The Path of the Moon, the Rising Points of the Sun, and the Oblique Great Circle on the Celestial Sphere

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General problem: who invented the ecliptic?

In Greek sources there are conflicting claims about whether Oenopides discovered the zodiacal band or the zodiacal circle. As a consequence, the discussion still goes on (Boehme 2001, Panchenko 1999). I am not in the position to judge between the different readings of Greek texts; nor am I in the position to evaluate the different and contradicting Greek passages on who invented the zodiac (or introduced it to Greece) or who discovered its being a great circle on the celestial sphere, making a fixed angle with the equator – which was such an important discovery that Pliny (in his *Natural History* 2.31) called it "to open the portals of science". But I feel able to put forward some ideas on how this theoretical geometrical model was discovered and introduced. In so doing I am inspired also by my former teacher, Olaf Schmidt. When talking about ancient astronomy he often stressed two points:

> (a) What concerned early Greek astronomers was to try to explain their own observations and the insights of the Babylonian astronomers by means of geometric models: they made drawings on the surface of a solid sphere, representing the celestial sphere, and in so doing, they tried to reproduce the heavens and to find mathematical methods for its description.

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> (b) The central question of ancient astronomy is the problem of the oblique ascension. This problem originates in the fact that times are measured along the celestial equator while the sun and the moon move along the ecliptic. The problem is solved when for an arbitrary arc E of the ecliptic, that arc A of the celestial equator which rises simultaneously with arc E is found.

In his thesis on ancient sphaerics (Schmidt 1943, p. 2), when reviewing the works of Autolycus, Theodosius and Euclid, Schmidt writes:

> It follows from the works of Autolycus that at the time we start our investigation some astronomical knowledge had already been acquired. These astronomical data are: first, the earth and the universe are spherical in form; second, the celestial sphere rotates about its axis; third, the stars are luminous and the only reason they are not visible during the day is the fact that the light of the sun is stronger; fourth, during one year the sun moves in a great circle, the ecliptic, which makes a fixed angle with the equator.

How the Great Circle, Oblique to the Equator, Might Have Been Discovered

What I shall do in this paper is to indicate one possible way to derive this fourth insight – that the path of the sun is a great circle inclined to the celestial equator. The process starts out with astronomical observations, which we know were undertaken by Babylonian (and Greek) astronomers, and it leads naturally to the recognition that the ecliptic is a great circle, which makes a fixed angle with the equator, if the stars are drawn on the surface of a sphere according to observational knowledge.

The Path of the Moon

Before the introduction of their “lu-maš” (i.e. the division of the path of the sun into 12 zodiacal signs of equal length), the Babylonians used a number of constellations to locate bodies in the sky. For example, in MUL.APIN[1] the path of the moon was traced through 17 constellations. By the fifth century B.C., this had been reduced to 12 constellations. Finally, shortly before 400 B.C., these 12 constellations were replaced by the 12 equal divisions of the ecliptic into zodiacal signs. We know that the sun and planets move along the ecliptic. That the planets move through the path of the moon can be seen directly; but it is of course not possible to observe the movement of the sun through the constellations directly.

Rising-Points and Setting-Points at the Horizon

In MUL.APIN (Hunger and Pingree 1982, pp. 67–75) the yearly movement of the sun is described through the movement of its rising point: After listing the constellations through which the moon passes and touches in the course of a month, the text affirms that the sun and the planets also travel through the same path. Then, in the following so-called intercalation scheme, the rising points of the sun are given for the cardinal points of the schematic year of 360 days.[2]

> On the 15th of month IV the Arrow becomes visible, and 4 minas is the day, 2 minas the night. The sun which rose towards the North with the head of the Lion turns and keeps moving down towards the South. The days become shorter at a rate of 40 NINDA per day, the nights longer. On the 15th of month VII the sun rises in the scales in the East, ..., 3 minas is the day and 3 minas is the night. On the 15th of month X, the Arrow becomes visible in the evening, 2 minas is the day, 4 minas the night. The sun which rose toward the South with the head of the Great One turns and keeps coming up towards the North. At a rate of 40 NINDA per day the days become longer, the nights become shorter.

We learn from MUL.APIN that the Babylonian astronomers (having remarked that the sun moves along the same path as the moon) knew the constellations through which the sun passes in the course of a year.[3] But they also knew the positions on the eastern horizon where the sun rose at equinoxes and solstices. These positions could be observed directly and were referred to as the rising points of stars or zodiacal constellations. Another example of this practice, i.e. using constellations to indicate directions toward the horizon, may be found in the Babylonian texts, LBAT 1494 and 1495 (Pinches 1955). These texts mention the morning shadow of Cancer and of Capricorn, which we understand as the shadow of the rising sun at summer solstice and at winter solstice (see Brack-Bernsen and Hunger 1999).

The interest in the direction in which celestial bodies rise is apparent in many early cultures. Early Greek stellar navigation should be mentioned here. By observation night at night, sailors learned to recognize all the stars

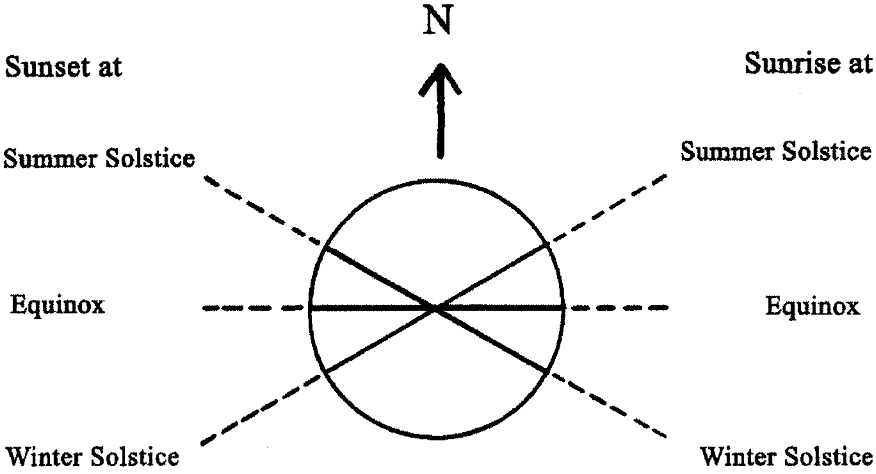

Fig. 1. The whole horizon at the latitude of Babylon, where the angle between the directions to SS and WS amount to almost 59 degree. The directions to sunrise at SS and WS were associated with those stars or constellations which rose in these directions.

which rose in some given direction. Then, when sailing at night, all they had to do was to sail towards stars which were known to rise in that direction.[4] Greek astronomers, too, were concerned with rising points. For example, the movement of the sun's rising point was remarked by early Greek writers and explained as the result of blowing winds.[5] As evidence for this interest in rising points of stars, we may also quote the introduction to Euclid's *Phaenomena.* The author argues:[6]

> The fixed stars are seen always rising from the same place and setting in the same place, those rising simultaneously always rising simultaneously and those setting simultaneously always setting simultaneously. Moreover, they are seen as always having the same distances from another as they move from rising to setting. Since this happens only with [things] that move in circular paths, ... one must postulate that the stars are carried in circles ...

Proposition 1 of this treatise also argues on the basis of the direction in which zodiacal signs rise and set. We see that Euclid's *Phenomena* is still witness to the intimate interaction between horizontal observations, the introduction of the celestial sphere, and the resulting mathematical astronomy.

Having referred to the Aristotelian ranking of sciences according to which "it is the task of the lower science – in this case, the science of the *phenom-*

ena – to establish the facts and that of the higher science (mathematical astronomy) to establish the reasons for these facts", Berggren and Thomas (p. 11) point to the connection between the works of Eudoxus and Euclid: "Seen from this perspective, then, the available evidence suggests that Eudoxus' *Phaenomena* was concerned with stating certain facts of the case, and that Euclid's *Phaenomena* was concerned with establishing the reasons why the facts must necessarily be as they are".

The Production of a Stellar Celestial Sphere

By reading Hipparchus' *Commentary on Aratus' and Eudoxus'* Phaenomena (Manitius, 1894) and Eudoxus' fragments (Lasserre, 1966) it seems to me that the structure of Eudoxus' texts reflect the process of producing a stellar sphere.

In short, the stars on the equator represent the stars which rise in the direction of due east. Similarly, the two tropic circles are also found through observation of rising stars. The summer tropic is the circle passing through those stars or parts of constellations which rise in the same direction as the sun at summer solstice. And the winter tropic is the circle passing through those stars and parts of constellations which are seen to rise close to the direction in which the sun rises at winter solstice.

Imagine these circles drawn on the surface of a sphere on which the stars and constellations are also depicted, in accordance with their (observed) positions in relation to each other and to the poles. Eudoxus tells us that the middle of Cancer is situated on the summer tropic, that the middle of Aries and the middle of Libra are on the equator, and that the middle of Capricorn is situated on the winter tropic. (Remark that this is in complete agreement with what we find in MUL.APIN.) When these zodiacal constellations are drawn on the sphere, one will immediately realize that the zodiacal constellations are situated along a circle passing through Aries, Cancer, Libra, and Capricorn, i.e., a great circle which is oblique to the equator and touches the two tropic circles.

Accordingly, I postulate that the first person who took the sphere as a model for the cosmos and depicted the stars together with the three important circles (celestial equator and the two tropics) on ist surface was the one to realize that the path of sun and moon is a great circle oblique to the

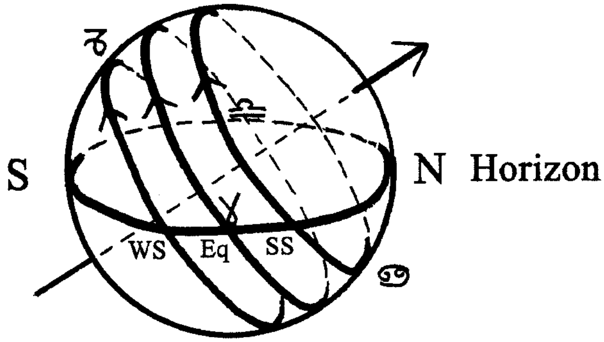

Fig. 2. The celestial sphere for the place of Eudoxus' observations. The celestial equator and the two tropic circles are drawn on the surface of the sphere. The arrows indicate the direction of the daily movement. The position of the zodiacal constellations Aries ♈, Cancer ♋, Libra ♎, and Capricorn ♑ are also indicated. In this example we have assumed Aries ♈ to be rising.

equator.[7] Therefore, he (who ever he might have been) was the person who "opened the portals of science".[8]

The Process Implicitly Given in Eudoxus' Fragments

To me the surviving remains of Eudoxus' *Phenomena* and *Enoptron* (Lasserre 1966, pp. 42–56, 183–98) are witness to this process of producing a celestial sphere which correctly depicts the stars and introduces special circles on that sphere. (By 'correctly' I mean 'in accordance with the observed rising points of stars, with simultaneous risings and settings, and with their relative position of the sky'.) In order to show this, I will summarize the information given in the fragments F 10–11, ..., F 79. First, the relative positions of constellations are given in relation to the northern (visible) pole and the southern (not visible) pole. Then, the following circles are introduced by mentioning the stars and parts of constellations situated on those circles:

1st circle:	the v-circle, which is the greatest of the always visible circles.
2nd circle:	the summer tropic, i.e. the circle parallel to the celestial equator through the summer point (i.e., through the middle of Cancer).
3rd circle:	the equator which is the great circle perpendicular to the axis

through the two poles said to pass through the middle of Aries and middle of Libra.

4th circle: the winter tropic, i.e. the circle parallel to the equator going through the winter point (i.e., through the middle of Capricorn).

5th circle: the greatest of the never visible circles is given by some stars situated near it.

Until now, the process is closely connected to observation. The relative position of constellations as well as the stars and those parts of constellations which are situated on (or near) the 5 circles mentioned above can all be found directly by observation (circles 2, 3 and 4 are those discussed in Figure 2). Then follows "more theoretical" circles: first the two special meridians called colures, one of which passes through the middle of Cancer and Capricorn, while the other circle, perpendicular to the first, goes through the middle of Libra. Then, finally, comes the circle of the zodiac. It is said to be in an oblique position, touching the two tropical circles symmetrically, and being bisected by the equator. This characterization of the zodiacal circle can be seen immediately on the stellar sphere, which Eudoxus had apparently produced – one just has to follow (or track down) the zodiacal constellations around the sphere (see Figure 2). But if it was found in this way, we must characterize it as a theoretical result intimately connected to the spherical representation of the sky.

I would like to emphasize the importance of this model of the heavens. Since it is a geometrical model it can be examined by means of mathematical methods. Such methods were developed by Autolycus, Theodosius, Euclid, Menelaus, and Ptolemy. For example, representing the path of the sun and moon as a great circle oblique to the equator has the consequence that the connection between solar movement and time keeping can be formulated geometrically (i.e. the problem of oblique ascension). This problem was finally solved by Ptolemy in the *Almagest*[9] by means of spherical geometry.

I do not know who was the first person to represent the stars on the surface of a sphere representing the sky; but Eudoxus surely (also) did it. His fragments bear witness to the process. The title of his *Enoptron*, a book almost identical with the *Phenomena*, may also indicate that process. It reminds us that all constellations when depicted on the surface of a sphere and seen from the outside, are mirror images of the constellations observed directly from within the sphere.

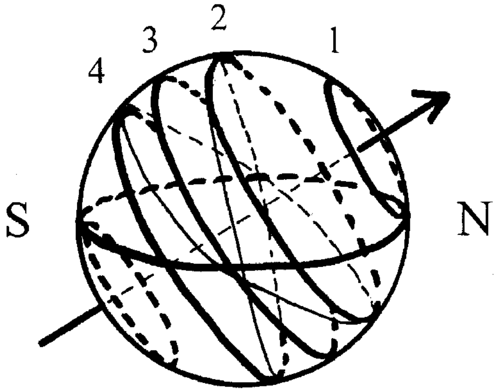

Fig. 3. The celestial sphere for the place of Eudoxus' observations. The five parallel circles mentioned in Eudoxus fragments are drawn with fat lines. During the daily movement of the sphere, these circles slide along themselves (so that the stars on each circle all rise at the same point of the horizon). The ecliptic, however, changes position during the daily movement. The two extreme positions of the ecliptic are indicated with thin lines.

We are so familiar with the spherical representation of the sky, that it is hard to imagine what was known about astronomy without this tool and how it was known. It has been argued, that "everybody who knows the belt of the zodiac immediately knows that it is inclined" (Panchenko 1999, p. 42). Or that the Babylonians conceived the sun's orbit as a "line intersecting the limiting circles of the zones of Enlil, Anu and Ea" (i.e. a great circle in Fig. 2, see van der Waerden, 1952, p. 221). I disagree with Panchenko (and also with van der Waerden) when he treats the different paths of Enlil, Anu and Ea in MUL.APIN as regions on the sphere, limited by circles. He sees the path of Anu as a belt of the sphere, parallel to the equator. As far as we know, the Babylonians did not have any geometric representation of the sky or of the solar, lunar, or planetary movements. Following Pingree (1993, pp. 266–271: see also Hunger and Pingree 1999 pp. 61 and 73) I read the passages on the paths of Enlil, Anu, and Ea as referring to arcs along the eastern (and the western) horizon over which the stars, the sun, the moon, and the planets rise (or set) and not as regions on a sphere. The Babylonians were, indeed, capable of finding important astronomical facts that we typically explain by reference to the celestial sphere. But they did it, as far as we know, through

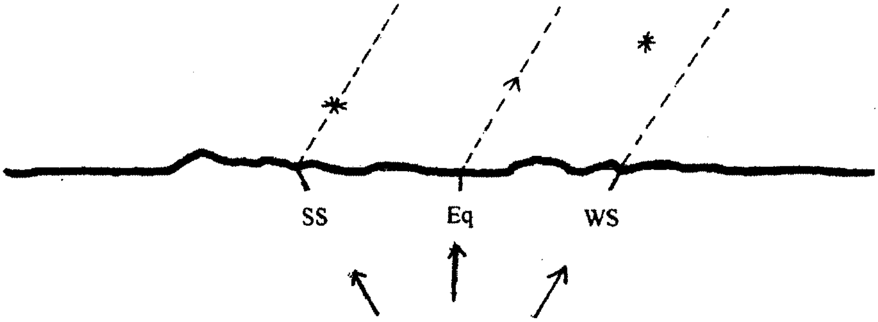

Fig. 4. The eastern horizon as seen from the latitude of Babylon. The direction to the cardinal points, i.e. the points over which the sun rises at summer solstice, equinox, and winter solstice, are indicated by arrows. The dashed lines show the direction along which all celestial bodies rise. The paths of Enlil, Anu and Ea are understood as intervals of the eastern horizon around SS, Eq, and WS, respectively.

observation and by numerical procedures, and without any geometrical model.

Aspects and Possibilities Within Babylonian Astronomy

MUL.APIN exhibits the knowledge of the constellations through which the moon and sun travel, and also the knowledge of the arc along the eastern horizon over which the sun and moon rise. But it does not necessarily recognize a celestial sphere with an oblique great circle.

The division of the ecliptic into 360 degrees may have its origin in the schematic year of 360 days. This schematic calendar probably has its origins in the administrative calendar of the Uruk III period – but it was still used in MUL.APIN, and the *tithi*=1/30 of the synodic month, found in mathematical astronomical texts of the Seleucid Era, likely has its origin in the ideal month of 30 days.[10] This schematic calendar provided the means by which the ecliptic could be divided up. Just as the schematic year had 12 months of 30 days, so there were 12 zodiacal signs, each of which was divided into 30 degrees.

But exactly how the transformation from a year of 360 days to a movement of 360 degrees took place, we do not know. In Brack-Bernsen and Hunger

(1999), we presented one possible way. Each schematic Babylonian month can be connected to that arc along the eastern horizon, over which the sun would rise. The 12 ideal months would hence lead to 12 intervals along the horizon; and the rising point of the sun would stay in each arc for 30 days.

There is another possible way (maybe connected to the first proposal). From Section 19 of TU 11, it is clear that the Babylonians identified differences in time between the risings of the sun and moon with their relative positions – the daily retardation of the moon was, e.g., used as the daily movement of the moon relative to the sun (see Brack-Bernsen and Hunger 2002, ch. 6).

It is, therefore, not too surprising to find (astrological) cuneiform texts in which, seemingly, the Babylonian months are identified with the zodiacal signs. In the *Kalendertexte*, the name (logogram) for a zodiacal sign is often exchanged with the name of the corresponding month. In the so-called *Dodekatemoria* scheme, the date (month M, day n) in the schematic calendar corresponds directly to the position (sign M, degree n) of the sun in the Babylonian 'lu-maš'. And to our surprise, in some of these astronomical schemes, the names for the months or zodiacal signs are given only by the numbers 1 through 12. These numbers can, hence, be interpreted either as indicating the month or as indicating the sign (Brack-Bernsen and Steele, 2002).

The concept of identifying times with positions may explain how the division of the ecliptic into 12 parts of 30 degrees was introduced. Is it possible that, at some time, the Babylonians indicated the position of the sun just by the date in the ideal calendar; and later, having recognized the constellations in the path of the moon, introduced the 12 signs divided into 30 parts each, in order to distinguish between dates and positions? This idea would explain the existence of very early *Kalendertexte* in which positions are given as numbers seemingly referring to zodiacal positions.[11]

A third possible way, leading from the schematic year of 360 days to the division of the ecliptic into 360 degrees, has been presented by David Brown (2000, pp. 111–113). This paper analyses the development of the various Babylonian units. Brown stresses the ambiguity of the Babylonian UŠ which was used as a unit for measuring celestial distances as well as times. (This is in line with the identification of time differences and relative positions, as mentioned above.)[12] Brown proposes that the *ziqpu* stars, which, by their culmination were used to indicate times at night, played an intermediate role in the development of the zodiacal system of space measurement. Concluding his analysis of measuring time in the late period (i.e., after c. -750), Brown suggests (p. 113) "that the system of time measure using *ziqpu* stars revealed how a circle in the sky could be divided *spatially* as well as *temporally* into 360 UŠ, which paved the way for dividing another circle in the sky, the ecliptic, into the same".

Rising Times of Ecliptic Arcs – Found by "Babylonian" Methods

Finally, I will demonstrate that it is possible to determine the rising-times of ecliptic arcs directly by observation, without the tool of the celestial sphere. In so doing, I shall only use concepts and observations known from cuneiform texts. Therefore, the two methods I present here could have been invented and used by Babylonian astronomers. I would not be surprised to find out that the Babylonians, indeed, had these methods; but I cannot prove it.

We must first recall the method for establishing rising-times of ecliptic arcs by means of culminating *ziqpu* stars. Some texts (published by Schaumberger, 1955) give the rising-times of twelfth of zodiacal signs in terms of simultaneous meridian crossings of *ziqpu* stars. Other *ziqpu* star texts (see Hunger and Pingree 1999, pp. 84–90) list the times between the culmination of consecutive *ziqpu* stars. Such texts allowed Babylonian astronomers to convert rising ecliptic arcs into time intervals. But as Schaumberger remarked, the texts relating risings of ecliptic segments to culminating *ziqpu* stars seem to have been constructed from the (known) rising time of each zodiacal sign. These rising times could have been found by means of *ziqpu* stars or by one of the two methods presented below.

The first method. The quantities ŠÚ, NA, ME, and GE_6 are time intervals between the risings and settings of the sun and moon, measured in the days around opposition. They were regularly observed, and their values were recorded month by month in so-called Goal-Year tables. Each such tablet collects lunar and planetary data to be used for prediction.[13] The Goal-Year method used for predicting lunar phases is reconstructed in Brack-Bernsen 1999. From this method we know that the daily retardation of the setting full moon was determined by the sum ŠÚ+NA, and the daily retardation of the rising full moon was found by $ME+GE_6$. Of course, these retardations are connected to the movement of the moon relative to the sun.[14] ŠÚ+NA measures the setting-time of an ecliptic arc, which I call the moon's elongation-arc. It is situated around the point of the ecliptic in which the opposition took place, and its length equals the moon's movement relative to the sun on the day of opposition. ME+GE$_6$ measures its rising-time.[15] From cuneiform texts we know that, in average, the elongation movement of the moon was taken to be 12°/day. These insights can be combined and for each month used to find the rising-time and setting-time of 12° (and, hence, also for n°) of the ecliptic. This I have done, and then simply taken the setting times of month M to be the setting-times of the zodiacal sign M. It turns out, that the numerical function for rising arcs found by means of the procedure text No. 201 (ACT pp. 239–240, Neugebauer 1955) represents a really good fit to the values found by means of the sum ME+GE$_6$. It is, therefore, possible that the Babylonian astronomers found their numerical functions for setting and rising arcs of the ecliptic by means of the sums ŠÚ+NA and ME+GE$_6$.

The second method. In the Diaries as well as in the Goal-Year tablets we find remarks, concerning the first or last visibility of planets, like: "Month VII ... On the 13th, sunset to setting of Saturn, 18 UŠ measured... around the 18th Saturn's last appearance [which took place] in Scorpius".[16] Such remarks indicate that the Babylonians knew for each planet how much time there should pass between sunset and setting of the planet at its last visibility in case of good visibility conditions, and that they used this empirical knowledge to adjust observations. According to the text quoted above, the time from sunset to the setting of Saturn was on day 13 measured to be 18 UŠ. However, 18 UŠ must have been longer than the ideal value. The Babylonians accordingly estimated that Saturn in principle could be visible 5 days later, and hence have its last visibility on the 18th. In the following, by 'visibility time', I mean the time from sunset to the setting of Saturn or the time from the rising of Saturn to sunrise. Behind this practice of correcting the day of last (and first) visibility, there seems to lay some knowledge of how much the visibility time is getting shorter (or longer) per day. And this knowledge can easily be found through observation.

One way of doing it would be to observe the visibility time say 10 days before last visibility and again on the day of last visibility (or at first visibility and again 10 days later). The difference in visibility times is a measure of the movement of the sun relatively to Saturn. But since Saturn moves extremely slowly, it can be taken to be at rest. Therefore, the difference in visibility times gives direct information on the sun's movement. It measures the setting-time or rising-time, respectively, of that ecliptic arc which is traversed by the sun during the 10 days in question.

Therefore, there exists an easy method for determining rising-times and setting-times of ecliptic-arcs by observation. For each zodiacal constellation, one just has to record the visibility times of Saturn at relevant time-intervals around conjunction. Let Saturn (e.g., in Aries) rise 18 UŠ before sunrise at its first visibility. And let the visibility-time measured 10 days later be 24 1/2 UŠ. The difference in visibility times is 6 1/2 UŠ. Assuming a solar velocity of 1 UŠ per day leads to the result, that the rising-time of 10 degrees of Aries equals to 6 1/2 time-degrees.

I do not claim, that this method was known to or invented by the Babylonians, although it is possible that it was. I just wanted to demonstrate that it is possible to find realistic values for rising arcs of the ecliptic with other means than spherical geometry. By the methods explained above one can evidently only determine the values for the geographic latitude where the observations are undertaken. So clearly, Ptolemy's method is superior.

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NOTES

1. MUL.APIN is an astrological-astronomical compendium, compiled around -1000; the preserved tablets were written c. -700.
2. I use the translation by H. Hunger (Hunger and Pingree 1989, pp. 72–75); with some small corrections as proposed in Hunger and Pingree 1999, pp. 75–76). The minas mentioned in the text give the length of the whole day or night and not just the length of a watch; 40 NINDA is the change of the day's length, and not the change in the sun's rising position; and Pingree reads the head of the "Great One", instead of the head of the "Lion" by winter solstice.
3. One might speculate about the kind of considerations that lead the Babylonians to conclude that the Sun and planets travel the same path as the Moon. This conclusion was perhaps based on connections found by observing both the daily movement of the celestial bodies across the sky and their risings at the horizon. The rising points of the Moon, Sun and planets all move northwards and southwards over the same interval along the eastern horizon. Each rising point is connected to a daily path that is a result of the diurnal motion of the celestial sphere. When a celectial bodies rise to the north, its path will be high on the sky; while the path will be lower on the sky when it rises to the south. The path of the Moon or a planet will be along the path of nearby stars; the same is true for the sun when it rises near the rising point of a star at its first visibility in the east, just before sunrise. In short, the claim that the Sun, Moon, and planets travel the same path may be based on the observation that over the course of time they all come to share the same daily paths. Observing which fixed stars and constellations are on these daily paths will facilitate describing this path. It should be mentioned that the expression used in MUL.APIN which is translated by "path" is the summerogram "KASKAL". And this sign seems to indicate the path by a crossroads: KASKAL in its archaic form looks like the crossing of two roads, i.e., the point of intersection at which the decision about which path to take is made. MUL.APIN treats

the path of the sun, moon, and planets; the daily path of each of these celestial bodies is uniquely determined by its rising point at the eastern horizon.

4. See Blomberg and Henriksson 1999 and the references given in that paper.
5. From many examples in Bowen and Goldstein 1988 it is evident, that early Greek astronomers were especially concerned with horizontal observations.
6. The translation here is taken from Berggren and Thomas 1996, pp. 43–44. On pp. 10–13 Berggren and Thomas have argued that it was probably not Euclid who wrote this introduction. But since it refers to observations of rising-positions of stars as well known phenomena it is still worth quoting. For the words of the authors fit the introduction "well with the rest of the treatise. For it complements the demonstrations contained in the propositions by arguing for the hypotheses on the basis of the phenomena ... and then by showing how these work together to give the reason for the phenomena".
7. According to Bowen and Goldstein 1988, p. 55, we do not have evidence of celestial mapping as opposed to mere description of the heavens until Eudoxus.
8. Panchenko (1999, p. 34) seems partly to have reached the same conclusion. He writes: "But it is hardly possible to discover the circle of the zodiac without discovering that this circle is inclined relatively to the celestial equator and the other so called parallel circles. Both discoveries in fact should have come together." He, however, seems to presuppose the model of a celestial sphere and claims Oenopides to be the inventor of the zodiac.
9. *Almagest* 1.8–2.9. See e.g. Manitius 1963, pp. 20–100, or Toomer 1984, pp. 45–104.
10. In MUL.APIN the schematic year shows up at several places, for instance in a scheme where the daily retardation of the moon (at new moon and full moon) was given as a function of the length of the night, the length of the night being a function of the date in the ideal year. This ideal year had 12 months of 30 days each; but it was known that, in reality, the lunar months were of different length, and that sometimes one month should be added, resulting in a year of 13 months. MUL.APIN, the Diviners Manual (edited in Oppenheim, 1974 pp. 197–220), and a part of the tablet TU 11, give indications as to how the Babylonian astronomers allowed for deviations from the scheme – and how they used the schemes for astronomical predictions. Seen from this perspective, the schematic year and the astronomical schemes of MUL.APIN can be understood as some practical approximations to nature by means of 'round numbers' about which the real quantities are known to fluctuate.
11. The *Kalendertext* tablets BM 96258 and BM 96293 come from a purchased collection which contains a substantial number of Neo-Babylonian tablets covering the time from Nebuchadnezzar to Artaxerxes.
12. The unit UŠ was introduced in Mesopotamia and transferred to Greece. It equals our time degree: 360 UŠ=1 day (i.e., the time of a whole revolution of the sky), so that 1 UŠ=4 minutes is the time it takes one degree of the equator to rise (above the horizin).
13. See Sachs 1948, pp. 282–285.
14. And this was known to the Babylonians. As mentioned above, section 19 of tablet TU 11 identified the retardation of the rising moon with its movement relative to the sun.
15. For further details, see Brack-Bernsen and Schmidt 1994.
16. See Sachs and Hunger 1989, II p. 31. Later in the same Diary, under the next month VIII we read "The 23rd, Saturns' first appearance in Scorpio". Evidently, Saturn is in Scorpio, and its last visibility took place in month VII and it became visible again in the next month VIII. But note that the time from sunset to setting of Saturn was measured on the 13th but not on the 18th. Therefore we know that Saturn was observed on the 13th, but probably not on the 18th, this date being predicted.