Dissertation Abstract – Joseph Leichter

This dissertation in under contract to be published as *The Astronomical Works of Gregory Chioniades Volume II* in the series *Corpus des astronomes byzantins* J. C. Gieben, Amsterdam.

In 1295, a priest in Constantinople named Gregory Chioniades became interested in Islamic science and astronomy. He set out for the Mongol (Ilkhani) capital of Tabrīz in modern Azerbaijan to pursue his studies. There he met and studied with Shams al-Bukhārī, who was familiar with the works of the great astronomer, Naṣīr al-Dīn aṭ-Ṭūsī. (Ṭūsī 's own work was based on that of the Hellenistic astronomer, Ptolemy, and would eventually influence even Copernicus). While in Tabrīz, Chioniades began to translate from Arabic into Greek the *az-Zīj as-Sanjarī* of al-Khāzinī – a mathematical and astronomical work also based on the principles of Hellenistic astronomy. He completed this translation in Constantinople a few years later, where he was apparently accused of heterodoxy because of his travels and studies. Nonetheless, in about 1305 he was elevated to the position of Bishop of Tabrīz.

My dissertation is an edition and translation of this *az-Zīj as-Sanjarī* of Gregory Chioniades. The text and translation are about two hundred pages each. It also includes a two hundred page Greek to Arabic glossary of the technical terms used in the text. The text was edited from the three surviving Greek manuscripts and the glossary was made by a comparison of the edited Greek to the two surviving Arabic manuscripts of the *az-Zīj as-Sanjarī*.

This text helps to document the re-introduction into the West of Hellenistic science through Arabic intermediaries.

I am including a short introduction to the text, which explains in greater detail the characters involved and the texts used, a sample of the edited Greek text, and a sample of the translation. The sample deals with the use of tables to calculate some basic trigonometric functions

PART I

Introduction

Introduction

The Characters

Gregory Chioniades

The main sources for the biography of Gregory Chioniades — bishop, physician, and translator of Persian and Arabic texts — are the prologue of Chrysococces's *Persian Syntaxis*, 15 or so letters written by Chioniades himself, a short text entitled the *Profession of Faith*[1] and the Greek texts of *az-Zīj as-Sanjarī*, *az-Zīj al-^{c}Alā'ī* and the *Zīj-i ĪlKhānī* . [2]

In his prologue to his *Persian Syntaxis*, written circa 1347[3], Chrysococces begins by reminding his bother, John, that he had wanted to learn this *Persian Syntaxis* for a long time. He then states that he acquired a teacher named Manuel in the city of Trebizond. Manuel explained to Chrysococces 'how this Syntaxis came from Persia and who translated it into Greek'. There was, he explained, a certain Chioniades who, after growing up in Constantinople, fell in love with the sciences. Since he heard that unless he travelled to Persia he would never satify his desire, he set out

[1] See Westerink [13] for a complete discussion of the sources, as well as for the text of the *Profession of Faith*.

[2] *az-Zīj al-^{c}Alā'ī* has been edited and translator by Pingree [7]. *Zīj-i ĪlKhānī* is lost, but was th basis for Chrysococces' *Persian Syntaxis*.

[3] Pingree [6] p. 141, Westerink [13] p. 234

to go there. After this Chioniades passed through Trebizond,

> ...in a short while he was taught by the Persians, having both consorted with the King, and met with consideration from him. Then he desired to study astronomical matters, but found that they were not taught. For it was the rule with the Persians, that all subjects were available to those who wished to study, except astronomy, which was for Persians only. He searched for the cause, which was that a certain ancient opinion prevailed among them, concerning the mathematical sciences, namely, that their king will be overthrown by the Romans, after consulting the practice of astronomy, whose foundation would first be taken from the Persians. He was at a loss as to how he might come to share this wonderful thing. In spite of being wearied, and having much served the Persian king, he had scarcely achieved his objective; when, by Royal command, the teachers were gathered. Soon Chioniades shone in Persia, and was thought worthy of the King's honor. Having gathered many treasures, and organized many subordinates, he again reached Trebizond, with his many books on the subject of astronomy. He translated these by his own lights, making a noteworthy effort. There are in fact other books of the Persian Syntaxis which he translated, those having certain examples with the years systematically at the beginning. However, he handed on the Syntaxis alone, the best and most accurate of all, as our teacher said, who appeared to be telling the truth. He translated seperately the commentary, which was taken from the Persians by word of mouth alone. In this way, the Syntaxis, called the Handy, was produced.[4].

From this we learn among other things that Chioniades' work forms the basis for the *Persian Syntaxis* of Chrysococces and that Chioniades went through Trebizond on his way to study astronomy in an unnamed Persian city. It is clear from the letters of Chioniades, however, that the city to which he travelled was the Mongol capital, Tabrīz.

The letters[5] of Chioniades which are important for a reconstruction of his life are

[4]The translation of this paragraph is from Mercier [4] pp. 35-36

[5] These are collected in I. V. Papdopoulos, Γρηγορίου Χιονιάδου τοῦ ἀστρονόμου Ἐπιστολαί, Ἐπιστημονικὴ Ἐπετηρὶς τῆς Φιλοσοφικῆς Σχολῆς τοῦ Πανεπιστημίου Θεσσαλονικῆς, I (1927), pp. 151-205.

summarized in Westerink as follows:[6]

- Letter 4. This was written in Constantinople to Constantine Lucites. It states that thanks to the warm reccommendations of Chioniades, many students from Constantinople were able to go to Trebizond to follow the courses of Lucites.
- Letter 5. This was written in Constantinople to the emperor Alexis II (1297 — 1339) of Trebizond. In this letter Chioniades states that the emperor of Constantinople (Andronicus II Palaeologus 1282 — 1328) and the Synod had made him archbishop of Tabrīz, and so he was asking for permission to cross the territory of Trebizond on the way to his diocese. He promises to pay back the emperor in services.
- Letter 6. This was also sent to to the emperor Alexis II (1297 — 1339) of Trebizond. Chioniades received the requested permission.
- Letter 7. This was written to Lucites of Constantinople. In this letter Chioniades denies having calumnied or insulted his correspondant.
- Letter 8. This was sent to Lucites from Trebizond. Lucites has gone into campaign with the emperor. The date of the expedition is September 1301.
- Letter 9. This was written in Tabriz to the partriarch. A patriarchal letter has been read to the Christian people. The precarious position of Chioniades in the midst of the barbarians is described. He apologizes for not being able to do a canonic visit to the patriarch, citing his old age and the dangers of travel.
- Letter 10. The στρατηγικώτατος to whom Lucites will give the letter is undoubtedly the emperor himself. Alexis is on campaign, and he should come back quickly for the feast of the Martyrs (Eugene and his companions, 21 January).
- Letter 11. This is written to an archbishop. Chioniades excuses himself for not being able to travel because of his health and becasue of Lent.
- Letter 12. This is written to Lucites. Chioniades must make a demand that he finds embarassing. Westerink suggests that it might be a request for money.
- Letter 15. This was written to a certain John — ὁ γλυκὺς Ἰωάννης. This is perhaps the emperor John Glykus (before his patriarchate of 1315 -1319).

Another important biographical document is the *Profession of Faith*, Ὁμολογία τοῦ ἰατροσοφιστοῦ Χιονιάδου, dated to about 1305. After spending so many years among the Persians, the Chaldaeans and the Arabs, Chioniades had apparently been

[6] Westerink [13] pp. 235 - 236.

accused of heterodoxy and of astrological superstition, and wrote the *Profession* in defense of himself.[7] It is also possible that it was written as a result of Chioniades' nomination for the episcopate of Tabrīz, since it was in 1304 that the Mongolian Ilkhans, whose capital was Tabrīz, opted definitively for Islam.[8] The *Profession*, Westerink notes,[9] could have been a way for Chioniades to distance himself from that conversion.

The following is a summary of the *Profession*:[10]

> Submitting with filial piety to the direction of the patriarch, Chioniades wants to repeat publicly the profession of faith that he has already committed during a private interview with his patriarch. Some suspect, he says, that because of his long stay among the Arabs he has been polluted by their beliefs. If such a thought ever came to him, he should share the punishment of Judas, his body should be devoured by the animals and the birds of prey and the worm that never dies. He declares as anathema 1) those who believe that Moses and the prophets relied upon astrology for their predictions and miracles, 2) the fatalists and 3) those who regard Chaldaean theology as superior to that of Moses. If he has ever expressed any Jewish, or Ismaelite doctrine other than to expose its fallacies, his name should be erased from the book of life. He declares a curse against those who do not accept the seven Ecumenical councils.

Based on the evidence presented above, as well as on some other documents, Westerink provides the following tentative sketch of the life of Chioniades:

- 1240 or 1250 - Chioniades is born. (Letter 9, in which he speaks of himself as an old man, can probably be dated between 1310 and 1314. This would place his birth 65 to 75 years earlier according to Westerink.)
- 1294 - He begins the study of astronomy and of the Arabic and Persian languages, perhaps in Trebizond[11].

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[7] Westerink [13] p. 236. The *Profession of Faith* is reproduced in Greek *ibid,*. pp. 243 — 245

[8] Westerink [13] p. 240.

[9] *ibid.*

[10] Westerink [13] p. 242.

[11] See the discussion of some of Chioniades' early notes on the subjects on ff. 113-115 of Smith Western Add. in Pingree [7] pp. 18 ff.

- 1295 – 1297 - He studies in Tabrīz with Shams al-Bukhārī and does preliminary work on the *zījes*.[12]
- 1297 or 1299/1300 - He returns to Trebizond (He is already a priest at this time).
- 1301 -1302 - He is in Constantinople[13]
- 1305 - He is ordained a bishop (letter 5) and writes the *Profession of Faith.*
- 1310 - 1314 - He is again in Tabrīz (letter 9).
- After 1315 - He stepped down and lived as a monk. (Letter 11, in which Chioniades is referred to as a monk, might belong to this period)

al-Khāzinī

Abū Manṣur ᶜAbd al-Raḥman al-Khāzinī was the Greek slave of Shaykh al-ᶜAmīd al-Qāḍī Abū al-Ḥasan ᶜAlī ibn Muḥammad, al-Khāzin, who resided in Merv, the modern Mary in Turkmenistan[14]. al-Khāzinī's *floruit* is given as *ca.* 1115. After he was given an education in mathematics, the philosophical disciplines and geometry, he was employed by the Seljuk court as a mathematician, most likely at Merv. It was here that Sanjar ibn Malikshāh ruled and that al-Khāzinī composed *az-Zīj as-Sanjarī* in his honor.

al-Khāzinī's two other known works are the *Risāla fi' l-ālāt* (*Treatise on Instruments*) and *Kitāb mīzān al-ḥikma.*[15] The *Risāla* is found in codices 682 f.1 and 681, pp 1-32 of the library of the Sipahsālār Mosque in Teheran and has not yet been published.[16] It is a short work concerning several astronomical instruments,

[12]Here Westerink assumes Chioniades is the author of the Greek *az-Zīj as-Sanjarī*, *az-Zīj al-ᶜAlā'ī* and the *Zīj-i Īlkhānī* , an assumption which will be discussed shortly. See Pingree [7] p. 21 for the dating of these texts.

[13] Pingree [7] p. 22 notes that the tables of the various *zījes* were put in their final form by Chioniades in Constantinople.

[14]The following description of al-Khāzinī is adapted from Hall[3].

[15] See Hall [3]p. 338 ff. for a complete bibliography of these two works.

[16]See Sayili [10].

including the astrolabe. The *Kitāb* has been published as the *Kitāb mīzān al-ḥikma* (Hyderabad, Deccan, A.H.1359 [A.D. 1940-1941]) and as the *Mīzān al-ḥikma*, Fu'ād Jamīᶜān, ed. (Cairo, [1947]). This text deals with weights and the construction of balances.

Shams al-Bukhārī

Shams is described in full in Pingree [7], pp. 16 - 17. He was born 11 June 1245 in Bukhārā. His references to Naṣīr al-Dīn aṭ-Ṭūsī indicate that he may have had contact with the famous observatory at Marāgha[17]. Shams was also the author of several astronomical treatises, Greek translations of some of which have come down to us in the same manuscripts as Chioniades' work. These include *On the Genethlialogical Computation*, which concerns the horoscope of a certain Fakhr al-Dīn born in Tabrīz on 25 August 1268[18] and a treatise on the astrolabe dedicated to Andronicus Palaeologus (Andronicus II, Byzantine Emperor 1282 – 1328).[19] Shams al-Bukhārī was in Tabrīz in the 1290's, as is clear from example computations in *az-Zīj al-ᶜAlā'ī* .[20] It is also clear that he was Chioniades' teacher, since Chioniades himself mentions the "oral teaching" of Shams in the *Revised Canons* of *az-Zīj al-ᶜAlā'ī* — ἀπὸ φωνῆς τοῦ Σὰμψ Μπουχαρῆ,[21] as well as in the second appendix of *az-Zīj as-Sanjarī* — ἀπὸ φωνῆς τοῦ Σάμψ .

[17]Pingree [6] p. 143.

[18]Pingree [7] p. 16.

[19]Pingree [7] p. 17 notes that this is found in *v* ff. 237 – 245v, Vaticanus graecus 210, ff. 3-7v, and Marcianus graecus 309, ff. 154-160v. A large fragment is also found in Parisinus Coislin 338, ff. 259-261v, he states.

[20]Pingree [7] p. 17.

[21]Pingree[7] p. 306-307.

History of *az-Zīj as-Sanjarī*

The text of *az-Zīj as-Sanjarī* (*the Astronomical Handbook of Sanjar*) has had a complex history[22]. The *Zīj* was originally composed in Arabic in Iran by Abū Manṣur ᶜAbd al-Raḥman al-Khāzinī and dedicated to the Sulṭān, Sanjar ibn Malikshāh, who ruled from 1118 to 1157. This version exists, at least partially, in two incomplete manuscripts: Oriental 6669 of the British Library, dated by the scribe to 26 July 1223 A.D. and Arabo 761 of the Vatican Library. Each of these manuscripts of the *Zīj* has 13 chapters, or *maqālāt*, ten of which are devoted to the central astronomical material of the *Zīj* (though the London manuscript omits all of *maqāla* 10). There are also about 145 astronomical tables that belong to this version of the *Zīj* but neither of the two manuscripts contains all of them.

In 1131 AD an Arabic epitome of this first version of the *Zīj* was made by Khāzinī himself, and was named the *Wajīz*. This summary exist in two essentially complete manuscripts: number 859 in the Hamadiye Collection in the Suleymaniye Library in Istanbul, and number 682 in the Library of the Sipahsālār Mosque in Teheran. The date of copying of the former is given in the manuscript as between 8 December 1268 and 5 January 1269. The date of the copying of the latter is given as between 31 May and 29 June 1234. The *Wajīz* covers the same material as the 10 central *maqālāt* of the first version of the *Zīj* but in 12 *maqālāt*. As for the astronomical tables, the *Wajīz* contains only 45, of which 30 are related to material in the *Zīj*.

Gregory Chioniades translated this *Wajīz* into Greek in Tabrīz in the 1290's, with the help of his teacher, Shams al-Bukhārī[23]. There are three manuscripts of this version: Vaticanus Graecus 211, copied before 1308; Laurentianus 28, 17 Florence, copied in 1323; and Vaticanus Graecus 1058[24], copied in the middle 1400's.

[22]The following textual history of the *Zīj* is adapted from Pingree [9].

[23]Pingree[6]

[24]Vaticanus Graecus 1058 is clearly a direct copy of Vaticanus Graecus 211.

With the exception of a few passages, some clearly attributed to Shams al-Bukhārī, Chioniades' translation is a fairly faithful rendering of the Arabic of the *Wajīz*. There are forty-one astronomical tables in Chioniades' version, but they are preserved only in the two Vatican manuscripts. Thirty three of these tables are similar to tables in the *Wajīz*.

Nature of the Text

Authorship

Pingree [6, 7, 8] suggested that Chioniades was the author of the Greek of *az-Zīj al-ᶜAlā'ī* and *az-Zīj as-Sanjarī*. In short, he has argued, [25] we have the testimony of Chrysococces, who states that he is basing some of his work on a set of astronomical tables which were translated into Greek by Chioniades.[26] Some of these tables to which Chrysococces refers are found in the Greek version of *az-Zīj as-Sanjarī*. This Greek version was made in Tabrīz, which we know from his letters [27] that Chioniades visited. Pingree then concluded that it was likely that Chioniades was the author of these texts.

Mercier, however, has argued somewhat unconvincingly, that since some of the material in Chrysococces's work is taken from the *Zīj-i Īlkhānī* of Naṣīr al-Dīn aṭ-Ṭūsī, Chioniades cannot be the author of those two Greek *zijes*. Pingree[28] has pointed out that while some of Chrysococces's material is taken from Naṣīr al-Dīn aṭ-Ṭūsī's *Zij*, most of the material is in fact taken from *az-Zīj al-ᶜAlā'ī* and *az-Zīj as-Sanjarī*. In addition, Mercier's suggestion seems to ignore completely Chrysococces's own words as to the authorship of the source of his work.

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[25] The following argument summarizes Pingree [8] p. 436

[26] See page 3 of this introduction and following.

[27] See page 4 of this introduction and following.

[28] Pingree [8].

What is perhaps another indication that Chioniades was the author of *az-Zīj as-Sanjarī* is the way Muslims and the Islamic faith are described in that work. Time after time[29] they are referred to as the impious (οἱ ἀσεβεῖς.). Their daily prayers are referred to as 'an accursed cry'. The author calls down God's wrath on the city of Mecca. It could be the case that this was the way Muslims were usually refered to in Constantinople at that time. It could also be the case that the author was trying to distance himself from Islam. We must recall that in 1305 – about the time these *zījes* were put in their final form [30]– Chioniades was called upon to write the *Profession of Faith*, a work in which he refers to unbelievers as τῶν ἀπ' αἰῶνος ἀσεβῶν[31]. These disparaging remarks made in *az-Zīj as-Sanjarī* are perfectly consistent with an author who had been trying to defend himself against a possible charge of heterodoxy – the very position in which Chioniades found himself in in the early 1300's.

It also seems fairly clear that *az-Zīj al-^{c}Alā'ī* and *az-Zīj as-Sanjarī* are works of the same author. They have come down to us as a group in the manusrcripts. The authors of both mention Shams al-Bukhārī as a teacher.[32] Neugebauer has noted[33] that "this [mention of Shams al-Bukhārī in both *zījes*] shows that it is not accidental that the text and table of the *az-Zīj al-^{c}Alā'ī* are combined in the same manuscript with text and tables of the *az-Zīj as-Sanjarī*." Both *zījes* not only use the same technical terminology,[34] but also the same incorrect technical terminology. For example, in chapter forty-one of *az-Zīj al-^{c}Alā'ī* , the author writes περὶ τῆς

[29]See 1.5 of the text of *az-Zīj as-Sanjarī* for a few examples

[30]Pingree [7] p. 22.

[31]Mercier [4] p. 244 l.39

[32]See page 7 of this introduction.

[33]Neugebauer [5] p. 31 .

[34]See Neugebauer [5].

ἐκβολῆς τῆς τύχης[35] "on the extraction of the fortune", when he clearly means not *fortune* (τύχη), but *ascendant.*[36] This type of repeated egregious error would suggest that rather than being the work of a "school" of Greek scholars working in Tabrīz, these texts are the work of a single individual.

The Method of Translation

Unlike *az-Zīj al-ᶜAlā'ī* , which seems to have been composed by Chioniades in Greek via a Persian intermediary (i.e., Shams would orally translate Arabic into Persian, which would then be translated into Greek by Chioniades[37]), *az-Zīj as-Sanjarī* seems to have been composed directly from Arabic with the help of a small Arabic-Greek dictionary. That this was the method of translation seems clear from the fact that there are far fewer transliterations of Arabic technical terms in the text than in Chioniades' version of *az-Zīj al-ᶜAlā'ī* [38], and there are seemingly no Persian terms.[39] The size or rather complexity of the dictionary Chioniades used is perhaps best indicated by the fact that ἀρχή is used to translate such varied terms as اوّل, نقطة, مدخل,مفتتح, رأس and بدأ. This lack of transliterations of Arabic technical terms – transliterations which abound in *az-Zīj al-ᶜAlā'ī* — would also seem to indicate that *az-Zīj as-Sanjarī* was composed later than *az-Zīj al-ᶜAlā'ī* , during which time

[35]Pingree [7] p. 184.

[36]See page 11 of this introduction for a discussion of the (mis)use of τύχη for the term 'ascendant' in *az-Zīj as-Sanjarī*.

[37]See Pingree [7] p. 17.

[38]See Pingree [7] pp. 395 - 401. See also the glossary of the *az-Zīj as-Sanjarī*.

[39]The one notable exception is perhaps Chioniades' use of τόπος τῆς τύχης –*place of fortune*– for the Arabic term مطالع,*rising time*. طالع in Persian means *luck*, which may explain Chioniades' use of terminology involving the word τύχη. This, however, is a mere guess.

Chioniades had improved his Arabic![40]

Technical Commentary

Neugebauer [5] provides an extensive discussion of the technical terms and techniques used in Chioniades' *az-Zīj as-Sanjarī*. A full technical commentary, however, will be provided with the edition of the Arabic *Wajīz*.

Notes on the Present Text

The Edition of Chioniades' *az-Zīj as-Sanjarī*

The sigla for the edition of Chioniades' text of *az-Zīj as-Sanjarī* are as follows:

- V – Vaticanus Graecus 211, ff. 38-106, copied before 1308.
- v – Vaticanus Graecus 1058, ff. 273v-316, copied in the middle 1400's and a direct copy of V.
- L – Laurentianus 28, 17, Florence, ff. 81-167, copied in 1323.

A complete list of the other contents of these manuscripts is given in Pingree [7] pp 23 – 28. What follows is a partial list of the contents of the manuscripts:

—L—

- Ff. 1r - 74r. *The Persian Composition of Astronomy.*
- Ff. 74r - 79v. *On the Genethlialogical Computation.*
- Ff. 169r-178r. ᶜIlm al-hay'a text.
- Ff. 179r- 201r. *Revised Canons.*
- Ff. 201r- 223v Short astronomical texts based on Shams al-Bukhārī, *az-Zīj as-Sanjarī.*

[40] This is consistent with the dating for the two texts proposed by Pingree [7] p. 21 ff. on internal evidence.

—*V*—

- *Revised Canons.*
- Ff. 37r. Arabic-Greek glossary preceeding chpater 23 of *The Persian Composition.*
- Ff. 38r-106r. *az-Zīj as-Sanjarī.*
- Ff. 106v-115r. ^{c}Ilm al-hay'a text.
- Ff. 122r-159v. Tables of *az-Zīj as-Sanjarī.*
- Ff. 161v-234r. Tables of the *Persian Composition* (*az-Zīj al-^{c}Alā'ī*).

—*v*—

- Ff. 92r-118v. George Chrysococces's *Introduction to the Persian Composition.*
- Ff. 237r-245v. Shams al-Bukhārī's *On the Use of the Astrolabe.*
- Ff. 261-272v. *Revised Canons.*
- Ff. 273v-316r. *az-Zīj as-Sanjarī.*
- Ff. 316r-321r. ^{c}Ilm al-hay'a text.
- Ff. 332r-369v. Tables of *az-Zīj as-Sanjarī.*
- Ff. 370r-440v. Tables of *az-Zīj al-^{c}Alā'ī* .

The English Translation of Chioniades' *az-Zīj as-Sanjarī*

The works referred to in the translation are as follows:

- *A1* – 859 in the Hamadiye Collection in the Suleymaniye Library in Istanbul
- *A2*– 682 in the Library of the Sipahsālār Mosque in Teheran.
- *A* – a reading in the *Wajīz* where both A1 and A2 agree.
- *Biruni – Chronology of Ancient Nations.* See Albīrūnī [1]

- *Ginzel – Handbuch der mathematischen und technischen Chronologie.* See Ginzel [2]
- *Neugebauer* – "Studies in Byzantine Astronomical Terminology". See Neugebauer [5].

Greek - Arabic Glossary to Chioniades' *az-Zīj as-Sanjarī*

The glossary was made by comparison of the Greek of the edition of *az-Zīj as-Sanjarī* to the Arabic of the two manuscripts of the *Wajīz*.

Software

This text was typeset with various flavors of Donald Knuth's TEX, including emTEX teTEX and MiKTEX. ArabTEX and IbyGreek were employed for the critical edition, as well as a version of EDMAC modified to produce an *apparatus criticus* consistent with that of the first volume of this series. Perl and Java were used extensively, as was the macro package LaTEX. The text editor used was Emacs.

Chrysococces's Prologue to the *Persian Syntaxis*

Τοῦ σωφωτάτου ἰατροῦ κυρίου Γεωργίου τοῦ Χρυσοκόκκη ἐξήγησις εἰς τὴν σύνταξιν τῶν Περσῶν ἐκτεθεῖσα πρὸς τὸν αὐτοῦ ἀδελφὸν κυρὸν Ἰωάννην τὸν Χαρσανίτην

Πάλαι μου καὶ αὐτοῦ, ὡς οἶσθα ὦ φίλτατε Ἰωάννη, τὴν τοῦ Περσικοῦ τοῦδε προχείρου σπουδάζοντος μάθησιν, διδασκάλῳ χρωμένου τινὶ ἱερεῖ , ὧ ὄνομα Μανουήλ, πόλεως ὄντι τῆς Τραπεζοῦντος· καὶ αὐτὸς δέ μοι πολλάκις συνὼν καὶ τοῖς λεγομένοις ἡδόμενος καὶ πόρρω τῆς τούτων καταλήψεως εἶναι μὴ ἀνεχόμενος ἤψω μὲν τοῦ μαθήματος, ἐμοὶ δ' ἐπέτρεψας μεθοδικώτερον ὑποδειγματίσασθαι τὰ λεγόμενα· ἐμοῦ τὰς τούτων ἐφόδους ψιλὰς παρατιθέντος καὶ τῶν διδασκαλικῶν ἐκείνων φωνῶν ὡς οἷόν τε ὑπομιμνήσκοντος ἄκουε. Πρῶτον τοίνυν ἄξιον ἐπιμνησθῆναι τῶν ἐκείνου τινός, ὅπως ἐκ Περσίδος ἐκομίσθη αὕτη ἡ σύνταξις καὶ παρὰ τίνος εἰς τὴν ἑλλάδα μετηνέχθη γλῶτταν. ἔλεγε τοίνυν ἐκεῖνος ὅτι Χιονιάδης τις ἐν Κωνσταντινουπόλει τραφεὶς καὶ πάντων ἐν καταλήψει τῶν μαθημάτων γενόμενος εἰς ἔρωτα πεσὼν καὶ ἑτέρας μαθήσεως διαλέκτου, δι' ἧς σοφίαν πορίσαιτο καὶ ἰατρικὴν ἀκριβῶς ἐξασκήσειεν, ἐπειδὴ παρά τινων ἤκουσεν, ὡς εἰ μὴ εἰς Περσίδα ἀφίκοιτο, τοῦ ποθουμένου οὐ τεύξεται, παντῶν καταφρονήσας ᾗ τάχους εἶχε τῆς ὁδοῦ εἴχετο· εἰς Τραπεζοῦντα δ' ὡς ἐν παρόδῳ ἐλθὼν καὶ τῷ μεγάλῳ Κομνηνῷ ὁμιλήσας χρόνον σύχνον, εἶτα καὶ τὰ τοῦ πράγματος κοινωσάμενος μεγίστης ἠξιώθη κηδεμονίας· πολλὰ γὰρ παρ' ἐκείνου λαβὼν ἀναλώματα εἰς Περσίδα ἀφίκετο. ἐν ολίγῳ δὲ τὰ Περσῶν παιδευθεὶς καὶ τῷ τούτων βασιλεῖ ὁμιλήσας προμηθείας τε παρ' ἐκείνου τετυχηκώς, ἐπειδὴ τὸ τῆς ἀστρονομίας μανθάνειν ἐβούλετο μέν, οὐκ εἶχε δὲ τὸν διδάξοντα. (νόμος γάρ ἐν Περσίδι, πάντα μὲν τὰ μαθήματα τοῖς βουλομένοις ἐξεῖναι μανθάνειν, ἀστρονομίαν δὲ μόνοις τοῖς Πέρσαις, ὁ δὲ τὴν αἰτίαν ἐξετάσας καὶ μαθὼν δόξαν εἶναί τινα παλαιὰν ἐπικρατήσησαν παρ' αὐτοῖς, ὡς [φδαρήσεσθαι] τὴν ἐκείνων βασιλείαν ὑπὸ Ῥωμαίων τῇ τέχνῃ τῆς ἀστρονομίας χρωμένων, παρ' ἐκείνων πρότερον ταύτης λαβόντες ἀφορμάς, διηπορεῖτο πῶς ἂν τοῦ τοιούτου μετάσχοι καλοῦ). ὅμως πολλὰ μοχθήσας καὶ πολλὰ δουλεύσας τῷ βασιλεῖ Περσῶν μόλις τοῦ ποθουμένου τετύχηκε· προστάγματι γὰρ βασιλικῷ τοὺς διδασκάλους συναγαγὼν ἐν ὀλίγῳ μέγας ἐν Περσίδι Χιονιάδης ἐφαίνετο καὶ τιμῆς ἠξιοῦτο βασιλικῆς. χρῆματα δὲ πολλὰ συλλεξάμενος καὶ πολλοὺς ὑπηκόους κτησάμενος εἰς τὴν Τραπεζοῦντα πάλιν ἀφίκετο, πολλὰ βιβλία τοῦ τῆς ἀστρονομίας μαθήματος μεθ' ἑαυτοῦ· οἰκείᾳ δὲ γνώμῃ ταῦτα ἐξελληνίσας μνήμης ἄξιον ἔργον ἐποίησεν. εἰσὶ μὲν οὖν καὶ ἕτερα βιβλία τῆς συντάξεως τῶν Περσῶν, ἅπερ αὐτὸς ἐξελλήνισεν ὑποδείγματά τινα μεθόδικα ἐν ἀρχῇ ἔχοντα ἐποχῶν· ταύτην δὲ μόνην τὴν σύνταξιν, ἣν καὶ ὡς κρείττονα πασῶν καὶ ἀκριβέστεραν παρέδωκεν, ὡς ὁ ἡμῶν διδάσκαλος ἔλεγε καὶ ἀληθεύων ἐφαίνετο, χωρὶς ἑρμηνείας ἐξελλήνισεν, οὕτω ταύτην δεξάμενος ἐκ Περσῶν διὰ ζώσης μόνης ἑρμηνευομένην φωνῆς· οὕτως ἐκομίσθη αὕτη ἡ σύνταξις, ἣ καὶ πρόχειρος λέγεται.[41]

[41] Usener [12] pp. 356-357

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Joseph Leichter

Dissertation Sample

Chapter 2 of the *Zīj as-Sanjarī*

Edited Greek Text

| Μοῖρα δευτέρα. Περὶ τῆς καταλήψεως τῶν ψηφῶν, τῆς περισσείας, 282vv
τῆς τραχηλαίας, τοῦ τόξου, τῆς σαγίτας καὶ τοῦ σκιάσματος κατὰ πολὺ λυσιτελούντων τούτων εἰς τὴν τῆς Συντάξεως μετάχειρσιν. αὕτη ἡ μοῖρα εἰς τρία διαιρεῖται τμήματα.

Τμῆμα α΄ . Περὶ τῆς ὀρθώσεως τοῦ μέσου ψήφου τῶν $\overline{\beta}$ κανονίων.

Δεῖ εἰδέναι ὅτι οἷον καὶ ἔστι κανόνιον, ἐκεῖνος ὁ τεθεὶς ψῆφος κατ' ἀρχὰς τῶν κανονίων οἷον θύρα τίς ἐστιν εἰς τὸν ψῆφον ἐκεῖνον τοῦ κανονίου. ἐκεῖνος οὖν ὁ ψῆφος οἷος καὶ ἔστι μέσον τῶν | κανονίων | καὶ ὁ κατὰ τὴν ἀρχὴν f50vV, f101rL
τοῦ κανονίου, ἀεὶ ὀρθός ἐστιν εἰς τὴν περισσείαν, ἐκείνη δὲ ἡ περισσεία ἡ μέσον τῶν δύο κανονίων πᾶσα οὐδὲ συμβαίνει ὀρθή. ἐὰν οὖν ἡ μέσον τοῦ κανονίου αὕτη περισσεία ἐγράφη εἰς τὸ κανόνιον, καὶ τὰ ζῴδια ἀπὸ τῶν ἄνω κατέρχονται, ἡ περισσεία κατ' ἐναντίον ἐκείνου τοῦ ψήφου κρατεῖται. εἰ δὲ τὰ ζῴδια ἀπὸ τῶν κάτω ἀνέρχονται, ἡ περισσεία ἀπὸ τοῦ β΄ ψήφου κρατεῖται. εἰ δ' οὐκ ἐγράφη ἡ περισσεία ἐν τῷ κανονίῳ, γίνεται ζήτησις εἰς τὸν ψῆφον ἐκεῖνον δι' οὗ ἐγένετο εἰσέλευσις. ὁ ψῆφος γοῦν ὁ μετ' ἐκεῖνον τηρεῖται καὶ ὁ ἐλάττων ἀφαιρεῖται τοῦ πλείονος. εἴπερ ὁ β΄ πλείων, ἐκεῖνος ὁ ψῆφος λέγεται

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1 –3 τῆς περισσείας. . . μετάχειρσιν] τῶν κατὰ πόλυ λυσιτελούντων εἰς τὴν μετάχειρσιν τῆς συντάξεως ἢ τῆς περισσείας τῆς τραχηλαίας τοῦ τόξου τῆς σαγίτας καὶ τοῦ σκιάσματος L ‖ 5 πρῶτον v | περὶ τῆς ὀρθώσεως] ἡ ὄρθωσις L | ψήφου post κανονίων Vv ‖ 8 οἷος] ὁποῖος Vv | τῶν + μέσον τῶν V | ὁ^2] ὅτι Vv ‖ 10 $\overline{\beta}$ L | οὐδὲν codd. ‖ 11 τὰ κανόνια v ‖ 13 δευτέρου Vv ‖ 16 δεύτερος Vv

περισσός. εἰ δὲ ὁ α΄ πλείων, ὁ ψῆφος ἔνευσε πρὸς ἀφαίρεσιν. οὗτος οὖν ὁ ψῆφος τῶν μέσων κανονίων ἐστίν, ἐπεὶ ὁ τῆς ἀρχῆς ἀεὶ πρὸς πλέον χωρεῖ.

Ἐπεὶ χρεία γενέσθαι τὴν ἐργασίαν ταύτην, εἴπερ λεπτὰ οὐκ εἴσιν εἰς τὸν ψῆφον τοῦτον τὸν παρ' ἡμῶν κρατηθέντα, χρεία οὐκ ἔστι τῆς τοιαύτης ἐργασίας. κατ' ἐναντίον δὲ τοῦ ψήφου ἐκείνου, εἴ τι εὑρεθῇ, κρατεῖται. εἰ δέ εἰσι λεπτὰ εἰς τὸν ψῆφον ἡμῶν, κατ' ἐναντίον τῶν μοιρῶν τοῦ κρατουμένου παρ' ἡμῶν ψήφου ἀπὸ τῆς ἀρχῆς τοῦ κανονίου γίνεται εἰσέλευσις, καὶ ἀπὸ τῆς μέσης τοῦ κανονίου κρατεῖται ὁ εὑρεθεὶς | ψῆφος καὶ τηρεῖται. ἔπειτα f101vL ἡ περισσεία τούτου φανεροῦται, καὶ ἐκείνη ἡ περισσεία εἰς τὰ λεπτὰ τοῦ κρατουμένου παρ' ἡμῶν ψήφου τηρεῖται. εἴ τι εὑρεθῇ, μερίζεται εἰς τὴν περισσείαν τῆς ἀρχῆς τοῦ κανονίου. εἴ τι ἐξέλθῃ, ἐὰν ὁ ψῆφος ὁ ἀπὸ τῆς μέσης τοῦ κανονίου τοῦ κρατηθέντος καὶ τηρηθέντος | χωρῇ πρὸς τὸ πλέον, f51rV ἐκεῖνο τὸ ἐξελθὸν ἑνοῦται τούτῳ. εἰ δὲ πρὸς τὸ ἔλαττον, ἀφαιρεῖται ἵνα γένηται ὁ ψῆφος ἐκεῖνος τέλειος μέσον τοῦ ψήφου τῶν $\overline{\beta}$ κανονίων.

Διαίρεσις

Εἴπερ ἐκεῖνος ὁ κρατηθεὶς παρ' ἡμῶν ψῆφός ἐστιν ἀπὸ τοῦ ἀπὸ τοῦ μέσου κανονίου ψήφου, καὶ δεήσει γενέσθαι ἀπὸ τούτου δῆλον τὸν ἀπὸ τῆς ἀρχῆς τοῦ κανονίου ψῆφον, οὗτος ὁ παρ' ἡμῶν κρατούμενος ψῆφος ζητεῖται μέσον

1 πρῶτος Vv ‖ 4 τοῦτον om. Vv ‖ 9 ἐκείνη om. Vv ‖ 14 τοῦ] τῶν v ‖ 17 ἀπὸ τούτου om. Vv

τοῦ κανονίου. εἴπερ τοίνυν εὑρεθῇ ὅμοιος τούτῳ ψῆφος ἐκεῖ, κατ' ἐναντίον ἐκείνου κρατεῖται ὁ ψῆφος τῆς ἀρχῆς τοῦ κανονίου καὶ χρεία οὐκ ἔστιν
| ἄλλου τινὸς εἰς τοῦτον τὸν ψῆφον. εἰ δ'οὐχ εὑρεθῇ ὅμοιος ἐκείνῳ, μέσον f283rv
τοῦ κανονίου ζητεῖται ὁ ψῆφος, ὃς ἀπὸ τοῦ κρατουμένου παρ' ἡμῶν ψήφου
5 ἐστὶν ἐλάττων καὶ ἐγγύτερον. εἶτα κατ' ἐναντίον ἐκείνου κρατεῖται ὁ ψῆφος ὁ κατὰ τὴν ἀρχὴν τοῦ κανονίου καὶ τηρεῖται. ἔπειτα ὁ ψῆφος ὁ εὑρεθεὶς μέσον τοῦ κανονίου ἀφ' οὗ κατ' ἐναντίον ἐγένετο εἰσέλευσις, ἀπὸ τοῦ κρατουμένου
| παρ' ἡμῶν ψήφου ἀφαιρεῖται. εἴ τι οὖν καταλειφθῇ, ἐκεῖνο τηρεῖται εἰς τὴν f102rL
περισσείαν τοῦ ψήφου τῆς ἀρχῆς τοῦ κανονίου καὶ τὸ εὑρεθὲν μερίζεται εἰς
10 τὴν περισσείαν τῆς μέσης τοῦ κανονίου. εἴ τι οὖν εὑρεθῇ ἀπὸ τῶν πρώτων καὶ δευτέρων λεπτῶν, ἑνοῦται μετὰ τοῦ ψήφου τοῦ κρατηθέντος ἀπὸ τῆς ἀρχῆς τοῦ κανονίου ὡς ἂν γένηται ὁ ψῆφος ἐκεῖνος ὁ κρατηθεὶς ἀπὸ τῆς ἀρχῆς τοῦ κανονίου τέλειος.

Τμῆμα δεύτερον. Περὶ τῆς καταλήψεως τῶν τόξων τῶν τραχηλαίων καὶ τῶν
15 σαγιτῶν.

Οἱ ἀρχαῖοι ἐκεῖνοι, ὁποῖος ἄρα καὶ ἔστι κύκλος εἰς τὴν σφαῖραν, εἰς τὰ $\overline{\tau\xi}$ ἐμέρισαν, εἰς τὸ γενέσθαι ἕκαστον μετὰ τοῦ ἄλλου ἴσον, καὶ τὰ τεμμάχια ἐκεῖνα ἐκάλεσαν μοίρας. καὶ τὴν διάμετρον δὲ τοῦ κύκλου εἰς $\overline{\rho\kappa}$ μοίρας

10 μέσων L ‖ 11 β′ L ‖ 14 β′ L ‖ 16 κύκλος post ἄρα L

ἐμέρισαν. ἑκάστη δὲ | μοῖρα παρ' αὐτῶν εἰς $\overline{\xi}$ διῃρέθη τμήματα, καὶ ἕκαστον f51vV
ἐκείνων λεπτὸν ἐκάλεσαν. καὶ αὖθις ἕκαστον ἐκείνων εἰς $\overline{\xi}$ διῃρέθη τμήματα,
ὧν ἕκαστον δεύτερον λεπτὸν ἐκάλεσαν. καὶ μετὰ τῆς τάξεως ταύτης ἐγένετο
ἡ διαίρεσις τῶν καθεξῆς λεπτῶν μέχρι τῶν ι΄ λεπτῶν.

Δεῖ εἰδέναι ὅτι ἡ τραχηλαῖα θεμέλιόν ἐστιν εἰς τὴν κατάληψιν τῆς τάξεως
τῶν τόξων. καὶ εἰς ἅπαντας δὲ τοὺς ψήφους οἱ ἀστρονόμοι ταύτῃ χρῶνται.
καὶ ἡ μεγάλη δὲ τραχηλαῖα ἥμισύ ἐστι τῆς διαμέτρου, ἧς ὁ ψῆφος μοῖραι
$\overline{\xi}$. οἷον οὖν | τόξον καὶ ἔστιν, δεῖ εἰδέναι τὴν τραχηλαῖαν ἐκείνου. εἰ τὸ f102vL
τόξον ἔλαττόν ἐστι τῶν $\overline{\rho}$, κατ' ἐναντίον ἐκείνου κρατεῖται ἡ τραχηλαῖα. εἰ
δὲ πλέον τῶν $\overline{\rho}$ καὶ ἔλαττον τῶν $\overline{\rho\pi}$, ἡ περισσεία τῆς μέσης τοῦ τόξου ἐκείνου
$\overline{\rho\pi}$ κρατεῖται, ἤγουν τὸ ἔλαττον ἀφαιρεῖται τοῦ πλείονος. εἴ τι καταλειφθῇ
ἐξ ἐκείνου, κατ' ἐναντίον κρατεῖται ἡ τραχηλαῖα. καὶ εἰ τὸ τόξον ἐκεῖνο
πλέον ἐστὶ τῶν $\overline{\rho\pi}$ μοιρῶν, ἐκεῖνο ἀφαιρεῖται ἀπὸ τῶν $\overline{\tau\xi}$ μοιρῶν. εἴ τι οὖν
καταλειφθῇ, κατ' ἐναντίον ἐκείνου κρατεῖται ἡ τραχηλαῖα.

Εἰ γένηται χρεία κατ' ἐναντίον τοῦ τόξου κρατηθῆναι τὴν σαγίταν, ἐὰν
τὸ τόξον ἔλαττόν ἐστι τῶν $\overline{\rho\pi}$ μοιρῶν, κατ' ἐναντίον ἐκείνου ἐκβάλλεται ἡ
σαγίτα. εἰ δ' ἐστὶ πλέον τῶν $\overline{\rho\pi}$, ἐκεῖνο ἀφαιρεῖται ἀπὸ τῶν $\overline{\tau\xi}$. εἴ τι οὖν
καταλειφθῇ, κατ' ἐναντίον ἐκείνου κρατεῖται ἡ σαγίτα. καὶ ἡ σαγίτα δὲ ἡ
μεγάλη διάμετρός ἐστι τοῦ κύκλου, καὶ ἐκεῖνο $\overline{\rho\kappa}$ μοῖραί εἰσιν. καὶ ἡ σαγίτα

3 δεύτερον... ἐκάλεσαν] β΄ ὠνόμασεν λεπτὸν L ‖ 4 δεκάτων V ‖ 8 ἐκείνου] ἐκείνην Vv ‖ 15 ἐὰν + οὖν L ‖ 19 μοῖραι post εἰσι L

αὕτη ἐκείνου τοῦ τόξου τοῦ $\overline{\rho\pi}$ ἐστίν.

| Διαίρεσις. Περὶ τοῦ εἰδέναι τὴν τραχηλαῖαν ἀπὸ τοῦ τόξου, καὶ τὸ τόξον 283vv
ἀπὸ τῆς τραχηλαίας.

Βουλομένων ἡμῶν ποιῆσαι ἐργασίαν, γίνεται εἰσέλευσις κατ' ἐναντίον τοῦ
5 τόξου εἰς τὸ ἄκρον τῆς ἀρχῆς τῆς τραχηλαίας. καὶ κατ' ἐναντίον ἐκείνου ἀπὸ
μέσου τοῦ κανονίου ἡ τραχηλαῖα | ἐκβάλλεται. ἐπεὶ οὖν μετὰ τοῦ τόξου οὗ f52rV
εἴχομεν ἦσαν λεπτά, ἐκείνη ἡ τραχηλαῖα τελεία γίνεται | μετὰ τῆς ὀρθώσεως f103rL
τοῦ μέσου τῶν $\overline{\beta}$ κανονίων. οὕτως ὡς ἐρρέθη εἰς τὴν ἀρχὴν τοῦ α΄ τμήματος. εἴ
τι εὑρεθῇ, τραχηλαῖά ἐστιν ἐκείνου τοῦ τόξου. καὶ ἂν γένηται χρεία γενέσθαι
10 τὴν τραχηλαῖαν ἐκείνου τοῦ τόξου τετελειωμένην, τὸ τόξον ἀφαιρεῖται ἀπὸ
τῶν $\overline{\rho}$. ἐκεῖνο εἴ τι καταλειφθῇ, τετελειωμένον ἐστὶ τὸ τόξον καὶ ἡ τραχηλαῖα
ἐκείνου κρατεῖται. εἴ τι εὑρεθῇ, τραχηλαῖά ἐστι τετελειωμένη ἐκείνου τοῦ
τόξου.

Καὶ ἂν κρατῆται παρ' ἡμῶν τραχηλαῖα, ἐκείνη εἰς τὸ μέσον τοῦ κανονίου
15 τῆς τραχηλαίας ζητεῖται, καὶ κατ' ἐναντίον ἐκείνου ἀπὸ τῆς ἀρχῆς τοῦ
κανονίου τὸ τόξον κρατεῖται καθ' ὡς εἴρειται εἰς τὴν διαίρεσιν τοῦ πρώτου
κεφαλαίου.

12–13 τετελειωμένη... τόξου] τοῦ τετελειωμένου ἐκείνου τόξου Vv ‖ 14 κρατεῖται L ‖ 15 ἀρχῆς] ἄκρας L ‖ 16 α΄ L ‖ 17 κεφάλου L

Διαίρεσις. Περὶ τῆς καταλήψεως τῆς σαγίτας ἀπὸ τοῦ τόξου καὶ τοῦ τόξου ἀπὸ τῆς σαγίτας ἀπὸ τοῦ κανονίου τῆς τραχηλαίας.

Ὅταν κρατῆται παρ' ἡμῶν τόξον, καὶ τὴν σαγίταν ἐκείνου βουλόμεθα εἰδέναι, γίνεται ζήτησις εἰς ἐκεῖνο τὸ τόξον. εἴπερ ἐστὶν ἐκεῖνο ἔλαττον τῶν $\overline{\rho}$, ἡ τετελειωμένη τοῦ τόξου ἐκείνου τραχηλαῖα ἀφαιρεῖται ἀπὸ τῶν $\overline{\xi}$. εἴ τι οὖν καταλειφθῇ, σαγίτα ἐστὶ τοῦ τόξου ἐκείνου. καὶ ἐὰν τὸ τόξον ἐκεῖνο $\overline{\rho}$ μοῖραι, ἡ σαγίτα ἐκείνη μοῖραι $\overline{\xi}$. εἰ δ' ἐκεῖνο τὸ τόξον πλέον τῶν $\overline{\rho}$, ἀφαιροῦνται ἐξ ἐκείνου $\overline{\rho}$. εἴ τι οὖν καταλειφθῇ, ἡ τραχηλαῖα ἐκείνου κρατεῖται καὶ ἑνοῦται | τοῖς $\overline{\xi}$. εἴ τι εὑρεθῇ, ἡ σαγίτα ἐστὶ τοῦ τόξου ἐκείνου. ὅταν ᾖ ἐν ἡμῖν σαγίτα, f103vL καὶ τὸ τόξον ἐκείνης βουλόμεθα ἐκβαλεῖν ἀπὸ τοῦ κανονίου τῆς τραχηλαίας, γίνεται τήρησις εἰς ἐκείνην τὴν σαγίταν. ἐὰν ᾖ ἐκείνη ἐλάττων τῶν $\overline{\xi}$, αὕτη ἀφαιρεῖται ἀπὸ τῶν $\overline{\xi}$. εἴ τι οὖν καταλειφθῇ, ἐκεῖνο τραχηλαῖά ἐστιν. τὸ τόξον ἐκείνης κρατεῖται, | καὶ εἴ τι εὑρεθῇ, ἀφαιρεῖται ἀπὸ τῶν $\overline{\rho}$. ἔπειτα f52vV εἴ τι καταλειφθῇ, τόξον ἐστὶ τῆς σαγίτας ἐκείνης. εἰ δὲ ἡ σαγίτα $\overline{\xi}$ μοῖραι, ὀρθή ἐστι καὶ τὸ τόξον ἐκείνης $\overline{\rho}$ μοῖραί εἰσιν. εἰ δὲ ἡ σαγίτα πλείων τῶν $\overline{\xi}$, ἀφαιροῦνται ἐξ ἐκείνης $\overline{\xi}$. εἴ τι καταλειφθῇ, τραχηλαῖά ἐστιν. τὸ τόξον οὖν ἐκείνης κρατεῖται. εἴ τι εὑρεθῇ, ἑνοῦνται τοῖς $\overline{\rho}$, καὶ εὑρίσκεται τὸ τόξον τῆς σαγίτας ἐκείνης.

4 γίνεται post ζήτησις L ‖ 5 οὖν om. Vv

Τμῆμα γ΄. Περὶ τοῦ σκιάσματος.

Εἰς τὸ πλάγιον τοῦ κανονίου τῆς τραχηλαίας ἐτέθη διὰ τοὺς δακτύλους καὶ τὰ ἰχνόποδα. κατ' ἐναντίον οὖν τῆς ἀναβάσεως γίνεται εἰσέλευσις καὶ κρατεῖται τὸ σκίασμα.

Joseph Leichter

Dissertation Sample

Chapter 2 of the *Zīj as-Sanjarī*

English Translation

Book 2

On the Comprehension of Interpolation, Sine, Arc, The *Sagitta*, and Tangent[1]–Things Which are Very Useful for the Astronomical Composition

This book is divided into 3 chapters.

2.1 On Interpolation

It is necessary to know the nature of a table. That number which has been placed at the edge of a table is a gate, as it were, into calculations involving that table. That number which is the difference of (two adjacent) entries in the table and that number at the edge of the table are always precise with respect to (calculations involving) tabular difference. That tabular difference,

[1] lit. shadow

however, which involves values (intermediate) between two (adjacent) table entries, is not always precise (with regard to such calculations). If this tabular difference (of adjacent entries) in the table has been written down for this table, and the zodiacal signs go (in order) from the top of the table down, then the tabular difference is reckoned opposite that number (with which you enter the table). If the zodiacal signs go (in order) from the bottom of the table up, the tabular difference is reckoned opposite the next number (after the one with which you enter the table). If the tabular difference has not been written down in this table, the number with which entrance was made into the table is examined. The number after it is examined, and the smaller (of the two) is subtracted from the larger. If the second number is greater, that column[2] is said to be *increasing*. If the first is greater, that column is said to be *decreasing*. This is a column of entries in the body of the table, since a column at the edge (of the table) is always increasing.

When it is necessary to engage in this labor, if the number we have reckoned does not have a fractional part, there is no need for (further) labor. The (desired) result is reckoned opposite that number. If, however, our number does have a fractional part, entrance is made (into the table) from the edge

[2]lit. number

of the table opposite the degrees of our reckoned number, and the (desired) number is found and reckoned in the body of the table and examined. Then its tabular difference is made clear, and that tabular difference is multiplied by the fractional part of our reckoned number. The result is divided by the tabular difference (of the two corresponding entries) at the edge of the table. If anything comes out, if the column in the body of the tables — after reckoning and examination — is increasing, this result is added to it (i.e., the number in the body of the table opposite the integer part of our number). If (the column) is decreasing, it is subtracted, so that the interpolated number may be complete.

2.1.1

If the number we have reckoned is a (type of) number in the body of the table, and if it is necessary that the (corresponding) number at the edge of the table be made clear from this (number of ours), the number we have reckoned is sought in the body of the table. If a number is found there equal to ours, the number at the edge of the table is reckoned opposite ours, and there is no need for anything else for this calculation. If, however, a number equal to ours is not found there (i.e., in the body of the table), the greatest number less than the number we have reckoned is sought in the body of the

table. Then the number at the edge of the table is reckoned opposite this (found) number and examined. Then that number found in the table — opposite which entrance was made into the table — is subtracted from the number we reckoned. The result is multiplied by the tabular difference of the number at the edge of the table and the result is divided by the tabular difference (of the corresponding numbers) in the body of the table. The resulting sexagesimal firsts and seconds are added to the number reckoned at the edge of the table so that the number reckoned at the edge of the table may be complete.

2.2 On the Comprehension of the Arcs of Sines and the *Sagitta*

Degrees and Sexagesimal Fractions

The ancients divided the circle on the sphere into 360 equal parts. They called those parts *degrees*. They divided the diameter of the circle into 120 units. Each of their degrees was divided into 60 parts, and they called each of them a sexagesimal first. Each of those (sexagesimal firsts) was in turn divided into 60 parts, each of which they called a sexagesimal second. This process of division was continued in the same way on the successive parts (of the circle) until (they reached) sexagesimal tenths.

The Sine

It is necessary to know that the Sine is a base-point for the comprehension of its arcs. Astronomers employ the Sine for all their computations. The maximum value of the Sine is half the diameter, the length of which (half) is 60 units.

Given an Arc to Find its Sine

It is necessary to find the Sine of an arc given the arc. If the arc is less than 90, the Sine is reckoned opposite that arc. If the arc is greater than 90 and less than 180, the difference between that arc and 180 is reckoned, that is, the smaller value is subtracted from the larger value. The Sine is reckoned opposite that result. If that arc is greater than 180 degrees, its value is subtracted from 360 degrees. The Sine is reckoned opposite this result.

Given an Arc to Find its Sagitta

If it is necessary that the *sagitta* be reckoned opposite the arc, if the arc is less than 180 degrees, the *sagitta* is extracted opposite that (arc). If the arc is greater than 180 degrees, its value is subtracted from 360. The *sagitta* is reckoned opposite the result. The maximum value of the *sagitta* is the (length) of the diameter of the circle, and this is 120 units. This (i.e., 120) is the *sagitta* of an arc of 180 degrees.

2.2.1 On Knowing the Sine from the Arc and the Arc from the Sine

When we wish to engage in this labor, entrance is made into the table opposite the arc at the top of the beginning of the Sine values. The Sine is extracted from the body of the table opposite this value. If there are fractional parts to the arc in question, that Sine becomes complete with interpolation. This was discussed at the beginning of the first chapter (*page 49*). The result is the Sine of that arc. If it is necessary that the Sine be of the complement of that arc, the arc is subtracted from 90. The result is the complement of the arc and the Sine is reckoned from this. The result (of that calculation) is the Sine of the complement of that arc.

Whenever we have reckoned a Sine, that Sine is sought in the body of the table of Sines, and its arc is reckoned opposite it (going down) from the top of the table, as was discussed in the beginning of the second chapter[3] (*page 53*).

[3]lit. "the section of the first chapter"–but this is incorrect

2.2.2 On Comprehending the *Sagitta* from the Arc and the Arc from the *Sagitta* Using the Sine Table

Whenever we have reckoned an arc, and we wish to know its *sagitta*, the arc is examined. If it is less than 90, the Sine of the complement of that arc is subtracted from 60. If the arc is 90 degrees, the *sagitta* is 60 units. If the arc is greater than 90, it is subtracted from 90. The Sine of this result is reckoned and added to 60. The result is the *sagitta* of that arc.

Whenever we have a *sagitta* and we wish to extract its arc from the table of Sines, the *sagitta* is examined. If it is less than 60, it is subtracted from 60. The result is a Sine. Its arc is reckoned and the result is subtracted from 90. That result is the arc of the *sagitta*. If the *sagitta* is 60 units, it is right and its arc is 90 degrees. If the *sagitta* is greater than 60, it is subtracted from 60. The result is a Sine. Its arc is reckoned. The result is added to 90 and the arc of the *sagitta* is found.

2.3 On the Tangent[4]

(A tangent table) in fingers and feet has been set down along side the Sine table. Entrance is made opposite the altitude and the tangent is reckoned.

[4]lit. shadow