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ORAZIO GRASSI AND A 1623 *TREATISE ON THE SPHERE*: ASTRONOMY AND PHYSICO-MATHEMATICS AT THE *COLLEGIO ROMANO* IN THE EARLY SEVENTEENTH CENTURY

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ORATIO GRASSI AND A 1623 *TREATISE ON THE SPHERE*: ASTRONOMY AND PHYSICO-MATHEMATICS AT THE COLLEGIO ROMANO IN THE EARLY SEVENTEENTH CENTURY

A THESIS APPROVED FOR THE
HISTORY OF SCEINCE

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Abstract

The University of Oklahoma History of Science Collections recently acquired a 1623 manuscript which has been attributed to the Jesuit mathematician Orazio Grassi. The first section of the manuscript, entitled "Tractatus de sphaera" or "Treatise on the sphere," is a fair copy of student notes on spherical astronomy. As such, it is a significant new primary source for understanding the teaching of astronomy at the Collegio Romano in the seventeenth century. Through a physical examination of the manuscript, critical discussion of its subject matter and comparison with other Jesuit writings, this thesis argues that Orazio Grassi was teaching physico-mathematics in his astronomy course at the Jesuit Roman College in 1623 as part of a concerted effort started by Christopher Clavius and institutionalized in Jesuit education. Jesuit educators such as Orazio Grassi were actively introducing novel observations and contemporary discoveries to astronomy students in the early seventeenth century.

Introduction

The Society of Jesus, also called the Jesuits, was an order of the Catholic Church established in the mid-sixteenth century by Ignatius of Loyola. Because of its association with the Catholic Church and the trial of Galileo, many historians have discussed the significance of the Society of Jesus for the history of science. Early histories of the Jesuits mainly discussed the Jesuits as Catholic reactionaries to Protestantism and the Scientific Revolution. However, more recent studies have also shown that the Catholic Church fostered medieval and early modern science, and Jesuits such as Christopher Clavius (1538-1612), were actively involved in the development of early modern science.[1] Other studies have revealed that science was considered a fundamental aspect of Jesuit culture and education, and that the Jesuits were actively involved in the science of their time.[2] In all of these narratives Jesuit education and its

[1] John Heilbron has discussed the importance of the Catholic Church and the Jesuit order in fostering medieval and early modern science in *The Sun in the Church: Cathedrals as Solar Observatories*. (Cambridge, Mass.: Harvard University Press, 1999). William Wallace has discussed the importance of Clavius and the Jesuit educational system in the development of Galileo's natural philosophy. See William A. Wallace, *Galileo, the Jesuits, and the Medieval Aristotle*. (Collected Studies; CS346. Hampshire, Great Britain: Brookfield, Vt.: Variorum; Gower, 1991) and *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo's Science*. (Princeton Legacy Library. Princeton, N.J.: Princeton University Press, 1984). James Lattis' study of the Jesuit mathematician Chritopher Clavius places Clavius between Copernicus and Galileo as a significant figure in the history of science not only for his role in the reformation of the calendar but also of early modern applied mathematics. See James M. Lattis, *Between Copernicus and Galileo: Christoph Clavius and the Collapse of Ptolemaic Cosmology*. (Chicago: University of Chicago Press, 1994).

[2] John O'Malley and his contributors have dedicated two separate volumes to examining the significance of the Society of Jesus. In both, science is considered a fundamental aspect of Jesuit culture. See John W. O'Malley, Gauvin Alexander Bailey, Steven J. Harris, and T. Frank Kennedy. *The Jesuits: Cultures, Sciences, and the Arts, 1540-1773*. (Toronto: University of Toronto Press, 1999) and *The Jesuits II Cultures, Sciences, and the Arts, 1540-1773*. (Toronto; Buffalo; London: University of Toronto Press, 2006). Mordechai Feingold and others show that the Jesuits were well educated and well connected in the scientific communities of the sixteenth and seventeenth centuries and that the Jesuits were actively involved in the science of their time; Mordechai Feingold, *The New Science and Jesuit Science: Seventeenth century Perspectives*. (Archimedes, New Studies in the History and Philosophy of Science and Technology; 6. Dordrecht: Springer Netherlands, 2003) and *Jesuit Science and the Republic of Letters*. (Transformations. Cambridge, Mass.: MIT Press, 2003).

educators played a vital role in both the Society of Jesus and the development of early modern science.

Jesuit involvement in the development of early modern science has now been connected to the trend away from Aristotelian physics toward a “physico-mathematics,” a turn of the century movement aimed at the physicalization of mathematical principles. John Schuster has examined the role of Jesuit education from a philosophical standpoint in his recent study of Descartes’ optics.[3] As traditional Aristotelean and Ptolemaic cosmologies were being increasingly criticized in the early modern period resulting in a movement away from earlier ways of thinking. At the core of this movement was the concept that “the mixed mathematical sciences offered windows into the realm of natural philosophical causation in the sense that one could read natural philosophical causes out of geometrical representations of such mixed mathematical results, and hence, in a way, ‘see the causes’.”[4]

Physico-mathematics as taught by Clavius and his students differed from mixed mathematics in the tradition of Aristotle by increasing the status of mathematics so that it was no longer subordinated to physics. Previously, mixed mathematics had been subalternate to natural philosophy because its proofs were not based on universal statements commonly evident to all, for example heavy bodies fall. Independent observations of natural phenomena could not be accepted as universally evident because they required expert knowledge. They were the result of contrived experience expressed in historical reports that could be easily fallible. Mixed mathematics in this system

[3] John Schuster. “Physico-mathematics and the Search for Causes in Descartes’ Optics 1619-1637.” *Synthese* 185, no. 3 (2012): 467-99.
[4] Schuster. “Physico-mathematics and the Search for Causes in Descartes’ Optics 1619-1637,” 469.

could serve natural philosophy but it could not make causal claims about nature. However, Clavius and his followers claimed parity for physico-mathematics and Aristotelian natural philosophy expressly because mathematical proofs were considered by many of their contemporaries to be one of the most certain kinds of demonstration.

Schuster did not consider this physico-mathematic movement "a coherent, self-conscious intellectual movement, but a diffuse set of gambits and agendas sitting loosely inside the field of natural philosophizing."[5] Peter Dear has extensively studied the influence of Clavius on the status of mathematics at the *Collegio Romano*, as well as the role of Jesuit mathematicians in advancing a physico-mathematic movement in the seventeenth century.[6] The Jesuit emphasis on physico-mathematics coupled with their influence as a world-wide organization with hundreds of colleges had far reaching implications for the history of early modern science. Dear argued that "the shifts in the concept of experience among Jesuit mathematicians impinge directly on the implications of moving from a scholastic to a characteristically early-modern natural philosophical paradigm. They also help to explain how mathematical models of scientific practice became so closely implicated in the new ideology of natural knowledge that had emerged by the end of the seventeenth century."[7]

The studies performed by Dear and others show Schuster's assessment of the Jesuit physico-mathematics movement as an unorganized and incoherent set of gambits to be incorrect. In fact, Clavius along with many of his fellow Jesuit mathematicians pushed to institutionalize their physico-mathematics views in the curriculum of the

[5] Schuster, "Physico-mathematics and the Search for Causes in Descartes' Optics 1619-1637," 471.
[6] Peter Dear. *Discipline & Experience: The Mathematical Way in the Scientific Revolution*. Science and Its Conceptual Foundations. (Chicago: University of Chicago Press, 1995).
[7] Dear, *Discipline and Experience*, 32.

Jesuit educational system; Clavius, his fellows, and his students were part of a coherent physico-mathematic movement. Jesuit mathematicians argued, following Clavius' lead, that mathematics was a science on par if not higher than natural philosophy because mathematical proofs were more reliable than philosophical reasoning. The physico-mathematical movement of the Jesuits was a concerted effort to apply mathematical proofs to what would otherwise have been mixed mathematical discussions. In this way observational evidence that would not have been acceptable in mixed mathematics was given credibility by applying known geometrical proofs to observations of physical objects. Proponents Aristotle's mixed mathematics separated the physical body of the moon and the mathematical concept of a sphere. If spheres existed at all it was in a separate mathematical realm, not in nature. By contrast Clavius and his followers asserted that the physical object was itself spherical. The combination of observational evidence and geometrical proofs was used by Jesuit physico-mathematicians to argue that their science could make natural philosophical claims.

Although the role of the Jesuit education in mathematics, and particularly in astronomy in the early seventeenth century has been discussed by some, because it is of paramount importance for the history of astronomy more study should be given to the role of the Jesuits and their educational culture as promoters of physico-mathematics. The recent acquisition by the University of Oklahoma History of Science Collections of

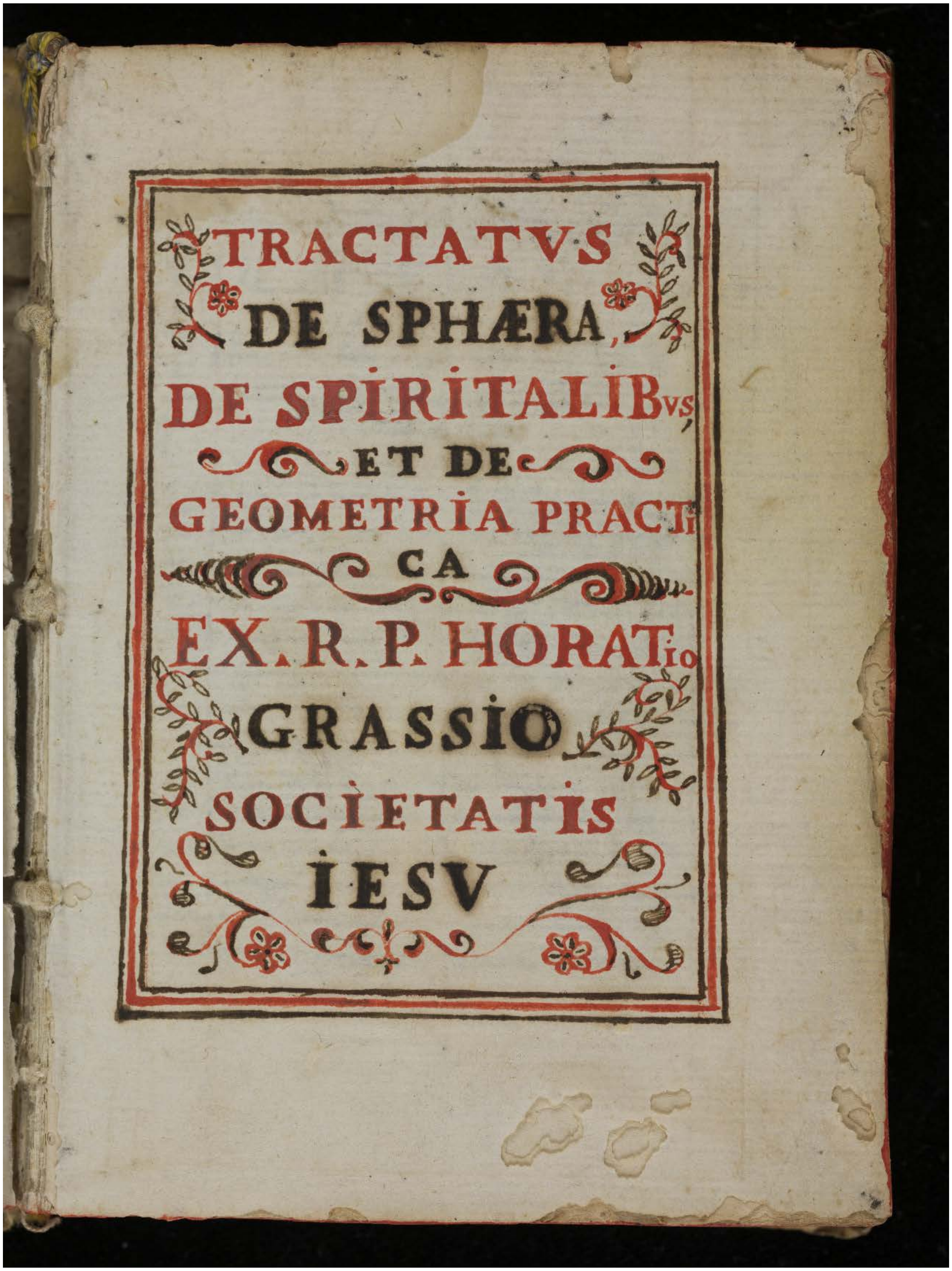

Figure 1: The general title page of the 1623 manuscript. Grassi, *Mathematica*, tp.

a 1623 manuscript record of student notes from the Jesuit *Collegio Romano* titled *Mathematica* adds new primary evidence to the discussion of early modern Jesuit education and Jesuit scientific practice. This manuscript is a fair copy of student notes from a series of lectures by Orazio Grassi (1583-1654), one of Clavius' successors who taught mathematics at the *Collegio Romano* in the early seventeenth century. [8] The *Mathematica* is divided into four sections: *Tractatus de sphaera, De spiritalibus, De geometria practica*, and *De mensuris corporum et solidorum.* The first section of the manuscript, the *Tractatus de sphaera*, is a record of Grassi's introductory astronomical lectures on the *Sphere* of Sacrobosco and is the main focus of this study, especially the third chapter of this treatise because of its discussion of novel astronomical observations in the early seventeenth century. Grassi's lectures on the *Sphere* of Sacrobosco reflect the contemporary physico-mathematic movement that was taking shape in the early seventeenth century at the *Collegio Romano*. Through a physical examination of the manuscript, a critical discussion of its subject matter and comparison with other Jesuit writings, it is clear that Orazio Grassi was teaching physico-mathematics in his astronomy course at the *Collegio Romano* in 1623 as part of an institutionalized tradition begun by Christopher Clavius. This thesis concludes that, based on the evidence found in this manuscript, Jesuit mathematicians were practicing their own

[8] The manuscript is currently held in the History of Science Collections at the University of Oklahoma, acquired in 2015. The codex is stored in a box container labeled "Grassi (1623)." I have chosen to refer to this manuscript by its label, *Mathematica*, in some cases in an effort to highlight that although Grassi is attributed the authorship of three of the four texts of the codex, there is no evidence that Grassi was involved in the production of this manuscript beyond the role of authoring its content. The label *Mathematica*, then, is meant to recognize the producer and reader of this codex, which is an important factor in this study, and the possibility that some of the content was authored by someone other than Grassi.

physico-mathematic science and teaching these methodologies at the university in Rome, demonstrating the utility of physico-mathematics to their students.

Physical Description

Because this manuscript was previously held in a private collection, it is necessary to begin with a description of the manuscript in order to establish its provenance.[9] Because the seller did not provide a detailed history of this manuscript, any information regarding its provenance must be gleaned from the material object itself and its contents. The physical construction, content and layout of the manuscript suggest that it is a fair copy of notes produced by a Jesuit student of Orazio Grassi at the *Collegio Romano* in the early seventeenth century.

The first indication of *Mathematica*'s provenance is apparent in its physical construction. The manuscript consists of 100 unnumbered paper folios bound inside a limp leather cover into a codex labeled *Mathematica* on the top of the spine.[10] The folios, many of which have catchwords in the bottom right hand corner, each measure 126mm tall and 90mm wide. The *Mathematica* contains 13 quires in total, the majority of which contain 8 folios each. The exceptions are the last quire, which contains only four folios, and the general title page, which is sewn into the first quire.[11] The codex

[9] Throughout this thesis I have provided reproductions of relevant pages of Grassi's lectures and I have chosen not to crop or adjust the images of its pages in an effort to highlight the unique character of the codex for historians of the book. There is a list of numbers written in pencil, resembling a call number, located on the front pastedown of the codex that reads "/4884 ILLL/2." Although I have not been able to discover the source of this text, it may offer more insight as to the provenance of the codex.

[10] Due to the absence of pagination, references are based on their physical location in relation to the first folio of text. For example, the first page of chapter 1 is referenced as "Grassi, *Tractatus de sphaera,* 1r."

[11] The exact quire structure is as follows: Quire 1 (1r-8v) The general title page was added independent of the first quire and was sewn in at the end of the first quire along with the front pastedown. The *Tractatus de sphaera* begins on 1r of the first quire; Quire 2 (9r-16v); Quire 3 (17r-24v); Quire 4 (25r-32v) The second section, *De machinis spiritalibus* begins on 28r; Quire 5 (33r-40v); Quire 6 (41r-48v); Quire 7

would have been small enough to be carried by one hand or easily pocketed, which would have made it both more affordable and easier to carry.[12] Although the manuscript exhibits some signs of wear on the cover and minor deterioration of the pages, it is overall in good condition suggesting that it was lightly used.[13]

The text is written in long lines in a very legible script, in a conventional style and with no more than 23 lines of script on each page.[14] Occasional blotches can be found in the codex, although these blotches rarely obscure the script. Grammatical corrections appear in a number of formats within the work. Most often these take the form of blacking or crossing out an incorrect word, followed by the corrected script in the same line. Other corrections were inserted later and appear as insertions above the text or in the margins.[15] For some of the marginal corrections, an asterisk was used to lead the reader to the margin for the corrected script.[16] None of these corrections appear to be distinguishable from the primary script in the *Mathematica* suggesting that the same writer who penned the original script also made the marginal corrections. The occasional blotches and corrections are evidence that the *Mathematica* was not an

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(49r-56v); *Summa geometriae practicae* begins on 49r; Quire 8 (57r-64v); Quire 9 (65r-72v); Quire 10 (73r-80v); Quire 11 (81r-88v) *De mensuris corporum et solidorum* begins on 84v; Quire 12 (89r-96v); Quire 13 (97r-99v) This quire also includes the rear pastedown which was glued to the back cover.

[12] Since the exact dimensions of the codex measure 127mm in height, 96mm in width, and 12.7mm in length, it could easily fit into a pocket or be carried in a single hand.

[13] The cover exhibits some signs of wear and deterioration on the edges. Many of the folios are visibly worn and in some cases damaged on the edges which is evident from the included images below. This type of damage is most apparent in the sections closest to the binding which may be taken as evidence that this manuscript may have travelled or circulated for a time. There is a slight foxing on all the folios which originates from the side opposite of the spine and proceeds inward almost reaching the edge of the script. There are also some signs of water damage on the upper side of the folios which spreads from the binding edge diagonally a third of the way down the page.

[14] All the folios show signs of lead ruling, possibly mechanical, which aid in the legibility of the script. The writer used of a number of conventional abbreviations. For example, the writer used macrons to signify that the reader should understand that an *n* or *m* be inserted behind an abbreviated word, with longer strokes indicating that several letters had been omitted in abbreviating a common word. The writer also employed a colon in place of a hyphen to signify the continuation of a word on the next line.

[15] Grassi, *Mathematica*, 1v, 37v, 66r, and 88r.

[16] Grassi, *Mathematica*, 3r and 6v.

official copy of Orazio Grassi's lecture notes, but rather a personal copy of student notes. That a student wrote this manuscript and not Grassi himself is also supported by a comparison of the handwriting in the *Mathematica* and one of Grassi's autographed letters which exposes significant differences in style, especially regarding the construction of the *p*'s and *q*'s.[17]

As mentioned above, the *Mathematica* contains four sections: *Tractatus de sphaera, De machinis spiritalibus, De geometria practica,* and *De mensuris corporum et solidorum,* respectively.[18] Only the first three sections are listed on the general title page and attributed to Father Orazio Grassi.[19] No date or location is given on the general title page of the *Mathematica* but, a colophon at the end of the *Tractatus de sphaera* divulges that the contents record material presented "in the *Collegio Romano* by Father Orazio Grassi of the Society of Jesus, on the 2nd day of June, 1623."[20] Based on the location of this information at the end of the section, this date presumably corresponds to the last date of a series of lectures given by Grassi on the *Sphere* of Sacrobosco while he was teaching at the *Collegio Romano.*

Although none of the other sections have colophons or dates that corroborate the 1623 date given in the *Tractatus de sphaera,* another manuscript record of Grassi's *Tractatus de sphaera* held at St. John's College at Cambridge corroborates the date in

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17 A photograph image of this autographed letter addressed to Giovanni Battista Balinani which is dated 1648 can be found in Redondi, *Galileo Heretic*, 50-51.
18 "Treatise on the Sphere, Concerning the Pressures of Machines, Concerning Practical Geometry, and Concerning the Measuring of Bodies and Solids"
19 Grassi *Mathematica*, 0tp. The fourth section, *De mensuris corporum et solidorum* is not listed on the general title page and cannot be attributed to Grassi without further evidence.
20 Grassi, *Tractatus de sphaera*, 27v. See Figure 2.

the colophon of the OU manuscript.[21] Though this does not necessitate that the manuscripts were bound in the same year, the St. John's manuscript does corroborate the authenticity of Grassi's *Tractatus de sphaera* as well as the authorship of the second section of the *Mathematica*, *De machinis spiritalibus.* The latter appears as the second section in the St. John's manuscript as well, and gives the year 1623, but no date.[22] The St. John's manuscript also suggests that those notes were written while Grassi was teaching. The title page of the astronomy lectures in the St. John's manuscript uses the terms *dictante'* and *scribente' auditori* to describe the manner in which the manuscript was produced indicating that the St. John's manuscript was penned from Grassi's dictation in the classroom.[23] However, this evidence is not conclusive and a more thorough comparison and collation of these manuscripts needs to be performed. Still, these manuscripts were most likely copies of notes bound together by students after the end of their mathematic instruction.

While the exact date the *Mathematica* notes were bound into their current form is unknown, the watermarks on the leaves indicate that the codex was produced shortly after the date given in the *Tractatus de sphaera*. There are two different watermarks in the *Mathematica.* The first appears only on the general title page and on two leaves in the third section of the codex.[24] This watermark depicts a bird standing upon three mounds within a circle and a G positioned above the circle. The second, more frequent

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[21] St. John's College I.37 (James 330), *"De Sphaera ... dictante per Horatio Grassi* [SJ, d. 1654], *1623/ Scribente Edm:* [cut away] *Auditore"* (1r). and *"De Machinis Spiritalibus ... Per Horatii Grassi, anno 1623,"* 20r.

[22] *"De Machinis Spiritalibus ... Per Horatii Grassi, anno 1623,"* 20r.

[23] St. John's College I.37 (James 330), *"De Sphaera ... dictante' per Horatio Grassi* [SJ, d. 1654], *1623 / Scribente Edm:* [cut away] *auditori"* (fo. 1r).

[24] Grassi, *Mathematica*, 0tp; 58 and 59. Because the paper is formed into quaternions, the watermarks have all been cut in half and appear on the fourth and fifth leaves of each quire.

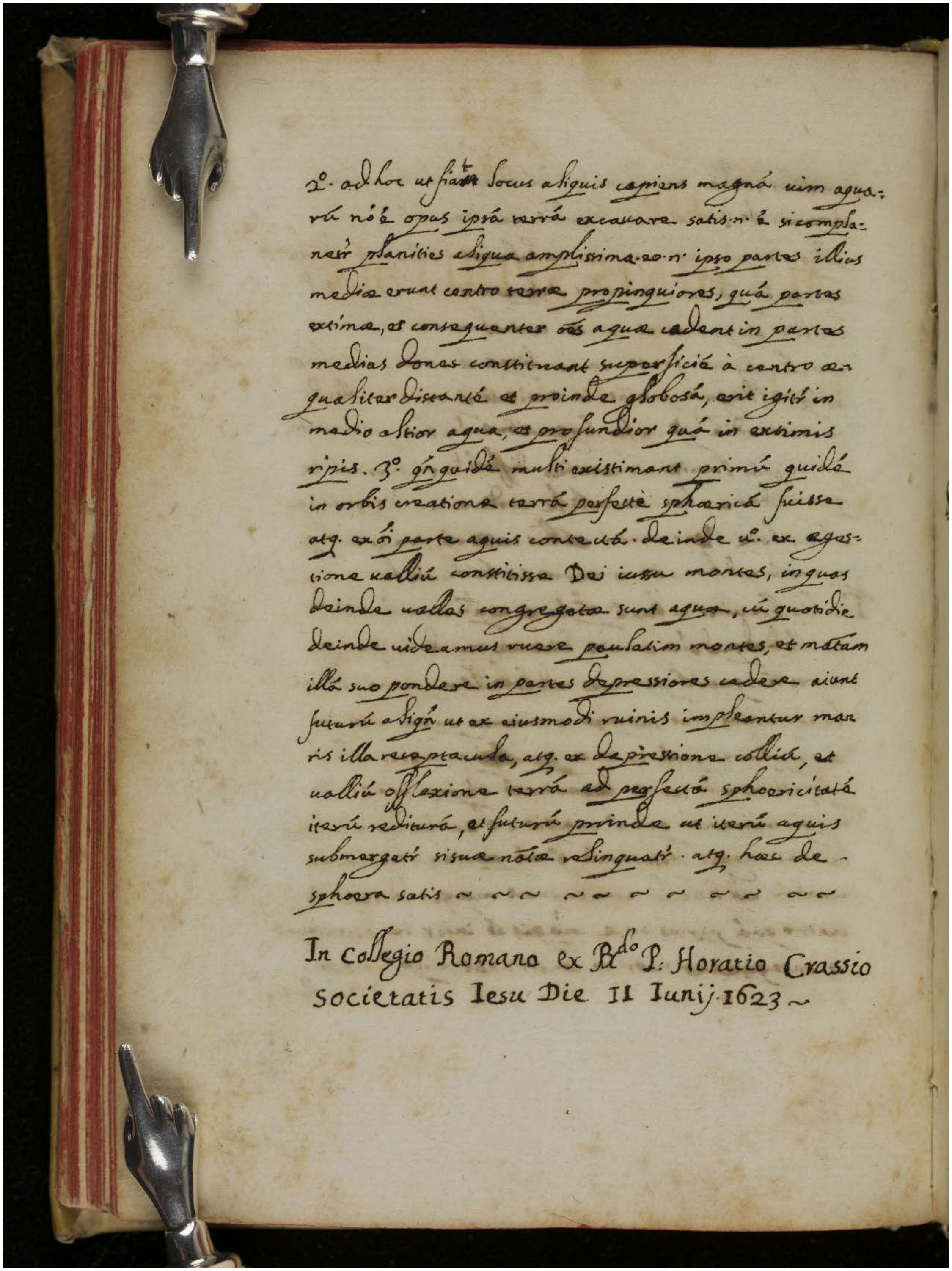

Figure 2: The colophon found at the end of the first section of the manuscript which cites Grassi as the source of the lectures at the *Collegio Romano* and gives the date 1623. Grassi, *tractatus de sphaera,* 27v.

watermark features an anchor within a circle with a six pointed star positioned above the circle.[25] Both of these watermarks have been cataloged and found in other texts produced during the early seventeenth century in and around Rome.[26] This evidence suggests that the *Mathematica* was most likely created in not long after Grassi concluded his lectures in 1623.

That these manuscripts were separate copies of notes taken by different students and not more closely connected is reinforced by a comparison of the two. When compared to the St. John's copy, the University of Oklahoma's *Mathematica* is similar in many respects but is also significantly different. The structure and wording of each manuscript are similar, with only minor differences in word order. For example, the title of the first section in the OU manuscript, "*De sphaera hoc est universi dispositione partibus earumque motu*" differs only slightly from the title of the same section in the

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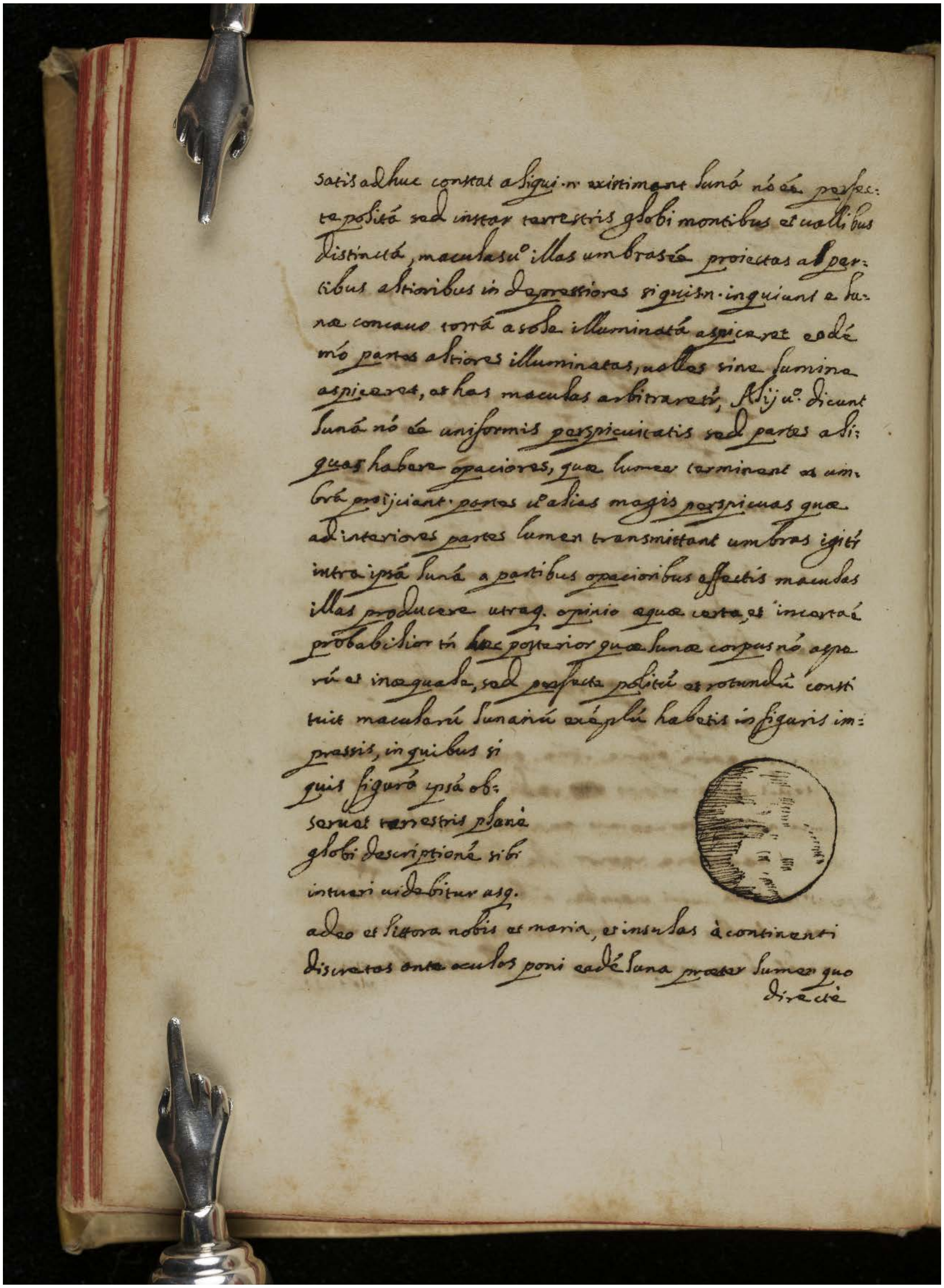
[25] Grassi, *Mathematica*, 5 and 6; 19 and 20; 23 and 24; 31 and 32; 37 and 38; 50 and 51; 76 and 77; 92 and 93

[26] Examples of other seventeenth century texts with these watermarks can be found in the Gravel Watermark archive which is associated with the University of Delaware Library. Gravel Watermark Archive, www.gravell.org. For examples see: http://www.gravell.org/record.php?&action=GET&RECID=5280&offset=50&rectotal=61&query=SELECT%20DISTINCT%20%2A%20FROM%20records%20WHERE%20MATCH%20%28P_DESC%29%20AGAINST%20%28%27%2B%22Anchor%22%27%20IN%20BOOLEAN%20MODE%29%20AND%20MATCH%20%28S_DESC%29%20AGAINST%20%28%27%2B%5C%22circle%3B%20star%5C%22%27%20IN%20BOOLEAN%20MODE%29%20ORDER%20BY%20YEAROFUSE%20; http://www.gravell.org/record.php?&action=GET&RECID=5220&offset=51&rectotal=61&query=SELECT%20DISTINCT%20%2A%20FROM%20records%20WHERE%20MATCH%20%28P_DESC%29%20AGAINST%20%28%27%2B%22Anchor%22%27%20IN%20BOOLEAN%20MODE%29%20AND%20MATCH%20%28S_DESC%29%20AGAINST%20%28%27%2B%5C%22circle%3B%20star%5C%22%27%20IN%20BOOLEAN%20MODE%29%20ORDER%20BY%20YEAROFUSE%20; http://www.gravell.org/record.php?&action=GET&RECID=1403&offset=6&rectotal=7&query=SELECT%20DISTINCT%20%2A%20FROM%20records%20WHERE%20MATCH%20%28P_DESC%29%20AGAINST%20%28%27%2B%22Bird%22%27%20IN%20BOOLEAN%20MODE%29%20AND%20MATCH%20%28S_DESC%29%20AGAINST%20%28%27%2B%5C%22circle%5C%22%27%20IN%20BOOLEAN%20MODE%29%20ORDER%20BY%20YEAROFUSE%20; and http://www.gravell.org/record.php?&action=GET&RECID=991&offset=0&rectotal=1&query=SELECT%20DISTINCT%20%2A%20FROM%20records%20WHERE%20MATCH%20%28P_DESC%29%20AGAINST%20%28%27%2B%22Bird%22%27%20IN%20BOOLEAN%20MODE%29%20AND%20MATCH%20%28S_DESC%29%20AGAINST%20%28%27%2B%5C%22G%3B%20mounds%5C%22%27%20IN%20BOOLEAN%20MODE%29%20ORDER%20BY%20YEAROFUSE%20. Accessed 3/14/2016.

St. John's manuscript, "*De sphaera seu de universi dispositione partibus earumque motu.*"[27] Word choice and order discrepancies add to the conclusion that the two works were produced by two different students. When the images of the two manuscripts are compared, major discrepancies are apparent. The OU manuscript omits an entire illustration despite including a description of the image in the script that is almost exactly the same as the St. John's manuscript, while the St. John's manuscript omits a conspicuous image of the moon in chapter 3.[28] These differences and similarities support the conclusion that the two were recorded by different students during Grassi's lectures in 1623.[29]

The visual elements of the *Mathematica* indicate that the final, bound form of the codex was produced outside the classroom. The general title page and the title pages of the different texts are elaborately decorated with pen-work flourishing in red and black ink.[30] The codex also contains finely detailed drawings and diagrams that do not always fill the space provided for them.[31] Many of these drawings are visual representations of the subject matter in the script, explaining or aiding the reader in understanding. The placement on the pages and detail of the diagrams and figures, all of which were hand drawn, indicate that they were added after the script had been written. Furthermore, contextual clues indicate that these images were circulated during class, and later were recopied into this codex. The discussion of the lunar surface in the

[27] St. John's College I.37 (James 330), "*De Sphaera ... dictante per Horatio Grassi* [SJ, d. 1654], *1623.* 1r.
[28] This description can be found in the OU manuscript on 5v and the corresponding image in the St. John's manuscript can be found on 4r of that manuscript. On the moon image see Grassi, *Mathematica,* 20v, and below in Figure 3.
[29] A full collation of these manuscripts will be the subject of further research.
[30] Grassi, *Mathematica,* 0tp and 1r.
[31] Grassi, *Mathematica*, 6v, 7r, 10r, 11r, 12r, 13r, 20v, 29r, 49v, 65r, 84v, 92v.



satis adhuc constat aliqui.n. existimant lunã nõ ẽe perfec-
te politã sed instar terrestris globi montibus et uallibus
distinctã, maculasq illas umbras ẽe proiectas a par-
tibus altioribus in depressiores siquidem inquiunt e lu-
na conuexa terrã a sole illuminatã aspiceret eodẽ
mõ partes altiores illuminatas, ualles sine lumine
aspiceret, et has maculas arbitraretur, Alijuo dicunt
lunã nõ ẽe uniformis perspicuitatis sed partes ali-
quas habere opaciores, quæ lumen terminant et um-
brã proijciunt, partes et alias magis perspicuas quæ
ad interiores partes lumen transmittunt umbras igitr
intra ipsã lunã a partibus opacioribus effectis maculas
illas producere utraq. opinio æque certa, et incertaẽ
probabilior tn hæc posterior quæ lunæ corpus nõ aspe-
rũ et inæquale, sed perfecte politũ et rotundũ consti-
tuit maculare lunariũ exẽplũ habetis in figuris im-
pressis, in quibus si
quis figurã ipsã ob-
seruet terrestris planã
globi descriptionẽ sibi
intueri uidebitur atq.
adeo et littora nobis et maria, et insulas à continenti
discretas ante oculos poni eadẽ luna praeter lumen quo
directe

Figure 3: The figure of the moon drawn into the manuscript, a visual representation of the uneven appearance of the moon and discussion in the script. Grassi, *Tractatus de sphaera*, 20v.

Tractatus de sphaera includes a shaded figure of the moon. The text describing this figure reads "You all have an example of the lunar spots in the printed figure."[32] The Latin word used in this case was *impressis,* meaning to stamp, impress, or print. However, the image in the *Mathematica* is clearly drawn not stamped or printed. The inclusion of this word in the script suggests that, at least in respect to this figure, a printed image was used as a guide. Both the decorations and the illustrations support the suggestion that the codex contains a fair copy, rather than the student's original notes.

The producer of the *Mathematica* made use of a number of conventional reading aids. As discussed above, the codex has a general title page with a reference to the author. It also includes section headers, chapter headers, and paragraph headers. The chapters are numbered and accompanied with a description of their content in bold script. The writer indicated paragraphs through the use of bold script and an indentation of the following lines. Numbered lists were also heavily incorporated into the content of the *Mathematica*.[33] These reading aids would have made it easier to reference the many different topics discussed in the *Mathematica,* supporting the conclusion that these were a copy of student notes. Other factors such as the funneling of the script and extra lines filled with tildes highlight that the codex was meant for personal use.[34] For example, many of the vignettes drawn at the beginning and end of sections are not referenced in the script and thus can be considered as extra evidence about the writer of the codex. In

[32] Grassi, *Mathematica,* 20v. See Figure 3 below.
[33] This is especially apparent in the second chapter of the Grassi's, *Tracatus de sphaera,* 3r-14v.
[34] The writer used a number of tildes (~) as a way to fill in extra lines at the end of a couple of sections of the codex. One particular example fills up four and a half lines with tildes at the end of that section. (Grassi, *Tractatus de sphaera,* 19r) Another way the writer finished out sections in this codex was by funneling the script. For example, on page 57r, over the course of ten lines, each line of script uniformly condenses from a full line into three letters at the bottom of the funnel on the second to last line of text on the page. (Grassi, *Tractatus de sphaera,* 57r and 65v)

one example the writer drew a vignette of a bleeding heart pierced by three nails.[35] This drawing was closely associated with the Jesuit order suggesting that this writer was, or aspired to be, a member of the Society of Jesus.

The many errors and information missing in the manuscript, along with the evidence taken from comparisons with the St. John's version, exclude the possibility that either could have been an official copy of Grassi's notes. This review suggests that both copies were recorded by Grassi's students during his lectures and bound shortly after completion of their mathematic instruction. Therefore, the *Mathematica* should be considered a fair copy of lecture notes bound into a codex recorded by a student of Grassi's at the *Collegio Romano*, and taken from his lectures in 1623, at least in the case of *the Tractatus de sphaera* and *De machinis spiritalibus.* Given that the codex was written by a student, the 1623 *Tractatus de sphaera* is primary evidence for the teaching of astronomy and mathematics at the *Collegio Romano*.

The *Collegio Romano* and the Jesuit *Ratio Studiorum*

In order to assess the import of the 1623 *Mathematica*, the subject of astronomy needs to be contextualized in the educational and intellectual culture of the society of Jesus at the *Collegio Romano* during the early seventeenth century. Education was an integral part of Jesuit culture, which is evident in the scope of their educational infrastructure. When the Society's founder, Ignatius Loyola, died in 1556, forty Jesuit schools were in operation. By 1599, they numbered more than 200 in Europe alone.[36]

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[35] Grassi, *Mathematica*, 83r.
[36] Vincent J. Duminuco, *The Jesuit Ratio Studiorum: 400th Anniversary Perspectives*. (New York: Fordham University Press, 2000), 80.

The *Collegio Romano* was the flagship college for the Jesuit educational system, the source of all the Society's teachers, schools and faculties.[37] The college was founded by Ignatius of Loyola in 1551 and officially became a university in 1553.[38] The Jesuit university in Rome would be a model for approximately 625 other Jesuit colleges and universities.[39] Jesuit colleges, especially the *Collegio Romano*, over time came to be considered by many as premier educational institutions in early-modern Europe.[40] Established throughout Catholic territories in Europe and elsewhere, they provided academic training in "theology, missionary skills, and general cultural excellence."[41]

The educational enterprise of the Society of Jesus had a very specific purpose, to teach "our neighbors in such a way that they are thereby aroused to a knowledge and love of our Maker and Redeemer."[42] This charter was outlined in the Jesuit plan of study, the *Ratio studiorum*.[43] This document governed the institutional culture of all Jesuit educational institutions by outlining the codes of conduct for the university students and faculty as well as the curriculum of the Jesuit colleges.[44] The *Ratio studiorum* was developed and revised four times over the course of more than thirty

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[37] This is the analogy painted by the colleges first dean, Father Ledesma quoted in Frederick A. Homann, Ladislaus Lukács, and Giuseppe Cosentino, *Church, Culture, & Curriculum: Theology and Mathematics in the Jesuit Ratio Studiorum*. (Philadelphia: St. Joseph's University Press, 1999), 21-22.
[38] William V. Bangert. *A History of the Society of Jesus*. (St. Louis: Institute of Jesuit Sources, 1972), 28.
[39] Augustin Udías Vallina. *Searching the Heavens and the Earth: The History of Jesuit Observatories*. (Astrophysics and Space Science Library; v. 286. Dordrecht; Boston: Kluwer Academic Publishers, 2003), 15; O'Malley, John W. *The Jesuits: Cultures, Sciences, and the Arts, 1540-1773*. (Toronto: University of Toronto Press, 1999), 132.
[40] Dear, *Discipline and Experience*, 32
[41] Dear, *Discipline and Experience*, 32. Also see Heilbron, *Electricity in the seventeenth and 18th Centuries*, 102-103.
[42] Claude Nicholas Pavur. *The Ratio Studiorum: The official plan for Jesuit education*. (St. Louis: Institute of Jesuit Sources, 2005), 7 and Allan P. Farrell. *The Jesuit Ratio Studiorum of 1599*. (Washington, D.C.: Conference of Major Superiors of Jesuits, 1970), 1. For discussion of this phrase see Vincent J. Duminuco, *The Jesuit Ratio Studiorum: 400th Anniversary Perspectives*. (New York: Fordham University Press, 2000), 97 and 104.
[43] For a translation of the entire Jesuit plan of study see Pavur, *The Ratio studiorum*. and Farrell, *The Jesuit Ratio Studiorum of 1599*.
[44] O'Malley, *The Jesuits*, 116.

years by members of the Society of Jesus, many of whom were scholars at the *Collegio Romano*, before it was officially finalized in 1599.[45]

The first edition of the definitive 1599 *Ratio studiorum* was published in Naples and was quickly followed by others in Munich (1600), a second edition in Naples (1603), Rome (1608, 1610, and 1616).[46] After some revisions in 1616, during the seventh general congregation, it was given authoritative approval and did not change for 175 years governing the Society's educational institutions up until their expulsion in 1773.[47] The Jesuit plan of study was an altogether top-down organization of Jesuit educational culture, beginning with the Jesuit Provincial Superior and working down to the students while simultaneously moving from the higher faculties "Scripture, scholastic theology, cases of conscience or ethics…through philosophy to rhetoric and grammar, the lowest disciplines in this system."[48]

A key component of the Jesuit plan of study was its inclusion of and attention to the discipline of mathematics.[49] According to the *Ratio studiorum,* mathematics instruction was placed during the second year of the three-year Philosophy cycle.[50] In the second year it mandated that philosophy students attend the mathematics courses in which mathematics professors "should teach the [natural philosophy] students Euclid's

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[45] Duminuco, *The Jesuit Ratio Studiorum*, 81. For the members of the *Collegio Romano* involved in the development of the *Ratio studiorum* see Homann, *et al*, *Church, Culture, & Curriculum*, 23.
[46] Duminuco, *The Jesuit Ratio Studiorum*, 95.
[47] Duminuco, *The Jesuit Ratio Studiorum,* 95.
[48] Duminuco, *The Jesuit Ratio Studiorum*, 137.
[49] For a discussion of the importance of the inclusion of mathematics in the curriculum of the *Raito studiorum* see Dennis Smolarski, "The Jesuit Ratio Studiorum, Christopher Clavius, and the Study of Mathematical Sciences in Universities." *Science in Context* 15, no. 3 (2002): 447-57.
[50] Lattis, *Between Copernicus and Galileo,* 32.; For discussion of the mathematical instruction at the *Collegio Romano* and Christoph Clavius see Mordechai Feingold. *Jesuit Science and the Republic of Letters*, 59. The order of mathematic instruction is also outlined in the 1599 *Ratio studiorum,* a translation of which can be found in Pavur. *The Ratio studiorum*, 109-110.

Elements in class around three quarters of an hour. After they have gained some experience with the material for about two months he should add something about geography or the *Sphere*, or about those things which are generally of interest."[51] Therefore, Grassi's lectures on the *Sphere* of Sacrobosco were presumably recorded by a natural philosophy student as part of his second year of instruction at the *Collegio Romano.*

One of the founding figures of the mathematics tradition at the *Collegio Romano* was Christopher Clavius (1537-1612), who played a key role in the attention given to the discipline of mathematics in the *Ratio studiorum*.[52] During his 37-year term at the *Collegio Romano,* Clavius placed special emphasis on the instruction of mathematics and training mathematicians in advanced topics.[53] Clavius reasoned that "because the mathematical disciplines discuss things that are considered apart from any sensible matter – although they are themselves immersed in matter – it is evident that they hold a place intermediate between metaphysics and natural science."[54] Above all, Clavius regarded astronomy as the most noble of the mathematical disciplines because it used certain geometrical demonstrations while discussing "the most noble of subjects, the heavens."[55] Dear explains that Clavius' promotion of mathematics "provided a basis for a treatment of aspects of the natural world that would stand on an equal methodological footing with Aristotelean natural philosophy (physics)"[56] that is physico-mathematics, in addition to instruction in purely mathematical subjects like geometry.

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[51] Pavur. *The Ratio studiorum,* 109. See also Allan Farrell, "The Jesuit Ratio Studiorum of 1599", 46.
[52] Lattis, *Between Copernicus and Galileo*, 35-38.
[53] Lattis, *Between Copernicus and Galileo*, 173.
[54] Dear, *Discipline and Experience*, 37
[55] Dear, *Discipline and Experience*, 38
[56] Dear, *Discipline and Experience,* 34.

When it was finalized, the *Ratio studiorum* of 1599 reflected Clavius' opinions regarding the importance of mathematics, including physico-mathematics, which had a lasting impact on the students at the *Collegio Romano* and the broader Jesuit university culture as a whole.[57] As has already been discussed, the study of mathematics was placed during the second year of the philosophy teaching cycle. In addition to this the *Ratio studiorum* called for the mathematics students to hold public disputations and gatherings during which a celebrated problem was to be solved in the presence of the students of philosophy and theology.[58] It also advised that any students who displayed an aptitude for mathematics "should work on them in private classes after the course."[59] All of these guidelines worked in concert in the *Ratio studiorum* of 1599 to elevate mathematics "from its former propaedeutic place as an arts subject to the second or third year of their advanced three-year philosophy course, where it was usually taught alongside either physics or metaphysics (after a year's training in logic.)"[60]

In addition to his role in framing the 1599 *Ratio studiorum*, Clavius also published textbooks that followed the Jesuit curriculum for the instruction of mathematics.[61] In order to train expert mathematicians and supply the Jesuit order with qualified teachers, Clavius also set up academies, the premier of which again was placed in Rome.[62] Clavius' numerous authoritative textbooks, his institutionalization of physico-mathematics and his influence on the Jesuit mathematicians who followed him

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[57] Wallace, *Galileo and His Sources*, 138.
[58] For more discussion on this topic see English translations of "the rules for professors of mathematics" in the *Ratio studiorum* in Pavur. *The Ratio studiorum,* 110 and Allan Farrell, "The Jesuit Ratio Studiorum of 1599."
[59] Pavur. *The Ratio studiorum,* 19-20.
[60] Dear, *Discipline and Experience*, 35.
[61] Lattis, *Between Copernicus and Galileo,* 32.
[62] O'Malley, *The Jesuits: Cultures, Sciences, and the Arts, 1540-1773*, 173.

at the *Collegio Romano* were his most important contributions to the history of science.[63] His work educating mathematicians and writing textbooks perpetuated his view of mathematics as an intermediary science for physics and metaphysics far beyond the *Collegio Romano*.[64]

Orazio Grassi was born in Savona in 1583, thirty years after the founding of the first Jesuit college in Rome. It was in the physico-mathematic academy set up by Clavius at the *Collegio Romano* that Orazio Grassi was educated and would later teach.[65] He began studying at the *Collegio Romano* in 1600 shortly after the 1599 *Ratio studiorum* was finalized. Grassi was named the Father General of mathematics at the Roman College in 1616, the same year that Copernicanism was condemned by the Catholic Church.[66] He held this position for more than 10 years, from 1616-1624 and again in 1626-1628, during which time he taught mathematics at the *Collegio Romano*.[67] By the time Grassi was delivering his lectures on astronomy in 1623, Clavius' agenda had been fully realized.[68] Orazio Grassi was a beneficiary of the physico-mathematic tradition Clavius institutionalized at the *Collegio Romano*, a tradition which he continued through his own teaching.

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[63] Lattis, *Between Copernicus and Galileo*, 218
[64] Lattis, *Between Copernicus and Galileo*, 4 and 37. For more on Clavius' impact on Galileo see Wallace's, "Galileo's Jesuit Connections and Their Influence on His Science" in Feingold, *Jesuit Science and the Republic of Letters*, 99-126.
[65] O'Malley, *The Jesuits: Cultures, Sciences, and the Arts, 1540-1773*, 173.
[66] Lattis, *Between Copernicus and Galileo*, 202.
[67] Redondi, *Galileo Heretic*, 12.
[68] O'Malley, *The Jesuits: Cultures, Sciences, and the Arts, 1540-1773,* 111.

Jesuit Scientific Practice in the Early Modern Period

For Clavius and his fellow Jesuits, Aristotelian physics and Ptolemaic cosmology were scientific orthodoxy. The adherence to Aristotle was reinforced in the definitive *Ratio studiorum.* The second point in the rules for the professors of philosophy states that "In matters of some importance, [a professor] should not depart from Aristotle, unless he comes across something that clashes with the teaching that educational institutions everywhere approve, and he should all the more depart from Aristotle if he contradicts orthodox belief."[69] This section and others in the *Ratio studiorum* clearly indicated to Jesuits that Aristotle was to be supported unless he contradicted orthodox belief, a position that was heavily reinforced by the Catholic Church. This position, however, would come under increased scrutiny throughout the course of the seventeenth century as the validity of Aristotle and Ptolemaic cosmologies were challenged by new observational evidence and new explanatory structures. It was precisely this new observational evidence that Grassi and other Jesuit educators had to make sense of for their students.

Observational contradictions and theoretical objections had been mounted against the authority of Aristotle and Ptolemy even before the Jesuits had formed their Society, but the new opinions also carried the burden of proof.[70] In 1543 Copernicus' *De revolutionibus* was published and advocated heliocentric cosmology. However, because this system required a moving earth and was found to be in contradiction to scripture many rejected his reordering of the cosmos while accepting his mathematics.[71]

[69] Pavur. *The Ratio studiorum*, 99. and Ferrell, "The Jesuit Ratio Studiorum of 1599," 40.
[70] Lattis, *Between Copernicus and Galileo*, 61
[71] Peter Barker, "Constructing Copernicus" *Perspectives on Science*, 10 (2002) 208-27.

Still, as novel observations of the heavens in the late sixteenth and early seventeenth centuries increased, they engendered more disagreement concerning the validity of Aristotelean physics and Ptolemaic cosmology.

Tycho Brahe (1546-1601) was another key figure in the debates concerning celestial phenomena and cosmology. Tycho's observations of the apparent parallax of the comet of 1577 and others suggested that the comets were positioned above the lunar orb and that their paths passed through numerous celestial orbs in the heavens according to the arrangement of Aristotle and Ptolemy, which called into question their cosmologies.[72] However, Tycho could not accept Copernicus' heliocentric cosmology based on theological and physical arguments raised against that system.[73] Additionally, Tycho's observations of Mars led him to conclude that the orb of Mars and the orb of the Sun intersected in a Ptolemaic cosmos, an impossibility for a heaven constructed of solid celestial spheres and orbs. It was not until Christoph Rothmann (d. ca. 1599-1608) introduced to Tycho the Stoic concept of a fluid heaven, that Tycho abandoned celestial orbs and postulated his own geo-heliocentric cosmology, outlined in 1588 in his *De mundi aetheri recentioribus phaenomenis liber secundus*.[74] In his system the planets

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[72] For more on the parallax of comets see Lattis, *Between Copernicus and Galileo,* 60.
[73]For a discussion of Tycho's rejection of Copernicanism and conception of his geo-heliocentric model see J. R. Christianson. *On Tycho's Island: Tycho Brahe and His Assistants, 1570-1601*. (Cambridge, U.K.; New York: Cambridge University Press, 2000), 121-124.
[74] Tycho Brahe. *Tychonis Brahe Mathim: Eminent: Dani Opera Omnia, Sive, Astronomiæ Instavratæ Progymnasmata, in Duas Partes Distributa, Qvorvm Prima De Restitvtione Motvvm Solis & Lunæ, Stellarumq́[ue] Inerrantium Tractat. Secvnda Avtem De Mvndi ætherei Recentioribus Phænomensis Agit.* Editio Ultima Nunc Cum Indicibus & Figuris Prodit..ed. Francofvrti: Impensis Ioannis Godofredi Schönvvetteri, 1648. For more on Tycho's conception of a fluid heaven see Goldstein, Bernard, and Peter Barker. "The Role of Rothmann in the Dissolution of the Celestial Spheres." *British Journal for the History of Science* 28, no. 99 (1995): 385-405.

revolved around the Sun as intelligent bodies directing their own motions through a fluid heaven while the sun revolved around the earth.[75]

Tycho's cosmology found some success among mathematicians and natural philosophers predisposed to a geocentric model. Indeed, his cosmology would later be supported by many Jesuit natural philosophers and mathematicians at the *Collegio Romano.*[76] However, this success was not ubiquitous. Others decided to abandon the concept of a mechanical heaven all together and postulated cosmologies that maintained a fluid heaven through which the planets moved themselves as birds of the air or fish of the sea.[77] By the time Grassi began teaching at the *Collegio Romano*, Aristotelean concepts of physics and Ptolemaic cosmology, namely the stability and centrality of the earth, as well as the incorruptibility of the heavens and the reality of celestial spheres were being seriously questioned.[78]

The invention of the telescope and its application to studying the heavens further destabilized traditional interpretations of cosmology during the early seventeenth century.[79] Galileo Galilei (1564-1642) relied extensively on the telescope for his observations of the moon which he began in 1609.[80] In 1610 Galileo published his *Sidereus nuncius* in which he described many of his telescopic observations which

[75] Christianson, *On Tycho's Island*, 122.
[76] For more on the Jesuit reception of Tychonism in the early seventeenth century see Luis Miguel Carolino. "The Making of a Tychonic Cosmology: Cristoforo Borri and the Development of Tycho Brahe's Astronomical System." *Journal for the History of Astronomy* 39, no. 3 (2008): 313-44.
[77] For the origins and significance of this metaphor see Peter Barker, "Stoic contributions to early modern science," in M. J. Osler (ed)., *Atoms, pneuma and tranquillity: Epicurean and Stoic Themes in European Thought*. Cambridge: Cambridge University Press, 1991, 135-154.
[78] Edward Grant, "The Partial Transformation of Medieval Cosmology by Jesuits in the Sixteenth and Seventeenth Centuries," in Grant, *Planets, Stars, and Orbs*, 127-128.
[79] For a general discussion see Albert Van Helden. "The Telescope in the Seventeenth century." *Isis* 65, no. 1 (1974): 38-58.
[80] Eileen Adair Reeves. *Galileo's Glassworks: The Telescope and the Mirror*. (Cambridge, Mass.: Harvard University Press, 2008), 139.

included the terrestrial nature of the moon, the discovery of numerous stars in the Milk Way, and the satellites of Jupiter. These latter observations posed significant problems for traditional cosmologies which only accepted the movement of perfect celestial bodies in the heavens centered about the earth.[81] In 1610-11, Galileo also announced his observations of sunspots, the phases of Venus, and satellites around Saturn.[82]

These revelations afforded the Jesuit mathematicians the opportunity to demonstrate the utility of physico-mathematics to their fellows at the *Collegio Romano* as well as to the broader scientific community of the early modern period. Following Galileo's 1611 visit to the *Collegio*, the prestige of the college of mathematics at the *Collegio Romano* lead Cardinal Roberto Bellarmine (1542-1621) to ask the mathematicians there for their opinion about Galileo's telescopic observations.[83] During his visit Galileo and the professors of the *Collegio* had performed telescopic observations together and most of the professors confirmed Galileo's observations.[84] Although the Jesuits confirmed that Galileo's observations of these phenomena were accurate, there was much disagreement on their interpretation. Peter Dear explains in his study of the physico-mathematical movement of the Jesuits that "Any simple techniques for identifying the character of something claimed as new, so as to determine its place in the existing scheme of knowledge, are always, in principle, open to unlimited interpretations. Which interpretation is deemed by the relevant community to be the proper one, and hence to be the correct application of the rules, is a matter of

[81] Galileo. *Sidereus nuncius* (Venice: Thomas Baglionus, 1610) and his Letters on Sunspots. For modern editions see Galilei, Galileo, and Van Helden, Albert. *Sidereus Nuncius or, The Sidereal Messenger*. (Second ed. 2016) and Eileen Reeves and Albert Van Helden, *On Sunspots: Galileo Galilei and Christoph Scheiner* (Chicago: Chicago University Press, 2010).
[82] Van Helden. "The Telescope in the Seventeenth century," 51.
[83] Lattis, *Between Copernicus and Galileo,* 190.
[84] Bangert, *History of the Society of Jesus,* 108.

social contingency."[85] Even though Galileo's novel observations had been confirmed as real, their interpretations were a matter of public debate and the Jesuits, and in particular Jesuit physico-mathematicians, contributed much to those debates.

Some of the history of science still depicts Jesuit scientists as mere ancillaries to the Catholic Church, blindly tied to that orthodoxy especially following the 1616 condemnations of Copernicanism.[86] Much of this is the result of the historiography concerning the Jesuits and their science which considered them a conservative and reactionary group. This position has been criticized in more recent years by Lattis and Dear, as well as others, precisely because of the mounting evidence that Jesuit scientists contributed much to the contemporary debates and conversations in the history of science. The Jesuits were practicing their own science, one that was directly related to the Catholic Church but a science nonetheless.[87] In the debates and controversies with Galileo and others, the Jesuits advanced their natural philosophical opinions often using physico-mathematical arguments to support their claims.

One example took place two years after Galileo's publication of *Sidereus nuncius* in 1610. Over the course of the next two years Galileo and Christopher Scheiner (1573-1650), publicly disagreed concerning observations of sunspots. Galileo argued that the sunspots existed on or near the surface of the sun itself and acted like terrestrial clouds.[88] This postulation posed a problem for the Jesuits because it

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[85] Dear, *Discipline and Experience*, 97
[86] Lattis, *Between Copernicus and Galileo*, 202
[87] Dear, *Discipline and Experience*; Lattis, *Between Copernicus and Galileo.*
[88] For discussion of this controversy see Reeves and Van Helden, *On Sunspots*. For discussion of Galileo's and Scheiner's use of visual imagery see Albert Van Helden. "Galileo and Scheiner on Sunspots: A Case Study in the Visual Language of Astronomy." *Proceedings of the American Philosophical Society* 140, no. 3 (1996): 358-396. On the treatment of sunspots at the *Collegio Romano* see Renee Raphael, "Teaching sunspots".

necessitated the acceptance of an imperfect, or at least changing heaven. Seeking to preserve the perfection of the heavenly body of the Sun, Scheiner, who specialized in astronomical observation, argued that the sunspots were not on the surface of the sun, but permanent bodies revolving around it, analogous to Jupiter's moons.

During his tenure at the *Collegio Romano,* Grassi also contributed to the discourse on the nature of sunspots and other celestial controversies, both in the classroom and the public forum. Grassi, following Clavius' example, used physico-mathematics to address these issues, the most important of which was his debate with Galileo concerning the comets of 1618-1619. The disagreement between Grassi and Galileo supplied the impetus for most of Grassi's publications and formed the backdrop against which the he gave his lectures in 1623 recorded in the *Tractatus de sphaera*.[89] Both Grassi and Galileo were university trained mathematicians and they shared much common ground concerning the authority of astronomical observations.[90] The main disagreement in the controversy over the comets was whether those phenomena were real bodies traversing the heavens, or optical illusions produced by refracted light below the lunar sphere. For Grassi, because the observational parallax of the comets showed them to be above the lunar sphere, the Aristotelian position that they were terrestrial phenomena had to be wrong.

In March 1619 the *Collegio Romano* anonymously published one of Grassi's lectures concerning the three comets of 1618, titled *Disputatio astronomica de tribus*

[89] Grassi's first publication, *De iride disputatio optico,* published in 1617 under the name of his student Galeatio Mariscotto was not directly related to his controversy over the comets with Galileo. However, Grassi's familiarity with optics is intrinsically important to his arguments about the apparent parallax of the comets. See Galeatus Mariscottus, *De iride disputatio optica*. (Romae: Mascardi, 1617).
[90] Wallace, *Galileo and His Sources,* 298.

cometis anni MDCXVIII.[91] In the disputation Grassi documented the scientific quality of observational astronomy. Grassi's disputation again demonstrated that the Jesuits were willing and able to take novel positions in natural philosophical questions despite the limitations placed on the Society by Catholic orthodoxy.[92] Grassi's placement of the comets above the lunar sphere, which supported a fluid interpretation of the heavens, was not an attack on Galileo, but still succeeded in provoking him to respond. Grassi's interpretation supported Tycho's cosmology, which refuted the Copernican conception of the cosmos that Galileo advocated.[93]

In June 1619 Galileo responded to the anonymous lecture through Mario Guiducci with a *Discourse on the Comets.*[94] Galileo proposed to explain the phenomena using an optical theory of the comets which placed them below the moon.[95] He also rejected Tychonic interpretations of the cosmos in support of the Copernican model. Galileo's reply provoked Grassi with the backing of his brethren to respond, this time in the form of a book, the *Libra astronomica ac philosophica.*[96] The *Libra* was published in December 1619 under the pseudonym Lotario Sarsi. In this book Grassi made the argument that the comets were above the lunar sphere based on their lack of parallax and their apparent size in telescopic observations. In his arguments in the *Libra* Grassi

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[91] Grassi, Orazio. *De tribus cometis anni* 1619. (Romae: Mascardi, 1619).
[92] For more discussion on this see Biagioli, *Galileo Courtier*, 273.
[93] For a discussion of Galileo's willingness to enter into debates see Mordechai Feingold's chapter "The Grounds for Conflict: Grienberger, Grassi, Galileo and Posterity" in Feingold, *The New Science and Jesuit Science*, 134 and 138-140.
[94] Stillman Drake and Charles Donald O'Malley. *The Controversy on the Comets of 1618*. (Philidelphia: University of Pennsylvania Press, 1960), 20.
[95] On this general view of comets see Peter Barker, "The Optical Theory of Comets from Apian to Kepler," *Physis*, 30 (1993) 1-25.
[96] Grassi, Orazio. *Libra astronomica ac philosophica qua Galilaei opiniones de cometis a Mario Guiducio in Florentina Academia expositæ, atque in lucem nuper editae, examinantur a Lothario Sarsio Sigensano.* (Pervsiæ, Ex typographia M. Naccarini, 1619).

was publically addressing Galileo's opinions, as is evident on the title page of his book, which reads "The Astronomical and Philosophical Balance on which the Opinions of Galileo Galilei regarding the Comets are weighed."[97] Just a few short years after the publication of the *Libra* and five months before Galileo's rebuttal would be published, Grassi delivered the lectures recorded in the *Tractatus de sphaera* at the *Collegio Romano* in June 1623.[98]

Throughout the controversy over the comets, Grassi emphasized the importance of mathematics and astronomical observations in natural philosophy, for example in his use of observational parallax as evidence for the location of comets. This reflected the concerted effort by Clavius and his school to answer outstanding questions about the heavens which had developed over the course of the last two centuries. In addition to his use of physico-mathematic arguments in the public controversy with Galileo, an examination of the 1623 *Tractatus de sphaera* reveals that Grassi incorporated these same principles in the classroom at the *Collegio Romano* in an effort to answer many of the same questions for his students. However, because the content of the classroom was regulated by the *Ratio studiorum* and the opinions of the contemporary Jesuit scientific community, this changed the manner of his presentation and content.

Rather than imagining Grassi's navigation of these complex cultural pressures as simply another example of the institutional and orthodox constraints placed on Jesuit scientists, his 1623 lectures should be understood as a unique opportunity to examine the reconstitution of observational experience in the context of the Jesuit physico-

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[97] "*Libra astronomica ac philosophica qua Galilaei opiniones de cometis ... examinantur*" Drake and O'Malley, *The Controversy on the Comets,* 66. See also Biagioli, *Galileo, Courtier,* 289.
[98] Grassi, *Tractatus de sphaera,* 27v.

mathematic movement. Because of the subject matter, the date and the context in which these lectures were given, they offer a unique insight into the teaching of astronomy in the early seventeenth century at the *Collegio Romano.* The lectures recorded in the 1623 *Tractatus de sphaera* were delivered by Orazio Grassi at one of the leading educational institutions of its time and during one of the most pivotal periods in the history of science. The 1623 treatise reflects the educational milieu in which Grassi was teaching. It reveals the manner in which Jesuit physico-mathematicians could negotiate the incorporation of new material and observational evidence in natural philosophy, based on their individual interests and student demand, into the disciplinary framework outlined in the *Ratio studiorum* and the broader Jesuit culture as a whole.[99]

The *Sphaera* tradition and Grassi's 1623 lectures

Orazio Grassi's astronomy lectures recorded in the 1623 *Tractatus de sphaera* were drawn from *The Sphere* of Sacrobosco. Sacrobosco's *Sphaera* was the single most important astronomy textbook in early modern European universities. Sacrobosco's *Sphaera* enjoyed over 400 years of study and application in teaching astronomy as "one of the most popular introductory astronomical texts in Europe."[100] It was used to teach astronomy all over Europe including at the *Collegio Romano*, as prescribed in the 1599 *Ratio studiorum*.[101] Because of this Grassi's lectures are an example of the long tradition Sacrobosco's astronomy textbook enjoyed in medieval and early modern

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[99] Raphael, "Teaching sunspots," 131.
[100] Lattis, *Between Copernicus and Galileo*, 45
[101] On the role of Sacrobosco's text see Kathleen Crowther, *et al.*, "The Book Everyone Read: Vernacular Translations of Sacrobosco's *Sphere* in the Sixteenth-century" *Journal for the History of Astronomy*, 46 (2015) 4-28; Kathleen Crowther and Peter Barker, "Training the Intelligent Eye: Understanding Illustrations in Early Modern Astronomy Texts." *Isis*, 104, (2013) 429-70.

university education. The *Tractatus de sphaera* also demonstrates another aspect of the *Sphaera* tradition, the inclusion of novel material and ideas.[102]

The *Sphaera* of Sacrobosco and its numerous commentaries were usually divided into four books or sections. The first book presented the structure of the world and introduced the theory of the elements. It often included an image of a cosmic section giving the order of the planets. The second book introduced the major celestial circles such as the ecliptic and tropics. The third book was devoted to celestial signs, day and night, and the terrestrial climes. And the fourth book, which was usually the briefest, gave a cursory introduction to the motion of the planets in agreement with Ptolemaic cosmology, and discussed eclipses of the sun and the moon.[103]

Following its initial success, Sacrobosco's *Sphere* was the subject of a multitude of commentaries, a tradition which continued well into the early modern period. Because most of these commentaries were used to refine astronomic knowledge and expanded on Sacrobosco's original, they were important vehicles "for disseminating and discussing new discoveries and ideas about the cosmos."[104] As part of his program to produce a Jesuit textbook tradition, Christopher Clavius wrote his own *Commentary on the Sphere of Sacrobosco* in 1570 which was revised and reproduced no fewer than seven times before his death and used in Jesuit schools for almost a century after its original publication.[105] In his commentaries on the *Sphere*, Clavius too acknowledged

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102 Crowther, *et al.*, "The Book Everyone Read", 5

103 For a translation of the *Sphere* see Edward Grant, *A Source Book in Medieval Science*. Source Books in the History of the Sciences. (Cambridge, Mass.: Harvard University Press, 1974), 442-465. For more detailed discussion, see Lynn Thorndike. *The Sphere of Sacrobosco and Its Commentators*. (University of Chicago Press, 1949) and Crowther *et al*. "The Book Everybody Read."

104 Kathleen Crowther, *et al.*, "The Book Everyone Read", 6.

105 *Christophori Clavii, Bambergensis, ... In Sphaeram Ioannis de Sacro Bosco commentarius* (Rome: Victor Helianus, 1570). Later editions are Rome: Francisco Zannetti, 1581; Rome: Dominic Basa, 1585; Venice: Ioannes Baptista Ciota Senense, 1591; Lyons: Gabiano, 1593; Lyons, Ioannes de Gabianus 1602;

the then dated content of the textbook and included novel material continuing the tradition of adding to Sacrobosco's original, a common approach to the subject in the late fifteenth and sixteenth centuries.[106] Orazio Grassi's lectures on the *Sphere* also continued this tradition.

Because Grassi was teaching astronomy in 1623 and Sacrobosco's *Sphere* had been increasingly shown to be insufficient, it is unlikely that Grassi was teaching directly from Sacrobosco's text. The very fact that Clavius was Grassi's mentor at the *Collegio* might be enough to assume he was using one of the textbooks authored by him since Clavius had advocated the use of distinctly Jesuit textbooks and labored throughout his career to produce a corpus to reach that end.[107] Further evidence that Grassi was using Clavius' textbook is supplied by a comparison of the images in the 1623 *Tractatus de sphaera* and those found in Clavius' commentaries on the *Sphere*. One of the many diagrams in the 1623 *Tractatus de sphaera* depicts a materialized eccentric and epicycle construction for the Sun which is almost identical to one adapted from Peurbach by Clavius in his commentaries on the *Sphere* of Sacrobosco.[108] The treatise also has a similar image used to demonstrate the calculation of observational

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Rome: Ioannes Paulus Gellius, 1607; and finally the third volume of the *Opera mathematica* (Mainz: A. Hierat, 1612) published in the year of the author's death. See also Edward Grant. "The Partial Transformation of Medieval Cosmology by Jesuits in the Sixteenth and Seventeenth Centuries" in Feingold, *Jesuit Science and the Republic of Letters*, 127-155; Lattis, *Between Copernicus and Galileo,* 44.

[106] Lattis, *Between Copernicus and Galileo,* 126; Kathleen Crowther, *et al.,* "The Book Everyone Read", 5-6.

[107] This is supported in the language of the *Ordo servandis* where Clavius continually uses forms of *noster*, or "ours" when describing textbooks for courses. Romano Gatto, "Christoph Clavius' '*Ordo Servandus in Addiscendis Disciplinis Mathematicis*' and the Teaching of Mathematics in Jesuit Colleges at the Beginning of the Modern Era." *Science & Education* 15, no. 2 (2006): 249-255. *Lattis, Between Copernicus and Galileo,* 174-175. Cf. 80. James Lattis, "Christopher Clavius and the 'Sphere' of Sacrobosco: The Roots of Jesuit Astronomy on the Eve of the Copernican Revolution," 1989, ProQuest Dissertations and Theses, 364-368.

[108] Lattis discussed this image and its application by Clavius. Lattis, *Between Copernicus and Galileo*, 68.

parallax.[109] Although these diagrams are not identical, they are similar enough in their representations to add support to the argument that Grassi may have been using one of Clavius' textbooks. Regardless of which or whose textbook Grassi was teaching from in 1623, and despite the fact that the 1623 *Tractatus de sphaera* is a record of his lectures, not a written commentary, they should be considered as part of the long *Sphaera* tradition in astronomical education. Because Grassi's lectures followed a similar structure and propounded new material, the 1623 built upon the previous studies of Sacrobosco continuing that tradition.

The lectures in the *Tractatus de sphaera* were divided into four parts like Sacrobosco's *Sphere*. In addition to being organized in a similar fashion, Grassi also discussed many of the same astronomical concepts discussed in Sacrobosco. Grassi's instruction on the *Sphere* began, like Sacrobosco's text, with a short introduction and a discussion of the different possible structures of the world.[110] The second chapter was primarily concerned with definitions of astronomical terms.[111] The third chapter discussed the movements, position and natures of the planets and the stars.[112] And the final, fourth chapter finished with a discussion about the divisions of the *Sphere*.[113] Although Grassi's lectures followed a similar structure to the *Sphaera* tradition, he also built on that tradition by adding contemporary material to his lectures. He discussed new cosmologies, the composition of the Milky Way, the observation of sunspots, the moons of Jupiter and the satellites of Saturn, as well as the newly invented telescope.[114]

[109] Lattis discussed Clavius' demonstration of the calculation of parallax from his commentaries as well. Lattis, *Between Copernicus and Galileo*, 92.
[110] Grassi, *Tractatus de sphaera*, 1r-3r.
[111] Grassi, *Tractatus de sphaera*, 3r-14v.
[112] Grassi, *Tractatus de sphaera*, 14v-23r.
[113] Grassi, *Tractatus de sphaera*, 23r-27v.
[114] Lattis, *Between Copernicus and Galileo*, 126.

The inclusion of novel material is evident in the content of Grassi's lectures and is an indication of the pivotal time within which his lectures were given. In his study of Clavius' career at the *Collegio Romano*, James Lattis noted that the evolution of his astronomical instruction reflected the development of Clavius' own thought, which he argued "mirrored the changes taking place in the early period of the scientific revolution."[115] One of the many aspects of Clavius' thought evident in his commentaries on Sacrobosco's *Sphere* is his support of physico-mathematics. Grassi also promotes physico-mathematics and in a similar way, his astronomical instruction can be taken as an indication of the status of the physico-mathematical tradition at the *Collegio*.

In his commentaries Clavius was careful to promote the recognized division between mathematics and natural philosophy admitting that some discussion, such as the motions of the heavens and especially that of the sun and the moon, should be part of instruction in physics (natural philosophy) rather than mathematics.[116] A similar division is echoed by Grassi in his lectures at the beginning of the *Tractatus de sphaera.* Grassi explained that "We leave the substance of the heavens to the physicists, who examine these things in another way."[117] This division of disciplines on the surface was meant to restrict the subject matter that was presented in mathematics courses at Jesuit universities.[118] However, for Clavius and his students, it worked to their advantage by insulating mathematics from natural philosophical attacks.

[115] Lattis, *Between Copernicus and Galileo*, 218.
[116] Lattis, *Between Copernicus and Galileo*, 126.
[117] Grassi, *Tractatus de sphaera*, 1r. "*substantiam enim physicis relinquimus quamquam aliquo modo videntur."*
[118] Renee Raphael has studied the division between natural philosophy and mathematics at the *Collegio Romano* and found that Gabriel Beati (1606-1673) and other Jesuit instructors commonly followed

Peter Dear has examined this aspect of the Jesuit physico-mathematical movement and has argued that this recognized division benefitted the mathematicians because it "simultaneously exploited and overrode the standard scholastic boundary division between physics and mathematics: it advocated mathematics as a tool for the creation of genuine physical knowledge, but did so by means of the Aristotelean characterizations of their subject matters."[119] Dear goes on to assert that "Physico-mathematics was a bid for disciplinary authority over knowledge of nature,"[120] and points to the "increasingly ambitious claims of mathematicians in the first few decades of the century" as evidence for his claims.[121] Grassi's lectures, demonstrate the evolving character of this aspect of early modern Jesuit science. Through an examination of the *Tractatus de sphaera* it is evident that Grassi was promoting the Jesuit physico-mathematical movement, started by Clavius. Hence Grassi's lectures can give insight into a number of historical questions, including: the status of early modern astronomy, the Jesuit scientific enterprise, and the role of Jesuit education in early modern history of science.

Although much had changed since Sacrobosco had written his textbook on spherical astronomy and since Clavius had finished the last version of his commentary, and despite the fact that Grassi included many contemporary novelties, he withheld discussion of some phenomena as well. One striking difference between Grassi and previous texts in the *Sphaera* tradition is the lack of a depiction of a complete

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Clavius' example of promoting this so called boundary between the two disciplines while simultaneously exploiting it. Raphael, "Teaching Sunspots," 132.

[119] Dear, *Discipline and Experience*, 168

[120] Dear, *Discipline and Experience*, 168

[121] Dear, *Discipline and Experience*, 168

cosmology. A complete picture of a Ptolemaic construction of the cosmos in cross section was a hallmark of *Sphaera* texts which is even included in Clavius' last commentary. Neither the OU manuscript nor the St. John's manuscript depict a complete cosmology. The lack of any discussion of comets is another striking omission for Grassi and one which will be discussed in more detail below. Despite these striking omissions, Grassi's lectures were relevant and up to date. Through an analysis of the content in the *Tractatus de sphaera*, it is clear that Grassi discussed almost every notable development in the subject of astronomy up to 1623. As his mentor had done before him, all of these were analyzed using physico-mathematics.

Physico-mathematics and the 1623 *Tractatus de sphaera*

By 1612, the cosmological views of the Jesuits at the *Collegio Romano* reflected the larger astronomical community in their differences.[122] These disagreements are reflected in Grassi's lectures from 1623. The 1623 *Tractatus de sphaera* records that Grassi introduced not one cosmology, as Sacrobosco had, but four different cosmologies to his students. Although, by the middle of the seventeenth century most Jesuits had adopted the Tychonic system of the universe, in the early years of the seventeenth century there was very little agreement among the scholars at the *Collegio Romano* about the structure of the cosmos and the validity of Aristotelian physics.[123]

[122] Lattis, *Between Copernicus and Galileo*, 218
[123] Udias *Searching the Heavens and the Earth*, 17; Christopher M. Graney. "Setting Aside All Authority: Giovanni Battista Riccioli and the Science against Copernicus in the Age of Galileo" (South Bend, IN: Notre Dame University Press, 2015); Lattis, *Between Copernicus and Galileo*, 219.

The first position that Grassi introduced denied the usual machinery of Ptolemaic astronomy like epicycles, and by implication the eccentrics that usually carried them, suggesting instead that the medium between the earth and the heavens was fluid. He explained to his students that:

> However, they postulate that the space between the [starry] heaven and the earth [is] fluid and leads/directs the paths of the planets. For they say that it is entirely ridiculous that there are so many spheres in the heaven and to make epicycles, since everything can be explained much more easily if we say that each planet is moved either by its individual firmament or by an assisting intelligence.[124]

Grassi goes on to say that many of the "Church Fathers" (*sanctorum Patrum)* supported this belief.[125] Robert Bellarmine, who was a Cardinal during Grassi's term at the *Collegio,* defended a similar fluid heaven cosmology in which the planets moved themselves in his Louvain lectures from the 1570s.[126]

The second position Grassi outlined was the geocentric system that was originally supported in the *Sphere* of Sacrobosco. In his lectures Grassi outlined the aspects of this system which included an immobile earth at the center of the world, surrounded by "water and then air, third the location of fire, afterwards the heaven of the moon, Mercury, Venus, and the Sun. [Then] Mars, Jupiter, Saturn, the firmament

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[124] Grassi, *Tractatus de sphaera,* 1v. *"spatium autem inter caelum hoc et terram fluidum et planetarum itineribus praevium posuerunt aiunt enim ridiculum omnino esse in caelo tot sphaeras, et epiciclos fingere cum omnia multo facilius explanari possint si dicamus unumquemque planetam vel a propria firmamenta, vel ab intelligentia assistente moveri qui cumque tandem fuerit eiusdem planetae motus haec autem opinio multos habet sanctorum Patrum, quorum autoritate fulcitur."*
[125] Grassi, *Tractatus de sphaera*, 1v.
[126] Reeves and van Helden, *On Sunspots,* 4.; On Bellarmine and the origins of the fluid heaven doctrine see: Peter Barker "Stoic contributions to early modern science," in M. J. Osler (ed)., Atoms, pneuma and tranquility: Epicurean and Stoic Themes in European Thought. Cambridge: Cambridge University Press, 1991, 135-154.

and the Prime Mover."[127] In the geocentric system, the movement of the heavens was attributed to a system of real spheres, eccentrics and epicycles.[128]

Grassi then went on to present a heliocentric system to his students. He reported that "Others placed an immobile sun as the center of the world around which they said the remaining planets are moved…indeed they wanted the earth itself to be carried around the sun just as one of the planets."[129] However, the *Tractatus de sphaera* makes no mention of Copernicus, presumably because his model had been condemned by the Catholic Church in 1616.[130] Another reason for this exclusion could again be attributed to the Jesuit *Ratio studiorum* since it outlined that professors should refrain from citing too many authors.[131] Although the Jesuits and Copernicus shared the assumption that causes could be reliably inferred from observed effects, Grassi was as mute on this point as his mentor, Clavius had been in his commentaries on the *Sphere*.[132] Still, Grassi demonstrated this shared assumption in his rebuttal to heliocentric cosmology. In his lectures, Grassi praised the heliocentric system for its ability to account for many of the

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[127] Grassi, *Tractatus de sphaera*, 1v-2r. "*hac secunda opinionam ponitur ab omnibus eodem modo aliqui enimque in centro totius mundi possunt terram immobilem et circa ipsam elementa, et coelos hoc ordine ut immediate supra terram sit aquaque deinde aer, tertio loco ignis, mox coelum lunae, Mercurii, Veneris, Solis. Martis Jouis Saturni, Firmamenti; Primi mobilis.*"

[128] For a discussion of the constructions of geocentric cosmology in the *Sphere* see Lattis, *Between Copernicus and Galileo*, 45-50.

[129] Grassi, *Tractatus de sphaera*, 2r-2v. "*Alii posuerunt solem pro centro mundi, et hunc quidem immobilem circa quam moveri reliquos planetas dixerunt, imo est terram ipsam veluti unum planetarum circa solem ferri voluerant.*"

[130] There are numerous studies of the 1616 condemnation of heliocentrism. Among the most notable are: Maurice A. Finocchiaro, *The Galileo Affair: A Documentary History*. Berkeley: University of California Press, 1989, pp. 47-153, for the relevant documents; Mario Biagioli, *Galileo Courtier*. Chicago: Chicago University Press, 313-352 for the patronage issues; and the papers collected in Ernan McMullin (ed). *The Church and Galileo*. Notre Dame, IN: Notre Dame University Press, 2005, especially pp. 88-190. For important new insights on the protocols of the Inquisition see Thomas F. Mayer, *The Roman Inquisition: Trying Galileo*, Philadelphia: University of Pennsylvania Press, 2015, esp. chapters 2-4 on the events of 1616.

[131] For more information on this see "the Rules for the Professors of the Higher Faculties" in the *Ratio studiorum* of 1599. In Pavur *the Ratio* Studiorum, 49. Farrell, "The Jesuit Ratio Studiorum of 1599," 26.

[132] For a discussion of Clavius and Copernicanism see Lattis chapter 5 especially page 110.

observed phenomena in the heavens and for its mathematical utility. However, he argued that heliocentric cosmology was insufficient due to its incompatibility with scripture and the objections made by Tycho Brahe.[133]

The last cosmology Grassi presented was the geo-heliocentric system Tycho Brahe had formulated. Grassi explained Tycho's cosmology as follows:

> The whole elemental region is defined and bounded by the moon. The nearest heaven to this is that of the sun, which they establish of such a thickness that Mercury and Venus are able to move around the Sun inside it. The heaven of Mars is added to the heaven of the Sun, then the heaven of Jupiter around which four planets are carried, then the heaven of Saturn and its two satellites, and also the firmament in which the fixed stars always maintain the same distances from each other. Next the *primum mobile,* between which and the firmament lie two other spheres which by their motions of small approach and recess cause the precession of the equinoxes and the solstices.[134]

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[133] Grassi, *Tractatus de sphaera*, 2r-2v. "*quamvis autem haec sententia satis bene explicat omnes caelestes apparentias habet tamen multa argumenta, quibus egrem satis facit, sed proscipumum ad illud quod a sacris fictoris ducitur inquibus saepissimem dicitur sol moveri, et terra stare, neque satis est si dicant scripturam loqui quo ad sensum qua nimirum est si sol non moveatur videtur tamen moveri et terra stare licet moveatur ea ratione qua dicimus terras et urbes recedare quando e[x] ponu solvimus, qua verba sacrae scripturae accipienda sunt ut sonant, nisi aliunde cogamur in aliam sensum trahere, nulla autem demonstratio praedictae opinionis qua nos a proprio sensu illorum verborum discedere cogat. cum igitur haec opinio sustineri non possit non eget longiori explicatione. dubium esset an sustineri possit ea quae soliditarem caelorum ass[e]rit videtur enim hanc opinionem omnino destrunino destruere Martis cursus a Ticone aliisque astronomis observatus.*"

[134] Grassi, *Tractatus de sphaera*, 2v-3r. "*dicunt enim facillimem decipi potuisse Ticonem, et reliquos astronomos, qui illum se observasse dictitant, atque ita diruto hoc fundamento aliam ineunt viam motuum coelestium explicandorum, et primo quidem loco statuunt coelum lunae, qua tota elementaris regio terminatur, et clauditur, huic proximum est caelum solis quod statuunt esse tantae crassitudinis ut intra ipsam suos motus conficere circa solem possint Mercurius, et Venus; caelo solis superinducitur caelum Martis, huic caelum Jovis capax motus quatuor planetarum qui circa ipsam feruntur . diende caelum Saturni et duorum ipsius satellitum. deniq[ue] firmamentum in quo stellae fixae easdem semper inter se distantias servant. mox primum mobile ita tamen ut inter hoc et firmamentum medient duae aliae sphaerae quae suis motibus exigui accessus et recessus causant praecassiones aequinotiorum et solstitionem*"

Unlike the presentation of the heliocentric system, Tycho was cited as the source of this cosmology and is elsewhere cited as an authority on astronomical observation in the treatise.

The first chapter of the *Tractatus de sphaera* includes Grassi's summary of Tycho Brahe's observations of Mars and their importance for any discussion of the construction of the heavens. Tycho had calculated that the heavens of Mars and the Sun intersected in Ptolemaic cosmology and Grassi explained to his students that this was evidence against a cosmos constructed of solid celestial orbs.[135] Later he argued that if the observational data Tycho had made concerning the intersection of the heavens of Mars and the Sun was accepted, "then the solidity of the heavens must be abandoned."[136] However, Grassi also admitted the fallibility of observational evidence in his lectures explaining to his students that "many errors have been committed in these observations," meaning astronomical observations in general rather than the specific observations of Tycho. [137] As an example he cited the uncertainty among the masters of astronomy who "disagree among themselves on the distances of the heavens and on the magnitudes of the stars." [138] Even so he was illustrating to his students the importance of observational data. In his discussion in the opening chapter Grassi asserted that if

[135] Grassi, *Tractatus de sphaera*, 2r-2v.
[136] Grassi, *Tractatus de sphaera*, 18v-19r. "*De Marte nihil peculiare dicendum super est. nam de ipsius motu, quo nunc infra coelum solis, et quidem inter solem, et ipsum constituta terra conspectum esse. nunc vero supra coelum eiusdem solis videri dicitur satis dictum est supra, et si haec observatio admittatur coeli soliditas rui, si quis tamen ad hanc eamdem soliditatem sustinendam huic observationi fidem neget non temerem id fecerit. cum facilem in his observationibus error aliquis committi posset. Imo vero cum compertum sit multos in huiusmodi observationibus commissos cum adeo discripent inter se in distantiis coelorum, et in astrorum magnitudinibus ipsi astronomiae magistri"*
[137] Grassi, *Tractatus de sphaera*, 19r.
[138] Grassi, *Tractatus de sphaera*, 19r.

Tycho's observations were accurate, certain earlier knowledge claims such as the solidity of celestial spheres had to be abandoned.[139]

By introducing so many different cosmologies, Grassi had conveyed to his students the uncertainty regarding Aristotelian physics and Ptolemaic cosmology characteristic of the early seventeenth century, as well as the insufficiency of Sacrobosco's *Sphaera*. Grassi's emphasis on the Tychonic system also served to highlight the importance of physico-mathematics for these disagreements because of the premium placed on the ability of geometrical demonstrations based on observational data to provide authoritative answers to natural philosophical questions.

The second chapter of the *Tractatus de sphaera* also demonstrates the physico-mathematical character of Jesuit science in the early modern period. This chapter was dedicated to the definitions of things found in the *Sphere* of Sacrobosco. One of the more illuminating definitions occurs in Grassi's discussion of observational parallax. The importance of a trigonometric parallax was a key issue in the controversy over the comets of 1618 with Galileo and the *Tractatus de sphaera* reveals that Grassi conveyed that importance to his students. For example, Grassi taught that parallactic measurement was used to accurately determine the order of many of the planets.[140] But comets were not mentioned here nor anywhere else in the *Tractatus de sphaera*, despite their relevance to this subject.

The third chapter of the *Tractatus de sphaera*, which is incidentally the longest chapter in the 1623 manuscript, addresses numerous topics of interest to early modern

[139] Grassi, *Tractatus de sphaera*, 2v.
[140] Grassi, *Tractatus de sphaera*, 12v. *"haec differentia inter veram et apparentem distantiam dicitur paralaxis, sive aspectuum diversitas. alter modus huius paralaxis investigandae est quando ex duobus locis in superficie terrae inter se distantibus eadem res inter firmamentum et terram posita aspicitur."*

historians of science. Grassi's lectures recorded in that section addressed the properties of the individual heavenly bodies.[141] Some of this chapter could be considered standard content for the *Sphere,* such as the definitions of right ascension and declination as well as the discussion of the vernal and autumnal equinoxes. However, Grassi's lectures also discussed many novel celestial phenomena discovered in the late sixteenth and early seventeenth century, including the phases of Venus, sunspots, the appearance of the moon and the Milky Way, and he also includes discussion of the newly invented telescope. This chapter includes a number of examples of physico-mathematical claims, both in his quantitative and qualitative arguments.

When Grassi discussed the telescope as an observational instrument, he reported that, although with the naked eye the stars were understood to number around 1022, this was not certain "for how many stars are there that might escape the eyes, since those more distant [stars] are easily seen by that newly invented telescope."[142] This reasoning was paramount in his discussion of the Milky Way where Grassi went on to assert that "the Milky Way [had] been confirmed through the telescope to consist of stars with tiny distances between them."[143] Thus, the Milky Way could no longer be considered a meteorological phenomenon as Aristotle suggested, because observational evidence contradicted that argument. In his discussion of the new instrument, Grassi accepted the authority of telescopic observation of the heavens only thirteen years after it was first

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[141] Grassi, *Tractatus de sphaera*, 14v.
[142] Grassi, *Tractatus de sphaera*, 15r. Here the writer used the word *specillum* referring to the telescope. This could be *speculum* which literally means 'mirror' or could have been an abbreviated form of the word *perspicillum* which Galileo himself had used in his *Sidereus Nuncius* (1610) on the title page, 6r (3 times), 6v, 6v-7r, and elsewhere.
[143] Grassi, *Tractatus de sphaera*, 15r.

applied to that field.[144] Even more important for this study, Grassi was proclaiming that observational astronomy could and did inform natural philosophy because it could provide information that was not available to natural philosophers prior to these observations.

Grassi's description of telescopic observations of the stars and much of the content of the third chapter of the *Tractatus de sphaera* discussed the observations Galileo published in his *Sidereus nuncius* of 1610.[145] Grassi's mentor, Clavius had referred to Galileo's *Sidereus nuncius* as "a reliable little book" and recommended that it be consulted for its description of the stars and various observations made by Galileo.[146] Grassi was not stealing Galileo's ideas. He was again entering into discussions concerning the construction and organization of the heavens as he had done in the controversy over the comets, this time in the context of the Jesuit classroom. The Jesuits were involved in their own scientific enterprise, as further examination of the *Tractatus de sphaera* reveals.

Grassi's discussion of Venus and Mercury is a prime example of the physico-mathematical approach to the heavens the Jesuits advocated. In his treatise, Grassi argued that his students must understand "that Mercury and Venus are moved around [the sun] itself. It is because of this that Venus receives light from the sun in various hornlike ways."[147] In this example Grassi was relying on observations of Venus and Mercury to support his claims. Because Mercury and Venus were always seen near the

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[144] For a discussion of Grassi's role in the acceptance of telescopic observations as discrete experiences that could be applied to natural philosophy see Peter Dear, "Jesuit Mathematical Science and the Reconstitution of Experience in the Early Seventeenth century." *Studies in History and Philosophy of Science* 18, no. 2 (1987): 133-75.
[145] See Galileo, *Sidereus nuncius* (1610).
[146] Lattis, *Between Copernicus and Galileo*, 198
[147] Grassi, *Tractatus de sphaera*, 19r.

Sun they should be understood as satellites not wandering stars, and only satellites could display the pattern of phases which Venus exhibited when observed through the telescope. By arguing that Venus and Mercury moved around the Sun, Grassi was explicitly admitting in an introductory astronomy course that Aristotelean physics as well as Ptolemaic cosmology were wrong. In both the discussion of Venus and Mercury as well as his discussion of lunar and solar eclipses and the circuit of the Sun, Grassi was using physico-mathematical results to make causal claims about the heavens.

That observational evidence in physico-mathematical astronomy could inform natural philosophy was made even more apparent in Grassi's discussion of the moons of Jupiter and Saturn. Grassi affirmed the telescopic observations of Galileo and his fellow Jesuits, explaining that two attendants were observed when Saturn was observed with the telescope and arguing that these were the cause of Saturn's oval appearance.[148] Grassi described Jupiter's moons in the same way, relating to his students that with the aid of the telescope four planets could be observed revolving around Jupiter, and giving their distances and periods.[149]

Despite the observation of the satellites of Jupiter, a strictly geocentric cosmology was still defended by many, including Clavius, because it was as compelling as any contemporary alternative cosmologies.[150] Observation was not enough by itself; the interpretation of the observation was just as important. Galileo relied on demonstrative regression that juxtaposed numerous observations of Jupiter to make his

[148] Grassi, *Tractatus de sphaera*, 18r.
[149] Grassi, *Tractatus de sphaera*, 18r-18v.
[150] Lattis, *Between Copernicus and Galileo*, 63

argument in the *Sidereus nuncius* that the stars were actually moons of Jupiter.[151] This was the same evidence Grassi used to explain the same phenomena to his students thirteen years after Galileo's little book was published.[152] But Grassi's conclusions were different. He did not take this to mean that the center of the universe was not the earth but simply as another example of more satellites. In the same way that Venus and Mercury moved around the sun, so too moved the satellites of Jupiter and Saturn.

Another example of Grassi's willingness to use physico-mathematic methodologies in his instruction of astronomy is evident in the treatment of sunspots. Like his colleague Christoph Scheiner, Grassi placed the phenomena of sunspots outside the sun itself arguing that "these spots, in my judgment, are erratic corpuscles around the sun, and perhaps planets moved variously and dissimilarly among themselves."[153] In this instance Grassi accepted the existence of sunspots, but agreed with the consensus of his fellow Jesuits rather than agreeing with Galileo. Grassi's discussion of torches, or bright spots on the sun, also reveals his willingness to make qualitative judgments based on observational evidence. He defined torches as those brighter parts of the sun which always exist in the same location following the Aristotelian view of a perfect heaven.[154] However, Grassi followed this with another

[151] Galileo Galilei, William F. Edwards, and William Augustine Wallace. *Tractatio De Praecognitionibus Et Praecognitis and Tractatio De Demonstratione*. (Padova: Antenore, 1988), LXXIV-LXXV.
[152] Grassi, *Tractatus de sphaera*, 18v.
[153] Grassi, *Tractatus de sphaera*, 19v. "*Maculae meo iudicio corpuscula sunt erratica circa solem fortasse planetae motibus inter se variis et dissimilibus, quorum tamen periodum audio quidam iam compertam esse.*" Peter Dear explains that "by 1614 [Scheiner] had adopted a view much closer to that later presentation in his great astronomical work of 1630, the *Rosa ursina*, which deals especially with the sun and sunspots: the sunspots have turned into features at no discernable distance from the sun's surface ('whether they be stars is hitherto disputed," he could say in 1614, but this was clearly answered in the negative by the time of the *Rosa ursina*'), while the Jovian companions are now four in number and just as Galileo had asserted." Dear, *Discipline and Experience*, 115.
[154] Grassi, *Tractatus de sphaera*, 19v.

opinion which claimed that the torches did move and change. Much in the same way that Clavius asserted that mathematically expressed observations required at the very least a reassessment of established knowledge, Grassi also reinforced this for his students. If the Torches were shown to move and change as others suggested, then they required reinterpretation. "Ether it must be said that the sun is not uniformly bright, or at least that its splendor is augmented in some places from those corpuscles nearest to the sun which reflect light onto the sun itself, or that those bright particles on the sun itself are more dense and because of this have more brightness." [155] Grassi's argument was that, if the torches moved and changed, this observation required a reassessment of the existing astronomical orthodoxy, but still preserves celestial perfection.

During his lectures concerning the moon Grassi related the utility and limitations of observational astronomy in the physico-mathematic movement of the Jesuits. Grassi's lectures reported that "some think the moon is not perfectly polished, but a likeness of the terrestrial globe with mountains and valleys."[156] Although he did not cite anyone specifically, it is hard to imagine that Grassi was not referencing the arguments which had been raised by Galileo concerning the terrestrial nature of the moon in this passage. Grassi's lectures refuted Galileo's position, arguing that absorption and re-emission of light through the body of the moon, which varied in opacity, could explain the spots without need for an irregular surface. Hence, "the more likely [opinion] follows that the body of the moon is not rough and unequal, but rather

[155] Grassi, *Tractatus de sphaera,* 19v. "*Sunt tamen aliqui qui affirment faculas etiam moveri, et mutari, quo si ita est vel dicendum erit solem non esse uniformiter lucidum vel certe ex illis corpusculis soli proximis remissam in ipsum solem lucem eius splendorem aliqua ex parte augeri, vel denique in ipso sole particulas illas magis lucidas densiores esse ac proinde plus luminis habere.*"
[156] Grassi, *Tractatus de sphaera,* 20v. *"Aliqui enim existimant lunam non esse perfecte politam sed instar terrestris globi montibus et vallibus distinctas"*

perfectly polished and round."[157] As he had done in his discussion of sunspots, Grassi was again defending perfection of the celestial realm in arguing that the moon is perfectly round.[158] Although some Jesuits such as Odo van Maelcote (1572 - 1615), Christoph Grienberger (1561-1636), Giovan Paolo Lembo (1570 - 1618) and Christoforo Borro (1583 - 1632) agreed with Galileo, Clavius and many other Jesuits, were reluctant to accept the existence of mountains and valleys on the lunar surface.[159]

These examples from the 1623 *Tractatus de sphaera* all demonstrate the utility of physico-mathematics in the study of the heavens during the early modern period. Because the telescope had increased the fidelity with which one could observe the heavens, novel observations were made which directly impinged upon early modern astronomy and cosmology. Jesuit physico-mathematicians were actively involved in assimilating these new observations into their contemporary understanding of the heavens. Grassi's lectures reveal that the Jesuits were teaching their students about novel opinions and forwarding their own interpretations based on physico-mathematical principles increasing the validity of observational evidence in natural philosophical discussion. Still, Grassi's lectures were a part of the Jesuit culture. Some content was left out of these discussions and these omissions give us valuable insight into Jesuit educational culture.

[157] Grassi, *Tractatus de sphaera*, 20v. *"Probabilior tamen haec posterior quae lunae corpus non asperum et inaequale, sed perfecta politum et rotundum constituit."*
[158] For a more detailed study of early modern rejections of Galileo's arguments about the lunar surface see Roger Ariew. "Galileo's Lunar Observations in the Context of Medieval Lunar Theory." *Studies in History and Philosophy of Science* 15, no. 3 (1984): 213-26.
[159] Lattis, *Between Copernicus and Galileo*, 199.

The limits of physico-mathematics: Comets and Jesuit Science

The absence of any discussion of comets and their observational parallax in the *Tractatus de sphaera* is a curious omission considering their general relevance to the history of astronomy in the early seventeenth century, especially for Grassi in the context of the controversy over the comets with Galileo. Measurements of the observational parallax of comets had been used by Grassi and others to determine that comets were beyond the lunar sphere, a prime example of how physico-mathematical observations could be applied to natural philosophy. Why Grassi chose to exclude material on comets from his lectures in 1623 can be used to examine key issues concerning the status of physico-mathematics in the context of the *Collegio Romano* and the limits of its methodologies in early seventeenth-century European science.

No less than five sixteenth-century astronomers, including Tycho Brahe, had calculated the apparent parallax of the comets of 1577, although their values differed considerably.[160] By the time Grassi was embroiled in his dispute with Galileo, these measurements had become important in arguments concerning the solidity of the heavens and the order of the planets. Although Grassi relied on the apparent parallax of the comets of 1618 in the controversy over the comets with Galileo, and he had in his lectures discussed the importance of observational parallax for determining the exact location of celestial bodies, no mention of comets was recorded in either the University of Oklahoma manuscript or the St. John's manuscript.[161] But why exclude such a seemingly important topic?

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[160] Mosley, *Bearing the Heavens*, 160-2; Lattis, *Between Copernicus and Galileo*, 158.
[161] For discussion of observational parallax see Grassi, *Tractatus de sphaera*, 6v-7v.

Grassi's mentor, Clavius was silent on the subject of comets in his commentaries on the *Sphere* of Sacrobosco as well. James Lattis argued that Clavius excluded comets in his commentaries because he was primarily a theorist and an educator, mainly concerned with "evaluating the claims of rival theories" not producing or assimilating new observations.[162] However, Lattis' reasoning cannot be applied to Grassi's context. Jesuit mathematicians demonstrated their ability to produce and assimilate new observations into their knowledge as was demonstrated by Scheiner in the disagreement over sunspots and other examples in the early seventeenth century.[163] This thesis has shown that Grassi did assimilate new observations in his lectures in 1623 and was willing to both produce new observations of comets and assimilate others' observations of those same comets using their apparent parallax in the controversy with Galileo. So the question remains.

One compelling explanation is again found in the Jesuit plan of study. The guidelines in the *Ratio studiorum* of 1599 stipulated in the rules for the professors of the higher faculties that:

> Even in matters that present no risk of faith and religious devotion, no one should introduce new articles for discussion in matter of any significance, nor any opinion that does not belong to any suitable authority, without consulting those who are in charge, nor anything contrary to axioms of the Doctors. And should teach the common understanding of the Schools. Everybody should

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[162] Lattis, *Between Copernicus and Galileo*, 160

[163] For more information on Scheiner and sunspots see Eileen Reeves and Albert van Helden *On Sunspots*. The most notable alternative example was Josephus Blancanus, also a Jesuit who in 1620 published his *Sphaera mundi* which explicitly sought to incorporate the elements Clavius had not addressed. For more on Blancanus see Peter Dear's *Discipline and Experience.*

> rather follow the most approved academic authorities and the positions that have been supported with the greatest preference in Catholic institutions, insofar as the tenor of the time allows.[164]

Based on this standard, Grassi may have excluded discussion of comets following the exemplar of Clavius, who by all accounts was "a suitable authority." Additionally, these rules are able to account for Grassi's inclusion of some novel material while leaving out others that had yet to reach a "common understanding" in the schools. Therefore, Grassi's decision to discuss some current material such as sunspots and telescopic observations of the moon and the heavens, while leaving out discussion of comets was in compliance with the expectations of the *Ratio studiorum* and in common with Jesuit scientific practice. Conversely, the novel material, or at the very least the observations of those phenomena, that Grassi did discuss should be considered to have been uncontroversial in the Jesuit schools based on their inclusion in his lectures on astronomy at the *Collegio Romano*.

This interpretation is complemented by other discussions concerning the history of the controversy over the comets. Mario Biagioli's analysis of the controversy over the comets in the context of his examination of the dynamics of patronage in Rome argued that Grassi and Galileo were appealing to a lay audience, not professional astronomers, but rather cardinals, other prelates and Roman literati.[165] Grassi's audience at the *Collegio Romano* was much different from that of the lay audience for whom Sarsi was writing. In Biagioli's assessment both Galileo and Grassi were aware of this

[164] Pavur, *The Ratio studiorum*, 49-50. Pavur explains in footnote 58 of on page 49 that "seemingly, *Doctor* is used here to indicate something like 'those writers who are acknowledged to be the principal teaching authorities in the disciplines.'"
[165] Biagioli, *Galileo, Courtier*, 290.

important factor. While Grassi's students were not yet professional astronomers, the material he presented them had to comply with the standards outlined in the Jesuit plan of study and at the same time provide them with an adequate outline of contemporary astronomy.

Another interpretation by Pietro Redondi suggests that the controversy over the comets had gone out of fashion by 1623 and was replaced by a debate concerning whether or not physics was perceptible to the senses.[166] Although Redondi's premise unnecessarily requires the controversy over the comets to have gone out of fashion, his observation that the conversation had evolved into a broader discussion about observational evidence in natural philosophy adds another layer of complexity to this issue. The physico-mathematical movement, because of its ability to incorporate novel astronomical observations into the existing ways of thinking, had a profound influence on early modern science. Mario Biagioli reinforces this argument by suggesting that the controversy over the comets had evolved into a broader conversation concerned with the intellectual authority of Grassi and the Jesuits, as well as Galileo, as astronomers.[167] Grassi's decision to exclude discussion of comets was a calculated one. Because the controversy had evolved into a broader discussion over intellectual authority, Grassi avoided the issue in the context of his astronomy course so as to not digress too far from the subject he was charged with teaching.

Although Grassi decided to exclude discussion of comets in his lectures, their omission was not much of a deficit for his students. Any opinion that could have been drawn from a discussion of comets was already apparent in Grassi's discussion of the

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[166] Redondi, *Galileo Heretic*, 51.
[167] For more on this dynamic see Biagioli, *Galileo, Courtier*, 274.

intersection of the heavens of Mars and the Sun during his introduction of the four different cosmologies recorded in the first chapter of the *Tractatus de sphaera*. The observations made by Tycho Brahe and subsequent mathematicians concerning the heavens of Mars and the Sun, if accurate, were more factual than observations of comets. This was because unlike comets, Mars and the Sun were known to be celestial phenomena and therefore they were not vulnerable to the same attacks Galileo had waged against Grassi in the controversy over the comets of 1618, when he claimed they were not real celestial phenomena. This enhances our view of the controversy over the comets because it exemplifies the intellectual relationship between the Jesuits and Galileo; Grassi responded to Galileo's arguments and found other examples supported by Jesuit physico-mathematical methodologies that he could present to his students.

The decisions Grassi made concerning what phenomena to include and exclude in his discussion are also manifest in the manner in which his evidence was presented to his students. Grassi repeatedly relied on observational evidence in his lectures and emphasized their importance to his students. As we have already seen, Grassi was willing to admit the observations of Galileo and many of his fellow Jesuits in his assessment of the constitution of the Milky Way as a body made of numerous tiny stars, and in recognizing the existence of satellites for Jupiter and Saturn. Grassi's lectures recorded in the *Tractatus de sphaera* did more than advocate for the importance of astronomical observation. He goes further to claim that observational evidence demanded reassessment of natural philosophical issues, best demonstrated by his discussion of Venus and Mercury. Although Grassi does not use the term physico-mathematics (*phisico-mathematica*), his presentation of the material did advocate the importance of observational evidence in astronomy. Again Grassi was conscious of his audience; he didn't go too far in his physico-mathematical claims, but presented them as a choice in authority. The choices he put to his students were both in compliance with Jesuit educational standards and in support of the intellectual authority of physico-mathematics. The way in which Grassi presented phenomena as observational evidence demonstrates the utility and limits of observational evidence in the Jesuit physico-mathematical tradition.

Peter Dear has identified *experience* as a key term for physico-mathematics. To be accepted as evidence, an observation or experience had to command assent because it was evident.[168] Because of this, observations were usually presented as universal statements rather than singular statements that relied on fallible historical reports.[169] Universality and common assent are evident in Grassi's discussion of astronomical observation as well as his discussion of the moon. Grassi's discussion of the spots on the moon highlights an important factor in the acceptance of observational experience, common assent or consensus, made evident in the phrase "which are widely recognized by all."[170] Because the spots were recognized by all, thereby satisfying the requirements of common assent, and generally understood to exist on the moon itself, Grassi had no issue with accepting the observation. However, his subsequent discussion of the cause of that observed phenomenon reveals the limits of consensus concerning observations. Although Grassi supported the common understanding of the Jesuit schools by asserting

[168] Dear, *Discipline and Experience*, 44.
[169] Dear, *Discipline and Experience*, 44.
[170] Grassi, *Tractatus de sphaera*, 20r. *"cuius maculae omnibus notissimae sunt."*

that the moon was not mountainous, he was also keen to point out to his students that there was no agreement concerning the cause of the lunar spots.[171]

Grassi's lectures demonstrate the authority of physico-mathematics and what claims it could make and what it could not, in effect demarcating the boundaries between physics/natural philosophy and mathematics while at the same time showing how permeable natural philosophy really was to physico-mathematical claims. In all of the previous examples Grassi was addressing current debates regarding the construction and motion of the heavens and the bodies therein. Grassi's 1623 lectures offer a glimpse into the kind of material that was presented to a student of mathematics at the *Collegio Romano* in 1623 and remains an example of the broader culture of education at the Jesuit university in Rome and elsewhere. Rather than sheltering students, the mathematics professors at the *Collegio Romano* were willing to confront current debates directly in their classes.

Conclusions

In October 1623 Galileo's *Assayer* was printed in Rome, dedicated to the newly elected pope Urban VIII.[172] The work was widely considered a masterfully written rebuttal from which Grassi never successfully recovered. In the *Assayer* Galileo ridiculed Sarsi, now revealed as Grassi, for his arguments in the *Libra.* Specifically, Galileo attacked Grassi for proposing that the senses, in particular that of sight, could be considered an authority on astronomical questions and praised Copernicus for accepting the sensory

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[171] Grassi, *Tractatus de sphaera*, 20v.
[172] Galilei, Galileo, *Il saggiatore*. Published in Rome 1623. For an English translation see Galilei, Galileo, and Maurice Finocchiaro, *The Essential Galileo*. (Indianapolis, Ind.: Hackett Pub., 2008)

contradictions of his positions.[173] Galileo also sought to discredit the authority of Sarsi by asking why it was "that Sarsi should of his own volition choose to be that mere anybody who would tuck up his sleeves and welcome a task which, in the judgment of the wisest men (and himself), should be given to any but the meanest servant."[174] Galileo's attacks against the credibility of Grassi's mathematical arguments and his credibility were executed in a rhetorical style which was widely praised in Rome.[175]

Although Grassi had proclaimed that he would respond to Galileo quickly, his response was impeded by his appointment to construct the Church of St. Ignatius in Rome, which also prompted Grassi to teach architecture in 1624 rather than astronomy.[176] During the two-year period during which the church was constructed, the positions of the Catholic Church officials as well as the Jesuit scholars were becoming more critical of unorthodox opinions. In November of 1624, Fabio Ambrosio Spinola gave an inaugural lesson which was "a vehement and violent invective against the followers of new opinions contrary to Peripatetic opinion."[177]

The conditions under which Grassi's response to Galileo appeared, finally published in 1626, reflected this shifting environment. The work, titled *Ratio ponderum librae et simbellae* again published under the pseudonym of Sarsi, but was printed in Paris rather than Rome.[178] This led to many difficulties further delaying its publication.

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[173] Drake and O'Malley, *The Controversy on the Comets,* xxiv.
[174] Drake and O'Malley, *the Controversy on the Comets*, 174.
[175] Biagioli, *Galileo, Courtier*, 297 and 303.
[176] Redondi, *Galileo, Heretic*, 131.
[177] Redondi, *Galileo, Heretic,* 132.; See also Feingold, Mordechai. *The New Science and Jesuit Science,* 149.
[178] Orazio Grassi and Sebastien Cramoisy. *Ratio ponderum librae et simbellae: in qua quid e Lotharij Sarsij libra astronomica, quidque e Galilei simbellatore, de cometis statuendum sit, ... proponitur*. (Lutetiae Parisiorum: sumptibus Sebastiani Cramoisy, 1626). In English "A reckoning of weights for the balance and the small scale" (Drake and O'Malley, *The Controversy on the Comets,* xx.)

Because Grassi was so far removed from the Parisian printers, he was forced to engage in an extended exchange with them regarding the proofing of the text. Why Grassi's response was published in Paris rather than Rome is curious. Some historians of science have conjectured that a lack of superior approval for the text because of its personal nature was the reason for its publication in Paris rather than Rome.[179] It is true that the *Ratio* is critical of Galileo, but Galileo's *Assayer* was no less critical of Sarsi and the Jesuits.[180] However, over the course of the dispute, the exchanges between Grassi and Galileo enjoyed a wide audience and Galileo proved to be better at appealing to this audience which caused damage to the public image of the Society of Jesus and their relationship with the Church.[181] Although Grassi's public reputation had suffered greatly following his controversy with Galileo, after completing his work on the Church of St. Ignatius, Grassi again taught mathematics at the *Collegio Romano* from 1626-1628, but Galileo had not felt the need to reply to Grassi's *Ratio ponderum* after it was published.[182]

The damage that Galileo inflicted upon his rival with the *Assayer* is reflected in the historiography of Grassi and the Society of Jesus. This is most evident in Stillman Drake's and Charles O'Malley's choice to exclude Grassi's *Ratio ponderum* from their study on *The Controversy on the comets.* Their reasoning for this egregious exclusion

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[179] Matteo Valleriani explained in his study of the controversy over the comets that "When Il Saggiatore was published, Grassi's superiors prohibited his scholars from publishing any further texts on the same subject, probably after having decided that Galileo's response had surpassed the boundaries of tolerance, and that any action against his work must be of a political nature. Grassi, however, did write another work, published in Paris in 1626 (EN, VI:375–500). Galileo also began annotating Grassi's works of 1626 but he ultimately chose to leave his notes in the drawer. Galileo's notes were published by Favaro together with Grassi's work of 1626." Valleriani, *Galieo Engineer,* 187, fn 78. Also see Redondi, *Galileo, Heretic*, 193.
[180] Redondi, *Galileo Heretic,* 194.
[181] Biagioli, *Galileo, Courtier,* 299-301.
[182] Biagioli, *Galileo Courtier,* 309.

was that Grassi's final response to Galileo dealt mostly with the minutiae of the dispute and made "little impression on the public."[183] Similar attitudes have led others to depict Grassi and the Jesuits as enemies and reactionaries to the real scientific minds of the era. However, more recent history of science and this study have shown that the Jesuits were actively involved with developing their own science.

Following the example of Christopher Clavius, Jesuit mathematicians began a tradition of physico-mathematics at the *Collegio Romano*. In this tradition mathematics could and was used to introduce novel observational evidence into Jesuit natural philosophy, especially in regard to celestial phenomena. This tradition produced a whole generation of Jesuits and professional laymen who were taught physico-mathematics. This conclusion is supported by other studies of mathematics professors at the *Collegio Romano* as well. Renee Raphael has done extensive work on the teaching of sunspots at the *Collegio Romano* and shows that many professors, such as Gabriele Beati (1607-1673), presented novel astronomical observations and participated in these lively debates during and after Grassi's term at the *Collegio Romano*.[184]

Grassi's lectures on the *Sphere* in 1623 reflect the Jesuit educational culture and also demonstrate the effectiveness of Clavius' emphasis on mathematics in the Jesuit university. The 1623 manuscript record of student notes reveal that Grassi was teaching physico-mathmatics to his students at the *Collegio Romano.* The consequence of this was that Grassi was able to incorporate novel astronomical observations into existing

[183] Drake and O'Malley, *The Controversy on the Comets*, xx. The exclusion is explained by a practice of history celebrating great men of science. This position is supported by the fact that the editors chose to end their exploration of the controversy over the comets with a series of translations with comments by Johann Kepler in place of Grassi's *Ratio*.

[184] Renee Raphael. "Teaching Sunspots: Disciplinary Identity and Scholarly Practice in the Collegio Romano." *History of Science* 52, no. 2, 130-52.

celestial knowledge demonstrating the utility of the physico-mathematical movement. For Grassi, the physicalization of mathematics meant the physicalization of observational evidence which was paramount in the early seventeenth-century discussions about the heavens.

Grassi's discussion of these observations and opinions conveys the state of the field of astronomy for the early seventeenth century. Grassi introduced four different cosmologies to his students, demonstrated the utility of the telescope for astronomy, presented the phases of Venus and Mercury as observational evidence of their relationship to the sun. In the same way Grassi related to his students that observational evidence of Jupiter and Saturn necessitated that those bodies be considered satellites of those planets. Grassi also discussed the observation of sunspots and the telescopic observations of the moon, only leaving out the discussion of comets for which he had good reason despite their relevancy to his topic.

As a record of student notes, the 1623 manuscript record of Grassi's lectures offer valuable insight into the physico-mathematical tradition of the Jesuits at the *Collegio Romano*. Grassi's inclusion of some novel material and exclusion of others demonstrates the complexity of Jesuit scientific culture. More work on the Jesuit physico-mathematic tradition could lead to a better understanding of how observational evidence was validated over the course of the early modern period. For example, more study of this issue may lend more insight into the adoption of Tychonic cosmology by Jesuits in the middle of the seventeenth century. Unless observational astronomy could be used to make causal claims about the natural world, there would have been little benefit for the Jesuits to adopt the Tychonic system, since it was in many respects mathematically on par with the Ptolemaic model of the cosmos. But there would have been every reason to adopt the Tychonic system for the Jesuits who worked in the physico-mathematical tradition of Clavius. Tycho had shown that the heaven of Mars and that of the Sun intersected which necessitated that the heavens were not completely solid. This paired with early seventeenth-century observations of Venus and Mercury would have been enough evidence for a physico-mathematician that Tycho's interpretation could be correct.

Continued study of this topic could also shed light on the application of mathematics and observational evidence to the development of early modern science. For example, more work should be done on the Jesuit concept of consensus or common assent. This study has shown that physico-mathematics could make claims about the heavens but only if the observations could be confirmed in the relevant social context demanding common assent. The way in which the Jesuits navigated these issues while striving to comply with the cultural norms of their society could lend valuable insights into the development of early modern scientific communities.

What is clear from Grassi's 1623 teaching is that the Jesuits were actively involved in the contemporary discussions concerning the heavens. The Jesuit physico-mathematical tradition was willing to accept observational evidence as a valid way of knowing. Based on their observational evidence, Jesuit physico-mathematicians could make claims about the structure of the heavens demonstrating that Aristotle was no longer authoritative and thus new knowledge about the heavens could be generated. They were not simply scholastic reactionaries as Galileo accused Grassi of being in the controversy over the comets. This image is largely the result of a skewed history of the controversy over the comets and the larger history of the Society as a result of their expulsion in 1773. The Jesuits were practicing their own science and should be understood on their own terms rather than merely contemporaries of Galileo. Grassi needs to be seriously considered precisely because he was taken seriously by Galileo and his contemporary Jesuit fellows. Grassi was working within a community and institution that demanded the refinement of his assumptions and arguments. The Jesuit tradition of physico-mathematics that was institutionalized by Clavius and continued by his successors who taught students literally across the known world, advanced the legitimacy of observational experience and the application of observational astronomy to causal statements about the heavens in the seventeenth century.

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