Geminos and Babylonian astronomy

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Introduction

Geminos' *Introduction to the Phenomena* is one of several introductions to astronomy written by Greek and Latin authors during the last couple of centuries BC and the first few centuries AD.[1] Geminos' work is unusual, however, in including some fairly detailed—and accurate—technical information about Babylonian astronomy, some of which is explicitly attributed to the "Chaldeans." Indeed, before the rediscovery of cuneiform sources in the nineteenth century, Geminos provided the most detailed information on Babylonian astronomy available, aside from the reports of several eclipse and planetary observations quoted by Ptolemy in the *Almagest*. Early-modern histories of astronomy, those that did not simply quote fantastical accounts of pre-Greek astronomy based upon the Bible and Josephus, relied heavily upon Geminos for their discussion of Babylonian (or "Chaldean") astronomy.[2] What can be learnt of Babylonian astronomy from Geminos is, of course, extremely limited and restricted to those topics which have a place in an introduction to astronomy *as this discipline was understood in the Greek world*. Thus, aspects of Babylonian astronomy which relate to the celestial sphere (e.g. the zodiac and the rising times of the ecliptic), the luni-solar calendar (e.g. intercalation and the 19-year ("Metonic") cycle), and lunar motion, are included, but Geminos tells us nothing about Babylonian planetary theory (the planets are only touched upon briefly by Geminos), predictive astronomy that uses planetary and lunar periods, observational astronomy, or the problem of lunar visibility, which formed major parts of Babylonian astronomical practice.

In this article I address two questions relating to Geminos' discussion of Babylonian astronomy. First, what material in Geminos' *Introduction to the Phenomena* has a Babylonian origin? This question has already been addressed by several authors, in particular Neugebauer,[3] Jones,[4] and Evans and Berggren,[5] and I add only a few comments to their findings. The second question is more interesting and has not been considered in detail before: where did Geminos obtain his knowledge of Babylonian astronomy? Did Geminos himself have experience of Babylonian astronomy or did he learn about it from earlier Greek authors? Did Geminos know that all of the things we can identify as Babylonian were Babylonian or had some of this material been incorporated into the general Greek astronomical tradition and its Babylonian origin been forgotten?

1 My study of Geminos is based upon the translation by Evans and Berggren 2006. I have also relied extensively upon their introduction and commentary.

2 See in particular Costard 1748 and Montucla 1758. On eighteenth century histories of astronomy and their accounts of Babylonian astronomy, see Steele 2012, 45–57.

3 Neugebauer 1975, 2.581–587.

4 Jones 1983, 23-24.

5 Evans and Berggren 2006, 15.

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The Zodiac

Geminos begins the *Introduction to the Phenomena* by discussing the signs of the zodiac. In I.1–8, Geminos explains that the signs of the zodiac differ from the zodiacal constellations in that the signs are a division of the zodiacal band into twelve equal 30 degree parts. This concept of the uniform zodiac was invented in Babylonia sometime around the end of the fifth century BC,[6] and was already widely used in Greek astronomy by the time Geminos was writing. Unsurprisingly, therefore, Geminos does not attribute the zodiac to the Babylonians, but he does implicitly acknowledge that the Babylonians knew about it at I.9 where he says that the "Chaldeans" placed the solstices and equinoxes at 8 degrees within the signs of Aries, Cancer, Libra and Capricorn in contrast to Greek astronomers who place them at the beginning of these signs. The placement of the solstices and equinoxes at 8 degrees within their zodiacal signs is in agreement with the Babylonian System B lunar theory and is widely attested in Greek and Latin sources from the first century BC onwards.[7]

Geminos returns to the zodiac in V.51–53 where he explains that the zodiac is an oblique circle composed of three lines, two of which define the edges of the zodiacal band and the third of which is called "the circle through the middle of the signs."[8] He continues by stating that the width of the zodiacal band is 12 degrees. This description of the zodiac as a band 12 degrees in width parallels the Babylonian conception of the zodiac as a band through which the moon travels which is 12 degrees in width. Four cuneiform tablets contain copies of a text which describes the 12 degree wide path of the moon relative to the Normal Stars (a group of reference stars distributed unevenly around the zodiacal band),[9] and a procedure text states that "the width of the path of the moon is 12 (degrees)."[10] In cuneiform texts, the middle of this band is named "the ribbon of the middle" (DUR MÚRUB),[11] a close parallel to Geminos' "circle through the middle of the signs."

Astrology

Chapter 2 of the *Introduction to the Phenomena* discusses astrological aspects of the signs of the zodiac. Geminos provides a short explanation of four geometrical arrangements of zodiacal signs which have astrological significance: opposition, trine, quartile and syzygy. Geminos' discussion of astrological aspect is predicated on the idea of the signs of the zodiac being arranged in a circle. First he describes the concept of opposition, which refers to signs that are on opposite ends of a diameter of the circle, or, in other words, signs that are six signs apart and that rise and set simultaneously. Geminos states that "signs in opposition are considered by the Chaldeans in connection with sympathies in nativities" (2.5).[12] Geminos next describes trine aspect, where signs of the zodiac form equilateral triangles and are separated by 4 signs, and he links each

6 Britton 2010, Steele 2007.

7 Neugebauer 1975, 2.594–598.

8 Evans and Berggren 2006, 157.

9 Steele 2007, 304–308.

10 BM 32167 Obv. I 20; edited by Ossendrijver 2012, text 53. See also BM 41004 Obv. 15 (Neugebauer and Sachs 1967, Text E) which contains a parallel statement but using cubits rather than degrees (1 cubit = 2 degrees).

11 Steele 2007, 315.

12 Evans and Berggren 2006, 125.

triplicity with wind directions and says that they too imply sympathies when interpreting nativities. He continues with quartile aspect, where the signs form squares and are separated by 3 signs, and syzygy, where the signs are linked pairs which rise and set in the same place.

Geminos only explicitly links the "Chaldeans" with opposition but it is quite possible that he considers all four astrological aspects to be of Babylonian origin. So far, only trine aspect has been identified in cuneiform sources. Triplicities of zodiacal signs and months in the schematic 360-day calendar are found quite widely among Babylonian and Assyrian astrological texts, including (in month form) from considerably earlier than the invention of the zodiac.[13] One text, BM 36747, seems to link the triplicities with wind directions, in accord with II.8–11.

Our knowledge of Babylonian astrology from the late period remains very incomplete and it strikes me as quite possible that the other astrological aspects may yet be discovered in cuneiform sources.

The Rising Time of the Zodiacal Signs

Geminos devotes chapter VII of the *Introduction to the Phenomena* to a discussion of the variation in the rising time of the different signs of the zodiac. The rising times of the zodiac can be used to determine the length of daylight on a given day by adding together the rising time for the stretch of the ecliptic which extends for 180 degrees from the sun's position on that day. Geminos does not discuss the calculation of daylength from the rising times, but, as Evans and Berggren have shown, his statement in chapter VI that the second differences in the length of day are constant (VI.38) and his claim in chapter VII that the total rising and setting time for a zodiacal sign is always equal to 4 equinoctial hours (VII.36) are consistent with the use of a rising time scheme in which the rising time of the zodiacal signs varies according to a linear zigzag function whose maximum and minimum are at the beginning of Aries and Libra.[14]

Several rising time schemes are known from Babylonian astronomy. In the System A and System B lunar theories, a rising time scheme underlies the calculation of the length of daylight given in column C.[15] In System A, the rising times follow a linear zigzag function with minimum 20 UŠ (= time degrees) and maximum 40 UŠ and a difference between the signs of 4 UŠ. System B follows a broken zigzag function with maximum 21 UŠ and minimum 39 UŠ but with differences between the signs of 3 UŠ except in the months around the solstices months where it is 6 UŠ.[16] System A-type rising time schemes are quite widely attested in Greek sources beginning with Hypsikles in the second century BC, and it is most likely that Geminos drew upon these Greek sources for what he knew about rising times.

The 19-Year Cycle

Chapter VIII of the *Introduction to the Phenomena* concerns the lunar month and luni-solar calendars. Lines VIII.50–58 describe the 19-year intercalation cycle often referred to in modern

13 Rochberg-Halton 1984.

14 Evans and Berggren 2006, 73–82.

15 Neugebauer 1953.

16 A third rising time scheme is known from a group of texts which divide each zodiacal sign into twelve 2½ degree parts; in this scheme, the rising times of the zodiacal signs are 20 UŠ for six signs of the zodiac and 40 UŠ for the other six signs. See Rochberg 2004 and Steele 2017.

scholarship as the "Metonic cycle."[17] Geminos explains that in 19 years there 235 months containing a total of 6940 days, implying that in the 19-year period there are 7 intercalary months. Of the 235 months, 110 are 29-day months and 125 are 30-day months. Geminos then describes a calendar in which every 63rd day is removed to determine whether months have 29 or 30 days.[18]

Geminos attributes the 19-year cycle to "the astronomers around Euktemon, Philippos and Kallippos" (VIII.50). The cycle is often attributed to Meton in other sources. The 19-year cycle was employed in the Babylonian calendar from the early fifth century BC,[19] and it has often been suggested that Greek knowledge of this cycle came from the Babylonians. Whilst this is quite possible, it is worth noting that the cycle is quite simple to identify and was discovered and used independently in early Chinese calendrical astronomy from at least the second century BC onwards.[20] Thus, an independent Greek discovery should not be ruled out.

Lunar Theory

The final chapter of the *Introduction to the Phenomena* is considerably more technical than the rest of the work. It deals with two aspects of lunar theory: the Exeligmos cycle of 669 months and a scheme for the lunar velocity of the moon. Geminos presents the Exeligmos as a cycle containing a whole number of days, synodic months and anomalistic months (19756 days = 669 synodic months = 717 anomalistic months) (XVIII.1–3). He also notes that over one Exeligmos the moon makes 723 passages through the zodiac plus 32 degrees. It is interesting to note that Geminos does not mention that the Exeligmos also contains close to a whole number (726) of draconitic months and may therefore be used as an eclipse cycle. Indeed, the Exeligmos was certainly derived by tripling the Saros cycle of 223 synodic months = 242 draconitic months = 239 anomalistic months = approximately 6585 1/3 days to eliminate its 1/3 day excess in a whole number of days. The Saros cycle from the basis of Babylonian methods of eclipse prediction and was also widely known in the Greek world in this context.[21]

Geminos uses the Exeligmos to derive the parameters for a linear zigzag function to describe the daily change in lunar velocity. He presents the results in sexagesimal format, explaining the (originally Babylonian) number system at XVIII.8. Geminos derives the value 13;10,35 degrees for the mean daily motion of the Moon, remarking that this value "has been found by the Chaldeans" (XVIII.9). He also determines that the maximum and minimum values of the zigzag function are 15;14,35 degrees and 11;6,35 degrees, with a daily difference of 0;18 degrees.[22] As is well known, the zigzag function Geminos describes is column F* of the Babylonian System B lunar theory.[23] Geminos' derivation of its parameters from the Exeligmos is clearly an after-the-fact

17 On the Metonic cycle, see Neugebauer 1975, 2.622–624.

18 A version of this calendar is found in the upper back dial of the Antikythera Mechanism; see Freeth, Jones, Steele and Bitsakis 2008.

19 Britton 2007a.

20 For the use of the 19-year cycle in China, see, for example, Sivin 1969. Various claims have been made for a Babylonian origin of early Chinese astral science, mainly by scholars who do not control one or both of the Chinese and the Babylonian sources, but these claims do not stand up to close scrutiny; see Pankenier 2014 and Steele 2013 and in press.

21 On the Babylonian use of the Saros, see Steele 2000a. On Greek knowledge of the Saros, see Steele 2000b, 88–91.

22 For Geminos' derivation of these values, see Neugebauer 1975, 2.584–587 and Evans and Berggren 2006, 96–99.

23 On this theory, see Neugebauer 1975, 1.480–481 and Ossendrijver 2012, 188–189.

justification of the already existing function and almost certainly does not reflect the original Babylonian route to the construction of the function.[24]

What Did Geminos Know about Babylonian Astronomy and How Did He Know It?

The preceding summary shows that in several chapters of the *Introduction to the Phenomena* Geminos discussed astronomical concepts and techniques which have a Babylonian origin. This raises the question of whether Geminos knew that this material was Babylonian and from where he might have obtained it. Geminos only directly attributes three things to the "Chaldeans": the placement of the solstices and equinoxes at 8 degrees within their zodiacal signs, the concept of oppositions within astrology, and 13;10,35 degrees for the mean value of the daily motion of the moon. The other material with a Babylonian origin is simply presented as basic astronomical fact without any attribution to either a Babylonian or a Greek source.

A considerable amount of Babylonian astronomy and astrology was transmitted to the Greek world, including reports of lunar eclipses and planetary observations used by Hipparchos and Ptolemy,[25] large parts (or perhaps all) of the lunar System B,[26] many of the System A and System B planetary schemes,[27] and many ideas from later Babylonian astrology,[28] as well as basic ideas and methods such as the zodiac, the sexagesimal number system, and step and zigzag functions. The transmission of much of this material, in particular the observations and the various systems of mathematical astronomy, must have involved direct contact between Babylonian and Greek astronomers: cuneiform astronomical texts are sufficiently technical that they probably could not have been translated into Greek by a Babylonian scribe who was not himself an astronomer,[29] but they are sufficiently formulaic, employing a limited vocabulary written with a comparatively small number of cuneiform signs (and in the case of the tabular material, no grammar) that a Greek astronomer would probably have been able to learn to read cuneiform astronomical texts after only a relatively short period of instruction by a Babylonian astronomer. How often this happened, and whether the transmission of Babylonian astronomy was a gradual process or took place more or less at one time, remains an open question.

According to Jones and others,[30] Geminos wrote the *Introduction to the Phenomena* sometime during the first half of the first century BC. Many aspects of Babylonian astronomy are already attested in Greek sources well before this time. For example, the zodiac already appears as a well known concept in the works of Autolykos and Euclid around 300 BC,[31] the 19-year cycle was known already in the fifth century BC (and may be an independent discovery anyway), System

24 The origin of column F* in System B is, like all other functions in Babylonian mathematical astronomy, never discussed in cuneiform texts. For a possible reconstruction of how the lunar anomaly functions of System A and B were derived, see Britton 2007b and 2009.

25 On the lunar eclipse observations and their transmission, see Steele 2000, 91–100 and 2011. On the planetary observations, see Jones 2006.

26 Jones 1993 and 2002.

27 Jones 1998.

28 Rochberg-Halton 1988.

29 Steele 2004.

30 Jones 1999, Evans and Berggren 2006, 17–22.

31 Neugebauer 1975, 2.593.

A-style rising time schemes were discussed by Hypsikles in the second century BC,[32] and Hipparchos clearly had knowledge of at least parts of the System B lunar theory, including its mean length for the synodic month and the period relation for column F and the 248-day scheme underlying column F*.[33] Thus all of the Babylonian astronomy which appears in Geminos' book, with the possible exception of the astrological aspects discussed in chapter II, was already known to Greek astronomers.

Given that all of the Babylonian astronomy that underlies parts of Geminos' book was already in circulation in the Greek world, there is no reason to suppose that Geminos had any contact with Babylonian astronomers himself. It is much more likely that he obtained this material from Greek sources. Indeed, as I have discussed, much of it had been assimilated into the general astronomical knowledge of the time and was no longer distinctly "Babylonian." Only the discussion of the lunar theory in chapter XVIII draws on what may not have been assimilated into this general astronomical knowledge. Nevertheless, even this material was fairly widely known among Greek astronomers: it was known to Hipparchos in the middle of the second century BC and appears in papyri astronomical tables, the earliest preserved of which dates to the latter part of the first century BC, but there is no reason to suppose that tables were not produced already at the time of Geminos. Evans and Berggren suggest that Geminos' discussion of the lunar theory is based upon his knowledge of such tables of lunar velocity.[34] While this is possible, it seems to me to be just as likely that Geminos knew the parameters for column F* from Hipparchos. Geminos employs the System B value for the mean length of the synodic month, a value which Hipparchos reports (along with a pretended derivation from observation), in the calculation of the number of days in the Exeligmos (XVIIII.3).[35] Thus, it would appear that Geminos knew not only column F* from System B but also the mean value of column G which gives the mean length of the synodic month. Geminos could in theory have determined the mean value of column G from analyzing a papyrus table containing calculated values of this function, but it seems more likely that he would simply have taken this value from Hipparchos.

There remains the question of why Geminos sometimes attributes items of knowledge to the "Chaldeans." Geminos cites many authorities throughout the *Introduction to the Phenomena*,[36] but he is not consistent in his practice: several important sources, including Euclid, Autolykos and Theodosios are not named even though he drew extensively upon their work.[37] As discussed above, only a small selection of the Babylonian material Geminos discusses is attributed to the "Chaldeans": the placement of the solstices and equinoxes at 8 degrees within their zodiacal signs, the astrological aspects, and the mean value of column F*. It is possible that the reference to the "Chaldeans" may be simply a literary device to suggest that this material is "old" or, perhaps, outside of the mainstream of astronomical practice, but given the common association of the term "Chaldean" with astrology in the Greco-Roman world, I wonder if Geminos is indicating that this material reflects the practices of everyday Greek astrologers. The 8 degree norm for the solstices and equinoxes is referred to in Greek and Latin astrological writings and (at least in later times) there is considerable papyrological evidence for the use of Babylonian mathematical

32 Neugebauer 1975, 2.715–718.

33 Jones 1993, 84–85.

34 Evans and Berggren 2006, 100.

35 Evans and Berggren 2006, 288 footnote 6.

36 For a list, see Evans and Berggren 2006, 301–302.

37 Evans and Berggren 2006, 13.

astronomy by practicing astrologers. Thus, it is possible that Geminos is labeling as "Chaldeans" those astronomical methods such as zigzag functions which are employed by everyday astrologers to distinguish them from what we might call "scholarly" astronomers and astrologers who used geometrical models.

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