Aristarchus of Samos and Graeco-Babylonian Astronomy

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IN THE HALF CENTURY following the death of Alexander the Great the history of astronomy amongst the Greeks is dominated by Aristarchus the Samian, who is best known for his theory of the earth's revolution about the sun. His life cannot be dated exactly, but it is clear that he was already of mature age by 280 B.C., for Ptolemy states that "the men around Aristarchus," that is to say his pupils, observed the summer solstice in that year, the 50th of the first Callippic period [Ptolemy, *Almagest* 3.1]. He was a pupil of Strato the Lampsacene, who succeeded Theophrastus as head of the Lyceum in *ca.* 288/7 B.C. [Apollodorus 244 F 40] and remained in that post for eighteen years till his death not later than 269 B.C. [Apollodorus 244 F 350]. The date of the publication of Aristarchus's heliocentric theory is not known, but the doctrine was attacked by Cleanthes the Stoic[1] and so must have been well known by 232 B.C., when Cleanthes died; but the heliocentric hypothesis may have been formulated much earlier than that.

Vitruvius spoke highly of the versatility of Aristarchus in geometry, astronomy, and music [*De Architectura* 1.1.16], and ascribes to him the invention of two kinds of sundial—the hemispherical σκάφη and the disc in the plane [9.8.1].[2] He perhaps made use of these improved instruments in his observations of the solstices. We are also told that Aristarchus studied vision, light, shadows and colours,[3] subjects which had also interested his master Strato. It is likely indeed that Aristarchus had close ties with the Lyceum, for not only was his master a distinguished Peripatetic, but also the heliocentric hypothesis was attacked by the Stoic Cleanthes.

In his discussion of the length of the year Censorinus[4] stated that astronomers were not able to determine exactly the time taken by the

[1] Plutarch, *De Fac. Lun.* 6; Diog. Laert. 7.174.
[2] See also Rehm, *Athen.Mitt.* 36 (1911) 253.
[3] Diels, *Doxographi Graeci* pp. 404 with 853; 313–314.
[4] *De Die natali* 19, p. 57 ed. O. Jahn (Berlin 1845)=p. 40 ed. F. Hultsch (Leipzig 1867).

sun to return to the point in the twelve signs of the zodiac from which it had started. Philolaus, he explains, had held the year to be $364\frac{1}{2}$ days long, but Aphrodisius (who is otherwise unknown) gave its length as $365\frac{1}{8}$ days. Censorinus continues, according to Jahn's text, *Callippus autem* CCCLXV, *et Aristarchus Samius tantundem et praeterea diei partem* ∞DCXXIII. We need to add ‹*et diei partem quartam*› after CCCLXV, for we are told elsewhere[5] that Callippus estimated the length of the year to be exactly $365\frac{1}{4}$ days. There is some difficulty over the number ascribed to Aristarchus also, because manuscript R, Hultsch's V, (Codex Vaticanus, *Saec.* X) has the number MDCXXII (1622), but D (Codex Darmstadiensis, *olim* Coloniensis, *Saec.* VII according to Jahn and Hultsch) has *mille* DCXXIII (1623), which Jahn prints. The reading of the older manuscript, which implies that Aristarchus held the length of the year to be $365\frac{1}{4}+\frac{1}{1623}$ days long, is preferable here, as can be seen from a simple calculation.

In the *Almagest* Ptolemy remarks that "the even earlier astronomers," earlier than Hipparchus that is,[6] believed that in $6585\frac{1}{3}$ days the sun passed through the zodiac circle 18 times and 10° 40′ more. To obtain whole numbers they trebled the period, and stated that in 19756 days the sun passed through the zodiac circle 54 times and 32° more. This period, Ptolemy adds, was called by the Greek name *exeligmos* "unravelling," no doubt because it was unravelled into whole numbers from the shorter period of $6585\frac{1}{3}$ days. To obtain the length of the sidereal year used in the *exeligmos* we divide 19756 by $54\frac{32}{360}$. Now $54\frac{32}{360} = \frac{19472}{360} = \frac{2434}{45}$. And $\frac{19756}{1} \div \frac{2434}{45} = 365\frac{1}{4} + \frac{1.5}{2434}$. Since the Greeks liked to write their fractions with 1 as numerator, the length of the year would have been given as $365\frac{1}{4}+\frac{1}{1623}$ to two places of fractions. This is the very length of the year in days ascribed to Aristarchus of Samos by manuscript D of Censorinus.

Since no other Greek astronomer is stated to have given $365\frac{1}{4}+\frac{1}{1623}$ days as the length of the year, Aristarchus may well have given the *exeligmos* its name, having taken over the period $6585\frac{1}{3}$ days and trebled it. It is clear moreover that Aristarchus learned of the period $6585\frac{1}{3}$

[5] Ptolemy, *Almagest* 3.1 (vol. 1, p. 145 Manitius).

[6] In *Almagest* 4.2 (vol. 1, pp. 194ff Manitius) Ptolemy distinguishes the παλαιοί (=οἱ πρὸ ἡμῶν), including Hipparchus, from οἱ ἔτι παλαιότεροι, the forerunners of Hipparchus. See A. Rome, *Studi e Testi* 106 (Vatican 1943) 971 n.2.

days from the Babylonians, for in his discussion of the period Ptolemy [*Almagest* 4.2][7] states that in 6585⅓ days there were

223 synodic months (μῆνας),
239 anomalistic months ("restorations of anomaly" ἀποκαταστάσεις ἀνωμαλίας),
242 draconitic months (ἀποκαταστάσεις πλάτους), and
241 sidereal months (περιδρομὰς μήκους).

Ptolemy adds that these period relations had been used by "the still earlier observers," amongst whom we may now include Aristarchus, and remarks that Hipparchus showed the equivalences to be inaccurate. Ptolemy does not mention the Babylonians or Chaldaeans in connexion with the *exeligmos*, but Geminus [*Elementa* 18] in his discussion of the period states that the Chaldaeans found the mean daily motion of the moon to be 13;10,35°, a value that is also used in the astronomical cuneiform texts. All the essential parameters of the period of 6585⅓ days (and so of the *exeligmos*) are found in *Astronomical Cuneiform Texts ed.* O. Neugebauer (Princeton/London 1955) No. 210, a procedure text for Systems A and B of the Babylonian lunar theory. The conclusion to be drawn from Aristarchus's length of the year is, then, that already by the middle of the third century B.C. a Greek astronomer had adopted and used Babylonian astronomical parameters. This was suggested long ago by P. Tannery[8] and is now confirmed by the cuneiform texts. Amongst the earlier astronomers whose work Hipparchus corrected and improved from his own and Chaldaean observations[9] therefore must be numbered Aristarchus of Samos.

The text of Censorinus 18 [p. 55, 15 Jahn] ascribes to Aristarchus a Great Year or *annus* ἡλιακός of 2484 years. This number is almost certainly corrupt, as Tannery pointed out, because Aristarchus calculated that one year was $365+\frac{610}{2434}$ days long. It is reasonable to suppose that he multiplied by 2434 to produce a Great Year of 2434 years+ 610 days= 2435 years+ 245 days, and to change the text of Censorinus so as to read *hunc* (*sc. annum*) *Aristarchus putavit esse annorum vertentium* II CCCCXXXIIII, . . . The context in Censorinus shows that the interval of 2434 years was in Aristarchus's opinion the interval between alter-

[7] See also A. Aaboe, *Centaurus* 4 (1955–56) 122.

[8] P. Tannery, *Mémoires scientifiques* 2 (Toulouse 1912) pp. 345–366. See also F. X. Kugler, *Babylonische Mondrechnung* (Frieburg/Br. 1900) pp. 4ff.

[9] Ptolemy, *Almagest* 4.2 (vol. 1, p. 196, 12–13 Manitius).

nate conflagrations and inundations of the world when the sun, moon, and stars all return to the same zodiacal sign.

It is very difficult to trace exactly the adoption of Babylonian ideas by the Greek astronomers. An active part in the diffusion of Babylonian astronomy is often ascribed to Berosus the Chaldaean, who was a contemporary of Aristarchus, and had a doctrine of cataclysms similar to his; for Berosus claimed that when all the planets were in Cancer the earth would be burned, and when they were in Capricorn there would be a flood.[10] But an examination of the astronomical fragments of Berosus suggests that he had a very inadequate knowledge of the subject. His views on the moon's phases are reported by Vitruvius,[11] who contrasts them with the explanation given by Aristarchus. It looks indeed as though Aristarchus set out deliberately to refute the views of his Babylonian contemporary, who settled in Cos, not far from Samos, the home of Aristarchus. Berosus supposed that the moon had light of her own, one half of her orb being luminous and the rest of a blue colour. The moon's phases thus in his view were caused by her luminous half being turned towards or away from the earth. Aristarchus, however, maintained that the moon receives her light from the sun, so that on the fourteenth day of the month when she is in opposition to the sun, she is full and rises when the sun is setting. Vitruvius shows that Aristarchus explained the first and last quarters and the new moons as well; and it is obvious from Aristarchus's book on the sizes and distances of the sun and moon that Berosus had nothing to teach the Samian about the phases of the moon. No doubt Aristarchus applied what he had learned from Strato and his own theory about light and shadow to the moon's phases and to eclipses also. The most obvious objection to Berosus's doctrine was that it failed to explain lunar eclipses, as Cleomedes [2.4] pointed out. It is most unlikely that Berosus had anything worth while to teach the Greeks about theoretical astronomy, though he did have a cursory interest in the subject, having treated it in the first book of the *Babyloniaca*.[12]

We are told also that he maintained that Babylonian astronomical records did not go back before the time of Nabonasar, that king

[10] *FGrHist* 680 F 21.

[11] 9.1.16–9.2.2 (Berosus fr. 22 Schnabel). See also Cleomedes, *De Motu circulari* 2.4, pp. 180–182 Ziegler, and O. Neugebauer, *Proc.Amer.Philosoph.Soc.* 107 (1963) 529.

[12] P. Schnabel, *Berossus* (Leipzig 1923) 19.

having destroyed the earlier ones.[13] In view of this clear statement it is surprising to find that according to our texts of Pliny[14] Berosus held that observations of the stars had been inscribed on baked tablets for 480,000 (!) years (490,000 in some copies). If we read CCCCLXXX for $\overline{\text{CCCCLXXX}}$ we can reduce the period to 480 years. Now Berosus dedicated his *Babyloniaca* to Antiochus I Soter,[15] who reigned from 281/0 to 262/1 B.C., and if we add 480 to a year in the reign of that king we are brought close to the epoch of Nabonasar. I think it likely therefore that Berosus stated that accurate observations had been made in Babylonia for 480 years from the time of Nabonasar,[16] and that earlier observations were not available to him. This suggestion is supported by the failure of Ptolemy in the *Almagest* to cite any Chaldaean observations earlier than the time of Nabonasar. If Ptolemy's dating of the first year of Nabonasar to 747 B.C.[17] was the same as Berosus's, then we have a date for the publication of the *Babyloniaca*, 480 years after 747 B.C. or 267 B.C., a year well within the reign of Antiochus I to whom the work was dedicated.

Like Aristarchus, Berosus was interested in sundials. His dial is said to have been semicircular, hollowed out of a square block, and cut under to correspond to the polar altitude.[18] The Babylonian was also interested in astrology, for Vitruvius[19] declares that Berosus founded an *astrological* school in Cos, and a remark by Pliny[20] confirms that he had a knowledge of technical astrology. According to Pliny, Epigenes held that a man could not live as long as 112 years, but Berosus claimed that a man could not live more than 116. We have

[13] *FGrHist* 680 F 16a.

[14] *NH* 7.193 (*FGrHist* 680 F 16b): Epigenes apud Babylonios $\overline{\text{DCCXX}}$ annorum observationes siderum coctilibus laterculis inscriptas docet, gravis auctor in primis; qui minimum, Berosus et Critodemus $\overline{\text{CCCCLXXX}}$, [ex quo apparet aeternus litterarum usus]. Fr. 16a and fr. 16b are cited by Jacoby as coming from "(Pseudo–) Berossos von Kos."

[15] *FGrHist* 680 T 2.

[16] This suggestion was made long ago by Worth; see Clinton *Fasti Hellenici* III (Oxford 1830) 505. The apparatus criticus of Sillig's edition (vol 2 [Hamburg and Gotha 1852] p. 61) is the fullest at Pliny *NH* 7.193. He notes that Perizonius added M to each of the numbers of years ascribed to Epigenes and Berosus. All manuscripts agree on DCCXX for Epigenes's figure, and β (Editio Dalecampiana), which represents one of the best MS traditions (see Sillig's *Praefatio*, vol. 1, p. lxiii), has CCCCLXXX for Berosus's. Perizonius was presumably led to introduce his two M's by the high antiquity for Babylonian observations claimed by Cicero (*De Div.* 2.46.97 and 1.19.36) and Diodorus (2.31.9). *Cf.* Schnabel, *Berossus* pp. 251–252.

[17] Ptolemy, *Almagest* 3.7 (vol. 1, p. 183, 6 Manitius).

[18] Vitruvius 9.8.1.

[19] 9.6.2. In 9.2.1 Vitruvius states vaguely that Berosus also taught in Asia.

[20] *NH* 7.160. See also Censorinus, *De Die nat.* 17.4.

here an allusion to the astrological doctrine that the number of years in a human life can never exceed the maximal possible number of degrees which is necessary for one quarter of the ecliptic to rise. As Neugebauer has shown,[21] Epigenes's remark applies to the latitude of Alexandria, but Berosus is speaking of Babylon. It is just, I think, to regard Berosus as an astrologer who brought his doctrines to Cos, but there is no sign that he helped to advance the study of astronomy amongst the Greeks. He belongs rather to the genethlialogists at Babylon, whom, Strabo reports, the geniune astronomers did not admit to their number.[22] Yet there may still be some truth in the statement of Josephus that Berosus introduced astronomical doctrines of the Chaldaeans to the Greeks, as well as their philosophical doctrines;[23] just as there is perhaps a sound basis for the remark of Moses of Chorene[24] that Ptolemy II Philadelphus (in whose empire Cos lay) incited Berosus to translate Chaldaean records into Greek. By Georgios Synkellos also the same Ptolemy, who reigned from 283 to 247 B.C., is said to have had Chaldaean works collected for his library and to have had them translated.[25]

If Berosus was not the bringer of Chaldaean astronomical knowledge to Aristarchus, then a possible intermediary is Epigenes. This scholar, who came from Byzantium,[26] is almost certainly a near contemporary of Aristarchus and Berosus, though various views about his date have been held.[27] His views are twice mentioned next to those of Berosus, once on the antiquity of Babylonian astronomical records[28] and once on the greatest length of human life.[29] His remark that a man could not live more than 112 years applies to the latitude of Alexandria, and shows that Epigenes had worked there. From Seneca[30] we learn also that he and Apollonius of Myndus had studied amongst

[21] *Trans.Amer.Philosoph.Soc.* 32 (1942) 260. See also Honigmann in *Michigan Papyri* III, pp. 307ff (Univ. of Mich. Humanistic Ser. XL [1936]).

[22] Strabo 16.739.

[23] Josephus *c. Ap.* 1.129.

[24] *Hist.Arm.* 1.1 (*FGrHist* 680 T 4).

[25] Georgios Synkellos p. 516, 6f (Bonn.)

[26] Diels, *Doxographi Graeci* 195.

[27] Honigmann in *Michigan Papyri* III, pp. 310–311 (see *supra* n.21) proposed to date him in the time of the second Lagid. The evidence is also discussed by Kroll, *Hermes* 65 (1930) 1–13. Boll (*Neue Jahrb.* 21 [1908] 106) preferred a date soon after Berosus. See also F. Susemihl, *Geschichte der gr. Litt. in d. Alexandrinerzeit* I (Leipzig 1891) 718 n.62.

[28] Pliny *NH* 7.193.

[29] Pliny *NH* 7.160 and Censorinus *De die nat.* 17.4.

[30] *NQ* 7.4.1 Compare also Kroll in *RE* Supplementband 5 (1931) Kol. 45, and F. Boll, *Sphaera* (Leipzig 1903) 368.

the Chaldaeans, in Babylon itself presumably, as Epigenes's reference to astronomical cuneiform texts—*observationes siderum coctilibus laterculis inscriptas*[31]—suggests. His statement that the astronomical records went back 720 years, not 480, looks like an attempt to correct Berosus. When we add that Epigenes believed that children could be born in the seventh month,[32] a view also held by Strato, Aristarchus's teacher; and find that Epigenes was, like Strato, interested in comets,[33] the case for dating him early in the third century looks strong, if not conclusive. But it is pointless to speculate about any ties he may have had with Aristarchus.

Finally, to return to Aristarchus himself, it is worth noting that $365+\frac{1}{4}+\frac{1}{1623}$ is not the only length of the year in days ascribed to him. In a corrupt passage in Vettius Valens[34] occurs the following:

> *τὸν μέν γε ἐνιαυτὸν ἄλλοι ἄλλως διέλαβον· Μέτων μὲν ὁ ᾿Αθηναῖος καὶ Εὐκτήμων καὶ Φίλιππος τξε′ ε′ ιθ′, ᾿Αρίσταρχος δὲ ὁ Σάμιος δ′ κ′ ξβ′, Χαλδαῖοι τξε′ δ′ ε′ ζ′, Βαβυλώνιοι δὲ τξε′ δ′ ρμδ′, καὶ ἕτεροι δὲ πλεῖστοι ἄλλως.*

This is Kroll's text, but parts of what he printed make no sense. The text correctly ascribes to Meton, Euctemon and Philip a year of $365\frac{5}{19}$ days, and the year of "the Babylonians" makes sense, $365+\frac{1}{4}+\frac{1}{144}$. The numbers ascribed to Aristarchus and "the Chaldaeans" however cannot be interpreted as fractions, and emendation is needed. We should perhaps read *᾿Αρίσταρχος δὲ ὁ Σάμιος ‹τξε′› δ′ ρξβ′, Χαλδαῖοι τξε′ δ′ ρζ′*, *i.e.* $365+\frac{1}{4}+\frac{1}{162}$ and $365+\frac{1}{4}+\frac{1}{107}$, or written sexagesimally 6,5;15,22,13,20 and 6,5;15,33,37, . . . The length of the sidereal year ascribed by conjecture here to Aristarchus is at least plausible, for the modern length of the year is close to 6,5;15,23 days.[35] Yet another corrupt number of days in the year is ascribed to Aristarchus by a list of Kanonographoi,[36] in which we find *τξε′ δι′ δ′ ᾿Αρίσταρχος σαβῖνος* [*σαβῖνος codex: Σάμιος* Maass]. As printed by Maass the fractions make no sense: possibly we should read *τξε′ δ′ ρδ′* that is $365+\frac{1}{4}+\frac{1}{104}$ days (6,5;15,34,36, . . .). This

[31] Pliny *NH* 7.193.

[32] *Doxographi Graeci* 195.

[33] *ibid.* 225f.

[34] *Anthologiae* 9.11, p. 353 Kroll.

[35] B. L. van der Waerden, *Vierteljahrschr. d. Naturforsch. Gesellschaft in Zürich* 100 (1955) 162.

[36] E. Maass, *Aratea* (Berlin 1892) 140.

is quite close to the length of year assumed in System B of the Babylonian lunar theory (6.5;15,34,18). Nothing can be made of these corrupt numbers, but they do suggest that Aristarchus had made several attempts to determine the length of the sidereal year.

Amongst the contemporaries of Aristarchus were the astronomers Timocharis and Aristyllus. Plutarch[37] mentions all three men together with Hipparchus, saying that they made their subject not less famous by writing about it in prose: *οὐδ' ἀστρολογίαν ἀδοξοτέραν ἐποίησαν οἱ περὶ Ἀρίσταρχον καὶ Τιμόχαριν καὶ Ἀρίστυλλον καὶ Ἵππαρχον καταλογάδην γράφοντες*. The work of Timocharis and Aristyllus and their school can be dated from the *Almagest*.[38] Ptolemy[39] remarks that Timocharis at Alexandria observed on 29 January 283 B.C. the moon's position with respect to the Pleiades, and earlier on 9 March 294 B.C. her position relative to Spica,[40] and again relative to Spica on 9 November 283.[41] Ptolemy also quotes an observation of the moon and Scorpio by Timocharis on 21 December 295 B.C.[42] and an observation of Venus made on 12 October 272 B.C.[43] Aristyllus is linked with Timocharis by Ptolemy,[44] but observations by Aristyllus alone on the declinations of fixed stars are quoted;[45] hence they sometimes worked independently. The dated observations of Timocharis extend from 295 to 272 B.C., and so fall within the lifetime of Aristarchus, who according to Hipparchus observed the summer solstice in 280 [*Almagest* 3.1]. In this passage Hipparchus mentions the "school" of Aristarchus, by which he may have meant Timocharis and Aristyllus; he made use of their observations as well as those of Aristarchus in his work on the length of the year and the precession of the equinoxes. Obviously these observations of the early third century B.C. would have been most valuable to him if they were all made in the same latitude, that of Alexandria, and though there is no statement extant that Aristarchus worked in

[37] *De Pyth. Or.* 18.
[38] *Laterc. Heraclianus* in *Mon.Germ.A.A.* 13 (Berlin 1898) 448 dates Timocharis to the time of Ptolemy I.
[39] *Almagest* 7.3 (vol. 2, p. 22 Manitius).
[40] *ibid.*, 7.3 (vol. 2, p. 24 Manitius).
[41] *ibid.*, 7.3 (vol. 2, p. 25 Manitius).
[42] *ibid.*, 7.3 (vol. 2, p. 27 Manitius).
[43] *ibid.*, 10.4 (vol. 2, p. 167 Manitius).
[44] *ibid.*, 7.1 (vol. 2, p. 4 Manitius).
[45] *ibid.* 7.3 (vol. 2, pp. 18–19 Manitius).

Alexandria, it is very likely that he, Aristyllus, and Timocharis were making observations jointly there about 280 B.C. Hipparchus, who did not accept the heliocentric hypothesis, must have found the observations of Aristarchus much more valuable and interesting than his doctrine of the moving earth.[46]

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[46] I thank Professor O. Neugebauer for reading and improving a draft of this paper.