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ʾABŪ SAᶜĪD AL-SIĞZĪ AND THE "STRUCTURE OF THE ORBS," THE EARLIEST KNOWN WORK ON *HAYʾA*

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Abstract. ʾAbū Saᶜīd al-Siğzī was a prominent fourth/tenth century astronomer and mathematician who was one of the first contributors to the new genre of *ᶜilm al-hayʾa* (science of the configuration). However, little is known about the initial steps taken in the formation of the discipline, or its independence from other astronomical writings and practices. In this paper, I will discuss new findings about Siğzī's life to determine details of his biography and a more precise time period for his scientific activities. I then describe, for the first time, a composition in theoretical astronomy from the fourth/tenth century, the "Structure of the orbs" (*Tarkīb al-aflāk*) by Siğzī to show its place in the formation of the discipline of *ᶜilm al-hayʾa*, comparing Siğzī's book to the earlier work of al-Farġānī on the size of the earth and the number of celestial spheres. I conclude that Siğzī's *Tarkīb al-aflāk* is the earliest known example of a book that contains only topics found in later *hayʾa* and may be the first appearance of the ninth celestial orb that became standard in the later genre.

Résumé. ʾAbū Saᶜīd al-Siğzī, astronome et mathématicien du IVᵉ/Xᵉ siècle, fut l'un des premiers auteurs du genre *ᶜilm al-hayʾa* (la science de la configuration) ; mais on connaît peu la genèse de cette discipline et sa relation aux autres écrits et pratiques en astronomie. Dans cet article, je présente de nouvelles découvertes permettant de préciser la biographie d'al-Siğzī. Je décris ensuite, pour la première fois, une composition d'astronomie théorique du IVᵉ/Xᵉ siècle, la « Structure des orbes » (*Tarkīb al-aflāk*) d'al-Siğzī, et je montre sa place dans la formation de la discipline *ᶜilm al-hayʾa* en comparant ce livre à l'ouvrage antérieur d'al-Farġānī sur la taille de la Terre et le nombre des sphères célestes. Je conclus que la *Tarkīb al-aflāk* d'al-Siğzī est le plus ancien exemple connu d'un livre traitant des sujets abordés plus tard en *hayʾa*, et qu'il contient peut-être la première occurrence du neuvième orbe céleste, classique dans les écrits du genre.

1. SIĞZĪ'S LIFE AND SCIENTIFIC ACTIVITIES

There is strikingly little information on the life and scientific career of ʾAbū Saᶜīd Aḥmad b. Muḥammad b. ᶜAbd al-Ğalīl al-Siğzī, one of the most prolific scientists of the tenth century. Besides making astronomical observations and instruments, Siğzī wrote about sixty-eight works

in three areas of knowledge. About thirty-six were in mathematics, on a variety of topics like conic sections, on the construction of a conic compass, on trisecting an angle by intersecting a circle and hyperbola applying "mobile geometry," on proportions and on the transversal figure (the Menelaus Theorem). He wrote eleven books on astronomy, mostly on astrolabes, and twenty-one on astrology[1]. Many of his mathematical works are now available in modern editions and translations along with commentaries[2], but almost none of his numerous astrological writings have

[1] I am counting Siǧzī's works based on multiple printed and manuscript sources, adding my own findings of a few lost works. Fuat Sezgin recorded eleven works in astronomy and nineteen works in astrology ascribed to Siǧzī, but Pingree found the *Kitāb al-qiranāt wa-taḥwīl sinī al-ʿālam* which is not mentioned in any biobibliographies on Siǧzī, and gave a complete analysis of it in *The Thousands of Abū Maʿshar*. Fuat Sezgin, *Geschichte des arabischen Schrifttums*, vol. VI, "Astronomie" (Brill, 1978), p. 225-26, and vol. VII, "Astrologie" (Brill, 1979), p. 178-82; David Pingree, *The thousands of Abū Maʿshar* (London: Warburg Institute, 1968), p. 70-127. Out of 35 works in mathematics counted by Sezgin, one is on the astrolabe. In Sezgin's list items 29-31 could be parts of one work, although those three and several others combined under item 29 in Sezgin's list, are catalogued as separate treatises in the Dublin MS Chester Beatty 3652. Sezgin's list is also missing *Fī tashīl al-subul* published in 1996. Fuat Sezgin, *Geschichte des arabischen Schrifttums*, vol. V, "Mathematik" (Brill, 1974), p. 331-34; ʾAbū Saʿīd Aḥmad b. Muḥammad b. ʿAbd al-Ǧalīl al-Siǧzī, *A collection of geometrical works: Maǧmūʿa min rasāʾil handasiyya* (facsimile, Frankfurt am Main, 2000), p. 156-82. There are two other works that we can add to the existing lists. In the third chapter of the *Kitāb al-qiranāt* Siǧzī mentioned *Fī imtiḥān al-munaǧǧimīn* ("On verifying the astrologers"), another work on astrology which does not exist today (Bibliothèque nationale de France, MS Arabe 2581, f. 12r). Moreover, in a work consisting of answers to questions asked by the geometers of Khurāsān and Shiraz, Siǧzī refers two times to his book "On triangles" (*Fī al-muṭallaṭāt*), of which I could not locate any copy. Al-Siǧzī, *A collection of geometrical works: Maǧmūʿa min rasāʾil handasiyya*, p. 10, 33. Based on the above lists and other discovered works, we can count 36 works in mathematics, 21 in astrology, and 11 in astronomy and instruments by Siǧzī which altogether amounts to 68 works.

[2] For modern editions and studies of Siǧzī's mathematical works see: Roshdi Rashed, *Œuvre mathématique d'al-Sijzī: Géométrie des coniques et théorie des nombres au x^e siècle* (Louvain-Paris: Peeters, 2004); Id. (ed.), *Geometry and dioptrics in classical Islam* (London: Al-Furqan Islamic Heritage Foundation, 2005); Pascal Crozet, "Al-Sijzi et les *Eléments* d'Euclide: commentaires et autres démonstrations des propositions," in Aḥmad Muḥammad Ḥasnāwī, A. Elamrani-Jamal, and Maroun Aouad (ed.), *Perspectives arabes et médiévales sur la tradition scientifique et philosophique grecque: actes du colloque de la SIHSPAI (Société internationale d'histoire des sciences et de la philosophie arabes et islamiques), Paris, 31 mars – 3 avril 1993* (Leuven-Paris: Peeters, 1997); Id., "L'idée de dimension chez al-Sijzī," *Arabic sciences and philosophy*, vol. 3, no. 2 (1993): 251-86; Id., "De l'usage des transformations géométriques à la notion d'invariant: La contribution d'al-Sijzī," *Arabic sciences and philosophy*, vol. 20, no. 1 (2010), p. 53-91; Sayyed Javad Hoseyni Tabatabayi, "A study of Zawraqī astrolabe," MA thesis, University of Tehran, 2010; Pouyan Shahidi Marnani,

gained attention in recent scholarship and they remain to be studied. Modern editions of his mathematical works devote very little attention to his biography and scientific career, except for a brief indication about his period of activity in the second half of the tenth century and early eleventh century.

One of the widely cited sources about Siğzī's life in English is the entry about him in the *Dictionary of scientific biography* (*DSB*) by Yvonne Dold-Samplonius (1937-2014) published in 1975[3]. More or less the same information about Siğzī's life provided in the *DSB* found its way into two later encyclopedia entries on him[4]. Fuat Sezgin also published a bibliography of Siğzī's works in three separate entries in the *Geschichte des arabischen Schrifttums* (hereafter *GAS*) along with some remarks on Siğzī's biography and activities which are in accordance with other accounts of him[5]. All these sources on Siğzī's life can be traced back to a work of Louis Massignon (1883-1962) published posthumously in 1963 in a collection of his works under the title of *Opera minora*[6]. Here Massignon

"Musarṭan astrolabe," Master's thesis, University of Tehran, 2011. Siğzī's *Fī tashīl al-subul li-istiḫrāğ al-aškāl al-handasiyya* ("On making easy the ways of deriving geometrical figures") was published three times along with English, French, and Persian translations: Aḥmad Salīm Saᶜīdān, *The works of Ibrāhīm ibn Sinān* (Kuwait, 1983); al-Siğzī and Jan Peter Hogendijk, *Treatise on geometrical problem solving*, trans. Mohammad Bagheri (Tehran: Fatemi, 1996); Roshdi Rashed, *Les mathématiques infinitésimales du IXe au XIe siècle*, vol. 4, "Ibn al-Haytham: Méthodes géométriques, transformations ponctuelles et philosophie des mathématiques" (London: Al-Furqan Islamic Heritage Foundation, 2002), p. 960-739, 766-831. For further studies on Siğzī's mathematics and geometry see: J. L. Berggren, "Al-Sijzī on the transversal figure," *Journal for the history of Arabic science*, vol. 5, no. 1-2 (1986), p. 23-36; Pascal Crozet, "À propos des figures dans les manuscrits arabes de géométrie: L'example de Siğzī," in *Editing Islamic manuscripts on science: Proceedings of the fourth conference of the Al-Furqān Islamic Heritage Foundation* (London, 1999), p. 131-63; Jan P. Hogendijk, "Traces of the lost *Geometrical elements* of Menelaus in two texts of al-Sijzī," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften*, vol. 13 (2000), p. 129-64.

[3] Yvonne Dold-Samplonius, "Al-Sijzī, Abū Saᶜīd Aḥmad ibn Muḥammad ibn ᶜAbd al-Jalīl," in Charles Coulston Gillispie, *Dictionary of Scientific Biography*, vol. 12 (Charles Scribner's Sons, 1975), p. 431-32.

[4] Glen van Brummelen, "Sijzī: Abū Saᶜīd Aḥmad ibn Muḥammad ibn ᶜAbd al-Jalīl al-Sijzī," in *The biographical encyclopedia of astronomers* (Springer, 2007), 1059; Yvonne Dold-Samplonius, "Al-Sijzī," in *Encyclopaedia of the history of science, technology, and medicine in non-Western cultures* (Springer, 2008), 159-60.

[5] Sezgin, *GAS*, vol. V, p. 329-34, vol. VI, p. 224-26; vol. VII, p. 177-82, 333-34. For further notices on Siğzī's life see: Carl Brockelmann, *Geschichte der arabischen Litteratur*, Supplementband I (Leiden: Brill, 1937), p. 388; George Sarton, *Introduction to the history of science* (Huntington, N. Y.: Krieger, 1975), vol. 1, p. 665.

[6] Louis Massignon, *Opera minora : Textes recueillis, classés et présentés avec une bi-*

confused the person to whom Siǧzī dedicated some of his mathematical and astrological works with ʾAbū Naṣr Aḥmad b. Muḥammad b. Farīġūn, a prince of Balkh who died in 410/1019. Based on this false identification, Dold-Samplonius incorrectly recorded Siǧzī's death around 1020. However, Massignon recorded the death of Siǧzī to have occurred around 370/980[7], but a note at the end of the chapter on Arabic occult literature, first published in 1963[8], reads as follows:

> *Note additionnelle A : Sur ʾAbū Saʿîd A b. M. Ibn ʿAbdaljalîl Sijazî Sinjârî (mort après 389/999). Complément aux notices de Brockelmann, G. A. L., S. I, 388 et de Sarton, I. H. S., I, 665) :*
>
> *L'année 358 òu ce mathématicien probablement sabéen acheva le texte du ms. Paris 2457 ne réfère pas à l'ère hégirienne, mais à l'ère de Yazdadjard II ; c'est donc l'année 380 de l'hégire, 990 de l'ère chrétienne.*
>
> *Son livre est dédié à un prince « al-mālik al-ʿadil ʾAbū Jaʿfar Ahmad-b-Muḥammad » qu'il y a lieu d'identifier avec le prince de Balkh-Jūzjān ʾAbū Naṣr(?) Aḥmad-b-Muḥammad Ibn Farighun (389 † 410) qui maria en 385 sa fille à Subuktakin (cfr. Minorskyr Ḥudūd é-ʿAlam, p. 173) ; c'est à son père, déjà surnomme "al-mālik al-ʿādil" que l'auteur anonyme des Ḥudūd é-ʿAlam, dédia cet important ouvrage de géographie descriptive*[9].

There are several corrections we need to make regarding the information in this note. First, the date Massignon gave for Siǧzī's death in this additional note, *mort après 389/999*, does not accord with one he gave in the text as *† vers 370/980*. Second, Massignon misread ʾAbū Ǧaʿfar's title *al-malik al-ʿādil* ("the just ruler") as *al-mālik al-ʿādil* ("the just owner"). Third, he was not even sure about the *kuniya* of the dedicatee and hesitantly assumed it to be *ʾAbū Naṣr(?)* although Siǧzī recorded ʾAbū Ǧaʿfar. Fourth, George Sarton recorded Siǧzī's birth and death dates around 951 and 1024[10]. It is not clear where the date 389/999 came from. David Pingree quoted this note in his *Thousands of Abū Maʿshar* and repeated the same false identification without mentioning Ibn Farīġūn's death date[11]. Fifth, the word "Sinjârî" is a misreading

bliographie, ed. Y. Moubarac (Beirut: Dar al-Maaref, 1963), vol. 1, p. 660, 665; Id., "Inventaire de la littérature hermétique arabe," in André-Jean Festugière and Louis Massignon, *La révélation d'Hermès Trismégiste*, vol. 1, "L'astrologie et les sciences occultes," reprint of the 1950 edition (Paris: Les Belles Lettres, 1981), p. 384-400.

[7] Massignon, *Opera minora*, p. 660; Id., "Inventaire de la littérature hermétique arabe," p. 395.

[8] Massignon first presented the contents of the chapter in a conference during August 3-9, 1942: see Massignon, "Inventaire de la littérature hermétique arabe," p. 384, n. 1.

[9] Massignon, *Opera minora*, vol. 1, p. 665; Id., "Inventaire de la littérature hermétique arabe," p. 400.

[10] Sarton, *Introduction to the history of science*, vol. 1, p. 665.

of the *nisba* "Siğzī" and not a part of Siğzī's name (see below). Sixth, Massignon does not tell us that Siğzī died around 1020. In any case, it was this note and the false identification of ʾAbū Ğaᶜfar that led astray Dold-Samplonius and others in dating Siğzī's death. There is no reason to rely on any of these accounts.

In the first part of this article, I will present new findings about Siğzī's life and journeys based on the dedications of his books, to determine a more precise time period for his scientific activities as well as suggestions on his birth and death dates. I first identify the prince that Siğzī dedicated some of his works to as ʾAbū Ğaᶜfar Bānūye (r. 311-351 / 923-962), whose reign and death helps us date Siğzī's works. In addition to that, based on the historical events and reports Siğzī recorded in his largest composition in astrology, "The royal compendium" (*Al-ğāmiᶜ al-šāhī*), and other indications in his mathematical works, I will give a report of Siğzī's travels and determine the period of his scientific activities and life span accurately for the first time.

1.1. Siğzī's early life

Al-Siğzī's *nisba* indicates that he was a native to Sīstān (ancient Sagistān, in Arabic Siğistān) a province located today in the southeast of Iran and southwest of Afghanistan. Because of the Arabic orthographical similarities between *s.ğ.z* and *s.n.ğ.r* his *nisba* was sometimes recorded as *al-Sanğarī*. ʾAbū Rayḥān al-Bīrūnī (362-440 / 973-1048) also called him *Sagzī*, the Persian pronunciation of *Siğzī*, when quoting Siğzī's geometrical proofs in his treatise on the derivation of the chords in the circle[12]. In other occasions, Bīrūnī gave the title *al-muhandis*[13] ("the geometer") to him. Siğzī did not identify his teachers, but he could have received his early education from his father ʾAbū al-Ḥusayn Muḥammad b. ᶜAbd al-Ğalīl who was knowledgeable in mathematics and astrology. In 340/972 Siğzī wrote a treatise on the properties of paraboloids and hyperboloids[14] for his father and called him *al-šayḫ al-fāḍil* (the virtuous old man). In another work[15] which includes geometrical problems discussed with Siğzī by the geometers of Shiraz and

[11] Pingree, *The thousands of Abū Maᶜshar*, p. 21.

[12] ʾAbū Rayḥān Aḥmad b. Muḥammad al-Bīrūnī and Abolghasem Ghorbani, *Taḥrīr istiḫrāğ al-awtār* (Tehran, 1976), 18-19.

[13] ʾAbū Rayḥān Aḥmad b. Muḥammad al-Bīrūnī, *Āṯār al-bāqiya ᶜan al-qurūn al-ḫāliya*, ed. C. Eduard Sachau (Leipzig, 1923), 42; *Istīᶜāb al-wuğūh al-mumkina fī ṣanᶜa al-usṭurlāb*, ed. Sayyid Muḥammad Akbar Ğawādī al-Ḥusaynī (Mashhad, 2001), 121.

[14] Rashed, *Œuvre mathématique d'al-Sijzī*, p. 191-209.

Khurasan, he answered some questions asked by his father with the same title *al-šayḫ al-fāḍil*. The Shiite jurist and historian Ibn Ṭāwūs (d. 664/1266) reported in his biobibliography of astronomers that he had seen two works by Siǧzī's father on astrology[16] and one by Siǧzī[17]. However, since Siǧzī wrote two works with the same titles as those ascribed to his father, some scholars doubt the authenticity of this attribution[18]. Siǧzī's dedications of scientific works to emirs and rulers provide us with solid evidence to determine his life span and know more about his ambitions for seeking courtly patronage. The names of three rulers appear as receivers of some of Siǧzī's works which I will introduce and discuss in the following pages.

1.1.1. Dedications to ʾAbū Ǧaᶜfar Bānūye

Among the three people to whom Siǧzī dedicated some of his works, he wrote five treatises for a person he called ʾAbū Ǧaᶜfar Aḥmad b. Muḥammad, with the titles *al-sayyid al-fāḍil* ("the meritorious lord") and *al-malik al-ᶜādil* ("the just ruler") accompanied with *maulā amīr al-muʾminīn* ("the patron, the commander of the faithful"). This person was ʾAbū Ǧaᶜfar Aḥmad b. Muḥammad b. Ḫalaf b. al-Layth, known as Bānūye after his mother's name Sayyida Bānū[19]. He was one of the emirs of Sīstān from the "second line" of the Ṣaffārids or the Khalafids[20]. ʾAbū Ǧaᶜfar was born on Šaᶜbān 293 / June 906 in Sīstān[21]. According to the anonymous history *Tārīkh-e Sīstān*[22] ("The history of Sīstān"), he rose to power in 311/923 and ruled over Sīstān for forty years until

[15] Al-Siǧzī, "Fī masāʾil al-muḫtāra al-latī ǧarat baynah wa-bayn muhandisī Šīrāz wa-Ḫurāsān wa-taᶜlīqātih," Dublin, Chester Beatty Library, MS 3652, n. d., f. 43r, 50r; al-Siǧzī, *A collection of geometrical works: Maǧmūᶜa min rasāʾil handasiyya*, p. 55-56.

[16] *Kitāb al-zāirǧāt fī istiḫrāǧ al-haylāǧ wa-al-kadḫudā* and the *Maqāla fī fatḥ al-bāb*.

[17] Ibn Ṭāwūs recorded the *Kitāb sinī al-mawālīd* of Siǧzī which presumably is *Kitāb taḥwīl sinī al-mawālīd*. Ibn Ṭāwūs, *Faraǧ al-mahmūm fī taʾrīḫ ᶜulamāʾ al-nuǧūm* (Qum: Iran, 1949), p. 127.

[18] Etan Kohlberg, *A medieval Muslim scholar at work: Ibn Ṭāwūs and his library* (Leiden: Brill, 1992), p. 253, 386-87.

[19] Moḥammad-Taqī Malek osh-Shoᶜarā Bahār (ed.), *Tārīkh-e Sīstān* (Tehran: Khāvar, 1935), 314.

[20] On the history of the Ṣaffārids and the Khalafids see: Clifford Edmund Bosworth, *The history of the Saffarids of Sistan and the Maliks of Nimruz (247/861 to 949/1542-3)* (Mazda Publishers, 1994), esp. 267-339.

[21] Bahār, *Tārīkh-e Sīstān*, 278-79.

[22] For a description of the text see Clifford Edmund Bosworth, "Tārīkh-e Sīstān," in *Encyclopaedia Iranica*, February 11, 2011, `http://www.iranicaonline.org/articles/tarikh-e-sistan`. The text is also available in English and Russian

his death. His reign was a period of peace and justice in the history of the Khalafids. Siğzī recorded ʾAbū Ğaᶜfar's death in his *Al-ğāmiᶜ al-šāhī* ("The royal compendium") in Rabīᶜ I 351 / Apr-May 962 on a Monday night and gave it in the Yazdgerdī calendar as 6 Farvardin 331, describing his murder by a conspiracy of his servants. Siğzī also recorded[23] the date ʾAbū Ğaᶜfar ascended the throne as 19 Mehr 292 Yazdgerdī (7 Rağab 311 / 20 Oct 923). However, in the *Tārīkh-e Sīstān* the murder occurs on 2 Rabīᶜ I 352 / 31 Mar 963. The Yazdgerdī date 6 Farvardin 331 Siğzī gave corresponds to 22 Ṣafar 351 / 1 April 962 on a Monday night. There are other inconsistencies in recorded dates in the *Tārīkh-e Sīstān*[24] but since Siğzī was an astrologer who lived at the time of ʾAbū Ğaᶜfar's death and probably observed the event, I will rely on his account.

ʾAbū Ğaᶜfar Bānūye (r. 311-351 / 923-962) had knowledge of Greek philosophy and was interested in the arts and sciences. The famous Persian poet Rūdakī (d. 329/940-41) composed a *qaṣīda* of ninety-four verses[25] in praise of ʾAbū Ğaᶜfar's knowledge and justice, beginning, "One must sacrifice the mother of the wine, take her child and imprison it." Rūdakī named the Saffarid emir personally in verse 36: "Say to Bū Ğaᶜfar Aḥmad b. Muhammad, that Lord of the noble ones and the glory of Iran." ʾAbū Sulaymān al-Siğistānī (d. c. 1000) described ʾAbū Ğaᶜfar as a philosopher and a wise man knowledgeable in politics, who had memorized the teachings of Aristotle to Alexander on politics besides other learning from Greek philosophy[26]. Siğzī wrote one short treatise on mathematics and five on astrology for ʾAbū Ğaᶜfar Bānūye.

The mathematical treatise is about the method of bisecting a straight line segment described in Euclid's *Elements*, I.10[27]. The earliest copy of Siğzī's text was made in his hand prior to 361/972[28] (more about this in

translations: Milton Gold (trans.), *The Tārikh-e Sistān* (Roma: Istituto italiano per il Medio ed Estremo Oriente, 1976); L. P. Smirnova (trans.), *Istorya Sistana* (Moscow, 1971).

[23] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, n. d., f. 313v.

[24] For example see: Bahār, *Tārīkh-e Sīstān*, 334, n. 5.

[25] Two English translations of the *qaṣīda* are available. One in Gold, *The Tārikh-e Sistān*, 259-64; and the other in E. Denison Ross, "A qasida by Rudaki," *Journal of the Royal Asiatic Society of Great Britain and Ireland*, no. 2 (1926), p. 213-37.

[26] ʾAbū Sulaymān Muḥammad b. Ṭāhir al-Siğistānī, *Ṣiwān al-ḥikma wa-ṭalāṭ rasāʾil*, ed. ᶜAbd al-Raḥmān Badawī (Tehran: Bunyad-e Farhang, 1974), p. 315-16.

[27] Euclid, *The thirteen books of the Elements*, ed. Thomas L. Heath (Dover Publications, 1908), vol. I, p. 267-268.

[28] Al-Siğzī, "Risāla Aḥmad b. Muḥammad b. ᶜAbd al-Ğalīl fī ğawāb masʾala ᶜan kitāb

section 1.2 below). The title reads:

> A treatise by Aḥmad b. Muḥammad b. ʿAbd al-Ǧalīl about answering a problem from Yūḥannā b. Yūsuf's book on bisecting a straight line and determining Yūḥannā's mistake on that[29].

Yūḥannā b. Yūsuf b. Ḥārith b. al-Biṭrīq al-Qass[30] (d. c. 370/980-81) was a mathematician contemporary to Siǧzī who had translated ten books of the *Elements* and written different proofs for some of the propositions in the book. The purpose of this treatise, as Siǧzī explained it at the outset, was to address a request by ʾAbū Ǧaʿfar Bānūye to solve the problem by methods other than those used by Euclid. Siǧzī reported that:

> The Commander, the Lord, the Just Ruler ʾAbū Ǧaʿfar Aḥmad b. Muḥammad, may God prolong his life and perpetuates his exaltedness and merit and consolidation, asked about bisecting a finite straight line into two halves without [using] the premises Euclid presented for this proposition or others. And by this he [ʾAbū Ǧaʿfar] wanted to follow a method in which only common notions are used. And he [ʾAbū Ǧaʿfar] reported from the proofs by Yūḥannā b. Yūsuf about the book of *Elements* what was made by direct [demonstration], and by modus tollens, and by reverse [argument]. He [Yūḥannā] moved up this proposition ahead of the other propositions in the book. And the request of Amīr, the Lord, may God prolong his life, was to compare my understanding with his understanding and to examine the preponderance of merit between us[31].

Evidently Siǧzī wrote his response to ʾAbū Ǧaʿfar before the year 361/972 when the earliest extant copy of the text was made, and before emir's death in 351/962. Moreover, it seems more plausible that

Yūḥannā b. Yūsuf min inqisām ḫaṭṭ mustaqīm bi-niṣfayn wa-tabyīn ḫaṭaʾ Yūḥannā fī ḏālik," Bibliothèque nationale de France, MS Arabe 2457/10, n. d., f. 52v-53v.

[29] Bibliothèque nationale de France, MS Arabe 2457/10, f. 52v-53v:
رسالة أحمد بن محمد بن عبد الجليل في جواب مسئلة عن كتاب يوحنّا بن يوسف من إنقسام خطّ مستقيم بنصفيْن وتبيين خطأ يوحنّا في ذلك.

[30] Heinrich Suter, *Die Mathematiker und Astronomen der Araber und ihre Werke* (B. G. Teubner, 1900), p. 60.

[31] Bibliothèque nationale de France, MS Arabe 2457/10, f. 52v-53v:
سأل الأمير السيد الملك العادل أبي جعفر أحمد بن محمد أطال الله بقاه وأدام علوّه وفضله وتمكينه عن انقسام خطّ مستقيم ذي نهاية بنصفين بغير مقدّمات يُستعمل فيها من مقدّمات قدّمها أوقليدس على هذا الشكل أو سواها. وأراد بذلك أن أسلك طريقاً استعمل فيها العلوم المتعارفة فقط. وحكى عن يوحنّا بن يوسف في براهينه لكتاب الأصول ما كان بالاستقامة وبالخلف وبالعكس إنّه قدّم هذا الشكل على سائر أشكال هذا الكتاب. وكان سؤال الأمير السيد أطال الله بقاه مقايسة فهمي إلى فهمه وإمتحاناً لرجحان الفضل بيننا.

the challenge between the two scholars should have happened during Yuḥannā's life, before his death around 370/980-81. All this is evidence for the identification of the dedicatee of Siğzī's other works with ʾAbū Ğaᶜfar Bānūye, the ruler of Sīstān.

Besides Siğzī's correspondence discussed above, several indications in his astrological works clearly confirm the identification of ʾAbū Ğaᶜfar Bānūye. Five other works Siğzī dedicated to ʾAbū Ğaᶜfar are as follows:

1. *Al-madḫal ilā ᶜilm aḥkām al-nuğūm* ("The introduction to astrology")

2. *Ğawāmiᶜ Kitāb taḥwīl sinī al-mawālīd*, a summary of the "Transformations of the years of nativities" of ʾAbū Maᶜšar.

3. *Kitāb al-mizāğğāt* [*al-kawākib*] ("The book on the combinations of the planets")

4. *Kitāb al-iḫtiyārāt* ("The book on elections")

5. *Muntaḫab min Kitāb al-ulūf*, a summary of *Kitāb al-ulūf* ("The thousands") of ʾAbū Maᶜšar.

In some catalogues the *Al-madḫal* is mistakenly recorded as Siğzī's *Tarkīb al-aflāk*[32] ("The structure of the orbs") a treatise on *hayʾa* which I will introduce and describe in the second part of this paper. In the *Al-madḫal*, following the dedication, Siğzī told about his deep interest in astrology and the purpose of the work. He wrote that after spending most of his time on astrology, he decided to write this book (*Al-madḫal*) to provide a comprehensive guide which saves readers from studying several other works in astrology[33]. *Al-madḫal* is written for "al-Amīr al-Sayyid al-Malik al-ᶜĀdil Abī Ğaᶜfar Aḥmad b. Muḥammad Mawlā Amīr al-Muᶜminīn." The book begins with numerical values for the distances of the orbs of the planets from the Earth followed by different values observed and calculated for the obliquity of the ecliptic. Siğzī recorded the results given by Ptolemy, the Indians, the Banū Mūsā (9th century), and finally the observations sponsored by the Abbasid caliph al-Maʾmūn

[32] Sezgin, *GAS*, vol. VI, p. 225; Ahmad Golchin-Ma'ani, *Fehrest-e kotob-e khati-e Ketābkhāney-e Āstān-e Quds-e Razavī*, vol. 8, 1971, 120; Yusof Etessami, *Fehrest-e ketābkhāne-ye majles-e shorā-ye mellī*, vol. 2 (Tehran: Majles, 1933), p. 94.

[33] Al-Siğzī, "Al-madḫal ilā ᶜilm aḥkām al-nuğūm," Central Library of the University of Tehran, MS 8609, 1074/1663, f. 1v.

(r. 813-833)[34] which resulted in the value of 23°35′. He then stated that this was the value he observed in Fārs with the geographical latitude of 29°36′, which is the latitude of Shiraz. We are informed by Bīrūnī that Siǧzī collaborated in another set of observations carried on later in 359/969-70 in Shiraz under the patronage of the Buyid emir ᶜAḍud al-Dawla (r. 949-983). Those observations, according to Bīrūnī[35], were directed by ᶜAbd al-Raḥmān al-Ṣūfī (d. 986) in the presence of other astronomers including Siǧzī, ᵓAbū Sahl al-Kūhī (late 10th century), Naẓīf b. Yumn al-Mutaṭabbib (d. 990) and ᵓAbū al-Qāsim Ġulām Zuḥal[36] (late 10th century). This group calculated the obliquity of the ecliptic as the same value given by Ḥabaš, 23°35′, and Siǧzī reported this in some of his works (see below). Since the *Al-madḫal* was dedicated to ᵓAbū Ǧaᶜfar it should have been written not later than Rabīᶜ I 351 / April 962, therefore his indication of the observation in *Al-madḫal* concerns other observations made by him, but earlier than those commissioned by ᶜAḍud al-Dawla and conducted by al-Ṣūfī (more about this below).

The second work dedicated to "al-Amīr al-Sayyid al-Fāḍil al-Malik al-ᶜĀdil Abī Ǧaᶜfar Aḥmad b. Muḥammad Mawlā Amīr al-Muᶜminīn," was *Ǧawāmiᵓ Kitāb taḥwīl sinī al-mawālīd*, a book in eighteen chapters of which two Persian translations are extant[37]. At the beginning, Siǧzī explicitly said that he wrote the book a gift to attract the attention of the amīr[38] who had a deep passion and interest in learning science. As

[34] Aydın Sayılı, *The observatory in Islam and its place in the general history of the observatory* (Türk Tarih Kurumu Basımevi, 1988), p. 50-87. On the numerical values in *Tarkīb al-aflāk*, see also sections 3 and 4 below.

[35] ᵓAbū Rayḥān Aḥmad b. Muḥammad al-Bīrūnī, *Taḥdīd nihāyāt al-amākin li-tashīḥ masāfāt al-masākin*, ed. P. Bulgakov and Imām Ibrāhīm Aḥmad [reprinted in Fuat Sezgin, *Islamic geography*, vol. 25, Frankfurt, 1992] (Cairo, 1962), 99-100.

[36] Gulām Zuḥal was a friend of ᵓAbū Sulaymān al-Siǧistānī (d. c. 1000) and Qifṭī described him an skilled mathematician and astronomer resident in Baghdad. ᶜAlī b. Yūsuf al-Qifṭī, *Taᵓrīḫ al-ḥukamāᵓ*, ed. Julius Lippert (Leipzig: Dieterich, 1903), p. 224-25.

[37] One is MS Or. 10879 at the British Museum and the other is MS 5632 kept in the Central Library of Āstān-e Qods-e Razavī in Mashhad. G. M. Meredith-Owens, *Handlist of Persian manuscripts [acquired by the British Museum] 1895-1966* (London: British Museum, 1968), p. 25, https//catalog.hathitrust.org/Record/001173294; Golchin-Ma'ani, *Fehrest-e kotob-e khati-e Ketabkhaney-e Astan-e Quds-e Razavi*, vol. 8, p. 440, no. 10. Meredith-Owens assumed that Siǧzī made the translation from ᵓAbū Maᶜšar, and since the Razavī copy does not have the author's name Golchin-Ma'ani did not identify the dedicatee and confused ᵓAbū Ǧaᶜfar with the Abbasid caliph Al-Mustaᶜīn (r. 862-866).

[38] Al-Siǧzī, "Ǧawāmiᵓ Kitāb taḥwīl sinī al-mawālīd," Central Library of the University of Tehran, MS 8609, 1074/1663, f. 25r: فجعلته وسيلتي إلى الملك وهديتي له.

the title of the treatise shows, and Siğzī's explained in the introduction, the text was meant to be a summary and improvement of ʾAbū Maᶜšar's *Taḥwīl sinī al-mawālīd* ("Transformations of the years of nativities")[39].

The third work, *Kitāb al-mizāğāt* (The Book of Combinations) includes a short introduction followed by tables of the combinations of two, three, four, five, six, and seven planets. It is written for "al-Malik al-ᶜĀdil Abī Ğaᶜfar Aḥmad b. Muḥammad." In a brief note at the end of the treatise Siğzī stated that he abstained from giving more tables since he had provided them in two other works, *Kitāb Zarādušt fī ṣuwar daraǧāt al-falak*[40] ("The book of Zoroaster on the pictures of the degrees of the zodiac") and *Kitāb al-maᶜānī fī aḥkām al-nuǧūm*[41] ("The book on the concepts of astrology"), both of which obviously had been written before 351/962. However, at the beginning of the *Kitāb al-maᶜānī* Siğzī stated that he began the book after he was done with three other works: 1) *Kitāb al-madḫal*, 2) *Kitāb taḥsīl al-qawānīn li-istinbāṭ al-aḥkām*, and 3) *Kitāb al-dalaʾil fī aḥkām al-nuǧūm*. This shows that, including *Al-madḫal*, Siğzī had written five other works in astrology prior to *Kitāb al-mizāğāt*.

The fourth book written for "al-Amīr ʾAbū Ğaᶜfar Aḥmad b. Muḥammad," *Kitāb al-iḫtiyārāt* ("The book on elections") is in three parts, Siğzī mentioned at the beginning that he aimed the book to be accessible to all readers familiar with astrology and devoted the first part to the definition of some basic concepts on elections. He began the first part with a discussion on the difference between Indian and other astrologers. In his explanation of the argument of one group Siğzī refers to one of his works with the title *Kitāb al-masāʾil fī asrār al-nuǧūm* ("On the problems of the secrets of astronomy") which is not currently extant. He refers to one of his books by the statement *fī kitābinā fī iṯbāt hāḏihi al-ṣanāᶜa* ("in our book on demonstrating this art/science," i. e. astrology).

The fifth book, the *Muntaḫab*, is a summary of ʾAbū Maᶜšar's *Ulūf* ("The thousands") in nine sections. The text begins with a description of the purpose and scope of the work and is followed by a relatively long dedication to "al-Amīr al-Sayyid al-Malik al-ᶜĀdil Abī Ğaᶜfar Aḥmad b. Muḥammad," praising his knowledge and patronage, and describing the author as the humblest servant to the ruler. Pingree (d. 2005) provided an outline of the contents of the *Muntaḫab* and estimated its composition

[39] Al-Siğzī, "Ğawāmiʾ," Central Library of the University of Tehran, MS 8609.
[40] Sezgin, *GAS*, vol. VII, p. 181.
[41] Sezgin, vol. VII, p. 179-80.

date as the year 925, based on the time given by Siǧzī elapsed from the Flood[42]. In the *Muntaḫab* Siǧzī used 4026 as the number of solar years since the Flood, which occurred in −3101[43], in an example of how to use tables for calculating revolutions for *tasyīr*[44]. The year 313/925 is the second year of ʾAbū Ǧaᶜfar's reign which corroborates Pingree's dating of the *Muntaḫab*. However, this inference is true on the condition that Siǧzī made that example of the year when he was writing the treatise, but on the other hand he could have obtained the number 4026 from an earlier source, which therefore makes it difficult to conclusively date the year 313/925 for the composition of the *Muntaḫab*[45].

So far, I have shown that Siǧzī dedicated six works to ʾAbū Ǧaᶜfar Bānūye, one short treatise in mathematics and five in astrology. Counting the citations of his other works in those five, altogether he composed twelve works, mostly astrological, prior to Rabīᶜ I 351 / April 962, as well as making astronomical observations in Shiraz and calculating the obliquity of the ecliptic as 23°35′. The number of works Siǧzī wrote before 962 is additional evidence that he was well enough engaged in astrology, but do not yet allow us to determine a beginning date for his scientific activities. What we can conclude at this point is that the above dedications conclusively show that the identification of Siǧzī's first patron by Massignon and Dold-Samplonius was incorrect, and that his true patron before April 962 was ʾAbū Ǧaᶜfar Aḥmad b. Muḥammad b. Ḫalaf b. al-Layth, known as Bānūye, who reigned in Sīstān from 923 to 962, the same place where Siǧzī was born and raised. However, In the following pages I introduce other dedications by Siǧzī to two other rulers, and discuss more about his scientific activities to finally determine a definite time period for his life and career.

1.1.2. Dedications to Ṭāhir b. Muḥammad al-Siǧzī

Siǧzī wrote the *Kitāb al-ᶜamal bi-al-ṣafīḥa al-āfāqiya*, a treatise on an astronomical instrument, for ʾAbū al-Ḥusayn Ṭāhir b. Muḥammad al-Siǧzī[46] (d. 359/970) the ruler of Bust (the Lashkargāh city in southwestern Afghanistan historically called Bost). He was appointed by ʾAbū

[42] Pingree, *The thousands of Abū Maᶜshar*, p. 23.

[43] According to ʾAbū Maᶜšar the Flood occurred at midnight of Thursday/Friday, 17/18 Feb. −3101. See Pingree, p. 37-38.

[44] Bibliothèque nationale de France, MS Arabe 6686, 1157/1744 f. 89r-89v. For a description of *Tasyīr* see: O. Schirmer, "Al-tasyīr," in *Encyclopaedia of Islam*, 2nd ed., 2012.

[45] Bibliothèque nationale de France, MS Arabe 6686, f. 89r.

[46] Sezgin, *GAS*, vol. VI, p. 226, n. 6.

Ğaᶜfar Bānūye and later made a regent and the co-ruler in Sīstān by ʾAbū Ğaᶜfar's son and successor Ḫalaf. According to *Tārīkh-e Sīstān* ʾAbū al-Ḥusayn Ṭāhir was a lover of learning and spent all his days in discussions and disputation with the jurists and *ᶜulamāʾ* of Bust[47]. ʾAbū al-Ḥusayn Ṭāhir had important tasks during Ḫalaf's reign such as collecting land-tax as well as subduing rebels and hunting down ʾAbū Ğaᶜfar's assassins. During Ḫalaf's pilgrimage to Mecca, ʾAbū al-Ḥusayn Ṭāhir, who was in charge of Sīstān, rebelled against him and declared himself ruler, but at the end died in Sīstan on 20 Ḏū al-Qaᶜda 359 / 24 September 970[48]. In the *Al-ğāmiᶜ al-šāhī* Siğzī recorded ʾAbū al-Ḥusayn Ṭāhir's birth date with his horoscope and stated that he rose to power at the end of his life with struggle and hardship and died in his bed. This accords with the corresponding report in *Tārīkh-e Sīstān*, which omits his death date[49], however other chronicles recorded ʾAbū al-Ḥusayn Ṭāhir's death in the year 354/965[50].

1.1.3. Dedications to ᶜAḍud al-Dawla

The third person to whom Siğzī dedicated two books, one in astrology and another in *hayʾa*, was the Buyid emir ʾAbū Šuğāᶜ Fannā (Panāh) Khusrow (r. 338-372 / 949-983) who received the title ᶜAḍud al-Dawla from the Abbasid caliph al-Muṭīᶜ in 351/962[51]. Siğzī wrote *Kitāb al-zāʾirğāt fī istiḫrāğ al-haylāğ wa-al-kadḫudāh* ("Tables for derivation of *haylāğ* and *kadḫudāh*") for ᶜAḍud al-Dawla. As it mentions his new title, the book was written after 351/962. This is after ʾAbū Ğaᶜfar's death, which also suggests Siğzī may have then sought patronage under ᶜAḍud al-Dawla as I will discuss later. The other book Siğzī wrote for ᶜAḍud al-Dawla was the *Tarkīb al-aflāk* ("The structure of the orbs") a work in *hayʾa* (lit. "structure" or "configuration"). In the *Tarkīb al-aflāk* Siğzī called ᶜAḍud al-Dawla *šahanšāh* (king of kings), a title that the emir had given himself as a connection with pre-Islamic Iranian kingship. ᶜAḍud al-Dawla was the first Muslim ruler in Islamicate history who re-

[47] Bahār, *Tārīkh-e Sīstān*, 325; Bosworth, *The history of the Saffarids of Sistan and the Maliks of Nimruz*, 298-99.

[48] Bahār, *Tārīkh-e Sīstān*, 334; Bosworth, *The history of the Saffarids of Sistan and the Maliks of Nimruz*, 302-6.

[49] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Tehran, Parliament Library, MS 6459, n. d., f. 307v.

[50] ʾAbū al-Ḥasan al-Šaybānī al-Ğazārī b. al-Aṯīr, *Al-kāmil fī al-taʾrīḫ*, ed. ᶜUmar ᶜAbd al-Salām Tadmurī (Beirut: Lebanon, 2012), vol. 7, p. 256-257.

[51] Ibn al-Aṯīr, vol. 7, p. 241; Aḥmad b. Muḥammad b. Yaᶜqūb ʾAbū ᶜAlī Miskawayh, *Tağārib al-umam wa-taᶜāqib al-himam*, ed. Sayyid Kasrawī Ḥasan (Beirut: Dār al-Kutub al-ᶜIlmiyya, 2003), vol. 5, p. 333.

ceived the title *šahanšāh*[52]. It is not known when exactly ʿAḍud al-Dawla named himself *šahanšāh*, but we know that he was called by that title as early as 354/965[53]. This means that since Siǧzī did not use the title *šahanšāh* for ʿAḍud al-Dawla in the first book *Kitāb al-zāʾirǧāt* he should have written that prior to 354/965. However, Siǧzī wrote the *Tarkīb al-aflāk* after 359/970 because in the book he reported his collaboration in the observations sponsored by ʿAḍud al-Dawla in Shiraz in that year (more about this below). Siǧzī served ʿAḍud al-Dawla in other ways. He made several mixed astrolabes of his own invention for the emir along with the instructions for using them[54]. There is also another type of evidence showing that Siǧzī authored more works on mathematics while serving ʿAḍud al-Dawla, to which I now turn.

1.2. Mathematical works copied by Siǧzī

Another source which tells us about Siǧzī's scientific activities is a manuscript copy assumed to have been written in his hand. The codex Arabe 2457 kept at the Bibliothèque nationale de France contains some fifty items in mathematics, almost all in the same hand[55]. The codex also includes some treatises of complex and high level mathematics by Siǧzī. Colophons of 11 items mention Aḥmad b. Muḥammad b. ʿAbd al-Ǧalīl as scribe, who is almost certainly Siǧzī. Some of the colophons have dates in the Hijri or Yazdegerdi calendars which range from 358-361 / 969 to 972 in the Christian era. In 1993 Paul Kunitzsch and Richard Lorch made a complete analysis of the codex and rearranged it in different sections based on old Abjad and new numerical paginations of the folios and fi-

[52] ʾAbu al-Fidāʾ Ismāʿīl b. ʿUmar b. Kaṯīr al-Qurašī, *Al-bidāya wa-al-nihāya* (Beirut: Maktaba al-Maʿārif, 1991), vol. 11, p. 299; Ṣalāḥ al-Dīn Ḫalīl b. Aybak al-Ṣafadī, *Al-wāfī bi-al-wafayāt*, ed. Aḥmad al-Arnāʾūṭ and Tazkī Muṣṭafā (Beirut: Dār Iḥyāʾ al-Turāth al-ʿArabī, 2000), vol. 24, p. 64.

[53] The poet ʾAbū al-Ṭayyib al-Mutanabbī (d. 354/965) used the title *šahanšāh* in a *qaṣīda* he composed in praise of ʿAḍud al-Dawla in 354/965. ʿAbd al-Raḥmān al-Burqūqī, *Šarḥ Dīwān al-Mutanabbī* (Beirut: Dār al-Kutub al-ʿArabī, 1986), vol. 4, p. 404-410.

[54] In his book *Fī ʿamal al-usṭurlāb*, he specified that he had made a fish-shaped (*samkī*, he also called it *ʿAḍudī*), a crescent-shaped (*hilālī*), and a boat-shaped (*zawraqī*) astrolabe, for ʿAḍud al-Dawla with their instructions. The book does not present the date of composition, but the value for the obliquity of the ecliptic Siǧzī used (f. 118r) was that he obtained during the observations of 359 / 969-970, so it is probable that he wrote *Fī ʿamal al-usṭurlāb* afterwards. Al-Siǧzī, *Fī ʿamal al-usṭurlāb*, Istanbul, Topkapi Museum, Ahmet III, MS 3342/9, f. 153r, 114r, 114v.

[55] A list of all titles in the codex is given in Baron De Slane, *Catalogue des manuscrits arabes* (Paris: Imprimerie nationale, 1883), 430-34.

nally concluded that the codex was made during the dates mentioned in the colophons and that its ascription to Siğzī as the scribe is authentic[56]. Roshdi Rashed also indicated some more evidence in the codex which testifies to Siğzī's hand[57]. However, some others decided that the codex was made in the seventh/thirteenth century from an original copy made in the hand of Siğzī. They argued that there are some mistakes in the geometrical drawings which are not to be expected from a sophisticated mathematician like Siğzī, besides pointing to a colophon which mentions Siğzī in the third person[58]. In either case we can definitely conclude that during 358-361 / 969-972 Siğzī was copying the works extant in the codex Arabe 2457 which includes some of his works as well. According to the last few items considered, we can extend Siğzī's activity period to 361/972. Further evidence is provided by records of historical events left by Siğzī.

1.3. Historical and astronomical events recorded by Siğzī

Al-Siğzī's main and indeed largest composition in astrology, was *Al-ğāmiᶜ al-šāhī* ("The royal compendium," henceforth the Compendium) completed in 393/1003. The Compendium is a large book that includes several indications about his activities and travels, in seven parts (*nawᶜ* = lit. type or category). It is dedicated to a ruler but does not specify the dedicatee's name. After the short dedicatory section comes the purpose of the book and a list of contents. Siğzī explains that he wanted to compose a comprehensive book on two subjects[59]: first *ᶜilm al-hayʾa*[60] (the science of *hayʾa*) and the structure of the orbs, and second *ᶜilm al-qaḍāʾ wa-al-aḥkām* (the science of judicial astrology). The first part of the Compendium includes a short discussion on *hayʾa* providing definitions of basic concepts like the names of the planets, both in Arabic and Greek (transcribed in Arabic script), and the names of the great celestial circles, followed by a description of the *hayʾa* (structure, configuration) of the orbs of each planet. In the definition of the great circle passing through the poles of the ecliptic and the equator, the solstitial colure[61],

[56] Paul Kunitzsch and Richard Lorch, "A note on codex Paris BN Ar. 2457," *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften*, vol. 8 (1993), p. 235-40.

[57] Roshdi Rashed, *Founding figures and commentators in Arabic mathematics* (Routledge, 2019), p. 125-28, esp. 465.

[58] Al-Siğzī, *A collection of geometrical works: Maǧmūᶜa min rasāʾil handasiyya*, p. VII-VIII.

[59] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Tehran, Parliament Library, MS 6459, f. 1v.

[60] For a description of *hayʾa* see the second part of this paper.

he reports the obliquity of the ecliptic calculated by Ptolemy as 23°51′ and the value by *Mumtaḥan* observations (see below) and by his own observation to be 23°35′, which denotes his observations in Shiraz. The section on *hayʾa* ends with the Moon's mansions[62]. The analysis of the contents of the Compendium deserves separate study and should not detain us here[63]. What is important for us now in regard to Siǧzī's life and career is the sixth part of the Compendium which includes reports of historical events as well as astronomical and meteorological phenomena[64].

The title of the sixth part reads "Remarks and selections from the utterances of the ancient and modern wise men on the influence of the planets on the earthly realm[65]." This part of the Compendium includes a variety of materials that are completely different from those usually discussed in astrology books. For instance, in a section entitled "That a proficient astrologer is one who is a perfect philosopher," Siǧzī discussed the place and nature of astrology as a discipline among other exact sciences[66]. In another section he discussed the instances in which error might occur for astrologers along with a comparison of the practice of astrology with medicine, claiming the priority of the former to the latter[67].

The section which is of greatest importance for mapping Siǧzī's activities is the one in which he recorded the events, either historical or

[61] F. Jamil Ragep, *Naṣīr al-Dīn al-Ṭūsī's* Memoir on astronomy *(Al-tadhkira fī ʿilm al-hayʾa)* (Springer, 1993), vol. 1, p. 114-115.

[62] Al-Siǧzī, "Al-ǧāmiʿ al-šāhī," Tehran, Parliament Library, MS 6459, f. 10r.

[63] There are some manuscript collections of Siǧzī's astrological works including those dedicated to ʾAbū Ǧaʿfar and ʿAḍud al-Dawla which are confused with his *al-Ǧāmiʿ al-šāhī* ("The royal compendium"), mostly by the scribes and later in almost all modern studies on Siǧzī (Cf. Pingree, *The thousands of Abū Maʿshar*, p. 21-23; Brummelen, "Sijzī."). I have discussed this confusion in great detail elsewhere (Younes Mahdavi, "Abū Saʿīd Sijzī and his *Jāmiʿ al-shāhī*," *Tarikh-e elm / Iranian journal for the history of science*, vol. 10, no. 1 [2013], p. 65-94, in Persian) but now I leave it for a later thorough study on the Compendium.

[64] Many of the events recorded in the Compendium have also been reported in the corresponding years in the contemporary and later Islamic chronicles like, ʾAbū ʿAlī Miskawayh's (d. 1013) *Taǧārib al-umam*, Ibn al-Ǧawzī's (d. 1201) *al-Muntaẓam fī taʾrīḫ al-mulūk wa-al-umam*, and Ibn al-Aṯīr's (d. 1232-33) *Al-kāmil fī al-taʾrīḫ*. More significant than all the correspondences between the reports in the Compendium and other chronicles are some reports in which Siǧzī explicitly stated his residence in a specific place.

[65] Al-Siǧzī, "Al-ǧāmiʿ al-šāhī," Tehran, Malik Library, MS 3621, n. d., f. 190v.

[66] Ibid., f. 201r.

[67] Ibid., f. 202r-203r.

phenomenal, from the years 312/924 to 393/1003[68]. Siğzī reported a variety of events including the death of some notables and courtiers, meteorological phenomena like atmospheric changes and precipitation, and astronomical phenomena like eclipses. In this section he reported 56 solar and lunar eclipses with varying details all to have occurred between 13 Ḏū al-ḥağğa 316 / 27 Feb 929 and 14 Rabīᶜ II 392 / 1 March 1002[69]. Following this section, up to the end of the sixth part, is a section containing horoscopes of the emirs of Sīstān and of other regions in Persia beginning with that of ʾAbū Ǧaᶜfar Bānūye and ending with the horoscope of the Samanid emir Nūḥ b. Manṣūr (Nūḥ II, r. 976-997). At the end of the previous section Siğzī stated that he did not follow the chronological order in recording the horoscopes and derived them based on the *Zīğ al-Sindhind*[70] and another source which he called *bi-al-raṣadī* (other times *bi-zīğ al-raṣadī*) followed by the statement *ka-mā waǧadtu*[71] ("as I found it"). The last reference seems peculiar since it is not clear whether it means another *zīğ*, or not, if considered without the definite article *al*. There is no indication in the text explaining this source, but in the *Istīᶜāb* Bīrūnī explained how to use an astrolabe named *al-Raṣadī* and reported that Siğzī informed him about that astrolabe. According to Bīrūnī a certain ᶜAbd Allāh Nīkmard from Qāʾin (NE of Iran) had made the astrolabe[72]. Based on this account, it could be that by the phrases *bi-al-raṣadī* or *bi-zīğ al-raṣadī* Siğzī meant the observations he had made with that astrolabe. However, according to other indications in the text, he used other sources for making horoscopes, including the *Zīğ* of ʾAbū Maᶜšar, the *Al-mumtaḥan zīğ* sponsored by al-Maʾmūn, and the *Zīğ* of Ḥabaš.

From the detailed information Siğzī provided for some events and astronomical phenomena observed there remains little doubt that he himself either witnessed those events or received the news of them around the same time they occurred. Siğzī's reports in the sixth part of the Compendium cover the span of about 81 years from 312/924 to 392/1002,

[68] Ibid., f. 220r-235r.

[69] A complete report of all these eclipses was presented in Mahdavi, "Abū Saᶜīd Siğzī and his *Ǧāmiᶜ al-šāhī*," p. 110-13.

[70] It is an astronomical handbook ascribed to Muḥammad b. Mūsā al-Ḫwārizmī (780-850) made based on the Indian *Sindhind*, which no longer exists in Arabic but is extant in Latin translation. Sonja Brentjes, "Khwārizmī: Muḥammad Ibn Mūsā Al-Khwārizmī," in *The biographical encyclopedia of astronomers* (Springer, 2007), 631-33.

[71] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, n. d., f. 313v.

[72] Al-Bīrūnī, *Istīᶜāb*, 157.

corresponding to the period from the ascension to the throne of ʾAbū Ǧaʿfar Bānūye up to the fall of the Khalafids and the end of Saffarid rule over Sīstān. The extent of the recorded information varies between years; some occupy two pages and some a few lines. For instance, in the latest year 392/1002 he only recorded a lunar eclipse that occurred on Monday 14 Rabīʿ II 392 / 1 March 1002[73]. This eclipse was the last of the 56 eclipses that Siǧzī reported in the sixth part of the Compendium.

1.3.1. Al-Siǧzī's travels to Khurasan and Iraq

Siǧzī seems to have spent most of his life in Sīstān and Shiraz, based on the astronomical observations he made in Shiraz before 351/962 and in 359/969-70, and, second, the number of works he dedicated to Ṣaffārid rulers and courtiers, particularly to ʾAbū Ǧaʿfar Bānūye (r. 311-351 / 923-962) and also to ʿAḍud al-Dawla (r. 338-372 / 949-983). However, there are some indications in the Compendium, as well as in his other mathematical works, showing that, for a period of time, he was travelling between multiple locations in Iraq and Khurasan.

In the notices for three separate years he specified his presence in various places while he received news of the events occurring in those years. The earliest report concerns the year 332/943 when Siǧzī was in Tikrit (Iraq). He reported that while in Tikrit he received the news that, in the middle of Ṣafar, ʾAbū ʿAbd Allāh al-Barīdī murdered his brother ʾAbū Yūsuf when ʾAbū Yūsuf went to his house in Basra[74]. Siǧzī reported twelve events that occurred in the year 332/943 in a chronological order beginning from 18 Muḥarram when Yūsuf b. Waǧīh, the ruler of Oman, retreated from Basra after a defeat. The second event before the murder of ʾAbū Yūsuf is a lunar eclipse that occurred on 13 Ṣafar / 16 Oct a quarter of an hour before sunrise[75]. Other nine reports tell about economic and meteorological events occurred in Baghdad and the deaths of notables and emirs in different places. ʾAbū ʿAlī Miskawayh, a contemporary to Siǧzī who also served ʿAḍud al-Dawla in Shiraz, recorded some events from the same year, but Miskawayh's report of this year could not have been a source for Siǧzī because there are several events in Siǧzī's report

[73] Al-Siǧzī, "Al-ǧāmiʿ al-šāhī," Tehran, Malik Library, MS 3621, f. 234v; "Al-ǧāmiʿ al-šāhī," Central Library of the University of Tehran, MS 6276, f. 318v. This lunar eclipse has also been calculated by NASA on 1 March 1002 (`https://eclipse.gsfc.nasa.gov/LEcat5/LE1001-1100.html`).

[74] Al-Siǧzī, "Al-ǧāmiʿ al-šāhī," Tehran, Malik Library, MS 3621, f. 224v-225r; "Al-ǧāmiʿ al-šāhī," Tehran, Parliament Library, MS 6459, f. 293v.

[75] This lunar eclipse is the eclipse no. 3324 in Theodor Ritter von Oppolzer, *Canon Der Finsternisse* (Vienna: Kaiserlich-Königliche Hof- und Staatsdruckerei, 1887).

that are absent in Miskawayh's[76]. Later chronicles like Ibn Ğawzī and Ibn al-Aṯīr reported the same events found in the Compendium, in some cases with wording and phrases identical to Siğzī[77].

In the relatively long notice on the events of the year 334/945 Siğzī recorded his presence in Hīt (or "Heyt," a city in al-Anbar province in Iraq) while he received the news that on 11 Muḥarram / 23 August the Abbasid caliph al-Mustakfī (r. 944-946) gave himself the title *imām al-ḥaqq* ("the true imam") and ordered the new title to be inscribed on coins besides his previous title *al-mustakfī bi-allāh* ("satisfied with God")[78].

In the reports of the year 353/964 Siğzī stated his presence in Mosul and very briefly recorded several events some of which are also reported by later chroniclers, like Ibn al-Ğawzī who wrote sentences identical to those in the Compendium[79]. Here it is worth noting some events of the year 353/964 just to show how Siğzī's accounts are confirmed by other sources. First, Siğzī reported that, as was customary in the previous years, on the day of *ᶜĀšūrāʾ*, the 10th of Muḥarram, the anniversary of the martyrdom of the third Shiite Imam, all of the shops were closed and no business was done, and that afterwards there was a fight between Shiites and Sunnis in Baghdad[80]. Siğzī added that, on 18 Rabīᶜ I / 4 April, he received news that in Antioch and surrounding cities prices rose so much that people were not even able to afford the cost of bread[81]. The other short report of this year says that at the end of Nisan locusts attacked the crops of Diyar Mudar (in upper Mesopotamia) and al-Rahba (Syria). Later he wrote that when he was in Mosul, he got the news that the Emperor of Byzantium had invaded Tarsus (in Turkey) and fought battles with the inhabitants of the city[82].

[76] ʾAbū ᶜAlī Miskawayh, *Taǧārib*, vol. 5, p. 259-268.

[77] Ibn al-Aṯīr, *Al-kāmil fī al-taʾrīḫ*, vol. 7, p. 178-185; Ğamāl al-Dīn ʾAbū al-Faraǧ ᶜAbd al-Raḥmān b. ᶜAlī b. Muḥammad b. al-Ğawzī, *Al-muntaẓam fī taʾrīḫ al-mulūk wa-al-umam* (Beirut: Dār al-Kutub al-ᶜIlmiyya, 1995), vol. 14, p. 34-38.

[78] This is also reported in other chronicles: Ibn al-Ğawzī, *Al-muntaẓam*, vol. 14, p. 42; Muḥammad b. ᶜAlī b. Muḥammad b. al-ᶜImrānī, *Al-inbāʾ fī taʾrīḫ al-ḫulafāʾ*, ed. Qāsim al-Sāmirī (Cairo: Dar al-Āfaq al-ᶜArabiyya, 1999), p. 176.

[79] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, f. 312r. Also see Ibn al-Ğawzī, *Al-muntaẓam*, vol. 14, p. 155-156.

[80] Al-Siğzī also specified the exact location as the "Qaṭiᶜa Umm Ğaᶜfar." For the place see Ṣafī al-Dīn al-Baġdādī, *Marāṣid al-iṭṭilāᶜ ᶜalā asmāʾ al-amkana wa-al-buqāᶜ*, ed. ᶜAlī Muḥammad al-Bağāwī (Beirut: Dār al-Ğīl, 1991), vol. 3, p. 1109.

[81] Ibn al-Ğawzī, *Al-muntaẓam*, vol. 14, p. 156. Ibn al-Ğawzī also added that about fifty thousand of the populace left Antioch for Damascus.

[82] Also see: Ibn al-Aṯīr, *Al-kāmil fī al-taʾrīḫ*, vol. 7, p. 250; ʾAbū ᶜAlī Miskawayh, *Taǧārib*, vol. 5, p. 337-338.

Accordingly, we can conclude that Siǧzī must have lived for some time in Tikrit, Hīt, and Mosul, and travelled between those cities and probably other locations during the years 332-353 / 943-964. Part of this period coincides with the period when he served ʾAbū Ǧaʿfar Bānūye (d. 351/962) in Sīstān and wrote five works in astrology for him, as well as making astronomical observations. For the year 353/964 we can be certain that Siǧzī was an adult when he witnessed the events, since he was occupied in writing and making observations before 351/962, but we do not know Siǧzī's age when he received the news in Tikrit. It is barely possible that he could have been a child accompanying his father and later reporting the events, but this seems very unlikely given the number of events and their details. He never mentioned his father as a source in the Compendium, although he referred to him in some of his mathematical works.

Another date in one of Siǧzī's mathematical works tells us more about his journeys and activities. In 12 Šawwāl 369 / 1 May 980, Siǧzī composed a treatise providing solutions for geometrical problems which had been given by the geometers of Khurasan (a region in the north east of Persia including part of Central Asia and Afghanistan)[83]. In solving one of the problems he mentioned the names of two geometers, al-Šayḫ Abī al-Ḥusayn al-Maṣrī and Abī Muḥammad al-Sayfī, and specified that they were present at the meeting in which that problem was discussed[84]. In his book on astrolabes, Bīrūnī also quoted a method from al-Sayfī on marking azimuth circles on the plate of an astrolabe, which identifies him an astronomer-mathematician[85]. The sole report in the treatise does not specify when or where exactly Siǧzī met those geometers, but it tells us that the meeting happened before the composition date, 12 Šawwāl 369 / 1 May 980.

1.4. Collaboration with other scholars

There is plenty of evidence that shows Siǧzī was actively collaborating with other scholars from different places, either meeting in person or corresponding with them on scientific issues. One famous example as I have discussed earlier is the series of observations he made in Shiraz in 359/969-970 under the patronage of ʿAḍud al-Dawla, for determining

[83] This is testified by the colophon of MS Chester Beatty 3652 which tells us the manuscript was copied from the autograph. Dublin, Chester Beatty Library, MS 3652, f. 58v.

[84] Dublin, MS Chester Beatty 3652, f. 54v.

[85] Al-Bīrūnī, *Istīʿāb*, 55.

the obliquity of the ecliptic. The most detailed account of this is provided by Bīrūnī in his book on the coordinates of locations. He reported that the observations were directed by al-Ṣūfī together with many other astronomers including Siğzī, al-Kūhī, Ġulām Zuḥal, and Naẓīf b. Yumn al-Mutaṭabbib. They were conducted once on 2 Ṣafar 359 / 15 December 969, and then again on 8 Šaᶜbān 359 / 16 June 970. Bīrūnī described only one instrument used for observations, a ring with the interior diameter of 2 $\frac{1}{2}$ *ḏirāᶜ* (cubits) or 5 *ašbār* (sing. *šibr* = span), which was graduated up to 5 minutes of arc[86]. Siğzī also mentioned the same instrument in the "Structure of the orbs" (see below) but named it the *ᶜAḍudiyya* Ring (*al-ḥalqa al-ᶜAḍudiyya*). Comparing Siğzī's reports of measuring the obliquity of the ecliptic, there is a slight difference between what he reported in the *Al-madḫal* and in the Structure. In the *Al-madḫal* Siğzī compared his measured value of 23°35′ with multiple values obtained by Ptolemy, Indian astronomers, the Banū Mūsā and the *Mumtaḥan* observations (*bi-raṣad Maʾmūnī*), but in the Structure he only certified that his value was identical with one measured by Ḥabaš. Also, in the Structure Siğzī mentioned the main astronomical instrument used for observations, the *ᶜAḍudiyya* Ring. The report in the *Al-madḫal* allows us to conclude that the observations sponsored by Aḍud al-Dawla was not the first time Siğzī measured the obliquity of the ecliptic, rather he had carried out another observation in Fars when under the patronage of ʾAbū Ğaᶜfar Bānūye.

Among contemporary scholars, Bīrūnī quoted most extensively from Siğzī and mentioned his name several times in his mathematical and astronomical works, sometimes by the titles *al-muhandis* (the geometer) or *al-šayḫ* (the old man) which denotes to Siğzī's old age[87]. Since Bīrūnī was born in 362/973 he may have met with Siğzī in his youth. In his treatise on trisecting an angle, Siğzī provided solutions and proofs for some problems posed by Bīrūnī and addressed him using the expression *ayyadah Allāh* ("may God support him"), indicating al-Bīrūnī's young age[88]. This difference of age between Bīrūnī and Siğzī is also corroborated by the twelfth century poet and writer Niẓāmī ᶜArūḍī (fl. 1110-1161) who described Siğzī an erudite astrologer and one of Bīrūnī's predecessors[89].

[86] Al-Bīrūnī, *Taḥdīd nihāyāt al-amākin li-tasḥīḥ masāfāt al-masākin*, 99.

[87] Al-Bīrūnī, *Istīᶜāb*, p. 121-22, 124-25, 128, 134-35.

[88] Rashed, *Œuvre mathématique d'al-Sijzī*, p. 341, 355, 357.

[89] Aḥmad b. ᶜUmar b. ᶜAlī Niẓāmī ᶜArūḍī Samarqandī, *A revised translation of the Chahár maqála ("Four discourses") of Nizámí-i'Arúdí of Samarqand, followed by an abridged translation of Mírzá Muhammad's notes to the Persian text*, trans. Edward Browne (London: Cambridge University Press, 1921), p. 62-63, 86.

In the *Maqālīd ʿilm al-hayʾa* ("Keys to the science of astronomy") Bīrūnī also reported that Siǧzī was aware of several methods from both geometers and astronomers for determining the *qibla* direction but did not have their proofs. After he informed Siǧzī that his mentor and master, ʾAbū Naṣr Manṣūr b. ʿAlī b. ʿIrāq (d. ca. 1036) had provided such proofs, Siǧzī requested ʾAbū Naṣr to write him a treatise on the subject, and he wrote the *Al-sumūt* ("The azimuths")[90] in response.

In addition to corresponding with Bīrūnī, Siǧzī had collaborations with other mathematicians and astronomers/astrologers too. In some places in the Compendium as well as in other astrological works he describes methods by ʾAbū al-Qāsim Ġulām Zuḥal. In the discussion of *ḥudūd* (terms) in the *Al-madḫal*, Siǧzī wrote that there was disagreement between ancient astrologers on using *ḥudūd*. Although using *ḥudūd* defined by the Egyptians was customary, he "the master ʾAbū al-Qāsim [Ġulām] Zuḥal" did not confine themselves to the Egyptian definitions but made a table to explain them[91]. Among leading contemporary mathematicians, Siǧzī corresponded with ʾAbū ʿAlī Naẓīf b. Yumn al-Mutaṭabbib and once wrote him a letter on construction of an acute-angled triangle from two different straight lines. In that treatise Siǧzī referred to his other work titled *Fī al-muṯallaṯāt* ("On the triangles") and clarified that he was going to introduce a method other than the one he had used in that book[92]. In his *Fī masāʾil al-muḫtāra* (*On Selected Problems*) Siǧzī answered several mathematical questions asked by al-Kūhī, al-Iqlīdusī, ʿAlā b. Sahl, and ʾAbū al-Ǧūd Muḥammd b. Layth[93] and in his treatise on trisecting an angle he answered questions raised by al-Kūhī, ʾAbū al-Ḥasan al-Šamsī al-Hirawī, and ʾAbū Ḥāmid al-Ṣāġānī[94].

1.5. Constructing astronomical instruments

Many extant copies of Siǧzī's works and abundant indications in other sources confirm him as a leading figure in making astronomical instruments, particularly astrolabes, although some of his works on instru-

[90] ʾAbū Rayḥān Aḥmad b. Muḥammad al-Bīrūnī and Marie-Thérèse Debarnot, *Kitāb maqālīd ʿilm al-hayʾa. La Trigonométrie sphérique chez les Arabes de l'Est à la fin du x^e siècle* (Damas, 1985), 96-97.

[91] Al-Siǧzī, "Al-madḫal," Central Library of the University of Tehran, MS 8609, f. 4v.

[92] An edition of the Arabic text with English translation is found in Hogendijk, "Traces of the lost *Geometrical elements* of Menelaus in two texts of al-Sijzī," p. 155-60.

[93] Al-Siǧzī, "Fī masāʾil al-muḫtāra," Dublin, Chester Beatty Library, MS 3652.

[94] Rashed, *Œuvre mathématique d'al-Sijzī*, p. 337-39, 339-41, 345-47.

ments are currently missing. In his *Al-madḫal ilā ᶜilm al-handasa* ("Introduction to geometry") he described a spherical instrument he had made representing the structure of the whole universe:

> And indeed, I made a great and important instrument in Siğistān, for the whole universe, including the orbs and celestial bodies and the circuits of their motions, accounting for their magnitudes and the sizes of their distances and bodies, and the illustration of the earth, the localities, cities, mountains, seas and deserts, inside a mesh sphere and I named it "configuration (*hayʾa*) of the whole[95].

Since the "Introduction to geometry" was completed in Ḏū al-Ḥağğa 368 / July 979[96], Siğzī must have made this instrument earlier than that date. Other substantive evidence is Siğzī's report about the astrolabes he made for ᶜAḍud al-Dawla[97].

Besides constructing astronomical instruments Siğzī composed about nine works on making instruments and one on determining the *qibla* direction[98]. Bīrūnī quoted several construction methods and functions of astrolabes from Siğzī and in some cases praised Siğzī's mastery and skillfulness in the field[99]. In his monumental work on astrolabes *Istīᶜāb al-wuğūh al-mumkina fī ṣanᶜat al-uṣṭurlāb* ("Comprehending all possible methods of constructing the astrolabe") Bīrūnī described Siğzī's Boat-shape (*al-Zawraqī*) astrolabe and stated that Siğzī made the instrument by attributing a diurnal motion to the Earth instead of to the heavens. Bīrūnī argued that neither the geometers and the practitioners of *hayʾa* nor their science, by which he meant astronomy, could disprove this assumption and that the problem could be solved, if at all, by natural philosophers[100]. In the *Istīᶜāb* Bīrūnī described the construction of five astrolabes by Siğzī[101] including the *al-Raṣadī* astrolabe discussed

[95] Al-Siğzī, "Al-madḫal ʾilā ᶜilm al-handasa" (Dublin, Chester Beatty Library, MS 3652, 612/1215), f. 16v:
وإنّي عملت آلة جليلة خطيرة بسجستان تحكى العالم بأسره من الأفلاك والأشخاص العالية ومدارات حركاتها بمقاديرها وكمّيّة أبعادها وأجرامها وصورة الأرض والبقاع والبلدان والجبال والبحار والرمال في جوف كرة مشبّكة وسمّيتها هيئة الكلّ.

[96] Ibid., f. 16v.

[97] Al-Siğzī, *Fī ᶜamal al-uṣṭurlāb*, Istanbul, Topkapi Museum, Ahmet III, MS 3342/9, f. 130r, 153r, 114r, 114v.

[98] Sezgin, *GAS*, vol. V, p. 334; vol. VI, p. 225-26. Two of these treatises have appeared in modern editions in Persian. Hoseyni Tabatabayi, "A study of Zawraqī astrolabe;" Pouyan Shahidi Marnani, "Musarṭan astrolabe," p. 84-197.

[99] Al-Bīrūnī, *Istīᶜāb*, 125.

[100] Ibid., 128.

[101] Ibid., 122-37.

above, which Siǧzī taught him to use[102].

1.6. Conclusions on Siǧzī's life and career

The latest date Siǧzī recorded in his mathematical works is the composition date of a treatise on the Transversal Figure (Menelaus theorem) which was written on 1 Muḥarram 389 / 23 December 998[103] and the last recorded event in the Compendium is a lunar eclipse in 393/1003. The following table shows the related dates I have derived so far both from Siǧzī's astrological works, notably from the Compendium, and from reports and indications by his contemporaries and subsequent scholars. Those dates in table 1 which I did not discuss earlier in this paper are based on modern studies and editions of Siǧzī's mathematical works, all accompanied with citations in the notes.

Table 1: A Chronology of ʾAbū Saʿīd Siǧzī

(In the left column, H and Y respectively denote Hijri and Yazdgerdī calendars, and all dates after "/" are equivalents from the Julian calendar.)

Date	Activity
312 H / 924	The first recorded event in the *Al-ǧāmiʿ al-šāhī* ("The royal compendium") on astrology.
[313 H / 925[104]]	[Siǧzī used this date in an example in the *Muntaḫab min Kitāb al-ulūf*, a summary of *Kitāb al-ulūf* ("The thousands") of ʾAbū Maʿšar for ʾAbū Ǧaʿfar Bānūye (r. 311-351 / 923-962).]
332-353 H / 943-964	Traveled between Tikrit, Hīt, and Mosul, as recorded in the Compendium.

Continued on next page

[102] Al-Bīrūnī, *Istīʿāb*, 157-64.

[103] Al-Siǧzī, "Fī taḥṣīl īqāʿ al-nisba al-muʾallifa," Leiden University Libraries, MS Or. 168, n. d., f. 44r. For a modern study of the work see J. L. Berggren, "Al-Sijzī on the transversal figure."

[104] As I explained earlier, we should not rely on this date as the composition date of the *Muntaḫab*, however, Pingree did.

Date	Activity
before 351 H / 962	Wrote 11 works in astrology and one short treatise in mathematics, six of them for ʾAbū Ğaᶜfar Bānūye. Made observations in Shiraz and calculated the obliquity of the ecliptic as 23°35′.
351-354 H / 962-965	Wrote the *Kitāb al-zāʾirğāt fī istiḫrāğ al-haylāğ wa-al-kadḫudāh* ("Tables for derivation of *haylāğ* and *kadḫudāh*") in astrology for ᶜAḍud al-Dawla (r. 338-372 / 949-983).
358-361 H / 969-972	Copied some 50 mathematical works including 11 of his own compositions (now extant in Paris, MS Arabe 2457).
before 359 H / 970	Wrote the *Kitāb al-ᶜamal bi-al-ṣafīḥa al-āfāqiya*, on construction of an astrolabe, for ʾAbū al-Ḥusayn Ṭāhir b. Muḥammad al-Siğzī (d. 359/970).
359 H / 969-970	Collaborated in an observation project for ᶜAḍud al-Dawla in Shiraz with other astronomers under the direction of ᶜAbd al-Raḥmān al-Ṣūfī.
359-372 H / 970-983	Wrote *Tarkīb al-aflāk* ("The structure of the orbs") for ᶜAḍud al-Dawla. Made several astrolabes of his invention along with their instructions for ᶜĀḍud al-Dawla.
before 340 Y / 972	Wrote the *Taᶜlīqāt al-handasiyya* ("Geometrical annotations"), also mentioned in the next item[105].
21 Bahman 340 Y / 7 Feb 972	Completed the treatise on the properties of paraboloids and hyperboloids for his father.
Ḏū al-Ḥağğa 368 H / July 979	Completed the *Al-madḫal ilā ᶜilm al-handasa* ("Introduction to geometry")
before 12 Šawwāl 369 H / 1 May 980	Discussed and answered geometrical problems with some geometers in Khurasan.

Continued on next page

[105] Rashed, *Œuvre mathématique d'al-Sijzī*, p. 209.

Date	Activity
before 349 Y / 980-981	Wrote the *Fī tashīl al-subul li-istiḫrāǧ al-aškāl al-handasiyya* ("Book on making easy the ways of deriving geometrical figures"), mentioned in the next item[106].
after 349 Y / 980-981	Wrote *Fī anna al-aškāl kulluhā min al-dāʾira* ("On that all figures are [derived] from the circle") for a certain Naṣr b. ʿAbd Allāh[107].
349 Y / 980-981	Completed the treatise on the hyperbola and asymptotes[108].
1 Muḥarram 389 H / 23 December 998	Completed the "Transversal figure" (on Menelaus Theorem).
393 H / 1003	The last recorded event in the Compendium of a lunar eclipse.

Since there are no indications in either the chronicles or in Siǧzī's compositions about his date of birth, according to table 1, he should have been born, most probably in Sīstān, no later than 332 H / 943 when he travelled to Tikrit. Based on the last observational record in the Compendium, the lunar eclipse of 393 H / 1003, which is the latest report of his activities, the year 393 H / 1003 can be taken as a *terminus ante quem* for his scientific activities. It is not, however, theoretically impossible to assume the year 410/1020 for Siǧzī's death, but as I have shown earlier, in 332/943 he had begun his travels to Iraq, in which case we would have to accept that he was active for at least 79 years, which is difficult to believe. Moreover, those scholars who claimed the year 410/1020 to be Siǧzī's death date did not provide any evidence for such a claim, except for misreading "ʾAbū Ǧaʿfar" as "ʾAbū Naṣr" to identify the dedicatee with the prince of Balkh ʾAbū Naṣr Aḥmad b. Muḥammad b. Farīġūn (d. 410/1019), thus imposing Ibn Farīġūn's death date as that for Siǧzī. But as I showed above, the dedicatee was the ruler of Sīstān ʾAbū Ǧaʿfar Bānūye (r. 311-351 / 923-962) whose name and death were both recorded by Siǧzī too. Our present findings do not let us determine a death date for Siǧzī, but the best determination for the duration of his life is the

[106] Rashed, *Œuvre mathématique d'al-Sijzī*, p. 313.
[107] Ibid., p. 313.
[108] Ibid., p. 295-309.

period of his activities during 332-393 / 943-1003, i. e. about 60 years. In the first part of this period Siğzī composed the earliest work in the new field of *ᶜilm al-hayʾa*, to which we now turn.

2. THE *STRUCTURE OF THE ORBS*

The *Tarkīb al-aflāk* ("The structure of the orbs," henceforth the Structure) is a composition on theoretical astronomy which does not deal with astrology. In this section I give the first modern description of this previously unavailable work, which counts as the earliest known example of the genre *hayʾa*. The Structure was written in Arabic and is extant in six manuscript copies. None of the extant copies have the composition date but Siğzī dedicated the work to the Buyid emir ᶜAḍud al-Dawla (r. 338-372 / 949-983). The Structure is on the configuration (*hayʾa*) or structure (*tarkīb*) of the cosmos, in three chapters. The author provided chapter headings at the end of the introduction as follows[109]: 1) On the introduction to the science of the configurations (*fī al-madḫal ilā ᶜilm al-hayaʾāt*), 2) On the science of the configurations (*fī ᶜilm al-hayaʾāt*), 3) On the way of drawing them [configurations] and the amounts of their distances and bodies (*fī kayfiyya taṣwīrihā wa-maqādīr abᶜādihā wa-aǧrāmihā*). The book does not cover terrestrial topics or the configuration (*hayʾa*) of the sublunary realm, but the second chapter includes a diagram for the climes along with their latitudes and a short discussion on the size of the Earth. The purpose of the work, however, was described in the *explicit* as to provide a treatise about both the configurations of the orbs and the configuration of the Earth (*hayaʾāt al-aflāk wa-hayʾa al-arḍ*).

2.1. The extant copies of the text

So far, the following six Arabic manuscript copies of the Structure along with a Persian translation (**P**) of the third chapter have been recognized[110]:

1. (**L**) MS Leiden Or. 2541/1, copied on Tuesday 28 Rabīᶜ I 646 / 21 July 1248;

[109] Al-Siğzī, "Tarkīb al-aflāk," Leiden, MS Or. 2541, 646/1248, f. 1v; "Tarkīb al-aflāk," Istanbul, Beyazıt State Library, MS 4627, n. d., f. 80v.

[110] Sezgin recorded seven Arabic copies of the Structure, but one of them, Ms. 174 kept in the Parliament Library in Tehran (*Maǧlis*), is Siğzī's *Al-madḫal* which had been mistakenly recorded in the library catalogue as the Structure. Sezgin, *GAS*, vol. VI, p. 225. See also note 61, above.

2. (**B**) MS Beyazit 4627/4, copied in 1179/1765-66;
3. (**S**) MS Laleli 2707, in the Sulaymaniyah Library (12th century);
4. (**I**) MS A. Y. 371, at the Istanbul University Library, copied in 1186/1772-73.
5. (**R**) MS 7503, in Mashhad Āstān Quds Razavī Library (13th century).
6. (**A**) MS 3692/3, in the Asiatic Museum (Institute Narodov Azii) in Saint Petersburg.
7. (**P**) MS Laleli 2141/3, in the Sulaymaniyah Library, copied in Ḏū al-Ḥağğa 644 / Apr-May 1247.

There are, however, other manuscripts wrongly catalogued under the same title as the Structure. Almost all of these are the *Al-madḫal*, Siğzī's introductory work on astrology dedicated to ʾAbū Ğaʿfar Bānūye. Catalogers may have been misled in identifying this work because *Al-madḫal* also begins with discussions on *ʿilm al-hayʾa*. Among the copies listed above only **A** was not accessible to me. **L** and **B** are the most complete copies, but **B** has nine more diagrams in the first chapter none of which appears in other copies. All these additional diagrams might have been added by the scribe though. **B** also repeats exactly the same errors or lacunae that occur in **L**. This suggests that, assuming the extra diagrams in **B** belonged to the original text, both **L** and **B** could have been made based on a unique source. **S** is also complete but only has a few descriptions of the diagrams, but with the addition of a diagram showing the configuration of the cosmos in concentric total orbs, something missing in all other copies. **R** includes the first two chapters but none of the diagrams except for the one showing the climes. However, it is odd that both **R** and **S** are in the same hand. The manuscript **I** includes the complete text but no diagram. The most reliable copy is **L**, in terms of both accuracy and contents, but I will also make references to other copies whenever needed.

The extant copy of the Persian translation (**P**) of the third chapter of the Structure was made two years earlier than the oldest copy of the original text in Arabic, **L**. The Persian text is in a collection of astronomical works[111]. It comes after Qāḍīzāda al-Rūmī's (b. c. 1352 – d. after 1440) commentary on Ğaġmīnī's (fl. early 13th century) *Mulaḫḫaṣ*

[111] I would like to express my thanks to the Research Heritage Institute (Tehran) which provided me with the image of this manuscript.

fī al-hayʾa al-basīṭa. The translation begins with the heading "Selections from Siğzī's book of *hayʾa* written for Aḍud al-Dawla" in Arabic and immediately starts the Persian translation of the third chapter of the Structure. Nothing more at the beginning or the end is given except for the copying date Ḏul Ḥağğa 644 in Abjad numerals.

2.2. A summary of the Structure

A brief account of the Structure will help us acquire a general impression of its contents before analyzing it in more detail. Chapter one, as its heading reads, provides definitions of eighty-one preliminary concepts needed in astronomy including definitions of celestial circles, orbs, and their motions. The definitions differ in length from a few sentences to a few words. A point of great importance in this chapter is the use of Greek and Persian terms (probably from Sasanid sources) for introducing some concepts. For instance, in the definition of the apogee Siğzī used *al-afīğiyun* (see fig. 2) equivalent to απόγειον and for perigee he recorded that *al-ifrīğiyun* was equivalent to the Greek περίγῆ. Similarly, parallax is defined with its Greek term as *al-barālaksīs* (παράλλαξις). The presence of Persian terms is also apparent, although as with the Greek terms he added the Arabic definite article *al* to all of them. When introducing the phases of the Moon in the first chapter Siğzī used the Persian terms *al-nīmpurīn* (Half Moon), *al-purmāhī* (Full Moon), *al-hamroušanī* (New Moon), and in a diagram showing the phases of the Moon in chapter two he added *ḫāydīs* (lit. egg-shaped, indicating the Gibbous Moon). However, in the definition of "phases," or the relative positions of planets with respect to the Sun, Siğzī again used the Greek *al-fāsīs* (φάσεις). This was not the first time Siğzī had used technical terms from Greek or Persian sources, he used them in two of his astrological works as well. One was the *Al-madḫal ilā ᶜilm aḥkām al-nuğūm* (see above), also cited in the second chapter of the Structure, where he used the same Greek terms for the apogee and perigee[112]. The other was the Compendium, where he devoted the first section to the domain of astronomy (see below) and listed the names of the twelve months in both Persian and Greek after giving their Arabic equivalents[113]. As I mentioned above one copy of the text, **B**, has nine more diagrams in the first chapter.

The second chapter bears the title *Fī ḏikr hayaʾāt al-aflāk* ("On the configurations of the orbs"), a slightly different title from the one given

[112] Al-Siğzī, "Al-madḫal," Central Library of the University of Tehran, MS 8609, f. 2r.

[113] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, f. 2r.

in the table of contents which was *Fī ʿilm al-hayaʾāt* ("On the science of the configurations"). This chapter is divided generally into two sections. The first section provides descriptions of the orbs of each planet and their motions with some numerical values, followed by a discussion on the size of the Earth, the latitudes of the climes and the length of the longest day of each clime. The second section includes all the diagrams of the climes, the eclipses of the Sun and Moon (see fig. 1), and of the orbs of the planets. As mentioned at the beginning of the chapter[114] Siǧzī provided two sets of diagrams for the orbs of each planet, one demonstrating the configuration of the orbs (see fig. 2), and another that describes the motion of each orb with numerical values of the sizes, distances, and motions[115]. The diagrams of the Sun come first followed by those of the Moon[116]. Afterwards the diagrams of the planets are given from the farthest to the nearest in this order: Saturn, Jupiter, Mars, Venus, and Mercury[117].

In the first section of the chapter before defining eclipses, Siǧzī gave the amount of the obliquity of the Ecliptic and reported the results of the observations he had made in Fars. Siǧzī collaborated in a set of observations carried on in 359/969-70 in Shiraz (the capital of Fars province) under the patronage of the ʿAḍud al-Dawla. As I discussed earlier, Bīrūnī gave a detailed account of this event but the Structure mentions the name of the major instrument they used as the *ʿAḍudiyya* ring (*al-ḥalqa al-ʿAḍudiyya*).

Finally, the third chapter of the Structure is something of a completely different nature compared to later works on *hayʾa*. In this chapter Siǧzī provided methods for drawing the orbs of each planet with compass and ruler. He states the purpose of it at the beginning:

> Since we have presented what was needed to be introduced from the matters of the configurations (*hayaʾāt*) of the Earth and the orbs, and their formations and magnitudes, and bodies and motions and other states specific to them, thus we put forth the discourse on the method of depicting them and the true way of drawing them, since it is the whole purpose of this book[118].

Siǧzī also added that because the diagrams and letterings in the book might be changed through scribal errors in future, something that had happened to others as well, this chapter can prevent corruption to the

[114] Al-Siǧzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 3v.
[115] Ibid., f. 6v-13r.
[116] Ibid., f. 6v-8r.
[117] Ibid., f. 8v-13r.
[118] Ibid., f. 13v.

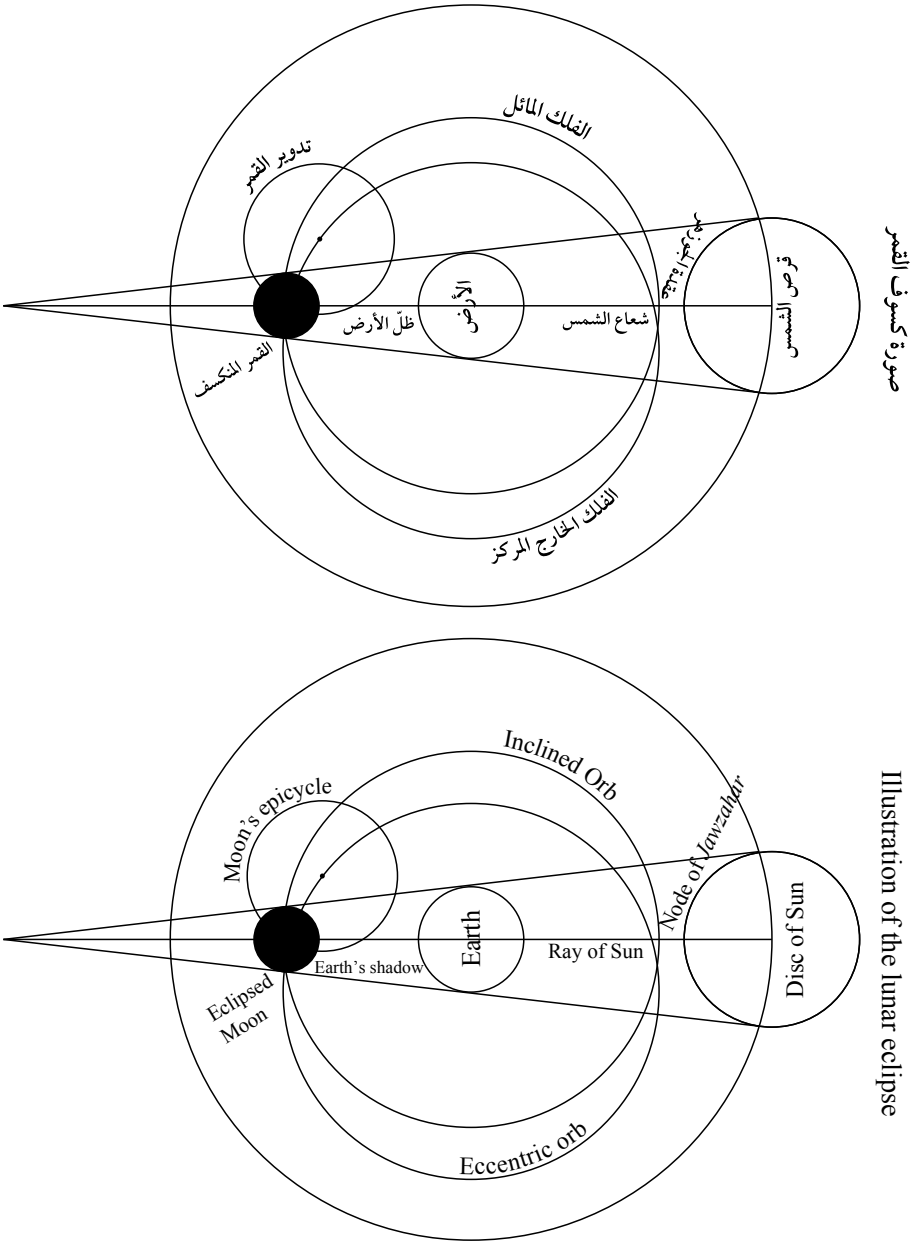

Figure 1: The diagram for the lunar eclipse in the Structure, reproduced and translated from MS Leiden 2541, f. 5v. Siǧzī defined lunar and solar eclipses in a few sentences and pointed to the reasons for differences in duration between the two types of eclipses.

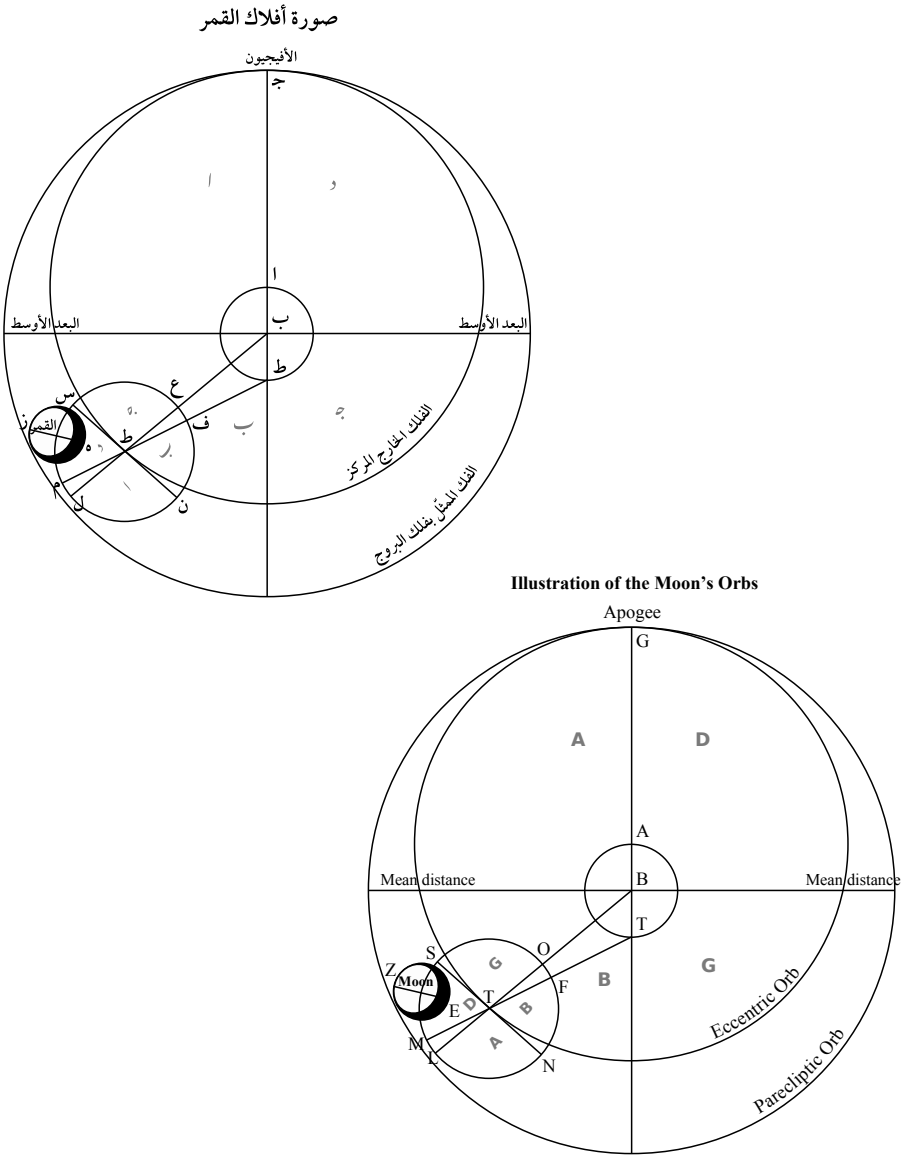

Figure 2: Orbs of the Moon in the Structure, reproduced and translated from MS Leiden 2541, f. 7v. This is one of the two diagrams Siğzī provided for the Moon. Another diagram he gave afterwards is accompanied by descriptions of the motion of the orbs together with numerical values of the sizes and distances of the orbs and the Moon's body. As shown on the diagram, the transcribed term *al-afīğiyun*, equivalent to the Greek απόγειον, is used to label the point of apogee.

material of the book. Another purpose for the final chapter, explained at the beginning of the second chapter, was to provide a guide for those who desire to build calendars for planets without using a *zīǧ*[119] (astronomical handbook with table). This is corroborated by the abundance of numerical values overall in the Structure, although it does not seem that the book provides sufficient material and methods for making calendars or tables of planetary motions.

The tools for drawing diagrams, according to Siǧzī, are a compass and a ruler one span in length graduated into sixty equal parts. The basis for drawing all diagrams is to draw a circle with radius of 60 equal to the length of the ruler as the eccentric orb of the planet, then given the eccentricity of that circle for each planet, drawing the par-ecliptic. The simplest model belongs to the Sun which ends with choosing a point on the eccentric to draw the disc of the Sun. For the Moon and other planets, the center of the epicycle is arbitrarily marked on the eccentric and, based on the same scale, the epicycle and the disc of the planet are drawn afterwards. This method, however, is not devoid of difficulties. Some planets, like Venus, are very small in respect to the size of their epicycles, therefore if one needs to draw a model which shows the planet in an appreciable size, then a very large eccentric and epicycle must be drawn, something not easily done on a single piece of paper. Apart from this issue, these diagrams not only provide readers with a real model for the orbs of each planet, but also give precise values for the eccentricities, the sizes of the epicycles and the sizes of planets' bodies in respect to the radius of the eccentric as 60.

3. THE *ʿILM AL-HAYʾA* IN THE FOURTH/TENTH CENTURY

The significance of *ʿilm al-hayʾa* (science of *hayʾa*, science of configuration) is well known in Islamicate astronomy. So, I do not intend to give an exhaustive account of the development of the discipline, nor will I discuss its emergence, which is still debated among scholars[120]. None of

[119] Ibid., f. 3v.

[120] The most recent study on the topic can be found in Sally P. Ragep, *Jaghmīnī's* Mulakhkhaṣ*: An Islamic introduction to Ptolemaic astronomy* (Springer, 2017), p. 27-65. For various definitions and interpretations of *ʿilm al-hayʾa* and possible explanations for its appearance in the Islamicate science see: David Pingree, "ʿIlm al-hayʾa," in *Encylopaedia of Islam*, 2nd ed.; Ḥasan b. al-Ḥasan b. al-Haytham and Y. Tzvi Langermann, *Ibn al-Haytham's On the configuration of the world* (New York & London: Garland, 1990), 25-34; Ragep, *Ṭūsī's Memoir*, p. 29-36; A. I. Sabra, "Configuring the universe: Aporetic, problem solving, and kinematic modeling as themes of

these are of primary importance for the discussion of this paper. Rather, I will describe the meaning and understanding of *ʿilm al-hayʾa* during the time Siǧzī wrote the Structure, to justify its categorization as a work of *hayʾa* within Islamicate astronomy.

The main purpose of *ʿilm al-hayʾa*, in its mature phase was to provide a scientific description of the whole universe, which accounted for all the different motions produced by celestial bodies, as well as for the arrangement of the sublunary elements and the Earth. Both astronomical and natural philosophical foundations of *ʿilm al-hayʾa* were initially based in Greek sources, the former in Ptolemy's *Almagest* and *Planetary hypotheses* and the latter in works like Aristotle's *De caelo* and *Metaphysics*. The *hayʾa* books described motions of the planets by means of geometrical models proposed in the *Almagest*. Although they assumed physical orbs carrying the planets and therefore causing the planetary motions, their authors did not always bother to provide proofs for the consistency of their models with the physical structure of the universe. A subcategory of the *ʿilm al-hayʾa* appeared as a separate genre under the general title of *hayʾa basīṭa* (simple *hayʾa*) giving a general picture of the cosmos devoid of geometrical proofs for the planetary models[121]. These simple treatises could vary significantly in size and content. Important examples are Ǧaġmīnī's (13th century) *Al-mulaḫḫaṣ fī al-hayʾa al-basīṭa*[122] ("The epitome of the simple *hayʾa*") and the concise treatise *Tašrīḥ al-aflāk* ("Dissection of the orbs") of Bahāʾ al-Dīn ʿĀmilī (1547-1621), both of which produced numerous commentaries.

Not many works are known from the fourth/tenth century that address the subject matter of *ʿilm al-hayʾa*. Taro Mimura has recently found the original Arabic text of the *Liber de orbe* and identified its author as Dūnaš bin Tamīm (d. after 344/955) who wrote the book around 344/955-56[123]. The Latin translation had been formerly attributed to

Arabic astronomy," *Perspectives on science*, vol. 6, no. 3 (1998), p. 288-330; George Saliba, "Astronomy and astrology in medieval Arabic thought," in *Les doctrines de la science de l'antiquité à l'âge classique*, ed. Roshdi Rashed and Joël Biard (Peeters, 1999), p. 131-64; Id., "Islamic astronomy in context: Attacks on astrology and the rise of the *hayʾa* tradition," *Bulletin of the Royal Institute for Inter-Faith Studies*, vol. 4, no. 1 (Spring-Summer 2002), p. 25-46; F. Jamil Ragep, "Hayʾa," in *Encyclopaedia of the history of science, technology, and medicine in non-Western cultures* (Springer, 2008), p. 1061-62.

[121] Ragep, *Ṭūsī's Memoir*, vol. 1, p. 35.

[122] Sally P. Ragep, *Jaghmīnī's Mulakhkhaṣ*.

[123] Taro Mimura, "The Arabic original of (ps.) Māshāʾallāh's *Liber de orbe*: its date and authorship," *British journal for the history of science*, vol. 48, no. 2 (June 2015): esp. 344-45; Id., "A glimpse of non-Ptolemaic astronomy in early *hayʾa* work: Planetary

the court astrologer of the Abbasids, Māšāʾallāh (d. c. 815), making it a work of the ninth century. Mimura classified the *Liber* under *ᶜilm al-hayʾa*, although Dūnaš's book, as Mimura explains[124], discussed a fairly large amount of non-astronomical materials including meteorology and theological topics to show "the creation of the cosmos by the one God." Besides this new identification and classification of the *Liber de orbe*, Siğzī's Structure is the only other example we have of *ᶜilm al-hayʾa* from the fourth/tenth century. Unlike the *Liber de orbe*, Siğzī's Structure is exclusively concerned with topics that became canonical in later works on *ᶜilm al-hayʾa*.

In the eleventh century *ᶜilm al-hayʾa* evolved into an independent discipline and formed a separate genre of writing sometimes understood as the whole science of astronomy[125]. It dealt with the physical structure of the universe in two main divisions, the celestial and terrestrial realms[126]. However, some evidence shows that before this time the term *hayʾa* was primarily used to specify a branch of astronomy (*ᶜilm al-nuğūm*, lit. = the science of the stars), while astronomy as a discipline encompassed other types of activities like constructing instruments, making observations, finding the direction of the *qibla*, making calendars and ephemerides, producing tables of planetary motions (*zīğ*), and practicing astrology.

In their *hayʾa* books Islamicate astronomers were not merely imitating Ptolemy. A good example of this is *On the configuration of the world* (*Al-maqāla fī hayʾa al-ᶜālam*, 11th century). *On the configuration* was one of the earliest attempts to harmonize the *Almagest*'s mathematical models of planetary motions with physical realities by assuming solid orbs instead of imaginary circles and spheres[127]. This atti-

models in ps. Māshāʾallāh's *Liber de orbe*," *Suhayl*, vol. 14 (2015), p. 89-114.

[124] Mimura, "The Arabic original of (ps.) Māshāʾallah's Liber de orbe," p. 340.

[125] Sally P. Ragep, *Jaghmīnī's Mulakhkhaṣ*, p. 28; Saliba, "Astronomy and astrology in medieval Arabic thought;" Id., "Islamic astronomy in context: Attacks on astrology and the rise of the *hayʾa* tradition."

[126] An early example of this dichotomy is ᶜAbd al-Ğabbār al-Ḫaraqī's (d. 553/1158) *Muntaha al-idrāk fī taqāsīm al-aflāk* ("The ultimate perception in the divisions of the orbs") which is available in modern Arabic edition with Persian commentary in Abū Muḥammad ᶜAbd al-Jabbār al-Kharaqī and Hanif Ghalandari, *Muntahā al-idrāk fī taqāsīm al-aflāk (The utmost attainment on the divisions of the orbs): The first comprehensive* hayʾa *work on Ptolemaic cosmology* (Tehran: Miras-e Maktoob, 2020).

[127] For the authorship of this title, Roshdi Rashed argued that the book *On the configuration* which has come down to us, probably belongs to Muḥammad b. al-Hayṯam (fl. 11th century), a physician-philosopher, and is not a work by the mathematician and

tude is found more emphatically in Ḥasan b. al-Hayṭam's (d. 1040) *Al-šukūk ʿalā Baṭlamiyūs* ("Doubts about Ptolemy") but with different objectives. Ibn al-Hayṭam systematically criticized Ptolemaic theories in the *Almagest*, the *Planetary hypotheses*, and the *Optics*[128]. His criticisms greatly influenced subsequent works in the field and inspired a model for later astronomers who proposed planetary models different than those of Ptolemy.

3.1. Early definitions of ʿilm al-hayʾa

The definitions of *ʿilm al-hayʾa* in the early Islamicate encyclopedias of the sciences give us an outsider's view about the initial stages in the formation of the discipline. Ibn Sīnā's (d. 1037) classification and definition, were different from those contemporary to Siǧzī in the tenth century. In his *Fī aqsām al-ʿulūm al-ʿaqliyya* ("On divisions of the rational sciences") Ibn Sīnā divided sciences or "wisdoms" (sing. *ḥikma*) into two main branches of Theoretical (*naẓarī*) and Practical (*ʿamalī*). Theoretical Wisdom (*ḥikma al-naẓariyya*) itself was divide into three branches of Physical (*ṭabīʿī*), Mathematical, and Divine (or metaphysical, *ilāhī*) sciences. He then classified *ʿilm al-hayʾa* under mathematical sciences. It is noticeable that, although Ibn Sīnā classified *zīǧ*s and calendars as ancillaries to *ʿilm al-hayʾa*, his definition for *ʿilm al-hayʾa* includes only the kinematic aspects of the celestial realm such as the forms and motions of the celestial orbs and bodies, or their sizes and distances. Ibn Sīnā's definition lacks natural philosophical topics discussed in later *hayʾa* texts and excludes any discussions about the constitution of the sublunary realm and the earth, such as the mathematical geography which formed an integral part of most subsequent works on *hayʾa*[129].

Other types of astronomical activity such as making instruments or finding the direction of the *qibla* are totally absent in Ibn Sīnā's definition of *hayʾa*[130]. He classified the matters related to the constituents of the cosmos, including the motions and natures (sing. *ṭabīʿa*) of the celestial element and the four sublunary elements as one of the main

physicist Ḥasan b. al-Hayṭam (d. 1040) who authored the *Doubts against Ptolemy*. Cf. Ibn al-Haytham and Langermann, *Ibn al-Haytham's On the configuration of the world*; Roshdi Rashed, "*The configuration of the universe*: A book by al-Ḥasan b. al-Haytham?" *Revue d'histoire des sciences*, vol. 60, no. 1 (2007), p. 47-63.

[128] Ibn al-Hayṭam, *Al-šukūk ʿalā Baṭlamyūs*, ed. A. I. Sabra and Nabil Shehabi, 1971.

[129] See for example: Ragep, *Ṭūsī's Memoir*, p. 245-87; Sally P. Ragep, *Jaghmīnī's Mulakhkhaṣ*, p. 148-61.

[130] ʾAbū ʿAlī Ḥusayn b. ʿAbd Allāh Ibn Sīnā, *Tisʿa rasāʾil fī al-ḥikma wa-al-ṭabīʿīyyāt* (Cairo: Dār al-ʿArab, 1908), 111-12.

divisions of another category, Physical Wisdom, and introduced only the *De caelo* as a reference. He also excluded astrology from other theoretical sciences and classified it as one of the ancillary branches of Physical Wisdom[131]. It is not clear, however, where he put the configuration (*hayʾa*) of the Earth, the topics of climes and mathematical geography, but it is obvious that Ibn Sīnā's definition of *ʿilm al-hayʾa* does not encompass the whole discipline and variety of astronomical practices, and separates subjects later gathered under *ʿilm al-hayʾa*. In the classification of sciences contemporary to Siğzī the definition and scope of *ʿilm al-hayʾa* appear in a different way from Ibn Sīnā.

By contrast, In his *Iḥṣāʾ al-ʿulūm* ("Enumeration of sciences") al-Fārābī (d. 339/950) divided astronomy (*ʿilm al-nuğūm*, the science of the stars) into astrology and mathematical astronomy (*al-nuğūm al-taʿlīmī*). Mathematical astronomy covered the topics discussed in *hayʾa* books, both celestial and terrestrial topics, including the climes, inhabited regions, and the lengths of days and nights[132]. Al-Fārābī classified sciences into five major categories[133], one of which was the mathematical sciences (*ʿulūm al-taʿālīm*) itself divided into seven branches. For some of these seven branches he defined theoretical and practical subdivisions[134], something that Ibn Sīnā approached differently by applying an overall dichotomy of Theoretical and Practical at the beginning of his classification.

The Iḫwān al-Ṣafā, or Brethren of Purity (10th century, Basra), also dedicated *Epistle* 3 of the mathematical section of their encyclopedic work to astronomy, using the title *Fī asṭirunumīyā* ("On astronomy") which is the equivalent of the Greek term αστρονομία[135]. They divided astronomy into three branches of *ʿilm al-hayʾa*, making *zīğ*s and calendars, and astrology. They also defined solid orbs in their descriptions[136]. The Brethrens' definition for *ʿilm al-hayʾa* begins with *tarkīb al-aflāk* (the structure of the orbs) and then includes the number of celestial bodies, their sizes and distances, and their motions, but lacks the configu-

[131] Ibn Sīnā, 108-9.

[132] ʾAbū Naṣr Muḥammad b. Muḥammad al-Fārābī, *Iḥṣāʾ al-ʿulūm*, ed. ʿUthmān Amīn [reprinted in Fuat Sezgin, *Islamic philosophy*, vol. 10, Frankfurt am Main, 1999] (Cairo: Dār al-Fikr al-ʿArabī, 1949), p. 84-86.

[133] Ibid., p. 43.

[134] Ibid., p. 75, 79, 86.

[135] F. Jamil Ragep and Taro Mimura (eds.), *Epistles of the Brethren of Purity: On astronomia. An Arabic critical edition and English translation of epistle 3* (Oxford University Press; Institute of Ismaili Studies, 2015), p. 5.

[136] Ibid., p. 6-9.

ration of the Earth.

Another important source of this period concerning the definition of astronomy is the "Keys of sciences[137]" (*Mafātīḥ al-ᶜulūm*, composed after 977), a famous manual for secretaries and men of letters by ᵓAbū ᶜAbd Allāh al-Kātib al-Ḫwārizmī, which was dedicated to Abu al-Ḥasan ᶜUtbī the vizier of the Samanid ruler Nūḥ II (r. 976-997). The "Keys" is in two parts, one on Islamic and Arabic literature, and the other on non-Arabic (*ᶜağamī*) sciences, including philosophy, medicine, mathematical sciences, and alchemy. Section six of the second part is on astronomy (*ᶜilm al-nuğūm*) in four chapters: i) On the names of the stars and planets, ii) On the structure of the orbs and the configuration of the Earth, iii) On the principles of astrology, iv) On astronomical instruments. At the beginning of the first chapter al-Ḫwārizmī gave a short etymology of the Greek term for astronomy[138] (again *aṣṭirunumīyā*). He begins the second chapter with the definition of *ᶜilm al-hayᵓa* as the knowledge of the structure of the orbs (*tarkīb al-aflāk*) and their configuration and the configuration (*hayᵓa*) of the Earth[139].

Both the Iḫwān al-Ṣafā and al-Ḫwārizmī gave broad definitions of astronomy including astrology, but the Iḫwān al-Ṣafā did not include the matters related to the Earth in their definition of *ᶜilm al-hayᵓa*. Al-Ḫwārizmī divided the *ᶜilm al-hayᵓa* into two celestial and terrestrial parts, similar to al-Fārābī's approach, though al-Fārābī did not use the term *hayᵓa*. Also, the Iḫwān al-Ṣafā and al-Ḫwārizmī beside using the term *hayᵓa* in their definitions used the specific term *tarkīb al-aflāk* for the structure of the celestial realm, the same phrase Siğzī used for the title of his book.

3.1.1. Siğzī's definition of astronomy

Siğzī defined astronomy (*ᶜilm al-nuğūm*, lit. science of the stars) in the Compendium by making distinction between astrology and *ᶜilm al-hayᵓa* as sub-disciplines. In the introduction of the Compendium he defined astronomy (*ᶜilm al-nuğūm*) as a science in two main parts. First is the science of the configuration (*ᶜilm al-hayᵓa*) of the orbs or the structure of the orbs (*tarkīb al-aflāk*) and of heavenly bodies, their motions,

[137] Muḥammd b. Aḥmad b. Yūsuf al-Ḫwārizmī, *Mafātīḥ al-ᶜulūm*, ed. Gerlog van Vloten [reprinted in Fauat Sezgin, *Historiography and classification of science in Islam*, vol. 4, Frankfurt am Main, 2005] (Leiden, 1895), p. 2; Clifford Edmund Bosworth, "A pioneer Arabic encyclopedia of the sciences: al-Khwārizmā's Keys of the Sciences," *Isis*, vol. 54, no. 1 (March 1963), p. 97-111.

[138] Al-Ḫwārizmī, *Mafātīḥ*, p. 209-35.

[139] Ibid., p. 215.

sizes, and distances. Second is the science of obtaining foreknowledge about the creatures in the sublunary realm. By the second definition he obviously meant astrology. Then Siğzī continued to define both parts of astronomy, each into two parts. For the *ᶜilm al-hayʾa* he made the following division: first, knowledge about general celestial phenomena like the sphere encompassing all of the orbs, the two primary motions, the rising and setting of the zodiac signs, and the characteristics of the great celestial circles; second, knowledge about the orbs of the seven planets including their forms, their states of motion, and the characteristics of each planet with respect to its form, state, and magnitude[140]. The above definition of *ᶜilm al-hayʾa* is what Siğzī approached in the Structure. After providing necessary definitions of *hayʾa*, the subject matter of the second chapter of the Structure is stated as follows:

> Thus, now in this chapter we have intended the reckoning of the constructions of the celestial bodies and their distances and the amount of their sizes, and the mode of their movements and requirements of their motions, and what belongs to every single of them separate from one another, and illustrating them to be grasped by the sense of vision and by that to make easy what is difficult to be comprehended[141].

We should notice that Siğzī's definition of astronomy has a common feature with those of his contemporaries. Siğzī, Fārābī, the Iḫwān al-Ṣafā, and al-Ḫwārizmī all included astrology as one main division of the discipline of astronomy. But Siğzī clearly differs from Ibn Sīnā in classifying *ᶜilm al-hayʾa* and astronomy. Siğzī's outlook about the *ᶜilm a-hayʾa* more represents the general understanding of the discipline in the tenth century, which took it as a *branch* of the science of astronomy, but we need to consider previous works on the subject to better judge the place of the Structure in the formation of the discipline.

[140] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, f. 1v-2a:
علم النجوم ينقسم قسمين، أحدهما علم هيئة الأفلاك والأشخاص العالية وحالاتها من الحركات والأبعاد والمقادير والآخر علم تقدمة المعرفة بالكائنات في الأشخاص السفليّة. علم الهيئة تنقسم قسمين، أحدهما علم هيئة الكلّ أعني الكرة المحيطة بجميع الأفلاك المحدثة للأزمان وأحوالها بحركاتها على بقاع الأرض ومايلزم من حركاتها / وحركات الأبراج من أشكال الطلوع والغروب والحركتين الأوليين وخواصّ الدوائر العظام. والثاني هيئة أفلاك الكواكب السبعة وأشكالها وحالاتها من الحركات وخواصّ كلّ منها في شكله وحاله ومقداره.

[141] Al-Siğzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 3v:
وإما الآن فقد قصدنا في هذا الفصل إحصاء أشكال الأجرام العالية وأبعادها ومقادير أجرامها وكيفية نقلتها ولوازم حركاتها وما يخصّ كلّ شيء منها دون الآخر وتصويرها ليقع تحت حسّ البصر ويسهل بذلك ما يصعب الوقوف عليه.

4. SIĞZĪ AND FARĠĀNĪ

Prior to Siğzī we know a few Islamicate works on theoretical astronomy excluding astrological topics which if not quite belonging to the genre of *ʿilm al-hayʾa*, shared similarities with later works on the discipline[142]. Those are the *Tarkīb al-aflāk* of Yaʿqūb b. Ṭāriq (fl. late 8th century, Baghdad), the *Ǧawāmiʿ ʿilm al-nuǧūm wa-uṣūl al-ḥarakāt al-samāwīyya* ("The compendium of astronomy and the principles of the celestial motions") of ʾAbū al-ʿAbbās Aḥmad b. Muḥammad b. Kaṯīr al-Farġānī (9th century), and two works by Ṯābit b. Qurra[143] (ca. 830-901, Baghdad), *Tashīl al-Maǧisṭī* ("The Almagest simplified") and *Fī ḏikr al-aflāk* ("On discussing the orbs"). Other works have been reported bearing the same title as the Structure, but are not extant today[144].

Among all these books, including Siğzī's Structure, Farġānī's *Ǧawāmiʿ* is considerably longer and covers more topics. Farġānī used the term *hayʾa* several times in his book both for the configuration of the Earth and the orbs[145], but did not give any definition of the term nor did he make any demarcation of the subject as a discipline. Several features of the *Ǧawāmiʿ* also suggest that Farġānī intended to provide an epitome of the *Almagest* which was less complex and accessible to a wider audience. He gave clear and brief explanations for necessary topics along with providing numerical values which were mostly buried in long and discursive proofs in the *Almagest*. But a major difference between Farġānī and the other two authors is that he restricted himself to the *Almagest* and did not have access to the *Planetary hypotheses*. He frequently referred to Ptolemy and once in chapter twenty-six he mentioned the title *Almagest*[146]. There are some indications in the

[142] It is also worth making a comparison with *Liber de orbe* another work contemporary to Siğzī, which includes topic of *hayʾa*. However, for two reasons I postpone this comparison for a future study. First, I await a critical edition of the text, as promised by Mimura. Second, Dūnaš's book includes a fairly large amount of non-astronomical as well as non-Ptolemaic materials.

[143] Nine works of Ṯābit's in astronomy are available in modern editions with French translation in Thabit b. Qurra and Régis Morelon, *Thabit ibn Qurra: Œuvres d'astronomie* (Paris: Les Belles Lettres, 1987).

[144] Al-Nadīm (d. 990) catalogued a book with the title *Kitāb tarkīb al-aflāk* by ʿUṭārid b. Muḥammad. Muḥammad b. Isḥāq al-Nadīm, *Kitāb al-fihrist lil-Nadīm*, ed. Reza Taǧaddod (Tehran, 1973), p. 336; *The Fihrist of al-Nadīm: A tenth-century survey of Muslim culture*, trans. Bayard Dodge (Columbia University Press, 1970), p. 658.

[145] ʾAbū al-ʿAbbās Aḥmad b. Muḥammad b. Kaṯīr al-Farġānī, *Elementa astronomica*, ed. and trans. Jacob Golius (Amsterdam, 1669), p. 8, 15, 45, 49.

[146] Ibid., p. 74, 97.

Table 2: The volumes of the planets recorded in the Structure

Ratio of the volumes	Ptolemy[a]	Farġānī[b]	Siğzī
Sun / Earth	$166\frac{1}{3}$	166	166
Jupiter / Earth	$82\frac{1}{2} + \frac{1}{4} + \frac{1}{20}$	95	95
Venus / Earth	$\frac{1}{44}$	$\frac{1}{37}$	$\frac{1}{37}$ [c]

[a] Bernard R. Goldstein, "The Arabic version of Ptolemy's Planetary hypotheses," *Transactions of the American Philosophical Society*, vol. 57, no. 4 (1967), p. 9.

[b] Al-Farġānī, *Elementa astronomica*, p. 83-84.

[c] The MS Leiden Or. 2541 reads $\frac{1}{27}$ (f. 12r) which could be a scribal error, but in the Compendium (f. 6v) Siğzī recorded the same value as $\frac{1}{37}$. Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Tehran, Parliament Library, MS 6459, f. 8r.

Ğawāmiᶜ that corroborate this idea. Once at the beginning of chapters 21 where Farġānī discussed the sizes of the planets, he wrote that "Ptolemy indeed mentioned in his book [the *Almagest*] only the values for the distances of the Sun and the Moon and we did not find him mentioning the distances for other planets[147]." Another time, at the beginning of chapter 22, giving the diameters and the volumes of the planets, he explained that "Ptolemy again mentioned only the volumes of the Sun and the Moon and did not mention the volumes of other planets[148]." In fact, Ptolemy provided all of these in his other book, the *Planetary hypotheses*, but obviously Farġānī either had not seen that book or restricted himself to making all references only to the *Almagest*, a further indication that the *Ğawāmiᶜ* was intended to be an epitome of the *Almagest*. In contrast, in the "Almagest simplified" Ṯābit recorded the same values for the planetary sizes and distances given in the *Planetary hypotheses*, except for the size of Venus which he gave as $\frac{1}{37}$ of the volume of the earth[149], the same as Farġānī, while Ptolemy recorded that as $\frac{1}{44}$ (table 2).

The amount of numerical values given in the Structure, as well as in the *Ğawāmiᶜ*, is something uncommon in later works of *hayʾa* which were generally more descriptive about the structure of the universe and less quantitative. Most of the values in the Structure appear in chapters

[147] Al-Farġānī, *Elementa astronomica*, p. 80.

[148] Ibid., p. 83.

[149] Thabit b. Qurra and Morelon, *Thabit ibn Qurra: Œuvres d'astronomie*, Arabic, p. 13-15.

two and three, the former dealing with the structure of the earth and the celestial orbs, and the latter on the methods of drawing the orbs of each planet, which Siǧzī described as the whole purpose of the work (*iḏ huwa tamām al-ġaraḍ fī haḏā al-kitāb*[150]). Like Farġānī, Siǧzī also used the *Mumtaḥan* updated values, but occasionally recorded more precise values than Farġānī. For instance, for the obliquity of ecliptic Siǧzī gave the result of his own observations in Shiraz and compared it with the value calculated by Ḥabaš[151].

4.1. The size of the Earth

Another significant difference with earlier work like Farġani's *Ǧawāmiᶜ* appears in the values calculated for the size of the Earth. Siǧzī, adopting 1° of the celestial orb to be equivalent to $66\frac{1}{2}$ miles[152], recorded the circumference of the Earth as 180000 *stadii*, in accordance with Ptolemy[153], and as 24000 miles. Then he calculated the Earth's diameter as 7636 miles, which is simply $24000 \div 3\frac{1}{7}$. Siǧzī also mentioned that each *stadium* equals 400 cubits (*ḏirāᶜ*) and one mile is 3000 cubits. These latter values give us the equality of 1 mile = $7\frac{1}{2}$ *stadii*[154]. In contrast to Siǧzī's use of Ptolemaic values, Farġānī adopted updated ones measured during al-Maʾmūn's reign[155]. Table 3 compares these

[150] Al-Siǧzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 13v.

[151] Ibid., f. 4v.

[152] This value in **L** was copied as $67\frac{1}{2}$ which considering the procedure Siǧzī explained for calculating the circumference should be $66\frac{1}{2}$, which is very close to $24000 \div 360 = 66\frac{2}{3}$.

[153] Goldstein, "The Arabic Version of Ptolemy's Planetary hypotheses," 7, 31; J. L. Berggren, Alexander Jones, and Ptolemy, *Ptolemy's Geography: An annotated translation of the theoretical chapters* (Princeton University Press, 2000), 110; Olaf Pedersen and Alexander Jones, *A Survey of the Almagest*, revised edition (Springer, 2011), p. 395.

[154] Nallino in his *Arabian astronomy* discussed in detail the difference between the Roman-Syriac mile and the Arabic mile. He explained that many Arabic authors used the value of $66\frac{2}{3}$ miles equivalent to 1° of the Equator and the circumference of the Earth as 24000 miles in accordance respectively with the Ptolemaic values of 500 *stadii* and 180000 *stadii*. But, 24000 (Arabic) miles equals 47352 km, while 180000 *stadii* equals 38340 km. The reason for this discrepancy, according to Nallino, was that Greek and Syriac authors of the first centuries in the Eastern Mediterranean region calculated 1 mile as $7\frac{1}{2}$ *stadii* and considered the circumference of the Earth based on Ptolemy's value as $180000 \div 7\frac{1}{2} = 24000$ miles and $500 \div 7\frac{1}{2} = 66\frac{2}{3}$ miles equivalent to 1° of the Equator. These numbers later found their way into Arabic texts and were adopted as Ptolemaic values. Carlo Alfonso Nallino, *ᶜIlm al-falak: Taʾrīḫuh ᶜind al-ᶜarab fī qurūn al-wusṭā*, 2nd ed. (Institute for the History of Arabic-Islamic Science at the Johann Wolfgang Goethe University, 1993), p. 278-79.

Table 3: numerical values of the size of the Earth in the Structure and the *Ğawāmiᶜ*

	Siğzī's Structure	Farġānī's *Ğawāmiᶜ*
1 celestial degree	$66\frac{1}{2}$ miles[a]	$56\frac{1}{2}$ miles
Earth's circumference	24000 miles	20400 miles
Earth's circumference	180,000 *stadii*	–
Earth's diameter	7636 miles	6500 miles
1 mile	3000 cubits	4000 black cubits
1 *stadii*	400 cubits	–

[a] The exact Ptolemaic value is $66\frac{2}{3}$.

values.

In the Compendium, however, Siğzī gave values totally at variance with those given in the Structure. Right before providing a table for the sizes and distances of the planets, he gave the following values for the Earth and attributed them to *Mumtaḥan* measurements[156]:

$$\text{Earth's circumference} = 6800 \text{ parasangs}$$
$$1 \text{ parasang} = 12000 \text{ black cubits}$$
$$\text{Earth's diameter} = 2164 \text{ parasangs}$$
$$1 \text{ cubit} = 25 + \frac{2}{3} \text{ digits}$$
$$1 \text{ digit} = 6 \text{ barleycorns}$$

If we assume one mile to be 4000 black cubits (or 1 parasang = 3 miles) according to what Farġānī recorded from the al-Maʾmūn measurements, we will get the same values as Farġānī's with only a slight difference for the diameter of the Earth, which is due to the approximation Farġānī adopted in his calculation. The Earth's circumference is 20400 miles, exactly the same as Farġānī, while the Earth's diameter becomes 6492 miles, a minor difference. What I can suggest at present is that in the Structure if Siğzī had lifted the numbers from Farġānī, he should have done the same for the sizes of the Earth too, but his use of Ptolemaic values for the Earth indicates that he obtained them from other sources.

[155] Al-Farġānī, *Elementa astronomica*, 30. Ḥabaš recorded that as 56 miles. Y. Tzvi Langermann, "The Book of bodies and distances of Ḥabaš al-Ḥāsib," *Centaurus*, vol. 28, no. 2 (1985), p. 111, 113.

[156] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Tehran, Parliament Library, MS 6459, f. 5v.

Siğzī's central approach in the Structure (*Tarkīb al-aflāk*), as its title also indicates, was to make an account of the configuration of the celestial bodies and motions, while not totally ignoring terrestrial matters. Besides giving the size of the Earth, required for calculating the planetary sizes and distances, Siğzī provided several numerical values for the boundaries and hours of the seven inhabited climes and presented them on a diagram[157]. Apart from the organization of the Structure and its contents, none of the above features can be regarded as a fundamental departure from the texts on *hayʾa* prior to Siğzī.

4.2. The ninth orb

A significant innovation in the Structure is the introduction of the ninth orb, which Siğzī called *al-falak al-mustaqīm* (Right Orb), *falak al-kull* (Total Orb) or *al-falak al-muḥīṭ* (Encompassing Orb) in Arabic[158] and *gūy-e rāst* (Right Ball) in Persian[159]. Siğzī defined it as the largest sphere (*kura*) whose center is the center of the Earth, encompassing all the stars and their orbs, and revolving in uniform rotations from east to west. Siğzī added that, "… its two poles are known to be the poles of the [first] motion and its equator is the equinoctial circle, since when the Sun in the course of its motion reaches that [its equator], day and night become equal[160]." Also in the second chapter, when discussing the order and motions of the planets' orbs he wrote that, "The Right Orb moves around the orbs of the planets from east to west in uniform rotations but the planets move in their orbs from west to east[161]." The use of the term "Right Orb" (*orbis rectus* in Latin)[162] was probably to make a distinction

[157] Al-Siğzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 4v-5r.

[158] Ibid., f. 2r.

[159] Ibid., f. 3v.

[160] Ibid., f. 2r:

الفلك المستقيم وفلك الكلّ والفلك المحيط أسماء الكرة العظمى التي مركزها مركز الأرض المحيط بجميع الكواكب وأفلاكها الدائرة بأدوار متساوية الأقدار من المشرق إلى المغرب ويُعرف قطباه بقطبي الحركة وتُسمّى منطقته دائرة معدّل النهار من أجل أنّ الشمس إذا بلغتها في مسيرها إستوى الليل و النهار.

[161] Ibid., f. 3v-4r:

ويُدير الفلك المستقيم / أُكَر الكواكب من المشرق إلى المغرب دوراً متساوياً، وأما الكواكب فإنّها تتحرّك على أفلاكها من المغرب إلى المشرق ولكلّ كوكب من الكواكب السبعة فلك خارج مركزه عن مركز الأرض يُسمّى الفلك الخارج المركز وفلك الأوج و فلك آخر يُسمّى الفلك الممثَّل بفلك البروج وذلك لأنّ سطحه سطح فلك البروج ومركزه مركز فلك البروج.

[162] Shlomo Sela, "Maimonides and Māshāʾallāh on the ninth orb of the signs and astrology," *Aleph*, vol. 12, no. 1 (2012), p. 113.

with the Ecliptic which was oblique in respect to the Right orb.

This was not the first use of the ninth orb by Siğzī. In his introductory work on astrology the *Al-madḫal*, also cited in the Structure and dedicated to ʾAbū Ğaᶜfar Bānūye, he had introduced the Right Orb while giving the order and distance of the total orbs[163]. Another example was the Compendium, where Siğzī dedicated a brief section to *ᶜilm al-hayʾa* at the beginning. In the Compendium, after discussing the orbs of upper planets, he added that, "All fixed stars are altogether within one orb encompassing all [other] orbs and its center is the center of the Ecliptic orb, [and it moves] toward the order of the signs in every 100 years 1° according to Ptolemy. And the orbs of the stars [planets] all move in every 100 years 1° in the same direction[164]," a motion known as the precession of the equinoxes. In the Structure Siğzī also attributed this slow eastward motion to the orbs of all planets.

In Siğzī's cosmology the ninth orb causes the daily motion of celestial bodies from east to west, i. e. the first primary motion, and the orb of the fixed stars together with the orbs of other planets move slowly from west to east. The definition for the orb of the fixed stars confirms this, as Siğzī gave it in the first chapter of the Structure: "The orb of the fixed stars, it is a sphere whose center is the center of the universe. All fixed stars move on its surface in parallel circles very slowly from west to east on the axis of the Ecliptic, and it is called the starred sphere[165]." This configuration of the universe is, however, in sharp contrast with Farġānī. Farġānī's universe, like Ptolemy's, ends with the eighth orb, the orb of the fixed stars or the Ecliptic orb[166]. Farġānī introduced the two primary motions. Although he did not indicate what mover causes the daily east-to-west motion of the planets, he did specify that the planets move eastward within their eccentric orbs[167]. He also introduced another motion common among all eight orbs. At the beginning of chapter thirteen Farġānī reported from Ptolemy that the sphere of the fixed stars moves from west to east and moves the spheres of the seven stars (planets) with itself around the poles of the Ecliptic orb 1° in every 100 years[168].

[163] Al-Siğzī, "Al-madḫal," Central Library of the University of Tehran, MS 8609, f. 2r.

[164] Al-Siğzī, "Al-ğāmiᶜ al-šāhī," Central Library of the University of Tehran, MS 6276, f. 5v.

[165] Al-Siğzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 2v:
فلك الكواكب الثابتة هي كرة مركزها مركز العالم يسير في بسيطها جميع الكواكب الثابتة في دوائر متوازية من المغرب إلى المشرق على محور فلك البروج و يُسمّى الكرة المكوكبة.

[166] Al-Farġānī, *Elementa astronomica*, p. 45-46.

[167] Ibid., p. 15-16.

Following Ptolemy, Farġānī attributed the precession of equinoxes to the orb of the fixed stars[169]. Farġānī, in fact, attributed two motions in opposite directions at the same time and around different axes to the eighth orb but did not explain how it was possible according to the principles of Aristotelian physics. A way to eliminate this problem, as Siğzī did, was to add another orb to cause precession above the orb of the fixed stars, which also produces the daily risings and settings of the Sun and other celestial bodies. However, in the Structure Siğzī did not specify which orb was responsible for the precession of the equinoxes[170].

Another attempt at incorporating more than eight orbs into the model of the celestial universe was made by a contemporary to Siğzī, but in the western part of the Islamicate world. Before the discovery of its Arabic original, the *Liber de orbe* was assumed to be a Latin translation of a work attributed to Māšāʾallāh b. Aṯrī (Messahala, d. c. 815) the court astrologer of the ʿAbbāsid caliphs al-Manṣūr (r. 754-775) and al-Maʾmūn. But Taro Mimura, who has recently found two manuscript copies of the Arabic text, attributes the authorship to Dūnaš b. Tamīm (d. after 955) a disciple of the Jewish scholar Isaac Israeli (c. 855 – c. 955) at the Fatimid court[171]. Dūnaš, in his "On the configuration of the world," proposed a ten-orb structure of the cosmos, instead of the well-known nine-orb structure in later *hayʾa* works[172] as well as in Siğzī's Structure[173].

[168] Al-Farġānī, *Elementa astronomica*, p. 46.

[169] Claudius Ptolemy, *Ptolemy's Almagest*, trans. Gerald J. Toomer (Duckworth, 1984), p. 321; al-Farġānī, *Elementa astronomica*, 49-50, 60.

[170] Siğzī also does not discuss variation of the rate of precession, known as trepidation, which, according to medieval astronomy, may also cause the obliquity of the ecliptic to change. Siğzī's use of the ninth orb in the Structure was different therefore from the function Ṯābit defined in his model for trepidation. Olaf Pedersen, *Early physics and astronomy: A historical introduction*, revised edition (Cambridge University Press, 1993), p. 161-63; F. Jamil Ragep, "Al-Baṭṭānī, cosmology, and the early history of trepidation in Islam," in *From Baghdad to Barcelona: Studies in the Islamic exact sciences in honour of Prof. Juan Vernet = De Baghdad a Barcelona: Estudios sobre historia de las ciencias exactas en el mundo Islámico en honor del Prof. Juan Vernet*, ed. Josep Casulleras and Julio Samsó (Barcelona: Instituto Millas Vallicrosa de Historia de la Ciencia Arabe, 1996), p. 267-98; James Evans, *The history and practice of ancient astronomy* (Oxford University Press, 1998), p. 274-77; Thabit b. Qurra and Morelon, *Thabit ibn Qurra: Œuvres d'astronomie*, p. 26-67.

[171] Mimura, "The Arabic original of (ps.) Māshāʾallah's Liber de orbe;" Id., "A glimpse of non-Ptolemaic astronomy in early *hayʾa* work: Planetary models in ps. Māshāʾallāh's *Liber de orbe*."

[172] Cf. Ibn al-Haytham and Langermann, *Ibn al-Haytham's On the configuration of the world*, Arabic text, p. 11; Ragep, *Ṭūsī's Memoir*, vol. 1, p. 109-111.

[173] Mimura, "The Arabic original of (ps.) Māshāʾallah's Liber de orbe," p. 338. For an investigation of the later use of Dūnaš's ten-orb cosmology (pseudo Māšāʾallāh) in

Prior to these a work by Muḥammad b. Mūsā b. Šākir, quoted in Quṭb al-Dīn Šīrāzī's (d. 1311) *Faᶜalta fa-lā talum* ("You committed so do not blame" i. e. You made a mistake so do not criticize other people) argues against the existence of the ninth orb by several geometrical proofs[174].

The first chapter of the Structure, giving definitions for basic concepts, is also another distinct feature of the text. Farġānī dealt with definitions wherever the context required and did not devote a chapter to them, but Ṯābit gave a few at the beginning of his "Almagest simplified[175]." The definition of "orb" in the Structure, besides Siğzī's use of the Right Orb, gives us his overall picture of the cosmos. Siğzī used the terms orb (*falak*) and sphere (*kura*) interchangeably, as Farġānī did in the *Ǧawāmiᶜ*, but gave separate definitions for each. The first chapter of the Structure begins with the definition of orb (*falak*) as a noble (*šarīf*) round circular body (*ğirm*) circumscribing the whole world. Siğzī added that this definition is based on what is needed in this science while the ancients might have proposed other definitions as well. This is followed by a definition for "sphere" (*kura*) as a circular body (*ğirm*) including a point inside it from which all produced lines to its surface are equal. Definitions for other types of orbs, like the eccentric, par-ecliptic, and epicycle were also given. In chapter two, while discussing the order of the planets, Siğzī explained the orbs of each planet as God's creations:

> Thus we say indeed God, be He blessed and elevated, made for each star of the seven wandering stars (*al-kawākib al-sayyāra*, i. e. the planets) arranged (*murattab*) orbs, one above another, and put all other fixed stars in a single sphere, and assumed for each pair of the wandering stars that once the lower ascends to the limit of its ascension and the upper descends to the limit of its descension, the body of one reaches the body of the other. Thus, Saturn in its ascension reaches the orb of the fixed stars and the Moon at the limit of its descension reaches the orb of Fire[176].

Although Siğzī's definition of orb (*falak*) is different from those of

Hebrew texts see: Sela, "Maimonides and Māshāʾallāh on the ninth orb of the signs and astrology."

[174] George Saliba, "Early Arabic critique of Ptolemaic cosmology: A ninth-century text on the motion of the celestial spheres," *Journal for the history of astronomy*, vol. 25, no. 2 (1994), p. 115-41.

[175] Thabit b. Qurra and Morelon, *Thabit ibn Qurra: Œuvres d'astronomie*, Arabic, p. 3-9.

[176] Al-Siğzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 3v:
فنقول إنّ الله تبارك وتعالى جعل لكلّ كوكب من الكواكب السبعة السيّارة أفلاك مرتّباً بعضها فوق بعض وجعل ساير الكواكب الثابتة في كرة واحدة وقدّر لكلّ كوكبين من الكواكب السيّارة أنّه إذا أصعد الأسفل منهما في غاية صعوده وهبط الأعلى منهما في غاية هبوطه يبلغ جرم أحدهما جرم الآخر. فزحل يبلغ في صعوده فلك الكواكب الثابتة والقمر يبلغ في غاية هبوطه فلك النار.

sphere and circle, it is not clear enough to decide if he believed in orbs as physical bodies having thickness or he simply dealt with spheres and circles. The copies of the Structure all depicted planetary diagrams by circles instead of physical orbs, in contrast to a common method in later *hayʾa* works for showing the physical structure of the universe[177], and Siǧzī's instructions for drawing the planetary models in the third chapter totally rely on circles. In the Compendium too, Siǧzī applied orbs in planetary models as if they were circles or spheres, and never assumed orbs having thickness bounded by two parallel spherical surfaces. The definition of circuit (*madār*) in the Structure is another example that shows that he imagined orbs as spherical bodies. He defined circuit as any given circle on the orb parallel to the equator of the orb and passing through a given point on it[178]. The physical nature of orb in Siǧzī's thought is more apparent when he defines the ninth orb as a sphere moving the orbs of other planets in their daily rising and settings, even if he assumed an action in distance for transmitting motion from an upper orb to a lower one. What we observe in his writings about planetary models and motions, both in the Structure and the Compendium, is that he dealt with physical spheres and circles instead of circular or spherical shells with thickness. Moreover, for Siǧzī, orbs like the eccentric, epicycle, and deferent, are places which planets travels through, not bodies that move planets by their motions.

5. CONCLUSION

Among the many dates in Siǧzī's works, there are two significant types of evidence which allow us to determine his period of activity and life. Those are his dedications of scientific books to rulers, and the historical reports he recorded in the "Royal compendium." Siǧzī wrote five works in astrology and a short treatise in mathematics for ʾAbū Ǧaʿfar Bānūye who ruled over Sīstān during 311-351 / 923-962. The Buyid emir ʿAḍud al-Dawla (r. 338-372 / 949-983) is the last known person to whom Siǧzī dedicated a work in astrology and the "Structure of the orbs" in *ʿilm al-hayʾa*, although the Compendium completed much later was also written for a courtier but it does not specify any name. Siǧzī served

[177] Ṭūsī believed that using circles is enough for understanding the models but for understanding "the principles of the motions" one needs to consider physical orbs. See: Ragep, *Ṭūsī's Memoir*, vol. 1, p. 141.

[178] Al-Siǧzī, "Tarkīb al-aflāk," MS Leiden Or. 2541, f. 2r:
المدار هو أيّ دائرة فُرضت في الفلك موازية لمنطقته لازمة لنقطة معلومة فُرضت لها.

ᶜAḍud al-Dawla even more than this. He collaborated in the observations commissioned by the emir and conducted by ᶜAbd al-Raḥmān al-Sūfī in Shiraz in 359/969-970. Siğzī also made several astrolabes for ᶜAḍud al-Dawla. We still do not have any record of his date of birth or his death in the sources but based on all the evidence presented above, his dedications to ʾAbū Ğaᶜfar Bānūye and the reports he gave about his travels in the Compendium and other mathematical works, we can conclude that Siğzī was active during 332-393 / 943-1003.

A review of his works tells us that Siğzī was more occupied with astrology in the first half of his life and began to write his significant and complicated works in mathematics in the second half of his life, after the death of his first patron ʾAbū Ğaᶜfar Bānūye. His early works in astrology mainly comment on and summarize his predecessors like ʾAbū Maᶜšar, but his major original composition in astrology was the "Royal compendium" completed in 1003, which includes the latest evidence for Siğzī's scientific activity. The number of Siğzī's compositions in mathematics exceeds his other works and certifies his authority as a highly skilled mathematician, but according to his own reports and those by contemporary and later scholars he was also known as a proficient astrologer as well as an instrument maker.

The "Structure of the orbs" (the *Tarkīb al-aflāk*) was a pioneering work in theoretical astronomy and particularly on the *ᶜilm al-hayʾa* from the tenth century. Siğzī's approach in the Structure and the Compendium shows that by his time *ᶜilm al-hayʾa* was a recognized genre in astronomical writings, but indeed a branch of, and not equivalent to, the whole discipline and practice of the science of the stars (*ᶜilm al-nuğūm*), that is, astronomy. The Structure is a book in the Ptolemaic astronomical tradition but compared to other books of *hayʾa* has some unique features of its own. Siğzī begins the book with defining necessary concepts in astronomy, then explains the structure of the earth and the cosmos in several diagrams in as simple a way as possible, and finally provides methods for drawing the orbs of each planet to scale. The method of the third chapter on drawing the diagrams is unique to the Structure and not found in any other work of the field, although the general topic of the dimensions of the orbs became canonical in later *hayʾa*. The introduction of the ninth orb by Siğzī was an outstanding difference with Ptolemy and Farġānī's cosmology, and as far as we know the first appearance of this idea. Siğzī assumed the ninth orb to be the encompassing orb moving the orbs of planets in a daily rising and setting motion. The configuration of the universe in nine orbs, became

a standard scheme in later *hayʾa* works. The Structure does not cover all topics of later *hayʾa*, like the natural philosophical or cosmological discussion found in subsequent works, but the title of the book, *Tarkīb al-aflāk*, clearly indicates that Siğzī's major concern was the configuration of the celestial realm and not the sublunary universe. All these characteristics suggest that we can categorize the "Structure of the orbs" as an early form of *ʿilm al-hayʾa* compositions in the Islamicate astronomy and the earliest known work containing only topics in the genre.

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