Evidence for Babylonian Arithmetical Schemes in Greek Astronomy

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The Greek astronomers of the late Hellenistic and Roman periods were fully conscious that their science drew on an earlier 'Chaldean' or 'Babylonian' astronomy; and this fact has never since been wholly forgotten. Aside from the Babylonian observations cited in Ptolemy's *Almagest* (ten lunar eclipses ranging from 721 to 382 B.C., and three planetary observations between 245 and 229 B.C.), there were numerous references to 'Chaldeans' in astronomical contexts in classical authors. In 1893 Tannery was perceptive enough to guess at the existence of an advanced Babylonian lunar theory that had influenced the Greek science:[1]

> Mais les Chaldéens avaient constitué une véritable théorie du mouvement de la lune qui, si imparfaite qu'elle soit, n'en mérite pas moins toute notre attention, car elle est évidemment l'origine des théories grecques, et elle a singulièrement influé, sinon sur leur forme géométrique, où le génie hellène s'est caractérisé, au moins sur la forme des tables et l'ensemble des procédés de calcul.

But it was the discovery and first analyses (by Strassmaier, Epping and Kugler) of lunar ephemerides in cuneiform tablets that revealed the specific debts of the Greeks to Babylonian theory. Kugler's classic *Babylonische Mondrechnung* (1900) revealed not only that Babylonian astronomers apparently anticipated the Greeks in knowledge of certain astronomical facts (for example, the unequal lengths of the seasons), but also that the precise lunar period relations attributed to Hipparchus in the Almagest were components of the lunar scheme now referred to as System B (Kugler's 'System I').[2]

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[1] Tannery (1893) 185.

[2] Kugler (1900) 20-24 and 40.

A perceptive and still valuable article by Cumont gave publicity to Kugler's discovery; bringing into play two Greek texts that had just come to light in the course of publishing the *Catalogus Codicum Astrologorum Graecorum*, Cumont argued that Sudines, Kidenas, and Naburianus, all 'Chaldeans' named in classical sources, were among the transmitters of the Babylonian mathematical astronomy to the Hellenistic Greeks.[3] The contributions of Schnabel in the 1920s at first seemed to cast new light on the transmission and influence of Babylonian astronomy, but proved in the end to amount to a tangle of speculations founded on tenuous or dubious evidence.[4] Trust in Schabel's misguided attribution of the discovery of precession to Kidenas (whose name Schiaparelli had found on a cuneiform tablet) vitiated an otherwise constructive survey by Fotheringham; in the end Neugebauer systematically demolished Schnabel's whole argument.[5] But one of Schnabel's finds was genuine: a Babylonian scheme for lunar daily motion, based on a 248-day anomalistic period, that was echoed in a Greek text (Geminus) and in Indian astronomy.[6]

After these decades of probing, Neugebauer initiated, and largely carried out himself, a systematic analysis of all the available astronomical documents of antiquity. In his work the investigation of the relations between Babylonian and Greek mathematical astronomy broadened from a matter of isolated parameters to one of transmitted methods and concepts. Surveys that he published between 1956 and 1975 show how the body of relevant evidence was expanding, but nevertheless express extreme caution about the means, magnitude, and influence of the transmission.[7] In his *History of Ancient Mathematical Astronomy* Neugebauer expressed his doubts as follows :

> It is much more difficult, however, to determine with reasonable accuracy the time of transmission or the mode of contact and to evaluate correctly the degree and importance of the influence of Babylonian astronomy on the nascent Greek science. Without insight into specific technical details one can easily overemphasize influences which in fact do not require more than the transmission of a few basic concepts....
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> For the Greek lunar theory we came to the conclusion that the Babylonian influence did not reach much farther than the communication of some basic concepts and related parameters. In the planetary theory the impact from Babylon seems to be limited even more to the transmission of fundamental period relations.[8]

To some extent this was intended as a corrective to the 'optimism' of the first decades of this century, when elaborate historical reconstructions were being erected on narrow textual evidence that, too often, turned out to consist of a misreading or a misunderstanding. But in fact there were already some evidences, actually discussed in Neugebauer's *History* although not in this context, that argued for a broader and more influential transmission of predictive methods. Among these, the most telling were the unmistakably Babylonian-style planetary schemes in the Sanskrit *Pañcasiddhāntikā* which must have passed through Greek intermediaries even if direct traces of these intermediaries were lacking. And such traces have now begun to turn up in papyri from Roman Egypt and in the *testimonia* for Hipparchus's solar and lunar theory.

What I attempt here is a survey of the current state of evidence for the transmission of specifically theoretical and predictive elements of Babylonian astronomy, and in particular the arithmetical schemes of the Seleucid and Parthian periods (the so-called *ACT* schemes), into Greek.[9] I omit discussion of general concepts, conventions, and metrology, some of which may have entered Greek use in conjunction with the predictive schemes, as well as the Babylonian observational records, which I think ought to be treated as a separate problem of transmission.[10] Even within my scope, new material is certain to turn up in coming years, especially from the many unexamined and unpublished astronomical papyri.

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[3] Cumont (1910).

[4] Schnabel (1923) and (1927).

[5] Schiaparelli (1908); Fotheringham (1928); Neugebauer (1950).

[6] Schnabel (1927) 35 and 60 n. 3.

[7] Neugebauer (1956), (1963), (1967), (1975) 589-614.

[8] Neugebauer (1975) 589-590 and 604.

[9] *ACT* is the acronym of Neugebauer (1955), the comprehensive edition of the relevant texts.

[10] For a partial review of these aspects, see Toomer (1988).

Period relations

The period relations that pervaded Babylonian astronomy even before the rise of the *ACT* schemes also seem to have been among the first theoretical elements to enter Greek astronomy. By far the earliest instance is Meton's use (ca. 432 B.C.) of the 19-year luni-solar period

(1) 19 years = 235 synodic months

in a calendric cycle.[11] About a century and a half later, we have oblique evidence for the 18-year 'Saros' eclipse period. Ptolemy (*Almagest* IV 2) describes this period relation (which he calls the 'Periodic') as a 'somewhat crude estimate' used by the 'still more ancient astronomers' (i.e. more ancient than Hipparchus and the other astronomers who attempted to find an accurate period of lunar anomaly), and defines it as follows:

(2) 6585 $^1/_3$ days = 223 synodic months
= 239 anomalistic months
= 242 draconitic months
= 241 sidereal months + 10 $^2/_3$°
= 18 sidereal years + 10 $^2/_3$°

This formulation goes beyond the Babylonian one (so far as we know) in associating a number of days and a correction for longitude with the 223 synodic months. Ptolemy goes on to say that this period was tripled to form a period, called *exeligmos* or 'turn of the wheel', containing an integer number of days (so that lunar eclipses bounded by the interval would always be visible in the same place):

(3) 19756 days = 669 synodic months
= 717 anomalistic months
= 726 draconitic months
= 723 sidereal months + 32°
= 54 sidereal years + 32°

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[11] Bowen & Goldstein (1988). I cannot here address the vexed question of whether the 19-year cycle was already in civil use in Babylonia at the beginning of the fifth century; but everything that we know about the character of Babylonian and Greek astronomy during this period points to a Babylonian origin for Meton's cycle.

This *exeligmos* is the topic of the last chapter (18) of Geminus's handbook, and Ptolemy's account implies that Hipparchus also knew of it. More remarkably, Tannery showed that an estimate of the length of the year that Censorinus attributes to Aristarchus of Samos (ca. 280 B.C.) was probably derived from the relation between the number of days and sidereal years in the *exeligmos*.[12] It is curious that Aristarchus seems only to have used the elements in the *exeligmos*, that are not known to be Babylonian; this does not of course affect the argument that Aristarchus's use of these numbers implies knowledge of the Babylonian 'Saros'.

In *Almagest* IX 3, Ptolemy lists a set of period relations for the five planets that he says he has taken, with corrections, from Hipparchus:

(4)	Saturn:	57 synodic periods	= 59 (tropical) years + 1 $^3/_4$ days = 2 longitudinal revolutions + 1;43°
	Jupiter:	65 syn. per.	= 71 years – 4 $^9/_{10}$ days = 6 long. rev. + 4 $^5/_6$°
	Mars:	37 syn. per.	= 79 years + 3;13 days = 42 long. rev. + 3 $^1/_6$°
	Venus:	5 syn. per.	= 8 years –2;18 days = 8 long. rev. –2 $^1/_4$°
	Mercury:	145 syn. per.	= 46 years + 1 $^1/_{30}$ days = 46 long. rev. + 1°

Hipparchus's period relations are based on the goal-year periods discovered by Sachs in the Goal-Year Texts (we cannot tell whether Hipparchus, like Ptolemy, gave corrections for the dates and longitudes of recurrence).[13] Ptolemy does not allude to the alternative goal-year periods for Jupiter and Mars. However, the 83-year period for Jupiter is mentioned in a Greek astrological text from late antiquity (attributed to Heliodorus, *c.* A.D. 500) in conjuction with the periods for the other four

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[12] Tannery (1888).

[13] First remarked by Neugebauer (1956) 294-295.

planets known to Ptolemy; and the same set of five periods underlay the Almanac of Heliodorus's brother Ammonius.[14]

Planetary schemes

The evidence for transmission of the *ACT* planetary theory is all later than Hipparchus. The long period relations on which the predictive schemes are based appear in Greek astrological sources of insecure date, for example Antiochus.[15] As for the schemes themselves, van der Waerden's analysis of the data for Mars in one of the Greco-Egyptian Sign-Entry Almanacs (the Stobart Tablets) yielded definite proof of use in Roman Egypt of the System A Mars scheme, with its six-zone division of the ecliptic.[16] The time intervals between Mars's predicted sign entries in these tables point to the use of a velocity scheme as yet unattested in cuneiform sources but compatible with the synodic arcs prescribed in the original System A scheme. On the other hand, the papyrus P. Heid. Inv. 4144 + P. Mich. 151 tabulates a new set of synodic arcs for the System A zones.[17] Van der Waerden also tried to demonstrate that the data for Jupiter in the Almanacs were computed according to System A', but the argument is less conclusive.[18] The third-century papyrus Dublin Inv. TCD Pap. F. 7 lists daily longitudes for Venus according to a scheme of linear interpolation between characteristic moments in the synodic cycle, and shows close affinities with the fragmentary evidence for Babylonian schemes for this planet.[19]

The principle of interpolating daily motion by higher-order arithmetical sequences between precomputed planetary phases is attested in two Babylonian ephemerides, and has an interesting descendent in the Greek so-called template schemes.[20] The Greek templates P. Carlsberg 32 (Mercury) and P.S.I. 1492 (Saturn) set out a standardized mean synodic cycle of daily longitudes following linear and second-order sequences between phases. The longitudinal intervals and times between phases in the template for Saturn closely resemble mean values from the Babylonian velocity scheme (*ACT* nos. 801 and 802).

Sanskrit texts based on translations of Greek treatises also contain descriptions of planetary motion clearly based on *ACT* patterns, although again with modifications.[21] Thus the *Yavanajātaka* of Sphujidhvaja (A.D. 269/270), adapting a translation (A.D. 149/150) of a Greek astrological treatise, sets out Babylonian-style linear velocity schemes bridging the phases of the five planets.[22] Each of these patterns was apparently meant to apply throughout the ecliptic, so that no allowance is made for variations in the spacing between the phases as in the System A and B schemes. The lost treatise of Vasiṣṭha, summarized in the *Pañcasiddhāntikā* of Varāhamihira (ca. A.D. 500), also gave single linear velocity schemes for Saturn, Jupiter, Venus, and Mercury, but for Mars it has six variant schemes associated with the six System A zones, and, for Mercury, a complex scheme that closely resembles the Babylonian System A rules.[23] One element of Vasiṣṭha's account is Babylonian without compromise: his retrogradation scheme for Mars (or one version of it) is precisely the Scheme R associated with System A.

Lunar schemes

The *ACT* lunar schemes bring us back to Hipparchus. Ptolemy (*Almagest* IV 2) tells us that Hipparchus established the following eclipse period:

$$\begin{aligned} (5)\quad 126007\ {}^{1}/_{24}\text{ days} \quad &= 4267 \text{ synodic months}\\ &= 4573 \text{ anomalistic months}\\ &= 4612 \text{ sidereal months} -7\ {}^{1}/_{2}^{\circ} \end{aligned}$$

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[14] Neugebauer (1975) 605 n. 6 and 1037; Boutelle (1967). Ammonius is named in the so far unpublished version of the 'Heliodorus' text in *Par.gr.* 2425, confirming the medieval tradition associating the Almanac with him.

[15] Neugebauer (1975) 605-606.

[16] Van der Waerden (1972), developing arguments in van der Waerden (1947) and (1960). The Sign-Entry Almanacs are tables listing dates of entry into zodiacal signs and sometimes also synodic phenomena for each of the five planets; they have an obvious affinity with the Babylonian Almanacs.

[17] Jones (1991b).

[18] Van der Waerden (1972).

[19] Jones (1991a).

[20] Huber (1957), Jones (1984).

[21] Compendious summary in Pingree (1978a) 540-542.

[22] Pingree (1978b) v. 2, 411-413.

[23] Neugebauer & Pingree (1970-1971) v. 2, 109-123, and Neugebauer (1975) 472-473.

From this, Ptolemy says, Hipparchus obtained a value for the mean synodic month:

(6) 1 synodic month = 29;31,50,8,20 days

As Kugler realized, this is precisely the Babylonian System B parameter incorporated in Column G.[24] Ptolemy also points out that the equation of synodic and anomalistic months in Hipparchus's eclipse period reduces (dividing by 17) to

(7) 251 synodic months = 269 anomalistic months

in which Kugler recognized the period relation of Columns F and G.[25] And finally, Ptolemy tells us that Hipparchus used the System B period relation for lunar latitudinal motion:[26]

(8) 5458 synodic months = 5923 draconitic months

It is beyond doubt that Hipparchus took these three parameters from System B, and constructed an eclipse period by combining them with a value for the mean number of synodic months in the year, possibly the parameter

(9) 1 year = 12;22,8 synodic months

that runs through the ACT schemes.[27]

Another link between Hipparchus and System B was found by Toomer.[28] Ptolemy (*Almagest* V 3) quotes Hipparchus's report of an observation that he made of the sun and moon in 128 B.C., in which he says that the 'course' (*δρόμος*) was the 241st. This 'course', as Toomer recognized, is the day number in a 248-day period of lunar anomaly beginning with an epoch when the lunar daily motion was at its minimum; this demonstrates that Hipparchus was familiar with the F^* scheme for lunar daily motion

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[24] Kugler (1900) 23-24.

[25] Kugler (1900) 20-21.

[26] Kugler (1900) 40.

[27] Aaboe (1955).

[28] Toomer (1981) 108 n. 12. Discussed in detail in Jones (1983) 24-27.

associated with System B. The exact parameters of the F^* zigzag function are set out by Geminus (18), and a modified version of the function was the central element in the standard Hellenistic scheme for predicting lunar positions.[29]

The schemes for length of daylight applied in column C of the syzygy-tables of both Systems A and B were incorporated in the elaborate arithmetical 'rising-time' schemes of Hellenistic astronomy, no longer connected with lunar theory.[30] We know from an allusion by Pappus (*Collection* VI 109) that Hipparchus used an arithmetic scheme for rising-times. His (probably slightly older) contemporary Hypsicles set out a more or less geometrical justification of the System A pattern, adapted to the ratio 7:5 between the longest and shortest day assumed for the latitude of Alexandria. The earliest known Hellenistic use of the System B pattern occurs in Manilius (III 458-462), for the latitude of Rome. Partly through the widespread use of the rising-time schemes, the Babylonian System B norm for placing the vernal point at Aries 8° appears over and over in Greek contexts from early in the first century B.C.; Manilius (III 681) mentions the System A norm of Aries 10°.[31]

It is only in recent years that other functions from the syzygy-tables have come to light in Hellenistic contexts. In 1988 Neugebauer published a papyrus (2nd or 3rd century) containing a run of consecutive values of Column G of System B, indistinguishable except for notation and medium from a fragment of a Babylonian syzygy tablet.[32] Meanwhile, Hipparchus turns out to have used a modified form of System A's Column B to compute solar longitudes at lunar eclipses.[33]

Finally, one can find occasional passages in Greek astronomical writings that imply an understanding of the workings of the *ACT* lunar schemes. In his extant *Commentary on the Phenomena of Aratus and Eudoxus* (I 9), Hipparchus at one point argues against the alleged latitudinal motion of the sun:

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[29] Jones (1983).

[30] Neugebauer (1975) 706-24.

[31] Neugebauer (1975) 593-98.

[32] Neugebauer (1988).

[33] Jones (1991c).

> For if the sun did not travel the circle through the middle of the signs [i.e. the ecliptic], but wavered to the north and to the south of it, as the moon does, obviously the earth' s shadow too would similarly waver about it. If this were so, then the lunar eclipses ought to disagree by much with the forecasts assembled by the astrologoi, who hypothesize in their methods [ἐν ταῖς πραγματείαις] that the middle of the shadow travels on the circle through the middle of the signs. But they do not disagree by more than two digits, and extremely seldom at that, with the most carefully assembled methods.

There can be no question that these *astrologoi* are the Babylonian astronomers, or other people using the *ACT* procedures : no other method of predicting eclipses with anything like this accuracy existed in Hipparchus's time. Hipparchus means that the Babylonian schemes incorporated no correction to the eclipse magnitude attributable to a latitudinal variation in the earth's shadow (which would mirror any solar latitude). This is true, but it is not the sort of thing that one could know except through considerable familiarity with the *ACT* procedures. Much the same can be said for another seemingly innocent remark by the astronomer Apollinarius (probably 1st century of our era), quoted by an anonymous author of the early third century, that 'the Chaldeans... believed that, with the moon moving at its middle [distances], the latitude is not subject to increase or decrease'.[34] This signifies, in a terminology based on an epicyclic or eccentric lunar model, that the Babylonian schemes make no correction to the lunar latitude to account for the variation caused by lunar anomaly in the moon's elongation from the nodes. Again the statement correctly describes a fact well below the surface of the Babylonian schemes.

The nature of the transmission

In order to estimate the full extent of the Babylonian material that was available to Greek astronomers, we have to weigh the specific Babylonian elements set out in the foregoing section in relation both to their original place in Babylonian astronomy and to the contexts in which they appear in the Hellenistic texts. Proved Greek knowledge of one element can imply knowledge of a host of other elements that are not explicitly attested in our sources. It must be remembered, moreover, that our ability to demonstrate the presence of Babylonian elements in Hellenistic astronomy is restricted by the scarcity of sources for this period in general, and we have to consider whether the sources that we do have, or our methods of analysing them, systematically favour some kinds of Babylonian data over others. This concern most obviously applies to the Babylonian observation reports in the *Almagest*, but it also extends to the testimony for the predictive schemes.

In this light, the pattern of attestations strongly suggests that the *ACT* predictive schemes were in large part available to Greek astronomers. That the lunar System B in particular was brought over more or less intact, is established beyond serious question by the mere existence of Neugebauer's Column G papyrus. Hipparchus's use of many parameters from System B indicate a latest possible date for the transmission of both the syzygy-table and lunar daily motion schemes. Traces of the lunar System A are fewer, but the Hipparchian solar computations demonstrate that he knew of at least part of this scheme too.

The evidence for Greek use of the *ACT* planetary schemes is patchy and relatively late, but this circumstance should probably not lead us to assume a transmission separate from the lunar schemes. What we know of the astronomy of the second century B.C. almost wholly derives from Ptolemy's discussions of Hipparchus's theoretical work; and Ptolemy tells us (*Almagest* IX 2) that Hipparchus made few positive contributions to the theory of the planets' motions. The preserved astronomical writings from between Hipparchus and Ptolemy also do little to inform us about details of planetary theory. Astronomical papyri from Egypt become reasonably numerous only from the second century of our era on, and the earliest translations into Sanskrit also date from about this time. There seems, then, to be no valid reason to dismiss the straightforward hypothesis that the *ACT* lunar and planetary schemes found their way into Greek astronomy at the same time, that is, not later than Hipparchus. The pattern of six equal zones in the System A scheme for Mars is very easy to recognize even in varieties of tables (such as the Egyptian Sign-Entry Almanacs) that are otherwise very resistant to analysis, and consequently we have much evidence for it. The traces of System A for the other planets are less numerous, but cumulatively they make it appear practically certain that System A procedures, including velocity schemes,

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[34] Jones (1991d) 42-43.

were transmitted for all the planets. Planetary System B, on the other hand, has so far failed to appear.

The general pattern of transmission of Babylonian astronomy seems to be a gradual trickle of basic concepts and the occasional parameter from about 500 B.C., followed by a sudden flood of detailed information in the second century B.C. The frequency with which Hipparchus appears as the first Greek witness to Babylonian observations, predictive methods, parameters, and concepts is striking. This has led Toomer to conjecture that it was Hipparchus himself who got this material through direct contact with Babylonian astronomers, and made it available to his Greek successors.[35] His case is strongest for the observations. These can only have been obtained in Babylon itself, from the archive of Diaries and Extracts, by someone who knew what he was looking for and who was equipped to carry out the arduous labour of converting the Babylonian dates to the Egyptian calendar. I am less convinced that it was Hipparchus who transmitted the *ACT* schemes to later practitioners, for all that he knew and used them; this would require that he published writings in which the procedures for the schemes were set out in considerable detail. A formal publication of the schemes (i.e. a 'Babylonian *Almagest*') probably never existed; it seems more plausible that scribes who had been trained in the temples in Babylon and Uruk carried their skills elsewhere in the Hellenistic world. This much is certain, that wherever Babylonian horoscopy was practised, the full range of predictive schemes on which horoscopy depended must have been known.

Among the 'Chaldean' astronomers known to Hellenistic authors are Sudines (ca. 240 B.C.?), Seleucus (mid second century B.C.), Kidenas, and Naburianus. The last two names also apparently occur in the colophons of *ACT* syzygy tables (as Kidinnu and Nabu-rimanni).[36]

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[35] Toomer (1988) 357-60.

[36] Nabu-rimanni: *ACT* no. 18. Kidinnu: *ACT* nos. 122 and 123a. Strabo (XVI 1.6) names 'Kidenas and Naburianus and Sudines', as well as Seleucus of Seleuceia, as Chaldean astronomers. Sudines and 'Kidynas' appear as authors of lunar tables in Vettius Valens (IX 11). An anonymous writer ca. A.D. 213 ascribes to 'Kedenas' the System B lunar period relation (3.6), while Pliny (*NH* II 39) cites 'Cidenas' for a value of Mercury's greatest elongation from the sun. Cf. Cumont (1910) and Neugebauer (1975) 610-12.

Kidinnu and Nabu-rimanni, it has often been maintained on the basis of these colophons, played an important role in the invention of the System A and B lunar schemes, but with increased familiarity with Babylonian scribal practices it now seems more likely that they were merely the owners, computers, or copyists of the tablets in question, and therefore lived as late as about 100 B.C. and 50 B.C. respectively.[37] The contacts between Babylonian and Greek astronomy may thus have extended over two centuries or more.

I would summarize the historical significance of the transmission of Babylonian predictive astronomy as follows.[38] Greek mathematical astronomy changed in the second century B.C. from a geometrical, qualitative science to one that sought numerical measurements of the elements of geometrical models. Two factors contributed to this change: the transmission of Babylonian astronomical methods, and Hipparchus. We now know that Hipparchus did not develop a predictive astronomy based directly on his geometrical models, but depended on Babylonian schemes for computing solar and lunar positions ; hence in his work there is a methodological rift between theory (numerical but geometrical) and prediction (arithmetical). Hipparchus tried to reduce the inconsistencies by imposing parameters derived from his models on the predictive schemes. This symbiotic relationship between prediction and theory persisted in Greek astronomy for three centuries, as we know through papyrus tables from Roman Egypt. The Greek tradition from which Indian astronomy descends marks a step towards integration; but it was Ptolemy who first fully appreciated the importance of consistent method and logical progression in deducing an astronomical system.

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[37] Rochberg-Halton (1988). The possibility that two scribes over an interval of several centuries bore the same name should perhaps not be dismissed.

[38] For a fuller discussion, see Jones (1991e).

Bibliographical Abbreviations

Aaboe (1955)	A. Aaboe, 'On the Babylonian Origin of Some Hipparchian Parameters'. *Centaurus* 4 (1955) 122-125.
Boutelle (1967)	M. Boutelle, 'The Almanac of Azarquiel'. *Centaurus* 12 (1967) 12-19.
Bowen & Goldstein (1988)	A. C. Bowen and B. R. Goldstein, 'Meton of Athens and Astronomy in the Late fifth Century B. C.'. *A Scientific Humanist: Studies in Memory of Abraham Sachs*, ed. E. Leichty, M. deJong Ellis and P. Gerardi (Occasional Publications of the Samuel Noah Kramer Fund, 9) Philadelphia, 1988, 39-81.
Cumont (1910)	F. Cumont, 'Comment les Grecs connurent les tables lunaires des Chaldéens'. *Florilegium... dédiés à M. le marquis Melchior de Vogüé...* Paris, 1910, 159-165.
Fotheringham (1928)	J. K. Fotheringham, 'The Indebtedness of Greek to Chaldaean Astronomy'. *The Observatory* 51 (1928) no. 653, 301-315. Revised version, *Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik* B 2 (1932) 28-44.
Huber (1957)	P. Huber, 'Zur täglichen Bewegung des Jupiter nach babylonischen Texten'. *Zeitschrift für Assyriologie* N.F. 18 (1957) 265-303.
Jones (1983)	A. Jones, 'The Development and Transmission of 248-Day Schemes for Lunar Motion in Ancient Astronomy'. *Archive for History of Exact Sciences* 29 (1983) 1-36.
Jones (1984)	A. Jones, 'A Greek Saturn Table'. *Centaurus* 27 (1984) 311-317.
Jones (1991a)	A. Jones, 'A Second-Century Greek Ephemeris for Venus'. *Archives Internationales d'Histoire des Sciences* 41 (1991) 3-12
Jones (1991b)	A. Jones, 'Babylonian and Greek Astronomy in a Papyrus Concerning Mars'. *Centaurus* 33 (1990) 97-114.
Jones (1991c)	A. Jones, 'Hipparchus's Computations of Solar Longitudes'. *Journal for the History of Astronomy* 22 (1991) 77-101.
Jones (1991d)	A. Jones, *Ptolemy's First Commentator*. (Transactions of the Philosophical Society, 80.7) Philadelphia, 1990.
Jones (1991e)	A. Jones, 'The Adaption of Babylonian Methods in Greek Numerical Astronomy'. *Isis* 82 (1991), 441-453.
Kugler (1900)	F. X. Kugler, *Die Babylonische Mondrechnung*. Freiburg i.B., 1900.
Neugebauer (1950)	O. Neugebauer, 'The Alleged Babylonian Discovery of the Precession of the Equinoxes'. *Journal of the American Oriental Society* 70 (1950) 1-8.
Neugebauer (1955)	O. Neugebauer, *Astronomical Cuneiform Texts*. 3 vols. london, 1955.
Neugebauer (1956)	O. Neugebauer, 'Notes on Hipparchus'. *The Aegean and the Near East: Studies Presented to Hetty Goldman*. Locust Valley, 1956, 292-296.

Neugebauer (1963)	O. Neugebauer, 'The Survival of Babylonian Methods in the Exact Sciences of Antiquity and Middle Ages'. *Proceedings of the American Philosophical Society* 107 (1963) 528-535.
Neugebauer (1967)	O. Neugebauer, 'Problems and Methods in Babylonian Mathematical Astronomy'. *Astronomical Journal* 72 (1967) 964-972.
Neugebauer (1975)	O. Neugebauer, *A History of Ancient Mathematical Astronomy*. (Studies in the History of Mathematics and Physical Sciences, 1) Berlin, 1975.
Neugebauer (1988)	O. Neugebauer, 'A Babylonian Lunar Ephemeris from Roman Egypt'. *A Scientific Humanist: Studies in Memory of Abraham Sachs*, ed. E. Leichty, M. deJong Ellis and P. Gerardi (Occasional Publications of the Samuel Noah Kramer Fund, 9) Philadelphia, 1988, 301-304.
Neugebauer & Pingree (1970-1971)	O. Neugebauer and D. Pingree, *The Pañca–siddhāntikā of Varāhamihira*. 2 vols. (*Hist. Filos. Skr. Dan. Vid. Selsk.* 6.1) Copenhagen, 1970-1971.
Pingree (1978a)	D. Pingree, 'History of Mathematical Astronomy in India'. *Dictionary of Scientific Biography* v. 15 (New York, 1978), 533-633.
Pingree (1978b)	D. Pingree, *The Yavanajātaka of Sphujidhvaja*. 2 vols. (Harvard Oriental Series, 48) Cambridge, Mass., 1978.

Rochberg-Halton (1988)	F. Rochberg-Halton, 'Nabu-rimanni'. *Great Lives from History: Ancient and Medieval Series* ed. F. Magill. 1988, 1439-1443.
Schiaparelli (1908)	G. V. Schiaparelli, 'I Progressi dell' Astronomia presso i Babilonesi'. *Scritti sulla storia della astronomia antica* v. 1 (Bologna, 1925).
Schnabel (1923)	P. Schnabel, *Berossos und die babylonisch-hellenistische Literatur*. Leipzig, 1923.
Schnabel (1927)	P. Schnabel, 'Kidenas, Hipparch und die Entdeckung der Präzession'. *Zeitschrift für Assyriologie* 37 (1927) 1-60.
Tannery (1888)	P. Tannery, 'La grande année d'Aristarque de Samos'. *Mémoires de la Société des Sciences physiques et naturelles de Bordeaux*, ser. 3, 4 (1888) 79-96. Reprinted in Tannery, *Mémoires Scientifiques.*, v. 2, 345-366.
Tannery (1893)	P. Tannery, *Recherches sur l'histoire de l'astronomie ancienne*. Paris, 1893.
Toomer (1981)	G. J. Toomer, 'Hipparchus's Empirical Basis for his Lunar Mean Motions'. *Centaurus* 24 (1981) 97-109.
Toomer (1988)	G. J. Toomer, 'Hipparchus and Babylonian Astronomy'. *A Scientific Humanist: Studies in Memory of Abraham Sachs*, ed. E. Leichty, M. deJong Ellis and P. Gerardi Occasional Publications of the Samuel Noah Kramer Fund, 9) Philadelphia, 1988, 353-362.

van der Waerden (1947) B. L. van der Waerden, 'Egyptian „Eternal Tables“'. *Koninklijke Nederlandsche Akademie van Wetenschappen, Proceedings* 50 (1947) 536-547 and 782-788.

van der Waerden (1960) B. L. van der Waerden, 'Babylonische Methoden in ägyptischen Planetentafeln'. *Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich* 105 (1960), 97-144.

van der Waerden (1972) B. L. van der Waerden, 'Aegyptische Planetenrechnung'. *Centaurus* 16 (1972) 65-91.

The Babylonian Tradition of Celestial Phenomena and Ptolemy's Fixed Star Calendar

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Contents