ON BABYLONIAN ASTRONOMY AND ITS GREEK METAMORPHOSES

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Transmission has long been a leading theme within the historiography of the ancient and medieval exact sciences. The subject is naturally subdivided by boundaries of language and culture, and the transfer of scientific concepts and methods across these boundaries is an often demonstrable fact even when our evidence allows us to say little else about the evolution of these concepts. To pursue a technical element in its wanderings can be a fascinating hunt in its own right, as when a specific value for the mean length of the synodic month crops up in sources ranging over two millennia of history, from Seleucid Babylonian tablets to medieval French books of hours.[1] Such fossils also are the key to establishing the underlying continuum of scientific traditions without which discussions of change and development have no meaning.

To study "transmission" in the narrow sense is to ask what information was transported, from whom, to whom, by whom, how, and when. Answers to such questions may be immediately forthcoming, as when attributed translations of key works survive. Or, if the evidence for transmission is well enough removed from the supposed contact, our conjectures may be interesting and controversial. Broadly speaking, the later the transmission, the better we seem to be informed about how it occurred. For example, we know more about the processes of transmission of mathematical astronomy from Islam to Latin and Byzantine Europe than we do about those that led from the Greek world and India to Islam, yet we are still much better informed about these transmissions than we are about those from the Greek world to India and from Mesopotamia to the Greek world.

Behind these questions that concern specifically and narrowly the manner and means by which scientific concepts found their way from one language or culture to another, and which A. I. Sabra has aptly described as a "kinematic" account of transmission,[2] lurk other

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[1] Neugebauer [1989].

[2] Sabra [1987], p. 223.

questions about the reasons why some of these concepts (and not others) took hold in their new environment and about the changes that accompanied or followed upon transmission. Sabra has illuminated an important aspect of this broader, "dynamic" approach with specific bearing on the medieval transmissions from Greek to Arabic, by stressing the active role of the recipients in seeking out and choosing the concepts to be transmitted (a process he calls "appropriation") and the process by which certain of these originally "foreign" concepts became "naturalized."

My intention in this paper is to make a preliminary statement (to appropriate Sabra's modest subtitle) concerning the possibility of attempting a "dynamic" interpretation of one of the most important and well-documented scientific transmissions in antiquity, that of the astral sciences of astrology and astronomy from Mesopotamia to the Greek-speaking world. I should say at the outset that I do not think it wise to transfer from the sphere of medieval Islamic scholarship and society to this context Sabra's category of "appropriation." It would be hazardous to ask to what extent the Hellenistic recipients went after and selected Mesopotamian scientific methods and concepts when the identity of the channels of transmission, and even the roughest places and dates, are still topics of controversy. For the present I take it as given that the elements of Mesopotamian astral science accessible to a Greek-speaking scholar working, say, in A.D. 150 were not coextensive with the contents of the cuneiform tablets of the last four centuries B.C., without asking why this was so. My concern will be, first, the nature in its own right of this transmitted subset of the Mesopotamian sciences, and secondly, the differences between the original Mesopotamian concepts and their Greek avatars.

These differences will turn out to be of two fundamentally distinct kinds. Components and methods of a science may be adapted to fit new applications or conditions of use. One modifies a borrowed tool, either so that it can do a slightly different job, or because it does not fit one's grip. This is essentially a change at the practical level, and I will refer to it as "adaptation." Secondly, the elements of a science may be reinterpreted to harmonize with preexisting concepts or habits of thinking. The outward sign is not necessarily changed, but it is given a new inward meaning that makes it fit into its new intellectual setting.

We first learned of the transmission of astronomy from Seleucid and Parthian Babylonia to the contemporary Hellenistic world at the turn of the century, and evidence for its extent and nature has since accumulated, at first gradually, but in the last two decades at an accelerating pace. One could compile a lengthy catalogue of direct and indirect testimonies;[3] but a more efficient way to convey some impression of what we now know is to sketch a comparison between two bodies of documents, the one Mesopotamian, the other Greco-Egyptian.

From roughly the last three centuries B.C. we have many hundreds of fragments of cuneiform tablets of an astronomical nature from two sites, Babylon and Uruk. Most of these fall into a small number of well-defined types and formats; for my purposes it will suffice to group them more broadly by the nature of their contents.[4] The largest group comprises observational records, among which the texts called Diaries are the most important. These cite observations of key stages in the synodic cycles of the moon and planets, such as their first and last appearances, and their passages by reference stars, along with much other information, both astronomical and non-astronomical. In another group are almanac-like texts that contain predictions of the same kind of phenomena that the Diaries record, without any overt indication of how these predictions were made. Thirdly, there are numerical tables, some of them of great complexity, that make up a highly developed body of schemes for predicting lunar and planetary synodic phenomena, and, by interpolation, day to day positions of the same bodies. These tables, and the instructions for compiling them, are the texts that Neugebauer published as *Astronomical Cuneiform Texts*, and they are commonly referred to by the acronym of that edition, *ACT*.[5] A fourth group of texts are horoscopes, which typically state the positions of the heavenly bodies at the time of birth of an individual, sometimes with predictions for the future life of the native, sometimes without. These are the four major groups; I do not claim that they exhaust all known astronomical texts of this period.

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3 Jones [1993].

4 Sachs [1952]; Rochberg [1989].

5 Neugebauer [1955].

From a very small number of documents of the Parthian period, we know that texts of the first three kinds, that is, observational diaries, almanacs, and numerical tables, were produced by highly trained specialists who belonged to a temple hierarchy.[6] We do not possess such explicit documentary evidence to connect the horoscopes with these same scholars. Nevertheless all four groups of texts seem to be connected by a network of mutual dependence. Predictions of the kind presented by the almanacs are to be found also in the Diaries, interspersed with observation reports, while observations from bygone years seem to have been used to generate further almanac predictions by the application of simple recurrence periods. Certain kinds of predicted information in both almanacs and Diaries almost certainly were computed by means of the *ACT* schemes; this is in particular true of the predicted dates when the planets were supposed to cross from one zodiacal sign to another. And the *ACT* schemes were also the probable source, either directly or through the intermediary of almanacs or Diaries, of the calculated positions of the heavenly bodies in the horoscopes. Because of the interdependency of the main groups, one can speak of their production as a *system* of astronomical practice.

I turn now to my second body of documents, which are the astronomical papyri from Roman Egypt.[7] These mostly date from the first four centuries of our era. They number in the hundreds, and derive (when their provenance is known) from various provincial towns of Egypt. More than half the known fragments were excavated at one site, Oxyrhynchus; these are at present unpublished.[8] With the accession of these new texts, it is now for the first time possible to speak with confidence of the range of astronomical activity that existed in these provincial centers. Again I limit myself to a broad classification. First, there are numerous horoscopes. Most of the papyrus horoscopes tersely list the date of birth and the positions of sun, moon, and planets, as in their Babylonian counterparts, as well as the ascendant point of the ecliptic. A few set out the celestial posi-

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[6] Rochberg [1993].

[7] Inventory of astronomical papyri: Neugebauer [1962]; of astrological papyri: Neugebauer and van Hoesen [1964]; of papyrus horoscopes: Neugebauer and van Hoesen [1959]; additions to all the above: Baccani [1992], especially pp. 20–21 and 32–36.

[8] I am preparing an edition.

tions and other astrologically useful facts derived from them in an elaborate prose text; but even these deluxe horoscopes do not usually interpret the data. Secondly, almanacs of two types exist. The most common variety are tables of dates when the planets crossed from one zodiacal sign to another; these sign-entry almanacs sometimes also indicate other synodic phenomena such as first or last appearances. Other almanacs tabulate positions primarily at fixed intervals of one month or five days or single days. Thirdly, we find numerical tables for predicting synodic phenomena or instantaneous positions. And lastly, there are a very few fragments of theoretical works.

It is easy to see that the first three groups of papyri are analogous to three of our four groups of cuneiform texts: numerical tables, almanacs, and horoscopes; and again they make up a system in which the almanacs depend for their predicted contents on the numerical tables, and the horoscopes depend on either the almanacs or the tables. We have no observational records on papyrus to correspond to the Babylonian Diaries; nor is there any counterpart to those elements of the Babylonian almanacs, such as predicted stellar passages of planets, that we believe were extrapolated from observations. The system represented by the papyri resembles a subset of the Babylonian system, specifically the part that could sustain itself cut off from observational activity. The handful of papyri concerned with theoretical astronomy, which had no analogues among the Babylonian texts, do not seem to belong to the system, having no known practical connection to the production of the other groups of papyri.

I think there can be no doubt that the chief goal of the system of practice to which the non-theoretical astronomical papyri belonged was the generation of horoscopes and other related astrological calculations such as the determination of auspicious and inauspicious days. The owners and authors of these texts were therefore astrologers. Such people could belong to temple organizations in Roman Egypt; papyri and ostraca found at the site of the temple of Narmouthis reveal an extensive business in horoscope casting.[9] Since the temple priesthoods of this period were predominantly Egyptian, it is not surprising that a fraction of the astronomical papyri and

[9] Baccani [1992], pp. 50–53.

horoscopes are written in Demotic rather than Greek. Other astrologers may have been independent professionals, even of fairly high social status; the Titus Pitenius who wrote and signed one of our deluxe horoscopes around A.D. 100 was a Roman citizen.[10]

Between the Babylonian and Greco-Egyptian systems of astronomical practice there is an obvious filiation. Babylonian and Greek horoscopes are not identical, but they share a wholly artificial correlation of a date of birth and a list of planetary longitudes expressed in conventional zodiacal signs and degrees. The computational apparatus on which both kinds of horoscopy depended also had much in common—how much, we are only now coming to realize. For the very same arithmetical schemes by which the Babylonians predicted lunar and planetary phenomena are now turning up repeatedly in papyrus tables.

The story one might venture to compose from the archeologically recovered contemporary documents would be something like this. During the first millennium B.C. programs of observation of the heavens were carried out at certain Mesopotamian temples, including those of Babylon and Uruk. By the fourth century B.C. the same observers were also practicing horoscopy, together with the mathematical predictive schemes on which horoscopy depended. This kind of astrology did not need sustained observation and recording of celestial phenomena, and consequently was easily transported. We can infer that horoscopic astrology and the associated predictive schemes did spread, since around the time that the Babylonian records cease we begin to have evidence of a very similar practice in Egypt. Egyptian horoscopes record a few data, such as the rising point of the ecliptic, that were not found in Babylonian horoscopes; but it would be impossible to tell from the horoscopes themselves just how important these innovations were. Of the computational methods in the papyri, some are identical to Babylonian methods, others are modified or streamlined. During the third century of our era, tables of a different kind, characterized by the use of trigonometrical functions, begin to appear alongside the Babylonian-style arithmetical methods. By the end of the fourth century, the trigonometrical methods are predominant.

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[10] Neugebauer and van Hoesen [1959], pp. 21–24.

Of course an account based only on archeologically recovered texts misses a great deal that we know by other means; I need merely remark that I have not yet named Ptolemy. But there is also some gain in comparing like with like. The remains of later Babylonian astronomy are entirely of the kind I have described: dry records, computations, instructions; nothing that sets out what its practitioners believed that they were doing, or for that matter what they believed the heavens were doing. To set this material beside such an interpretative, methodologically conscious treatise as the *Almagest* is to run the risk of grave misunderstandings about the relationship between Greek and Babylonian astronomy. Yet until recently this has been nearly the only comparison that we were in a position to make.

It was indeed in the *Almagest* that the first clues to the transmission of Babylonian mathematical astronomy into Greek were discovered.[11] But the papyri alone reveal the breadth and nature of the transmission: no mere epitome of isolated theoretical parameters and concepts, but a whole system of practical astronomy, maintained by roughly the same kind of practitioners before and after the transplantation, and surely conveyed from Mesopotamia to Hellenistic Egypt by these same people.

Yet despite this unexpected continuity of practice, changes are also obvious, and these it is our business to explain. For the time being I wish to focus on the computational methods used by the astrologers, rather than their almanacs and horoscopes. On the Babylonian side of the transmission, this is the domain of the *ACT* texts. Now it is a remarkable fact that the schemes employed by the Babylonians of the last three centuries B.C. for computing lunar and planetary phenomena show a high degree of methodological uniformity, and, during this period, little sign of evolution. The planetary schemes, for example, are unified by a common assumption, which we can fairly name the fundamental model of Babylonian planetary theory: that the intervals of longitude and time between two synodic events of a planet are functionally dependent on the planet's longitude at the first event alone. The various predictive schemes are actually quantifications of these functional relationships, often by way of a further level of mathematical modeling. Thus the

[11] Originally by F. X. Kugler. For references, see Jones [1993].

so-called System A models assume that occurrences of a specific kind of synodic event are evenly spaced within defined partitions of the ecliptic. Another modeling rule, which van der Waerden has named the "Sun-Distance Principle," is that the interval of time between successive events differs by a constant from the number of degrees between them, counted as lunar days. Between synodic events, the planet's motion could be modeled as either a constant number of degrees per day, or increasing or decreasing progress according to arithmetic sequences. No document tells us where these rules come from, or how they may be related to deeper assumptions about the causes of the planetary phenomena. Their structure suggests that they were patterns induced very directly from the phenomena, and then shaped into convenient arithmetical rules that would reproduce the pattern within an acceptable degree of precision. For all we know, the development of the *ACT* schemes may have come pretty much to a halt by the third century B.C., and the later Babylonian astronomers who used them may have known little about their origin.

Crossing over to the Greek side, we find that the papyri corresponding in function to the *ACT* texts exhibit a greater variety and even, seemingly, traces of development. Unfortunately, we still have far fewer papyri of this class than *ACT* texts, so that there remain huge gaps in our knowledge of how Greco-Egyptian astrologers computed the positions of the heavenly bodies. But at least we can discern certain trends. As I have said, we find three kinds of predictive schemes in use: first, schemes that are identical to known *ACT* schemes; secondly, schemes that are similar to *ACT* methods; and thirdly, schemes that use trigonometrical functions. Perhaps I should now reveal a circumstance that I suppressed before, namely that the trigonometrically based schemes, with very rare exceptions, are versions of Ptolemy's tables. Since their relation to the Babylonian schemes is at best indirect, they do not come into our discussion at this point.

The second group of Greek predictive schemes, those that are akin to but not identical to *ACT* schemes, are all of the nature of adaptations, and in some instances we can confront the original and the adapted version in papyri of about the same date.[12] Greco-Egyp-

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[12] Such practical adaptations of Babylonian methods are discussed further in

tian practical astronomy was egalitarian, not to say chaotic, in preserving old methods alongside new ones; this makes it harder for us to date innovations, but on the other hand we are exposed to a wider range than if new method had quickly superseded old.

For example, we have two unpublished scraps of tables of first and last appearances of Mercury, found together and apparently both dating to the middle of the third century.[13] The first fragment lists dates of appearances computed according to one of the System A schemes for Mercury well known from cuneiform texts. The second fragment also lists dates of appearances, but the scheme is simpler: the intervals of time cycle repeatedly through three constant values. At first glance it is only the similar arrangement of the table that suggests that this scheme had anything to do with the *ACT* procedures. But there is indeed a connection. The three constants in the simpler scheme turn out to be the intervals of time computed according to the System A rules for three specific initial longitudes, and then assumed to apply to whole zones of the ecliptic following these points.

Hence we know how the adaptation was made; but the reason for it we can only conjecture. Reducing the range of predicted synodic times to three constant values diminishes the quality of the predictions, and it is doubtful whether any theoretical considerations could have inspired this move. The arithmetic does become easier, but it was never very difficult in the System A scheme anyway. My suspicion is that an indefinite variety of intervals of time was replaced by a few standard intervals in order that these intervals could then be bridged by a few standard patterns to describe the planet's motion from day to day. Mercury's synodic periods are too variable to allow one to simulate its motion by repeating a single "average" pattern, but by rotating through a short, medium, and long pattern one could generate acceptable predictions.

This Greek adaptation of a System A scheme for Mercury illustrates a difficulty inherent in the Babylonian methodology. The fundamental insights on which Babylonian planetary theory was erected concern first of all the relationship between the dates and longitudes of certain key moments in each planet's synodic cycle. These synodic events could also be predicted more easily by apply-

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Jones [1991].

[13] These fragments will be published with the texts from Oxyrhynchus.

ing recurrence periods to earlier observations. Only the *ACT* schemes, however, supplied precise longitudes in degrees and fractions of a degree, which were a prerequisite if one wanted to interpolate patterns of daily motion in order to find either the planet's position on a given day or the date when the planet crossed from one zodiacal sign to another; in other words, the standard horoscope of late Babylonian and Greek astrology could only exist because the *ACT* schemes were able to yield instantaneous positions.

I therefore do not concur with the tendency in modern treatments of Babylonian astronomy to depreciate the importance of the daily motion schemes. But the extant specimens testify to the difficulty with which Babylonian scribes bridged the always varying gaps in time and longitude between successive synodic events. Linear interpolation was the easiest, and consequently the most commonly used method, but it did not satisfactorily reflect the planets' varying speed. Second and third order arithmetical sequences could achieve this object, but the problems involved in computing such sequences to link arbitrary dates and longitudes were not trivial. Templates, that is, standard patterns of fixed length, would allow one to represent the fluctuating speed of a heavenly body by means of higher order functions, and this solution is found in papyrus tables. To date fragments of templates for the moon, Saturn, Mercury, and the sun have come to light; and it is very probable that template schemes once existed for all the planets.

The templates constitute an important modification of Babylonian methodology in Greek astronomy. Nevertheless the templates for the moon, Saturn, and Mercury that we possess are manifestly adapted from Babylonian patterns for imitating the variable motion of those bodies through arithmetical sequences. Once the principle was established of tabulating a cycle of motion once and for all as a template, however, there was no compulsion for the template to use only arithmetical functions. And in fact an unpublished solar template gives trigonometrically computed values for the sun's progress in longitude day by day from its perigee according to Hipparchus's kinematic model.[14] Adaptation has here progressed to the point where no obvious features of Babylonian ancestry remain.

[14] To be published with the Oxyrhynchus material.

As these examples illustrate, adaptation is easy to detect from plain documentary evidence, if not always so easy to explain. What is most difficult to discover by contrasting cuneiform and papyrus tables is change, not in the methods used, but the meanings imposed on them. Sometimes even this is possible, as when our solar template computes the day to day progress of the sun by means of trigonometric functions instead of the arithmetical sequences that prevail in the other templates and the *ACT* schemes. Trigonometrical functions might suggest kinematic modeling and circular motions to a modern analyst, even one ignorant of Ptolemaic astronomy. On the other hand, the complete absence in the *ACT* schemes of trigonometry, or any other computational symptoms of kinematic modeling, is a weighty argument that Babylonian astronomers never thought of the celestial phenomena in such terms. In fact, the phenomenological interpretation of Babylonian mathematical astronomy that is generally held by present day historians rests on our analysis of how the *ACT* schemes worked; for we possess no Babylonian *Almagest*, not even a Babylonian Theon of Smyrna. This situation is in stark contrast to the way we have come to interpret Greek mathematical astronomy, using the theoretical pronouncements as a key to understanding the technical details.

The Ptolemaic astronomy of the *Almagest* is shaped by geometrical modeling in two ways: the use of a conceptual celestial sphere concentric with the spherical earth, and to which all appearances in the heavens are referred, and the hypothesis that the appearances of the sun, moon, and planets are perspective views of kinematic models built up out of circular motions. Looking backwards, we tend to define the main stream of Greek astronomy by these concepts, but at earlier periods they were not the only viable hypotheses. Eudoxus's spheres are kinematic, but not perspective; Pliny the Elder's planets driven inwards and outwards by solar rays are not kinematic but do assume perspective; Epicurean astronomy had no place even for the celestial sphere. What all these approaches had in common was that they sought to explain the appearances of the heavens by either regular physical processes or regular, geometrically defined motions. Babylonian predictive astronomy shows no symptoms of underlying explanatory theories, whether physical or geometrical. We do have some tenuous evidence, not indeed from actual Babylonian texts, but from classical authors reporting the opinions of so-called "Chaldeans," that is, Babylonian scholars who had contact with Greek culture, that physical explanations of astronomical and meteorological phenomena were current among some of these authorities. But this may be the effect of Greek ideas passing the other way.

Let us imagine a Greek astronomer of the third or second century B.C. curiously looking over the shoulder of a "Chaldean" as he went through the computations involved in one of the *ACT* schemes for predicting lunar phenomena.[15] In an *ACT* lunar table, each row or line may correspond to a consecutive new moon, and the columns represent various components involved in calculating the circumstances of the appearance of the new moon. Right at the beginning is a column (*B*) giving the longitude of the sun and moon at the moment of the conjunction that precedes the appearance of the new moon crescent. These longitudes, in zodiacal signs and degrees, are computed just like the planetary phenomena in the *ACT* planetary schemes: the interval from one new moon to the next is a simple function of the starting longitude. Next to this column is a column (*C*) giving the length of daylight for the day in question, measured in units of 360ths of one day. The scribe computes the length of daylight as a function of the sun's longitude in the preceding column, referring to a handy auxiliary table. So much the Chaldean can explain to the Greek.

If the Greek is accustomed to referring the phenomena to the celestial sphere, he will almost automatically reinterpret the column for length of daylight along the following lines. Daylight is the time from when the sun rises to when it sets, at which moment the opposite point on the celestial sphere is rising on the eastern horizon. If we assume that the sun's apparent path, the ecliptic, is actually a great circle on the sphere, the rising point at sunset must be half that circle, that is, exactly six zodiacal signs, away from the sun. So this column of the table is giving the time it takes for the six zodiacal signs starting with the sun's longitude to rise. But on the celestial sphere there is another great circle, the equator, that rises uniformly

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[15] Whether this "Chaldean" was actually a Babylonian scribe or, for example, an Egyptian trained in the same methods is immaterial. That the situation imagined here is not fanciful can be seen from Hipparchus's informed discussion of the methods of predicting eclipses employed by people he calls *astrologoi* (ed. Manitius [1894], p. 90).

with the passage of time; so instead of counting in 360ths of a day, we can measure time by the rising of 360ths, that is, degrees, of the equator circle. This entails a small discrepancy, because during the day the sun moves about one degree in its own right with respect to the equator, but let us neglect that. So we can now say—as the Chaldean certainly would not—that the Chaldean's auxiliary table is a table correlating simultaneously rising arcs of the ecliptic and equator circles.

An important consequence of modeling the earth and the heavens as concentric spheres is that the correlation between these rising arcs is different for localities at different distances from the earth's equator. In particular, the duration of the longest daylight of the year increases with greater terrestrial latitudes; and this predicted variation corresponded to noticeable differences in day length in different parts of the Hellenistic world. The ratio of longest to shortest day built into the *ACT* schemes, exactly 3 to 2, should only be applicable to places with the same approximate latitude as Babylon. But the auxiliary table for daylight length in the *ACT* schemes follows a simple arithmetical pattern that can easily be stretched out or compressed to fit a different pair of extreme values. And this is just what we find in Hellenistic astronomy. In the mid-second century B.C. Hypsicles wrote a short book in which the Babylonian daylight scheme is adapted to a ratio of extreme values appropriate for Alexandria, and all of this described in terms of arcs on the celestial sphere.[16] Astrologers of the Roman period had at their disposal a whole set of Babylonian-style ascension tables adapted to fit a wide range of latitudinal zones.[17] Who was responsible for this extension of the system we are not told, but we do have sources from Roman times that associate Hipparchus in some way with arithmetical ascension tables. What is of interest here is that the practical adaptation of the Babylonian scheme, that is, its extraction from the mechanism of the lunar syzygy tables and its extension to other latitudinal belts, was motivated, and indeed only made possible, by a reinterpretation of what the scheme meant—a reinterpretation, moreover, so natural to anyone trained to think in terms of the geometry of the celestial sphere that it may have been unconscious.

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[16] De Falco, Krause, and Neugebauer [1966].
[17] Neugebauer [1975], pp. 712–733.

It was by means of the ascension tables that the astrologers of the Roman period were able to determine the rising point and other cardinal points recorded in their horoscopes. And in fact the Greek horoscope itself is another product of the same process of adaptation following reinterpretation that we have seen in the evolution of the ascension tables. For the meaning of the horoscope in Greek astrology was bound up with the supposed relative configuration of the celestial and terrestrial spheres for a specific place and time; and the counterpoint between the great circles of horizon, equator, and ecliptic generated those additional data that distinguish a papyrus horoscope from a Babylonian one.

I return to the imaginary Greek and Chaldean astronomers poring over the lunar table. The first column of numbers that I mentioned was the one giving longitudes of successive conjunctions of sun and moon. From line to line it marks the sun's progress of about a zodiacal sign per month, but also the moon's full revolution plus a zodiacal sign in the same time. In principle it ought to reflect the irregularities in the apparent movements of both luminaries; but the *ACT* rules give the monthly progress only one periodic variation, with a period of 12 and a fraction months. What this variation represents is a fluctuation in the sun's rate of progress through the year; the moon's anomaly turns out to contribute so little to the longitude of conjunction that it is legitimately neglected in the Babylonian reckoning. In the version of *ACT* lunar tables known as System A, the monthly advance in longitude is a function of the starting longitude alone, so that the periods of longitudinal return and anomaly are identical. In the other version, System B, the monthly advance is a periodic function, so that the sun's variations in speed could conceivably have a different period from the mean period in which it returns to the same longitude; in fact the function used has an almost identical period, the small discrepancy being perhaps due to the exigencies of convenient calculation with sexagesimal numerals. In both versions the length of daylight is, as I have said, a function of the longitude, which, as always in Babylonian astronomy, is to be understood as a longitude with respect to the fixed stars. In other words, in the *ACT* schemes the sidereal, tropical, and anomalistic years are assumed to be the same. Besides these schemes, the Babylonians also had a calendrical cycle equating 235 months with 19 years; since the dates of solstices and equinoxes were predicted according to this cycle, a value for the tropical year could be extracted from this period relation. This value is shorter than the year built into the *ACT* schemes by roughly $\frac{1}{2000}$ of a month, that is, roughly $\frac{1}{70}$ of a day. To the Babylonian astronomers this discrepancy was probably of no theoretical significance (in the same way that the year length implied by the Gregorian calendar reform is not a fair measure of the tropical year assumed by astronomers in the late sixteenth century).

In the Greek astrological practice represented by the papyri, no distinction was drawn between the three kinds of solar period, just as in the *ACT* schemes. Longitudes were reckoned according to a sidereal frame of reference, the tables assumed that the sun's speed varied with sidereal longitude, and the cardinal points of the horoscope were computed by entering the ascension tables with sidereal solar longitudes.

For an astronomer like Hipparchus operating with a simple kinematic model for the sun, the identity of the longitudinal, anomalistic, and tropical years would not have been a foregone conclusion. A possible analogy with the moon, which exhibits similar but not identical periods of longitude, anomaly, and latitude, would be an encouragement to check whether the Babylonian value for the length of the year was accurate by each of the three criteria. We know that Hipparchus determined or confirmed that the sidereal year was very close to the Babylonian estimate, but that the tropical year was shorter—it has been noticed that his tropical year is suspiciously close to the value derivable from the 19-year calendric cycle, which was familiar to Greek astronomers of Hipparchus's time through its embodiment in the 76-year Callippic cycles.[18] Finally three hundred years later Ptolemy claimed to have established the equality of the tropical and anomalistic years on the grounds that the lengths of the astronomical seasons had not changed between Hipparchus's time and his own. For subtle reasons arising from uniform motion and the problem of measuring constant units of time, Ptolemy's analysis of the periodicity of solar motion forced him to adopt a tropical frame of reference for reckoning celestial longitudes instead of the traditional sidereal coordinates.

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[18] Swerdlow [1980]; cf. p. 293 note b for earlier literature.

If Ptolemy was correct, then the astrologers of his time were incorporating two systematic errors in their horoscopes. First, their sidereal longitudes of the sun would have been progressively in error because of the tropical precession of the solar apogee. Secondly, the determination of the cardinal points in the horoscope would have been erroneously computed from sidereal rather than tropical longitudes. What is interesting is that, so far as our documents tell us, no one undertook the necessary adaptations of existing solar schemes to bring them into line with the Hipparcho-Ptolemaic theory of precession. Nay, the astrologers adapted Ptolemy's tables to the strictly sidereal convention, by devising a formula to convert Ptolemy's tropical longitudes to sidereal longitudes. An unexpected offspring of this formula was the medieval theory of the trepidation of the equinoxes.[19]

In the end, of course, Ptolemy's tables did win out over the arithmetical methodology, although the victory was slow to arrive: by the end of the fourth century few traces of Babylonian astronomical practice remained in use. I do not think, however, that the competition would have been seen at the time as one between "Babylonian" and "Greek" science; it is even far from obvious whether Ptolemy and his contemporaries had as clear a notion of the separate Greek and Mesopotamian components in their astronomy as we think we have. At any rate, Ptolemy never speaks in national or linguistic terms, but only of sound or unsound deductive methodology. And the very circumstance that it was a rigorously kinematic and numerical approach that superseded the arithmetical schemes resulted from the ease with which kinematic modeling could give a new meaning to so many components of the *ACT* schemes and ultimately reshape them into tables that, in Ptolemy's words, "exhibit the regular and circular motions."

Bibliographical Abbreviations

ACT. See Neugebauer [1955].

Baccani, Donata [1992]. *Oroscopi greci: documentazione papyrologica*. Messina: Sicania, 1992.

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[19] I will discuss the evidence for the continued use of sidereal longitudes and its relevance to trepidation in a forthcoming paper.

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Additional note:

The papyri referred to in notes 13 and 14 will be published as *P. Oxy.* LXI.4153–4154 (Mercury) and LXI.4162 (solar template) in A. Jones, *Astronomical Papyri from Oxyrhynchus*.