well-established in furanosylation chemistry.^[73-74] Furthermore, the observed 1,2-*cis* selectivity under iron catalysis mirrors our previous findings with copper-catalyzed furanosylation, where we attributed the *cis*-selectivity to C2–O–Cu coordination.^[38,40]

disaccharide **4.35** in good yield, but as an equimolar mixture of α/β anomers (1:1), indicating the loss of stereocontrol. Next, to compare C2–O chelation with anchimeric assistance, we employed a peracylated ribose thioglycoside donor (**4.1k**) bearing a C2-O-acetyl group. Glycosylation with the model acceptor delivered disaccharide **4.36** with exclusive 1,2-*trans* selectivity, consistent with strong anchimeric participation overriding any potential iron-chelation effects. Collectively, these findings indicate that the presence of a heteroatom at C2, whether strongly or weakly coordinating, can engage with iron to promote 1,2-*cis* selectivity. In contrast, the absence of a coordinating group results in poor stereocontrol, and when anchimeric assistance is operative (as with the C2-acetyl group), it dominates over metal-chelation effects. After gaining insights into the reactivity of the system, we proposed a mechanistic pathway for the carbene-mediated activation of thioglycosides and the origin of 1,2-*cis* selectivity (**Figure 4.2.4c**). The reaction is initiated with the activation of diazo compound **3.2c** by the iron catalyst, forming the reactive iron-carbene complex **A**. This carbene species undergoes thioaryl insertion, leading to the formation of an iron-bound ribosyl sulfonium ylide **B**. Subsequent protonation of **B** yields the ribosyl sulfonium ion **C**, which then eliminates byproduct **3.5c**, generating the oxocarbenium ion **D**, a key intermediate in furanosylation reactions. From this oxocarbenium intermediate, two distinct mechanistic pathways can account for the observed 1,2-*cis* selectivity. In the first pathway, selectivity is governed by iron-chelation control. Here, the oxocarbenium ion **D** interacts with the iron catalyst and the glycosyl acceptor through two possible transition states. In transition state **E**, strong coordination between the C2-heteroatom of the donor and the iron center stabilizes the intermediate, directing the approach of the glycosyl acceptor from the *cis*-face and thereby favoring the formation of the 1,2-*cis* product. In contrast, transition state **F** lacks this C2–Fe chelation, resulting in a less stabilized transition structure that allows approach from the opposite face, leading to the minor 1,2-*trans* product. These observations

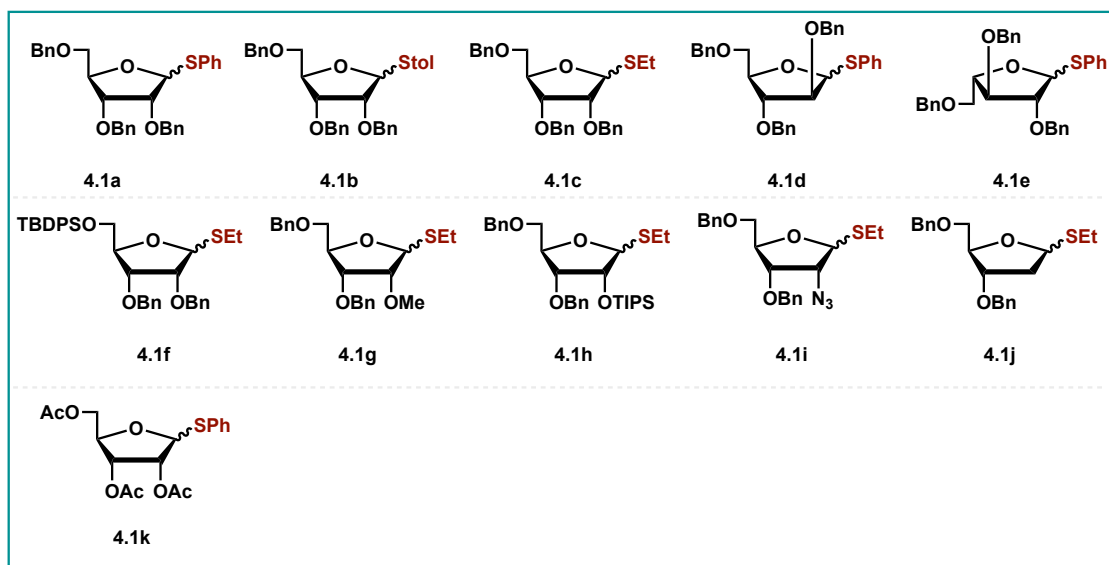
underscore the crucial role of a coordinating heteroatom at the C2 position and the essential function of the iron catalyst in enforcing cis selectivity. In the second mechanistic scenario, stereoselectivity arises from the conformational preferences of the oxocarbenium ion **D**. As described by Codée and coworkers,^[75] this intermediate can adopt two envelope conformations: E₃ and ³E. The E₃ envelope is energetically more favorable due to electronic and steric stabilization, which facilitates the inside attack of the glycosyl acceptor, ultimately producing the 1,2-*cis* linkage. Conversely, the less stable ³E conformation prefers an inside approach, resulting in the formation of the minor 1,2-*trans* product. Taken together, these mechanistic insights suggest that both iron-mediated C2-chelation and oxocarbenium conformational bias work in concert to drive high 1,2-*cis* selectivity in our furanosylation system. Furthermore, density functional theory (DFT) studies also supported the mechanistic pathway. These studies were performed in collaboration with Dr. Yihan Shao; the detailed analysis is published in *ACS Catalysis*.

4.3. Conclusion

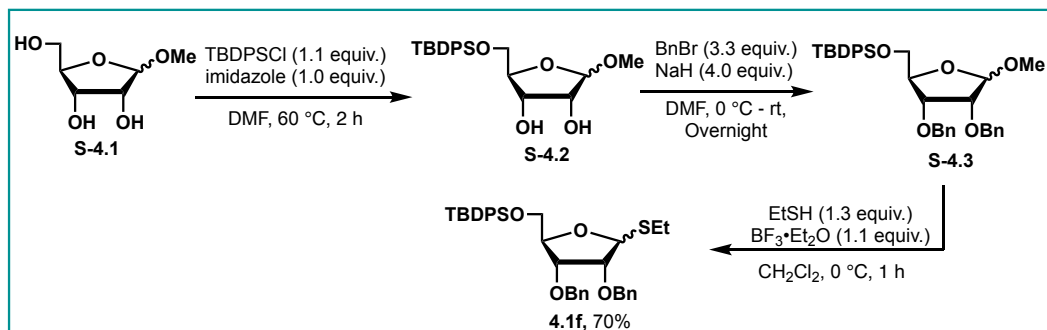
In conclusion, in this chapter we report the catalytic activation of conventional thiofuranosides using iron carbenes, enabling highly efficient and selective 1,2-*cis* furanosylations. These thiofuranosides, readily synthesized in just 1-2 steps from commercially available starting materials, offer a more accessible alternative to established methods. Earth-abundant, inexpensive, and non-toxic iron catalysis distinguishes this strategy from other metal-catalyzed approaches. Comprehensive substrate scope studies consistently demonstrated high yields and excellent 1,2-*cis* selectivity across various furanosyl donors and acceptors. The late-stage furanosylation of biologically relevant molecules, including cholesterol and oleanolic acid, further underscores the utility of this method. A gram-scale reaction was also achieved, followed by an iterative synthesis of 1,2-*cis* ribotetrasaccharide with an overall fair yield over five steps. Finally, we investigated the influence of the C2 functional group, providing insights into the favored reaction pathway responsible for 1,2-*cis* selectivity. These findings highlight the unique reactivity of iron catalysis in achieving highly selective 1,2-*cis* furanosylations, offering a powerful tool for furanosylation chemistry.

4.4. Experimental Section

4.4.1. List and syntheses of conventional thioglycosides used in this chapter



Synthesis of ethyl 2,3-bis-O-benzyl-5-O-tertbutyldiphenylsilyl-1-thio-D-ribofuranoside (4.1f)



In an oven-dried round-bottom flask, methyl ribofuranoside **S-4.1** (1.0 equiv.) was dissolved in dimethylformamide (0.5 M), followed by the addition of imidazole (1.0 equiv.) at room temperature, and stirred at the same temperature for the next 15 minutes. Then, TBDPSCI (1.1 equiv.) was added into the stirred suspension, and the resulting mixture was stirred at 60 °C for the next 2 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50 $\times$ 2 mL). Then, the combined organic layers were carefully washed with aq. sat. NaHCO_3 , brine, and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-4.2**, which was then used in the next step without further purification. To the crude **S-4.2**, anhydrous DMF (0.5

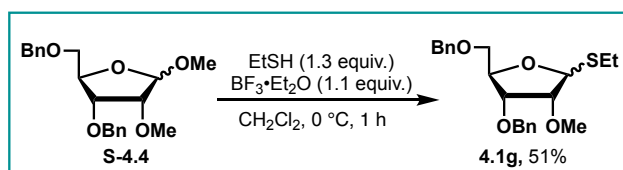
M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, NaH (4.0 equiv., 60% in mineral oil) was added carefully in one portion, and the reaction was allowed to stir at the same temperature for the next 30 minutes. Then, benzyl bromide (3.3 equiv.) was added to the stirred suspension, and the reaction was allowed to warm up to room temperature and was stirred at the same temperature overnight. The reaction was quenched by the careful addition of methanol (2.0 mL), then the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50x2 mL). Then, the combined organic layers were carefully washed with aq. sat. NaHCO₃, brine, and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-4.3**. To the crude **S-4.3**, anhydrous dichloromethane (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of BF₃•Et₂O (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour; then, it was quenched by the careful addition of aq. sat. NaHCO₃ followed by the addition of H₂O. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc: hexane = 5:95) to afford ribofuranoside donor **4.1f** (1.61 g, 70%, α : β =1:3). R_f = 0.6 (EtOAc: hexane= 10:90).

¹H NMR (399 MHz, CDCl₃) δ 7.71 – 7.59 (m, 7H), 7.46 – 7.40 (m, 4H), 7.31 (d, J = 5.3 Hz, 1H), 5.26 (d, J = 4.5 Hz, 1H), 4.72 – 4.63 (m, 3H), 4.56 (d, J = 8.4 Hz, 2H), 4.24 – 4.19 (m, 1H), 4.17 – 4.10 (m, 2H), 3.90 – 3.87 (m, 1H), 3.77 – 3.69 (m, 2H), 2.69 – 2.59 (m, 2H), 1.28 (td, J = 7.4, 0.8 Hz, 3H), 1.08 (dd, J = 2.3, 0.8 Hz, 3H), 1.03 (d, J = 0.9 Hz, 10H), 0.98 (d, J = 0.9 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 135.8, 135.8, 135.8, 135.8, 129.9, 129.8, 128.6, 128.5, 128.5, 128.2, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 85.9, 83.3, 81.1, 77.7, 72.4, 72.4, 64.0, 27.0, 26.9, 25.2, 19.4, 15.2.

HRMS (ESI): calc. for C₃₇H₄₄O₄NaSSi (M+Na): 635.2627; found: 635.2624.

Synthesis of ethyl 2-O-methyl,3,5-bis-O-benzyl-1-thio-D-ribofuranoside (**4.1g**)



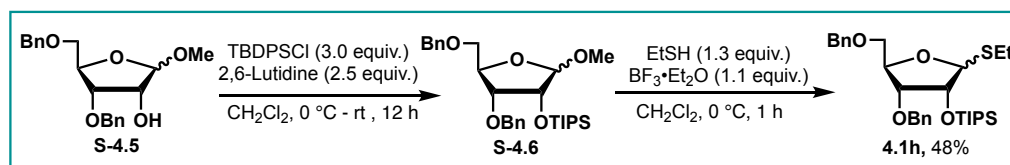
The solution of **S-4.4**^[40] (1.0 equiv.) in anhydrous dichloromethane (0.5 M) was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of BF₃•Et₂O (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour; then, it was quenched by the careful addition of aq. sat. NaHCO₃ followed by the addition of H₂O. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc: hexane = 5:95) to afford ribofuranoside donor **4.1g** (0.221 g, 51%, $\alpha:\beta=1:4$). R_f = 0.6 (EtOAc: hexane = 10:90).

¹H NMR (399 MHz, CDCl₃) δ 7.26 – 7.18 (m, 10H), 5.15 (d, *J* = 4.1 Hz, 1H), 4.52 (dd, *J* = 12.1, 5.3 Hz, 4H), 4.20 – 4.15 (m, 1H), 3.99 (t, *J* = 5.4 Hz, 1H), 3.53 – 3.50 (m, 2H), 3.44 (s, 1H), 3.36 (s, 3H), 2.64 – 2.55 (m, 2H), 1.20 (d, *J* = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 138.3, 137.7, 128.5, 128.5, 128.2, 128.1, 128.0, 127.8, 127.7, 85.5, 83.5, 81.6, 78.1, 73.4, 72.5, 70.9, 58.3, 25.2, 15.1.

HRMS (ESI): calc. for C₂₂H₂₈O₄NaS (M+Na): 411.1606; found: 411.1608.

Synthesis of ethyl 2-O-triisopropyl,3,5-bis-O-benzyl-1-thio-D-ribofuranoside (**4.1h**)



To a CH₂Cl₂ solution (0.5 M) of compound **S-4.5**^[40] (1.0 equiv.) at 0 °C were added 2,6-lutidine (2.5 equiv.) and triisopropylsilyl triflate (3.0 equiv.). The reaction was warmed to room temperature and monitored by TLC. After completion, it was quenched with aq. sat. NaHCO₃; the aqueous layer was separated and extracted with CH₂Cl₂. The organic layers were collected, dried over Na₂SO₄, filtered, and concentrated by rotary evaporation to afford the crude product. The solution of crude **S-4.6** in anhydrous dichloromethane (0.5 M) was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of BF₃•Et₂O (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour, then it was quenched by the careful addition of aq. sat. NaHCO₃ followed by the addition of H₂O. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude

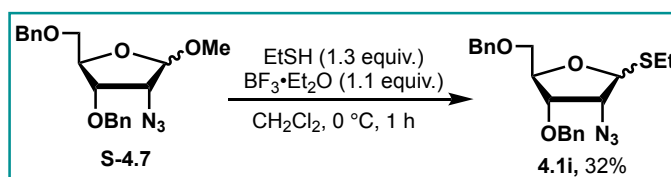
syrup was purified by column chromatography (EtOAc: hexane = 5:95) to afford ribofuranoside donor **4.1h** (0.350 g, 80%, $\alpha:\beta=1:3$). $R_f=0.7$ (EtOAc: hexane= 10:90).

^1H NMR (400 MHz, CDCl_3) δ 7.34 – 7.27 (m, 10H), 5.12 (d, $J = 3.0$ Hz, 1H), 4.67 (d, $J = 11.6$ Hz, 1H), 4.59 (d, $J = 12.0$ Hz, 1H), 4.50 (dd, $J = 16.7, 11.8$ Hz, 2H), 4.34 – 4.26 (m, 2H), 3.99 (dd, $J = 6.5, 4.5$ Hz, 1H), 3.61 (dd, $J = 10.6, 3.6$ Hz, 1H), 3.55 (dd, $J = 10.6, 5.4$ Hz, 1H), 2.76 – 2.67 (m, 1H), 2.61 (dt, $J = 12.9, 7.5$ Hz, 1H), 1.27 (s, 3H), 1.09 – 1.06 (m, 18H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.3, 138.0, 128.4, 128.4, 127.9, 127.8, 127.7, 127.6, 88.8, 80.9, 80.1, 75.9, 73.5, 72.4, 71.4, 25.1, 18.1, 15.1.

HRMS (ESI): calc. for $\text{C}_{30}\text{H}_{46}\text{O}_4\text{NaSSi}$ ($\text{M}+\text{Na}$): 553.2784; found: 553.2767.

Synthesis of ethyl 2-azido-3,5-bis-O-benzyl-1-thio-D-ribofuranoside (**4.1i**)



The solution of **S-1.7**^[76] (1.0 equiv.) in anhydrous dichloromethane (0.5 M) was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of $\text{BF}_3\cdot\text{Et}_2\text{O}$ (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour; then, it was quenched by the careful addition of aq. sat. NaHCO_3 followed by the addition of H_2O . The layers were separated, and the organic layer was washed with brine and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc: hexane = 5:95) to afford ribofuranoside donor **1i** (0.180 g, 32%, $\alpha:\beta=1:4$). $R_f=0.6$ (EtOAc: hexane= 10:90).

^1H NMR (400 MHz, CDCl_3) δ 7.35 – 7.29 (m, 10H), 5.17 (d, $J = 5.9$ Hz, 1H), 4.69 (d, $J = 11.8$ Hz, 1H), 4.63 – 4.54 (m, 2H), 4.51 (d, $J = 12.0$ Hz, 1H), 4.19 (dq, $J = 9.8, 4.5$ Hz, 2H), 3.74 (dd, $J = 5.8, 5.1$ Hz, 1H), 3.56 (dd, $J = 4.2, 1.3$ Hz, 2H), 2.77 – 2.64 (m, 2H), 1.29 (t, $J = 7.4$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.0, 137.3, 128.7, 128.5, 128.2, 128.1, 127.9, 127.8, 86.0, 82.5, 79.9, 77.5, 76.8, 73.6, 72.9, 70.6, 65.2, 25.2, 15.3.

HRMS (ESI): calc. for $\text{C}_{21}\text{H}_{25}\text{O}_3\text{N}_3\text{NaS}$ ($\text{M}+\text{Na}$): 422.1514; found: 422.1502.

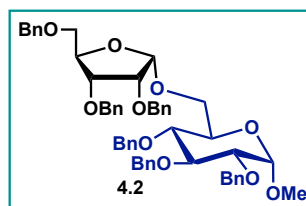
4.4.2. Reaction development

General synthetic procedure for the catalytic iron-carbene-based intermolecular 1,2-*cis* furanosylations.

General procedure A: In an oven-dried vial equipped with a stir bar, acceptor **A** (0.025 mmol) was combined with thioglycoside donors **4.1 (a-k)** (0.031 mmol, 1.2 equiv.), additive (0.2-1.0 equiv.) 4Å molecular sieves (50 mg or 100 wt.%), and iron salts (0.005 mmol, 0.2 equiv.) and dissolved in CH₂Cl₂ (0.05M). The mixture was stirred at room temperature for 5 minutes before adding diazo **3.2 (a-e)** (0.063 mmol, 2.5 equiv.) to the stirred suspension. Upon addition of the diazo compound, bubbles appeared immediately, indicating the evolution of nitrogen gas and the progress of the reaction. The reaction was monitored by TLC and quenched with saturated aqueous NaHCO₃ upon completion. The layers were then separated, with the aqueous layer washed with ethyl acetate. The organic layers were combined, dried over Na₂SO₄, filtered, and evaporated under reduced pressure. The crude product was dissolved in ethyl acetate and passed through a short silica pad to remove traces of iron (for crude material analysis via ¹H-NMR). The filtrate was evaporated, and the resulting crude material was purified by column chromatography.

Methyl (2,3,5-tri-O-benzyl-α-D-ribofuranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (4.2)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μmol) to afford **4.2** (16.5 mg, 19 μmol, 73% yield, α:β=7:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).



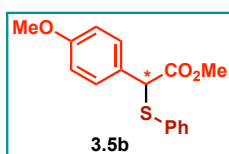
¹H NMR (399 MHz, CDCl₃) δ 7.38 – 7.35 (m, 2H), 7.34 – 7.17 (m, 28H), 5.15 – 5.13 (m, 1H), 4.94 (d, *J* = 11.0 Hz, 1H), 4.81 (d, *J* = 11.0 Hz, 1H), 4.77 – 4.72 (m, 3H), 4.70 (d, *J* = 15.9 Hz, 1H), 4.66 – 4.56 (m, 3H), 4.50 (d, *J* = 12.2 Hz, 1H), 4.42 (dd, *J* = 12.0, 5.3 Hz, 2H), 4.23 – 4.12 (m, 2H), 3.97 – 3.92 (m, 1H), 3.90 – 3.85 (m, 2H), 3.78 – 3.72 (m, 2H), 3.66 (dd, *J* = 11.2, 1.6 Hz, 1H), 3.46 (dt, *J* = 9.6, 3.4 Hz, 2H), 3.39 (dd, *J* = 10.6, 4.0 Hz, 1H), 3.33 (s, 3H).

¹H NMR (500 MHz, benzene-*D*₆) δ 7.41 – 7.39 (m, 2H), 7.36 – 7.33 (m, 2H), 7.32 – 7.30 (m, 2H), 7.29 – 7.27 (m, 2H), 7.26 – 7.24 (m, 2H), 7.13 (dt, *J* = 6.3, 3.1 Hz, 9H), 7.07 (s, 2H), 7.03 (td, *J* = 13.3, 6.2 Hz, 9H), **5.17 (d, *J* = 4.2 Hz, 1H)**, 4.99 (d, *J* = 11.4 Hz, 1H), 4.95 – 4.91 (m, 2H), 4.81 (d, *J* = 11.3 Hz, 1H), 4.74 (d, *J* = 11.6 Hz, 1H), 4.62 (d, *J* = 11.5 Hz, 1H), **4.60 (d, *J* = 3.4 Hz, 1H)**, 4.40 – 4.36 (m, 4H), 4.34 (dd, *J* = 11.4, 2.8 Hz, 2H), 4.24 – 4.14 (m, 4H), 4.07 (t, *J*

= 9.5 Hz, 1H), 3.92 (dd, J = 6.2, 3.5 Hz, 1H), 3.82 – 3.77 (m, 2H), 3.63 (dd, J = 11.3, 1.7 Hz, 1H), 3.48 (dd, J = 9.5, 3.5 Hz, 1H), 3.30 (dd, J = 10.5, 3.9 Hz, 1H), 3.26 (dd, J = 10.5, 3.7 Hz, 1H), 3.05 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.2, 138.7, 138.4, 138.3, 138.3, 138.1, 128.5, 128.5, 128.4, 128.4, 128.3, 128.2, 128.1, 127.9, 127.9, 127.7, 127.7, 127.6, 127.5, 102.2, 98.3, 82.1, 81.5, 80.1, 77.9, 77.9, 76.2, 75.6, 75.1, 73.5, 73.5, 72.5, 72.5, 70.3, 69.8, 66.7, 55.2. The data are identical to the literature report.^[77-78]

Methyl 2-(4-methoxyphenyl)-2-(phenylthio)acetate (**3.5b**)

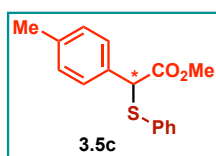


Following the general procedures, **A**, **3.5b** was isolated as a byproduct of colorless viscous oil, R_f = 0.9 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, $\text{CHLOROFORM-}D$) δ 7.39 – 7.34 (m, 4H), 7.26 (td, J = 3.0, 1.2 Hz, 3H), 6.85 (dd, J = 8.8, 1.2 Hz, 2H), 4.88 (s, 1H), 3.80 (s, 3H), 3.66 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.2, 159.7, 133.9, 132.7, 130.4, 129.8, 129.1, 128.1, 127.2, 114.2, 114.1, 55.7, 55.4, 52.8.

Methyl 2-(phenylthio)-2-(*p*-tolyl)acetate (**3.5c**)

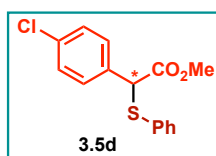


Following the general procedures, **A**, **3.5c** was isolated as a byproduct of colorless viscous oil, R_f = 0.9 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.35 (dd, J = 15.5, 6.0 Hz, 3H), 7.28 – 7.24 (m, 4H), 7.13 (d, J = 7.8 Hz, 2H), 4.89 (s, 1H), 3.66 (s, 3H), 2.33 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.2, 138.3, 132.5, 129.5, 129.1, 128.4, 128.0, 56.1, 52.8, 21.3.

Methyl 2-(4-chlorophenyl)-2-(phenylthio)acetate (**3.5d**)

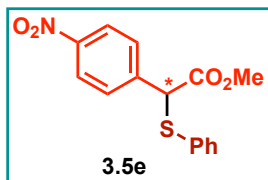


Following the general procedures, **A**, **3.5d** was isolated as a byproduct of colorless viscous oil, $R_f = 0.9$ (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.38 – 7.32 (m, 4H), 7.30 – 7.26 (m, 4H), 4.85 (s, 1H), 3.68 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.6, 134.4, 133.1, 130.0, 129.2, 128.9, 128.5, 55.8, 52.9.

Methyl 2-(4-nitrophenyl)-2-(phenylthio)acetate (3.5e).



Following the general procedures, **A**, **3.5e** was isolated as a byproduct of colorless viscous oil, $R_f = 0.9$ (hexane: EtOAc = 70:30).

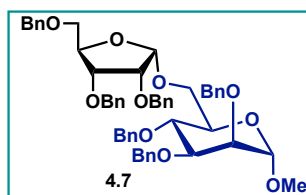
^1H NMR (399 MHz, CDCl_3) δ 8.18 – 8.14 (m, 2H), 7.56 (d, $J = 8.4$ Hz, 2H), 7.36 – 7.27 (m, 5H), 4.93 (s, 1H), 3.72 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 169.8, 143.2, 133.7, 129.7, 129.3, 129.0, 123.9, 55.9, 53.2.

4.4.3. Substrate scope of intermolecular activation

Methyl (2,3,5-tri-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (4.7)

Following the general procedure, **A**, glycosyl acceptor **A9** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μmol) to afford **4.7** (16.5 mg, 19 μmol , 73% yield, α : β =7:1) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).



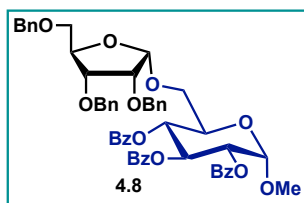
^1H NMR (500 MHz, CDCl_3) δ 7.36 (dd, $J = 6.9, 2.5$ Hz, 2H), 7.33 – 7.26 (m, 11H), 7.25 – 7.18 (m, 17H), 5.32 (d, $J = 3.6$ Hz, 1H), 4.80 (d, $J = 12.0$ Hz, 1H), 4.76 (d, $J = 10.8$ Hz, 1H), 4.72 – 4.68 (m, 2H), 4.67 – 4.60 (m, 5H), 4.55 – 4.51 (m, 2H), 4.45 (d, $J = 12.2$ Hz, 1H), 4.40 (d, $J = 11.9$ Hz, 1H), 4.27 (q, $J = 4.0$ Hz, 1H), 3.88 – 3.81 (m, 4H), 3.79 – 3.76 (m, 1H), 3.71 (dd, $J = 10.2, 3.8$ Hz, 1H), 3.54 (dd, $J = 10.7, 3.3$ Hz, 1H), 3.45 (dd, $J = 10.7, 4.0$ Hz, 1H), 3.25 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.9, 138.5, 138.2, 128.4, 128.4, 128.4, 128.3, 128.3, 128.3, 128.2, 128.1, 128.0, 128.0, 127.7, 127.7, 127.6, 127.6, 127.5, 127.5, 127.5, 102.2, 99.3,

80.8, 80.3, 73.5, 72.9, 72.7, 72.3, 72.3, 72.0, 69.7, 66.5, 54.8. The data are identical to the literature report.^[79]

Methyl (2,3,5-tri-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-glucopyranoside (4.8)

Following the general procedure, **A**, glycosyl acceptor **A11** (13.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μ mol) to afford **4.8** (15.5 mg, 18.0 μ mol, 71% yield, α : β =8:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

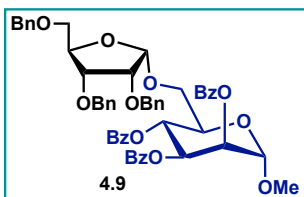


¹H NMR (399 MHz, CDCl₃) δ 7.98 – 7.90 (m, 4H), 7.84 (d, J = 7.2 Hz, 2H), 7.52 – 7.46 (m, 2H), 7.35 (td, J = 8.1, 5.5 Hz, 8H), 7.31 – 7.26 (m, 12H), 7.21 – 7.17 (m, 2H), 6.11 (t, J = 10.0 Hz, 1H), 5.49 (t, J = 9.9 Hz, 1H), 5.21 – 5.16 (m, 2H), 4.99 (d, J = 4.1 Hz, 1H), 4.66 – 4.59 (m, 4H), 4.54 – 4.45 (m, 3H), 4.41 (s, 1H), 4.31 (t, J = 3.9 Hz, 2H), 3.93 (dd, J = 11.3, 6.7 Hz, 1H), 3.84 (dd, J = 6.6, 3.8 Hz, 1H), 3.80 – 3.72 (m, 2H), 3.40 (t, J = 3.3 Hz, 1H), 3.35 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.9, 165.4, 138.4, 138.1, 138.0, 133.4, 133.1, 130.0, 129.9, 129.8, 129.4, 129.2, 128.6, 128.5, 128.5, 128.4, 128.3, 128.1, 128.1, 127.9, 127.7, 127.7, 127.7, 101.5, 96.7, 81.7, 73.5, 72.6, 72.3, 70.8, 69.9, 69.8, 68.9, 66.8, 55.5. The data are identical to the literature report.^[77-78]

Methyl (2,3,5-tri-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (4.9)

Following the general procedure, **A**, glycosyl acceptor **A13** (13.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μ mol) to afford **4.9** (15.0 mg, 15.3 μ mol, 69% yield, α : β =9:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



¹H NMR (399 MHz, CDCl₃) δ 8.07 (dd, J = 8.3, 1.4 Hz, 2H), 7.96 (dd, J = 8.4, 1.3 Hz, 2H), 7.82 (dd, J = 8.3, 1.4 Hz, 2H), 7.58 – 7.48 (m, 2H), 7.45 – 7.38 (m, 4H), 7.36 (d, J = 7.3 Hz, 2H), 7.32 – 7.26 (m, 9H), 7.25 – 7.22 (m, 5H), 7.20 (dd, J = 7.5, 2.1 Hz, 2H), 5.84 (dd, J = 10.1, 3.3 Hz,

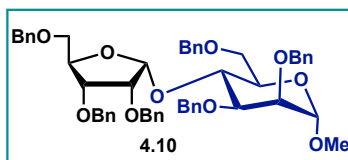
1H), 5.77 (t, $J = 10.1$ Hz, 1H), 5.63 (dd, $J = 3.4, 1.7$ Hz, 1H), 5.01 (d, $J = 4.1$ Hz, 1H), 4.93 (d, $J = 1.8$ Hz, 1H), 4.60 (d, $J = 9.6$ Hz, 3H), 4.50 – 4.45 (m, 2H), 4.42 (s, 1H), 4.37 (d, $J = 11.9$ Hz, 1H), 4.32 (q, $J = 3.8$ Hz, 1H), 4.04 – 3.98 (m, 1H), 3.85 (dd, $J = 6.9, 3.9$ Hz, 1H), 3.81 – 3.75 (m, 2H), 3.45 (d, $J = 11.7$ Hz, 1H), 3.40 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.8, 165.5, 133.5, 133.2, 130.0, 129.9, 129.8, 128.6, 128.5, 128.5, 128.4, 128.4, 128.3, 128.1, 127.7, 127.7, 101.7, 98.3, 73.5, 72.6, 72.3, 70.8, 70.1, 69.9, 67.7, 55.4.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{52}\text{NaO}_{13}$ ($\text{M}+\text{Na}$): 931.3306; found: 931.3339.

Methyl (2,3,5-tri-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 4)-2,3,4-tri-*O*-benzyl- α -D-mannopyranoside (4.10)

Following the general procedure, **A**, glycosyl acceptor **A14** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1a** (16.5 mg, 31.0 μmol) to afford **4.10** (17.3 mg, 20.0 μmol , 77% yield, $\alpha:\beta=8:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

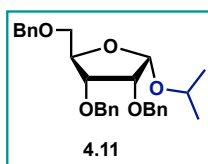


^1H NMR (400 MHz, CDCl_3) δ 7.35 (d, $J = 7.0$ Hz, 2H), 7.32 – 7.26 (m, 17H), 7.24 – 7.12 (m, 9H), 7.04 – 7.01 (m, 2H), 5.61 (d, $J = 4.5$ Hz, 1H), 4.82 (d, $J = 1.8$ Hz, 1H), 4.66 (d, $J = 6.2$ Hz, 2H), 4.64 – 4.56 (m, 4H), 4.55 – 4.48 (m, 3H), 4.42 – 4.32 (m, 3H), 4.21 (t, $J = 9.7$ Hz, 1H), 4.08 (dd, $J = 9.5, 3.1$ Hz, 1H), 4.02 (ddd, $J = 9.4, 5.9, 2.1$ Hz, 2H), 3.93 (dd, $J = 10.6, 2.0$ Hz, 1H), 3.83 – 3.79 (m, 2H), 3.72 (dd, $J = 6.6, 2.4$ Hz, 1H), 3.64 (dd, $J = 6.6, 4.5$ Hz, 1H), 3.36 (s, 3H), 3.24 – 3.20 (m, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.8, 138.5, 138.1, 138.0, 137.8, 128.5, 128.5, 128.4, 128.3, 128.3, 128.3, 127.8, 127.7, 127.7, 127.7, 127.6, 127.5, 127.4, 127.3, 127.0, 101.9, 98.7, 82.3, 80.4, 75.3, 74.1, 73.5, 73.4, 72.5, 71.9, 71.9, 71.4, 71.3, 70.7, 70.4, 70.3, 54.6. The data are identical to the literature report.^[40]

Isopropyl 2,3,5-tri-*O*-benzyl-D-ribofuranoside (4.11)

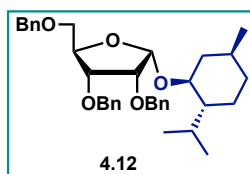
Following the general procedure, **A**, isopropanol (5.0 mg, 83.0 μmol) was coupled with thiofuranoside donor **4.1a** (51.0 mg, 100.0 μmol) to afford **4.11** (26.0 mg, 56.0 μmol , 68% yield, $\alpha:\beta=4:1$) as a colorless viscous oil. $R_f = 0.6$ (hexane: EtOAc = 80:20).



^1H NMR (400 MHz, CDCl_3) δ 7.41 – 7.27 (m, 13H), 7.23 (dq, J = 7.2, 0.7 Hz, 2H), 5.13 (d, J = 4.3 Hz, 1H), 4.76 – 4.68 (m, 2H), 4.64 (d, J = 12.3 Hz, 1H), 4.55 (d, J = 12.7 Hz, 1H), 4.50 (d, J = 12.1 Hz, 1H), 4.44 (d, J = 12.1 Hz, 1H), 4.24 (q, J = 4.0 Hz, 1H), 3.97 (p, J = 6.2 Hz, 1H), 3.84 (dd, J = 6.9, 4.2 Hz, 1H), 3.77 (dd, J = 6.9, 4.2 Hz, 1H), 3.47 (dd, J = 10.5, 3.8 Hz, 1H), 3.38 (dd, J = 10.6, 4.2 Hz, 1H), 1.30 (d, J = 6.3 Hz, 3H), 1.23 (d, J = 6.1 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.7, 138.3, 138.2, 128.5, 128.5, 128.4, 128.2, 128.1, 127.8, 127.8, 127.7, 127.6, 99.8, 81.2, 75.5, 73.5, 72.5, 72.3, 70.1, 23.8, 21.9. The data are identical to the literature report.^[78,80]

***l*-Menthyl 2,3,5-tri-*O*-benzyl- α -D-ribofuranoside (4.12)**



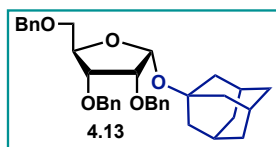
Following the general procedure, **A**, *l*-menthol (5.0 mg, 32.0 μmol) was coupled with thiofuranoside donor **4.1a** (20.0 mg, 38.5 μmol) to afford **4.12** (15.0 mg, 26.9 μmol , 84% yield, α : β =6:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 80:20).

^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.25 (m, 13H), 7.25 – 7.19 (m, 2H), 5.16 (d, J = 4.3 Hz, 1H), 4.77 – 4.53 (m, 5H), 4.51 – 4.40 (m, 2H), 4.26 (q, J = 4.0 Hz, 1H), 3.84 (dd, J = 6.9, 3.9 Hz, 1H), 3.76 (dd, J = 6.9, 4.3 Hz, 1H), 3.46 (dd, J = 10.5, 3.9 Hz, 1H), 3.38 (ddd, J = 11.0, 6.9, 4.3 Hz, 2H), 2.35 (ddt, J = 14.1, 7.0, 3.6 Hz, 1H), 2.15 (dd, J = 10.0, 5.4 Hz, 1H), 1.62 (dt, J = 12.9, 3.8 Hz, 2H), 1.42 (tdd, J = 9.8, 7.3, 3.1 Hz, 2H), 1.30 – 1.15 (m, 3H), 1.02 – 0.79 (m, 11H), 0.76 (d, J = 6.9 Hz, 3H).

^{13}C NMR (125 MHz, CDCl_3) δ 138.7, 138.3, 138.2, 128.5, 128.4, 128.3, 128.2, 127.8, 127.8, 127.7, 127.6, 102.6, 81.2, 80.0, 78.0, 75.5, 73.5, 72.5, 72.2, 70.3, 48.3, 43.4, 34.5, 32.0, 25.1, 23.0, 22.5, 21.4, 16.1. The data are identical to the literature report.^[78,81-82]

Adamantanyl 2,3,5-tri-*O*-benzyl- α -D-ribofuranoside (4.13)

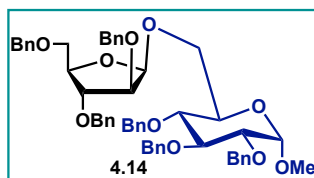
Following the general procedure, **A**, 1-adamantanol (5.0 mg, 33.0 μmol) was coupled with thiofuranoside donor **4.1a** (20.0 mg, 39.5 μmol) to afford **4.13** (13.5 mg, 24.3 μmol , 74% yield, α : β =8:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 80:20).



^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.26 (m, 15H), 5.41 (s, 1H), 4.65 (s, 2H), 4.63 – 4.54 (m, 3H), 4.54 – 4.49 (m, 1H), 4.26 (d, J = 5.6 Hz, 1H), 3.97 (t, J = 5.5 Hz, 1H), 3.77 (q, J = 2.0 Hz, 1H), 3.57 (d, J = 5.3 Hz, 2H), 2.11 (s, 2H), 1.77 (d, J = 11.9 Hz, 3H), 1.70 (d, J = 11.9 Hz, 3H), 1.57 (q, J = 7.7 Hz, 7H).

^{13}C NMR (125 MHz, CDCl_3) δ 138.6, 138.3, 138.2, 128.5, 128.4, 128.1, 127.9, 127.8, 127.8, 127.6, 99.1, 81.1, 80.3, 78.7, 74.4, 73.3, 72.3, 72.3, 72.0, 42.8, 36.4, 30.7. The data are identical to the literature report.

Methyl (2,3,5-tri-O-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (4.14)

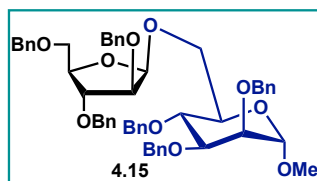


Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 32.0 μmol) to afford **4.14** (14.5 mg, 17.0 μmol , 65% yield, $\alpha:\beta=1:5$) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).

^1H NMR (399 MHz, CDCl_3) δ 7.43 (tt, J = 5.3, 3.1 Hz, 2H), 7.38 – 7.26 (m, 33H), 7.23 – 7.18 (m, 3H), 5.03 – 4.95 (m, 3H), 4.85 – 4.76 (m, 4H), 4.67 (s, 1H), 4.64 (d, J = 2.8 Hz, 1H), 4.62 – 4.59 (m, 3H), 4.55 – 4.51 (m, 4H), 4.45 (d, J = 12.0 Hz, 2H), 4.13 – 4.06 (m, 4H), 4.00 – 3.92 (m, 2H), 3.71 (d, J = 10.1 Hz, 2H), 3.63 – 3.47 (m, 7H), 3.36 (s, 0.6H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.9, 138.4, 138.3, 138.3, 138.2, 137.8, 129.1, 128.8, 128.6, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 106.8, 101.1, 98.2, 98.0, 88.0, 84.3, 83.7, 83.4, 82.2, 81.3, 80.8, 80.1, 80.0, 79.0, 78.8, 78.1, 73.5, 73.4, 72.8, 72.3, 72.1, 70.2, 66.5, 55.2, 53.5, 52.9, 52.5. The data are identical to the literature report.^[83]

Methyl (2,3,5-tri-O-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-mannopyranoside (4.15)



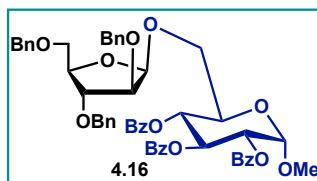
Following the general procedure, **A**, glycosyl acceptor **A9** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 32.0 μmol) to afford **4.15** (17.5 mg, 20.2 μmol , 78% yield, $\alpha:\beta=1:4.5$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.33 (m, 3H), 7.33 – 7.26 (m, 26H), 7.25 – 7.21 (m, 8H), 5.13 (d, $J = 4.0$ Hz, 1H), 4.90 (d, $J = 11.0$ Hz, 1H), 4.74 (s, 1H), 4.70 (d, $J = 5.9$ Hz, 2H), 4.67 (q, $J = 2.1$ Hz, 2H), 4.62 – 4.60 (m, 3H), 4.59 (d, $J = 1.2$ Hz, 2H), 4.56 – 4.54 (m, 2H), 4.52 (d, $J = 1.4$ Hz, 1H), 4.44 (d, $J = 12.1$ Hz, 2H), 4.15 – 4.06 (m, 4H), 4.02 (d, $J = 1.4$ Hz, 1H), 3.87 (d, $J = 3.0$ Hz, 1H), 3.84 (d, $J = 9.2$ Hz, 1H), 3.78 (dd, $J = 3.0, 1.9$ Hz, 2H), 3.76 – 3.73 (m, 1H), 3.68 (d, $J = 10.7$ Hz, 1H), 3.62 (s, 1H), 3.60 (s, 2H), 3.28 (s, 0.7H), 3.18 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.7, 138.6, 138.4, 138.4, 138.3, 138.1, 128.4, 128.4, 128.4, 128.2, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 106.8, 101.2, 99.2, 98.9, 88.0, 84.2, 83.8, 83.7, 80.7, 80.4, 75.3, 75.0, 74.8, 74.6, 73.3, 72.9, 72.8, 72.3, 72.2, 71.9, 71.8, 69.8, 67.3, 54.7. The data are identical to the literature report.^[83]

Methyl (2,3,5-tri-*O*-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-glucopyranoside (4.16)

Following the general procedure, **A**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 31.0 μmol) to afford **4.16** (14.6 mg, 16.0 μmol , 68% yield, $\alpha:\beta=1:7$) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 70:30).

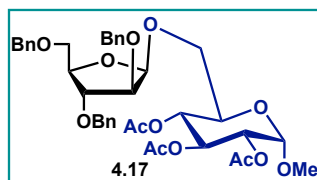


^1H NMR (399 MHz, CDCl_3) δ 7.98 (d, $J = 7.1$ Hz, 2H), 7.93 (d, $J = 7.1$ Hz, 2H), 7.85 – 7.81 (m, 2H), 7.54 – 7.47 (m, 3H), 7.44 – 7.40 (m, 4H), 7.39 – 7.34 (m, 5H), 7.33 (s, 2H), 7.31 – 7.27 (m, 11H), 6.12 (t, $J = 9.7$ Hz, 1H), 5.54 (t, $J = 9.9$ Hz, 1H), 5.24 – 5.17 (m, 2H), 5.06 (t, $J = 3.7$ Hz, 1H), 4.82 (d, $J = 11.8$ Hz, 1H), 4.67 – 4.55 (m, 3H), 4.50 – 4.41 (m, 3H), 4.22 – 4.17 (m, 1H), 4.13 – 4.09 (m, 3H), 3.89 (dd, $J = 11.6, 2.2$ Hz, 1H), 3.61 (dd, $J = 11.7, 5.9$ Hz, 1H), 3.52 (d, $J = 5.4$ Hz, 2H), 3.36 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.9, 165.9, 165.4, 138.3, 138.2, 138.1, 133.5, 133.4, 133.2, 130.0, 130.0, 129.8, 129.8, 129.4, 129.2, 129.1, 128.5, 128.5, 128.5, 128.4, 128.4, 128.4, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 101.4, 96.8, 84.3, 83.3, 80.6, 73.3, 72.5, 72.3, 72.2, 72.2, 70.7, 69.5, 69.0, 66.0, 55.6. The data are identical to the literature report.^[83]

Methyl (2,3,5-tri-*O*-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-acetyl- α -D-glucopyranoside (4.17)

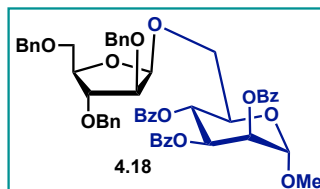
Following the general procedure, **A**, glycosyl acceptor **A10** (8.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 31.0 μmol) to afford **4.17** (12 mg, 16.0 μmol , 68% yield, α : β =1:7) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



^1H NMR (500 MHz, CDCl_3) δ 7.32 (tdd, J = 12.1, 7.5, 3.2 Hz, 22H), 5.46 (dd, J = 10.2, 9.2 Hz, 1H), 5.06 – 4.99 (m, 2H), 4.98 – 4.82 (m, 4H), 4.72 (d, J = 11.7 Hz, 1H), 4.66 (d, J = 11.8 Hz, 1H), 4.61 – 4.51 (m, 7H), 4.13 – 4.05 (m, 4H), 3.95 – 3.87 (m, 2H), 3.73 (dd, J = 11.6, 2.6 Hz, 1H), 3.62 – 3.53 (m, 3H), 3.48 (dd, J = 11.5, 5.9 Hz, 1H), 3.37 (s, 1H), 3.29 (s, 3H), 2.08 (s, 1H), 2.07 (s, 2H), 2.00 (s, 1H), 1.99 (s, 3H), 1.97 (s, 1H), 1.96 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 170.4, 170.3, 170.3, 169.8, 169.6, 138.2, 138.2, 138.0, 138.0, 137.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.0, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.7, 106.2, 101.3, 96.9, 96.7, 96.5, 88.4, 84.3, 83.3, 83.1, 82.4, 80.5, 80.5, 73.4, 73.4, 72.4, 72.3, 72.2, 72.1, 71.0, 70.6, 70.4, 69.5, 69.4, 69.1, 68.5, 68.1, 66.0, 55.4, 55.4, 20.9, 20.9, 20.8, 20.8. The data are identical to the literature report.

Methyl (2,3,5-tri-*O*-benzyl- β -D-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzoyl- α -D-mannopyranoside (4.18)



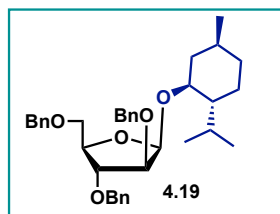
Following the general procedure, **A**, glycosyl acceptor **A13** (13.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 32.0 μmol) to afford **4.18** (13.2 mg, 14.5 μmol , 61% yield, α : β =1:5) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

¹H NMR (399 MHz, CDCl₃) δ 8.10 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.95 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.83 (dd, *J* = 8.5, 1.4 Hz, 2H), 7.55 – 7.48 (m, 2H), 7.43 – 7.39 (m, 4H), 7.39 – 7.33 (m, 4H), 7.32 – 7.26 (m, 8H), 7.25 – 7.19 (m, 7H), 5.96 – 5.89 (m, 1H), 5.85 (dd, *J* = 10.0, 3.3 Hz, 1H), 5.12 (d, *J* = 4.0 Hz, 1H), 4.90 (d, *J* = 1.9 Hz, 1H), 4.82 (d, *J* = 11.7 Hz, 1H), 4.62 – 4.57 (m, 2H), 4.52 (d, *J* = 11.8 Hz, 1H), 4.44 (d, *J* = 12.0 Hz, 1H), 4.36 (d, *J* = 12.0 Hz, 1H), 4.26 – 4.20 (m, 1H), 4.11 – 4.05 (m, 3H), 3.93 (dd, *J* = 11.5, 2.1 Hz, 1H), 3.68 (dd, *J* = 11.3, 6.1 Hz, 1H), 3.50 (dd, *J* = 5.9, 3.1 Hz, 2H), 3.40 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 165.9, 165.9, 165.4, 138.3, 138.2, 138.1, 133.5, 133.4, 133.2, 130.0, 130.0, 129.8, 129.8, 129.4, 129.2, 129.1, 128.5, 128.5, 128.5, 128.4, 128.4, 128.4, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 101.4, 96.8, 84.3, 83.3, 80.6, 73.3, 72.5, 72.3, 72.2, 72.2, 70.7, 69.5, 69.0, 66.0, 55.6. The data are identical to the literature report.^[83]

***l*-Menthyl 2,3,5-tri-*O*-benzyl-β-*D*-arabinofuranoside (4.19)**

Following the general procedure, **A**, *l*-menthol (5.0 mg, 32.0 μmol) was coupled with thiofuranoside donor **4.1d** (20.0 mg, 38.5 μmol) to afford **4.19** (15.5 mg, 27.8 μmol, 87% yield, α:β=1:6) as a colorless viscous oil. *R*_f = 0.5 (hexane: EtOAc = 80:20).

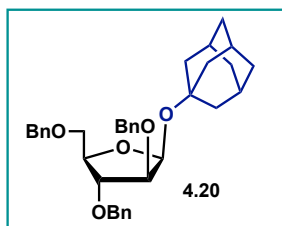


¹H NMR (400 MHz, CDCl₃) δ 7.38 – 7.34 (m, 4H), 7.33 – 7.26 (m, 11H), 5.19 – 5.17 (m, 1H), 4.73 (d, *J* = 11.7 Hz, 1H), 4.67 (d, *J* = 11.7 Hz, 1H), 4.62 (d, *J* = 11.7 Hz, 1H), 4.59 (d, *J* = 12.0 Hz, 1H), 4.54 (d, *J* = 11.7 Hz, 1H), 4.48 (d, *J* = 12.0 Hz, 1H), 4.08 – 4.05 (m, 3H), 3.58 – 3.55 (m, 2H), 3.46 (td, *J* = 10.6, 4.2 Hz, 1H), 2.23 (td, *J* = 7.0, 2.6 Hz, 1H), 2.05 – 1.99 (m, 1H), 1.63 (dq, *J* = 9.6, 3.5 Hz, 2H), 1.35 – 1.27 (m, 3H), 0.92 (d, *J* = 6.6 Hz, 4H), 0.85 (d, *J* = 7.1 Hz, 6H), 0.73 (d, *J* = 6.9 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 138.4, 138.2, 137.9, 128.5, 128.4, 128.4, 128.3, 128.0, 127.9, 127.8, 127.7, 127.7, 97.1, 83.6, 83.4, 79.1, 73.4, 72.7, 72.7, 72.4, 47.6, 40.4, 34.5, 31.5, 25.0, 22.9, 22.5, 21.2, 15.8. The data are identical to the literature report.^[81-82]

Adamantanyl 2,3,5-tri-*O*-benzyl-β-*D*-arabinofuranoside (4.20)

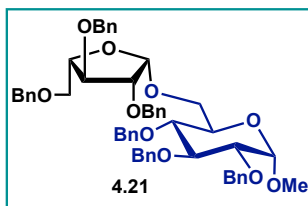
Following the general procedure, **A**, 1-adamantanol (5.0 mg, 33.0 μmol) was coupled with thiofuranoside donor **4.1d** (20.0 mg, 39.5 μmol) to afford **4.20** (13.2 mg, 23.8 μmol, 72% yield, α:β=1:6) as a colorless viscous oil. *R*_f = 0.5 (hexane: EtOAc = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 7.39 – 7.25 (m, 15H), 5.43 (d, *J* = 4.4 Hz, 1H), 4.66 (dd, *J* = 11.8, 9.8 Hz, 2H), 4.59 (d, *J* = 22.2 Hz, 3H), 4.49 (d, *J* = 11.6 Hz, 1H), 4.11 – 4.05 (m, 2H), 4.02 (dd, *J* = 6.6, 4.5 Hz, 1H), 3.69 – 3.64 (m, 1H), 3.59 (dd, *J* = 9.6, 5.5 Hz, 1H), 2.16 – 2.12 (m, 3H), 1.86 (dq, *J* = 11.2, 2.6 Hz, 3H), 1.78 – 1.73 (m, 3H), 1.66 – 1.58 (m, 6H).

¹³C NMR (100 MHz, CDCl₃) δ 138.5, 138.3, 138.0, 128.5, 128.4, 128.4, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 93.9, 84.2, 83.8, 79.9, 74.4, 73.4, 73.3, 72.4, 72.0, 42.9, 36.3, 30.7. The data are identical to the literature report.^[82]

Methyl (2, 3, 5-tri-*O*-benzyl-β-*L*-arabinofuranosyl)-(1→6) 2,3,4-tri-*O*-benzoyl-α-*D*-glucopyranoside (4.21)

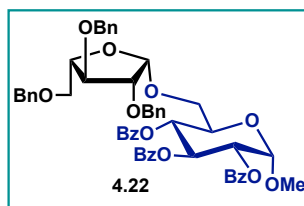


Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1e** (16.0 mg, 32.0 μmol) to afford **4.21** (16.5 mg, 19.0 μmol, 74% yield, α:β=1:4) as a colorless viscous oil. *R*_f = 0.4 (hexane: EtOAc = 70:30).^[53,84]

¹H NMR (400 MHz, CDCl₃) δ 7.33 (d, *J* = 4.3 Hz, 9H), 7.31 – 7.23 (m, 33H), 5.08 (d, *J* = 2.8 Hz, 1H), 4.95 (d, *J* = 11.0 Hz, 1H), 4.82 (dd, *J* = 12.6, 10.9 Hz, 3H), 4.72 (d, *J* = 12.1 Hz, 1H), 4.65 (dd, *J* = 12.6, 1.9 Hz, 3H), 4.62 – 4.54 (m, 4H), 4.51 (d, *J* = 2.8 Hz, 2H), 4.43 (d, *J* = 10.6 Hz, 2H), 4.14 – 4.08 (m, 1H), 4.07 – 4.04 (m, 2H), 3.96 (t, *J* = 9.2 Hz, 2H), 3.90 – 3.84 (m, 1H), 3.74 – 3.68 (m, 2H), 3.67 – 3.53 (m, 3H), 3.50 (d, *J* = 6.2 Hz, 2H), 3.38 (dd, *J* = 9.6, 3.6 Hz, 1H), 3.34 (s, 0.65H), 3.32 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 139.0, 138.4, 138.3, 138.2, 138.2, 138.1, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 101.6, 98.0, 84.1, 83.3, 82.1, 80.3, 80.1, 77.9, 75.7, 75.1, 73.5, 73.4, 73.2, 72.8, 72.3, 72.0, 72.0, 70.4, 66.4, 55.2. The data are identical to the literature report.^[53,84]

Methyl (2, 3, 5-tri-*O*-benzyl-β-*L*-arabinofuranosyl)-(1→6) 2,3,4-tri-*O*-benzoyl-α-*D*-glucopyranoside (4.22)

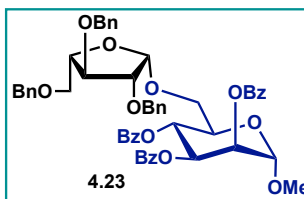


Following the general procedure, **A**, glycosyl acceptor **A11** (13.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1e** (16.0 mg, 31.0 μmol) to afford **4.22** (15.5 mg, 17.0 μmol , 66% yield, $\alpha:\beta=1:5$) as a colorless viscous oil. $R_f=0.3$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 8.01 – 7.93 (m, 5H), 7.89 – 7.85 (m, 2H), 7.55 – 7.49 (m, 3H), 7.41 – 7.27 (m, 24H), 6.15 – 6.09 (m, 1H), 5.55 (t, $J = 9.9$ Hz, 1H), 5.16 (d, $J = 8.5$ Hz, 2H), 4.92 (d, $J = 3.0$ Hz, 1H), 4.68 – 4.59 (m, 4H), 4.59 – 4.52 (m, 2H), 4.41 (d, $J = 3.2$ Hz, 2H), 4.24 – 4.18 (m, 1H), 4.09 (dd, $J = 10.2, 3.8$ Hz, 3H), 3.88 (dd, $J = 11.3, 6.0$ Hz, 1H), 3.54 – 3.49 (m, 3H), 3.43 (s, 0.6H), 3.38 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.9, 165.9, 165.2, 138.3, 138.3, 138.0, 133.5, 133.4, 133.2, 130.0, 130.0, 129.8, 129.8, 129.4, 129.2, 129.2, 128.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.1, 128.1, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.7, 101.1, 96.8, 84.3, 83.4, 80.6, 73.2, 72.9, 72.4, 72.4, 72.3, 70.8, 69.5, 68.7, 66.3, 55.6. The data are identical to the literature report.^[53,84]

Methyl (2,3,5-tri-O-benzyl- β -L-arabinofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzoyl- α -D-mannopyranoside (4.23)



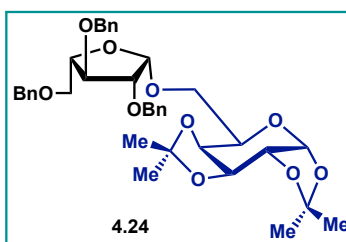
Following the general procedure, **A**, glycosyl acceptor **a13** (13.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1e** (16.0 mg, 31.0 μmol) to afford **4.23** (16.1 mg, 17.7 μmol , 69% yield, $\alpha:\beta=1:4$) as a colorless viscous oil. $R_f=0.3$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 8.09 – 8.05 (m, 2H), 7.97 – 7.94 (m, 2H), 7.83 – 7.80 (m, 2H), 7.55 – 7.52 (m, 1H), 7.50 (d, $J = 7.4$ Hz, 1H), 7.41 (q, $J = 1.5$ Hz, 1H), 7.39 (d, $J = 3.4$ Hz, 2H), 7.37 – 7.33 (m, 2H), 7.33 – 7.26 (m, 10H), 7.24 – 7.16 (m, 7H), 5.86 (s, 1H), 5.85 (t, $J = 2.2$ Hz, 1H), 5.67 – 5.64 (m, 1H), 4.90 (d, $J = 1.8$ Hz, 1H), 4.87 (d, $J = 4.0$ Hz, 1H), 4.64 (d, $J = 11.7$ Hz, 1H), 4.60 (d, $J = 3.5$ Hz, 1H), 4.58 – 4.55 (m, 2H), 4.53 – 4.49 (m, 1H), 4.42 (d, $J = 11.9$ Hz, 1H), 4.34 (d, $J = 12.0$ Hz, 1H), 4.25 (s, 1H), 4.08 (dd, $J = 7.9, 4.4$ Hz, 2H), 4.03 (d, $J = 4.0$ Hz, 1H),

3.97 (dd, $J = 11.2, 6.3$ Hz, 1H), 3.57 (d, $J = 2.2$ Hz, 1H), 3.55 – 3.52 (m, 2H), 3.47 (s, 0.7H), 3.44 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.7, 165.6, 165.5, 138.3, 138.2, 138.0, 137.9, 133.5, 133.5, 133.5, 133.2, 130.0, 130.0, 129.9, 129.8, 129.4, 129.3, 129.3, 129.2, 128.7, 128.6, 128.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.1, 128.1, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 107.2, 101.0, 98.5, 88.5, 84.1, 83.4, 83.4, 80.6, 73.4, 73.3, 73.0, 72.4, 72.2, 72.1, 70.6, 70.5, 70.4, 70.2, 70.1, 69.8, 69.5, 67.4, 66.8, 55.5. The data are identical to the literature report.^[53,84]

Methyl (2,3,5-tri-*O*-benzyl- β -L-arabinofuranosyl)-(1 $\rightarrow$ 6)1,2:3,4-di-*O*-isopropylidene- α -D-galactopyranoside (4.24)



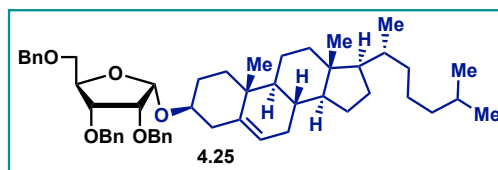
Following the general procedure, **A**, glycosyl acceptor **A8** (7.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **4.1e** (17.0 mg, 32.0 μmol) to afford **4.24** (12.2 mg, 18.5 μmol , 68% yield, $\alpha:\beta=1:2$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.27 (m, 21H), 7.25 – 7.22 (m, 1H), 5.53 (d, $J = 5.0$ Hz, 1H), 5.07 (d, $J = 4.1$ Hz, 1H), 4.71 (d, $J = 12.2$ Hz, 1H), 4.67 (s, 1H), 4.63 (d, $J = 5.5$ Hz, 1H), 4.57 (td, $J = 6.9, 3.0$ Hz, 6H), 4.53 – 4.50 (m, 1H), 4.45 (d, $J = 12.2$ Hz, 1H), 4.33 – 4.26 (m, 3H), 4.24 – 4.20 (m, 1H), 4.15 – 4.05 (m, 4H), 4.04 – 3.99 (m, 1H), 3.93 – 3.87 (m, 1H), 3.83 (dd, $J = 10.0, 6.2$ Hz, 1H), 3.75 – 3.69 (m, 1H), 3.61 (ddd, $J = 15.7, 6.3, 3.1$ Hz, 3H), 1.53 (s, 1H), 1.52 (s, 3H), 1.45 (s, 3H), 1.44 (s, 1H), 1.33 (s, 4H), 1.30 (d, $J = 2.6$ Hz, 5H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.3, 138.3, 138.2, 138.1, 137.9, 137.8, 128.8, 128.5, 128.5, 128.4, 128.2, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 109.4, 109.3, 108.6, 108.6, 106.7, 100.8, 96.4, 87.9, 84.2, 83.6, 83.5, 80.6, 80.6, 73.4, 72.8, 72.3, 72.1, 72.0, 71.9, 71.3, 70.8, 70.8, 70.7, 70.6, 69.8, 68.0, 66.7, 65.9, 65.6, 26.2, 26.1, 26.1, 25.1, 25.0, 24.7, 24.5. The data are identical to the literature report.^[52]

4.4.4. Application of this method

Cholesteryl 2,3,5-tri-*O*-benzyl- α -D-ribofuranoside (4.25)



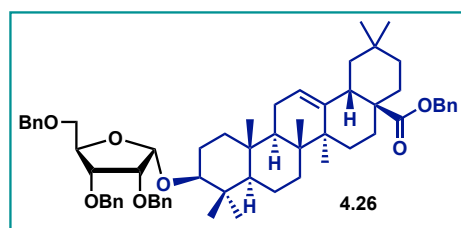
Following the general procedure, **A**, cholesterol (10.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μmol) to afford **4.25** (11.8 mg, 14.95 μmol , 58% yield, $\alpha:\beta=9:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 80:20).^[82]

^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.26 (m, 15H), 5.32 (s, 1H), 5.15 (s, 1H), 4.65 (s, 2H), 4.59 – 4.53 (m, 3H), 4.48 (t, $J = 11.1$ Hz, 1H), 4.30 (dd, $J = 8.4, 3.3$ Hz, 1H), 4.01 (t, $J = 5.8$ Hz, 1H), 3.83 (d, $J = 4.7$ Hz, 1H), 3.62 – 3.42 (m, 3H), 2.35 – 2.24 (m, 1H), 2.09 (s, 1H), 1.98 (t, $J = 16.1$ Hz, 2H), 1.76 (d, $J = 11.6$ Hz, 2H), 1.49 – 1.32 (m, 10H), 1.11 (q, $J = 10.8$ Hz, 6H), 0.98 (d, $J = 15.6$ Hz, 7H), 0.91 (d, $J = 6.4$ Hz, 4H), 0.88 – 0.83 (m, 9H), 0.67 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 140.6, 138.4, 138.0, 128.5, 128.4, 128.4, 128.1, 127.9, 127.9, 127.8, 127.8, 127.6, 122.0, 103.5, 80.3, 80.3, 78.7, 73.2, 72.5, 72.4, 71.7, 56.8, 56.2, 50.2, 42.4, 39.8, 39.6, 38.6, 37.3, 36.8, 36.3, 35.9, 32.0, 32.0, 29.8, 29.7, 28.3, 28.1, 24.4, 23.9, 22.9, 22.7, 21.1, 19.4, 18.8, 11.9. The data are identical to the literature report.^[82]

Benzyl 3-O-(2,3,5-tri-O-benzyl- α -D-ribofuranosyl) oleanate (**4.26**)

Following the general procedure, **A**, benzyl oleanate (14.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1a** (16.0 mg, 31.0 μmol) to afford **4.26** (17.8 mg, 18.75 μmol , 73% yield, $\alpha:\beta=10:1$) as a colorless viscous oil. $R_f = 0.3$ (hexane: EtOAc = 80:20).



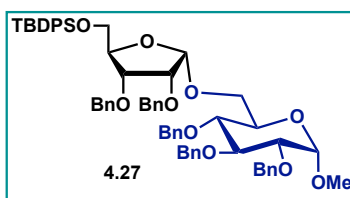
^1H NMR (400 MHz, CDCl_3) δ 7.34 (d, $J = 2.6$ Hz, 7H), 7.33 – 7.27 (m, 13H), 5.30 – 5.28 (m, 1H), 5.10 (d, $J = 12.5$ Hz, 1H), 5.07 (d, $J = 1.8$ Hz, 1H), 5.04 (d, $J = 12.6$ Hz, 1H), 4.63 (d, $J = 1.7$ Hz, 2H), 4.56 (dd, $J = 11.9, 6.6$ Hz, 3H), 4.52 – 4.48 (m, 1H), 4.30 (td, $J = 6.2, 4.3$ Hz, 1H), 3.93 (dd, $J = 6.4, 4.8$ Hz, 1H), 3.81 (dd, $J = 4.8, 1.8$ Hz, 1H), 3.60 – 3.52 (m, 2H), 2.98 (dd, $J = 11.7, 4.4$ Hz, 1H), 2.90 (dd, $J = 13.9, 4.5$ Hz, 1H), 1.98 (d, $J = 4.1$ Hz, 1H), 1.84 (dd, $J = 9.0, 3.7$ Hz, 2H), 1.78 (d, $J = 10.1$ Hz, 1H), 1.72 – 1.53 (m, 8H), 1.46 (d, $J = 2.9$ Hz, 1H), 1.42 – 1.28 (m, 4H), 1.26 (s, 1H), 1.24 – 1.17 (m, 3H), 1.13 (s, 3H), 1.04 (d, $J = 14.1$ Hz, 2H), 0.92 (s, 3H), 0.90 (s, 4H), 0.87 (s, 4H), 0.83 (s, 3H), 0.69 (s, 4H), 0.59 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 177.6, 143.8, 138.4, 138.0, 138.0, 136.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.1, 128.1, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 122.6, 107.9, 88.4, 80.3, 80.1, 78.4, 73.3, 72.3, 72.3, 71.9, 66.0, 55.5, 47.6, 46.8, 45.9, 41.8, 41.5, 39.4, 38.8, 38.5, 36.8, 33.9, 33.2, 32.8, 32.5, 30.8, 28.3, 27.7, 26.0, 25.6, 23.7, 23.5, 23.1, 18.4, 17.0, 16.5, 15.4.

HRMS (ESI): calc. for C₆₃H₈₂O₇ (M+H): 949.5982; found: 949.5987.

Methyl (2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl-α-D-ribofuranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (4.27)

Following the general procedure, **A**, glycosyl acceptor **A1** (450.0 mg, 0.967 mmol) was coupled with thiofuranoside donor **4.1f** (712.0 mg, 1.16 mmol) to afford **4.27** (530 mg, 0.611 mmol, 64% yield, α:β=16.5:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

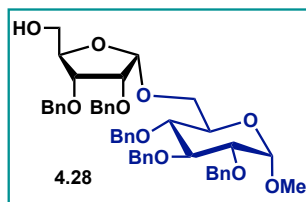


¹H NMR (400 MHz, CDCl₃) δ 7.64 – 7.60 (m, 2H), 7.59 – 7.56 (m, 2H), 7.42 – 7.37 (m, 4H), 7.36 – 7.27 (m, 15H), 7.25 (t, *J* = 2.2 Hz, 4H), 7.23 – 7.17 (m, 8H), 5.14 (d, *J* = 4.1 Hz, 1H), 4.94 (d, *J* = 11.0 Hz, 1H), 4.82 (d, *J* = 11.0 Hz, 1H), 4.78 – 4.71 (m, 4H), 4.67 (d, *J* = 12.1 Hz, 1H), 4.62 (d, *J* = 12.1 Hz, 2H), 4.57 (d, *J* = 3.6 Hz, 1H), 4.46 (d, *J* = 11.9 Hz, 1H), 4.15 (dt, *J* = 6.6, 3.5 Hz, 2H), 4.05 (dd, *J* = 6.1, 3.6 Hz, 1H), 3.98 – 3.91 (m, 2H), 3.80 – 3.62 (m, 4H), 3.58 (dd, *J* = 11.2, 3.0 Hz, 1H), 3.46 (dd, *J* = 9.6, 3.6 Hz, 1H), 3.34 (s, 3H), 0.96 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 139.2, 138.8, 138.5, 138.4, 138.4, 135.7, 135.6, 133.4, 133.2, 129.8, 129.8, 128.5, 128.4, 128.4, 128.3, 128.1, 128.1, 127.9, 127.9, 127.9, 127.8, 127.8, 127.7, 127.6, 127.5, 102.2, 98.3, 83.1, 82.1, 80.1, 78.3, 77.9, 75.1, 73.5, 72.6, 72.4, 70.3, 66.7, 63.9, 55.2, 26.9, 19.3.

HRMS (ESI): calc. for C₆₃H₇₀O₁₀SiNa (M+Na): 1037.4636; found: 1037.4616.

Methyl (2,3-di-O-benzyl-5-hydroxy-α-D-ribofuranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (4.28)



Silylated furanoside **4.27** (530 mg, 522 μmol) was dissolved in THF (0.1M), and TBAF (1M, 783 μL , 1.5 equiv.) was added to the reaction mixture at room temperature. Reaction progress was monitored by TLC, and upon complete consumption of the starting material, the reaction mixture was condensed and purified by column chromatography to afford **4.28** (335 mg, 0.432 mmol, 83% yield) as a viscous oil. R_f = 0.2 (hexane: EtOAc = 60:40).

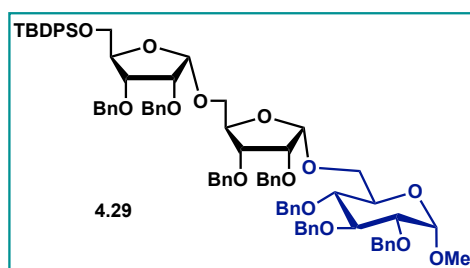
^1H NMR (400 MHz, CDCl_3) δ 7.41 – 7.37 (m, 2H), 7.37 – 7.19 (m, 23H), 5.15 (d, J = 3.9 Hz, 1H), 4.95 (d, J = 11.0 Hz, 1H), 4.83 (d, J = 11.0 Hz, 1H), 4.80 – 4.70 (m, 5H), 4.64 – 4.57 (m, 3H), 4.47 (d, J = 11.8 Hz, 1H), 4.15 (dq, J = 8.8, 3.1 Hz, 2H), 3.97 (t, J = 9.2 Hz, 1H), 3.89 (t, J = 5.6 Hz, 1H), 3.85 (dd, J = 6.3, 3.9 Hz, 1H), 3.78 (dd, J = 3.7, 1.6 Hz, 1H), 3.75 – 3.66 (m, 3H), 3.45 (dd, J = 9.6, 3.6 Hz, 2H), 3.35 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.1, 138.8, 138.4, 138.3, 138.3, 128.5, 128.4, 128.4, 128.4, 128.4, 128.2, 128.0, 127.9, 127.9, 127.8, 127.7, 127.6, 127.5, 102.4, 98.3, 82.2, 82.1, 80.1, 78.0, 78.0, 77.4, 77.1, 76.9, 75.9, 75.7, 75.2, 73.5, 72.7, 72.6, 70.3, 66.8, 62.4, 55.2.

HRMS (ESI): calc. for $\text{C}_{47}\text{H}_{52}\text{O}_{10}$ ($\text{M}+\text{Na}$): 799.3458; found: 799.3436.

Methyl (2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 5)-(2,3-di-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (4.29)

Following the general procedure **A**, glycosyl acceptor **4.28** (21.0 mg, 27.03 μmol) was coupled with thiofuranoside donor **4.1f** (20.0 mg, 33.0 μmol) to afford **4.29** (21.0 mg, 15.82 μmol , 58% yield, α : β =12:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).



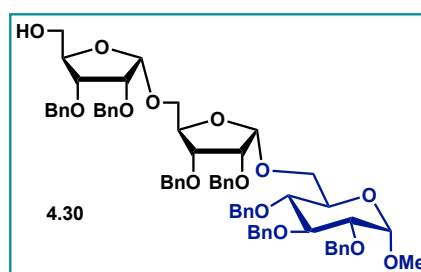
^1H NMR (400 MHz, CDCl_3) δ 7.59 (ddd, J = 15.7, 8.0, 1.6 Hz, 4H), 7.41 (dd, J = 7.4, 5.3 Hz, 2H), 7.38 – 7.26 (m, 26H), 7.25 – 7.16 (m, 14H), 7.14 – 7.04 (m, 3H), 5.08 (d, J = 4.1 Hz, 1H), 5.04 (d, J = 4.2 Hz, 1H), 4.91 (d, J = 11.0 Hz, 1H), 4.80 (d, J = 11.0 Hz, 1H), 4.73 (dd, J = 11.5, 7.7 Hz, 2H), 4.69 – 4.66 (m, 2H), 4.64 (d, J = 2.8 Hz, 1H), 4.61 (d, J = 4.3 Hz, 1H), 4.58 (d, J = 3.5 Hz, 1H), 4.55 (d, J = 3.4 Hz, 1H), 4.49 (dd, J = 12.0, 6.7 Hz, 2H), 4.39 (d, J = 11.6 Hz, 1H), 4.31 (d, J = 11.6 Hz, 1H), 4.26 – 4.23 (m, 1H), 4.14 – 4.09 (m, 2H), 4.04 (t, J = 3.3 Hz, 1H), 4.01 (dd, J = 6.2, 3.0 Hz, 1H), 3.96 – 3.90 (m, 2H), 3.86 (dd, J = 6.3, 4.2 Hz, 1H), 3.77 (dd, J = 11.2,

2.7 Hz, 1H), 3.71 (d, $J = 7.3$ Hz, 2H), 3.61 (dd, $J = 11.2, 2.9$ Hz, 2H), 3.54 (td, $J = 11.1, 3.1$ Hz, 2H), 3.41 (dd, $J = 9.6, 3.4$ Hz, 1H), 3.32 (s, 3H), 0.96 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.2, 138.9, 138.9, 138.7, 138.6, 138.5, 138.2, 135.7, 135.7, 135.6, 133.3, 133.1, 129.9, 129.8, 128.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.3, 128.2, 128.2, 128.2, 128.1, 128.1, 128.0, 127.9, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 127.6, 127.5, 127.4, 127.4, 127.3, 102.2, 101.7, 98.3, 83.6, 82.3, 82.1, 80.1, 78.9, 78.8, 77.9, 77.4, 77.1, 76.9, 75.6, 75.1, 73.5, 72.7, 72.6, 72.3, 72.2, 70.4, 67.5, 66.5, 64.0, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{82}\text{H}_{90}\text{O}_{14}\text{SiNa}$ ($\text{M}+\text{Na}$): 1349.5998; found: 1349.5951.

Methyl (2,3-di-*O*-benzyl-5-hydroxy- α -D-ribofuranosyl)-(1 $\rightarrow$ 5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (4.30)



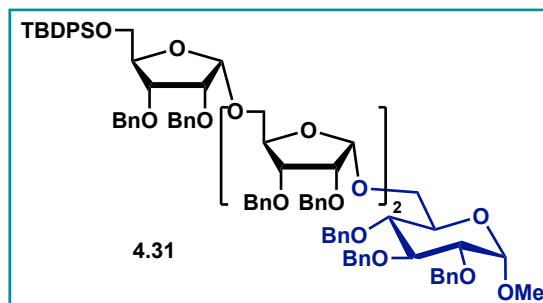
^1H NMR (400 MHz, CDCl_3) δ 7.35 – 7.27 (m, 23H), 7.25 – 7.22 (m, 8H), 7.21 – 7.18 (m, 3H), 7.17 – 7.13 (m, 2H), 5.08 – 5.06 (m, 1H), 5.02 (d, $J = 4.1$ Hz, 1H), 4.92 (dd, $J = 11.0, 1.3$ Hz, 1H), 4.80 (dd, $J = 11.0, 1.3$ Hz, 1H), 4.72 (ddd, $J = 16.0, 12.0, 7.5$ Hz, 5H), 4.65 – 4.59 (m, 2H), 4.58 – 4.54 (m, 2H), 4.51 (dd, $J = 11.8, 5.5$ Hz, 3H), 4.42 (d, $J = 11.8$ Hz, 1H), 4.33 (d, $J = 11.6$ Hz, 1H), 4.25 (d, $J = 3.3$ Hz, 1H), 4.15 – 4.07 (m, 2H), 4.01 (q, $J = 3.7$ Hz, 1H), 3.96 – 3.89 (m, 2H), 3.87 (ddd, $J = 6.7, 4.1, 1.1$ Hz, 1H), 3.78 – 3.71 (m, 5H), 3.62 (td, $J = 11.6, 2.2$ Hz, 2H), 3.54 (dd, $J = 11.2, 3.5$ Hz, 1H), 3.47 – 3.40 (m, 2H), 3.33 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.2, 138.9, 138.8, 138.6, 138.5, 138.4, 138.1, 128.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.4, 128.2, 128.2, 128.1, 128.1, 128.1, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7, 127.6, 127.5, 127.5, 127.4, 102.2, 101.9, 98.3, 82.8, 82.1, 82.1, 80.1, 78.8, 78.5, 77.9, 77.4, 77.1, 76.9, 76.6, 75.6, 75.5, 75.1, 73.5, 72.7, 72.7, 72.4, 72.3, 70.3, 67.6, 66.6, 62.6, 55.2.

HRMS (ESI): calc. for $\text{C}_{66}\text{H}_{72}\text{O}_{14}\text{Na}$ ($\text{M}+\text{Na}$): 1111.482; found: 1111.4789.

Methyl (2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (4.31)

Following the general procedure, **A**, glycosyl acceptor **4.30** (29.0 mg, 26.62 μmol) was coupled with thiofuranoside donor **4.1f** (20.0 mg, 32.0 μmol) to afford **4.31** (26.4 mg, 15.95 μmol , 60% yield, $\alpha:\beta=8:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).

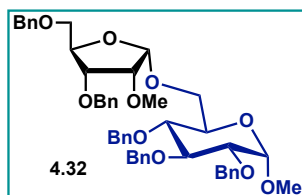


¹H NMR (400 MHz, CDCl₃) δ 7.62 – 7.56 (m, 4H), 7.44 – 7.40 (m, 2H), 7.36 (tt, *J* = 6.7, 1.1 Hz, 6H), 7.33 – 7.27 (m, 20H), 7.24 – 7.20 (m, 15H), 7.18 – 7.15 (m, 5H), 7.13 – 7.09 (m, 3H), 5.04 (d, *J* = 4.2 Hz, 1H), 5.02 (d, *J* = 4.3 Hz, 1H), 4.98 – 4.96 (m, 1H), 4.91 (dd, *J* = 11.2, 1.1 Hz, 1H), 4.80 (d, *J* = 10.8 Hz, 1H), 4.76 – 4.69 (m, 3H), 4.67 (d, *J* = 4.5 Hz, 1H), 4.65 (s, 1H), 4.62 (d, *J* = 11.3 Hz, 3H), 4.58 (d, *J* = 1.8 Hz, 1H), 4.56 – 4.51 (m, 3H), 4.49 (s, 1H), 4.47 (d, *J* = 4.6 Hz, 1H), 4.44 (s, 1H), 4.41 (d, *J* = 11.1 Hz, 1H), 4.35 (dd, *J* = 11.8, 9.6 Hz, 2H), 4.28 – 4.20 (m, 3H), 4.15 – 4.04 (m, 5H), 4.03 – 3.99 (m, 1H), 3.93 – 3.86 (m, 4H), 3.79 – 3.73 (m, 2H), 3.71 (d, *J* = 5.4 Hz, 2H), 3.62 (dd, *J* = 11.2, 4.0 Hz, 1H), 3.59 – 3.55 (m, 2H), 3.51 (dd, *J* = 11.0, 3.4 Hz, 1H), 3.46 (dd, *J* = 10.7, 3.6 Hz, 1H), 3.42 (d, *J* = 1.2 Hz, 1H), 3.32 (d, *J* = 1.1 Hz, 3H), 0.97 (d, *J* = 1.2 Hz, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 139.3, 139.0, 139.0, 138.9, 138.8, 138.7, 138.6, 138.5, 138.2, 135.7, 135.7, 135.7, 133.3, 133.1, 129.9, 129.9, 128.5, 128.5, 128.5, 128.5, 128.4, 128.3, 128.3, 128.3, 128.3, 128.2, 128.2, 128.2, 128.1, 128.1, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 127.6, 127.5, 127.5, 127.5, 127.4, 127.4, 127.3, 127.3, 102.2, 101.7, 101.7, 101.4, 98.3, 98.0, 83.7, 82.7, 82.4, 82.1, 80.1, 77.4, 77.1, 76.9, 67.7, 67.3, 66.5, 64.1, 55.1, 26.9, 19.3.

HRMS (ESI): calc. for C₁₀₁H₁₁₀O₁₈SiNa (M+Na): 1661.7359; found: 1661.7309.

Methyl (2-methoxy-3,5-di-*O*-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (4.32)



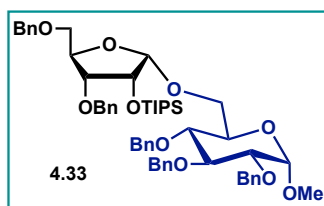
Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **4.1g** (12.0 mg, 31.0 μ mol) to afford **4.32** (13.3 mg, 16.82 μ mol, 65% yield, α : β =10:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.27 (m, 18H), 7.25 – 7.19 (m, 7H), **5.16 (d, J = 4.2 Hz, 1H)**, 4.95 (d, J = 11.0 Hz, 1H), 4.84 – 4.75 (m, 4H), 4.67 – 4.62 (m, 2H), **4.57 (d, J = 3.6 Hz, 1H)**, 4.51 – 4.40 (m, 3H), 4.19 – 4.10 (m, 2H), 3.99 – 3.88 (m, 2H), 3.79 – 3.75 (m, 1H), 3.70 – 3.65 (m, 3H), 3.54 (dd, J = 9.6, 3.6 Hz, 1H), 3.45 (s, 3H), 3.42 (d, J = 3.6 Hz, 1H), 3.37 (d, J = 1.4 Hz, 1H), 3.34 (s, 3H).s

^{13}C NMR (100 MHz, CDCl_3) δ 139.1, 138.7, 138.4, 138.2, 138.1, 128.5, 128.5, 128.4, 128.3, 128.2, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7, 127.7, 127.6, 127.5, 101.9, 98.2, 82.2, 81.6, 80.6, 79.9, 77.9, 75.7, 75.1, 73.5, 72.5, 70.1, 69.9, 66.7, 59.0, 55.2. The data are identical to the literature report.^[77]

Methyl (2-O-triisopropylsilyl-3,5-di-O-benzyl- α -D-ribofuranosyl)-(1 $\rightarrow$ 6)-2,3,4-tri-O-benzyl- α -D-glucopyranoside (4.33)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **4.1h** (17.0 mg, 31.0 μ mol) to afford **4.33** (15.0 mg, 16.07 μ mol, 62% yield, α : β =8:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 70:30).

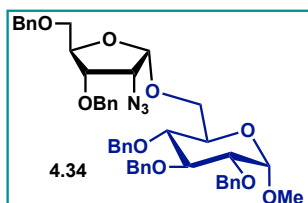


^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.28 (m, 13H), 7.25 – 7.09 (m, 11H), **4.99 (d, J = 4.4 Hz, 1H)**, 4.93 (d, J = 11.1 Hz, 1H), 4.86 – 4.79 (m, 3H), **4.76 (d, J = 3.2 Hz, 1H)**, 4.70 (d, J = 18.3 Hz, 1H), 4.66 – 4.60 (m, 2H), 4.54 – 4.49 (m, 2H), 4.44 (dd, J = 11.8, 1.6 Hz, 2H), 4.25 (dd, J = 6.2, 4.4 Hz, 1H), 4.19 – 4.15 (m, 1H), 4.10 (dd, J = 11.0, 3.1 Hz, 1H), 3.97 – 3.91 (m, 1H), 3.81 (dd, J = 6.1, 2.5 Hz, 1H), 3.75 – 3.68 (m, 2H), 3.56 (dd, J = 11.1, 1.3 Hz, 1H), 3.49 – 3.43 (m, 3H), 3.31 (s, 3H), 1.05 (m, 21H).

¹³C NMR (100 MHz, CDCl₃) δ 139.4, 139.1, 139.0, 138.5, 138.2, 128.5, 128.4, 128.4, 128.2, 128.0, 127.9, 127.9, 127.7, 127.7, 127.5, 127.4, 127.3, 102.9, 98.2, 82.5, 82.2, 79.7, 78.1, 78.0, 77.4, 75.6, 75.1, 74.5, 73.5, 73.4, 72.9, 70.7, 70.4, 66.5, 18.2, 18.1, 12.4. The data are identical to the literature report.^[77]

Methyl (2-azido-3,5-di-O-benzyl-α-D-ribofuranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (4.34)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **4.1i** (12.4 mg, 31.0 μmol) to afford **4.34** (11.2 mg, 13.97 μmol, 54% yield, α:β=9:1) as a colorless viscous oil. *R_f* = 0.3 (hexane: EtOAc = 70:30).



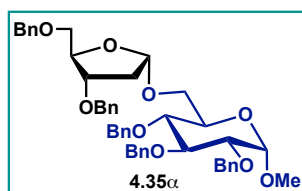
¹H NMR (400 MHz, CDCl₃) δ 7.37 – 7.27 (m, 17H), 7.22 (tdd, *J* = 9.8, 7.6, 5.9 Hz, 9H), **5.26 (d, *J* = 4.6 Hz, 1H)**, 4.94 (d, *J* = 11.0 Hz, 1H), 4.79 (d, *J* = 11.4 Hz, 2H), 4.76 (d, *J* = 11.1 Hz, 1H), 4.72 – 4.67 (m, 2H), 4.64 (d, *J* = 12.0 Hz, 1H), **4.57 (d, *J* = 3.5 Hz, 1H)**, 4.51 – 4.45 (m, 2H), 4.39 (d, *J* = 12.1 Hz, 1H), 4.22 (dd, *J* = 10.9, 2.7 Hz, 1H), 4.18 (q, *J* = 3.6 Hz, 1H), 4.01 (dd, *J* = 6.9, 3.3 Hz, 1H), 3.96 (dd, *J* = 9.7, 8.2 Hz, 1H), 3.77 – 3.71 (m, 2H), 3.64 (dd, *J* = 11.0, 1.6 Hz, 1H), 3.53 (dd, *J* = 9.7, 3.5 Hz, 1H), 3.41 (dd, *J* = 10.5, 3.8 Hz, 1H), 3.34 (s, 4H), 3.26 (dd, *J* = 6.9, 4.6 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 139.1, 138.8, 138.3, 137.8, 137.5, 128.5, 128.5, 128.4, 128.3, 128.1, 127.9, 127.9, 127.8, 127.7, 127.6, 127.5, 103.7, 98.4, 82.7, 82.0, 80.0, 78.9, 75.7, 75.1, 73.7, 73.5, 73.1, 70.0, 69.7, 66.7, 61.1, 55.2.

HRMS (ESI): calc. for C₄₇H₅₁O₉N₃Na (*M*+Na): 824.3523; found: 824.3505.

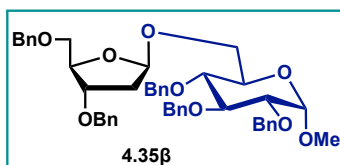
Methyl (2-deoxy-3,5-di-O-benzyl-α/β-D-ribofuranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (4.35α)

Following the general procedure, **A**, glycosyl acceptor **A1** (15.0 mg, 33.0 μmol) was coupled with thiofuranoside donor **4.1j** (14.0 mg, 39.0 μmol) to afford **4.35α** (7 mg, 9.9 μmol, 29% yield, α-anomer; 7.5 mg, 10 μmol, 30% yield, β-anomer; α:β=1:1) as a colorless viscous oil. *R_f* = 0.3 (hexane: EtOAc = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 7.37 – 7.27 (m, 17H), 7.24 (d, *J* = 4.5 Hz, 8H), **5.26 (dd, *J* = 5.5, 1.7 Hz, 1H)**, 4.95 (d, *J* = 10.9 Hz, 1H), 4.84 – 4.77 (m, 2H), 4.75 (s, 2H), 4.69 – 4.60 (m, 2H), 4.53 – 4.42 (m, 4H), 4.36 (d, *J* = 11.8 Hz, 1H), 4.23 – 4.14 (m, 2H), 4.02 – 3.93 (m, 2H), 3.72 (d, *J* = 7.6 Hz, 2H), 3.58 – 3.51 (m, 2H), 3.46 (t, *J* = 4.4 Hz, 2H), 3.35 (s, 3H), 2.28 (ddd, *J* = 13.5, 7.8, 5.7 Hz, 1H), 2.18 – 2.12 (m, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 139.10, 138.74, 138.38, 138.17, 128.58, 128.51, 128.48, 128.28, 128.10, 128.08, 128.01, 127.83, 127.78, 127.76, 127.71, 127.63, **104.36, 98.47**, 79.89, 78.92, 75.85, 75.21, 73.56, 73.49, 71.61, 70.03, 69.98, 65.74, 55.30, 38.80.

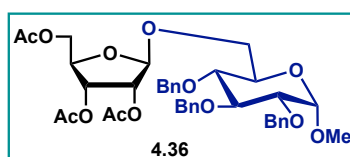


¹H NMR (400 MHz, CDCl₃) δ 7.32 (dddd, *J* = 17.8, 9.8, 8.0, 3.7 Hz, 25H), 4.98 (d, *J* = 10.7 Hz, 1H), 4.89 – 4.77 (m, 4H), 4.71 – 4.64 (m, 3H), 4.59 – 4.49 (m, 4H), 3.98 (t, *J* = 9.2 Hz, 1H), 3.89 – 3.83 (m, 2H), 3.78 – 3.65 (m, 4H), 3.54 – 3.44 (m, 3H), 3.32 (s, 3H), 2.17 (td, *J* = 11.8, 3.3 Hz, 1H), 1.86 – 1.78 (m, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 138.82, 138.71, 138.61, 138.32, 138.30, 128.62, 128.59, 128.49, 128.22, 128.19, 128.07, 127.99, 127.97, 127.93, 127.83, 127.72, 127.68, **98.35, 98.04**, 82.29, 80.07, 77.87, 75.97, 75.20, 73.47, 72.68, 72.36, 71.56, 70.50, 70.10, 66.34, 61.25, 55.17, 32.31.

The data are identical to the literature report.^[85]

Methyl (2,3,5-tri-*O*-acetyl-β-*D*-ribofuranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-*D*-glucopyranoside (4.36)

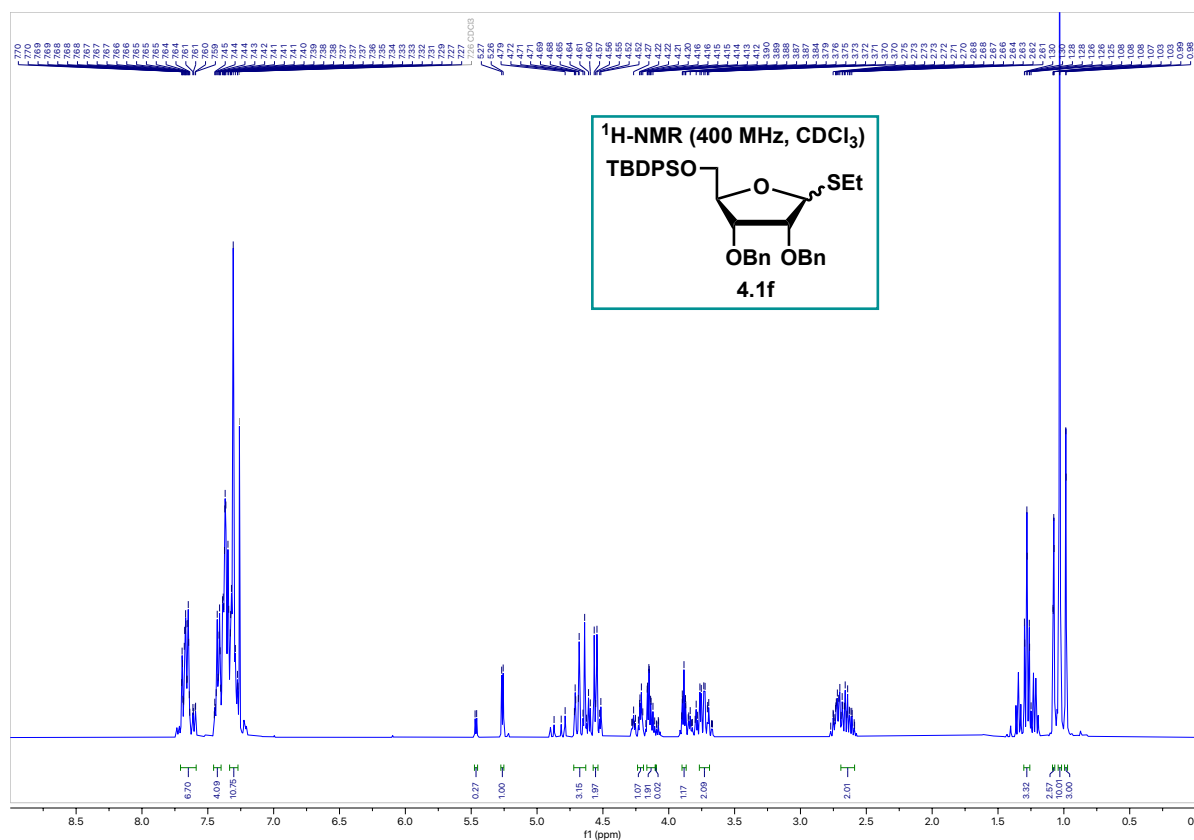


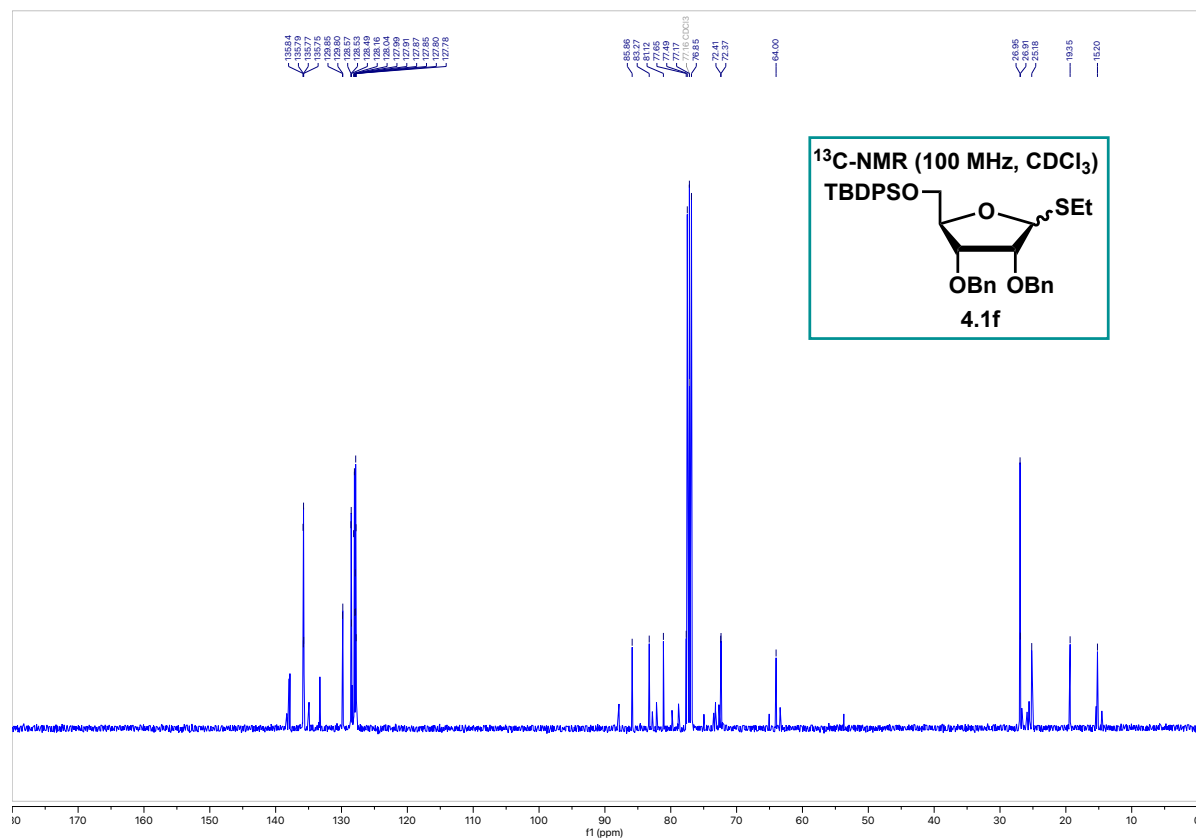
Following the general procedure, **A**, glycosyl acceptor **A1** (15.0 mg, 33.0 μmol) was coupled with thiofuranoside donor **4.1k** (13.0 mg, 39.0 μmol) to afford **4.36** (16 mg, 22.5 μmol , 66% yield, only β -anomer;) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 70:30).

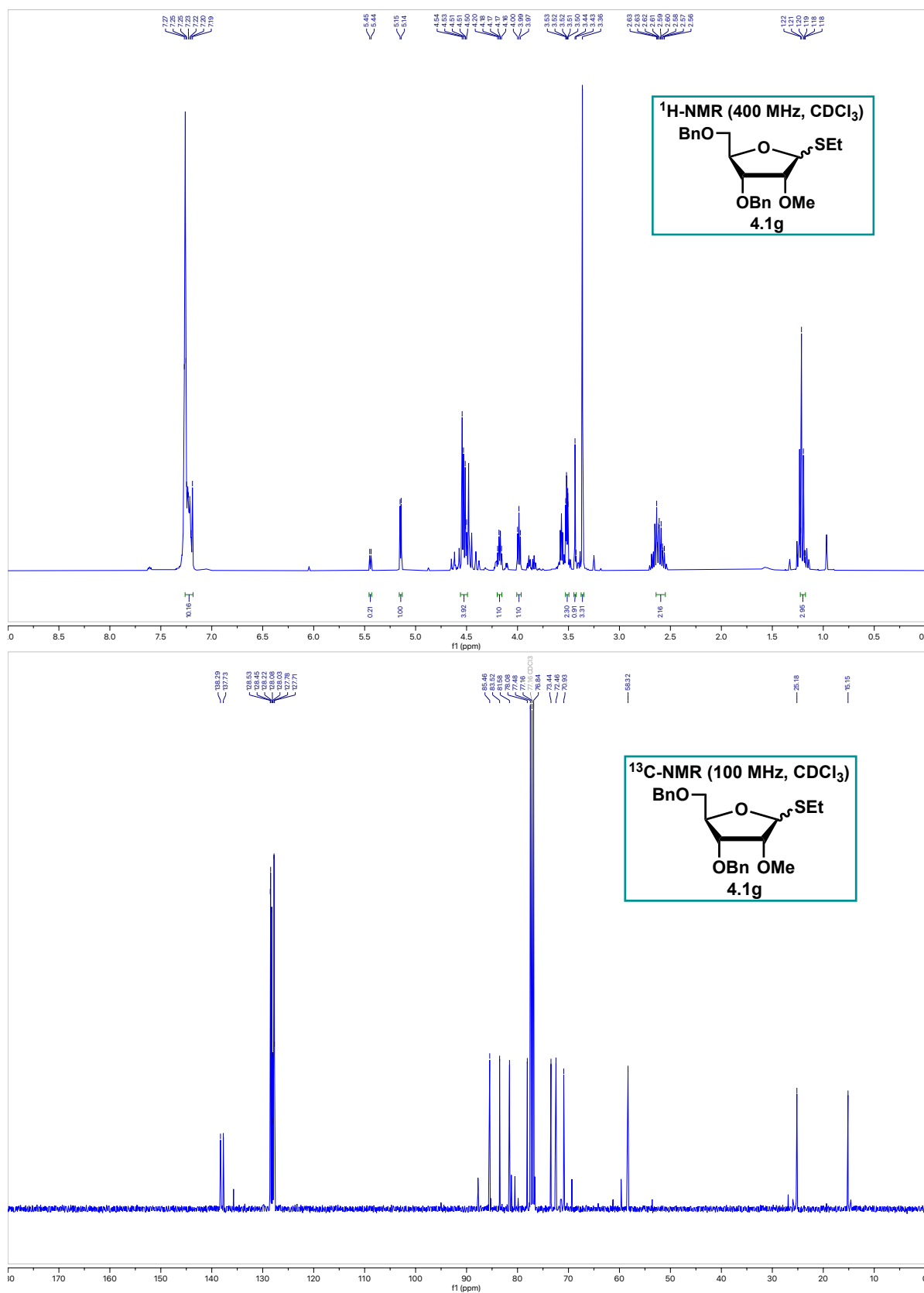
^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.27 (m, 14H), 7.25 (s, 2H), 5.32 (dd, J = 6.8, 4.9 Hz, 1H), 5.21 – 5.18 (m, 1H), 4.98 (d, J = 10.9 Hz, 1H), 4.88 (d, J = 11.3 Hz, 2H), 4.82 – 4.76 (m, 2H), 4.67 (d, J = 12.1 Hz, 1H), 4.59 – 4.54 (m, 2H), 4.33 – 4.24 (m, 2H), 4.11 (dd, J = 11.3, 5.5 Hz, 1H), 3.97 (t, J = 9.3 Hz, 1H), 3.89 (dd, J = 10.8, 1.9 Hz, 1H), 3.73 – 3.68 (m, 1H), 3.55 – 3.50 (m, 2H), 3.46 (dd, J = 10.1, 8.9 Hz, 1H), 3.36 (s, 3H), 2.09 (s, 3H), 2.05 (s, 3H), 2.03 (s, 3H).

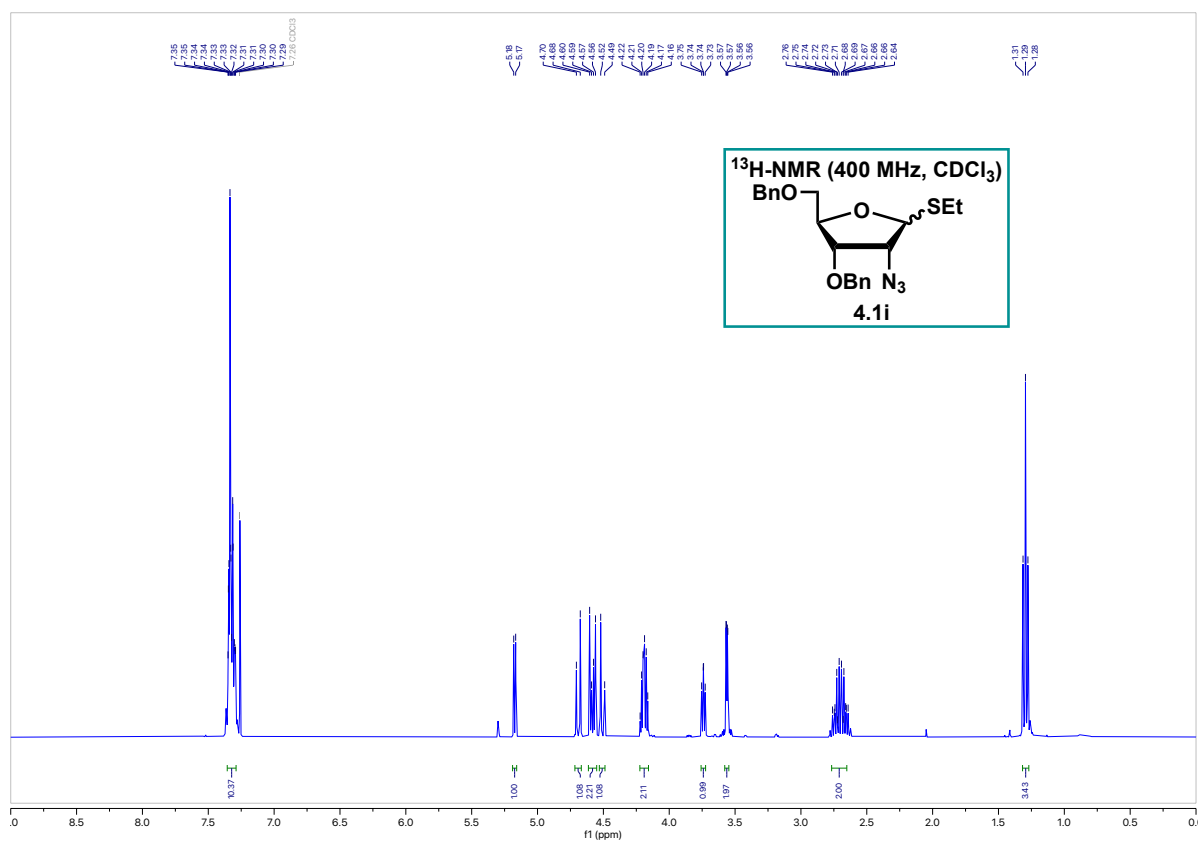
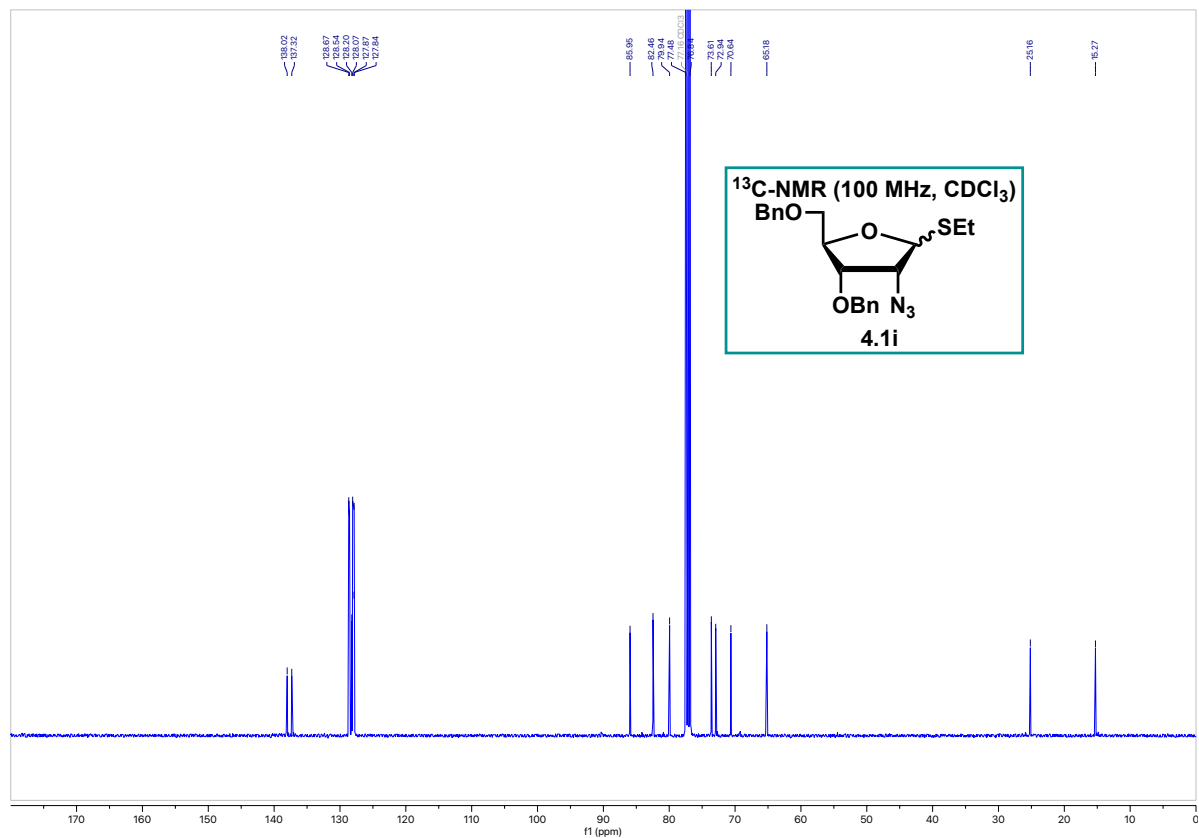
^{13}C NMR (100 MHz, CDCl_3) δ 170.86, 169.84, 169.68, 138.86, 138.40, 138.26, 128.61, 128.54, 128.28, 128.07, 128.05, 128.01, 127.85, 127.73, 105.54, 98.01, 82.21, 66.61, 64.59, 55.32, 20.88, 20.74, 20.68. The data are identical to the literature report.^[86]

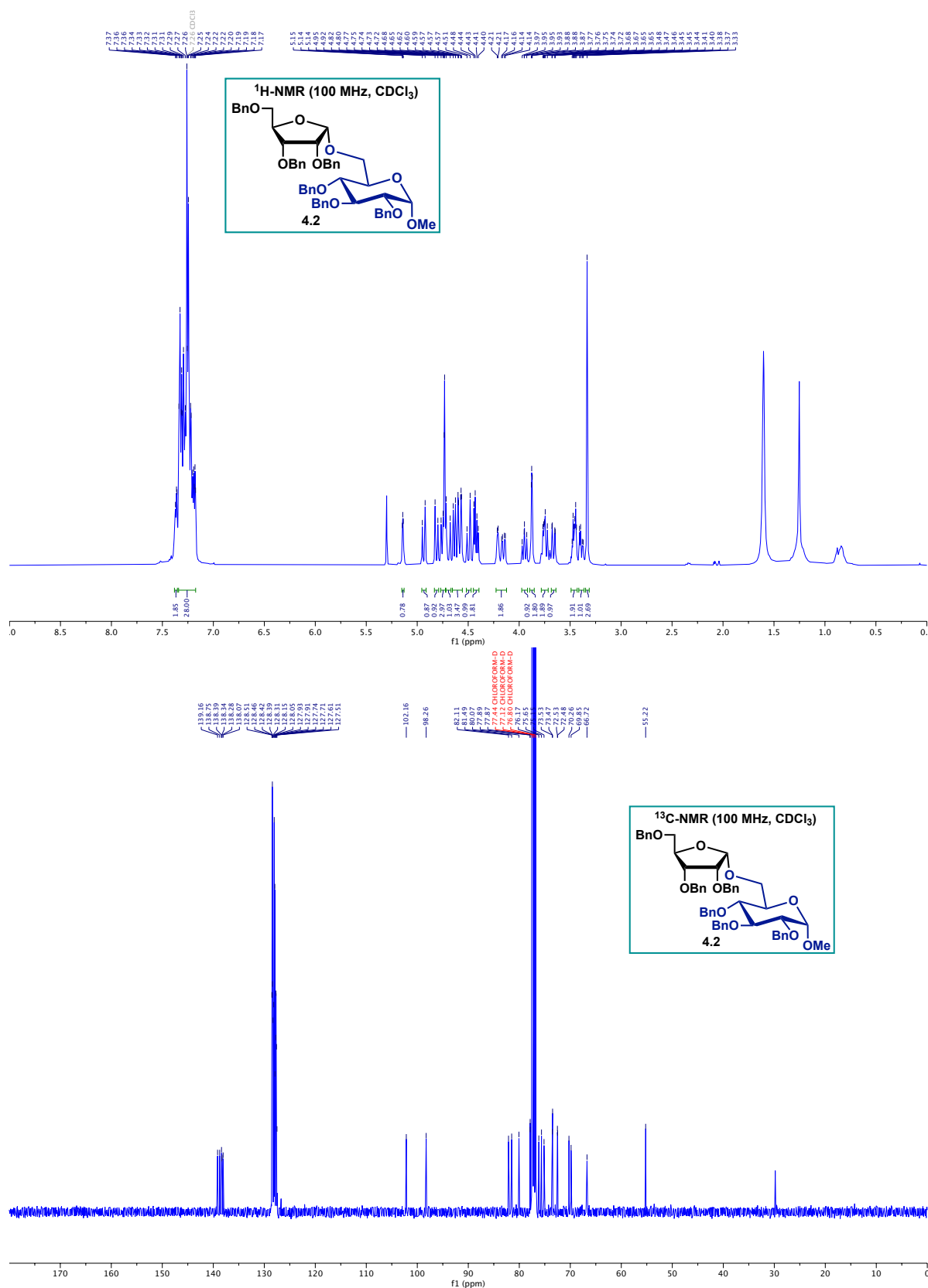
4.5. NMR Spectra of Newly Synthesized Compounds (All the spectra for this chapter are reported in our published article *ACS Catal.* **2025**)^[87]

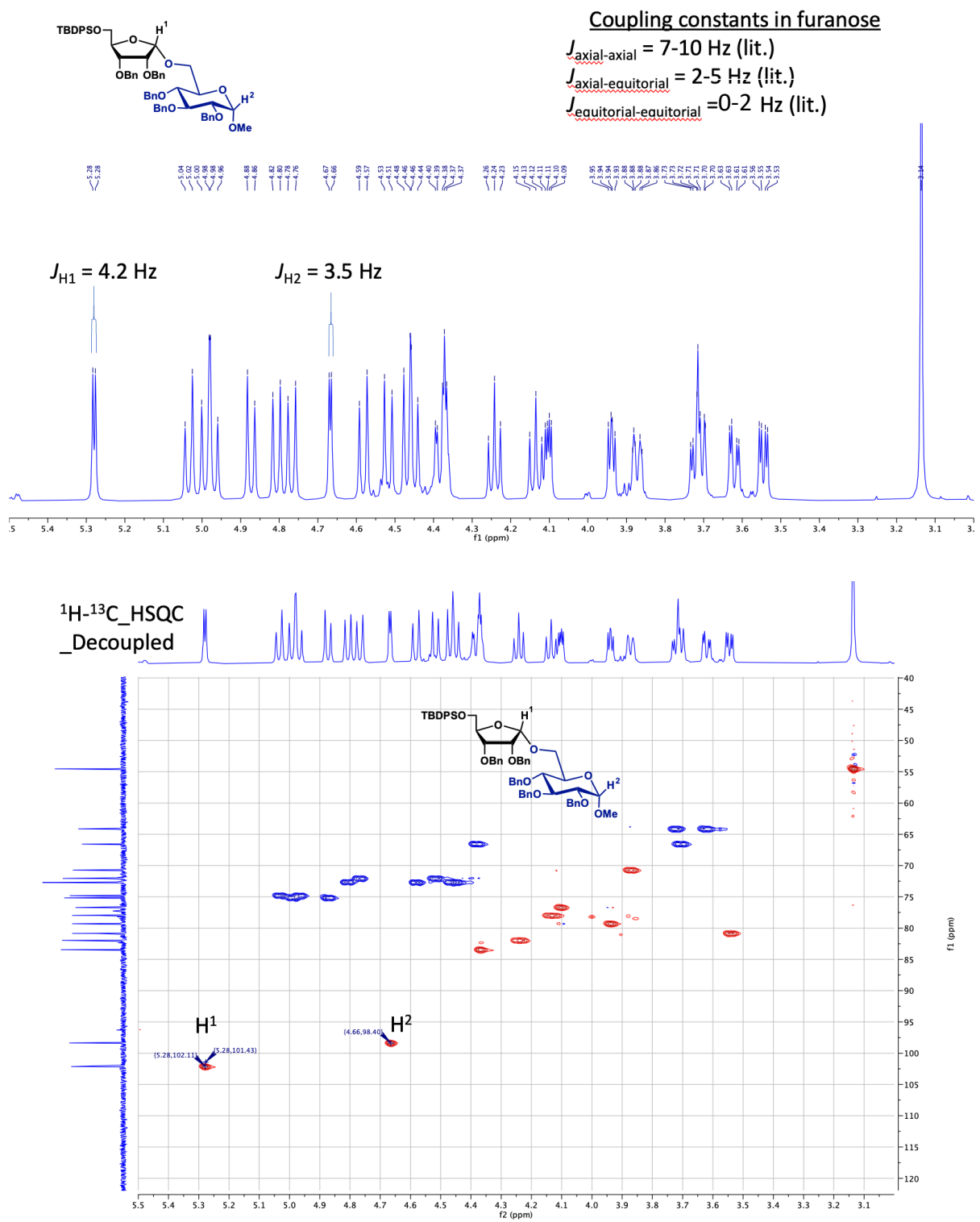


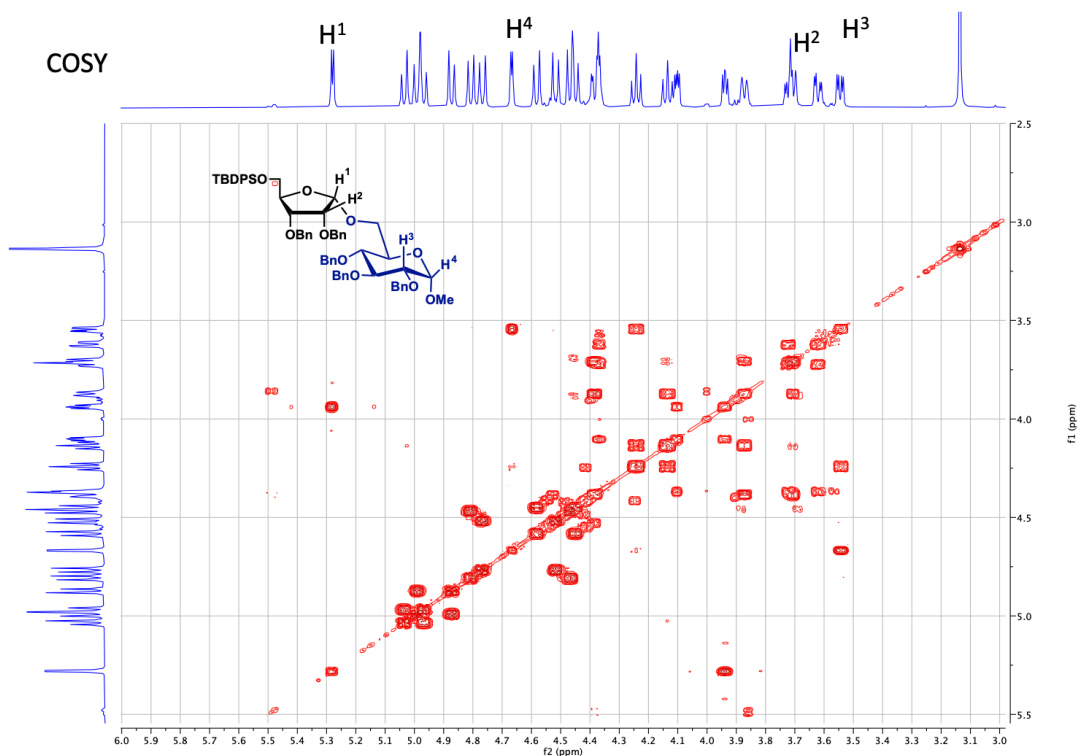


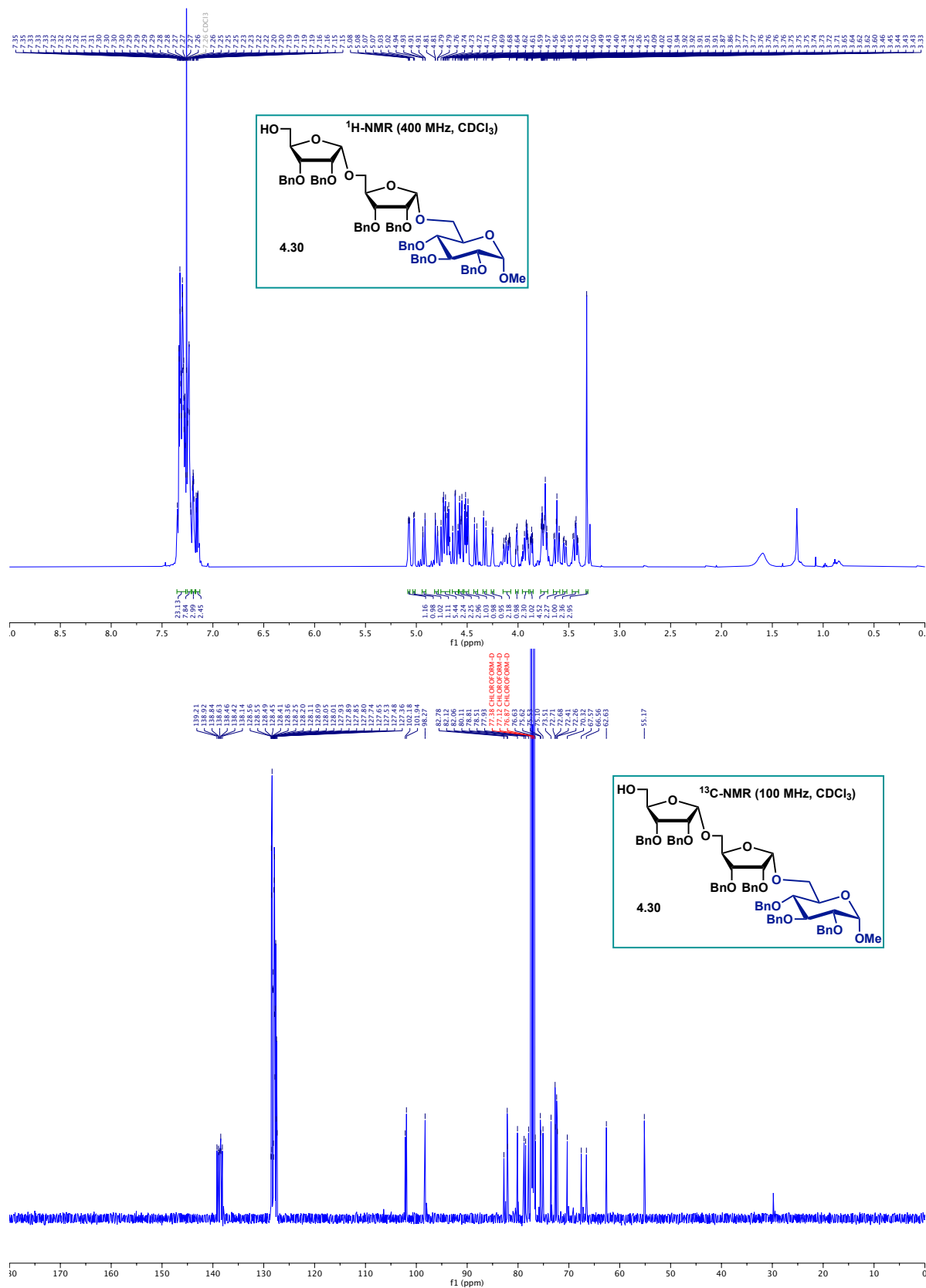


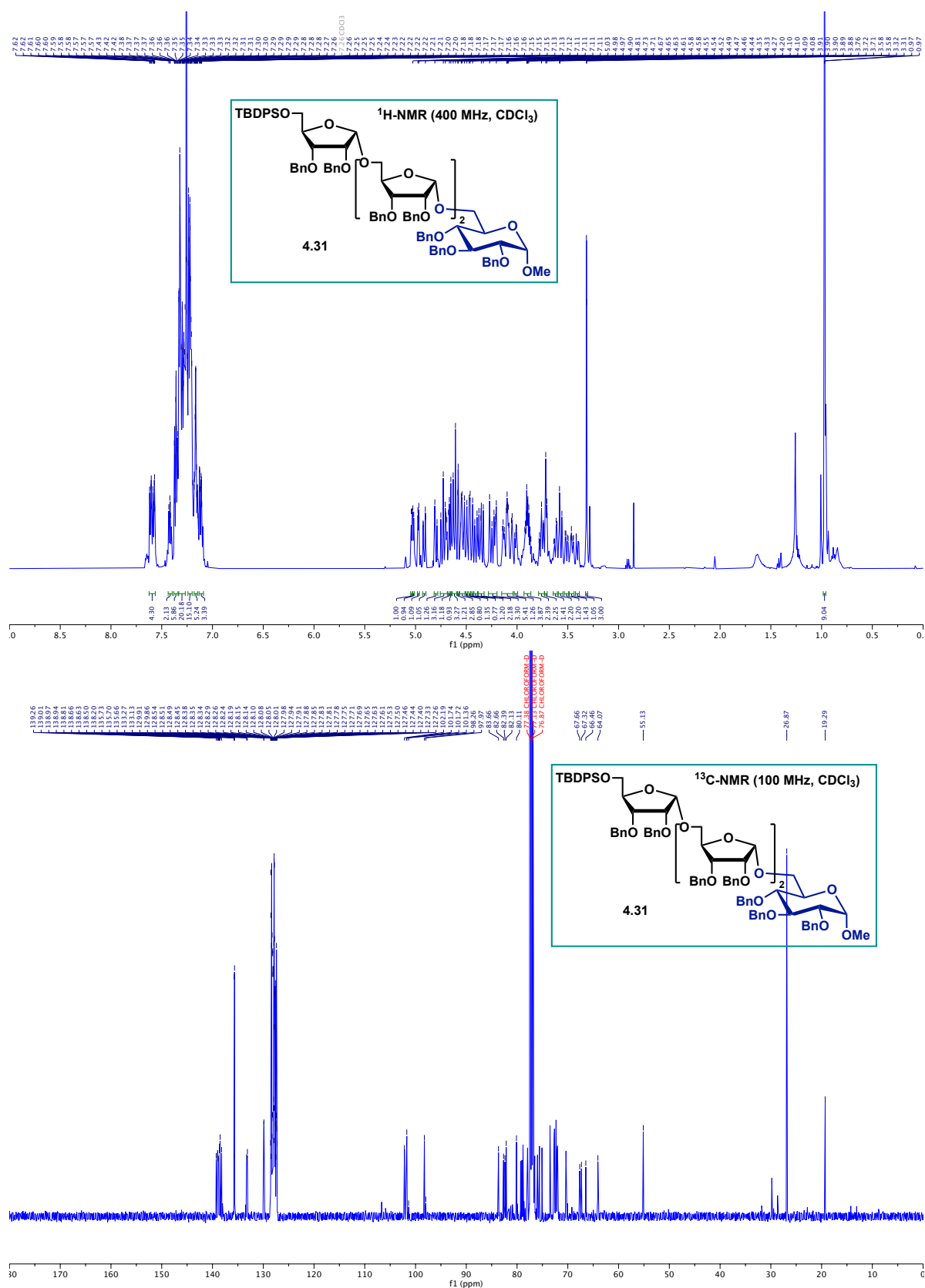












4.6. References

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CHAPTER 5

Photochemically Generated Sulfenylnitrene for the Activation of Conventional Thioglycoside for 1,2-cis Furanosylations

5.1. Introduction

The controlled generation and use of nitrenes has long fascinated chemists, offering access to highly reactive intermediates capable of enabling diverse bond constructions.^[1-4] Early developments involving transition metal-nitrenes^[5-12] established versatile platforms for single nitrogen-atom transfer, C–H amination, and aziridination. Despite these advances, such systems generally rely on precious or redox-active transition metals, whose cost, toxicity, and environmental footprint limit sustainable application.^[13] To overcome these constraints, iodine(III)-derived iodonitrenes were introduced, significantly expanding the scope of metal-free nitrene transfer reactions.^[14-15] However, their generation typically requires strong oxidants, which restrict functional-

group compatibility and narrow the accessible substrate space, particularly for oxidation-sensitive functionalities.

Sulfur-based chemistry offers a promising platform for metal-free activation and oxidation-sensitive systems.^[16-17] As the 5th most abundant and biologically essential element on Earth, sulfur can function as a metallomimetic center, accessing multiple oxidation states that emulate metal-like reactivity.^[18-20] This intrinsic redox flexibility enables the generation of three distinct classes of nitrenes, sulfonyl,^[21-24] sulfinyl,^[25] and sulfenyl,^[19,26-27] each possessing characteristic electronic and stereoelectronic properties. Recently, we reported sulfenylnitrene-mediated skeletal editing of *N*-heterocycles with broad functional-group tolerance, with *N*-sulfenylepiminonaphthalene- and *N*-sulfenylsulfodiimides-based nitrene precursors.^[19,28] Remarkably, these sulfenylnitrenes can be generated under thermal or visible-light, neutral, additive- and photosensitizer-free conditions, obviating the need for metals or photosensitizers (**Figure 5.1a**).^[19,28] Their exceptional chemoselectivity toward alkenes and thioethers, combined with their inertness toward *O*- and *N*-nucleophiles, highlights their potential as reactive yet precisely controllable intermediates for site-selective transformations.

Inspired by nature's remarkable ability to execute site-selective reactions with exquisite precision, chemists strive to achieve comparable control in synthetic settings.^[29-32] While enzymes direct reactivity effortlessly to specific positions within complex molecules, replicating such selectivity in the laboratory remains a major challenge, particularly in stereoselective furanosylation.^[33-34] Constructing 1,2-*cis* furanosidic linkages, as found in DNA, arabinogalactans, and microbial glycans, is difficult.^[33-37] Thioglycosides serve as versatile and stable furanose precursors, but classical activation

strategies, pioneered by Lowery^[33,37-38] and others^[36,39] using strong thiophilic reagents, precious metals, or harsh acids at cryogenic temperatures, offer limited stereocontrol.^[38,40-43]

The intrinsic reactivity of furanose oxocarbenium ions exacerbates the problem: their geometry allows nucleophilic attack from either face, or harsh conditions often induce epimerization of kinetic 1,2-*cis* products to thermodynamic 1,2-*trans* isomers (**Figure 5.1b**).^[44-46] This reactivity aspect limits traditional approaches to achieve high 1,2-*cis* selectivity and remains a challenge in furanosylation chemistry. Furthermore, the furanose oxocarbenium ion exhibits key reactivity differences from pyranose sugar systems, which hinder the applications of many established pyranosylation activation methods for stereocontrolled 1,2-*cis* furanosylations.^[34,36] More precisely, due to the higher stability of the oxocarbenium ion, the rate of epimerization is high in furanose sugars (**Figure 5.1b**).^[45-49] Which increases the epimerization dramatically under traditional thioglycoside activation conditions and often leads to the complete decomposition of the disaccharide at ambient reaction conditions.

Over the past decade, several elegant S_N2-type strategies have been developed to address the enduring challenge of 1,2-*cis* furanosylation. Notably, Jacobsen and co-workers introduced bithiourea-catalyzed phosphate donors,^[46] Nguyen and Tiefenbacher reported phenanthroline- and supramolecular capsule-catalyzed halide donors,^[50-51] and Zhang demonstrated gold- and bromonium-ion-mediated activations for achieving 1,2-*cis* selectivity.^[52-53] Our group has also advanced this field through earth-abundant metal-catalyzed activation of enynals,^[47,54] and intramolecular diazo-based thioglycosides,^[55-57] which generate oxocarbenium ions that deliver nucleophiles

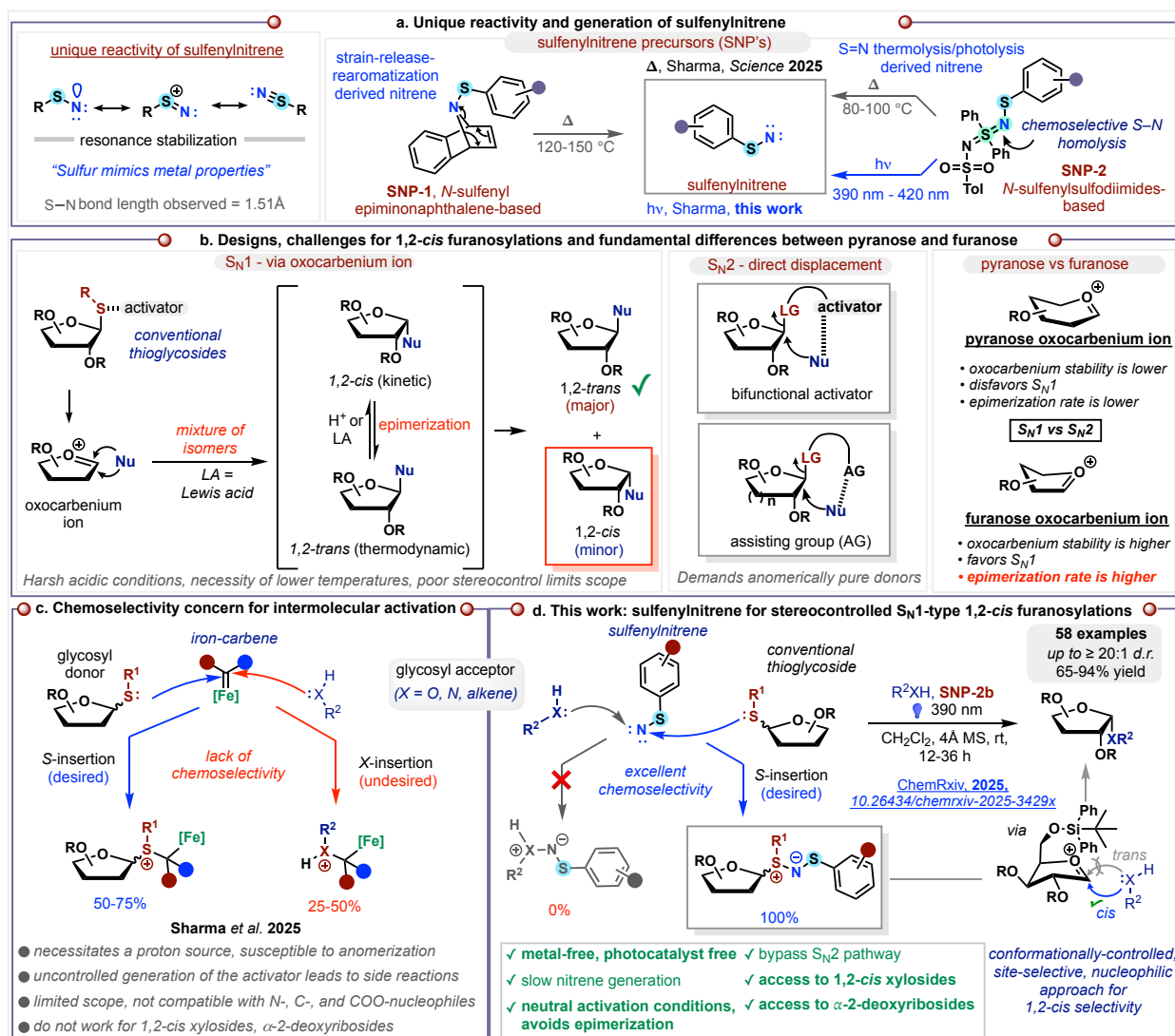


Figure 5.1: Sulfinylnitrenes and their application in 1,2-*cis* furanosylations. (a) Unique reactivity and generation of sulfinylnitrene. (b) Designs, challenges for 1,2-*cis* furanosylations, and fundamental differences between pyranose and furanose. (c) Chemoselectivity concern for our previous report on iron-carbene mediated intermolecular activation of conventional thioglycosides. (d) **This work:** sulfinylnitrene for stereocontrolled S_N1-type 1,2-*cis* furanosylations.

preferentially from the *cis* face via C2–O–metal coordination. While these approaches represent significant progress, they share inherent limitations: the activators often require multistep synthesis^[46], the donors can be unstable^[50–51] or derived from thioglycosides themselves,^[50–51] and precise linker design,^[47,52–57] often coupled with expensive or air-sensitive metal catalysts,^[51–52] restricts general applicability (**Figure 4.1.2a**).

Recently, we reported the first carbene-mediated intermolecular activation of easily accessible, bench-top-stable conventional thioglycosides for 1,2-*cis* furanosylation,^[58] which demonstrated the viability of catalytic carbene transfer to sulfur as a new activation mode. Despite its conceptual appeal, this method suffered from incomplete chemoselectivity due to competitive nucleophilic insertion into reactive iron-carbene intermediates, resulting in only moderate formation of the desired sulfonium ylide, a transient precursor for oxocarbenium ion (**Figure 5.1c**). Moreover, the high intrinsic reactivity of the iron-carbene intermediate not only necessitates a proton source but also confines the nucleophile scope predominantly to alcohols. These limitations underscore the need for a highly chemoselective, metal-free activation strategy capable of engaging a broad range of nucleophiles and sterically and electronically diverse donor types while maintaining precise stereocontrol.

Here, in this chapter, we report a metal- and photosensitizer-free strategy in which blue light induces chemoselective photolysis of a single S–N bond in the sulfenylnitrene precursor (**SNP-2b**), generating sulfenylnitrenes that enable mild, Lewis acid-free, neutral, and highly site-selective intermolecular activation of conventional thioglycoside donors (**Figure 5.1d**). Previously, visible-light-mediated strategies including thioglycoside activation^[59-60] have been employed for glycosylation reactions^[61-64]; however, most of these were limited to pyranose systems, with only a single report describing their application to certain furanose derivatives^[64]. This approach overcomes stereochemical barriers, providing efficient access to 1,2-*cis* linkages in the furanose series. Mechanistic studies revealed that steric or chelating substituents at C5 induce *cis* selectivity, bypassing the need for S_N2-type pathways. Remarkably, this donor design remains

effective across diverse activation conditions, consistently delivering high 1,2-*cis* selectivity. The synthetic utility of this platform is demonstrated in the glycosylation of bioactive molecules and the streamlined assembly of a 1,2-*cis* ribopentasaccharide. More broadly, this work establishes sulfenylnitrenes as a sustainable class of metallomimetic nitrene intermediates and highlights a donor-design strategy that enables improved control in challenging 1,2-*cis*-furanosylation reactions.

5.2. Results and Discussion

5.2.1. Optimization of the Reaction Conditions

We began by examining conditions for sulfenylnitrene generation in the site-selective activation of the conventional thioglycoside donor **4.1a**. Using our previously reported thermally activated sulfenylnitrene precursor **SNP-1**,^[19] we observed donor decomposition without the formation of the desired disaccharide **4.2** (Figure 5.4.4, experimental section). To improve reactivity, we next synthesized a series of *N*-sulfenylsulfodiimide-based precursors **SNP-2(a-c)**, where **SNP-2a** and **SNP-2b** were derived from our prior *N*-atom insertion strategies,^[19,28] and **SNP-2c** was newly developed in this work (Figure 5.2.1A). Under thermal activation, **SNP-2(a-c)** induced only partial donor conversion, affording the glycoside product in low yields.

Inspired by the photochemical generation of sulfenylnitrenes, we examined the absorption profiles of **SNP-2(a-c)**. **SNP-2a** exhibited maximum absorption at 420 nm, while **SNP-2b** and **SNP-2c** showed maxima around 390 nm. Blue-light irradiation under these conditions efficiently generated sulfenylnitrenes and enabled smooth activation of donor **4.1a**, affording the desired disaccharide in good yield with good 1,2-*cis* selectivity

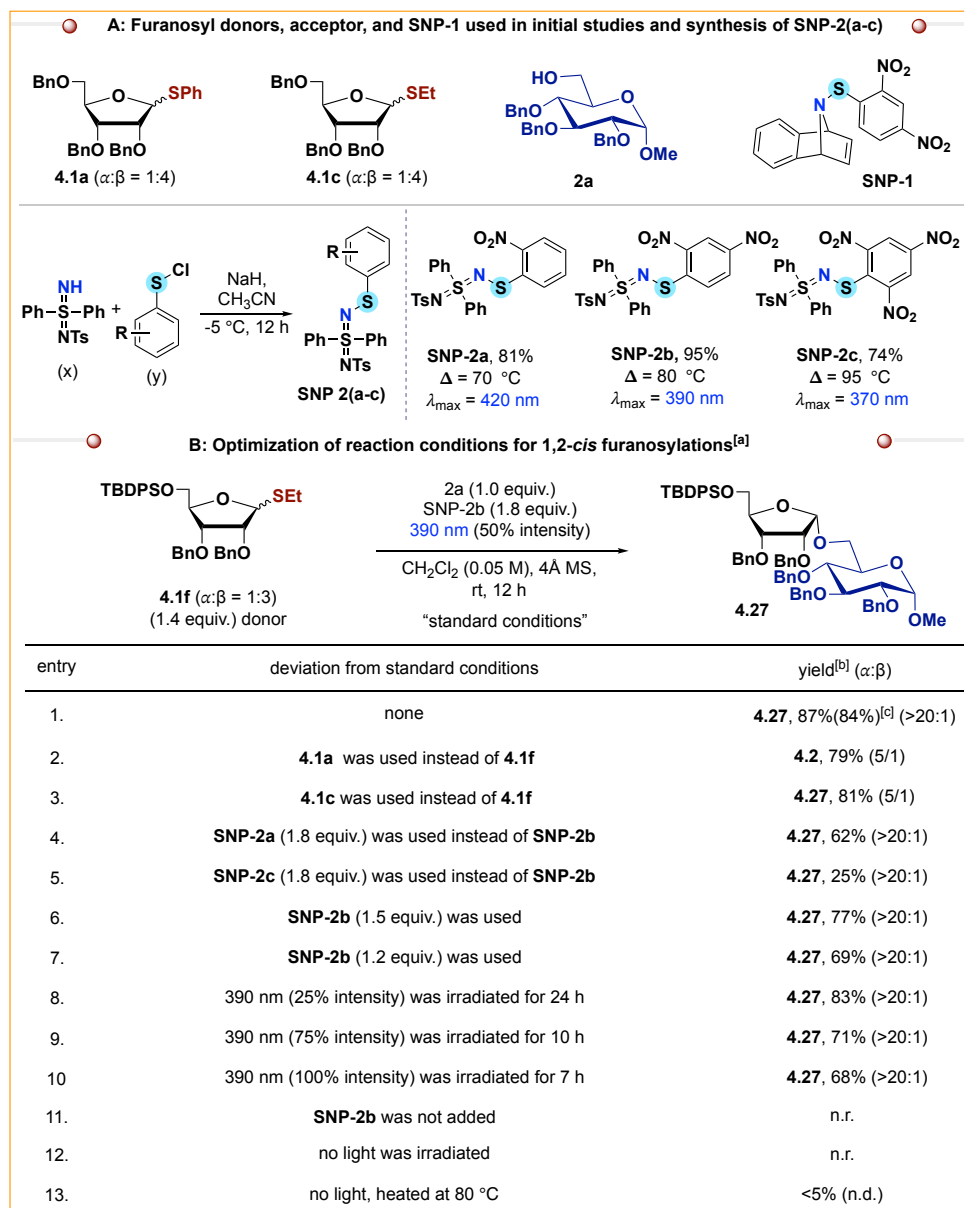


Figure 5.2.1: Reaction development for sulfenylnitrene-mediated 1,2-*cis* glycosylations. (A) furanosyl donors, acceptor used, and synthesis of sulfenylnitrene precursors [SNP-2(a-c)], and their decomposition wavelengths. (B) Optimization of reaction conditions for 1,2-*cis* furanosylations. [a] Reactions were conducted with acceptor **A1** (0.026 mmol), donor **4.1** (a, c, and f) (0.036 mmol), SNP-2 (0.047), blue-light (390-440 nm), and CH₂Cl₂ (0.05 M). [b] Yield was determined by ¹H NMR using 1,3,5-trimethoxybenzene as the internal standard. [c] Isolated yields. Note: ¹H-NMR of the crude reaction mixture was analyzed to determine the diastereoselectivity. Ph, phenyl; Ts, tosyl; TBDPS, tert-butyldiphenylsilyl; Bn, benzyl; Et, ethyl; MS, molecular sieves; SNP, sulfenylnitrene precursor; Tol, tolyl; n.r., no reaction.

(Figure 5.4.4, experimental section). The reactions proceeded under neutral conditions, and no anomeric epimerization was observed even upon prolonged irradiation. Among

the tested precursors, **SNP-2a** and **SNP-2c** furnished desired outcomes; however, **SNP-2b** emerged as the optimal sulfonylnitrene precursor. Consequently, transitioning from thermal to photochemical activation proved crucial for achieving the desired glycosidic linkage with high chemoselectivity (**Figure 5.4.4**, experimental section).

We next optimized conditions for 1,2-*cis* furanosylation (**Figure 5.2.1B**). The C5–O protecting group proved decisive for stereocontrol: replacing TBDPS with benzyl in donors **4.1a** or **4.1c** markedly attenuated selectivity, underscoring the unique steric design of **4.1f** (entries 2 and 3). The stereoselectivity was determined by characterizing the product using NMR techniques, ^1H - ^{13}C -HSQC. The coupling constant $J_{(\text{H}1-\text{H}2)}$ value for the 1,2-*cis* isomer (major) was found to be 4.2 Hz, consistent with the literature.^[55,64-65] Among the precursors, **SNP-2a** and **SNP-2c** maintained high *cis* selectivity but afforded lower yields, reflecting the delicate balance between precursor photophysics and productive glycosylation (entries 4 and 5). The light intensity was also critical for efficient furanosylation; optimal results were obtained at 25% intensity, which furnished high yields and excellent stereocontrol, albeit with slightly longer reaction times (entry 8). While 75% and 100% intensity shortened the reaction time, the product yield decreased significantly (entries 9 and 10). Control experiments confirmed that both light and the SNP activator were indispensable, as reactions performed in their absence returned only the starting material. Under otherwise identical thermal conditions, donor **4.1f** decomposed to an unproductive pathway, highlighting the essential role of photochemical activation for this chemoselective transformation (entries 11-13). Finally, the optimized conditions, donor **4.1f**^[58,66] (1.4 equiv.) with acceptor **A1**, **SNP-2b**, CH_2Cl_2 (0.05 M), and 4 Å MS afforded disaccharide **4.27** in 84% yield with excellent stereocontrol ($\alpha:\beta = >20:1$).

5.2.2. Substrate scope of this approach

Having established the viability of the sulfenylnitrene activation platform, we next examined its generality across a broad spectrum of furanosyl donors and alcohol acceptors (**Figure 5.2.2**).

Ribosylations. We began with ribose donor **4.1f** (**Figure 5.2.2b**). Primary hydroxyl acceptors, including glucose and mannose derivatives bearing either electron-rich benzyl (Bn) or electron-deficient benzoyl (Bz) groups at C2-C4, reacted smoothly to furnish disaccharides **5.2-5.4** in high yields and *cis*-selectivity, irrespective of protecting-group electronics or sterics. A propargyl group at C1, a handle frequently employed in gold catalysis, was equally well-tolerated, affording products **5.5-5.6**, and highlighting the compatibility of alkyne donors under our mild and neutral conditions for orthogonal reactivity to access one-pot oligosaccharides. Secondary hydroxyl acceptors also performed efficiently: acetonide-protected allose delivered disaccharide **5.7** with high selectivity, while menthol afforded **5.8** with excellent *cis*-stereocontrol. Even the sterically demanding tertiary alcohol 1-adamantanol underwent coupling to give **5.9** in good yield. Beyond these alcohols, the ribosyl donor **4.1f** was coupled efficiently with the amino acid analogue, serine hydroxyl groups, to furnish O-ribosylated derivatives **5.10** and **5.11**.

Xylosylations. Encouraged by these results, we next examined the more demanding xylose donor **5.1a**, whose oxocarbenium ions can adopt multiple low-energy conformations [$E_3(gg)$ and $^4T_3(gg)$],^[67-68] often leading to erosion of stereocontrol (**Figure 5.2.2c**). Remarkably, under our sulfenylnitrene-mediated activation, xylose donors exhibited exceptional conformational fidelity, consistently affording 1,2-*cis* products with high selectivity. Couplings with C6-hydroxy glucose and mannose acceptors, bearing either benzyl or benzoyl protecting groups at C2-C4, furnished disaccharides **5.12-5.15**

in high yields and *cis* selectivity. Likewise, a galactose acetonide acceptor delivered **5.16** efficiently, while a mannosyl acceptor bearing an alkyne handle provided **5.17** with high stereocontrol. Secondary hydroxyl acceptors such as acetonide-protected glucose and allose underwent clean coupling to give **5.18** and **5.19**, respectively, highlighting the robustness of this method even toward less reactive secondary alcohols. Notably, the consistent *cis* selectivity across this series indicates that C5 steric and electronic effects effectively bias the oxocarbenium ion toward an $E_3(gg)$ envelope conformation, directing nucleophilic approach from the inside face. These findings mark a significant advance, as previous S_N2 -based or acid-catalyzed methods often yielded mixtures of anomers in xylose series due to conformational lability. Thus, this sulfonylnitrene and C5-sterically driven activation provides an efficient solution for stereocontrolled xylosylations across diverse nucleophiles and protecting-group patterns.

Arabinosylations. The 1,2-*cis* selectivity of arabinose donors is often dictated by conformational bias.^[67-69] We therefore evaluated both D- and L-arabinose thiofuranosides (**4.1d**, **4.1e**) with model glucose acceptor **A1**. In both cases, the desired disaccharides **5.20-5.21** were obtained in high yield and moderate 1,2-*cis* selectivity (**Figure 5.2.2d**), further demonstrating the generality of this activation method.

2-Deoxy-ribosylations. In contrast to ribose and xylose, the 2-deoxy-D-ribose system remains particularly challenging because the absence of the C2-oxygen atom removes neighboring-group participation and destabilizes oxocarbenium formation, often leading to poor anomeric control. To overcome this limitation, we designed a thioglycoside donor **5.1b** bearing a sterically demanding TBDPS group at C5, intended to bias the intermediate toward the α -face during nucleophilic capture (**Figure 5.2.2e**). Under

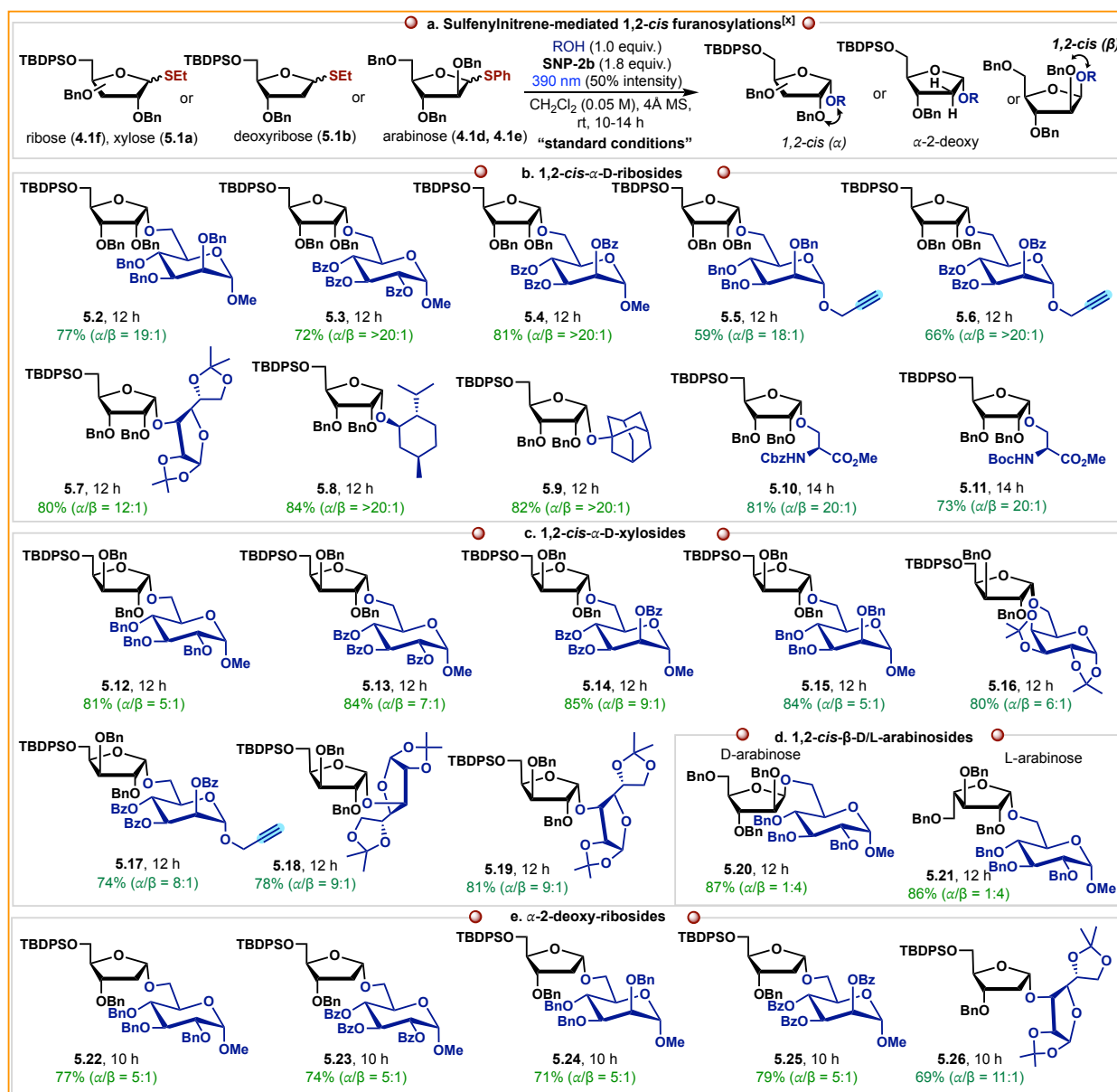


Figure 5.2.2: Scope of sulfenylnitrene-mediated 1,2-*cis* furanosylations. (a) General scheme for 1,2-*cis* furanosylations. (b) Scope of 1,2-*cis* D-ribosides. (c) Scope of 1,2-*cis* D-xylosides. (d) Scope of 1,2-*cis* β-D/L-arabinoside (e) Scope of α-2-deoxy-D-ribosides. [x] Reactions were conducted with acceptor **2** (0.026 mmol), glycosyl donor (0.036 mmol), SNP-2b (0.047), blue-light (390 nm, 50% intensity), and CH₂Cl₂ (0.05 M). **Note:** ¹H-NMR of the crude reaction mixture was analyzed to determine the diastereoselectivity, and the stereochemistry of the newly formed furanosyl linkage was determined from the coupling constant (*J* = 3.3–4.5 Hz) between the anomeric proton (H₁) and its neighbouring proton (H₂), confirming the *cis* selectivity. All newly formed anomeric proton couplings (H₁–H₂) are highlighted in bold in the Supporting Information. Ph, phenyl; Ts, tosyl; TBDPS, *tert*-butyldiphenylsilyl; Bn, benzyl; Et, ethyl; MS, molecular sieves; SNP, sulfenylnitrene precursor; Tol, tolyl.

sulfenylnitrene activation, donor **5.1b** exhibited high reactivity, delivering 1,2-*cis* (α) products across a wide range of acceptors. Couplings with C6-hydroxy glucose and

mannose acceptors, protected with benzyl or benzoyl groups at C2-C4, afforded disaccharides **5.22-5.25** in good yields and high α -selectivity. Notably, even secondary hydroxyl acceptors, such as acetonide-protected allose, underwent smooth coupling to furnish **5.26** cleanly and stereoselectively.

Mechanistically, the C5-OTBDPS group exerts dual influence: steric hindrance blocks β -face approach, while donation from the C5–O–Si bond stabilizes the developing positive charge, favoring an E_3 (*gg*) envelope conformation consistent with inside face attack. This interplay between remote steric bias and conformational control establishes a reliable design for 2-deoxy systems, where traditional electronic directing effects are absent. Collectively, these results represent a solution to the stereoselective synthesis of α -2-deoxy-D-ribosides.

Taken together, these results underscore the generality and robustness of sulfonylnitrene-mediated activation. The method tolerates a wide spectrum of furanosyl donors, including ribose, xylose, 2-deoxy-ribose, and arabinose, and accommodates a broad range of O-nucleophiles, spanning primary, secondary, and tertiary alcohols. Beyond enabling straightforward access to otherwise challenging 1,2-*cis* furanosides, this study also provides mechanistic insight into how nucleophile reactivity and oxocarbenium-ion conformational control operate synergistically under sulfonylnitrene activation, establishing a unified and predictable framework for stereocontrolled furanosylation.

5.2.3. Applications to bioactive substrates, other nucleophiles, and pentasaccharide synthesis

Having established the generality of the transformation, we next explored the scope of sulfonylnitrene activation in complex and bioactive molecules (**Figure 5.2.3**). The reaction proved equally effective with steroidal frameworks: ribosyl donor **4.1f**

coupled smoothly with cholesterol and oleanolic acid to afford glycosteroids **5.27** and **5.28** in high yield and excellent 1,2-*cis* selectivity. Nucleoside analogues were also accessible, as 2-deoxy- and 2,3-deoxy-3-azidothymidine derivatives underwent efficient coupling to give ribosylated thymidines **5.29** and **5.30**.

Extending the scope to carboxylic acids, both electron-rich (4-methoxy) and electron-poor (4-nitro) benzoic acids delivered esters **5.31** and **5.32** in high yield, albeit in low diastereoselectivity. Importantly, electronically and sterically demanding substrates such as 8-bromo-naphthoic acid were furnished **5.33** efficiently, demonstrating compatibility with challenging aryl acids. Clinically relevant molecules were also amenable: ciprofibrate (a lipid-lowering agent) and dehydrocholic acid (a hepatic therapeutic) yielded ribosides **5.34** and **5.35** in good yield. Ribosyl donor **4.1f** coupled efficiently with Boc-L-Ala-OH to furnish O-ribosylated alanine **5.36**. These stereochemical outcomes with carboxylic acids were consistent with the studies reported by Filippov and coworkers.^[70]

Next, we studied the reactivity of amides. In that realm, we coupled donor **4.1f** with amide acceptor (Z-L-Gln-OMe), which furnished *N*-ribosylated glutamine **5.37** in high yield and stereoselectivity. Likewise, *p*-toluenesulfonylamide and the sulfonamide-based drug topiramate underwent clean glycosylation to yield *N*-glycosides **5.38** and **5.39**, respectively. Finally, a C-nucleophile, allyltrimethylsilane, participated readily, affording the C-riboside **5.40** in good yield and excellent *cis* selectivity.

Collectively, these examples highlight the broad functional-group tolerance, scalability, and operational simplicity of this platform, enabling direct access to glycopeptides, glycosteroids, glyconucleosides, and glycodrugs with high chemoselect-

-ivity and well-defined stereochemical outcomes.

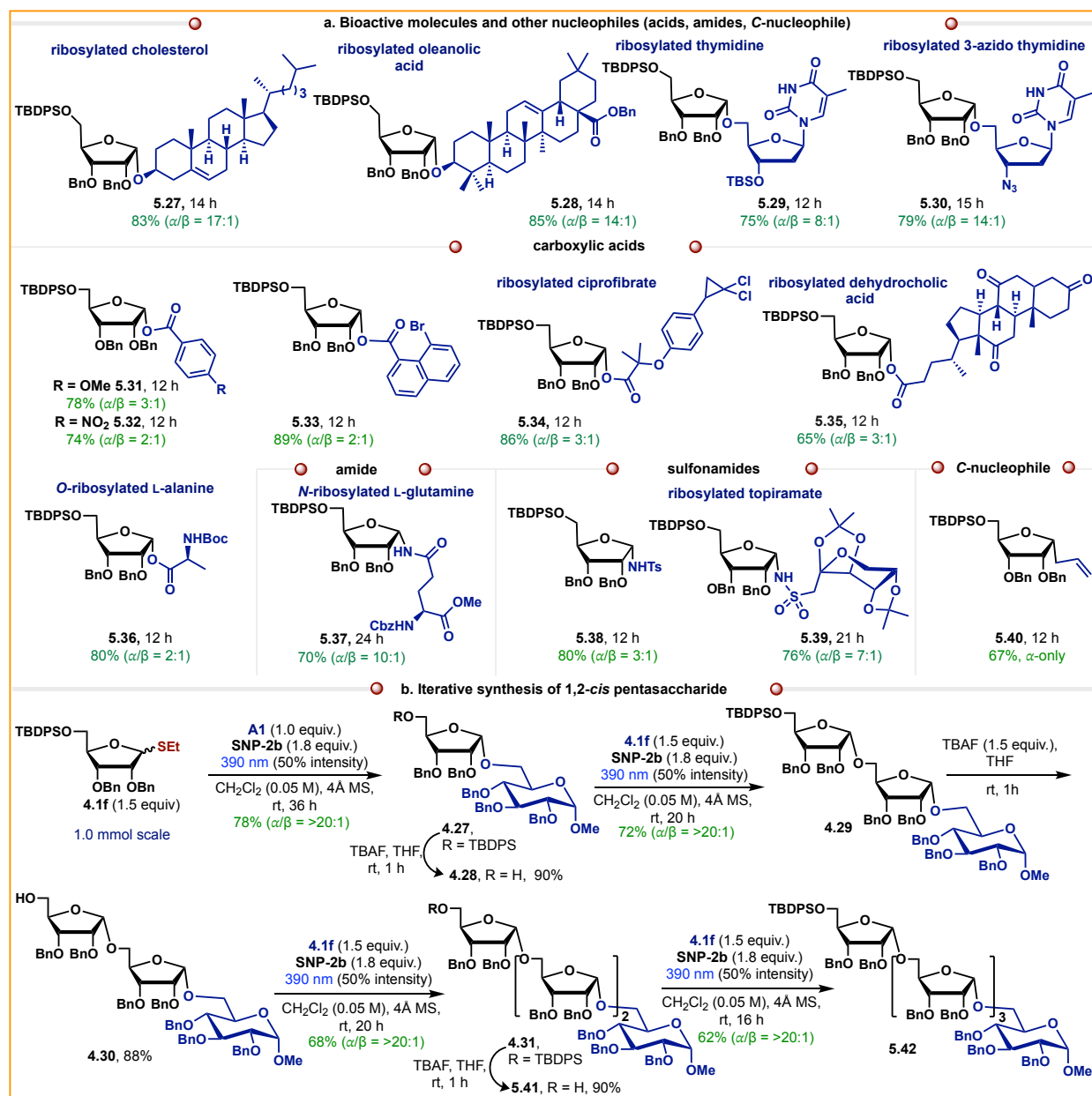


Figure 5.2.3: Application of sulfonylnitrene-mediated 1,2-*cis* furanosylations strategy. (a) Scope of bioactive molecules and other nucleophiles. (b) Iterative synthesis of 1,2-*cis* ribopentasaccharide, including 1.0 mmol scale.

Encouraged by this versatility, we applied the method to oligosaccharide assembly, a long-standing challenge in achieving uniform 1,2-*cis* control (**Figure 5.2.3b**).^[37,71] Iterative couplings of ribosyl donor **4.1f** enabled the construction of a ribopentasaccharide **5.42** with uniformly high 1,2-*cis* selectivity. Notably, the first

disaccharide was prepared on a 1 mmol scale, underscoring the scalability and robustness of the process. Each subsequent coupling proceeded in good to excellent yields and stereoselectivity, providing a streamlined and protecting-group-compatible route to *cis*-rich oligosaccharides.

In summary, these applications underscore the synthetic power and generality of sulfenylnitrene activation, extending seamlessly from simple donors to complex biomolecular architectures, and establishing it as a unifying platform for stereocontrolled glycoside construction.

5.2.4. Mechanistic investigations

5.2.4.1. Effect of C5 protecting groups on 1,2-*cis* selectivity

To probe the origins of stereocontrol, we first examined the influence of C5 protecting groups on ribosyl donors (**Figure 5.2.4.1a**). Donors bearing C5-OMe (**5.1c**) or C5-OBn (**4.1c**) underwent sulfenylnitrene activation to afford disaccharides **5.43** and **4.2** in high yields and *cis*-selectivity. This outcome is consistent with the conformational bias of the transient oxocarbenium ion, which favors *cis*-face attack and furnishes kinetically controlled 1,2-*cis* products.^[44,67] In contrast, activation of analogous thioglycosides under Lewis acidic conditions produced extensive epimerization at the anomeric center, highlighting the mildness and stereochemical fidelity of sulfenylnitrene activation. Expanding to electronically distinct and sterically demanding groups, the C5-OBz donor (**5.1d**) gave high yield with enhanced *cis*-selectivity **5.44**. We attribute this to a remote group effect^[72], wherein the benzoyl substituent disfavors the *trans*-face approach through an anchimeric-type interaction. Further increasing steric bulk with C5-OTrt (**5.1e**),

OTIPS (**5.1f**), and OTBDPS (**4.1f**) substituents maintained excellent selectivity, confirming that large groups at C5 reinforce *cis* outcomes in ribose (**5.45**, **5.46**, and **4.27**).

By contrast, xylosyl donors exhibited different behavior. Whereas ribose derivatives inherently favor *cis* products, xylose donors with small substituents, such as C5-OMe (**5.1g**) or C5-OBn (**5.1h**), produce nearly equimolar mixtures of anomers **5.47**, **5.48**, reflecting their intrinsic conformational flexibility.^[68] Introduction of a benzoyl group (**5.1i**), however, restored high *cis* selectivity **5.49** through the same remote group effect^[72-73] as observed in ribose. Likewise, bulky substituents such as trityl (Trt, **5.1j**), TIPS (**5.1k**), and TBDPS (**5.1a**) yielded high *cis*-selective products **5.50**, **5.51**, **5.12**, with trityl providing marginally superior control over the silyl groups.

A complementary picture emerged for arabinose donors, where the spatial orientation of the C5 substituent favored the opposite oxocarbenium ion conformation ³*E* (*gg*).^[67-68] For instance, the C5-OBn donor (**4.1d**) furnished high yields of **5.20** with good *cis* (β) selectivity, whereas C5-OBz (**5.1l**) slightly diminished this selectivity to **5.52** through electronic effects. Strikingly, increasing steric demand with C5-OTBDPS (**5.1m**) significantly reversed the stereochemical outcome **5.53**, favouring the *trans*-anomer, underscoring the profound impact of C5 steric effects in arabinose.

Taken together, these studies reveal that stereoselectivity in furanosylation is finely modulated by the steric and electronic properties of the C5 substituent. While ribose, xylose, and 2-deoxy ribose donors are predisposed toward *cis*- or α -selective outcomes under sulfonylnitrene activation, arabinose sugars provide a unique case where steric congestion at C5 can invert the stereochemical course. Importantly, unlike Lewis acid activation, sulfonylnitrene-mediated conditions preserve these inherent preferences

without anomeric scrambling, offering a powerful handle for predictable stereocontrol.

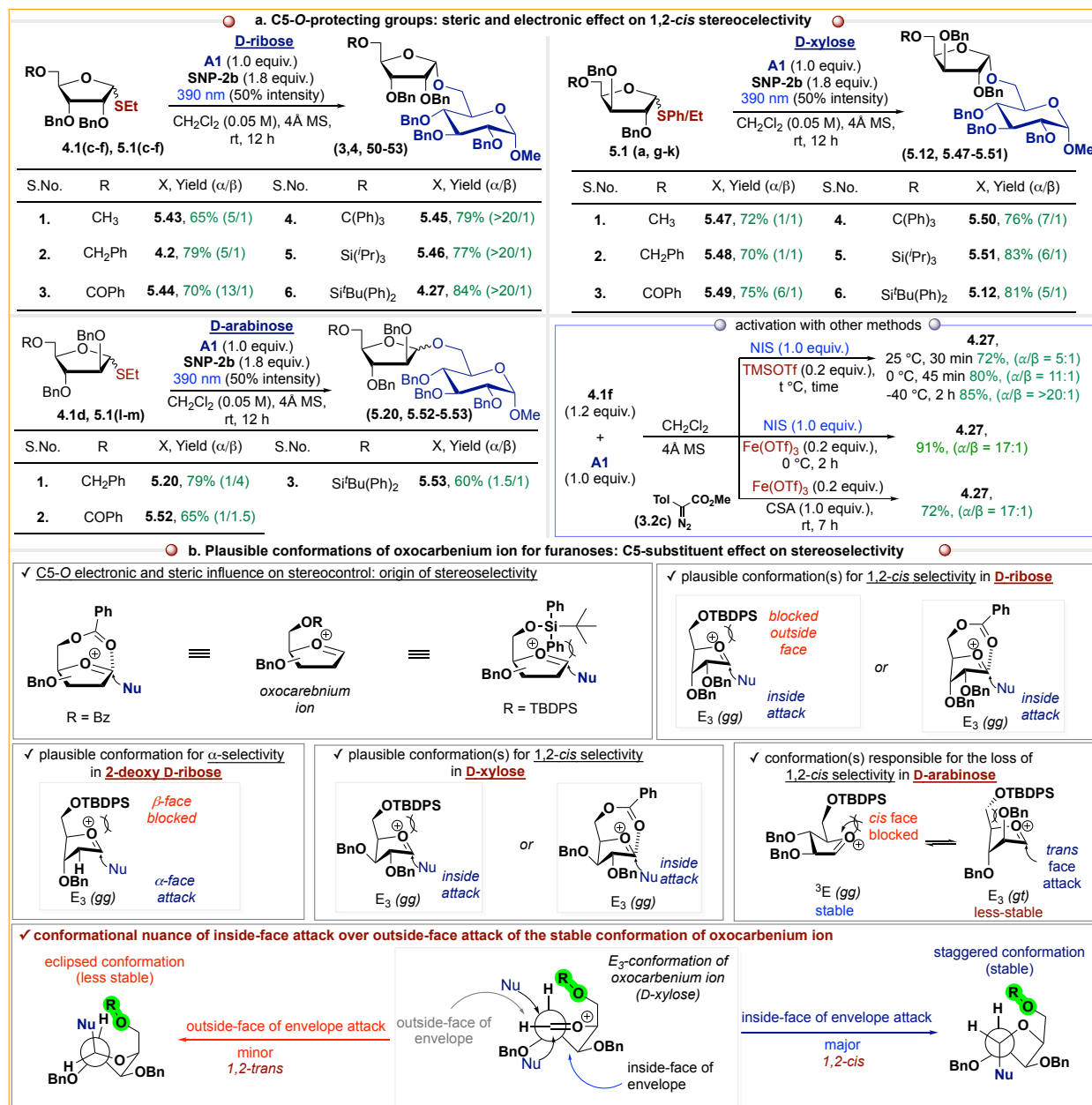


Figure 5.2.4.1: Studies of the C5-O-protecting group effect on 1,2-*cis* stereoselectivity. (a) The effect of C5-O protecting groups on the induction of *cis* selectivity, and the activation of our designed donor with the established thioglycoside activation method. (b) The conformational explanation for the induction of 1,2-*cis* selectivity, and the importance of inner face attack in Newman projection of a stable conformer of oxocarbenium ion.

5.2.4.2. Activation of model donor (4.1f) with traditional and established activation methods

To benchmark the inherent 1,2-*cis*-directing ability of our donor design, we next evaluated the activation of model donor **4.1f** under several established glycosylation

conditions (**Figure 5.2.4.1a**). Activation with NIS/TMSOTf furnished the disaccharide product with high *cis* selectivity; however, at ambient temperature the reaction proceeded rapidly, delivering high yield but reduced diastereoselectivity ($\alpha:\beta = 5:1$). Lowering the temperature to 0 °C improved stereocontrol ($\alpha:\beta = 11:1$) and conducting the reaction at -40 °C proved most effective, affording excellent 1,2-*cis* selectivity ($\alpha:\beta = >20:1$). These observations are consistent with the known propensity of strong Lewis acids to induce anomeric epimerization, necessitating strict cryogenic control and short reaction times to preserve stereochemical integrity.^[45-46] Activation with our NIS/Fe(OTf)₃ protocol^[66] delivered the same high *cis* selectivity, in agreement with the outcome of sulfonylnitrene activation. Finally, application of iron-carbene-mediated activation^[58] likewise afforded the *cis* product as the major isomer. Collectively, these comparisons demonstrate that the C5-substituent-driven stereocontrol observed under sulfonylnitrene conditions is intrinsic to the donor architecture and is preserved across mechanistically distinct activation modes. This reinforces the central role of C5 sterics and electronics in governing anomeric selectivity in furanosylations.

5.2.4.3. Detailed conformational analysis of C5-steric effects governing *cis* selectivity

The stereochemical outcome in furanosylations has traditionally been governed by S_N2-type displacement mechanisms, which often demand elaborate donor design and multistep synthesis.^[46,50-53] In contrast, our studies reveal that the steric and electronic environment at the C5 position exerts a decisive influence on the facial selectivity of the intermediate oxocarbenium ion (**Figure 5.2.4.1b**). Computational and experimental analyses indicate that, for D-ribose derivatives, the oxocarbenium ion preferentially adopts an *E*₃(*gg*) envelope conformation,^[67-69] in which the C5 substituent projects toward

the electron-deficient anomeric center. This orientation both stabilizes the developing positive charge and sterically shields the *trans* face, thereby directing nucleophilic attack from the in-face to afford the 1,2-*cis* (a) product. Minor formation of *trans* isomers can be attributed to population of higher-energy conformers, such as ${}^4T_3$ (*gg*), ${}^4E$ (*gg*), or ${}^3E$ (*gg*), consistent with conformational analyses reported by Woerpel^[69] and Codée^[67-68] (see **section 5.4.8** in experimental section).

Similarly, 2-deoxyribose exhibits a dominant E_3 (*gg*) envelope, where steric shielding of the β -face enforces high α -selectivity. For D-xylose, the coexistence of E_3 (*gg*) and ${}^4T_3$ (*gg*) conformations rationalizes the observed *cis* preference with minor *trans* formation. In contrast, D-arabinose primarily adopts a ${}^3E$ (*gg*) envelope that initially promotes *cis* selectivity, yet subtle C5 steric or electronic perturbations can shift the equilibrium toward an E_3 (*gg*) conformation, allowing competitive *trans* formation. The preference for inside face attack in oxocarbenium ion envelope conformations was first studied by Woerpel.^[69] More specifically, nucleophiles approach from the inside, derived by the stable staggered conformational output; however, the outside face approach leads to less stable eclipsed conformational output and makes it highly disfavored (**Figure 5.2.4.1b**).

Overall, these findings establish that C5 substituents function as conformational “steering elements”, dictating oxocarbenium ion geometry and, consequently, governing 1,2-*cis* selectivity across diverse furanose systems. This insight provides a unifying stereoelectronic rationale for donor-controlled selectivity and underscores the role of C5 architecture as a broadly applicable design for stereocontrolled furanosylation.

5.2.4.4. Plausible Mechanistic Pathway

To probe the activation mode, irradiation of **SNP-2b** under blue light was first examined, which predominantly furnished sulfinimine **5.54**, while the corresponding nitrene fragment could not be directly detected (**Figure 5.2.4.2a**). Then light ON-OFF experiments demonstrated that continuous irradiation is required for reactivity, confirming the involvement of a short-lived photogenerated species (**Figure 5.2.4.2c**). Furthermore, to assess the possible involvement of an anomeric *N*-tosyl sulfimide intermediate, as reported by Rollin^[74], donor **4.1f** was mixed with isolated byproduct **5.54** under the reaction conditions. No reaction was observed, and both starting materials were recovered unchanged, excluding this pathway in the present system (**Figure 5.2.4.2d**). When ribosyl donor **4.1f** was irradiated under identical nucleophile-free conditions, hydrolyzed donor **5.55** was observed along with **5.54**, likely arising from reaction with trace water, consistent with donor activation via a transient reactive intermediate (**Figure 5.2.4.2b**). In contrast, photolysis of a simple non-glycosyl thioether model substrate (tolyl methyl sulfide, **5.1n**) failed to produce any sulfilimide **5.56** and afforded only **5.54**, indicating that non-glycosyl thioethers do not undergo productive nitrene trapping (**Figure 5.2.4.2e**). Prompted by this result, we evaluated acceptors bearing pendant thioether functionalities [thioaryl (STol) and thioalkyl (SEt)] to assess site selectivity directly (**Figure 5.2.4.2f**). In all cases, glycosylation proceeded exclusively through the alcohol nucleophile to furnish products **5.57** (STol) and **5.58** (SEt) in high yield and stereoselectivity, with no detectable reaction at the external thioether. Similarly, reactions employing donor **5.1o** bearing an STol thioglycoside in the presence of pendant thioether acceptors (STol or SEt) gave outcomes identical to those observed for donor **4.1f**, further confirming selective activation of the glycosyl anomeric thioether. Notably, both donors

4.1f and **5.1o** exhibited anomeric configurations; still, the selectivity was excellent and identical, further demonstrating that selectivity is independent of anomeric configuration. Which further strongly indicated the reaction pathway proceeding via a common oxocarbenium ion intermediate.

To examine the reversibility of sulfenylnitrene-thioether interactions, **2-(ethylthio)- and 2-(tolylthio)ethan-1-ol** were subjected to the standard photolysis conditions (**Figure 5.2.4.2g**). In both cases, only decomposition of the sulfenylnitrene precursor to the byproduct **5.54** was observed; there was no indication of sulfur-bound sulfenylnitrene **5.59** formation. While the thioether substrates remained intact, this supported a reversible, non-productive interaction between sulfenylnitrenes and non-glycosyl thioethers. Furthermore, these experiments were validated by density functional theory (DFT) studies (performed by Deacon Herndon). The computed energy profile shows that the association of sulfenylnitrene with a ribose thioglycoside donor is thermodynamically favored, with formation of **A** (**Figure 5.2.4.2h**) being downhill by 9.5. In contrast, sulfenylnitrene associates with a non-glycosyl thioether (NGT) to form intermediate **5.59**, which is favored only by 2.3 kcal/mol, suggesting a reversible nature of this interaction. Consistent with this conclusion, collectively, these studies support a mechanism in which sulfenylnitrenes engage selectively with thioglycoside donors, enabling productive donor activation while leaving non-glycosyl thioethers unreactive under the standard reaction conditions.

Finally, we examined whether disaccharide **4.27** ($\alpha:\beta = 60:1$) would undergo epimerization under commonly used thioglycoside activation conditions (**Figure 5.2.4.2h**). When treated with NIS/TMSOTf at room temperature, compound **4.27** decomposed completely, and at 0 °C, significant epimerization of **4.27** ($\alpha:\beta = 1:1$) was

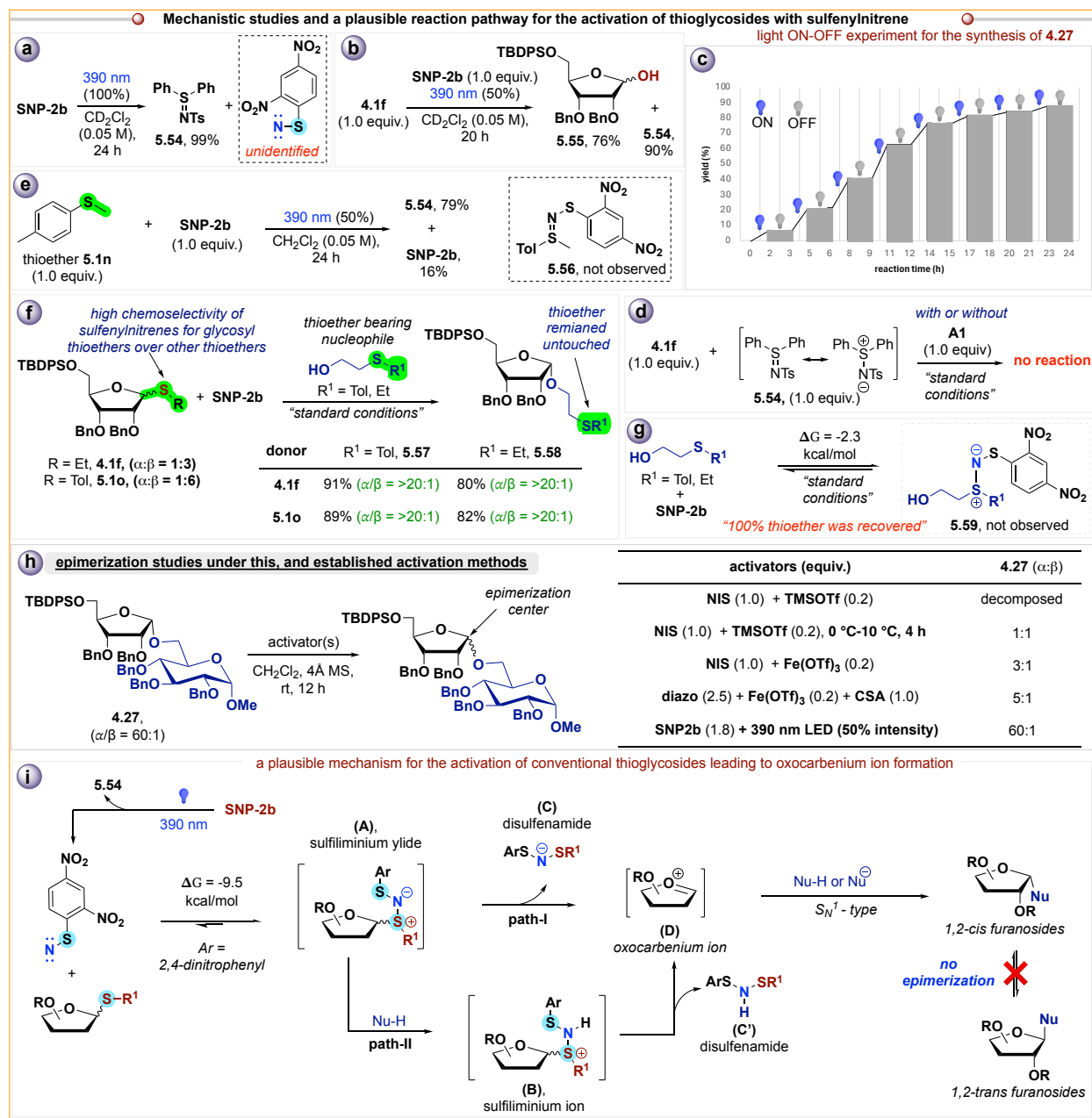


Figure 5.2.4.2 Mechanistic studies (computational and epimerization studies) and a plausible reaction pathway for sulfonylnitrene-mediated activation of conventional thioglycosides. Diazo, methyl 2-diazo-2-(*p*-tolyl)acetate; CSA, camphorsulfonic acid.

observed. Likewise, NIS/Fe(OTf)₃ resulted in pronounced epimerization ($\alpha:\beta = 3:1$), and iron-carbene activation also led to significant loss of stereochemical integrity ($\alpha:\beta = 5:1$). In contrast, subjecting disaccharide **4.27** to our sulfonylnitrene conditions caused no detectable epimerization. These observations highlight the mild and neutral character of

this activation strategy, which promotes efficient donor activation while preserving stereochemical purity under ambient conditions.

Taken together, these observations support the mechanistic proposal outlined in **Figure 5.2.4.2i**. Upon irradiation, **SNP-2b** undergoes chemoselective S–N bond photolysis to generate the sulfenylnitrene, with sulfinimine **5.54** formed as the major byproduct. The photogenerated sulfenylnitrene engages selectively with thioglycosides in a reversible but favored fashion, forming a sulfiliminium ylide **A**. This intermediate can then evolve along two productive pathways to generate the oxocarbenium ion **D**, the key intermediate in glycosylation. In Path **I**, ylide **A** undergoes direct fragmentation to furnish the oxocarbenium ion **D** along with disulfenamide **C** as the byproduct. In Path **II**, ylide **A** may undergo protonation, depending upon the nucleophile's acidity, to afford sulfonium ion **B**, which subsequently fragments to oxocarbenium ion **D** with release of disulfenamide **C'**. The resulting oxocarbenium ion **D** then undergoes stereocontrolled nucleophilic attack, with the observed high *cis* selectivity dictated by the conformation of the oxocarbenium ion and C5-protecting-group effects. This plausible mechanism is supported by DFT calculations, experimental observations, including compatibility with various nucleophiles and functional groups, such as non-anomeric thioethers.

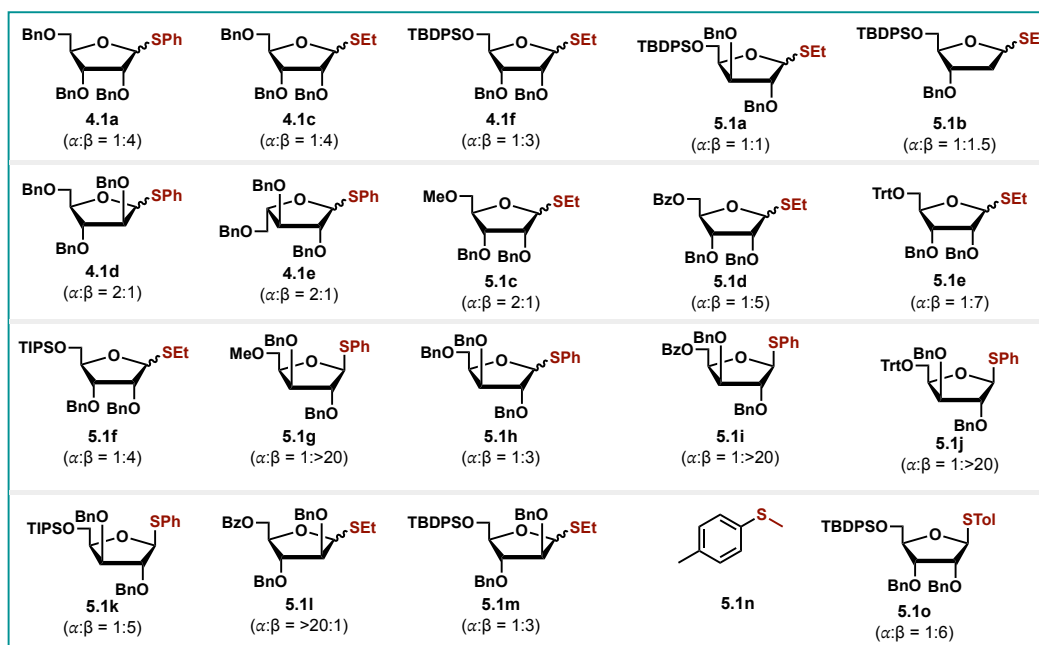
5.3. Conclusion

In this chapter, we report a general, metal- and photosensitizer-free strategy for stereocontrolled furanosylation via sulfenylnitrene-mediated highly chemoselective intermolecular activation of conventional thioglycoside donors. Chemoselective photolysis of an S–N bond under blue light generates transient sulfenylnitrenes that

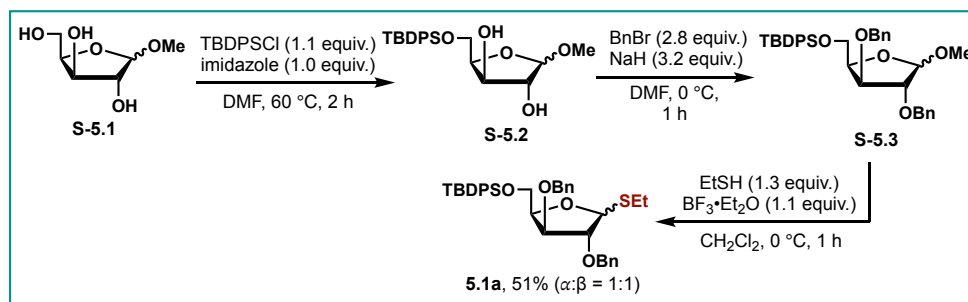
enable neutral, Lewis-acid-free, and highly 1,2-*cis*-selective furanosylations. This approach uniquely delivers challenging 1,2-*cis* xylosides and previously inaccessible stereodefined α -2-deoxy-D-ribosides, long-standing challenges in carbohydrate chemistry. Mechanistic studies reveal that the sterics and electronic properties of the C5-protecting groups govern the conformation of oxocarbenium ions, providing a broadly applicable design for furanose 1,2-*cis* selectivity. Overall, this sulfenylnitrene photochemistry provides a sustainable activation method for precise bond formation, expanding the scope of sulfur-based nitrene chemistry to complex glycosides and bioactive architectures.

5.4. Experimental Section

5.4.1. List and synthesis of conventional thioglycosides used in this chapter



Synthesis of ethyl 2,3-bis-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl-1-thio-D-xylofuranoside (5.1a)



In an oven-dried round-bottom flask, methyl xylofuranoside **S-5.1** (1.0 equiv.) was dissolved in dimethylformamide (0.5 M), followed by the addition of imidazole (1.0 equiv.) at room temperature, and stirred at the same temperature for the next 15 minutes. Then, TBDPSCI (1.1 equiv.) was added to the stirred suspension, and the resulting mixture was stirred at 60 °C for the next 2 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50 mL x2). Then, the combined organic layers were carefully washed with aq. sat. NaHCO₃, brine, and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-5.2**, which was then used in the next step without further purification. To the crude **S-5.2**, anhydrous DMF (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, NaH (3.2 equiv., 60% in mineral oil) was added carefully in one portion, and the reaction was allowed to stir at the same temperature for the next 30 minutes. Then, benzyl bromide (2.8 equiv.) was added to the stirred suspension, and the reaction was stirred at the same temperature for 2 hours. Upon completion, the reaction was quenched by the careful addition of methanol (2.0 mL), then the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50 × 2 mL). Then, the combined organic layers were carefully washed with aq. sat. NaHCO₃, brine, and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-5.3**. The crude material was purified using column chromatography and moved to the next step without further purification. To the **S-5.3** (1.0 g, 1 equiv.), Anhydrous dichloromethane (0.5 M) was added, and the solution

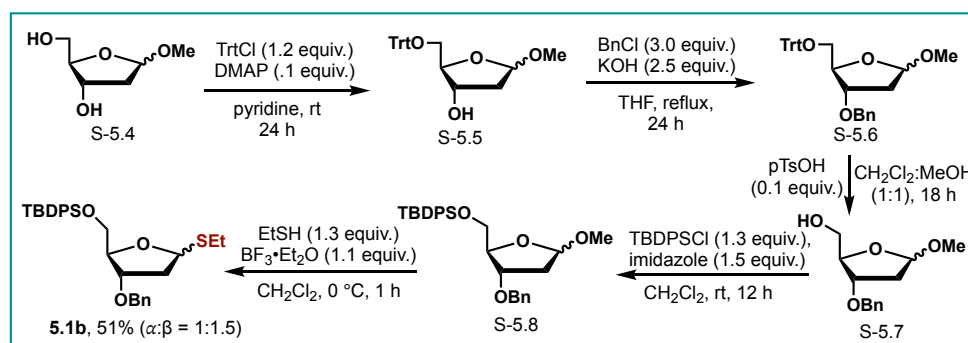
was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour; then, it was quenched by the careful addition of aq. sat. NaHCO_3 followed by the addition of H_2O . The layers were separated, and the organic layer was washed with brine and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc: hexane = 3:97) to afford ribofuranoside donor **5.1a** (0.535 g, 53%, $\alpha:\beta=1:1$). $R_f = 0.6$ (EtOAc: hexane= 10:90).

^1H NMR (400 MHz, CDCl_3) δ 7.74 – 7.65 (m, 10H), 7.43 – 7.27 (m, 31H), 7.21 (dd, $J = 6.7, 2.9$ Hz, 2H), 5.54 (d, $J = 5.0$ Hz, 1H), 5.07 (d, $J = 3.2$ Hz, 1H), 4.66 (d, $J = 12.0$ Hz, 1H), 4.60 (dd, $J = 11.9, 1.7$ Hz, 2H), 4.53 (d, $J = 2.1$ Hz, 2H), 4.51 – 4.49 (m, 3H), 4.47 – 4.40 (m, 1H), 4.24 (dt, $J = 6.8, 5.0$ Hz, 1H), 4.17 (dd, $J = 5.1, 2.6$ Hz, 1H), 4.10 (dd, $J = 4.7, 2.6$ Hz, 1H), 4.06 – 4.00 (m, 3H), 3.96 – 3.82 (m, 3H), 2.74 – 2.62 (m, 4H), 1.29 (dt, $J = 10.9, 7.4$ Hz, 6H), 1.04 (d, $J = 3.1$ Hz, 18H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.1, 138.0, 137.7, 137.6, 135.8, 135.7, 135.7, 135.3, 134.9, 133.7, 133.5, 133.4, 129.8, 129.8, 129.7, 129.7, 128.6, 128.6, 128.5, 128.1, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.8, 87.6, 87.5, 87.3, 84.0, 82.5, 82.0, 81.7, 79.3, 77.5, 77.2, 76.8, 73.0, 72.5, 72.2, 72.2, 61.9, 61.6, 27.0, 26.9, 25.9, 25.1, 19.3, 19.3, 15.3, 15.1.

HRMS (ESI): calc. for $\text{C}_{37}\text{H}_{44}\text{O}_4\text{NaSSi}$ ($\text{M}+\text{Na}$): 635.2627; found: 635.2627.

Synthesis of ethyl 3-O-benzyl-5-O-tertbutyldiphenylsilyl-1-thio-2-deoxy-D-ribofuranoside (**5.1b**)



In an oven-dried round-bottom flask, methyl 2-deoxyribofuranoside **S-5.4** (2.2 g, 1.0 equiv.) was dissolved in Pyridine (0.8 M), followed by the addition of TrtCl (1.2 equiv.) and DMAP (0.1 equiv.) at room temperature, and stirred at the same temperature for the next 24 hours. Upon complete consumption of the starting material, pyridine was removed, and the residue was dissolved in CH₂Cl₂, washed with water and brine. The layers were separated, and the organic layer was dried over anhydrous Na₂SO₄, filtered, and evaporated under reduced pressure to afford a syrupy residue. The crude material was purified by column chromatography (EtOAc: hexane= 15:85) to afford **S-5.5** (3.5 g, 61%). To the **S-5.5** (3.5 g, 1.0 equiv.) anhydrous THF (0.5 M) was added, followed by powdered KOH (2.5 equiv.) and BnCl (3.0 equiv.) addition. The reaction mixture was refluxed for 24 hours. Upon complete consumption of the starting materials, the reaction mixture was filtered, and the filtrate was evaporated under reduced pressure to afford crude material. This crude material was purified by column chromatography (EtOAc: hexane= 07:93) to afford **S-5.6** (2.6 g, 61%). To the **S-5.6** (1.8 g, 1.0 equiv.), a mixture of CH₂Cl₂:MeOH (1:1, 0.5 M) and pTsOH (0.1 equiv.) was added at room temperature. The reaction mixture was stirred at room temperature for 18 hours, and upon complete consumption of solvent, it was evaporated, and crude material was purified by column chromatography (EtOAc: hexane= 20:80) to afford **S-5.7** (0.63 g, 71%). To the **S-5.7** (0.630g, 1.0 equiv.) was dissolved in CH₂Cl₂ (0.5 M), followed by the addition of imidazole (1.5 equiv.) at room temperature, and stirred at the same temperature for the next 15 minutes. Then, TBDPSCI (1.3 equiv.) was added to the stirred suspension, and the resulting mixture was stirred at room temperature for the next 12 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with water (50 mL) and CH₂Cl₂ (30 mL). The layers were separated, and the aqueous layer was washed with CH₂Cl₂ (50 mL x2). Then, the combined organic layers were carefully washed with aq. sat. NaHCO₃, brine, and dried over Na₂SO₄. The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-5.8**, and the crude material was purified by column chromatography (EtOAc: hexane= 5:95) to afford **S-5.8** (1.24 g, 98%). which was then used in the next step without any characterization. To the **S-5.8** (1.25 g, 1.0 equiv.), Anhydrous dichloromethane (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added,

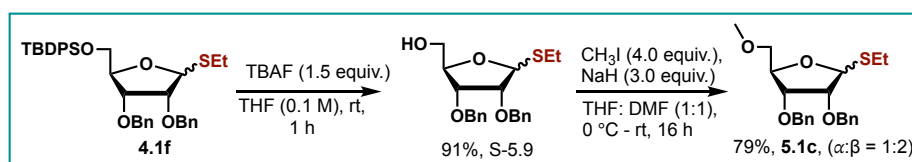
followed by the addition of $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (1.1 equiv.). The reaction was stirred at 0 °C for the next 1 hour; then, it was quenched by the careful addition of aq. sat. NaHCO_3 followed by the addition of H_2O . The layers were separated, and the organic layer was washed with brine and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc : hexane = 3:97) to afford 2-deoxy ribofuranoside donor **5.1b** (0.68 g, 51%, α : β =1:1.5). R_f = 0.6 (EtOAc : hexane= 10:90).

^1H NMR (400 MHz, CDCl_3) δ 7.67 (dtd, J = 11.0, 4.8, 3.0 Hz, 7H), 7.44 – 7.29 (m, 18H), 5.46 (dd, J = 7.5, 4.2 Hz, 1H), 5.37 (dd, J = 9.0, 5.7 Hz, 1H), 4.58 – 4.52 (m, 3H), 4.48 (d, J = 11.8 Hz, 1H), 4.28 (q, J = 4.0 Hz, 1H), 4.22 – 4.14 (m, 3H), 3.80 – 3.74 (m, 2H), 3.62 (dd, J = 10.6, 7.2 Hz, 1H), 2.69 (ttt, J = 15.7, 8.2, 5.4 Hz, 4H), 2.56 (dt, J = 14.4, 7.4 Hz, 1H), 2.35 (ddd, J = 13.6, 5.8, 1.8 Hz, 1H), 2.08 – 1.93 (m, 2H), 1.33 (d, J = 7.4 Hz, 2H), 1.28 (t, J = 7.4 Hz, 3H), 1.06 (s, 8H), 1.04 (s, 4H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.2, 138.1, 135.8, 135.8, 135.8, 135.7, 133.5, 133.4, 133.3, 129.9, 129.9, 129.8, 128.6, 128.5, 127.9, 127.8, 127.8, 127.8, 127.7, 85.7, 84.3, 83.8, 83.5, 80.6, 78.8, 77.5, 77.2, 76.8, 71.7, 71.3, 64.5, 64.0, 39.3, 38.7, 27.0, 26.9, 25.9, 25.5, 19.4, 19.3, 15.4, 15.2.

HRMS (ESI): calc. for $\text{C}_{30}\text{H}_{38}\text{NaO}_3\text{SSi}$ ($M+\text{Na}$): 529.2209 ; found: 529.2203.

Synthesis of phenyl 2,3,5-tri-*O*-benzyl-1-thio-D-arabinofuranoside (**5.1c**)



In an oven-dried round-bottom flask, **4.1f** (2.0 g, 1.0 equiv.) was dissolved in anhydrous THF (0.1 M), and TBAF (1.5 equiv., 1 M solution in THF) was added dropwise at room temperature. The reaction was stirred at the same temperature for the next 1 hour, and TLC was monitored to track the progress. Upon complete consumption of the starting material, the reaction mixture was quenched by the addition of aqueous saturated NH_4Cl . The solution was diluted by ethyl acetate and washed with water, brine, and dried over Na_2SO_4 , filtered, and the solvent was evaporated under reduced pressure to afford **S-5.9** as a colorless oil. The crude **S-5.9** was used in the next steps without further purification.

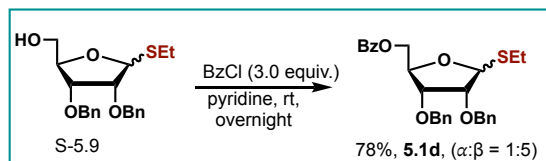
To the solution of **S-5.9** (0.160 g, 1.0 equiv.) in THF: DMF (4.2 mL, 1:1), NaH (3.0 equiv.) was added at 0 °C, and the reaction was stirred at the same temperature for 10 minutes. Then MeI (4.0 equiv.) was added to the stirred solution and allowed to warm up to room temperature and stirred for 16 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with ethyl acetate and poured into ice-cold water. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄, filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude product was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1c** (0.131 g, 79%, a:b = 1:2) R_f = 0.5 (EtOAc: hexane = 15:85).

¹H NMR (400 MHz, CDCl₃) δ 7.40 – 7.27 (m, 15H), 5.23 (dd, J = 3.9, 1.2 Hz, 1H), 4.71 (d, J = 10.5 Hz, 1H), 4.68 (s, 1H), 4.64 – 4.58 (m, 3H), 4.51 (dd, J = 11.8, 1.2 Hz, 1H), 4.26 – 4.22 (m, 2H), 4.08 (ddd, J = 7.4, 2.8, 1.2 Hz, 1H), 3.96 (ddd, J = 6.3, 5.1, 1.3 Hz, 1H), 3.89 (ddd, J = 7.5, 3.5, 1.2 Hz, 1H), 3.86 (ddd, J = 5.1, 3.9, 1.2 Hz, 1H), 3.54 – 3.51 (m, 1H), 3.51 – 3.45 (m, 4H), 3.36 (d, J = 1.3 Hz, 3H), 3.31 (d, J = 1.3 Hz, 2H), 2.73 – 2.59 (m, 4H), 1.27 (td, J = 7.4, 1.3 Hz, 4H), 1.22 (ddd, J = 16.0, 7.4, 1.3 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 138.5, 138.3, 137.8, 137.7, 128.6, 128.5, 128.5, 128.4, 128.2, 128.1, 128.1, 128.0, 128.0, 128.0, 127.8, 127.7, 86.0, 82.2, 81.5, 81.3, 80.8, 79.0, 78.3, 77.5, 77.2, 76.8, 74.7, 73.7, 73.7, 72.7, 72.4, 72.3, 59.5, 59.2, 58.4, 53.9, 26.4, 25.2, 25.2, 15.1, 14.6, 14.6.

HRMS (ESI): calc. for C₂₂H₂₈NaO₄S (M+Na): 411.1606 ; found: 411.1601.

Synthesis of ethyl 2,3-bis-O-benzyl-5-O-benzoyl-1-thio-D-ribofuranoside (**5.1d**)



To the solution of **S-5.9** (0.130 g, 1.0 equiv.) in pyridine (0.5 M), BzCl (3.0 equiv.) was added at rt, and the reaction was stirred at the same temperature overnight. Upon complete consumption of the starting material, pyridine was evaporated under reduced pressure to afford crude material. The crude material was purified by column

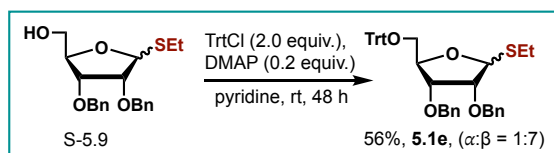
chromatography (EtOAc: hexane = 10:90) to afford product **5.1d** (0.130 g, 78%, a:b = 1:5) as a viscous oil. R_f = 0.5 (EtOAc: hexane = 15:85).

^1H NMR (400 MHz, CDCl_3) δ 8.15 – 8.12 (m, 3H), 8.04 – 8.01 (m, 2H), 7.62 (t, J = 7.4 Hz, 2H), 7.49 (t, J = 7.7 Hz, 4H), 7.43 – 7.38 (m, 4H), 7.36 – 7.33 (m, 2H), 7.30 – 7.28 (m, 3H), 5.35 (d, J = 2.1 Hz, 1H), 4.74 – 4.70 (m, 1H), 4.64 (d, J = 6.4 Hz, 1H), 4.62 – 4.60 (m, 1H), 4.58 – 4.54 (m, 1H), 4.50 (d, J = 9.2 Hz, 1H), 4.45 (dt, J = 7.7, 2.3 Hz, 1H), 4.37 (ddd, J = 11.9, 4.3, 1.3 Hz, 1H), 4.21 (ddd, J = 7.4, 4.8, 1.3 Hz, 1H), 3.94 (dd, J = 4.7, 2.2 Hz, 1H), 2.73 – 2.64 (m, 1H), 2.61 – 2.52 (m, 1H), 1.32 (t, J = 7.4 Hz, 1H), 1.21 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 172.0, 166.5, 137.7, 137.5, 137.4, 133.9, 133.2, 133.1, 130.3, 130.0, 129.9, 129.7, 129.5, 128.6, 128.6, 128.6, 128.6, 128.5, 128.5, 128.4, 128.3, 128.1, 128.0, 128.0, 88.1, 85.8, 80.5, 79.8, 78.6, 78.1, 78.0, 77.5, 77.2, 76.8, 73.5, 72.8, 72.6, 72.2, 64.3, 64.0, 25.3, 25.1, 15.3, 14.9.

HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{30}\text{NaO}_5\text{S}$ ($\text{M}+\text{Na}$): 501.1712 ; found: 501.1706.

Synthesis of ethyl 2,3-bis-*O*-benzyl-5-*O*-trityl-1-thio-*D*-ribofuranoside (**5.1e**)



To the solution of **S-5.9** (0.130 g, 1.0 equiv.) in pyridine (0.5 M), TrtCl (2.0 equiv.), and DMAP (0.2 equiv.) was added at rt, and the reaction was stirred at the same temperature for 48 h. Upon complete consumption of the starting material, pyridine was evaporated under reduced pressure to afford crude material. The crude material was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1e** (0.120 g, 56%, a:b = 1:7) as a viscous oil. R_f = 0.4 (EtOAc: hexane = 15:85).

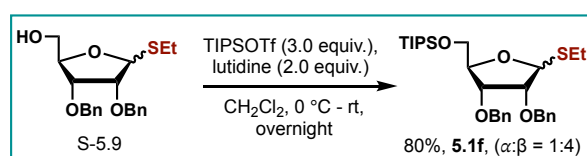
^1H NMR (400 MHz, CDCl_3) δ 7.47 (dt, J = 8.1, 1.3 Hz, 5H), 7.43 – 7.38 (m, 2H), 7.35 (d, J = 1.3 Hz, 2H), 7.34 (d, J = 0.9 Hz, 1H), 7.33 – 7.30 (m, 6H), 7.28 (d, J = 2.6 Hz, 4H), 7.25 (t, J = 0.9 Hz, 2H), 7.23 – 7.21 (m, 3H), 5.31 (d, J = 4.0 Hz, 1H), 4.69 (d, J = 12.1 Hz, 1H), 4.62 (d, J = 12.1 Hz, 1H), 4.51 (d, J = 11.9 Hz, 1H), 4.44 (d, J = 11.8 Hz, 1H), 4.29 – 4.25 (m, 1H), 4.11 – 4.07 (m, 1H), 3.92 – 3.88 (m, 1H), 3.32 (ddd, J = 10.3, 4.0,

1.1 Hz, 1H), 3.13 (ddd, $J = 10.2, 4.2, 1.0$ Hz, 1H), 2.79 – 2.72 (m, 1H), 2.71 – 2.64 (m, 1H), 1.31 – 1.27 (m, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 147.0, 144.0, 144.0, 137.8, 134.9, 129.8, 128.9, 128.8, 128.5, 128.5, 128.4, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.4, 127.1, 127.1, 86.7, 85.9, 81.8, 81.0, 78.1, 77.5, 77.2, 76.8, 72.4, 72.3, 63.8, 26.7, 25.3, 15.2.

HRMS (ESI): calc. for $\text{C}_{40}\text{H}_{40}\text{NaO}_4\text{S}$ ($\text{M}+\text{Na}$): 639.2545; found: 639.2540.

Synthesis of ethyl 2,3-bis-*O*-benzyl-5-*O*-triisopropyl-1-thio-*D*-ribofuranoside (**5.1f**)



To the solution of **S-5.9** (0.150 g, 1.0 equiv.) in CH_2Cl_2 (0.1 M), TIPSOTf (3.0 equiv.), and 2,6-lutidine (2.0 equiv.) was added at 0 °C, and the reaction was allowed to warm to room temperature overnight. Upon complete consumption of the starting material, the reaction mixture was diluted with CH_2Cl_2 and washed with aqueous saturated NaHCO_3 . Layers were separated, and the organic layer was washed with brine, dried over Na_2SO_4 , filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude material was purified by column chromatography (EtOAc: hexane = 3:97) to afford product **5.1f** (0.171 g, 80%, $\alpha:\beta = 1:4$) as a viscous oil. $R_f = 0.7$ (EtOAc: hexane = 15:85).

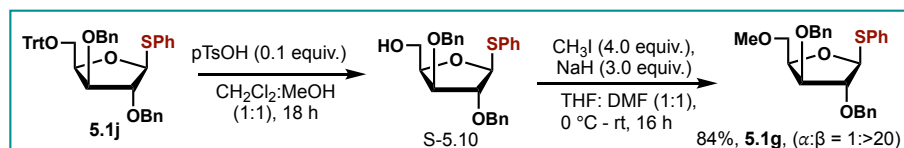
^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.29 (m, 12H), 5.22 (d, $J = 5.0$ Hz, 1H), 4.65 (d, $J = 7.5$ Hz, 2H), 4.57 (s, 2H), 4.17 (q, $J = 4.6$ Hz, 1H), 4.09 (t, $J = 4.9$ Hz, 1H), 3.84 (t, $J = 5.0$ Hz, 1H), 3.75 (t, $J = 4.8$ Hz, 2H), 2.72 – 2.66 (m, 1H), 2.66 – 2.59 (m, 1H), 1.27 (t, $J = 7.4$ Hz, 3H), 1.05 (s, 25H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.0, 137.8, 134.9, 128.5, 128.5, 128.4, 128.1, 128.0, 128.0, 127.9, 127.9, 85.7, 83.6, 80.9, 77.5, 77.2, 76.8, 72.3, 72.2, 63.8, 25.0, 18.1, 17.8, 15.2, 12.4, 12.0.

HRMS (ESI): calc. for $\text{C}_{30}\text{H}_{46}\text{NaO}_4\text{SSi}$ ($\text{M}+\text{Na}$): 553.2784; found: 553.2778.

Synthesis of phenyl 2,3-bis-O-benzyl-5-O-methyl-1-thio-D-xylofuranoside (**5.1g**)

To the **5.1j** (3.7 g, 1.0 equiv.), a mixture of CH₂Cl₂:MeOH (1:1, 0.5 M) and pTsOH (0.1 equiv.) was added at room temperature. The reaction mixture was stirred at room temperature for 18 hours, and upon complete consumption of solvent was evaporated, and crude material was purified by column chromatography (EtOAc: hexane= 20:80) to afford **S-5.10** (0.63 g, 71%), *R_f* = 0.4 (EtOAc: hexane = 20:80).



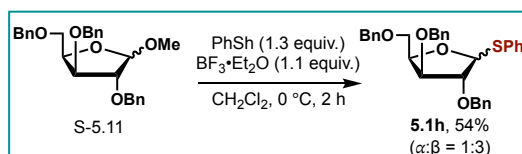
The compound was used in the next step without any further characterization. To the solution of **S-5.10** (0.130 g, 1.0 equiv.) in THF: DMF (3.6 mL, 1:1), NaH (3.0 equiv.) was added at 0 °C, and the reaction was stirred at the same temperature for 10 minutes. Then MeI (4.0 equiv.) was added to the stirred solution and allowed to warm up to room temperature and stirred for 16 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with ethyl acetate and poured into ice-cold water. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄, filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude product was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1g** (0.130 g, 84%, a:b = 1:>20) *R_f* = 0.5 (EtOAc: hexane = 15:85).

¹H NMR (400 MHz, CDCl₃) δ 7.52 – 7.48 (m, 2H), 7.38 – 7.27 (m, 12H), 7.25 – 7.20 (m, 1H), 5.35 (d, *J* = 3.0 Hz, 1H), 4.58 (dd, *J* = 14.1, 11.9 Hz, 2H), 4.51 (d, *J* = 11.8 Hz, 1H), 4.45 (d, *J* = 12.1 Hz, 1H), 4.34 (q, *J* = 5.4 Hz, 1H), 4.13 (dd, *J* = 3.1, 1.8 Hz, 1H), 4.03 (dd, *J* = 4.8, 1.9 Hz, 1H), 3.72 (d, *J* = 5.8 Hz, 2H), 3.40 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 137.8, 137.4, 135.4, 131.2, 129.0, 128.6, 128.6, 128.6, 128.1, 128.0, 127.9, 127.9, 127.1, 90.3, 86.8, 81.8, 81.3, 77.5, 77.2, 76.8, 72.2, 72.0, 71.3, 59.4.

HRMS (ESI): calc. for C₂₆H₂₈NaO₄SSi (M+Na): 459.1606; found: 459.1601.

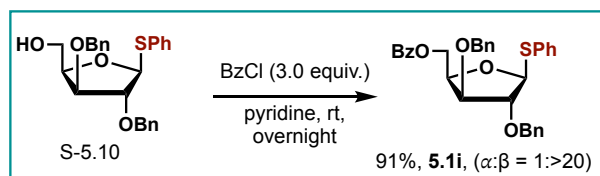
Synthesis of ethyl 2,3-bis-O-benzyl-5-O-benzyl-1-thio-D-xylofuranoside (**5.1h**)



To the **S-5.11** (0.5 g, 1.0 equiv.), anhydrous dichloromethane (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, PhSH (1.3 equiv.) was added, followed by the addition of $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (1.1 equiv.). The reaction was stirred at 0 °C for the next 2 hours; then, it was quenched by the careful addition of aq. sat. NaHCO_3 followed by the addition of H_2O . The layers were separated, and the organic layer was washed with brine and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude thick syrup. This crude syrup was purified by column chromatography (EtOAc: hexane = 6:94) to afford ribofuranoside donor **5.1h** (0.32 g, 54%, $\alpha:\beta=1:3$). $R_f = 0.6$ (EtOAc: hexane = 15:85). The data were in accordance with the literature.^[75]

Synthesis of phenyl 2,3-bis-O-benzyl-5-O-benzoyl-1-thio-D-xylofuranoside (**5.1i**)

To the solution of **S-5.10** (0.166 g, 1.0 equiv.) in pyridine (0.5 M), BzCl (3.0 equiv.) was added at room temperature, and the reaction was stirred at the same temperature overnight. Upon complete consumption of the starting material, pyridine was evaporated under reduced pressure to afford crude material. The crude material was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1i** (0.188 g, 91%, $\alpha:b = 1:>20$) as a viscous oil. $R_f = 0.5$ (EtOAc: hexane = 15:85).

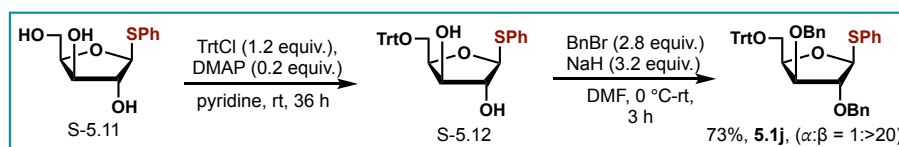


^1H NMR (400 MHz, CDCl_3) δ 8.04 (dd, $J = 8.4, 1.3$ Hz, 2H), 7.59 – 7.55 (m, 1H), 7.54 – 7.50 (m, 2H), 7.46 – 7.41 (m, 2H), 7.37 – 7.34 (m, 2H), 7.33 – 7.28 (m, 9H), 7.26 (d, $J = 3.2$ Hz, 2H), 5.41 (dd, $J = 3.1, 1.2$ Hz, 1H), 4.73 – 4.68 (m, 1H), 4.67 – 4.57 (m, 3H), 4.56 – 4.52 (m, 2H), 4.45 (d, $J = 12.1$ Hz, 1H), 4.20 (dd, $J = 3.1, 2.0$ Hz, 1H), 4.14 (dd, $J = 4.9, 2.0$ Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.5, 137.4, 137.3, 134.8, 133.1, 131.7, 130.3, 130.2, 129.9, 129.0, 128.7, 128.6, 128.5, 128.2, 128.1, 128.0, 127.9, 127.4, 90.4, 86.3, 81.7, 79.8, 77.5, 77.2, 76.8, 72.2, 72.0, 63.6.

HRMS (ESI): calc. for $\text{C}_{32}\text{H}_{30}\text{NaO}_5\text{S}$ ($\text{M}+\text{Na}$): 549.1712; found: 635.2627.

Synthesis of phenyl 2,3-bis-O-benzyl-5-O-trityl-1-thio-D-xylofuranoside (**5.1j**)



To the solution of **S-5.11** (2.0 g, 1.0 equiv.) in pyridine (0.5 M), TrtCl (1.2 equiv.), and DMAP (0.2 equiv.) were added at rt, and the reaction was stirred at the same temperature for 36 h. Upon complete consumption of the starting material, pyridine was evaporated under reduced pressure to afford crude material. The crude material was purified by column chromatography (EtOAc: hexane = 40:60) to afford **S-5.11** (3.2 g, 80%) as a viscous oil. R_f = 0.4 (EtOAc: hexane = 40:60). The compound was used in the next step without any further characterization. To the solution of **S-5.11** (1.8 g, 1.0 equiv.) in DMF (0.1 M), NaH (3.2 equiv.) was added at 0 °C, and the reaction was stirred at the same temperature for 30 minutes. Then BnBr (2.8 equiv.) was added to the stirred solution and allowed to warm up to room temperature, and stirred for 3 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with ethyl acetate and poured into ice-cold water. The layers were separated, and the organic layer was washed with brine and dried over Na_2SO_4 , filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude product was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1j** (1.8 g, 73%, α : β = 1:>20) R_f = 0.5 (EtOAc: hexane = 15:85).

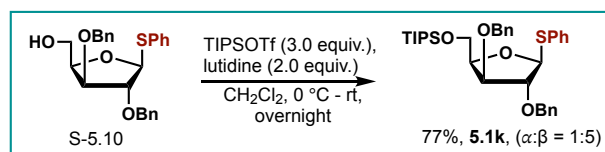
^1H NMR (400 MHz, CDCl_3) δ 7.51 (d, J = 7.6 Hz, 2H), 7.49 – 7.44 (m, 7H), 7.34 (t, J = 6.7 Hz, 3H), 7.31 – 7.28 (m, 4H), 7.26 – 7.23 (m, 7H), 7.12 – 7.08 (m, 2H), 5.44 (d, J = 2.4 Hz, 1H), 4.60 (d, J = 11.9 Hz, 1H), 4.50 (d, J = 12.4 Hz, 2H), 4.42 (q, J = 5.5 Hz, 1H), 4.31 (d, J = 12.3 Hz, 1H), 4.11 (s, 1H), 3.99 (d, J = 4.5 Hz, 1H), 3.60 (dd, J = 9.7, 6.4 Hz, 1H), 3.30 (dd, J = 9.8, 5.3 Hz, 1H).

¹³C NMR (100 MHz, CDCl₃) δ 144.1, 137.7, 137.5, 135.9, 130.7, 129.0, 128.9, 128.9, 128.8, 128.7, 128.5, 128.1, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.0, 126.9, 90.1, 86.9, 86.9, 81.9, 81.2, 77.5, 77.2, 76.8, 72.1, 71.8, 62.7.

HRMS (ESI): calc. for C₄₄H₄₀NaO₄S (M+Na): 687.2545; found: 687.2540.

Synthesis of phenyl 2,3-bis-O-benzyl-5-O-triisopropyl-1-thio-D-xylofuranoside (5.1k)

To the solution of **S-5.10** (0.2 g, 1.0 equiv.) in CH₂Cl₂ (0.1 M), TIPSOTf (3.0 equiv.), and 2,6-lutidine (2.0 equiv.) was added at 0 °C, and the reaction was allowed to warm to room temperature overnight.



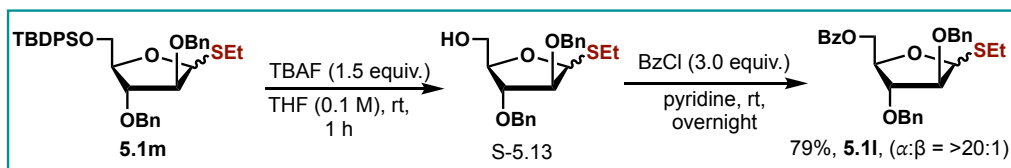
Upon complete consumption of the starting material, the reaction mixture was diluted with CH₂Cl₂ and washed with aqueous saturated NaHCO₃. Layers were separated, and the organic layer was washed with brine, dried over Na₂SO₄, filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude material was purified by column chromatography (EtOAc: hexane = 3:97) to afford product **5.1k** (0.21 g, 77%, a:b = 1:>20) as a viscous oil. R_f = 0.7 (EtOAc: hexane = 15:85).

¹H NMR (400 MHz, CDCl₃) δ 7.46 – 7.40 (m, 3H), 7.29 – 7.27 (m, 3H), 7.25 – 7.18 (m, 11H), 7.15 (dd, *J* = 6.9, 1.7 Hz, 1H), 5.28 (d, *J* = 2.6 Hz, 1H), 4.53 – 4.46 (m, 4H), 4.40 (d, *J* = 12.1 Hz, 1H), 4.17 (dt, *J* = 7.0, 5.1 Hz, 1H), 4.06 – 3.95 (m, 4H), 3.89 (dd, *J* = 10.1, 5.5 Hz, 1H), 3.82 – 3.75 (m, 1H), 1.01 – 0.97 (m, 25H).

¹³C NMR (100 MHz, CDCl₃) δ 138.4, 137.8, 131.4, 131.3, 129.3, 129.3, 129.0, 128.8, 128.8, 128.4, 128.3, 128.2, 128.2, 128.2, 128.1, 128.1, 127.3, 90.6, 87.6, 83.7, 81.4, 77.8, 77.5, 77.2, 72.6, 72.4, 61.8, 18.5, 18.2, 12.7, 12.4.

HRMS (ESI): calc. for C₃₄H₄₆NaO₄SSi (M+Na): 601.2784; found: 601.2778.

Synthesis of ethyl 2,3-bis-O-benzyl-5-O-benzoyl-1-thio-D-arabinofuranoside (5.1l)



In an oven-dried round-bottom flask, **5.1m** (0.5 g, 1.0 equiv.) was dissolved in anhydrous THF (0.1 M), and TBAF (1.5 equiv., 1 M solution in THF) was added dropwise at room temperature. The reaction was stirred at the same temperature for an additional hour, and TLC was monitored to track the progress. Upon complete consumption of the starting material, the reaction mixture was quenched by the addition of aqueous saturated NH_4Cl . The solution was diluted with ethyl acetate and washed with water and brine, then dried over Na_2SO_4 , filtered, and the solvent was evaporated under reduced pressure to afford **S-5.13** as a colorless oil. The crude **S-5.13** was used in the next steps without further purification. To the solution of **S-5.13** (0.305 g, 1.0 equiv.) in pyridine (0.5 M), BzCl (3.0 equiv.) was added at room temperature, and the reaction was stirred at the same temperature overnight. Upon complete consumption of the starting material, pyridine was evaporated under reduced pressure to afford crude material. The crude material was purified by column chromatography (EtOAc: hexane = 10:90) to afford product **5.1l** (0.3 g, 78%, $\alpha:\beta = >20:1$) as a viscous oil. $R_f = 0.5$ (EtOAc: hexane = 15:85).

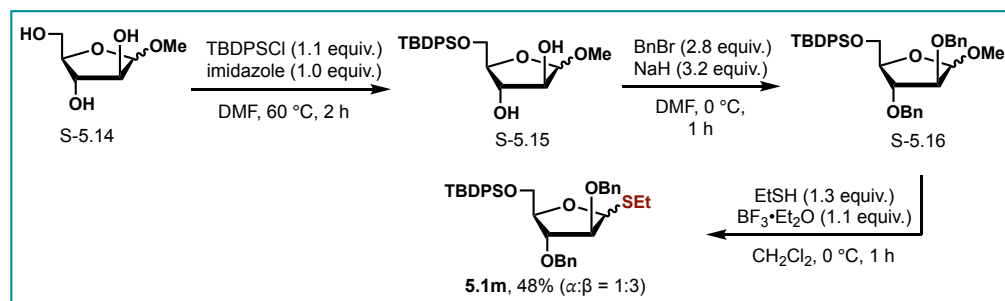
^1H NMR (400 MHz, CDCl_3) δ 8.18 (dd, $J = 8.3, 1.4$ Hz, 1H), 8.02 – 7.99 (m, 2H), 7.57 – 7.52 (m, 2H), 7.40 – 7.35 (m, 6H), 7.30 – 7.28 (m, 4H), 5.44 (d, $J = 2.1$ Hz, 1H), 4.65 (d, $J = 11.7$ Hz, 1H), 4.60 (d, $J = 11.8$ Hz, 1H), 4.58 – 4.42 (m, 5H), 4.04 (dd, $J = 3.8, 1.4$ Hz, 2H), 2.75 (dq, $J = 12.9, 7.4$ Hz, 1H), 2.66 (dq, $J = 12.9, 7.4$ Hz, 1H), 1.32 (t, $J = 7.4$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.4, 137.5, 137.4, 134.7, 133.2, 130.7, 129.9, 129.9, 129.0, 128.6, 128.6, 128.4, 128.1, 128.0, 128.0, 88.8, 87.5, 83.8, 78.8, 77.5, 77.2, 76.8, 72.5, 72.2, 63.8, 25.5, 15.1.

HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{30}\text{NaO}_5\text{S}$ ($\text{M}+\text{Na}$): 501.1712 ; found: 501.1706.

Synthesis of ethyl 2,3-bis-O-benzyl-5-O-tertbutyldiphenylsilyl-1-thio-D-arabinofuranoside (5.1m)

In an oven-dried round-bottom flask, methyl arabinofuranoside **S-5.14** (1.0 equiv.) was dissolved in dimethylformamide (0.5 M), followed by the addition of imidazole (1.0 equiv.) at room temperature, and stirred at the same temperature for the next 15 minutes. Then, TBDPSCI (1.1 equiv.) was added to the



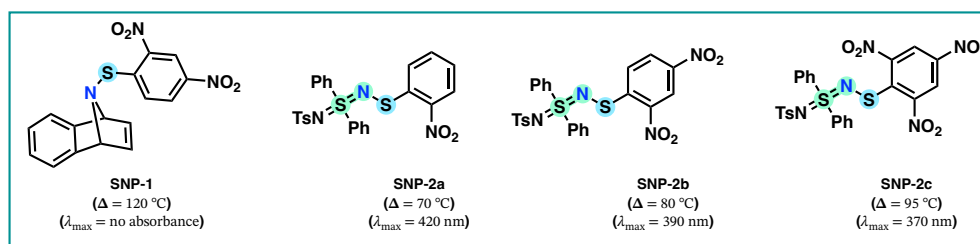
stirred suspension, and the resulting mixture was stirred at 60 °C for the next 2 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50 mL x 2). Then, the combined organic layers were carefully washed with aq. sat. NaHCO_3 , brine, and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-5.15**, which was then used in the next step without further purification. To the crude **S-5.15**, anhydrous DMF (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, NaH (3.2 equiv., 60% in mineral oil) was added carefully in one portion, and the reaction was allowed to stir at the same temperature for the next 30 minutes. Then, benzyl bromide (2.8 equiv.) was added to the stirred suspension, and the reaction was stirred at the same temperature for 2 hours. Upon completion, the reaction was quenched by the careful addition of methanol (2.0 mL), then the reaction mixture was diluted with water (50 mL) and ethyl acetate (50 mL). The layers were separated, and the aqueous layer was washed with ethyl acetate (50 x 2 mL). Then, the combined organic layers were carefully washed with aq. sat. NaHCO_3 , brine, and dried over Na_2SO_4 . The solutions were filtered and evaporated under reduced pressure to afford the crude viscous oil **S-5.16**. The crude material was purified using column chromatography and moved to the next step without further purification. To the **S-5.16** (1.0 g, 1 equiv.), Anhydrous dichloromethane (0.5 M) was added, and the solution was cooled to 0 °C. To the above-cooled reaction mixture, ethanethiol (1.3 equiv.) was added, followed by the addition of

in DMF (0.3 M), NaH (2.8 equiv.) was added at 0 °C, and the reaction was stirred at the same temperature for 10 minutes. Then BnBr (2.3 equiv.) was added to the stirred solution and allowed to warm up to room temperature and stirred for 3 hours. Upon complete consumption of the starting material, the reaction mixture was diluted with ethyl acetate and poured into ice-cold water. The layers were separated, and the organic layer was washed with brine and dried over Na₂SO₄, filtered, and the solvents were removed under reduced pressure to afford a viscous oil as the crude product. The crude product was purified by column chromatography (EtOAc: hexane = 07:93) to afford product **5.1o** (0.325 g, 59%, a:b = 1:6), R_f = 0.5 (EtOAc: hexane = 10:90).

¹H NMR (400 MHz, CDCl₃) δ 7.68 – 7.63 (m, 4H), 7.46 – 7.40 (m, 3H), 7.38 – 7.33 (m, 7H), 7.32 (d, *J* = 2.2 Hz, 4H), 7.29 (dd, *J* = 4.3, 1.9 Hz, 4H), 7.06 (d, *J* = 7.8 Hz, 2H), 5.42 (d, *J* = 4.7 Hz, 1H), 4.62 (d, *J* = 12.1 Hz, 1H), 4.54 – 4.48 (m, 3H), 4.22 (q, *J* = 4.7 Hz, 1H), 4.08 (t, *J* = 5.0 Hz, 1H), 3.88 (t, *J* = 4.8 Hz, 1H), 3.69 (dd, *J* = 11.3, 4.1 Hz, 1H), 3.62 (dd, *J* = 11.2, 4.6 Hz, 1H), 2.33 (s, 1H), 2.31 (s, 3H), 1.03 (s, 9H), 0.96 (s, 2H).

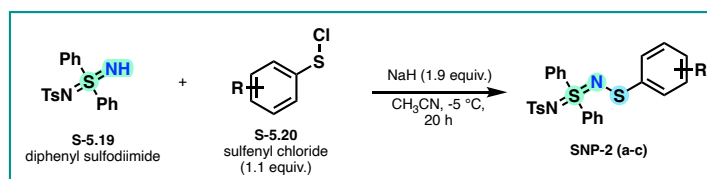
¹³C NMR (100 MHz, CDCl₃) δ 137.9, 137.8, 137.7, 135.9, 135.8, 135.7, 133.0, 131.4, 129.9, 129.9, 129.8, 129.8, 129.7, 128.5, 128.5, 128.2, 128.0, 127.9, 127.8, 88.9, 83.3, 80.5, 77.5, 77.2, 76.9, 76.8, 72.2, 72.2, 63.7, 27.0, 26.9, 21.3, 19.3

5.4.2. Synthetic procedures to access sulfenylnitrene precursors [SNP-1,2] are listed below



Note: SNP-1 was synthesized using literature reported protocol.^[19]

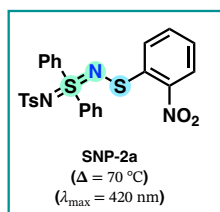
General procedure for the synthesis of sulfenylnitrene precursor-2 [SNP-1(a-c)]



To a solution of **S-5.19** (1.0 equiv) in CH₃CN (0.1 M), NaH (1.9 equiv.) was added at -5 °C, followed by the addition of sulfenyl chloride (1.1 equiv.). The resulting solution was

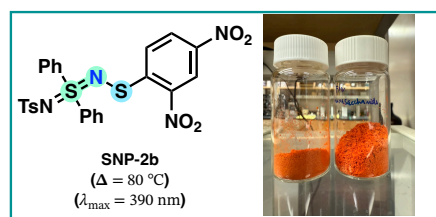
stirred at -5 °C for 20 hours until the compound **S-5.20** was completely consumed. The reaction mixture was diluted with dichloromethane and washed with aq. saturated NaHCO₃ (3X), water (2X), brine, and dried over Na₂SO₄. It was then concentrated under reduced pressure to obtain pure compound **SNP-2 (a-c)** as an orange to yellow solid. Crude sulfenylnitrene precursors were pure enough to use in the final glycosylation reactions.

Synthesis of SNP-2a



S-5.19 (0.2 g, 1.0 equiv.) was coupled with 2-nitrobenzene sulfenyl chloride (1.1 equiv.) according to the general procedure for the synthesis of SNP-2 and afforded **SNP-2a** (0.27 g, 96%). The data were consistent with the existing literature.^[19]

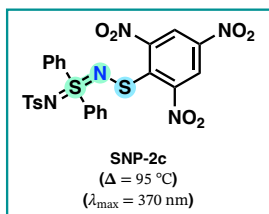
Synthesis of SNP-2b



S-5.19 (3.0 g, 1.0 equiv) was coupled with 2,4-dinitrobenzene sulfenyl chloride (1.1 equiv.) according to the general procedure for the synthesis of SNP-2 and afforded **SNP-2b** (4.1 g, 89%). The data were consistent with the existing literature.^[19]

Synthesis of SNP-2c

S-5.19 (0.1 g, 1.0 equiv) was coupled with 2,4,6-trinitrobenzene sulfenyl chloride^[76] (1.1 equiv.) according to the general procedure for the synthesis of SNP-2 and afforded **SNP-2c** (0.15 g, 91%).

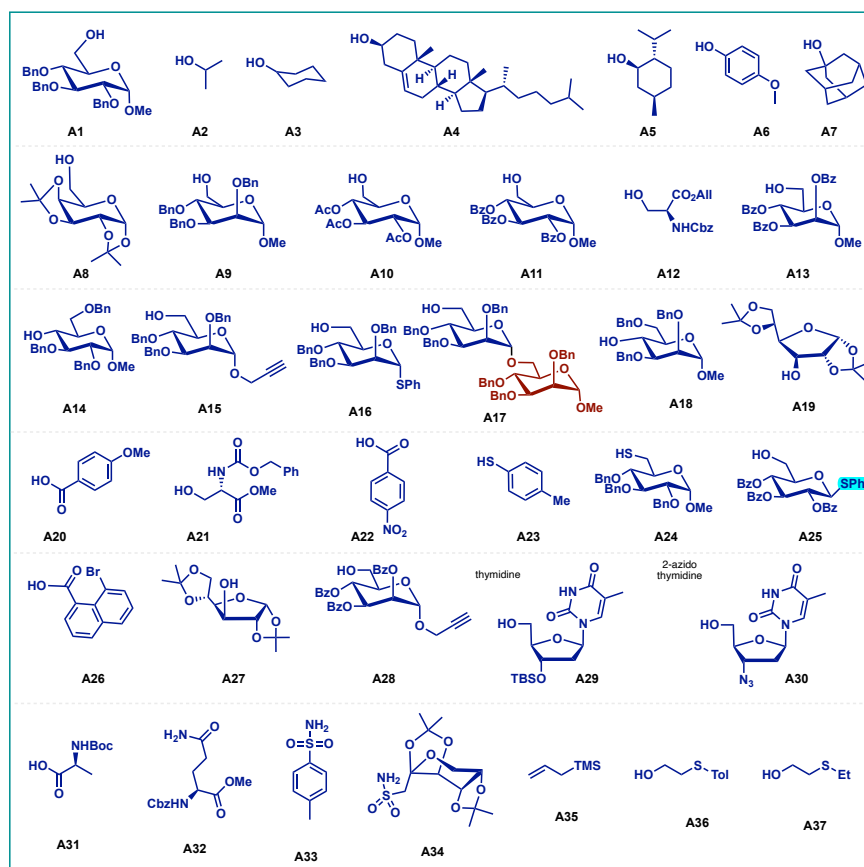


^1H NMR (400 MHz, CDCl_3) δ 8.59 (s, 2H), 7.90 (dd, $J = 7.7, 1.7\text{ Hz}$, 4H), 7.60 (dd, $J = 8.4, 6.5\text{ Hz}$, 2H), 7.51 (t, $J = 7.8\text{ Hz}$, 4H), 7.45 (d, $J = 8.2\text{ Hz}$, 2H), 7.03 (d, $J = 8.1\text{ Hz}$, 2H), 2.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) 146.0, 143.7, 139.1, 139.1, 138.9, 134.0, 129.9, 129.3, 127.4, 126.8, 122.7, 77.5, 77.2, 76.8, 21.5.

LRMS (ESI): calc. for $\text{C}_{25}\text{H}_{20}\text{O}_8\text{N}_5\text{S}_3$ ($\text{M}+\text{H}$): 614.1; found: 614.1.

5.4.3. List of acceptors used in this chapter

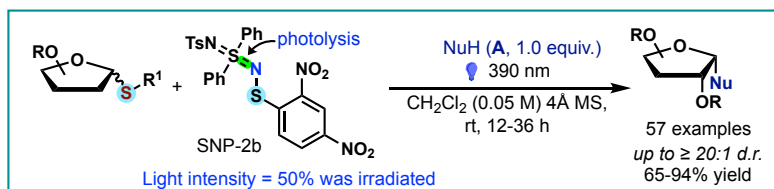


5.4.4. Screening of sulfenylnitrene precursors

S.No.	4.1a (z equiv.)	SNP	Δ	λ (% intensity)	solvent	time	4.2, yield, ($\alpha:\beta$)
1.	1.0	1	120 °C	-	PhCl	1 h	n.d.
2.	1.0	2a	70 °C	-	PhCl	1 h	8%, ($\alpha:\beta$ = n.d.)
3.	1.0	2b	80 °C	-	PhCl	1 h	6%, ($\alpha:\beta$ = n.d.)
4.	1.0	2c	95 °C	-	PhCl	1 h	n.d.
5.	1.0	2a	25 °C	440 nm (100%)	CH ₂ Cl ₂	12 h	48%, ($\alpha:\beta$ = 5:1)
6.	1.0	2b	25 °C	390 nm (100%)	CH ₂ Cl ₂	12 h	54%, ($\alpha:\beta$ = 5:1)
7.	1.0	2c	25 °C	390 nm (100%)	CH ₂ Cl ₂	36 h	19%, ($\alpha:\beta$ = 5:1)

Figure 5.4.4: Initial optimization of reaction conditions with sulfenylnitrene precursors.

5.4.5. General procedure A for 1,2-*cis* furanosylations

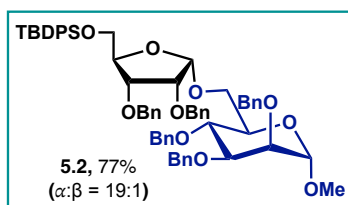


To a 4 ml screw-capped vial that contained a magnetic stir bar was sequentially added a conventional thioglycoside **4.1** and **5.1** (40.0 mmol, 1.4-1.5 equiv.), an acceptor **A** (25.0 mmol, 1.0 equiv.), **SNP-2b** (45.0 mmol, 1.8 equiv.), 4 Å molecular sieves (100 wt%) and CH₂Cl₂ (0.05M) under ambient conditions. The vial was tightly sealed with a Teflon-lined cap and allowed to stir for 10-36 h at room temperature, with irradiation from a 40 W, 390 nm blue LED (50-75% intensity) placed ~5 cm on the right side. Upon complete consumption of the nucleophile, the reaction mixture was then quenched by the addition of aq. sat. NaHCO₃. The organic layer was separated, and the aqueous layer was washed with ethyl acetate (2 times). The combined organic layers were dried over anhydrous Na₂SO₄ and filtered through a pad of cotton, and solvents were removed under reduced pressure. The residue was purified by silica gel chromatography to give the desired product.

5.4.6. Substrate Scope of 1,2-*cis* furanosylations

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-ribofuranosyl)- α -D-mannopyranoside (5.2)

Following the general procedure, **A**, glycosyl acceptor **A9** (12.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **4.1f** (24.0 mg, 36.0 μ mol) to afford **5.2** (20.0 mg, 19.7 μ mol, 77% yield, α : β = 19:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).



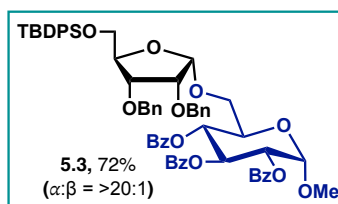
^1H NMR (400 MHz, CDCl_3) δ 7.67 – 7.62 (m, 2H), 7.62 – 7.58 (m, 2H), 7.41 – 7.27 (m, 18H), 7.25 – 7.18 (m, 13H), **5.30 (d, J = 3.8 Hz, 1H)**, 4.82 (d, J = 12.2 Hz, 1H), 4.77 (d, J = 10.7 Hz, 1H), 4.73 (q, J = 2.1 Hz, 2H), 4.70 – 4.57 (m, 7H), 4.44 (d, J = 12.0 Hz, 1H), 4.22 – 4.16 (m, 2H), 4.15 (d, J = 9.8 Hz, 1H), 4.06 (t, J = 5.3 Hz, 1H), 3.91 – 3.81 (m, 3H), 3.79 – 3.68 (m, 3H), 3.63 (dd, J = 11.2, 3.0 Hz, 1H), 3.26 (s, 3H), 0.97 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.9, 138.6, 138.6, 135.8, 135.7, 133.5, 133.4, 129.8, 129.8, 128.4, 128.4, 128.4, 128.2, 128.2, 128.0, 127.9, 127.8, 127.8, 127.7, 127.6, 127.6, 127.5, 127.5, 102.3, 99.3, 82.5, 80.3, 77.7, 77.5, 77.2, 76.8, 76.1, 75.2, 75.1, 75.0, 72.9, 72.7, 72.4, 72.3, 72.1, 66.7, 63.7, 54.8, 26.9, 19.4.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{70}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 1037.4636; found: 1037.4646.

Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-ribofuranosyl)- α -D-glucopyranoside (5.3)

Following the general procedure, **A**, glycosyl acceptor **A11** (12.0 mg, 24.0 μ mol) was coupled with thiofuranoside donor **4.1f** (20.0 mg, 33.0 μ mol) to afford **5.3** (18.0 mg, 17.1 μ mol, 72% yield, α : β = >20:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 80:20).



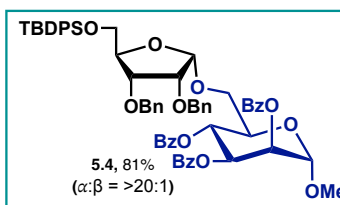
¹H NMR (400 MHz, CDCl₃) δ 7.99 – 7.95 (m, 2H), 7.94 – 7.91 (m, 2H), 7.86 – 7.83 (m, 2H), 7.57 (ddd, *J* = 9.9, 7.9, 1.5 Hz, 4H), 7.53 – 7.46 (m, 2H), 7.45 – 7.39 (m, 4H), 7.37 – 7.33 (m, 10H), 7.32 – 7.26 (m, 9H), 6.12 (t, *J* = 9.7 Hz, 1H), 5.48 (t, *J* = 9.9 Hz, 1H), 5.22 – 5.16 (m, 2H), **5.01 (d, *J* = 4.2 Hz, 1H)**, 4.62 (d, *J* = 16.9 Hz, 3H), 4.53 (d, *J* = 12.2 Hz, 1H), 4.35 – 4.30 (m, 1H), 4.26 (q, *J* = 3.3 Hz, 1H), 4.00 (dd, *J* = 6.4, 3.1 Hz, 1H), 3.94 (dd, *J* = 11.3, 6.8 Hz, 1H), 3.83 (dd, *J* = 6.5, 4.2 Hz, 1H), 3.78 (dd, *J* = 11.2, 2.0 Hz, 1H), 3.64 – 3.54 (m, 2H), 3.32 (s, 3H), 0.93 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 165.9, 165.4, 138.5, 138.1, 135.7, 135.6, 133.4, 133.3, 133.1, 133.1, 130.0, 129.9, 129.8, 129.8, 129.4, 129.3, 129.2, 128.5, 128.3, 128.0, 128.0, 127.9, 127.8, 127.8, 127.6, 101.6, 96.6, 83.4, 78.2, 77.4, 77.1, 76.8, 75.5, 72.6, 72.4, 72.4, 70.8, 69.9, 69.0, 66.8, 64.0, 55.5, 26.8, 19.3.

HRMS (ESI): calc. for C₆₃H₆₄O₁₃SiNa (M+Na): 1079.4014; found: 1079.4014.

Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)- α -D-mannopyranoside (5.4)

Following the general procedure, **A**, glycosyl acceptor **A13** (12.0 mg, 24.0 μ mol) was coupled with thiofuranoside donor **4.1f** (20.0 mg, 33.0 μ mol) to afford **5.4** (20.4 mg, 19.3 μ mol, 81% yield, α : β = >20:1) as a colorless viscous oil. *R*_f = 0.2 (hexane: EtOAc = 80:20).



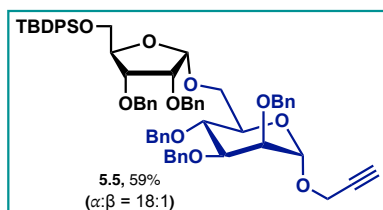
¹H NMR (400 MHz, CDCl₃) δ 8.09 – 8.06 (m, 2H), 7.98 – 7.94 (m, 2H), 7.84 – 7.80 (m, 2H), 7.59 – 7.53 (m, 5H), 7.49 (d, *J* = 7.4 Hz, 1H), 7.45 – 7.30 (m, 14H), 7.29 – 7.26 (m, 6H), 7.24 (dd, *J* = 7.3, 1.6 Hz, 3H), 5.84 (d, *J* = 3.4 Hz, 1H), 5.78 (d, *J* = 9.9 Hz, 1H), 5.63 (dd, *J* = 3.4, 1.7 Hz, 1H), **5.03 (d, *J* = 4.1 Hz, 1H)**, 4.91 (d, *J* = 1.7 Hz, 1H), 4.63 (s, 2H), 4.60 (d, *J* = 12.2 Hz, 1H), 4.50 (d, *J* = 12.1 Hz, 1H), 4.37 (ddd, *J* = 9.6, 7.4, 1.9 Hz, 1H), 4.25 (q, *J* = 3.3 Hz, 1H), 4.05 – 3.98 (m, 2H), 3.81 (dt, *J* = 10.2, 3.0 Hz, 2H), 3.60 (qd, *J* = 11.2, 3.4 Hz, 2H), 3.37 (s, 3H), 0.92 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.8, 165.6, 138.5, 138.1, 135.7, 135.7, 133.5, 133.5, 133.4, 133.2, 130.1, 130.0, 129.9, 129.8, 129.5, 129.3, 129.3, 128.7, 128.5, 128.5, 128.4, 128.4, 128.1, 128.0, 127.9, 127.8, 127.8, 127.6, 101.7, 98.3, 83.4, 78.1, 77.5, 77.2, 76.8, 75.5, 72.7, 72.4, 70.8, 70.4, 70.2, 67.8, 67.5, 64.0, 55.4, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{64}\text{O}_{13}\text{SiNa}$ ($\text{M}+\text{Na}$): 1079.4014; found: 1079.4031.

Propargyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)- α -D-mannopyranoside (5.5)

Following the general procedure, **A**, glycosyl acceptor **A15** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1f** (21.0 mg, 33.0 μmol) to afford **5.5** (15.0 mg, 14.5 μmol , 59% yield, $\alpha:\beta = 18:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).



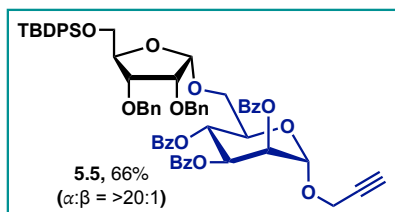
^1H NMR (400 MHz, CDCl_3) δ 7.65 – 7.61 (m, 2H), 7.60 – 7.57 (m, 2H), 7.42 – 7.35 (m, 6H), 7.32 (ddd, $J = 14.0, 7.8, 2.9$ Hz, 1H), 7.25 – 7.19 (m, 14H), **5.25 (d, $J = 3.9$ Hz, 1H)**, 5.04 (d, $J = 1.8$ Hz, 1H), 4.78 (dd, $J = 11.5, 6.6$ Hz, 2H), 4.74 – 4.56 (m, 8H), 4.46 (d, $J = 12.1$ Hz, 1H), 4.21 (t, $J = 3.6$ Hz, 1H), 4.16 (dt, $J = 4.7, 2.3$ Hz, 2H), 4.12 (dt, $J = 7.3, 3.4$ Hz, 2H), 4.05 (dd, $J = 6.0, 4.3$ Hz, 1H), 3.90 – 3.82 (m, 4H), 3.78 (dd, $J = 10.5, 4.0$ Hz, 1H), 3.69 (dd, $J = 11.2, 3.5$ Hz, 1H), 3.62 (dd, $J = 11.2, 3.0$ Hz, 1H), 2.35 (t, $J = 2.4$ Hz, 1H), 0.96 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.9, 138.6, 138.5, 138.4, 135.8, 135.7, 133.3, 129.8, 129.8, 128.4, 128.4, 128.2, 128.2, 128.0, 128.0, 127.8, 127.8, 127.7, 127.6, 127.6, 127.5, 102.2, 96.7, 82.7, 80.2, 79.2, 77.8, 77.5, 77.2, 76.8, 76.0, 75.3, 75.0, 74.7, 73.0, 72.6, 72.4, 72.3, 66.7, 63.8, 54.1, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{65}\text{H}_{70}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 1061.4636; found: 1061.4645.

Propargyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)- α -D-mannopyranoside (5.6)

Following the general procedure, **A**, glycosyl acceptor **A28** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1f** (21.0 mg, 33.0 μmol) to afford **5.6** (16.0 mg, 14.8 μmol , 66% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).



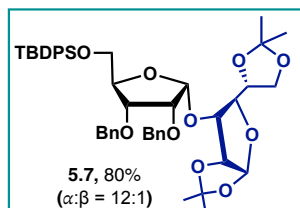
^1H NMR (400 MHz, CDCl_3) δ 8.10 – 8.06 (m, 2H), 7.98 – 7.94 (m, 2H), 7.82 – 7.78 (m, 2H), 7.54 (ddd, $J = 15.3, 7.5, 6.0$ Hz, 6H), 7.47 (d, $J = 10.0$ Hz, 1H), 7.45 – 7.38 (m, 5H), 7.37 – 7.27 (m, 14H), 7.23 (d, $J = 7.9$ Hz, 3H), 5.85 (dd, $J = 10.0, 3.5$ Hz, 1H), 5.74 (t, $J = 10.1$ Hz, 1H), 5.69 (dd, $J = 3.5, 1.7$ Hz, 1H), 5.28 (d, $J = 1.7$ Hz, 1H), **4.98 (d, $J = 4.1$ Hz, 1H)**, 4.63 (dd, $J = 12.1, 7.7$ Hz, 3H), 4.56 (d, $J = 12.3$ Hz, 1H), 4.43 – 4.34 (m, 2H), 4.28 – 4.20 (m, 2H), 4.01 – 3.95 (m, 2H), 3.84 – 3.77 (m, 2H), 3.58 (qd, $J = 11.2, 3.3$ Hz, 2H), 2.39 (t, $J = 2.4$ Hz, 1H), 0.91 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.8, 165.7, 165.5, 138.5, 138.0, 135.7, 135.7, 133.6, 133.3, 133.2, 133.2, 130.1, 130.0, 129.9, 129.8, 129.5, 129.3, 129.1, 128.7, 128.6, 128.5, 128.4, 128.4, 128.2, 128.1, 127.9, 127.8, 127.8, 127.7, 101.7, 95.2, 83.7, 78.6, 78.2, 77.5, 77.2, 76.8, 75.7, 75.2, 72.7, 72.5, 70.8, 70.6, 70.3, 67.6, 64.1, 54.3, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{65}\text{H}_{64}\text{O}_{13}\text{SiNa}$ ($\text{M}+\text{Na}$): 1103.4014; found: 1103.4027.

1,2:5,6-bis-*O*-(1-methylethylidene)-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl)- α -D-ribofuranosyl)- α -D-allofuranoside (**5.7**)

Following the general procedure, **A**, glycosyl acceptor **A19** (7.0 mg, 27.0 μmol) was coupled with thiofuranoside donor **4.1f** (23.0 mg, 38.0 μmol) to afford **5.7** (17.5 mg, 21.6 μmol , 80% yield, $\alpha:\beta = 12:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).



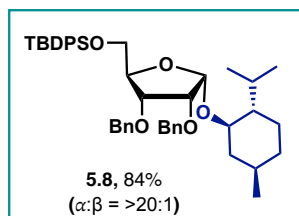
¹H NMR (400 MHz, CDCl₃) δ 7.58 (d, *J* = 1.5 Hz, 1H), 7.56 (d, *J* = 1.5 Hz, 1H), 7.54 (d, *J* = 1.4 Hz, 1H), 7.52 (d, *J* = 1.5 Hz, 1H), 7.42 – 7.39 (m, 4H), 7.35 (d, *J* = 1.3 Hz, 2H), 7.34 – 7.32 (m, 6H), 7.31 – 7.30 (m, 1H), 7.30 – 7.26 (m, 3H), **5.89 (d, *J* = 3.9 Hz, 1H)**, **5.27 (d, *J* = 4.2 Hz, 1H)**, 4.88 (d, *J* = 12.4 Hz, 1H), 4.80 (t, *J* = 4.4 Hz, 1H), 4.71 (d, *J* = 7.9 Hz, 1H), 4.68 (d, *J* = 7.9 Hz, 1H), 4.58 (d, *J* = 12.4 Hz, 1H), 4.50 (td, *J* = 7.2, 2.0 Hz, 1H), 4.44 (dd, *J* = 8.8, 4.8 Hz, 1H), 4.37 – 4.28 (m, 2H), 4.26 (dd, *J* = 8.8, 2.0 Hz, 1H), 4.01 (dd, *J* = 6.6, 2.5 Hz, 1H), 3.90 – 3.80 (m, 2H), 3.61 (dd, *J* = 11.2, 3.4 Hz, 1H), 3.52 (dd, *J* = 11.2, 3.2 Hz, 1H), 1.53 (s, 3H), 1.41 (s, 3H), 1.39 (s, 3H), 1.33 (s, 3H), 0.90 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 138.5, 138.4, 135.8, 135.7, 135.7, 135.7, 133.2, 133.2, 129.9, 129.8, 128.6, 128.5, 128.5, 128.3, 128.1, 127.9, 127.9, 127.8, 127.6, 112.9, 109.5, 104.6, 98.5, 83.9, 78.3, 78.1, 77.5, 77.2, 76.8, 75.8, 74.0, 72.4, 71.8, 71.5, 64.1, 27.0, 27.0, 26.8, 26.1, 25.0, 19.3.

HRMS (ESI): calc. for C₄₇H₅₈O₁₀SiNa (M+Na): 833.3697; found: 833.3691.

1-*l*-Menthyl 2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.8**)

Following the general procedure, **A**, glycosyl acceptor (menthol) **A5** (5.0 mg, 32.0 μ mol) was coupled with thiofuranoside donor **4.1f** (28.0 mg, 45.0 μ mol) to afford **5.8** (19.0 mg, 27.0 μ mol, 84% yield, α : β = >20:1) as a colorless viscous oil. *R*_f = 0.6 (hexane: EtOAc = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 7.64 – 7.60 (m, 2H), 7.59 – 7.56 (m, 2H), 7.44 – 7.39 (m, 2H), 7.36 (dt, *J* = 7.4, 1.2 Hz, 5H), 7.33 (dt, *J* = 5.1, 2.0 Hz, 2H), 7.31 – 7.27 (m, 5H), **5.15 (d, *J* = 4.1 Hz, 1H)**, 4.74 – 4.62 (m, 3H), 4.53 (d, *J* = 12.8 Hz, 1H), 4.20 (q, *J* = 3.6 Hz, 1H), 3.95 (dd, *J* = 6.4, 3.8 Hz, 1H), 3.79 (dd, *J* = 6.5, 4.1 Hz, 1H), 3.65 (dd, *J* = 11.1, 3.6 Hz, 1H), 3.56 (dd, *J* = 11.1, 3.7 Hz, 1H), 3.37 (td, *J* = 10.6, 4.4 Hz, 1H), 2.37 (qt, *J* = 7.0, 3.5 Hz, 1H), 2.17 (dd, *J* = 12.2, 4.6 Hz, 1H), 1.63 (ddt, *J* = 8.1, 5.7, 2.9 Hz, 3H), 1.47 –

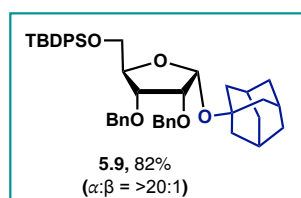
1.37 (m, 2H), 1.23 – 1.16 (m, 1H), 0.96 (s, 9H), 0.90 (dd, $J = 6.8, 2.4$ Hz, 7H), 0.78 (d, $J = 7.0$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.7, 138.4, 135.8, 135.7, 133.4, 133.3, 129.8, 129.8, 128.4, 128.4, 128.3, 128.0, 127.8, 127.8, 127.7, 127.6, 102.7, 82.7, 80.1, 78.1, 77.5, 77.2, 76.8, 75.4, 72.5, 72.2, 64.2, 48.2, 43.3, 34.5, 32.0, 26.9, 25.1, 23.0, 22.5, 21.3, 19.3, 16.1.

HRMS (ESI): calc. for $\text{C}_{45}\text{H}_{58}\text{O}_5\text{SiNa}$ ($\text{M}+\text{Na}$): 729.3951; found: 729.3952.

1-Adamantyl 2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.9**)

Following the general procedure, **A**, glycosyl acceptor (1-adamantanol) **A7** (5.0 mg, 33.0 μmol) was coupled with thiofuranoside donor **4.1f** (28.0 mg, 46.0 μmol) to afford **5.9** (19.0 mg, 27.0 μmol , 82% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.6$ (hexane: EtOAc = 80:20).



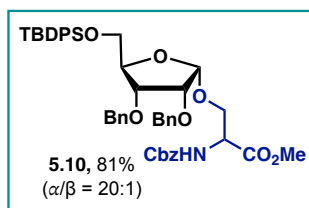
^1H NMR (400 MHz, CDCl_3) δ 7.68 – 7.65 (m, 2H), 7.63 – 7.60 (m, 2H), 7.44 – 7.38 (m, 4H), 7.36 (dd, $J = 7.0, 1.1$ Hz, 3H), 7.34 – 7.27 (m, 9H), **5.45 (d, $J = 3.6$ Hz, 1H)**, 4.86 (d, $J = 12.4$ Hz, 1H), 4.69 (d, $J = 4.5$ Hz, 1H), 4.66 (d, $J = 4.7$ Hz, 1H), 4.47 (d, $J = 12.5$ Hz, 1H), 4.25 (dt, $J = 6.0, 3.1$ Hz, 1H), 4.07 (t, $J = 5.7$ Hz, 1H), 3.80 – 3.72 (m, 2H), 3.61 (dd, $J = 11.2, 3.1$ Hz, 1H), 2.18 – 2.13 (m, 3H), 1.91 (dt, $J = 14.7, 11.5$ Hz, 6H), 1.63 (d, $J = 3.1$ Hz, 6H), 0.96 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.7, 138.6, 135.8, 135.7, 133.6, 133.5, 129.8, 129.7, 128.4, 128.4, 128.2, 127.9, 127.8, 127.7, 127.6, 95.5, 81.4, 77.5, 77.2, 77.0, 76.8, 75.7, 74.4, 72.6, 72.1, 63.6, 42.7, 36.5, 30.8, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{45}\text{H}_{54}\text{O}_5\text{SiNa}$ ($\text{M}+\text{Na}$): 725.3638; found: 725.3632.

N-Benzyloxycarbonyl-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-*L*-serine methyl ester (**5.10**)

Following the general procedure, **A**, glycosyl acceptor (Z-L-serine-OMe) **A21** (7.0 mg, 27.7 μ mol) was coupled with thiofuranoside donor **4.1f** (24.0 mg, 38.7 μ mol) to afford **5.10** (18.0 mg, 22.4 μ mol, 81% yield, α : β = 20:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 75:25).



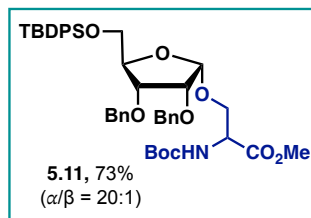
^1H NMR (400 MHz, CDCl_3) δ 7.58 (d, J = 1.5 Hz, 1H), 7.56 (d, J = 1.5 Hz, 1H), 7.55 (t, J = 1.4 Hz, 1H), 7.53 (d, J = 1.5 Hz, 1H), 7.43 – 7.36 (m, 3H), 7.35 (d, J = 1.4 Hz, 2H), 7.33 – 7.30 (m, 6H), 7.28 (d, J = 7.6 Hz, 7H), 7.24 (d, J = 6.3 Hz, 3H), 6.38 (d, J = 9.0 Hz, 1H), 5.10 (d, J = 12.4 Hz, 1H), 5.03 (d, J = 12.4 Hz, 1H), 4.95 (d, J = 4.1 Hz, 1H), 4.65 (d, J = 12.3 Hz, 1H), 4.58 (s, 2H), 4.55 – 4.50 (m, 2H), 4.15 (dd, J = 10.5, 3.2 Hz, 2H), 3.99 (dd, J = 6.2, 2.4 Hz, 1H), 3.92 – 3.85 (m, 2H), 3.67 (s, 3H), 3.60 (dd, J = 11.3, 3.5 Hz, 1H), 3.49 (dd, J = 11.3, 3.0 Hz, 1H), 0.94 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.1, 156.5, 138.3, 137.9, 136.6, 135.7, 135.6, 133.2, 132.9, 129.9, 129.9, 128.5, 128.5, 128.4, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.6, 101.2, 84.1, 78.8, 77.4, 77.1, 76.8, 75.5, 72.6, 72.5, 68.1, 66.9, 64.0, 54.6, 52.5, 26.8, 19.2.

HRMS (ESI): calc. for $\text{C}_{47}\text{H}_{53}\text{O}_9\text{SiNNa}$ ($\text{M}+\text{Na}$): 826.3387; found: 826.3393.

N-tert-Butoxycarbonyl-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-L-serine methyl ester (5.11)

Following the general procedure, **A**, glycosyl acceptor (Boc-L-serine-OMe) (7.0 mg, 32.0 μ mol) was coupled with thiofuranoside donor **4.1f** (27.40 mg, 44.7 μ mol) to afford **5.11** (18.0 mg, 23.4 μ mol, 73% yield, α : β = 20:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 75:25).



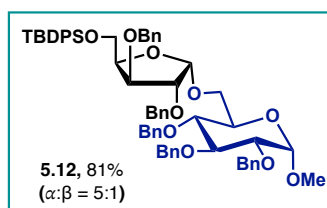
^1H NMR (400 MHz, CDCl_3) δ 7.61 – 7.53 (m, 4H), 7.46 – 7.39 (m, 2H), 7.33 (tdd, J = 12.7, 6.2, 2.0 Hz, 14H), 6.05 (d, J = 9.1 Hz, 1H), 4.94 (d, J = 4.1 Hz, 1H), 4.70 (d, J = 12.3 Hz, 1H), 4.63 – 4.54 (m, 3H), 4.49 – 4.44 (m, 1H), 4.17 (q, J = 3.1 Hz, 1H), 4.12 (dd, J = 10.5, 3.3 Hz, 1H), 4.00 (dd, J = 6.2, 2.5 Hz, 1H), 3.91 – 3.84 (m, 2H), 3.67 (s, 3H), 3.62 (dd, J = 11.2, 3.5 Hz, 1H), 3.52 (dd, J = 11.2, 3.0 Hz, 1H), 1.39 (s, 9H), 0.94 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 171.5, 156.1, 138.4, 137.9, 135.7, 135.7, 133.2, 133.1, 129.9, 129.9, 128.6, 128.5, 128.1, 128.0, 127.9, 127.9, 127.7, 101.3, 83.9, 79.7, 78.7, 77.5, 77.2, 76.8, 75.6, 72.6, 68.2, 64.0, 54.2, 52.5, 28.5, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{44}\text{H}_{55}\text{O}_9\text{SiNa}$ ($\text{M}+\text{Na}$): 792.3544; found: 792.3538.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.12)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **5.1a** (22.0 mg, 36.0 μmol) to afford **5.12** (21.2 mg, 20.88 μmol , 81% yield, $\alpha:\beta$ = 5:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).



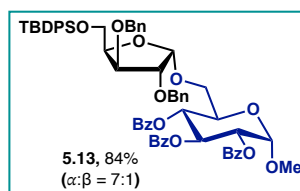
^1H NMR (400 MHz, CDCl_3) δ 7.68 – 7.62 (m, 5H), 7.39 – 7.27 (m, 25H), 7.25 – 7.20 (m, 8H), **5.11** (d, J = 4.4 Hz, 1H), 4.97 (d, J = 11.0 Hz, 1H), 4.85 – 4.80 (m, 2H), 4.75 (d, J = 12.1 Hz, 1H), 4.69 – 4.63 (m, 4H), 4.61 – 4.57 (m, 1H), 4.56 – 4.49 (m, 4H), 4.32 – 4.28 (m, 1H), 4.27 – 4.22 (m, 1H), 4.16 (dd, J = 5.9, 4.3 Hz, 1H), 4.06 (dd, J = 11.2, 3.8 Hz, 2H), 4.00 – 3.94 (m, 2H), 3.83 (dd, J = 10.8, 4.6 Hz, 1H), 3.75 (dq, J = 7.7, 3.9 Hz, 3H),

3.70 – 3.64 (m, 2H), 3.45 (dd, $J = 9.7, 3.5$ Hz, 1H), 3.35 (s, 3H), 3.25 (s, 1H), 1.03 (s, 2H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.1, 138.5, 138.4, 138.3, 138.3, 135.8, 135.8, 135.8, 135.7, 133.6, 133.5, 129.7, 129.6, 128.6, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.7, 127.6, 107.6, 100.7, 98.2, 97.9, 83.2, 82.1, 81.5, 80.1, 78.2, 77.9, 77.4, 77.2, 76.9, 73.6, 73.5, 72.8, 72.3, 72.3, 72.1, 70.3, 70.1, 67.1, 66.7, 62.7, 55.2, 55.1, 26.9, 19.2.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{70}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 1037.4636; found: 1037.4631.

Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.13)



Following the general procedure, **A**, glycosyl acceptor **A11** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **5.1a** (20.0 mg, 33.0 μmol) to afford **5.13** (21.0 mg, 19.9 μmol , 84% yield, $\alpha:\beta = 7:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

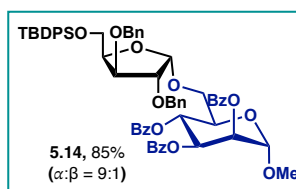
^1H NMR (400 MHz, CDCl_3) δ 8.01 – 7.97 (m, 2H), 7.95 – 7.91 (m, 2H), 7.88 (dt, $J = 8.5, 2.3$ Hz, 3H), 7.67 – 7.60 (m, 5H), 7.54 – 7.44 (m, 3H), 7.43 – 7.27 (m, 25H), 7.24 (d, $J = 7.6$ Hz, 3H), 6.17 – 6.11 (m, 1H), 5.66 (t, $J = 9.9$ Hz, 1H), 5.26 – 5.20 (m, 2H), **4.95 (d, $J = 4.2$ Hz, 1H)**, 4.67 (t, $J = 11.2$ Hz, 2H), 4.60 – 4.52 (m, 3H), 4.39 (t, $J = 6.8$ Hz, 1H), 4.27 – 4.11 (m, 4H), 3.97 – 3.91 (m, 1H), 3.73 (qd, $J = 11.0, 4.4$ Hz, 2H), 3.63 (dd, $J = 11.3, 2.3$ Hz, 1H), 3.43 (s, 3H), 1.02 (s, 1H), 0.97 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.0, 166.0, 165.2, 138.6, 138.2, 135.8, 135.8, 135.8, 135.7, 133.6, 133.5, 133.5, 133.4, 133.2, 130.1, 130.0, 129.9, 129.9, 129.8, 129.6, 129.6, 129.5, 129.3, 129.3, 128.6, 128.5, 128.5, 128.5, 128.4, 128.2, 128.0, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 99.8, 97.0, 83.4, 81.4, 77.4, 77.2, 76.9, 73.0, 72.6, 72.4, 70.9, 69.4, 68.9, 66.0, 62.8, 55.7, 55.4, 26.9, 26.8, 19.3, 19.2.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{64}\text{O}_{13}\text{SiNa}$ ($\text{M}+\text{Na}$): 1079.4014; found: 1079.4014.

Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-mannopyranoside (5.14)

Following the general procedure, **A**, glycosyl acceptor **A13** (12.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **5.1a** (22.0 mg, 36.0 μ mol) to afford **5.14** (21.3 mg, 20.2 μ mol, 85% yield, α : β = 9:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).



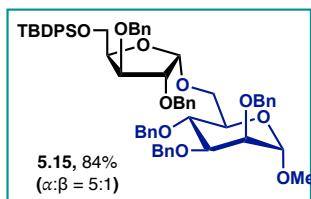
^1H NMR (400 MHz, CDCl_3) δ 8.13 – 8.08 (m, 2H), 7.95 (dd, J = 8.3, 1.4 Hz, 2H), 7.85 – 7.80 (m, 2H), 7.62 (ddd, J = 7.2, 5.1, 1.4 Hz, 4H), 7.55 – 7.46 (m, 2H), 7.35 (ddd, J = 32.0, 15.8, 7.5 Hz, 18H), 7.24 – 7.20 (m, 5H), 5.97 (t, J = 10.0 Hz, 1H), 5.86 (dd, J = 10.1, 3.3 Hz, 1H), 5.68 (dd, J = 3.4, 1.8 Hz, 1H), 4.98 (d, J = 1.8 Hz, 1H), **4.94 (d, J = 4.2 Hz, 1H)**, 4.66 (d, J = 11.8 Hz, 1H), 4.62 (d, J = 12.0 Hz, 1H), 4.54 (dd, J = 11.9, 2.4 Hz, 2H), 4.39 (t, J = 6.8 Hz, 1H), 4.27 (ddt, J = 15.4, 7.4, 3.2 Hz, 2H), 4.14 (dd, J = 6.6, 4.2 Hz, 1H), 4.00 (dd, J = 11.1, 5.5 Hz, 1H), 3.77 (dd, J = 11.0, 4.4 Hz, 1H), 3.72 – 3.63 (m, 2H), 3.49 (s, 3H), 0.95 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.8, 165.7, 165.5, 138.6, 138.2, 135.8, 135.8, 133.6, 133.5, 133.4, 133.2, 130.2, 129.9, 129.9, 129.6, 129.6, 129.5, 129.4, 129.3, 128.7, 128.6, 128.4, 128.4, 128.2, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 99.8, 98.7, 83.3, 81.5, 77.4, 77.2, 76.9, 73.0, 72.6, 70.6, 70.5, 70.0, 67.3, 66.5, 62.8, 55.5, 26.8, 19.2.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{64}\text{O}_{13}\text{SiNa}$ ($\text{M}+\text{Na}$): 1079.4014; found: 1079.4013.

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-mannopyranoside (5.15)

Following the general procedure, **A**, glycosyl acceptor **A9** (12.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **5.1a** (22.0 mg, 36.0 μ mol) to afford **5.15** (22.0 mg, 21.7 μ mol, 84% yield, α : β = 7:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 70:30).



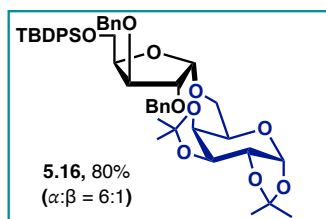
^1H NMR (400 MHz, CDCl_3) δ 7.69 – 7.62 (m, 6H), 7.32 (qd, J = 9.7, 4.6 Hz, 22H), 7.24 – 7.17 (m, 14H), **5.28 (d, J = 4.2 Hz, 1H)**, 4.85 (t, J = 11.2 Hz, 1H), 4.74 – 4.68 (m, 3H), 4.67 – 4.55 (m, 8H), 4.47 (dd, J = 16.8, 12.0 Hz, 3H), 4.29 (t, J = 4.1 Hz, 2H), 4.11 – 4.01 (m, 4H), 3.85 (td, J = 10.5, 6.8 Hz, 4H), 3.79 – 3.67 (m, 5H), 3.26 (s, 3H), 3.15 (s, 1H), 1.01 (s, 2H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.8, 138.5, 138.4, 135.8, 135.8, 135.7, 133.7, 133.6, 129.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.7, 127.7, 127.7, 127.6, 127.6, 100.5, 99.1, 98.8, 83.2, 81.7, 81.4, 80.2, 77.5, 77.2, 76.8, 75.3, 75.0, 74.9, 72.9, 72.7, 72.6, 72.4, 72.2, 72.1, 66.3, 62.7, 54.8, 26.9, 26.9, 19.3, 19.3.

HRMS (ESI): calc. for $\text{C}_{63}\text{H}_{70}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 1037.4636; found: 1037.4635.

1,2:3,4-bis-*O*-isopropylidene-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-galactopyranoside (5.16**)**

Following the general procedure, **A**, glycosyl acceptor **A8** (8.0 mg, 31.0 μmol) was coupled with thiofuranoside donor **5.1a** (26.0 mg, 43.0 μmol) to afford **5.16** (20.0 mg, 24.7 μmol , 80% yield, $\alpha:\beta$ = 6:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).



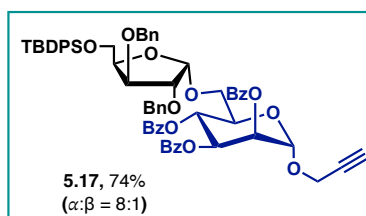
^1H NMR (400 MHz, CDCl_3) δ 7.69 – 7.64 (m, 5H), 7.39 – 7.32 (m, 9H), 7.32 – 7.27 (m, 7H), 7.24 (d, J = 2.6 Hz, 2H), **5.54 (d, J = 5.0 Hz, 1H)**, **5.10 (d, J = 4.4 Hz, 1H)**, 4.70 (dd, J = 16.3, 11.9 Hz, 2H), 4.56 (td, J = 11.8, 7.3 Hz, 4H), 4.35 – 4.26 (m, 4H), 4.17 (dd, J = 6.0, 4.4 Hz, 1H), 4.10 – 4.05 (m, 1H), 3.93 – 3.81 (m, 3H), 3.73 (ddd, J = 21.5, 10.5, 6.3

Hz, 2H), 1.52 (s, 3H), 1.47 (s, 3H), 1.41 (s, 1H), 1.32 (d, $J = 3.3$ Hz, 6H), 1.03 (s, 2H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.5, 138.1, 135.8, 135.8, 135.8, 133.7, 133.5, 129.7, 129.7, 128.5, 128.4, 128.1, 128.0, 127.9, 127.9, 127.8, 127.7, 127.6, 127.6, 109.2, 108.7, 100.1, 96.5, 83.5, 81.5, 77.7, 77.5, 77.2, 76.8, 72.7, 72.2, 70.9, 70.8, 70.7, 66.2, 65.7, 62.8, 26.9, 26.9, 26.2, 26.2, 25.1, 24.7, 19.2.

HRMS (ESI): calc. for $\text{C}_{47}\text{H}_{58}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 833.3697; found: 833.3696.

Propargyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-mannopyranoside (5.17)



Following the general procedure, **A**, glycosyl acceptor **A28** (14.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1a** (23.0 mg, 37.0 μmol) to afford **5.17** (21.0 mg, 19.5 μmol , 74% yield, $\alpha:\beta = 8:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).

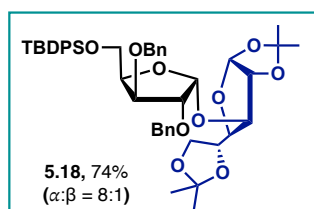
^1H NMR (400 MHz, CDCl_3) δ 8.13 – 8.09 (m, 2H), 7.96 – 7.93 (m, 2H), 7.84 – 7.80 (m, 2H), 7.61 (td, $J = 6.4, 3.1$ Hz, 4H), 7.56 – 7.46 (m, 3H), 7.41 (q, $J = 7.7$ Hz, 4H), 7.35 (d, $J = 7.9$ Hz, 4H), 7.32 (d, $J = 2.5$ Hz, 4H), 7.31 – 7.27 (m, 6H), 7.23 (d, $J = 7.0$ Hz, 4H), 5.98 (t, $J = 10.1$ Hz, 1H), 5.87 (dd, $J = 10.1, 3.3$ Hz, 1H), 5.73 (dd, $J = 3.4, 1.8$ Hz, 1H), 5.31 (d, $J = 1.8$ Hz, 1H), 4.91 (d, $J = 4.2$ Hz, 1H), 4.68 (d, $J = 11.8$ Hz, 1H), 4.62 (d, $J = 12.1$ Hz, 1H), 4.55 (dd, $J = 11.9, 4.9$ Hz, 2H), 4.41 (d, $J = 6.8$ Hz, 1H), 4.38 (t, $J = 2.1$ Hz, 2H), 4.33 – 4.28 (m, 1H), 4.27 – 4.22 (m, 1H), 4.15 (dd, $J = 6.7, 4.2$ Hz, 1H), 3.99 (dd, $J = 11.1, 5.4$ Hz, 1H), 3.76 (dd, $J = 11.0, 4.3$ Hz, 1H), 3.69 (dd, $J = 11.0, 4.3$ Hz, 1H), 3.63 (dd, $J = 11.1, 2.2$ Hz, 1H), 2.49 (t, $J = 2.4$ Hz, 1H), 0.95 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.6, 165.5, 138.6, 138.2, 135.8, 135.8, 133.6, 133.6, 133.5, 133.5, 133.2, 130.2, 129.9, 129.6, 129.6, 129.4, 129.3, 129.3, 128.7, 128.6, 128.4, 128.3, 127.8, 127.8, 127.7, 127.7, 127.6, 99.8, 96.1, 83.3, 81.5, 78.4, 77.5, 77.2, 76.8, 75.8, 73.0, 72.6, 70.7, 70.4, 70.4, 67.2, 66.3, 62.8, 54.9, 26.8, 19.2.

HRMS (ESI): calc. for C₆₅H₆₄O₁₃SiNa (M+Na): 1103.4014; found: 1103.4004.

1,2:5,6-bis-O-(1-methylethylidene)-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-glucofuranoside (5.18)

Following the general procedure, **A**, glycosyl acceptor **A27** (7.0 mg, 27.0 μ mol) was coupled with thiofuranoside donor **5.1a** (23.0 mg, 38.0 μ mol) to afford **5.18** (17.0 mg, 21.0 μ mol, 78% yield, α : β = 8:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 75:25).

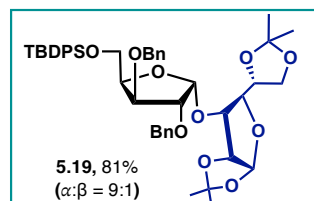


¹H NMR (400 MHz, CDCl₃) δ 7.67 (td, J = 7.7, 1.5 Hz, 4H), 7.42 – 7.33 (m, 8H), 7.31 (s, 6H), 7.20 (dd, J = 6.9, 2.5 Hz, 2H), **5.88 (d, J = 3.5 Hz, 1H)**, **5.26 (d, J = 4.4 Hz, 1H)**, 4.77 – 4.73 (m, 2H), 4.64 (d, J = 11.8 Hz, 1H), 4.51 (t, J = 11.6 Hz, 2H), 4.35 (dd, J = 9.5, 4.3 Hz, 1H), 4.27 (d, J = 5.2 Hz, 2H), 4.21 (d, J = 3.0 Hz, 1H), 4.16 – 4.10 (m, 2H), 4.04 (qd, J = 8.8, 5.5 Hz, 2H), 3.85 (dd, J = 11.2, 3.2 Hz, 1H), 3.79 (dd, J = 11.3, 4.3 Hz, 1H), 1.51 (s, 3H), 1.43 (s, 3H), 1.30 (s, 3H), 1.24 (s, 3H), 1.00 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 138.3, 138.0, 135.8, 135.8, 133.6, 133.4, 129.8, 129.7, 128.6, 128.4, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 112.0, 109.2, 105.5, 101.4, 84.1, 83.6, 81.8, 81.4, 81.3, 78.0, 77.5, 77.2, 76.8, 72.7, 72.6, 72.3, 67.5, 62.9, 27.1, 26.9, 26.5, 25.5, 19.2.

HRMS (ESI): calc. for C₄₇H₅₈O₁₀SiNa (M+Na): 833.3697; found: 833.3698.

1,2:5,6-bis-O-(1-methylethylidene)-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl)- α -D-xylofuranosyl)- α -D-allofuranoside (5.19)



Following the general procedure, **A**, glycosyl acceptor **A19** (7.0 mg, 27.0 μmol) was coupled with thiofuranoside donor **5.1a** (23.0 mg, 38.0 μmol) to afford **5.19** (17.7 mg, 21.8 μmol , 81% yield, $\alpha:\beta = 9:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).

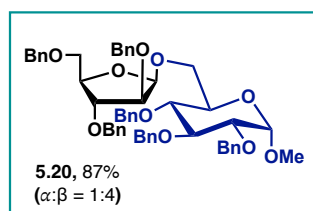
^1H NMR (400 MHz, CDCl_3) δ 7.68 – 7.63 (m, 5H), 7.40 – 7.37 (m, 4H), 7.36 – 7.32 (m, 5H), 7.32 – 7.29 (m, 3H), 7.23 (dt, $J = 6.8, 3.5$ Hz, 3H), **5.88 (d, $J = 3.9$ Hz, 1H)**, **5.25 (d, $J = 4.3$ Hz, 1H)**, 4.83 – 4.77 (m, 2H), 4.71 (d, $J = 11.8$ Hz, 1H), 4.56 (d, $J = 11.6$ Hz, 2H), 4.51 (d, $J = 3.6$ Hz, 1H), 4.44 (ddd, $J = 18.4, 7.7, 3.5$ Hz, 2H), 4.38 – 4.31 (m, 2H), 4.22 – 4.15 (m, 2H), 4.07 – 4.00 (m, 2H), 3.84 (dd, $J = 11.1, 4.1$ Hz, 1H), 3.74 (dd, $J = 11.1, 4.8$ Hz, 1H), 1.52 (s, 3H), 1.44 (s, 3H), 1.38 (s, 3H), 1.35 (s, 3H), 0.98 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.4, 138.3, 135.8, 135.8, 135.7, 133.7, 133.5, 129.7, 129.6, 128.5, 128.4, 128.1, 128.0, 127.9, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 112.9, 109.9, 104.5, 97.0, 83.2, 81.4, 78.2, 78.0, 77.5, 77.2, 76.8, 74.4, 72.8, 72.5, 71.8, 64.8, 63.0, 27.0, 26.9, 26.9, 26.8, 26.2, 25.0, 19.2.

HRMS (ESI): calc. for $\text{C}_{47}\text{H}_{58}\text{O}_{10}\text{SiNa}$ ($\text{M}+\text{Na}$): 833.3697; found: 833.3698.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,5-tri-*O*-benzyl- β -D-arabinofuranosyl)- α -D-glucopyranoside (**5.20**)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1d** (16.0 mg, 36.0 μmol) to afford **5.20** (19.5 mg, 22.5 μmol , 87% yield, $\alpha:\beta = 1:4$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

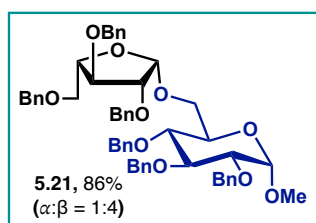


^1H NMR (400 MHz, CDCl_3) δ 7.43 (tt, $J = 5.3, 3.1$ Hz, 2H), 7.38 – 7.26 (m, 33H), 7.23 – 7.18 (m, 3H), 5.03 – 4.95 (m, 3H), 4.85 – 4.76 (m, 4H), 4.67 (s, 1H), 4.64 (d, $J = 2.8$ Hz, 1H), 4.62 – 4.59 (m, 3H), 4.55 – 4.51 (m, 4H), 4.45 (d, $J = 12.0$ Hz, 2H), 4.13 – 4.06 (m, 4H), 4.00 – 3.92 (m, 2H), 3.71 (d, $J = 10.1$ Hz, 2H), 3.63 – 3.47 (m, 7H), 3.36 (s, 0.6H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.9, 138.4, 138.3, 138.3, 138.2, 137.8, 129.1, 128.8, 128.6, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.7, 127.6, 106.8, 101.1, 98.2, 98.0, 88.0, 84.3, 83.7, 83.4, 82.2, 81.3, 80.8, 80.1, 80.0, 79.0, 78.8, 78.1, 73.5, 73.4, 72.8, 72.3, 72.1, 70.2, 66.5, 55.2, 53.5, 52.9, 52.5. The data are identical to those reported in the literature.^[77]

Methyl 2,3,4-tri-O-benzoyl-6-O-(2, 3, 5-tri-O-benzyl- β -L-arabinofuranosyl)- α -D-glucopyranoside (5.21)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μmol) was coupled with thiofuranoside donor **4.1e** (16.0 mg, 36.0 μmol) to afford **5.21** (19.1 mg, 22.2 μmol , 81% yield, $\alpha:\beta = 1:4$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 70:30).

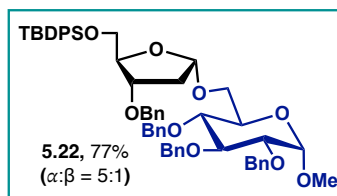


^1H NMR (400 MHz, CDCl_3) δ 7.33 (d, $J = 4.3$ Hz, 9H), 7.31 – 7.23 (m, 33H), **5.08 (d, $J = 2.8$ Hz, 1H)**, 4.95 (d, $J = 11.0$ Hz, 1H), 4.82 (dd, $J = 12.6, 10.9$ Hz, 3H), 4.72 (d, $J = 12.1$ Hz, 1H), 4.65 (dd, $J = 12.6, 1.9$ Hz, 3H), 4.62 – 4.54 (m, 4H), 4.51 (d, $J = 2.8$ Hz, 2H), 4.43 (d, $J = 10.6$ Hz, 2H), 4.14 – 4.08 (m, 1H), 4.07 – 4.04 (m, 2H), 3.96 (t, $J = 9.2$ Hz, 2H), 3.90 – 3.84 (m, 1H), 3.74 – 3.68 (m, 2H), 3.67 – 3.53 (m, 3H), 3.50 (d, $J = 6.2$ Hz, 2H), 3.38 (dd, $J = 9.6, 3.6$ Hz, 1H), 3.34 (s, 0.65H), 3.32 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.4, 138.3, 138.2, 138.2, 138.1, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 101.6, 98.0, 84.1, 83.3, 82.1, 80.3, 80.1, 77.9, 75.7, 75.1, 73.5, 73.4, 73.2, 72.8, 72.3, 72.0, 72.0, 70.4, 66.4, 55.2. The data are identical to those reported in the literature.^[50,78]

Methyl 2,3,4-tri-O-benzyl-6-O-(3-O-benzyl-5-O-tertbutyldiphenylsilyl- α -2-deoxy-D-ribofuranosyl)- α -D-glucopyranoside (5.22)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 25.0 μ mol) was coupled with thiofuranoside donor **5.1b** (18.0 mg, 36.0 μ mol) to afford **5.22** (18.0 mg, 19.8 μ mol, 77% yield, α : β = 5:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 80:20).

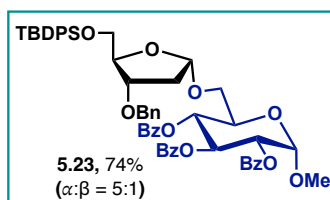


^1H NMR (400 MHz, CDCl_3) δ 7.60 (ddd, J = 15.0, 8.0, 1.5 Hz, 4H), 7.40 – 7.37 (m, 2H), 7.36 – 7.28 (m, 15H), 7.21 (d, J = 10.4 Hz, 9H), **5.25** (dd, J = 4.6, 2.3 Hz, 1H), 4.93 (d, J = 10.9 Hz, 1H), 4.83 – 4.73 (m, 2H), 4.72 – 4.62 (m, 3H), 4.61 (d, J = 3.6 Hz, 1H), 4.47 (d, J = 11.8 Hz, 1H), 4.36 (d, J = 11.9 Hz, 1H), 4.19 (dd, J = 11.0, 2.1 Hz, 1H), 4.13 (q, J = 3.3 Hz, 2H), 3.93 (t, J = 8.7 Hz, 1H), 3.71 (d, J = 7.3 Hz, 2H), 3.61 (dd, J = 8.4, 3.6 Hz, 2H), 3.57 – 3.50 (m, 2H), 3.34 (s, 3H), 2.22 (q, J = 4.1 Hz, 2H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.1, 138.7, 138.4, 138.3, 135.8, 135.7, 133.4, 133.4, 129.9, 129.8, 128.6, 128.5, 128.5, 128.3, 128.1, 128.1, 128.0, 127.8, 127.8, 127.7, 127.7, 127.6, 104.6, 98.5, 84.7, 82.2, 79.9, 79.1, 77.7, 77.5, 77.2, 76.8, 75.8, 75.2, 73.6, 71.4, 70.0, 65.6, 64.2, 55.3, 38.8, 26.9, 19.4.

HRMS (ESI): calc. for $\text{C}_{56}\text{H}_{64}\text{O}_9\text{SiNa}$ ($\text{M}+\text{Na}$): 931.4217; found: 931.4217.

Methyl 2,3,4-tri-O-benzoyl-6-O-(3-O-benzyl-5-O-tertbutyldiphenylsilyl- α -2-deoxy-D-ribofuranosyl)- α -D-glucopyranoside (5.23)



Following the general procedure, **A**, glycosyl acceptor **A11** (13.0 mg, 26.0 μ mol) was coupled

with thiofuranoside donor **5.1b** (18.0 mg, 36.0 μ mol) to afford **5.23** (18.0 mg, 18.92 μ mol, 74% yield, α : β = 5:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 80:20).

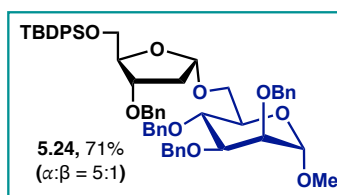
^1H NMR (400 MHz, CDCl_3) δ 8.00 – 7.97 (m, 2H), 7.93 – 7.89 (m, 2H), 7.88 – 7.85 (m, 2H), 7.66 (dt, $J = 7.7$, 1.6 Hz, 1H), 7.62 – 7.59 (m, 3H), 7.43 – 7.27 (m, 24H), 6.12 (t, $J = 9.6$ Hz, 1H), 5.62 (t, $J = 9.8$ Hz, 1H), 5.27 – 5.21 (m, 2H), 5.18 – 5.14 (m, 1H), 4.51 – 4.42 (m, 2H), 4.24 (dt, $J = 9.2$, 3.9 Hz, 1H), 4.17 (q, $J = 3.9$ Hz, 1H), 4.11 (dt, $J = 7.7$, 3.6 Hz, 1H), 3.97 (dd, $J = 11.0$, 4.5 Hz, 1H), 3.67 (ddd, $J = 11.1$, 7.7, 3.6 Hz, 2H), 3.57 (dd, $J = 11.1$, 4.0 Hz, 1H), 3.42 (s, 3H), 2.21 – 2.13 (m, 1H), 1.97 (dt, $J = 13.8$, 2.3 Hz, 1H), 1.05 (s, 2H), 1.00 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.0, 165.9, 165.3, 135.8, 135.8, 135.7, 135.7, 133.9, 133.5, 133.5, 133.3, 130.1, 130.1, 130.1, 129.9, 129.9, 129.9, 129.8, 129.8, 129.3, 128.7, 128.7, 128.6, 128.6, 128.5, 128.5, 128.4, 128.4, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.8, 127.7, 127.7, 110.2, 107.4, 105.3, 103.9, 99.6, 97.3, 96.9, 84.1, 83.6, 80.3, 80.1, 77.5, 77.2, 76.8, 72.2, 72.2, 71.6, 71.4, 70.2, 69.9, 69.7, 68.8, 61.2, 59.0, 55.6, 55.5, 27.0, 26.9, 26.9, 26.9, 26.7, 19.4, 19.3.

HRMS (ESI): calc. for $\text{C}_{56}\text{H}_{58}\text{O}_{12}\text{SiNa}$ ($\text{M}+\text{Na}$): 973.3595; found: 973.3597.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(3-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -2-deoxy-D-ribofuranosyl)- α -D-mannopyranoside (5.24)

Following the general procedure, **A**, glycosyl acceptor **A9** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1b** (18.0 mg, 36.0 μmol) to afford **5.24** (16.7 mg, 18.4 μmol , 71% yield, $\alpha:\beta = 5:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 80:20).



^1H NMR (400 MHz, CDCl_3) δ 7.66 – 7.60 (m, 4H), 7.41 (d, $J = 2.6$ Hz, 1H), 7.40 – 7.35 (m, 5H), 7.34 – 7.31 (m, 5H), 7.30 – 7.26 (m, 8H), 7.24 – 7.17 (m, 8H), 5.34 (dd, $J = 5.2$, 1.8 Hz, 1H), 4.78 (d, $J = 1.9$ Hz, 1H), 4.73 (dd, $J = 8.9$, 1.4 Hz, 4H), 4.61 (d, $J = 3.2$ Hz, 2H), 4.50 (d, $J = 11.7$ Hz, 1H), 4.36 (d, $J = 11.8$ Hz, 1H), 4.23 – 4.13 (m, 4H), 3.85 (dd, J

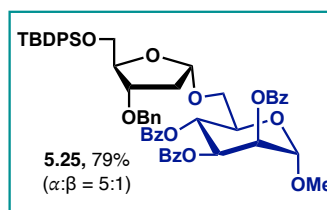
= 9.5, 3.2 Hz, 1H), 3.79 (dd, J = 3.2, 1.8 Hz, 1H), 3.70 – 3.61 (m, 4H), 3.29 (s, 3H), 2.32 – 2.19 (m, 2H), 1.02 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.1, 138.9, 138.6, 138.4, 135.8, 135.7, 133.5, 133.5, 129.8, 129.8, 128.4, 128.4, 128.4, 128.1, 128.0, 127.9, 127.8, 127.8, 127.7, 127.6, 127.5, 127.5, 104.6, 99.3, 84.5, 80.3, 79.1, 77.5, 77.2, 76.8, 74.7, 72.7, 72.4, 71.6, 71.3, 66.1, 64.2, 54.8, 38.6, 26.9, 19.4.

HRMS (ESI): calc. for $\text{C}_{56}\text{H}_{64}\text{O}_9\text{SiNa}$ ($\text{M}+\text{Na}$): 931.4217; found: 931.4222.

Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(3-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -2-deoxy-D-ribofuranosyl)- α -D-mannopyranoside (5.25)

Following the general procedure, **A**, glycosyl acceptor **A13** (13.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1b** (18.0 mg, 36.0 μmol) to afford **5.25** (19.2 mg, 20.2 μmol , 79% yield, $\alpha:\beta$ = 5:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 80:20).



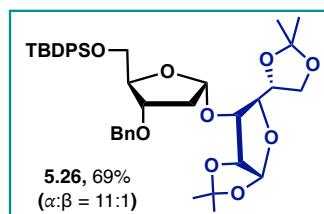
^1H NMR (400 MHz, CDCl_3) δ 8.09 (dd, J = 8.2, 1.4 Hz, 2H), 7.95 – 7.92 (m, 2H), 7.87 – 7.83 (m, 2H), 7.60 (ddd, J = 7.9, 3.8, 1.6 Hz, 5H), 7.55 – 7.50 (m, 1H), 7.47 – 7.36 (m, 9H), 7.35 – 7.27 (m, 14H), 5.99 (t, J = 10.0 Hz, 1H), 5.84 (dd, J = 10.1, 3.3 Hz, 1H), 5.65 (dd, J = 3.4, 1.8 Hz, 1H), 5.20 (dd, J = 5.6, 1.7 Hz, 1H), 4.97 (d, J = 1.9 Hz, 1H), 4.42 (s, 2H), 4.25 (dt, J = 9.9, 3.9 Hz, 1H), 4.19 (q, J = 4.0 Hz, 1H), 4.11 (dt, J = 7.8, 3.7 Hz, 1H), 4.02 (dd, J = 11.0, 4.6 Hz, 1H), 3.81 – 3.72 (m, 1H), 3.70 (t, J = 3.4 Hz, 1H), 3.67 (d, J = 3.4 Hz, 1H), 3.61 (dd, J = 11.1, 4.0 Hz, 1H), 3.47 (s, 3H), 3.40 (s, 1H), 2.23 – 2.16 (m, 1H), 1.97 (ddd, J = 13.9, 3.3, 1.7 Hz, 1H), 1.01 (s, 2H), 0.98 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 165.7, 165.7, 165.5, 138.5, 135.8, 135.7, 133.5, 133.3, 133.2, 130.1, 130.0, 129.9, 129.9, 129.9, 129.9, 129.8, 129.7, 129.6, 129.5, 129.4, 128.7, 128.5, 128.5, 128.4, 127.9, 127.9, 127.8, 103.9, 98.6, 83.5, 78.4, 77.5, 77.2, 76.8, 67.8, 66.3, 63.8, 55.5, 38.8, 26.9, 26.9, 19.4.

HRMS (ESI): calc. for $C_{56}H_{58}O_{12}SiNa$ ($M+Na$): 973.3595; found: 973.36.

1,2:5,6-bis-O-(1-methylethylidene)-6-O-(3-O-benzyl-5-O-tertbutyldiphenylsilyl- α -2-deoxy-D-ribofuranosyl)- α -D-allofuranoside (5.26)

Following the general procedure, **A**, glycosyl acceptor **A19** (8.0 mg, 31.0 μ mol) was coupled with thiofuranoside donor **5.1b** (22.0 mg, 43.0 μ mol) to afford **5.26** (15.0 mg, 21.3 μ mol, 69% yield, α : β = 11:1) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 80:20).



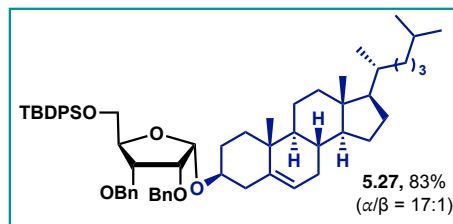
^1H NMR (400 MHz, $CDCl_3$) δ 7.64 (td, J = 8.1, 1.5 Hz, 4H), 7.45 – 7.40 (m, 2H), 7.37 (t, J = 7.5 Hz, 4H), 7.31 (d, J = 3.5 Hz, 5H), 5.83 (d, J = 3.8 Hz, 1H), **5.35 (dd, J = 4.3, 2.0 Hz, 1H)**, 4.72 (t, J = 4.2 Hz, 1H), 4.46 (dd, J = 12.6, 2.9 Hz, 3H), 4.38 (q, J = 3.8 Hz, 1H), 4.32 (dd, J = 8.9, 4.6 Hz, 1H), 4.16 – 4.10 (m, 3H), 3.83 (t, J = 7.8 Hz, 1H), 3.73 – 3.64 (m, 2H), 2.21 (dd, J = 6.2, 4.1 Hz, 2H), 1.56 (s, 3H), 1.43 (s, 3H), 1.36 (s, 3H), 1.34 (s, 3H), 1.03 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.3, 135.8, 135.7, 129.9, 129.9, 128.6, 128.4, 128.2, 128.0, 127.9, 127.9, 127.8, 127.7, 112.9, 109.6, 104.5, 104.3, 102.1, 102.0, 84.7, 79.1, 78.0, 77.5, 77.2, 76.8, 74.3, 73.6, 71.9, 71.4, 71.2, 64.4, 64.2, 62.7, 39.2, 29.9, 26.9, 26.9, 26.1, 25.2, 19.4.

HRMS (ESI): calc. for $C_{40}H_{52}O_9SiNa$ ($M+Na$): 727.3278; found: 727.3273.

1-Cholesteryl-2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl (5.27)

Following the general procedure, **A**, glycosyl acceptor (cholesterol) **A4** (10.0 mg, 26.0 μ mol) was coupled with thiopyranoside donor **4.1f** (24.0 mg, 39.0 μ mol) to afford **5.27** (20.2 mg, 21.6 μ mol, 83% yield, α : β = 17:1) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 80:20).



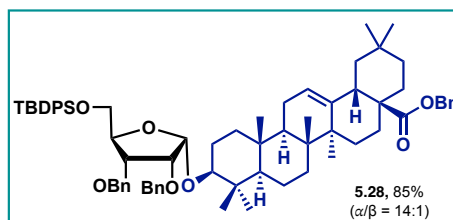
^1H NMR (400 MHz, CDCl_3) δ 7.61 – 7.58 (m, 2H), 7.57 – 7.54 (m, 2H), 7.43 – 7.28 (m, 16H), 5.36 – 5.33 (m, 1H), 5.14 (d, J = 4.2 Hz, 1H), 4.75 – 4.64 (m, 3H), 4.55 (d, J = 12.7 Hz, 1H), 4.18 (q, J = 3.4 Hz, 1H), 3.97 (dd, J = 6.5, 3.6 Hz, 1H), 3.79 (dd, J = 6.6, 4.1 Hz, 1H), 3.63 (dd, J = 11.2, 3.5 Hz, 1H), 3.53 (dd, J = 11.1, 3.5 Hz, 2H), 2.54 – 2.46 (m, 1H), 2.44 – 2.38 (m, 1H), 2.05 – 1.79 (m, 5H), 1.73 – 1.65 (m, 1H), 1.60 – 1.46 (m, 8H), 1.45 – 1.31 (m, 5H), 1.17 – 1.07 (m, 6H), 1.05 – 1.00 (m, 6H), 0.93 (s, 9H), 0.87 (d, J = 1.8 Hz, 3H), 0.86 (d, J = 1.8 Hz, 3H), 0.68 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 141.4, 138.7, 138.3, 135.8, 135.7, 133.4, 133.3, 129.8, 129.8, 128.5, 128.4, 128.1, 128.0, 127.9, 127.8, 127.8, 127.6, 121.5, 100.0, 82.9, 77.8, 77.7, 77.5, 77.2, 76.8, 75.4, 72.5, 72.3, 64.1, 56.9, 56.3, 50.3, 42.5, 40.4, 39.9, 39.7, 37.5, 36.9, 36.3, 35.9, 32.1, 32.0, 28.4, 28.2, 28.2, 26.9, 24.4, 24.0, 23.0, 22.7, 21.2, 19.6, 19.3, 18.9, 12.0.

HRMS (ESI): calc. for $\text{C}_{62}\text{H}_{83}\text{O}_5\text{SiNa}$ ($\text{M}+\text{Na}$): 958.5907; found: 958.6525.

1-Oleanolic acid-2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl (5.28)

Following the general procedure, **A**, glycosyl acceptor (oleanolic acid) (14.0 mg, 25.6 μmol) was coupled with thiopyranoside donor **4.1f** (23.5 mg, 38.4 μmol) to afford **5.28** (24.0 mg, 21.9 μmol , 85% yield, $\alpha:\beta=14:1$) as a colorless viscous oil. R_f = 0.5 (hexane: EtOAc = 80:20).



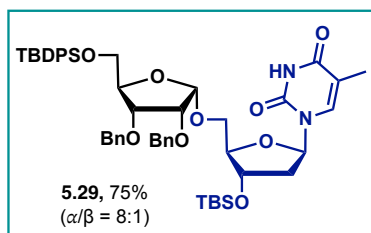
¹H NMR (400 MHz, CDCl₃) δ 7.64 – 7.57 (m, 4H), 7.43 – 7.38 (m, 3H), 7.38 – 7.34 (m, 9H), 7.34 – 7.28 (m, 8H), 7.25 – 7.23 (m, 1H), 5.31 – 5.28 (m, 1H), **5.19 (d, *J* = 4.1 Hz, 1H)**, 5.10 (d, *J* = 12.5 Hz, 1H), 5.05 (d, *J* = 12.5 Hz, 1H), 4.77 (d, *J* = 12.2 Hz, 1H), 4.70 (d, *J* = 12.1 Hz, 1H), 4.59 (d, *J* = 12.2 Hz, 1H), 4.48 (d, *J* = 12.2 Hz, 1H), 4.18 (q, *J* = 3.6 Hz, 1H), 4.00 (dd, *J* = 6.3, 3.7 Hz, 1H), 3.86 (dd, *J* = 6.3, 4.1 Hz, 1H), 3.67 (dd, *J* = 11.1, 3.6 Hz, 1H), 3.61 (dd, *J* = 11.1, 3.5 Hz, 1H), 3.27 (dd, *J* = 11.5, 4.2 Hz, 1H), 2.90 (dd, *J* = 13.9, 4.5 Hz, 1H), 2.02 – 1.93 (m, 1H), 1.88 – 1.83 (m, 2H), 1.75 – 1.48 (m, 14H), 1.19 (d, *J* = 15.4 Hz, 3H), 1.12 (s, 3H), 1.01 (d, *J* = 4.4 Hz, 4H), 0.97 (s, 9H), 0.92 – 0.89 (m, 9H), 0.87 (s, 3H), 0.61 (s, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 177.6, 143.9, 138.9, 138.6, 136.6, 135.8, 135.7, 133.5, 133.4, 129.8, 129.8, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 128.1, 128.0, 127.8, 127.8, 127.7, 127.4, 122.7, 98.3, 82.6, 82.5, 77.5, 77.2, 76.8, 72.3, 72.2, 66.1, 64.2, 55.9, 47.7, 46.9, 46.0, 41.8, 41.5, 39.5, 38.5, 38.4, 37.1, 34.0, 33.3, 32.9, 32.5, 30.8, 28.3, 27.7, 26.9, 26.9, 26.0, 23.8, 23.6, 23.2, 22.5, 19.3, 18.5, 17.0, 16.8, 15.5.

HRMS (ESI): calc. for C₇₂H₉₂O₇SiNa (M+Na): 1119.651; found: 1119.6502.

3-*O*-*tert*-butyldimethylsilyl-5-*O*-(2,3-di-*O*-benzyl-5-*O*-*tert*butyldiphenylsilyl- α -D-ribofuranosyl)-thymidine (5.29)

Following the general procedure, **A**, glycosyl acceptor (3-OTBS thymidine) **A29** (10.0 mg, 28.0 μ mol) was coupled with thiopyranoside donor **4.1f** (24.0 mg, 39.3 μ mol) to afford **5.29** (19.0 mg, 21.0 μ mol, 75% yield, α : β = 8:1) as a colorless viscous oil. *R_f* = 0.3 (hexane: EtOAc = 75:25).



¹H NMR (400 MHz, CDCl₃) δ 7.87 (d, *J* = 7.9 Hz, 1H), 7.66 – 7.58 (m, 6H), 7.44 (dt, *J* = 7.1, 3.6 Hz, 2H), 7.37 (dt, *J* = 7.3, 3.5 Hz, 5H), 7.30 (s, 6H), 7.22 (p, *J* = 2.9 Hz, 5H), 6.37 (dd, *J* = 9.6, 5.4 Hz, 1H), **4.84 (d, *J* = 4.3 Hz, 1H)**, 4.69 (d, *J* = 12.3 Hz, 1H), 4.56 – 4.49 (m, 2H), 4.46 (d, *J* = 11.3 Hz, 1H), 4.34 (d, *J* = 5.3 Hz, 1H), 4.11 (d, *J* = 4.4 Hz, 1H), 3.99

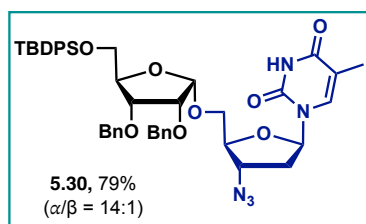
(d, $J = 7.8$ Hz, 2H), 3.88 (dd, $J = 6.4, 4.4$ Hz, 1H), 3.75 (d, $J = 9.8$ Hz, 1H), 3.67 (dd, $J = 10.5, 1.9$ Hz, 1H), 3.61 (d, $J = 3.8$ Hz, 2H), 2.31 (ddd, $J = 14.4, 9.6, 5.6$ Hz, 1H), 1.80 (d, $J = 1.2$ Hz, 3H), 1.73 – 1.68 (m, 2H), 0.99 (s, 9H), 0.86 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 163.7, 150.5, 137.7, 137.5, 137.5, 135.7, 135.6, 133.1, 132.9, 130.0, 130.0, 128.6, 128.5, 128.3, 128.3, 128.2, 128.1, 128.1, 127.9, 127.9, 127.8, 111.0, 100.7, 87.2, 84.9, 84.7, 78.8, 77.4, 77.1, 76.8, 74.6, 73.2, 72.9, 67.6, 64.4, 40.1, 26.9, 25.9, 19.3, 18.1, 12.2, -4.6, -4.7.

HRMS (ESI): calc. for $\text{C}_{51}\text{H}_{66}\text{N}_2\text{NaO}_9\text{Si}_2$ ($\text{M}+\text{Na}$): 929.4205; found: 929.4199.

3-deoxy-3'-azido-5-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-thymidine (**5.30**)

Following the general procedure, **A**, glycosyl acceptor (3-azido thymidine) **A30** (12.0 mg, 44.9 μmol) was coupled with thiopyranoside donor **4.1f** (38.6 mg, 62.9 μmol) to afford **5.30** (29.0 mg, 35.5 μmol , 79% yield, $\alpha:\beta = 14:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 75:25).



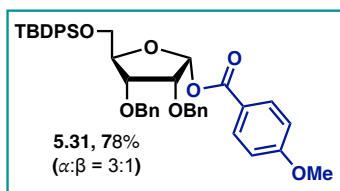
^1H NMR (400 MHz, CDCl_3) δ 7.87 (s, 1H), 7.62 – 7.58 (m, 4H), 7.54 (d, $J = 1.4$ Hz, 1H), 7.45 – 7.41 (m, 2H), 7.38 (ddd, $J = 8.2, 6.4, 4.8$ Hz, 4H), 7.29 (s, 5H), 7.25 (s, 2H), 7.20 (dd, $J = 6.6, 3.1$ Hz, 2H), 6.22 (dd, $J = 8.6, 5.7$ Hz, 1H), **4.84 (d, $J = 4.3$ Hz, 1H)**, 4.68 (d, $J = 12.2$ Hz, 1H), 4.52 (d, $J = 12.2$ Hz, 1H), 4.49 – 4.40 (m, 2H), 4.13 (p, $J = 2.5$ Hz, 2H), 4.00 (dt, $J = 4.0, 1.5$ Hz, 2H), 3.91 (dd, $J = 6.2, 4.3$ Hz, 1H), 3.75 (dd, $J = 10.8, 1.8$ Hz, 1H), 3.69 – 3.58 (m, 3H), 2.29 (ddd, $J = 14.4, 8.6, 6.5$ Hz, 1H), 1.82 – 1.76 (m, 4H), 0.99 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 163.6, 150.3, 137.5, 137.4, 136.9, 135.8, 135.7, 133.1, 132.9, 130.1, 130.1, 128.6, 128.5, 128.4, 128.3, 128.3, 128.0, 127.9, 111.2, 100.4, 84.8, 84.3, 83.3, 79.0, 77.5, 77.2, 76.8, 73.4, 73.0, 66.9, 64.5, 62.6, 36.5, 29.9, 26.9, 19.3, 12.3.

HRMS (ESI): calc. for C₄₅H₅₁N₅NaO₈Si (M+Na): 840.3405; found: 840.3399.

1-4-methoxybenzoyl-2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl (5.31)

Following the general procedure, **A**, glycosyl acceptor (4-methoxybenzoic acid) **A20** (5.0 mg, 33.0 μ mol) was coupled with thiofuranoside donor **4.1f** (28.0 mg, 46.0 μ mol) to afford **5.31** (18.0 mg, 26.0 μ mol, 78% yield, α : β = 3:1) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 80:20).

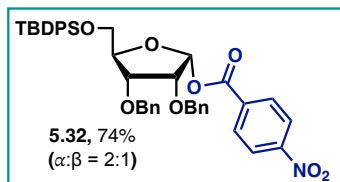


¹H NMR (400 MHz, CDCl₃) δ 8.08 – 8.04 (m, 2H), 7.85 (d, J = 8.9 Hz, 1H), 7.67 – 7.57 (m, 6H), 7.45 – 7.35 (m, 10H), 7.33 – 7.27 (m, 10H), 6.82 (d, J = 8.9 Hz, 2H), 6.77 (d, J = 8.8 Hz, 1H), 6.58 – 6.56 (m, 1H), 4.86 – 4.80 (m, 1H), 4.74 – 4.54 (m, 4H), 4.38 (d, J = 3.9 Hz, 1H), 4.17 (d, J = 3.0 Hz, 2H), 3.85 (s, 3H), 3.83 (s, 1H), 3.67 (qd, J = 11.3, 3.3 Hz, 2H), 0.98 (s, 3H), 0.97 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 165.9, 163.6, 163.5, 138.6, 137.8, 135.7, 135.7, 135.6, 133.1, 132.8, 132.4, 132.0, 130.0, 129.9, 128.6, 128.5, 128.4, 128.3, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.6, 122.8, 113.6, 113.6, 94.9, 85.8, 79.0, 77.4, 77.3, 77.1, 76.8, 76.3, 72.9, 72.9, 64.0, 55.5, 26.9, 26.8, 19.2.

HRMS (ESI): calc. for C₄₃H₄₆O₇SiNa (M+Na): 725.291; found: 725.2917.

1-4-nitrobenzoyl-2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl- α -D-ribofuranosyl (5.32)



Following the general procedure, **A**, glycosyl acceptor (4-nitrobenzoic acid) **A22** (6.0 mg, 36.0 μ mol) was coupled with thiofuranoside donor **4.1f** (31.0 mg, 50.0 μ mol) to afford **5.32**

(19.0 mg, 26.0 μ mol, 74% yield, α : β = 2:1) as a colorless viscous oil. R_f = 0.6 (hexane: EtOAc = 80:20).

α -anomer: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.2 – 8.2 (m, 2H), 8.1 – 8.1 (m, 2H), 7.6 (td, J = 8.0, 1.6 Hz, 4H), 7.5 – 7.4 (m, 2H), 7.4 – 7.4 (m, 4H), 7.4 (dd, J = 2.4, 1.5 Hz, 1H), 7.4 – 7.3 (m, 4H), 7.3 – 7.3 (m, 5H), **6.6 (d, J = 4.0 Hz, 1H)**, 4.8 (d, J = 11.2 Hz, 1H), 4.7 (d, J = 1.4 Hz, 2H), 4.6 (d, J = 11.2 Hz, 1H), 4.4 (q, J = 2.4 Hz, 1H), 4.2 (dd, J = 5.9, 4.1 Hz, 1H), 4.2 (dd, J = 5.9, 1.5 Hz, 1H), 3.7 (qd, J = 11.3, 3.3 Hz, 2H), 1.0 (s, 9H).

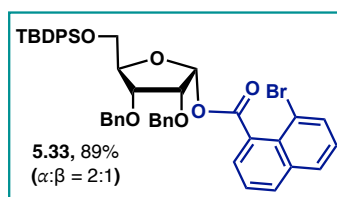
$^{13}\text{C NMR}$ (100 MHz, CDCl_3) δ 164.3, 150.6, 138.3, 137.5, 135.9, 135.7, 135.7, 133.0, 132.7, 131.4, 130.1, 130.1, 128.7, 128.6, 128.2, 128.2, 128.1, 128.0, 128.0, 127.8, 123.5, 96.3, 86.6, 79.3, 77.5, 77.2, 76.8, 73.2, 73.1, 64.0, 26.9, 19.3.

β -anomer: $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.0 – 8.0 (m, 2H), 7.9 – 7.9 (m, 2H), 7.6 – 7.6 (m, 2H), 7.6 – 7.5 (m, 2H), 7.4 (dd, J = 7.9, 1.8 Hz, 2H), 7.4 – 7.3 (m, 3H), 7.3 (q, J = 3.2 Hz, 7H), 7.3 – 7.3 (m, 4H), **6.5 (s, 1H)**, 4.8 (d, J = 12.2 Hz, 1H), 4.7 (d, J = 12.2 Hz, 1H), 4.6 (d, J = 11.8 Hz, 1H), 4.5 (d, J = 11.8 Hz, 1H), 4.4 (d, J = 2.9 Hz, 2H), 4.1 (d, J = 3.1 Hz, 1H), 4.0 (dd, J = 11.5, 1.8 Hz, 1H), 3.8 (dd, J = 11.4, 2.2 Hz, 1H), 0.9 (s, 9H).

$^{13}\text{C NMR}$ (100 MHz, CDCl_3) δ 163.8, 150.6, 137.6, 137.4, 135.6, 135.5, 135.0, 133.4, 133.1, 131.0, 129.9, 129.8, 128.7, 128.7, 128.3, 128.3, 128.1, 127.9, 127.9, 127.8, 123.5, 100.6, 83.4, 79.2, 77.5, 77.2, 76.8, 75.8, 72.7, 72.4, 62.9, 27.0, 19.5.

1-8-bromonaphtoyl-2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (5.33)

Following the general procedure, **A**, glycosyl acceptor (4-methoxybenzoic acid) **A26** (7.0 mg, 28.0 μ mol) was coupled with thiofuranoside donor **4.1f** (24.0 mg, 39.0 μ mol) to afford **5.33** (20.0 mg, 25.0 μ mol, 89% yield, α : β = 2:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 80:20).



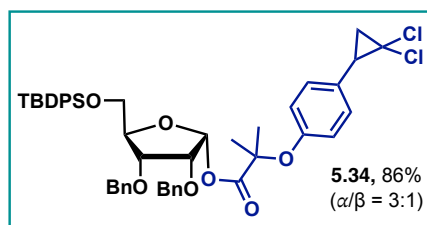
¹H NMR (400 MHz, CDCl₃) δ 7.89 – 7.81 (m, 5H), 7.76 (dd, *J* = 7.2, 1.3 Hz, 1H), 7.64 – 7.57 (m, 7H), 7.50 – 7.42 (m, 4H), 7.40 – 7.34 (m, 10H), 7.33 – 7.27 (m, 9H), 7.23 – 7.20 (m, 3H), **6.78 (d, *J* = 4.2 Hz, 1H)**, **6.58 (s, 1H)**, 4.89 (d, *J* = 12.2 Hz, 1H), 4.83 – 4.73 (m, 3H), 4.69 (d, *J* = 12.0 Hz, 1H), 4.59 (d, *J* = 11.9 Hz, 1H), 4.47 (s, 1H), 4.45 (q, *J* = 2.8 Hz, 1H), 4.41 – 4.36 (m, 1H), 4.31 – 4.25 (m, 2H), 4.16 (dd, *J* = 6.1, 2.1 Hz, 1H), 3.93 (dd, *J* = 11.6, 2.8 Hz, 1H), 3.75 (ddd, *J* = 11.3, 5.3, 3.5 Hz, 2H), 3.65 (dd, *J* = 11.3, 2.8 Hz, 1H), 0.98 (s, 9H), 0.76 (s, 4H).

¹³C NMR (100 MHz, CDCl₃) δ 169.4, 169.3, 138.4, 137.9, 137.7, 137.6, 135.8, 135.7, 135.7, 135.7, 135.6, 133.4, 133.3, 133.3, 133.2, 132.8, 132.1, 131.6, 131.4, 131.3, 130.0, 129.7, 129.7, 129.6, 129.1, 128.8, 128.6, 128.6, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 127.6, 126.9, 126.8, 125.5, 125.4, 119.9, 119.7, 100.9, 96.8, 85.9, 83.2, 79.4, 78.4, 77.5, 77.2, 76.8, 73.3, 72.8, 72.5, 72.2, 64.0, 62.9, 26.9, 26.6, 19.3, 19.1.

HRMS (ESI): calc. for C₄₆H₄₅NaBrO₆Si (M+Na): 823.2066; found: 823.2057.

1-Ciprofibrate-2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.34**)

Following the general procedure, **A**, glycosyl acceptor (ciprofibrate) (8.0 mg, 27.7 μ mol) was coupled with thiopyranoside donor **4.1f** (23.8 mg, 38.8 μ mol) to afford **5.34** (20.0 mg, 23.8 μ mol, 86% yield, α : β = 3:1) as a colorless viscous oil. *R*_f = 0.2 (hexane: EtOAc = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 7.61 (dddd, *J* = 19.3, 11.3, 7.4, 1.5 Hz, 6H), 7.45 – 7.40 (m, 2H), 7.40 – 7.36 (m, 4H), 7.36 – 7.31 (m, 9H), 7.31 – 7.27 (m, 5H), 7.21 (dd, *J* = 6.5, 2.8 Hz, 1H), 6.96 – 6.87 (m, 5H), 6.75 – 6.70 (m, 1H), **6.51 (d, *J* = 4.0 Hz, 1H)**, 4.73 – 4.63 (m, 3H), 4.59 – 4.50 (m, 3H), 4.38 (dd, *J* = 11.6, 9.3 Hz, 1H), 4.32 – 4.26 (m, 2H), 4.15 – 4.08 (m, 2H), 3.87 (ddd, *J* = 13.8, 6.9, 4.7 Hz, 1H), 3.76 (dd, *J* = 16.4, 4.0 Hz, 1H), 3.65 (qt, *J* = 11.3, 3.1 Hz, 3H), 2.72 (ddd, *J* = 19.0, 10.3, 8.1 Hz, 1H), 1.90 – 1.83 (m, 1H), 1.69

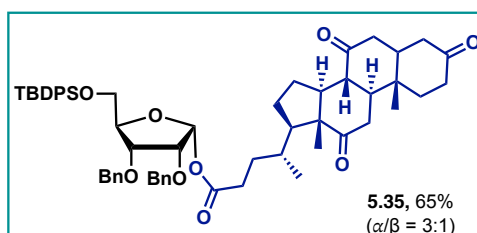
(ddd, J = 8.6, 7.2, 1.8 Hz, 2H), 1.58 (d, J = 5.1 Hz, 7H), 1.45 (d, J = 2.4 Hz, 1H), 1.02 (s, 3H), 0.97 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 173.7, 155.0, 138.5, 137.7, 137.6, 135.7, 135.7, 135.7, 135.7, 133.3, 133.1, 132.8, 130.0, 130.0, 129.9, 129.8, 129.8, 129.7, 129.5, 128.7, 128.6, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7, 127.6, 119.4, 118.4, 118.3, 100.5, 96.2, 86.2, 83.5, 79.6, 79.6, 79.4, 79.0, 79.0, 77.5, 77.2, 76.8, 75.8, 75.8, 73.1, 73.1, 72.8, 72.4, 72.1, 63.9, 61.1, 34.9, 34.8, 27.0, 26.9, 25.9, 25.8, 25.8, 25.2, 25.1, 19.4, 19.3.

HRMS (ESI): calc. for $\text{C}_{48}\text{H}_{52}\text{Cl}_2\text{O}_7\text{SiNa}$ ($\text{M}+\text{Na}$): 861.2757; found: 861.2751.

1-Dehydrocholic acid-2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.35**)

Following the general procedure, **A**, glycosyl acceptor (dehydrocholic acid) (11.0 mg, 27.3 μmol) was coupled with thiopyranoside donor **4.1f** (23.4 mg, 38.3 μmol) to afford **5.35** (17.0 mg, 65.3 μmol , 65% yield, $\alpha:\beta$ = 3:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).



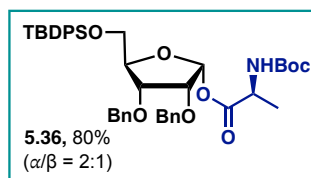
^1H NMR (400 MHz, CDCl_3) δ 7.59 (t, J = 1.4 Hz, 1H), 7.57 (d, J = 1.5 Hz, 1H), 7.55 (t, J = 1.4 Hz, 1H), 7.53 (d, J = 1.5 Hz, 1H), 7.43 – 7.39 (m, 2H), 7.37 (dd, J = 2.0, 0.9 Hz, 2H), 7.36 – 7.35 (m, 3H), 7.34 – 7.31 (m, 8H), 7.31 – 7.29 (m, 3H), 6.39 – 6.37 (m, 1H), 4.76 (dd, J = 12.2, 3.2 Hz, 1H), 4.66 (d, J = 12.3 Hz, 1H), 4.63 – 4.57 (m, 2H), 4.31 – 4.27 (m, 2H), 4.09 – 4.06 (m, 2H), 3.64 (dd, J = 11.3, 3.6 Hz, 1H), 3.55 (dd, J = 11.3, 2.8 Hz, 1H), 2.94 – 2.83 (m, 3H), 2.81 (d, J = 12.7 Hz, 1H), 2.40 – 2.28 (m, 5H), 2.27 – 2.19 (m, 5H), 2.17 – 2.10 (m, 3H), 2.01 (t, J = 2.3 Hz, 1H), 1.99 (d, J = 7.0 Hz, 2H), 1.95 (d, J = 3.4 Hz, 1H), 1.82 (td, J = 11.1, 7.2 Hz, 2H), 1.65 – 1.57 (m, 3H), 1.39 (s, 3H), 1.26 (d, J = 1.8 Hz, 3H), 1.03 (d, J = 1.9 Hz, 6H), 0.84 (d, J = 6.6 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 212.1, 209.3, 208.9, 174.0, 138.4, 137.7, 137.6, 135.7, 135.7, 135.7, 135.6, 133.1, 132.8, 130.0, 130.0, 129.9, 129.9, 129.8, 128.6, 128.6, 128.6, 128.5, 128.4, 128.3, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 94.9, 85.6, 78.5, 77.5, 77.2, 76.8, 75.6, 73.0, 72.6, 63.9, 57.0, 57.0, 51.9, 51.8, 49.1, 49.1, 47.0, 47.0, 45.8, 45.7, 45.6, 45.1, 42.9, 38.7, 36.6, 36.1, 35.6, 35.4, 32.1, 30.4, 27.7, 26.9, 26.8, 25.3, 22.0, 19.2, 18.8, 12.0.

HRMS (ESI): calc. for C₅₉H₇₂O₉SiNa (M+Na): 975.4843; found: 975.4834.

***N*-tert-Butoxycarbonyl-carboxyl-*O*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl)- α -D-ribofuranosyl)-L-alanine (**5.36**)**

Following the general procedure, **A**, glycosyl acceptor (Boc-L-ala-OH) **A31** (7.0 mg, 37.0 μ mol) was coupled with thiofuranoside donor **4.1f** (32.0 mg, 51.8 μ mol) to afford **5.36** (22.0 mg, 29.8 μ mol, 80% yield, α : β = 2:1) as a colorless viscous oil. *R*_f = 0.3 (hexane: EtOAc = 70:30).



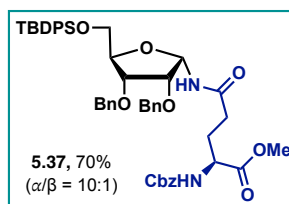
¹H NMR (400 MHz, CDCl₃) δ 7.67 – 7.54 (m, 9H), 7.42 – 7.28 (m, 31H), 6.44 (d, *J* = 3.6 Hz, 1H), 6.27 (s, 1H), 5.20 (d, *J* = 7.7 Hz, 1H), 4.92 (d, *J* = 8.0 Hz, 1H), 4.76 (dd, *J* = 12.1, 7.2 Hz, 2H), 4.66 – 4.49 (m, 5H), 4.43 (d, *J* = 11.7 Hz, 1H), 4.33 (dt, *J* = 7.4, 3.5 Hz, 2H), 4.21 (dd, *J* = 7.5, 4.6 Hz, 1H), 4.13 – 4.06 (m, 3H), 4.00 (d, *J* = 4.6 Hz, 1H), 3.87 (dd, *J* = 11.6, 3.2 Hz, 1H), 3.75 (dd, *J* = 11.5, 4.0 Hz, 1H), 3.67 (dd, *J* = 11.3, 3.5 Hz, 1H), 3.59 (dd, *J* = 11.4, 2.8 Hz, 1H), 1.43 (d, *J* = 2.9 Hz, 18H), 1.34 (d, *J* = 7.2 Hz, 3H), 1.14 (d, *J* = 7.2 Hz, 3H), 1.03 (s, 9H), 0.95 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 172.8, 172.6, 138.4, 137.7, 137.4, 135.7, 135.7, 135.6, 133.4, 133.2, 133.1, 132.8, 130.0, 130.0, 129.9, 129.8, 128.6, 128.6, 128.5, 128.4, 128.2, 128.0, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.7, 100.3, 96.3, 86.2, 83.3, 79.3, 79.1, 77.5, 77.2, 76.8, 75.7, 73.1, 72.8, 72.6, 72.3, 63.9, 63.5, 49.7, 49.2, 28.5, 28.5, 26.9, 26.9, 19.4, 19.3, 19.0, 18.3.

HRMS (ESI): calc. for C₄₃H₅₃O₈SiNNa (M+Na): 762.3468; found: 762.3433.

***N*-Benzyloxycarbonyl-*N*-(2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-L-glutamine methyl ester (**5.37**)**

Following the general procedure, **A**, glycosyl acceptor (Z-L-gln-OMe) **A32** (10.0 mg, 34.0 μ mol) was coupled with thiofuranoside donor **4.1f** (29.0 mg, 48.0 μ mol) to afford **5.37** (20.0 mg, 23.7 μ mol, 70% yield, α : β = 2:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 65:35).

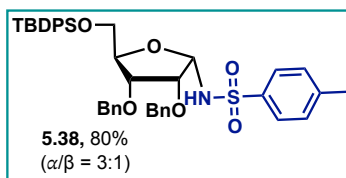


¹H NMR (400 MHz, CDCl₃) δ 7.6 (ddd, J = 12.2, 8.0, 1.6 Hz, 4H), 7.4 – 7.4 (m, 2H), 7.4 (s, 1H), 7.4 (s, 2H), 7.3 – 7.3 (m, 16H), 7.0 (d, J = 9.2 Hz, 1H), **5.9 (dd, J = 9.2, 5.3 Hz, 1H)**, **5.7 (d, J = 8.0 Hz, 1H)**, 5.1 – 5.0 (m, 2H), 4.7 (d, J = 11.8 Hz, 1H), 4.6 (d, J = 11.8 Hz, 1H), 4.5 (d, J = 2.7 Hz, 2H), 4.4 – 4.3 (m, 1H), 4.2 (s, 1H), 4.1 – 4.1 (m, 2H), 3.7 (s, 3H), 3.6 – 3.6 (m, 2H), 2.3 – 2.2 (m, 2H), 2.1 (t, J = 6.4 Hz, 1H), 2.0 (dd, J = 13.6, 6.3 Hz, 1H), 1.0 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 172.6, 172.3, 156.2, 137.9, 137.5, 136.4, 135.7, 135.6, 133.1, 132.8, 130.0, 128.8, 128.7, 128.7, 128.6, 128.3, 128.2, 128.2, 128.1, 128.0, 127.9, 127.8, 83.1, 78.7, 78.2, 77.5, 77.4, 77.2, 77.0, 76.8, 72.7, 72.7, 67.1, 64.1, 53.8, 52.6, 32.7, 27.6, 26.9, 19.3.

***1*-4-methyl-benzenesulfonamide-2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.38**)**

Following the general procedure, **A**, glycosyl acceptor (4-methyl benzenesulfonamide) **A33** (5.0 mg, 29.0 μ mol) was coupled with thiofuranoside donor **4.1f** (25.0 mg, 41.0 μ mol) to afford **5.38** (17.0 mg, 23.6 μ mol, 80% yield, α : β = 3:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 70:30).



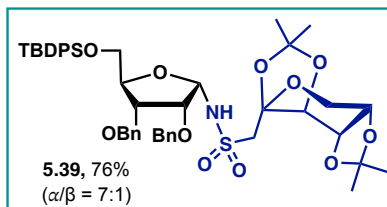
^1H NMR (400 MHz, CDCl_3) δ 7.78 (d, J = 8.2 Hz, 2H), 7.64 – 7.48 (m, 7H), 7.45 – 7.40 (m, 3H), 7.38 – 7.29 (m, 16H), 7.21 – 7.18 (m, 3H), 6.24 (d, J = 9.2 Hz, 1H), 5.50 (dd, J = 9.2, 5.3 Hz, 1H), 4.75 – 4.59 (m, 2H), 4.58 – 4.34 (m, 4H), 4.05 – 3.96 (m, 3H), 3.90 (td, J = 3.8, 1.8 Hz, 1H), 3.51 – 3.46 (m, 2H), 2.41 (s, 1H), 2.37 (s, 3H), 0.99 (s, 3H), 0.94 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 143.0, 139.4, 137.7, 137.3, 135.7, 135.6, 133.1, 132.9, 130.0, 130.0, 129.5, 128.7, 128.7, 128.6, 128.1, 128.1, 128.0, 127.9, 127.9, 127.9, 127.1, 83.3, 82.9, 77.7, 77.5, 77.2, 76.8, 73.0, 72.4, 63.9, 27.1, 26.9, 21.7, 19.2.

HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{47}\text{NNaO}_6\text{SSi}$ ($\text{M}+\text{Na}$): 744.2791; found: 744.2786.

1-Topiramate-2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl (**5.39**)

Following the general procedure, **A**, glycosyl acceptor (topiramate) **A34** (12.0 mg, 35.36 μmol) was coupled with thiopyranoside donor **4.1f** (30.4 mg, 49.5 μmol) to afford **5.39** (24.0 mg, 26.9 μmol , 76% yield, $\alpha:\beta$ = 7:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 75:25).



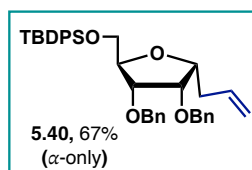
^1H NMR (400 MHz, CDCl_3) δ 7.59 – 7.53 (m, 4H), 7.42 (dd, J = 7.4, 2.1 Hz, 2H), 7.38 – 7.30 (m, 15H), 7.28 (d, J = 2.5 Hz, 1H), 6.32 (d, J = 9.2 Hz, 1H), 5.46 (dd, J = 9.3, 5.5 Hz, 1H), 4.71 (t, J = 12.0 Hz, 2H), 4.59 (d, J = 12.0 Hz, 1H), 4.56 – 4.50 (m, 2H), 4.46 (d, J = 2.6 Hz, 1H), 4.30 (d, J = 10.2 Hz, 1H), 4.24 (d, J = 3.7 Hz, 1H), 4.23 – 4.18 (m, 1H), 4.16 – 4.08 (m, 3H), 4.05 (dd, J = 5.0, 1.5 Hz, 1H), 3.88 (dd, J = 12.9, 1.9 Hz, 1H), 3.71 (d, J = 13.0 Hz, 1H), 3.59 – 3.55 (m, 2H), 1.50 (s, 3H), 1.38 (s, 6H), 1.23 (s, 3H), 0.95 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 137.6, 137.2, 135.7, 135.7, 135.6, 135.6, 135.6, 133.0, 132.7, 130.0, 130.0, 128.7, 128.7, 128.6, 128.6, 128.3, 128.2, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 109.2, 109.1, 101.1, 83.6, 83.4, 77.6, 73.1, 72.5, 70.8, 70.2, 69.9, 69.1, 63.8, 61.4, 26.8, 26.6, 26.0, 25.3, 24.1, 19.2.

HRMS (ESI): calc. for C₄₇H₅₉NNaO₁₂SSi (M+Na): 912.3425; found: 912.3419.

2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl-1-deoxy-1-allyl- α -D-ribofuranose (**5.40**)

Following the general procedure, **A**, glycosyl acceptor (allyltrimethyl silane) **A35** (24.0 mg, 204.0 μ mol) was coupled with thiofuranoside donor **4.1f** (25.0 mg, 41.0 μ mol) to afford **5.40** (16.3 mg, 27.49 μ mol, 67% yield, α -only) as a colorless viscous oil. *R*_f = 0.5 (hexane: EtOAc = 90:10).



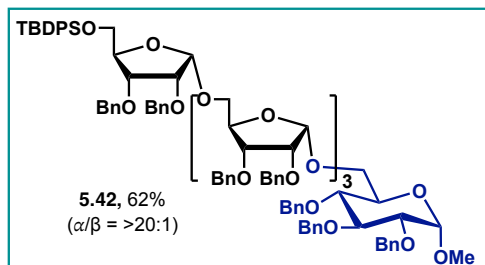
¹H NMR (400 MHz, CDCl₃) δ 7.70 – 7.65 (m, 2H), 7.65 – 7.61 (m, 2H), 7.42 – 7.30 (m, 16H), 5.84 (ddt, *J* = 17.1, 10.3, 6.9 Hz, 1H), 5.16 – 5.04 (m, 2H), 4.81 (d, *J* = 11.8 Hz, 1H), 4.66 – 4.59 (m, 2H), 4.53 (d, *J* = 12.0 Hz, 1H), 4.29 (dd, *J* = 6.5, 4.3 Hz, 1H), 4.13 (dt, *J* = 6.3, 3.0 Hz, 1H), 4.07 (td, *J* = 5.4, 2.8 Hz, 1H), 4.02 (t, *J* = 4.1 Hz, 1H), 3.83 (dd, *J* = 11.2, 3.3 Hz, 1H), 3.69 (dd, *J* = 11.2, 2.8 Hz, 1H), 2.60 – 2.42 (m, 2H), 1.00 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 138.6, 138.2, 135.8, 135.7, 135.5, 133.6, 133.3, 129.8, 129.7, 128.5, 128.4, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 116.7, 80.9, 80.3, 79.6, 78.1, 77.4, 77.3, 77.1, 76.8, 73.3, 72.7, 63.9, 34.6, 26.9, 19.3.

HRMS (ESI): calc. for C₃₈H₄₄NaO₄Si (M+Na): 615.2907; found: 615.2913.

Methyl (2,3-di-*O*-benzyl-5-*O*-tertbutyldiphenylsilyl- α -D-ribofuranosyl)-(1→5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1→5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1→5)-(2,3-di-*O*-benzyl- α -D-ribofuranosyl)-(1→6)-2,3,4-tri-*O*-benzyl- α -D-glucopyranoside (**5.42**)

Following the general procedure, **A**, glycosyl acceptor **5.41**^[66] (63.0 mg, 45.0 μmol) was coupled with thiofuranoside donor **4.1f** (49.6 mg, 81.0 μmol) to afford **5.42** (54.0 mg, 27.66 μmol , 62% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 70:30).



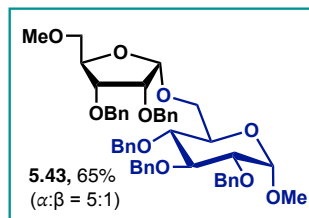
^1H NMR (400 MHz, CDCl_3) δ 7.80 (d, $J = 7.9$ Hz, 1H), 7.58 (dd, $J = 13.2, 7.0$ Hz, 4H), 7.40 (dd, $J = 7.1, 4.1$ Hz, 3H), 7.35 (d, $J = 7.3$ Hz, 5H), 7.30 (t, $J = 4.6$ Hz, 15H), 7.21 (dt, $J = 9.8, 5.1$ Hz, 25H), 7.16 – 7.07 (m, 12H), **5.02 (d, $J = 4.2$ Hz, 1H)**, **4.99 (s, 1H)**, **4.95 (s, 1H)**, 4.89 (d, $J = 10.9$ Hz, 2H), 4.77 (d, $J = 10.9$ Hz, 2H), 4.66 (q, $J = 10.8$ Hz, 7H), 4.58 (d, $J = 7.3$ Hz, 3H), 4.49 (dd, $J = 23.9, 11.8$ Hz, 4H), 4.37 (d, $J = 13.9$ Hz, 3H), 4.26 (d, $J = 15.3$ Hz, 2H), 4.22 – 4.15 (m, 4H), 4.13 – 3.98 (m, 9H), 3.88 (d, $J = 16.2$ Hz, 5H), 3.71 (d, $J = 17.9$ Hz, 5H), 3.60 – 3.49 (m, 4H), 3.40 (s, 3H), 3.29 (s, 3H), 0.95 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.3, 139.1, 139.0, 138.9, 138.8, 138.7, 138.6, 138.5, 138.2, 135.7, 135.7, 135.7, 133.3, 133.1, 129.9, 129.9, 128.5, 128.5, 128.5, 128.5, 128.4, 128.3, 128.3, 128.3, 128.2, 128.2, 128.2, 128.1, 128.1, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 127.6, 127.5, 127.5, 127.4, 127.4, 127.4, 127.4, 127.3, 127.3, 102.2, 101.8, 101.7, 98.2, 98.0, 83.7, 82.8, 82.7, 82.4, 82.1, 80.1, 79.4, 79.3, 79.0, 78.9, 77.9, 76.5, 76.5, 76.0, 75.6, 75.1, 73.5, 73.4, 72.7, 72.6, 72.3, 72.1, 72.0, 71.9, 70.4, 67.7, 67.5, 67.2, 66.4, 64.1, 55.1, 26.9, 19.3.

HRMS (ESI): calc. for $\text{C}_{120}\text{H}_{130}\text{O}_{22}\text{SiNa}$ ($\text{M}+\text{Na}$): 1973.8721; found: 1973.8652.

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-methyl- α -D-ribofuranosyl)- α -D-glucopyranoside (5.43)

Following the general procedure, **A**, glycosyl acceptor **A1** (20.0 mg, 43.0 μmol) was coupled with thiofuranoside donor **5.1c** (23.5 mg, 60.3 μmol) to afford **5.43** (22.0 mg, 27.8 μmol , 65% yield, $\alpha:\beta = 5:1$) as a colorless viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).



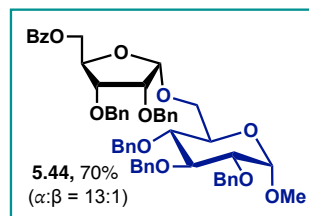
^1H NMR (400 MHz, CDCl_3) δ 7.39 – 7.36 (m, 2H), 7.34 – 7.28 (m, 13H), 7.25 – 7.19 (m, 10H), **5.15 (d, J = 3.3 Hz, 1H)**, 4.93 (d, J = 11.0 Hz, 1H), 4.81 (d, J = 11.0 Hz, 1H), 4.76 (d, J = 5.4 Hz, 1H), 4.73 (d, J = 5.7 Hz, 4H), 4.62 – 4.55 (m, 4H), 4.46 (d, J = 11.9 Hz, 1H), 4.21 – 4.13 (m, 2H), 3.93 (d, J = 9.0 Hz, 1H), 3.86 (t, J = 2.7 Hz, 2H), 3.73 (d, J = 9.2 Hz, 2H), 3.66 (d, J = 11.2 Hz, 1H), 3.42 (ddd, J = 11.5, 8.0, 3.4 Hz, 2H), 3.33 (s, 3H), 3.28 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.2, 138.8, 138.5, 138.4, 130.3, 128.6, 128.5, 128.4, 128.4, 128.4, 128.2, 128.1, 128.1, 128.0, 127.8, 127.7, 127.5, 102.3, 98.3, 82.1, 81.1, 80.1, 78.0, 77.9, 77.4, 77.2, 76.9, 76.1, 75.7, 75.2, 73.6, 72.6, 72.6, 72.4, 70.3, 66.8, 59.5, 55.3, 29.9.

HRMS (ESI): calc. for $\text{C}_{48}\text{H}_{54}\text{O}_{10}\text{Na}$ ($\text{M}+\text{Na}$): 813.3615; found: 813.3609.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-benzoyl- α -D-ribofuranosyl)- α -D-glucopyranoside (5.44)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1d** (27.2 mg, 56.8 μmol) to afford **5.44** (16.0 mg, 18.2 μmol , 70% yield, $\alpha:\beta$ = 13:1) as a colorless viscous oil. R_f = 0.2 (hexane: EtOAc = 80:20).



^1H NMR (400 MHz, CDCl_3) δ 7.91 – 7.86 (m, 2H), 7.56 (t, J = 7.5 Hz, 1H), 7.42 – 7.36 (m, 5H), 7.35 – 7.27 (m, 14H), 7.25 (s, 6H), 7.19 (d, J = 7.1 Hz, 2H), **5.18 (d, J = 4.0 Hz, 1H)**, 4.95 (d, J = 11.0 Hz, 1H), 4.85 – 4.78 (m, 2H), 4.78 – 4.73 (m, 4H), 4.72 (s, 1H), 4.63 (s, 1H), 4.60 (s, 1H), 4.58 (d, J = 3.5 Hz, 1H), 4.47 (d, J = 11.9 Hz, 1H), 4.38 (dd, J = 12.2,

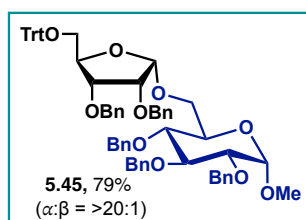
2.5 Hz, 2H), 4.25 – 4.15 (m, 2H), 3.97 (t, J = 9.1 Hz, 1H), 3.93 – 3.90 (m, 2H), 3.80 – 3.67 (m, 3H), 3.46 (dd, J = 9.6, 3.5 Hz, 1H), 3.34 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.3, 139.1, 138.7, 138.4, 138.1, 138.0, 133.2, 130.3, 129.8, 129.7, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.0, 128.0, 128.0, 128.0, 128.0, 127.9, 127.8, 127.7, 127.6, 102.3, 98.3, 82.1, 80.1, 79.9, 78.0, 77.5, 77.4, 77.2, 76.9, 76.4, 75.7, 75.2, 73.6, 72.8, 72.6, 70.3, 66.9, 64.5, 55.3.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{56}\text{O}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 903.372; found: 903.3715.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-trityl- α -D-ribofuranosyl)- α -D-glucopyranoside (5.45)

Following the general procedure, **A**, glycosyl acceptor **A1** (13.0 mg, 28.0 μmol) was coupled with thiofuranoside donor **5.1e** (24.2 mg, 39.2 μmol) to afford **5.45** (22.5 mg, 22.2 μmol , 79% yield, $\alpha:\beta$ = >20:1) as a colorless viscous oil. R_f = 0.4 (hexane: EtOAc = 80:20).



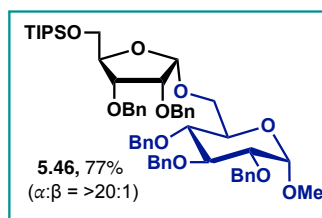
^1H NMR (400 MHz, CDCl_3) δ 7.38 – 7.27 (m, 19H), 7.25 – 7.19 (m, 16H), 7.15 (dq, J = 6.4, 3.6 Hz, 5H), **5.19 (d, J = 4.0 Hz, 1H)**, 4.94 (d, J = 11.0 Hz, 1H), 4.82 (d, J = 11.0 Hz, 1H), 4.76 (d, J = 4.6 Hz, 1H), 4.73 (d, J = 3.1 Hz, 3H), 4.64 – 4.57 (m, 4H), 4.40 (d, J = 12.0 Hz, 1H), 4.22 (q, J = 3.8 Hz, 1H), 4.16 (dd, J = 11.3, 3.3 Hz, 1H), 3.95 (dd, J = 6.6, 3.8 Hz, 2H), 3.89 (dd, J = 6.2, 3.6 Hz, 1H), 3.80 – 3.73 (m, 2H), 3.72 – 3.68 (m, 1H), 3.46 (dd, J = 9.6, 3.5 Hz, 1H), 3.34 (s, 3H), 3.20 (dd, J = 10.2, 4.1 Hz, 1H), 3.00 (dd, J = 10.2, 3.6 Hz, 1H).

^{13}C NMR (100 MHz, CDCl_3) δ 143.9, 139.2, 138.8, 138.5, 138.4, 138.4, 128.8, 128.5, 128.5, 128.5, 128.4, 128.3, 128.2, 128.1, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.6, 127.5, 127.5, 127.1, 102.1, 98.3, 86.7, 82.2, 82.0, 80.1, 78.2, 77.9, 77.4, 77.2, 76.9, 75.7, 75.2, 73.6, 72.5, 70.4, 66.8, 63.9, 55.3, 29.9.

HRMS (ESI): calc. for $\text{C}_{66}\text{H}_{66}\text{O}_{10}\text{Na}$ ($\text{M}+\text{Na}$): 1041.4554; found: 1041.4548.

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-triisopropyl- α -D-ribofuranosyl)- α -D-glucopyranoside (5.46)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **5.1f** (19.2 mg, 36.2 μ mol) to afford **5.46** (18.5 mg, 19.8 μ mol, 77% yield, α : β = >20:1) as a colorless, viscous oil. R_f = 0.5 (hexane: EtOAc = 80:20).

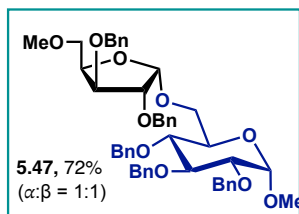


^1H NMR (400 MHz, CDCl_3) δ 7.37 (dd, J = 7.3, 2.1 Hz, 2H), 7.34 – 7.31 (m, 6H), 7.30 – 7.26 (m, 6H), 7.26 – 7.22 (m, 8H), 7.18 (dd, J = 9.4, 7.0 Hz, 3H), **5.09 (d, J = 4.2 Hz, 1H)**, 4.93 (d, J = 11.0 Hz, 1H), 4.81 (d, J = 11.0 Hz, 1H), 4.77 – 4.67 (m, 5H), 4.62 (d, J = 2.9 Hz, 1H), 4.59 (dd, J = 6.3, 3.2 Hz, 2H), 4.50 (d, J = 11.9 Hz, 1H), 4.16 – 4.11 (m, 2H), 4.01 (dd, J = 6.1, 3.3 Hz, 1H), 3.95 (t, J = 8.7 Hz, 1H), 3.86 (dd, J = 6.1, 4.1 Hz, 1H), 3.74 (d, J = 7.6 Hz, 2H), 3.68 – 3.62 (m, 3H), 3.46 (dd, J = 9.6, 3.6 Hz, 1H), 3.33 (s, 3H), 0.99 (d, J = 2.2 Hz, 21H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.2, 138.9, 138.6, 138.5, 138.4, 128.5, 128.4, 128.4, 128.3, 128.2, 128.1, 128.0, 128.0, 127.9, 127.7, 127.6, 127.5, 102.1, 98.3, 83.6, 82.2, 80.1, 78.3, 78.0, 77.4, 77.2, 76.9, 76.2, 75.7, 75.1, 73.6, 72.6, 72.4, 70.3, 66.7, 63.6, 55.2, 18.1, 18.0, 12.0.

HRMS (ESI): calc. for $\text{C}_{56}\text{H}_{72}\text{O}_{10}\text{NaSi}$ ($\text{M}+\text{Na}$): 955.4792; found: 955.4787.

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-methyl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.47)



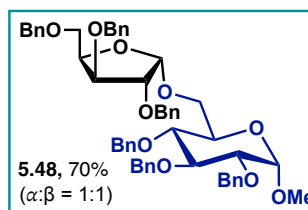
Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **5.1g** (14.0 mg, 36.2 μ mol) to afford **5.47** (14.8 mg, 18.7 μ mol, 72% yield, α : β = 1:1) as a colorless, viscous oil. R_f = 0.2 (hexane: EtOAc = 80:20).

^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.25 (m, 50H), **5.13 (d, J = 4.2 Hz, 1H)**, 5.07 (s, 1H), 4.97 (dd, J = 10.9, 7.6 Hz, 2H), 4.88 – 4.76 (m, 5H), 4.75 (s, 1H), 4.64 (t, J = 11.1 Hz, 5H), 4.57 (dt, J = 10.4, 5.1 Hz, 5H), 4.49 (dd, J = 12.5, 7.1 Hz, 5H), 4.42 – 4.32 (m, 2H), 4.29 (t, J = 6.4 Hz, 1H), 4.09 – 3.94 (m, 7H), 3.81 – 3.71 (m, 2H), 3.69 – 3.61 (m, 5H), 3.60 – 3.40 (m, 6H), 3.35 – 3.32 (m, 9H), 3.31 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.9, 138.4, 138.3, 138.3, 138.1, 138.0, 137.6, 128.6, 128.6, 128.5, 128.5, 128.5, 128.3, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 107.4, 100.5, 98.2, 98.0, 86.9, 84.0, 82.2, 82.1, 82.1, 81.6, 80.1, 80.0, 80.0, 78.2, 77.9, 77.5, 77.2, 76.8, 75.3, 75.2, 73.5, 73.5, 72.5, 72.2, 72.1, 72.1, 72.0, 70.3, 70.1, 67.0, 66.6, 59.4, 59.3, 55.2, 55.1.

HRMS (ESI): calc. for $\text{C}_{48}\text{H}_{54}\text{O}_{10}\text{Na}$ ($\text{M}+\text{Na}$): 813.3615; found: 813.3609.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-tri-*O*-benzyl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.48)



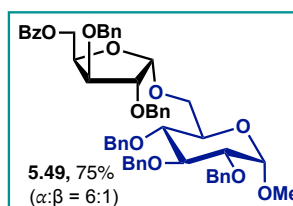
Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **5.1h** (17.0 mg, 36.2 μ mol) to afford **5.48** (15.6 mg, 18.0 μ mol, 70% yield, α : β = 1:1) as a colorless, viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).

^1H NMR (400 MHz, CDCl_3) δ 7.37 – 7.33 (m, 12H), 7.32 – 7.27 (m, 36H), 7.23 (d, J = 2.7 Hz, 12H), **5.13 (d, J = 4.2 Hz, 1H)**, **5.07 (d, J = 1.7 Hz, 1H)**, 4.97 (dd, J = 10.9, 6.1 Hz, 2H), 4.83 (td, J = 11.1, 8.0 Hz, 5H), 4.77 – 4.71 (m, 2H), 4.67 – 4.62 (m, 5H), 4.60 – 4.54 (m, 7H), 4.49 (ddd, J = 13.7, 11.3, 4.0 Hz, 10H), 4.38 (dt, J = 6.8, 3.4 Hz, 1H), 4.31 – 4.26 (m, 1H), 4.10 – 3.94 (m, 8H), 3.79 (dt, J = 10.1, 5.0 Hz, 3H), 3.74 – 3.62 (m, 6H), 3.60 – 3.41 (m, 5H), 3.34 (s, 3H), 3.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 139.0, 138.9, 138.5, 138.4, 138.3, 138.3, 138.3, 138.1, 138.0, 137.6, 128.6, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.2, 128.1, 128.0, 128.0, 128.0, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 107.5, 100.6, 98.2, 98.0, 86.8, 83.8, 82.2, 82.1, 82.0, 81.7, 80.1, 80.1, 80.1, 78.2, 77.9, 77.5, 77.2, 76.8, 76.3, 75.9, 75.8, 75.3, 75.1, 73.5, 73.5, 72.6, 72.2, 72.2, 72.1, 70.3, 70.1, 69.8, 69.5, 67.0, 66.7, 55.2, 55.1.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{58}\text{O}_{10}\text{Na}$ ($\text{M}+\text{Na}$): 889.3928; found: 889.3922.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-benzoyl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.49)



Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1i** (17.3 mg, 36.2 μmol) to afford **5.49** (17.0 mg, 19.3 μmol , 75% yield, $\alpha:\beta = 6:1$) as a colorless, viscous oil. $R_f = 0.2$ (hexane: EtOAc = 80:20).

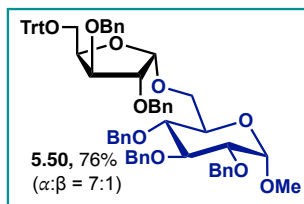
^1H NMR (400 MHz, CDCl_3) δ 7.98 – 7.94 (m, 2H), 7.54 (t, $J = 7.4$ Hz, 1H), 7.41 – 7.26 (m, 22H), 7.24 (d, $J = 6.7$ Hz, 10H), 5.13 (d, $J = 4.2$ Hz, 1H), 4.96 (d, $J = 10.9$ Hz, 1H), 4.83 (t, $J = 10.2$ Hz, 2H), 4.77 – 4.64 (m, 4H), 4.62 (s, 1H), 4.57 (td, $J = 8.0, 3.8$ Hz, 4H), 4.48 (dd, $J = 11.2, 6.8$ Hz, 2H), 4.37 (dt, $J = 13.0, 6.5$ Hz, 2H), 4.08 – 4.02 (m, 2H), 3.97 (t, $J = 9.1$ Hz, 1H), 3.74 (t, $J = 6.3$ Hz, 1H), 3.69 – 3.62 (m, 2H), 3.44 (dd, $J = 9.6, 3.5$ Hz, 1H), 3.34 (s, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 166.5, 139.0, 138.4, 138.3, 138.0, 138.0, 133.1, 130.2, 129.8, 129.8, 128.6, 128.6, 128.5, 128.5, 128.5, 128.2, 128.2, 128.1, 128.0, 128.0, 128.0, 127.9, 127.8, 127.7, 100.8, 98.2, 83.6, 82.1, 81.4, 80.1, 77.9, 77.5, 77.2, 76.8, 75.8, 75.3, 75.1, 73.5, 72.5, 72.3, 70.3, 66.8, 64.1, 55.3.

HRMS (ESI): calc. for $\text{C}_{54}\text{H}_{56}\text{O}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 903.372; found: 903.3715

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-trityl- α -D-xylofuranosyl)- α -D-glucopyranoside (5.50)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1j** (24.0 mg, 36.0 μmol) to afford **5.50** (20.0 mg, 19.6 μmol , 76% yield, $\alpha:\beta = 7:1$) as a colorless viscous oil. $R_f = 0.4$ (hexane: EtOAc = 80:20).



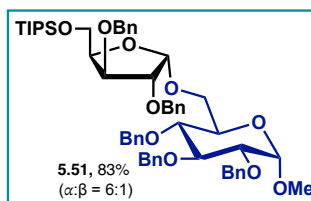
^1H NMR (400 MHz, CDCl_3) 7.44 – 7.40 (m, 6H), 7.36 – 7.29 (m, 14H), 7.25 – 7.18 (m, 19H), 7.06 – 7.01 (m, 2H), **5.14** (d, $J = 4.1$ Hz, 1H), 4.97 (d, $J = 11.0$ Hz, 1H), 4.84 (d, $J = 10.6$ Hz, 2H), 4.75 (d, $J = 12.1$ Hz, 1H), 4.70 – 4.62 (m, 3H), 4.60 – 4.58 (m, 1H), 4.54 – 4.48 (m, 2H), 4.43 (d, $J = 5.8$ Hz, 1H), 4.37 (d, $J = 11.9$ Hz, 1H), 4.22 (t, $J = 5.7$ Hz, 1H), 4.11 (dd, $J = 11.4, 3.5$ Hz, 1H), 4.02 (t, $J = 4.7$ Hz, 1H), 3.98 (t, $J = 9.1$ Hz, 1H), 3.77 – 3.67 (m, 3H), 3.45 (dd, $J = 9.6, 3.5$ Hz, 1H), 3.35 (s, 3H), 3.27 (dd, $J = 8.3, 5.5$ Hz, 2H).

^{13}C NMR (100 MHz, CDCl_3) δ 144.1, 139.1, 138.4, 138.3, 138.3, 138.2, 128.9, 128.6, 128.6, 128.5, 128.5, 128.3, 128.2, 128.2, 128.1, 128.1, 128.0, 127.9, 127.9, 127.8, 127.6, 127.5, 127.0, 101.1, 98.3, 86.9, 83.4, 82.1, 81.9, 80.1, 77.9, 77.5, 77.2, 76.8, 75.3, 73.6, 72.5, 72.4, 70.3, 66.8, 63.1, 55.3.

HRMS (ESI): calc. for $\text{C}_{66}\text{H}_{66}\text{O}_{10}\text{Na}$ ($\text{M}+\text{Na}$): 1041.4554; found: 1041.4548.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-triisopropyl- α -D-xylofuranosyl)- α -D-glucopyranoside (**5.51**)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μmol) was coupled with thiofuranoside donor **5.1k** (21.0 mg, 36.2 μmol) to afford **5.51** (20 mg, 21.4 μmol , 83% yield, $\alpha:\beta = 6:1$) as a colorless, viscous oil. $R_f = 0.5$ (hexane: EtOAc = 80:20).



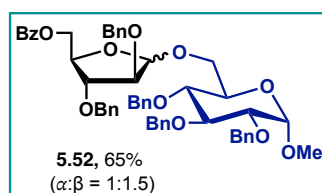
¹H NMR (400 MHz, CDCl₃) δ 7.36 – 7.27 (m, 27H), 7.25 (d, *J* = 2.2 Hz, 3H), 5.11 (d, *J* = 4.3 Hz, 1H), 4.96 (d, *J* = 10.8 Hz, 1H), 4.82 (dd, *J* = 10.7, 4.6 Hz, 2H), 4.75 (d, *J* = 12.1 Hz, 1H), 4.67 (d, *J* = 2.1 Hz, 1H), 4.65 – 4.62 (m, 2H), 4.61 – 4.55 (m, 4H), 4.51 – 4.45 (m, 2H), 4.23 (p, *J* = 5.8 Hz, 2H), 4.07 (td, *J* = 6.3, 2.7 Hz, 2H), 4.02 – 3.94 (m, 2H), 3.91 (dd, *J* = 10.6, 4.9 Hz, 1H), 3.78 (dd, *J* = 10.6, 4.6 Hz, 2H), 3.73 (d, *J* = 3.5 Hz, 1H), 3.70 – 3.64 (m, 2H), 3.46 – 3.41 (m, 1H), 3.34 (s, 3H), 1.06 – 1.02 (m, 6H), 1.00 (d, *J* = 3.4 Hz, 18H).

¹³C NMR (100 MHz, CDCl₃) δ 139.1, 138.5, 138.5, 138.3, 138.3, 128.6, 128.6, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.2, 128.2, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 100.9, 98.2, 83.3, 82.1, 81.6, 80.1, 78.4, 77.9, 77.5, 77.2, 76.8, 75.8, 75.3, 73.6, 72.7, 72.3, 70.3, 66.7, 62.2, 55.2, 18.1, 12.0.

HRMS (ESI): calc. for C₅₆H₇₂O₁₀NaSi (M+Na): 955.4792; found: 955.4787.

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3-di-*O*-benzyl-5-*O*-benzoyl-β-*D*-arabinofuranosyl)-α-*D*-glucopyranoside (5.52)

Following the general procedure, **A**, glycosyl acceptor **A1** (20.0 mg, 43.0 μmol) was coupled with thiofuranoside donor **5.11** (28.9 mg, 60.3 μmol) to afford **5.52** (24.7 mg, 28.0 μmol, 65% yield, α:β = 1:1.5) as a colorless, viscous oil. *R_f* = 0.3 (hexane: EtOAc = 80:20).



¹H NMR (400 MHz, CDCl₃) δ 8.05 – 8.02 (m, 2H), 7.55 – 7.51 (m, 1H), 7.42 – 7.35 (m, 5H), 7.30 (q, *J* = 5.5 Hz, 20H), 7.17 (dd, *J* = 7.5, 2.0 Hz, 2H), **5.06 (d, *J* = 4.2 Hz, 1H)**, 4.95 (d, *J* = 11.0 Hz, 1H), 4.79 (dd, *J* = 12.4, 10.5 Hz, 3H), 4.74 – 4.67 (m, 3H), 4.63 (dt, *J* = 8.0, 4.3 Hz, 3H), 4.58 (d, *J* = 11.4 Hz, 2H), 4.46 – 4.43 (m, 2H), 4.30 – 4.26 (m, 2H), 4.13 (dd, *J* = 4.3, 2.6 Hz, 1H), 3.97 (ddd, *J* = 12.8, 8.5, 6.7 Hz, 2H), 3.76 (dd, *J* = 10.3, 4.9 Hz, 1H), 3.65 (dd, *J* = 11.0, 4.5 Hz, 1H), 3.57 – 3.50 (m, 2H), 3.24 (s, 3H).

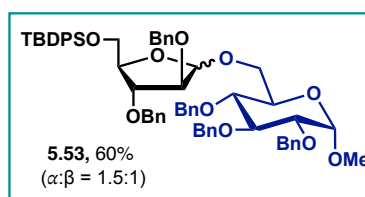
¹³C NMR (100 MHz, CDCl₃) δ 166.4, 138.9, 138.5, 138.4, 137.9, 137.7, 133.2, 130.1, 129.9, 129.8, 128.6, 128.6, 128.5, 128.5, 128.2, 128.1, 128.0, 127.9, 127.9, 127.9, 127.8,

127.7, 127.7, 101.0, 97.9, 84.3, 83.0, 82.1, 80.2, 79.3, 78.0, 77.5, 77.2, 76.8, 75.8, 74.9, 73.4, 72.7, 72.2, 70.0, 66.7, 66.5, 55.2.

HRMS (ESI): calc. for C₅₄H₅₆O₁₁Na (M+Na): 903.372; found: 903.3715.

Methyl 2,3,4-tri-O-benzyl-6-O-(2,3-di-O-benzyl-5-O-tertbutyldiphenylsilyl-b/a-D-arabinofuranosyl)- α -D-glucopyranoside (5.53)

Following the general procedure, **A**, glycosyl acceptor **A1** (12.0 mg, 26.0 μ mol) was coupled with thiofuranoside donor **5.1m** (22.0 mg, 36.0 μ mol) to afford **5.53** (15.8 mg, 15.5 μ mol, 60% yield, α : β = 1.5:1) as a colorless viscous oil. R_f = 0.3 (hexane: EtOAc = 80:20).

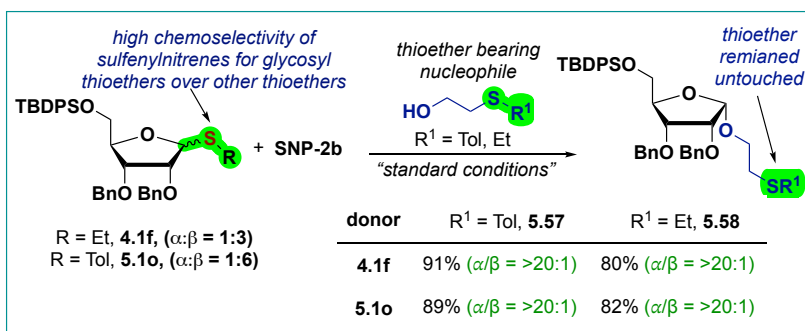


¹H NMR (400 MHz, CDCl₃) δ 7.71 – 7.63 (m, 8H), 7.35 (dddd, J = 26.7, 12.9, 6.4, 3.8 Hz, 55H), 7.27 (d, J = 1.7 Hz, 5H), 7.25 (d, J = 2.4 Hz, 3H), 7.19 – 7.16 (m, 2H), 5.19 (s, 1H), 5.04 (d, J = 4.3 Hz, 1H), 5.00 (dd, J = 10.9, 8.4 Hz, 2H), 4.88 – 4.75 (m, 7H), 4.72 (d, J = 2.7 Hz, 1H), 4.70 – 4.63 (m, 6H), 4.58 (ddd, J = 11.6, 7.5, 2.8 Hz, 5H), 4.50 (dd, J = 11.8, 1.6 Hz, 2H), 4.46 (d, J = 3.6 Hz, 1H), 4.23 (dd, J = 6.4, 4.6 Hz, 1H), 4.17 (t, J = 4.7 Hz, 1H), 4.14 – 4.09 (m, 5H), 4.00 (dd, J = 17.6, 8.9 Hz, 2H), 3.85 (td, J = 6.6, 2.7 Hz, 3H), 3.80 – 3.63 (m, 7H), 3.61 – 3.53 (m, 3H), 3.51 – 3.44 (m, 2H), 3.40 (s, 3H), 3.25 (s, 3H), 1.08 (s, 9H), 1.05 (s, 9H).

¹³C NMR (100 MHz, CDCl₃) δ 139.0, 138.4, 138.4, 138.3, 138.1, 135.8, 135.7, 135.7, 135.7, 133.5, 133.5, 129.9, 129.8, 129.8, 129.7, 128.6, 128.5, 128.5, 128.4, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 106.9, 100.9, 98.3, 97.9, 87.9, 84.5, 84.5, 83.2, 83.1, 82.7, 82.2, 82.2, 80.2, 80.0, 78.0, 77.5, 77.2, 76.8, 75.2, 74.9, 73.5, 73.5, 72.4, 72.2, 72.1, 71.8, 70.1, 70.1, 66.2, 66.2, 65.8, 63.7, 55.3, 55.1, 27.0, 26.9, 19.4, 19.4.

HRMS (ESI): calc. for C₆₃H₇₀O₁₀SiNa (M+Na): 1037.4636; found: 1037.4.

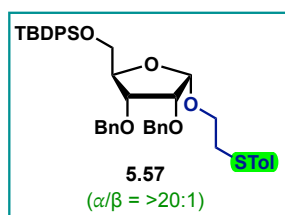
5.4.7. Reactivity of sulphenylnitrene with non-glycosyl thioethers



To a 4 mL screw-capped vial that contained a magnetic stir bar was sequentially added donor **4.1f** or **5.1o** (83.0 mmol, 1.4 equiv.), **SNP-2b** (89.0 mmol, 1.5 equiv.), 2-(tolylthio)ethanol **A36** or 2-(ethylthio)ethanol **A37** (60 mmol, 1.0 equiv.), 4Å molecular sieves (100 wt%) and CH₂Cl₂ (0.05 M) under ambient conditions. The vial was tightly sealed with a Teflon-lined cap and stirred for 10-14 h at room temperature, with irradiation from a 40 W, 390 nm blue LED (50% intensity) placed ~5 cm to the right. TLC analysis indicated complete consumption of the nucleophile. Upon complete consumption of the nucleophile, the reaction mixture was then quenched by the addition of aq. sat. NaHCO₃. The organic layer was separated, and the aqueous layer was washed with ethyl acetate (2 times). The combined organic layers were dried over anhydrous Na₂SO₄ and filtered through a pad of cotton, and solvents were removed under reduced pressure. The residue was purified by silica gel chromatography to give the desired products **5.57** and **5.58**.

Access to 5.57 by reacting with donor **4.1f** (38.5 mg, 53.6 μmol, 91% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 85:15).

Access to 5.57 by reacting with donor **5.1o** (38.0 mg, 52.9 μmol, 89% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 85:15).



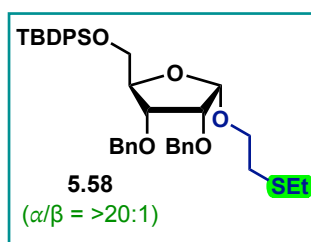
¹H NMR (400 MHz, CDCl₃) δ 7.6 (dt, $J = 6.7, 1.4$ Hz, 2H), 7.6 (dt, $J = 6.7, 1.4$ Hz, 2H), 7.4 (dtt, $J = 7.7, 6.3, 1.4$ Hz, 2H), 7.4 – 7.3 (m, 16H), 7.1 (d, $J = 8.0$ Hz, 2H), **5.0 (d, $J = 4.3$ Hz, 1H)**, 4.7 (d, $J = 12.2$ Hz, 3H), 4.6 (d, $J = 12.7$ Hz, 1H), 4.2 (q, $J = 3.3$ Hz, 1H), 4.0

(ddd, $J = 6.6, 3.0, 1.2$ Hz, 1H), 3.9 – 3.7 (m, 3H), 3.6 – 3.6 (m, 1H), 3.5 – 3.5 (m, 1H), 3.2 – 3.1 (m, 2H), 2.3 (s, 3H), 0.9 (s, 9H).

^{13}C NMR (100 MHz, CDCl_3) δ 138.5, 138.0, 136.3, 135.7, 135.7, 133.3, 133.2, 132.2, 130.2, 129.9, 129.8, 128.5, 128.4, 128.2, 128.1, 127.9, 127.9, 127.8, 127.7, 101.9, 83.6, 78.1, 77.5, 77.2, 76.8, 75.2, 72.7, 72.5, 67.4, 64.1, 33.7, 26.8, 21.1, 19.3.

Access to 5.58 by reacting with donor **4.1f** (34.5 mg, 52.5 μmol , 80% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 85:15).

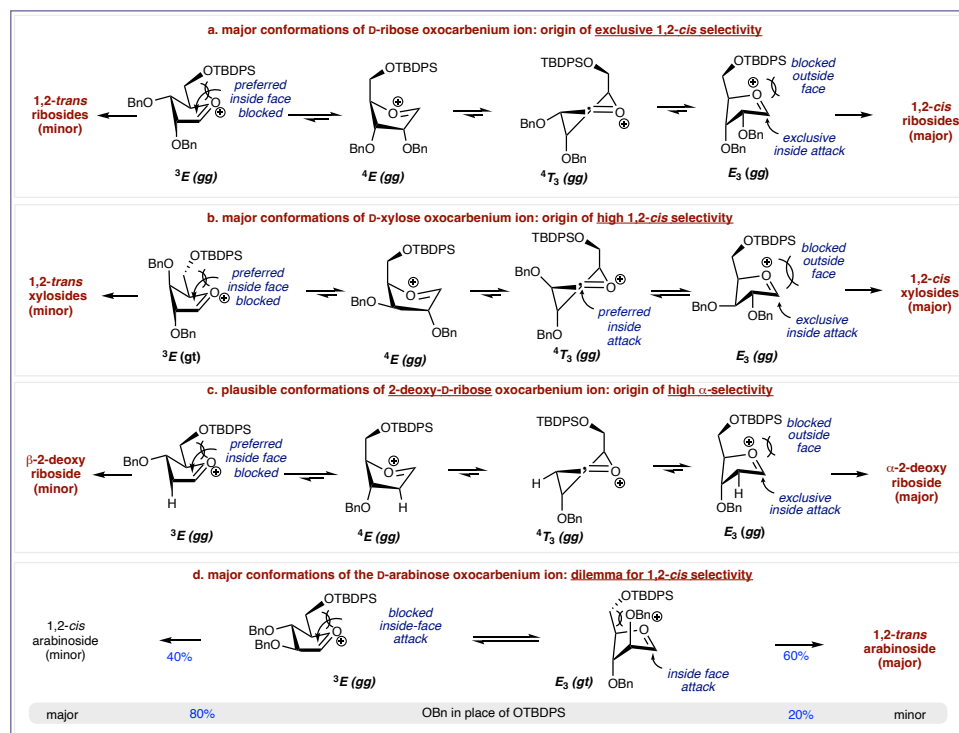
Access to 5.58 by reacting with donor **5.1o** (35.5 mg, 54.1 μmol , 82% yield, $\alpha:\beta = >20:1$) as a colorless viscous oil. $R_f = 0.5$ (hexane: EtOAc = 85:15).



^1H NMR (400 MHz, CDCl_3) δ 7.61 – 7.57 (m, 2H), 7.57 – 7.53 (m, 2H), 7.41 (dd, $J = 7.3, 5.5$ Hz, 2H), 7.38 – 7.34 (m, 6H), 7.33 – 7.27 (m, 8H), **5.03 (d, $J = 4.3$ Hz, 1H)**, 4.70 – 4.64 (m, 3H), 4.56 (d, $J = 12.6$ Hz, 1H), 4.17 (t, $J = 3.3$ Hz, 1H), 3.97 (dd, $J = 6.6, 2.9$ Hz, 1H), 3.91 – 3.81 (m, 2H), 3.74 (dt, $J = 10.5, 7.3$ Hz, 1H), 3.62 (dd, $J = 11.2, 3.6$ Hz, 1H), 3.52 (dd, $J = 11.2, 3.3$ Hz, 1H), 2.81 (t, $J = 7.5$ Hz, 2H), 2.58 (q, $J = 7.4$ Hz, 2H), 1.22 (d, $J = 7.4$ Hz, 3H), 0.94 (s, 9H).

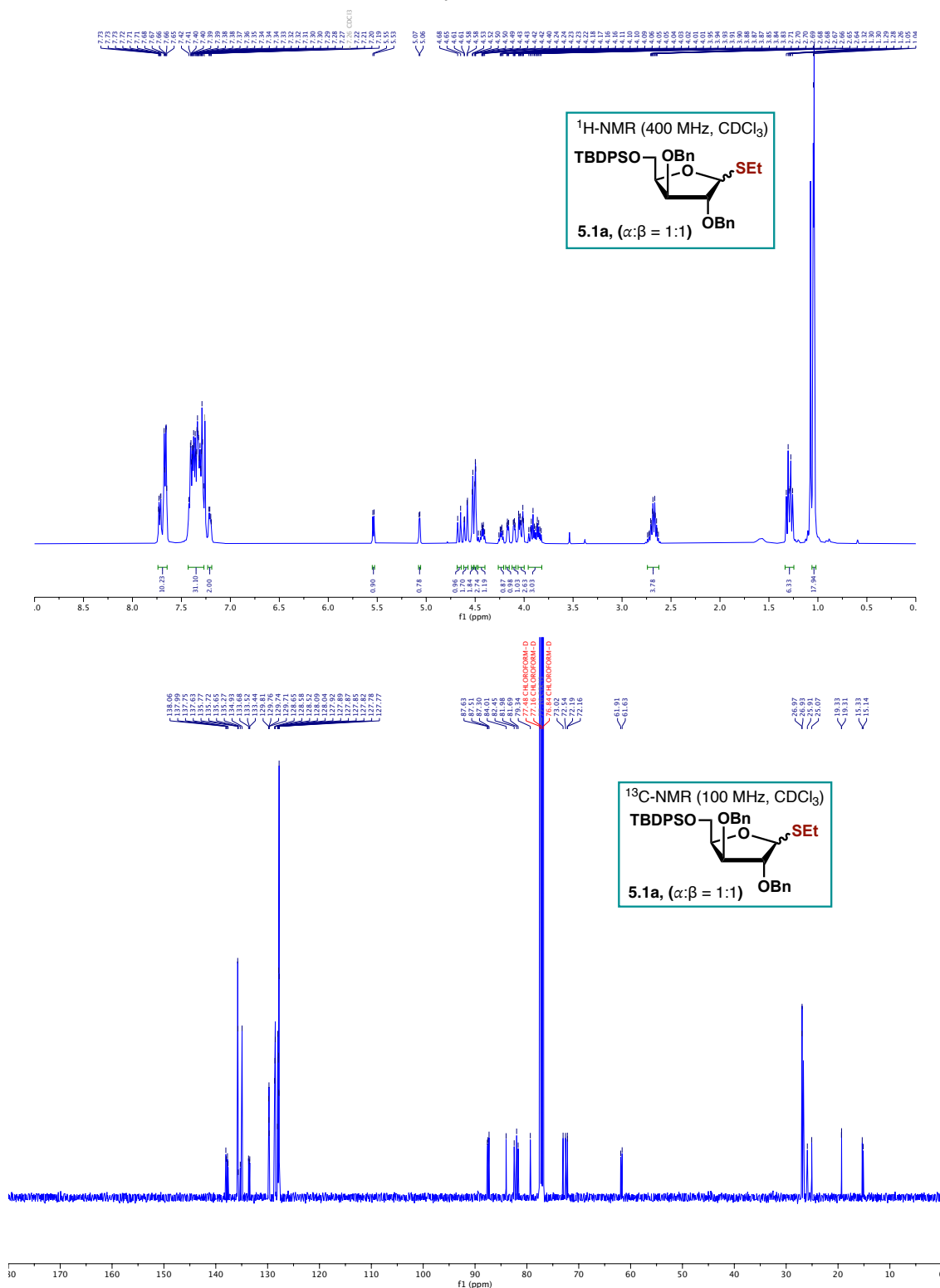
^{13}C NMR (100 MHz, CDCl_3) δ 138.5, 138.0, 135.8, 135.7, 135.7, 133.3, 133.2, 129.9, 129.8, 128.5, 128.4, 128.2, 128.1, 127.9, 127.9, 127.8, 127.7, 101.8, 83.6, 78.2, 77.5, 77.2, 76.8, 75.2, 72.6, 72.5, 68.3, 64.2, 31.1, 29.9, 26.9, 26.3, 19.3, 15.1.

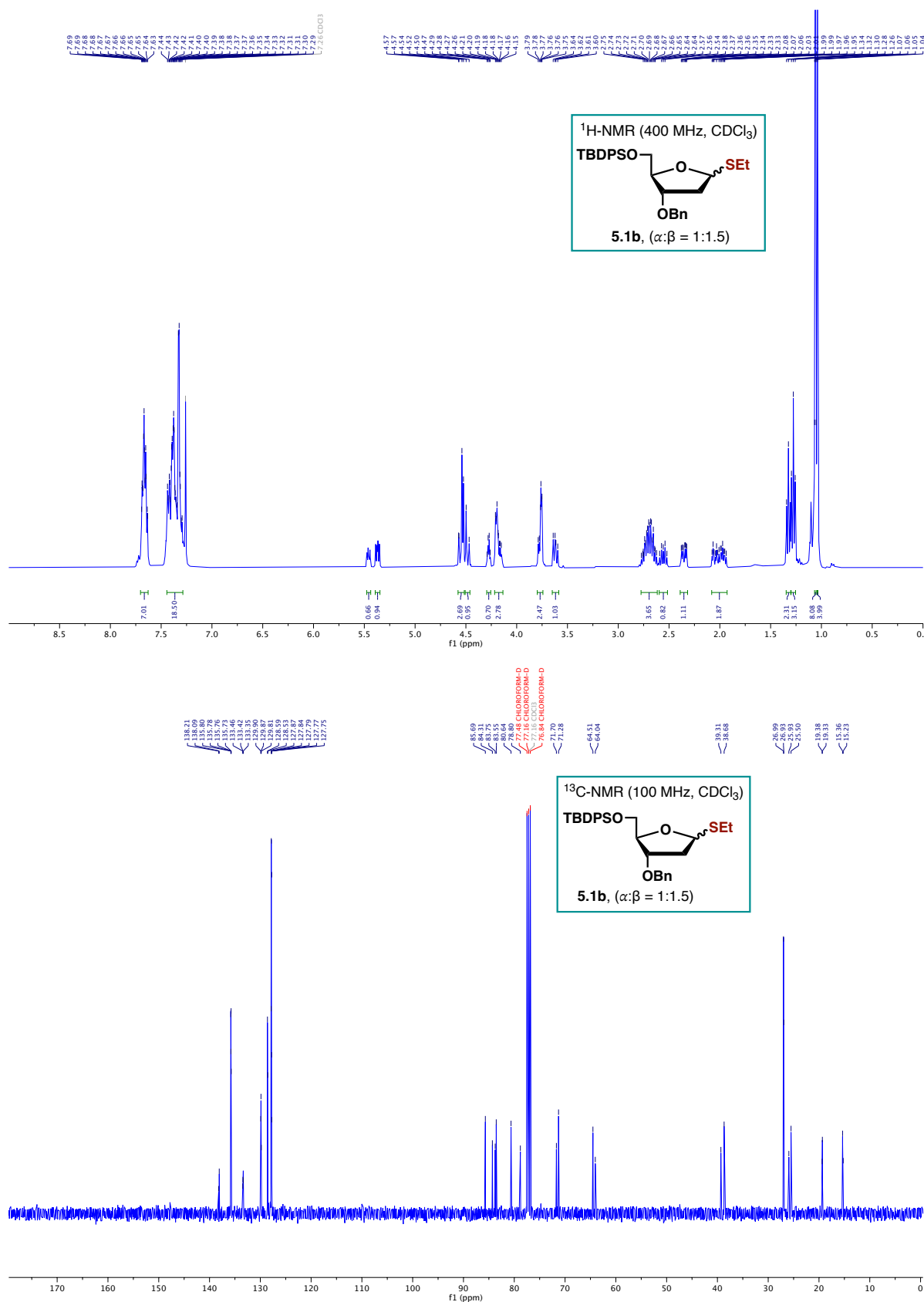
5.4.8. Detailed conformational analysis for the C5-protecting group influence on the 1,2-cis selectivity of each furanose discussed in this work

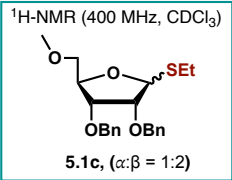
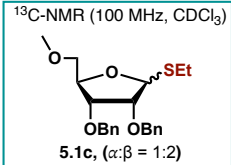


For ribose, the oxocarbenium ion predominantly adopts the E_3 (*gg*) envelope conformation, favoring inside attack (*cis* product). C5 substituents align towards the electron-deficient C1 center, blocking the trans face and stabilizing the cation. Minor trans products arise from less stable conformations ($^4T_3$ (*gg*), ^4E (*gg*), ^3E (*gg*)) as supported by prior work from Woerpel^[67-69] and Codée^[67-68] (**Fig. S7**). Similarly, 2-deoxyribose also prefers the E_3 (*gg*) envelope, where steric shielding of the β -face enforces α -selectivity. In xylose, the dominant E_3 (*gg*) and $^4T_3$ (*gg*) conformations rationalize the observed high *cis* selectivity with minor trans formation. In contrast, arabinose predominantly adopts the ^3E (*gg*) conformation, which initially promotes *cis* selectivity; however, C5 steric/electronic influences can redirect the system into an E_3 (*gg*) envelope, leading to competing *trans* selectivity. Overall, these combined studies highlight that sulfenylnitrene-mediated activation proceeds through a distinct sulfiliminium-sulfonium-oxocarbenium ion pathway, and that the C5 steric and electronic environment in furanosyl oxocarbenium ions is the dominant factor controlling the remarkable stereoselectivity.

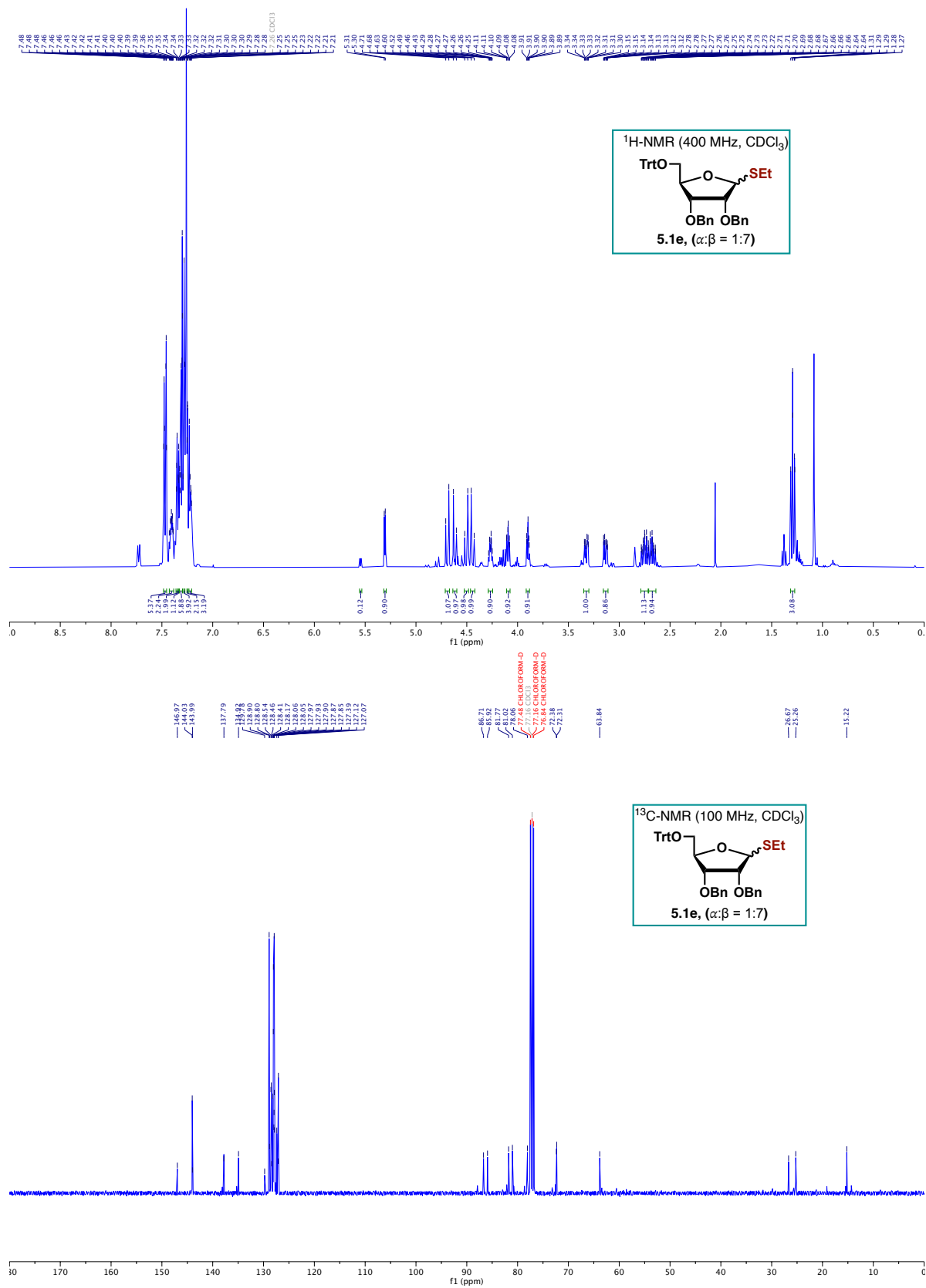
5.5. NMR Spectra of Newly Synthesized Compounds (All the spectra for this chapter are reported in our ChemRxiv)^[79]

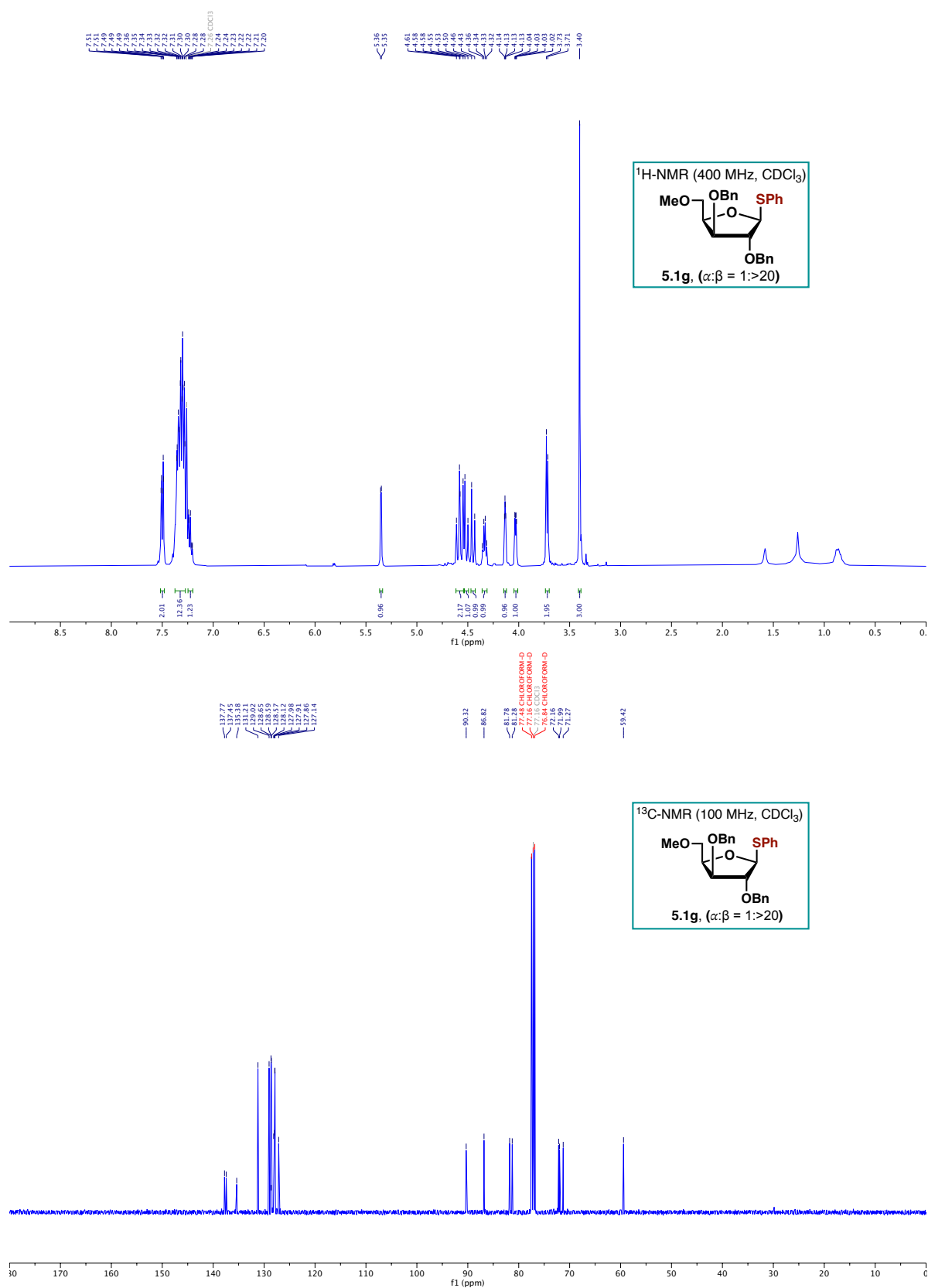


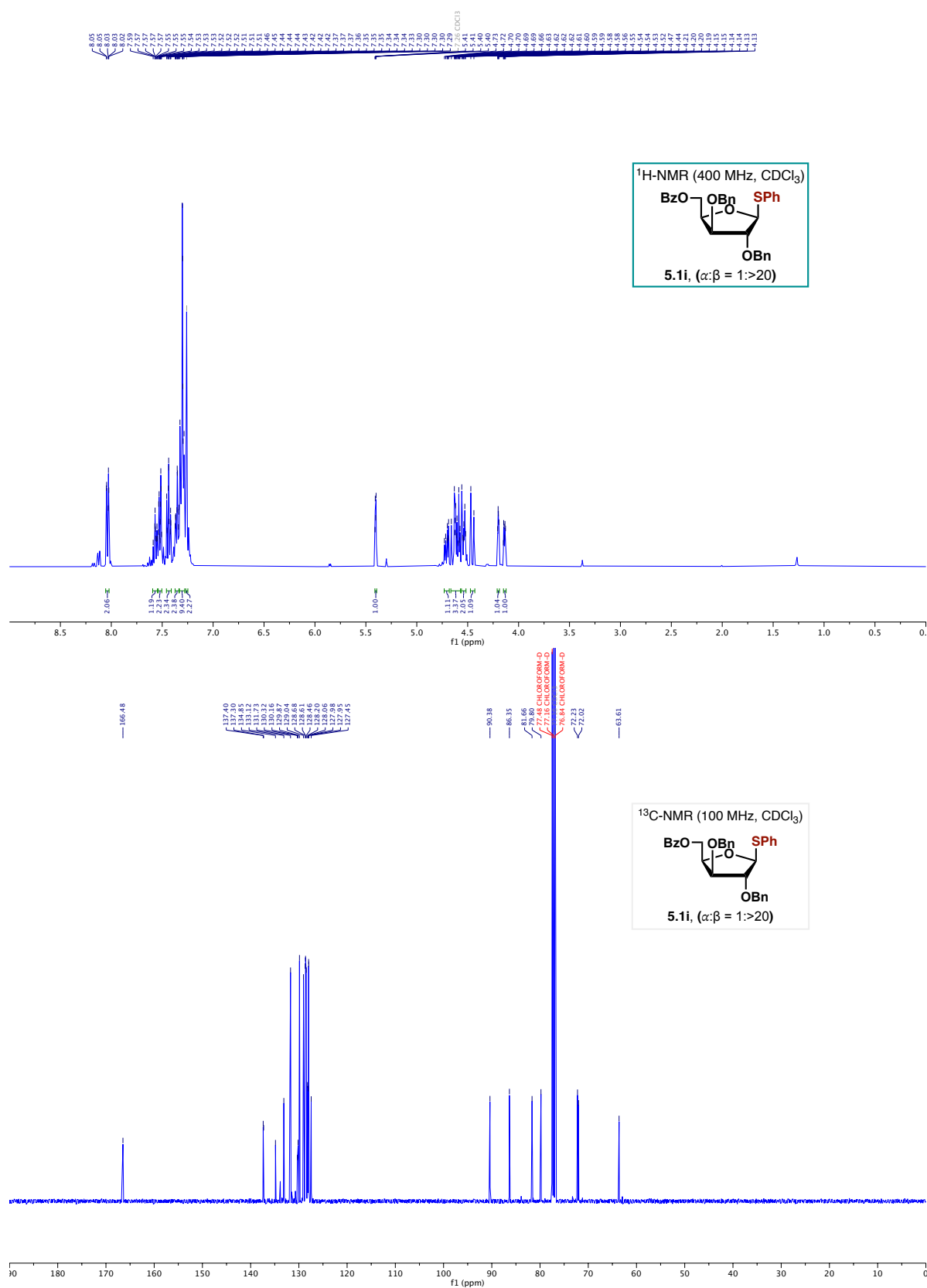


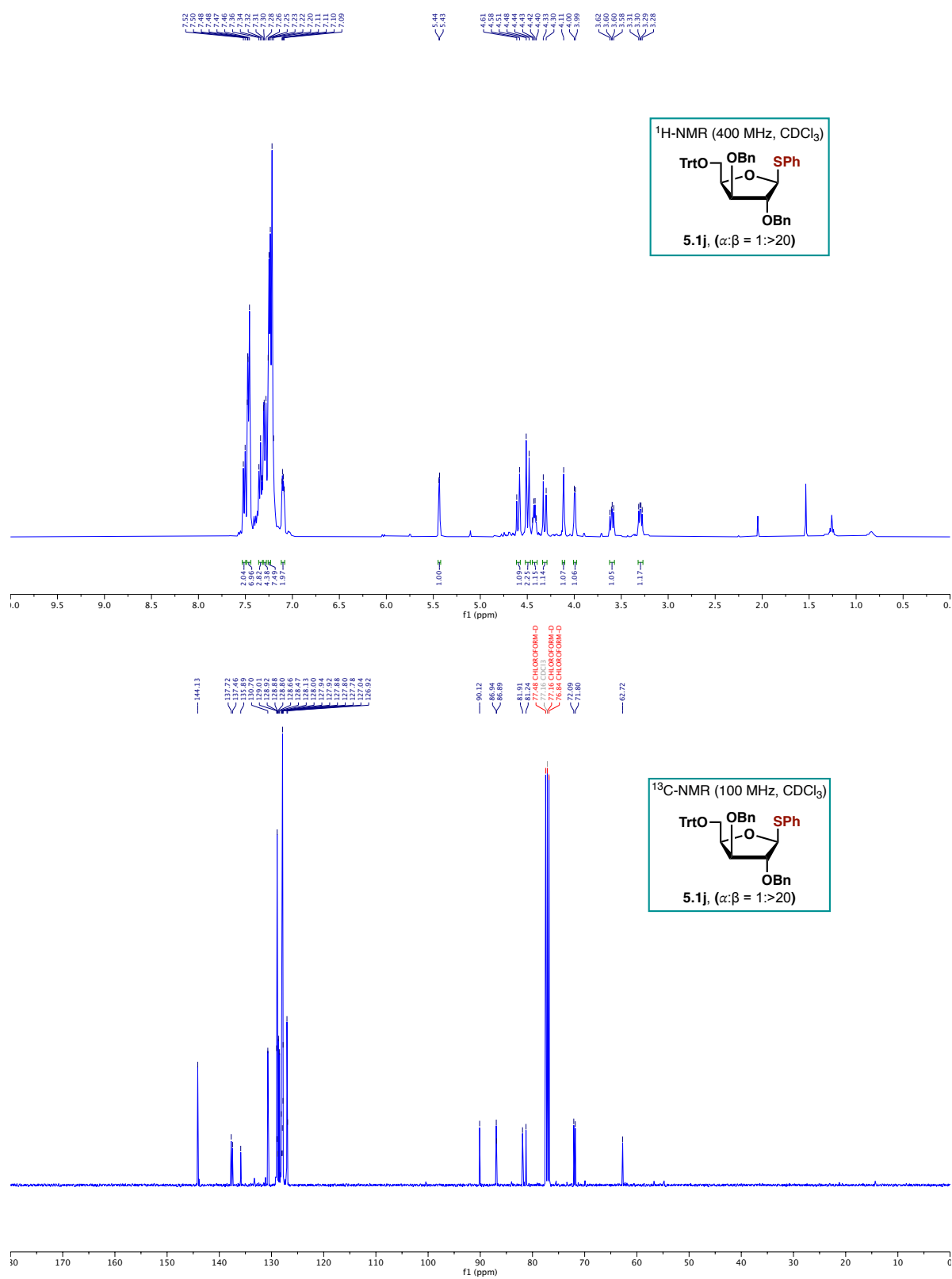


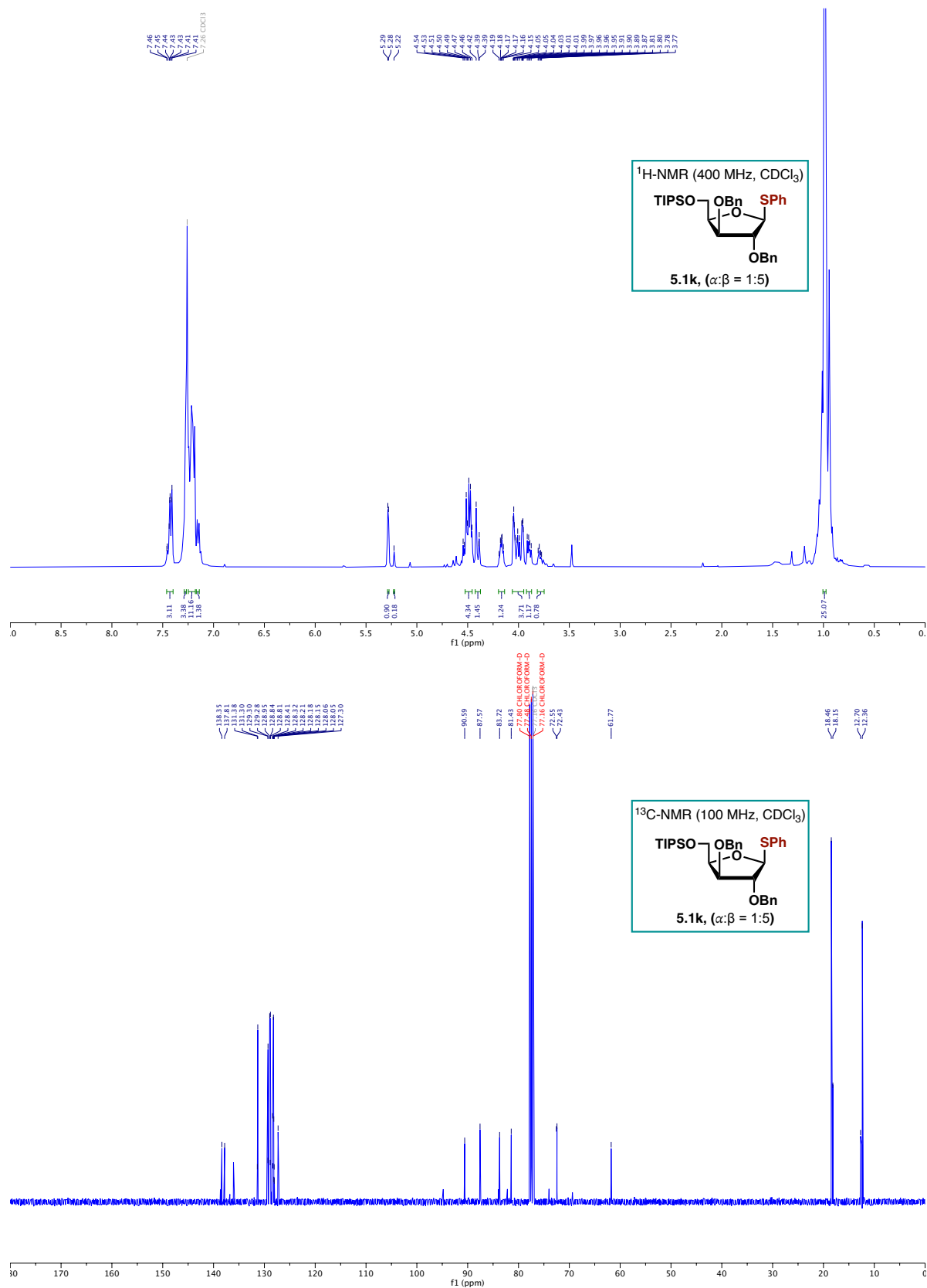
427

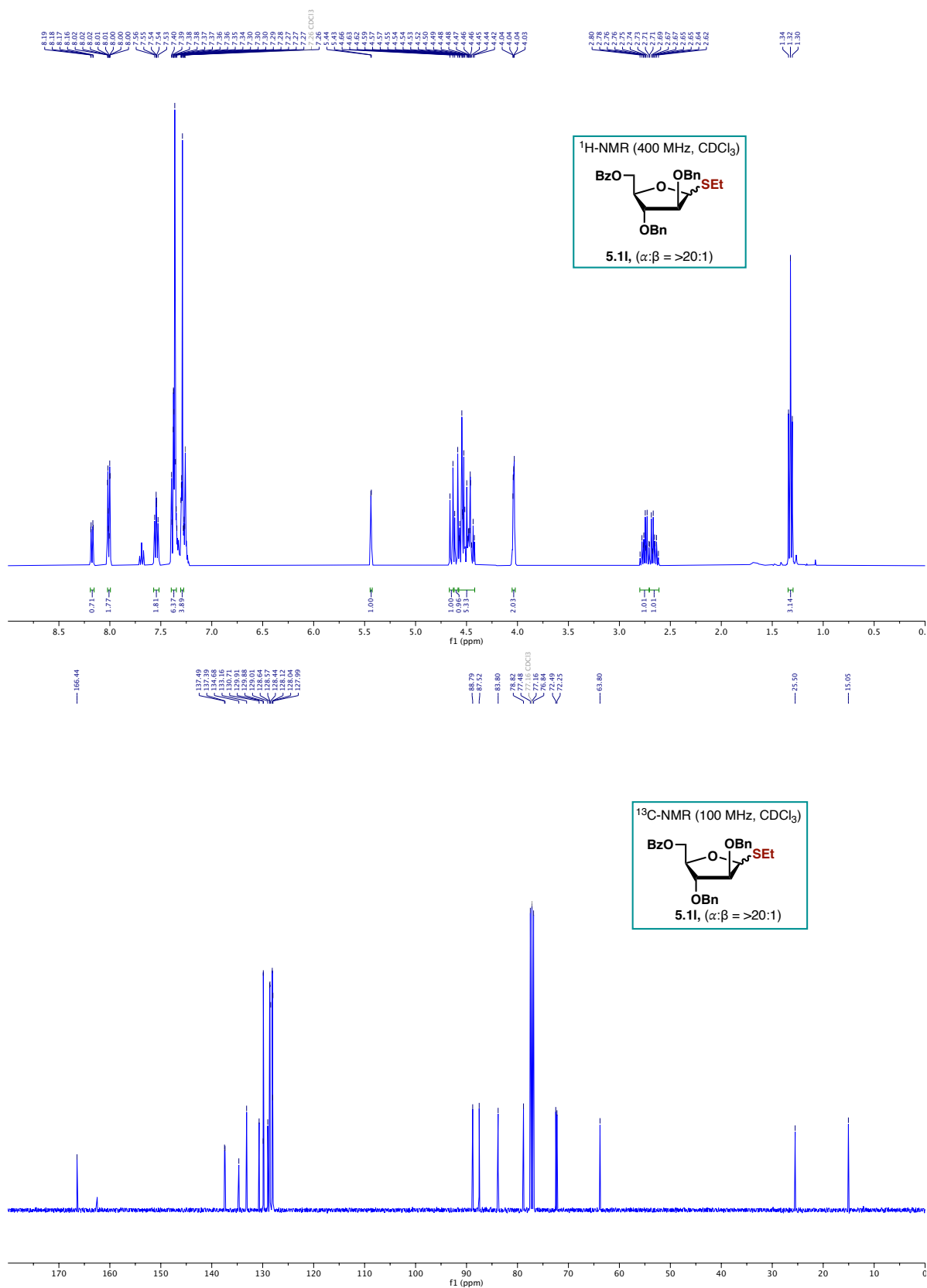


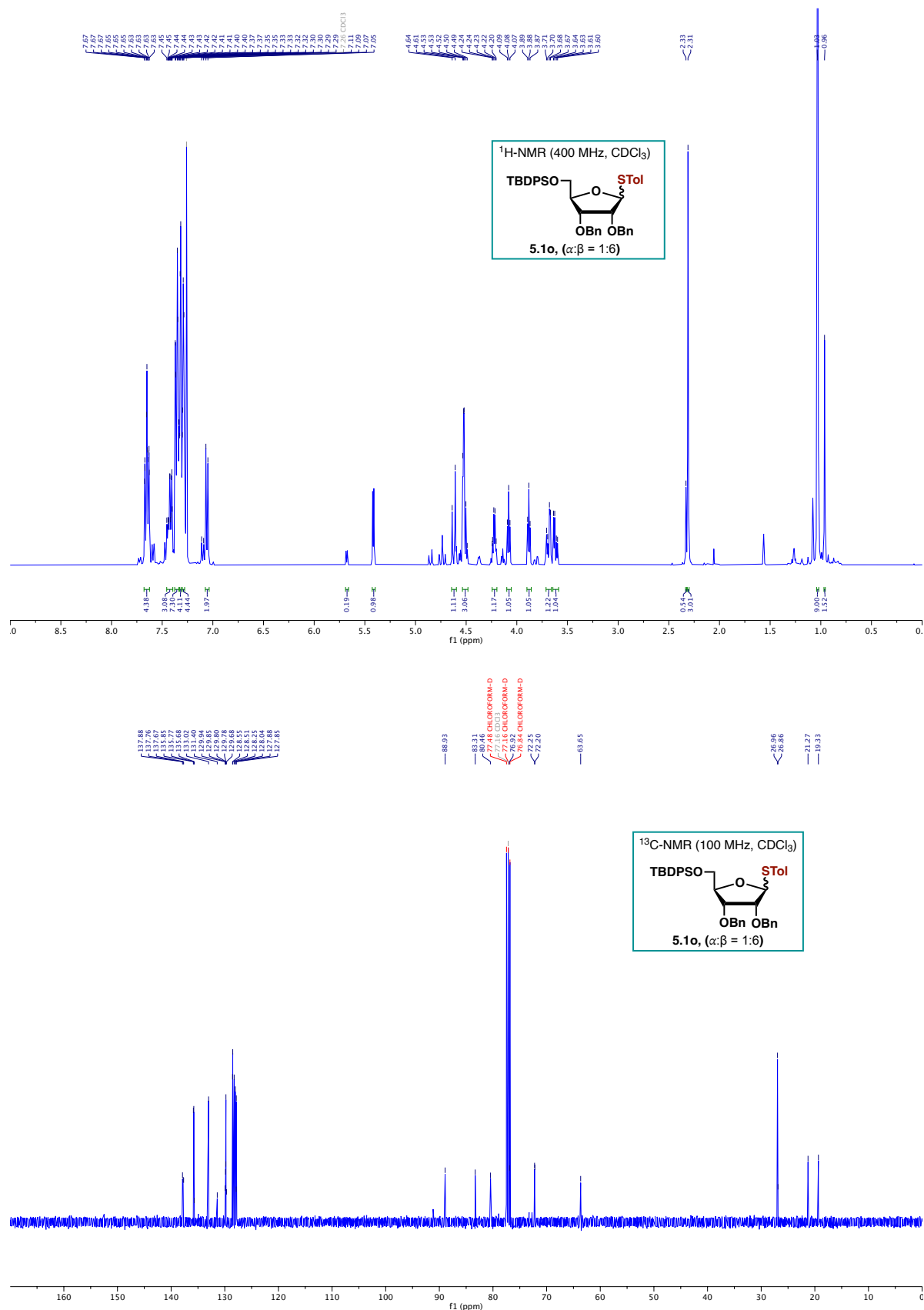


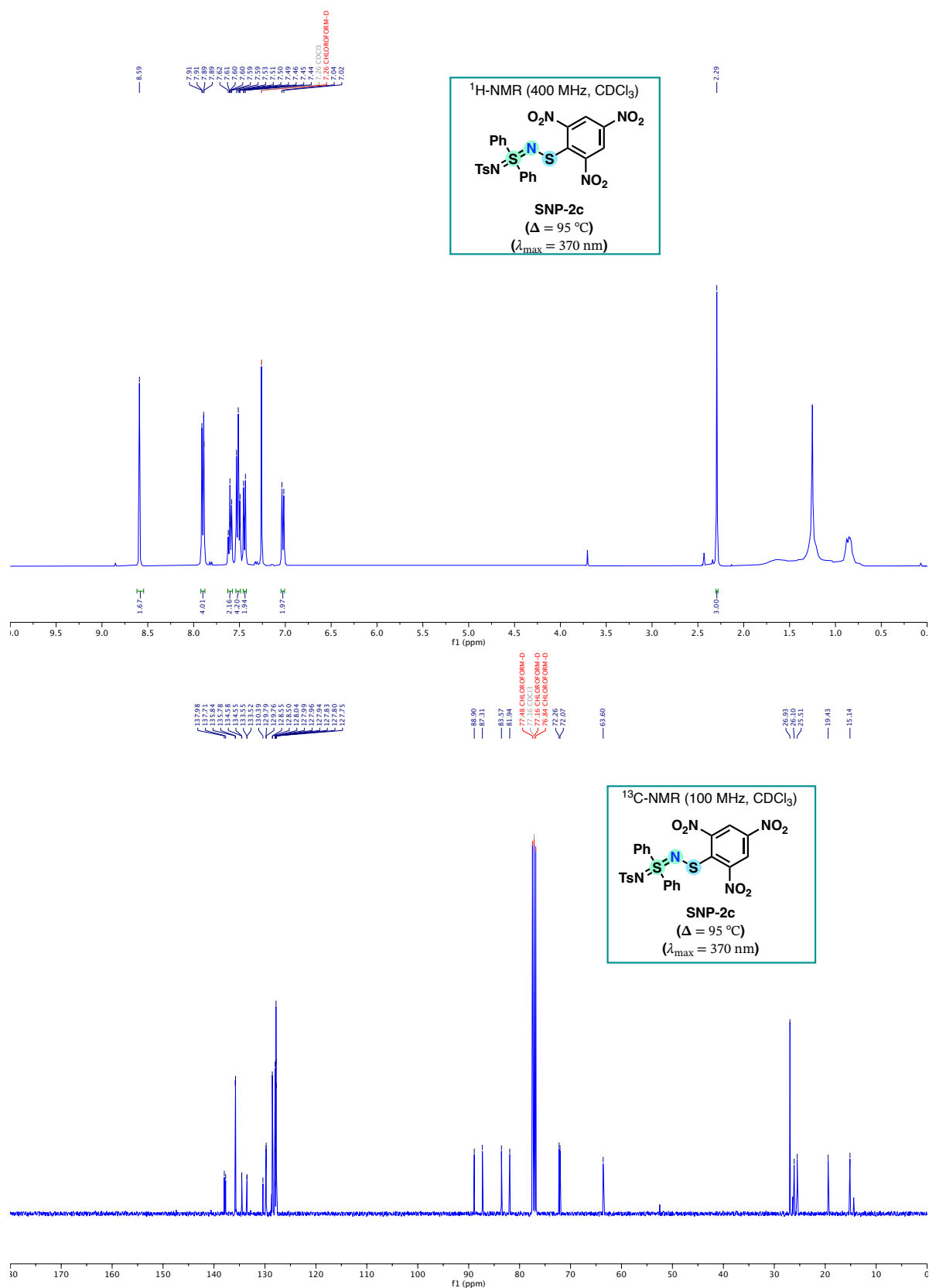


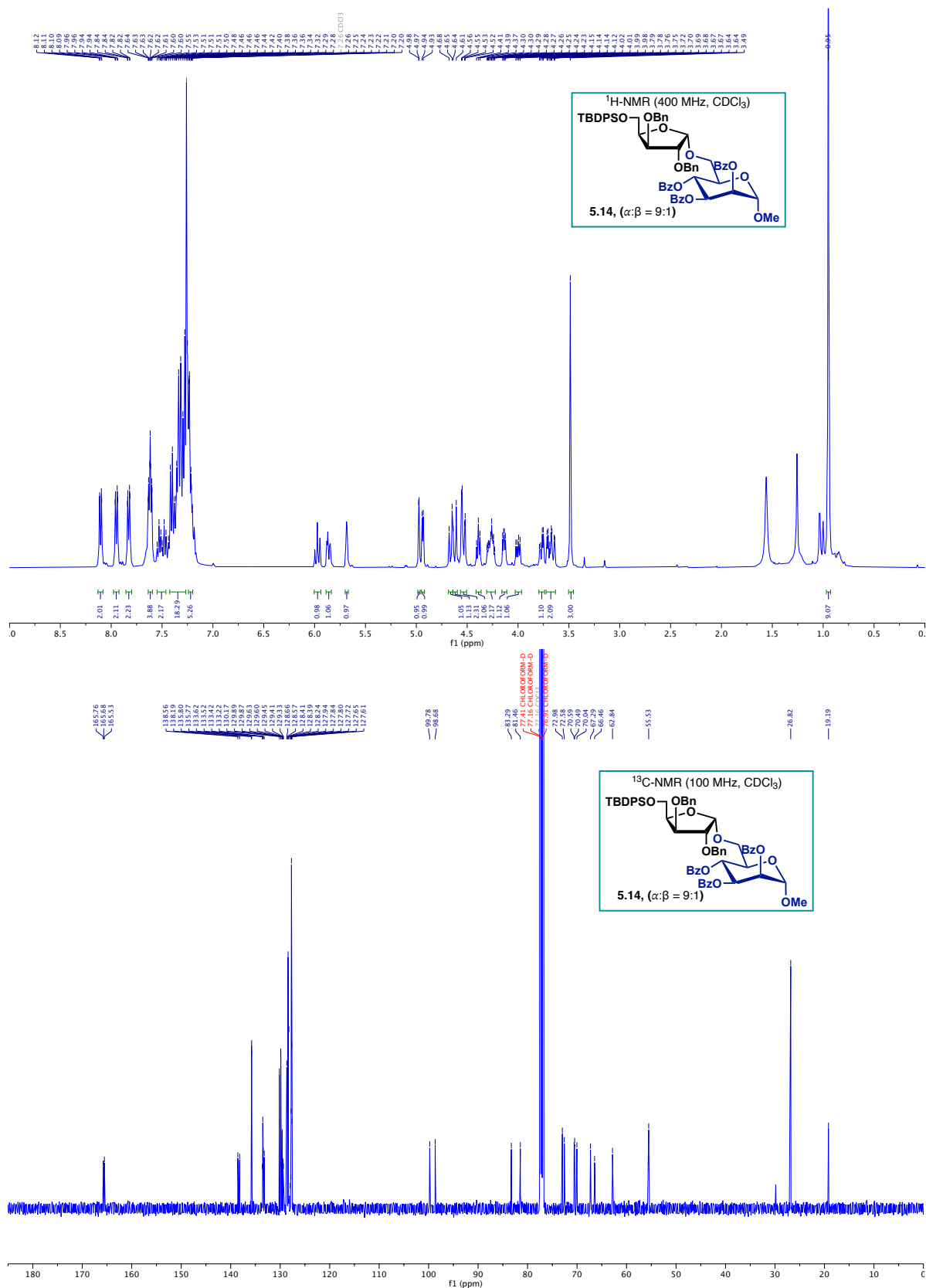


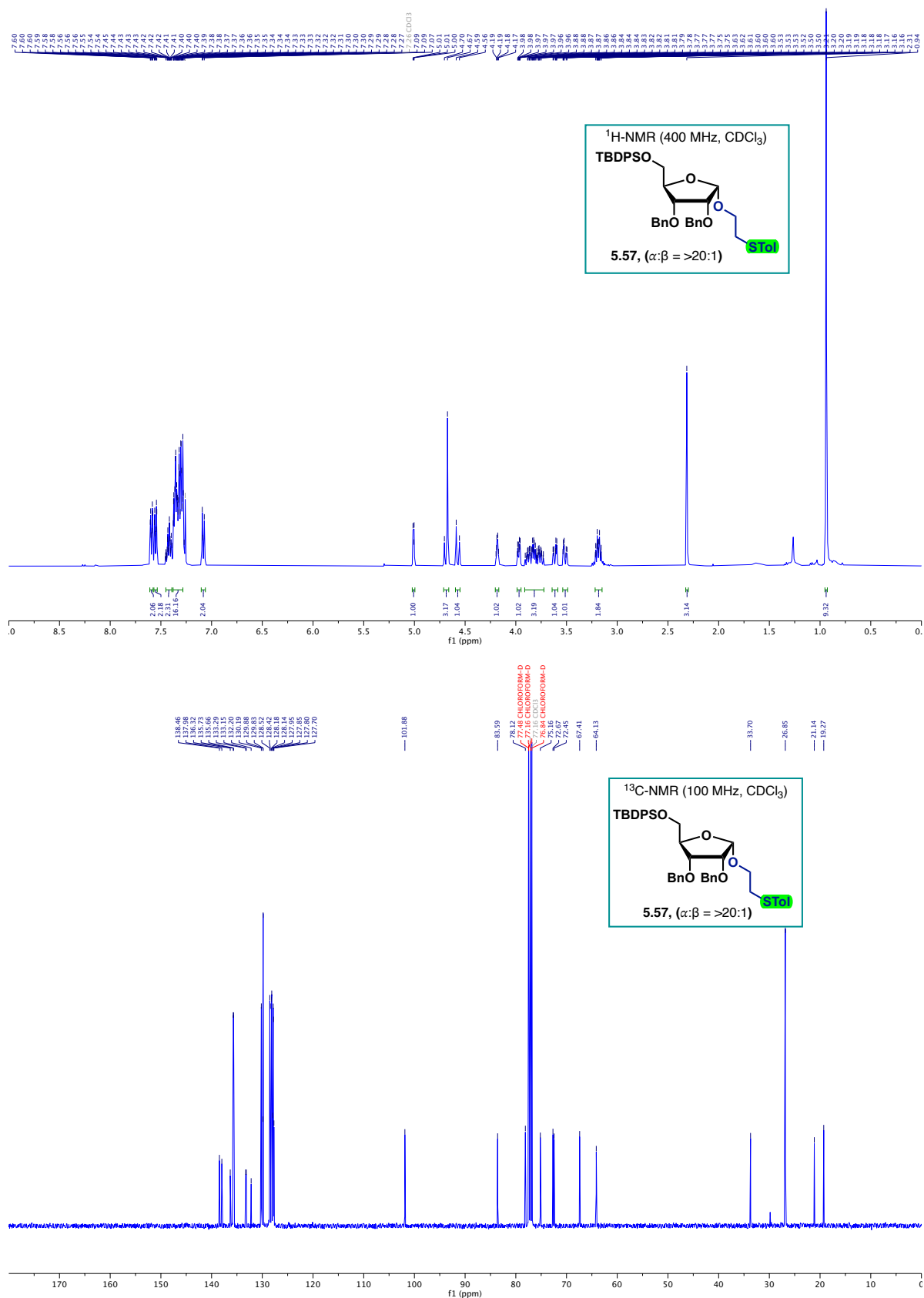












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Education and Training

- 06/2026*- **Post-Doctoral Associate** with Prof. **Tristan Lambert** at Cornell University, Ithaca, NY
“Applications of Electrophotocatalysis”
- 08/2021–05/2026 **PhD in Chemistry** with Prof. **Indrajeet Sharma** at the University of Oklahoma, Norman, OK
“Applications of carbene and nitrene in stereoselective glycosylations”
- 08/2018–04/2021 **Undergraduate Research Assistant** with Prof. **Anand Singh** at the Indian Institute of Technology Kanpur (IITK), Kanpur (Uttar Pradesh), India
“Synthetic Utility of Ketene Dithioacetals”
- 07/2016–05/2018 **M.Sc. in Chemistry** with Prof. **Sriram Kanvah** at the Indian Institute of Technology Gandhinagar (IITGN), Gandhinagar, Gujarat, India
“Branching effect on triphenylamine- CF_3 cyano stilbenes: enhanced emission and aggregation in water.”
- 07/2013–06/2016 **B.Sc. (Honors) in Chemistry**, University of Delhi, India

Fellowships and Awards

- 11/2025 **Finalist and People’s Choice Award Winner, Three-Minute Thesis (3MT) Competition**, University of Oklahoma (OU).
- 05/2025 Selected among the **top 65 fourth-year graduate** students nationwide to present at the **ACS Graduate Research Symposium**, Division of Organic Chemistry.
- 05/2025 Recipient of **DFCAS Dissertation Completion Fellowship** from the University of Oklahoma (OU) (*only 10 awards all over OU*).
- 04/2025 Awarded as a **Premier Scholar Award** in OU for the 2024-2025 academic year.

04/2024	Awarded second time as an <u>Outstanding Organic Teaching Assistant</u> for the 2023-2024 academic year.
05/2023	Awarded as an <u>Outstanding Organic Teaching Assistant</u> for the 2022-2023 academic year.
05/2023	Recipient of DFCAS Dissertation Research Fellowship from the University of Oklahoma (OU) (<i>only 15 awards all over OU</i>).
05/2018-11/2018	Qualified for the CSIR-NET (Council of Scientific and Industrial Research - National Eligibility Test) for the Junior Research Fellowship in December 2017 and June 2018, securing <u>All India Ranks (AIR) of 45 and 63.</u>
07/2018	Secured among the <u>Top-3</u> students in the Master of Science (M.Sc.-Chemistry) batch of 2018 at the Indian Institute of Technology, Gandhinagar (IITGN), India.
03/2018	Qualified for the Indian Institute of Technology (IIT)- GATE (Graduate Aptitude Test for Engineering) 2018 and secured <u>All India Rank (AIR) – 262</u>
03/2018	Awarded the <u>Best Poster</u> at the National Conference on Applied Material Science 2018 , Central University of Gujarat (CUG).
01/2018	Awarded the <u>Best Poster</u> at the National Conference on the Chemistry of Materials and Biologicals 2018 , Indian Institute of Technology, Gandhinagar (IITGN), India.

Publications

Under preparation

21. Singh, S.P.; Chaudhary. U.; Mukherjee, R.; Sharma, I.; Bypassing leaving-group dependence in glycosyl donor activation through chloronium-ion-promoted C–H activation. **2026, *in progress*.**

20. Singh, S. P.; Sharma, I.; Application of carbene and nitrene in glycosylation chemistry, *Chem. Soc. Rev.* **2026, under preparation (review article).**

18. Singh, S. P.; Nilson, D.; Chaudhary, U.; Kharel, P.; Herndon, D.; Chinthamani, S. P.; Chatterjee, U.; Sharma, I.; Photochemical Activation of Chalcogen Glycosides for Stereocontrolled 1,2-*cis* and 1,2-*trans* Glycosylations, **2026, (manuscript under preparation).**

Under review or just accepted

- 18. Singh, S. P.;** Kafle, P.; Sharma, I.; Large-scale efficient synthesis of 9-((2,4-dinitrophenyl)thio)-1,4-dihydro-1,4-epiminonaphthalene, *Org. Synth.* **2026**, (*under revision*).
- 17. Singh, S. P.;** S. P. Chinthamani; Sharma, I.; Iron carbene activation enables stereocontrolled glycosylations from conventional thioglycosides, *Eur. J. Org. Chem.* **2026**, (*just accepted*).
- 16. Singh, S. P.;** Kharel, P.; Sharma, I.; Photochemically generated sulfenyl nitrene unlocks chemoselective activation of conventional thioglycosides for 1,2-*cis*-furanosylations, *Angew. Chem. Int. Ed.* **2026**, (*just accepted*).
- 15. Singh, S. P.;** Chatterjee, U.; Sharma, I.; TEMPO-promoted thioacid–amine coupling for peptide synthesis, *Org. Chem. Front.* **2026**, (*under revision*).

Published

- 14. Singh, S. P.;** Kharel, P.; Chatterjee, U.; Sharma, I. Harnessing photochemically generated sulfenyl nitrene for stereocontrolled 1,2-*cis* glycosylations, *ChemRxiv* **2025**, DOI: 10.26434/chemrxiv-2025-3429x.
- 13. Singh S. P.;** Chaudhary. U.; Daróczy A.; Sharma I.; Iron-catalyzed iodonium ion promoted activation of conventional thioglycosides for stereoselective 1,2-*cis* furanosylations, *Chem. Commun.* **2025**, 61, 9638.
- 12. Singh S. P.;** Chaudhary. U.; Chance W. L.; Daróczy A.; Shao Y.; Sharma I.; Iron-carbene-mediated catalytic activation of conventional thioglycosides for stereoselective 1,2-*cis*-furanosylations, *ACS Catal.* **2025**, 15, 9886.
- 11. Singh S. P.;** Chaudhary. U.; Daróczy A.; Sharma I.; Fe(OTf)₃ or Photosensitizer-free blue light activated diazo-thioglycoside donors for iterative and stereoselective glycosylations. *Nat. Commun.* **2025**, 16, 3651.
- 10. Singh, S. P.;** Herndon, D.; Chatterjee, U.; Nicholas, K. M.; Sharma, I. Investigating the reactivity of nitrous oxide with lithiated hydrazines: application to the synthesis of diarylethanes from diarylmethylhydrazines. *New. J. Chem.* **2025**, 49 (4), 1182-1188.
- 9. Singh, S. P.;** Chaudhary, U.; Sharma, I. Catalytic thioglycoside activation with diazo-derived copper carbenes. *Molecules* **2024**, 29 (22), 5367.
- 8. Attah, S. I.;** Okoro, U. C.; Onoadbedje, E.; Ugwu, D.; **Singh, S. P.;** Eze, C. C.; Ibeji, C. U.; Okonkwo, V. I.; Akor, J.; Novel dipeptides incorporating sulphonamide functionality: synthesis, biological and computational studies. **2024**, Pre-print <http://dx.doi.org/10.2139/ssrn.4395192>.
- 7. Singh, S. P.;** Ghosh, B.; Sharma, I., Catalytic orthogonal glycosylation enabled by enynal-

derived copper carbenes, *Adv. Synth. Catal.* **2024**, 366 (8), 1847-1856.

6. Singh, S. P.; Arora, S.; Singh, A., FeCl₃-catalyzed three-component synthesis of chromanes and dihydrocoumarins, *Asian J. Org. Chem.*, **2023**, 12(8), p.e202300279.

5. Singh, S. P.; Arora, S.; Bhardwaj, P. K.; Singh, A., Annulation of *ortho* and *para*-quinone methides with 2-benzylidene dithiolanes: synthesis of spiro chroman dithiolanes, *Org. Biomol. Chem.*, **2023**, 21, 4962.

4. Singh, S. P.; Arora, S.; Sharma, P.; Singh, A., Brønsted acid-catalyzed annulations of ketene dithioacetals: synthesis of 3-aryl coumarins and indenenes, *Org. Biomol. Chem.* **2022**, 20 (45), 8907-8911.

3. Attah, S. I.; Okoro, U. C.; **Singh, S. P.**; Eze, C. C.; Ibeji, C. U.; Ezugwu, J. A.; Okenyeka, O. U.; Ekoh, O.; Ugwu, D. I.; Eze, F. U., Pro-Gly based dipeptide containing sulphonamide functionality, its antidiabetic, antioxidant, and anti-inflammatory activities. Synthesis, characterization, and computational studies, *J. Mol. Struct.* **2022**, 1264, 133280.

2. Balasubramaniam[†], B.; Prateek[‡]; Ranjan, S.; Saraf, M.; Kar, P.; **Singh, S. P.**; Thakur, V. K.; Singh, A.; Gupta, R. K., Antibacterial and antiviral functional materials: chemistry and biological activity toward tackling COVID-19-like pandemics, *ACS Pharmacol. Transl. Sci.* **2020**, 4(1), 8-54.

1. Kumari, B.; **Singh, S. P.**; Santosh, R.; Dutta, A.; Mallajosyula, S. S.; Ghosal, S.; Kanvah, S., Branching effect on triphenylamine-CF₃ cyano stilbenes: enhanced emission and aggregation in water, *New J. Chem.* **2019**, 43(10), 4106-4115

Outreach Activities and Teaching Experience

07/2022-12/2024	Trained Eight Junior Graduate Students and Two Undergraduate Students in the Sharma Lab.
06/2022	Hosted the <u>NSF-funded</u> "Summer Research Camp" for High School Students at the University of Oklahoma.
07/2022-05/2025	Teaching Assistant for Organic Chemistry I (CHEM 3152) (3-Year Experience).
07/2021-05/2022	Teaching Assistant for General Chemistry I (CHEM 1315) (1-Year Experience).