The Inconstant Moon: Lunar Astronomies in Different Cultures[1]

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Earlier in this conference, Breen Murray (2000) reminded us of the crucial anthropological distinction between etic and emic perspectives. An etic observer would describe a culture's astronomical practices from the perspective of an outsider, using presumably universal values and scientific methods. An emic observer would take the perspective of an insider and use the natives' values and perceptions of nature.

To this historian, and to most of my colleagues, either of these options raises serious difficulties. If we describe a culture's astronomy from the outside using modern astronomy as the norm, we will paint a false picture of what they are doing. If we try to describe a culture's astronomy from the inside using that culture's categories, we are likely to fail, for it is difficult, if not impossible, to get inside an alien mind. In the unlikely event that our description fully incorporates a culture's viewpoint, it is likely to be unintelligible to anyone outside that culture.

Since we historians and anthropologists are perennial outsiders, we must reconcile the etic and emic extremes by using rigorous, modern presentations to translate other peoples' astronomical categories and practices into terms that would be intelligible to our colleagues. The following examples are not insiders' views, but neither are they, I hope, locked into the categories of the outsider.

In these examples I will look in some detail at the ways in which a number of different cultures have investigated the changing appearances of the Moon. At first glance the questions they raise seem to be very similar, but on closer examination these questions are seen to embody subtly different conceptual frameworks. In turn, the differences among these frameworks influence how astronomical problems are posed and what solutions are obtained.

In approaching such a comparative study of astronomies, we must tread very carefully to avoid two closely related interpretative fallacies. One is the ethnocentric fallacy that would compare different astronomical traditions against that of modern astronomy as the presumed standard of astronomical practice. The related evolutionary fallacy would assume that insofar as other astronomies have not achieved the state of modern astronomy, the practitioners of these astronomies have somehow failed to achieve the goal toward which they were, perhaps unconsciously, striving.

Note that the comparisons I wish to avoid are comparisons that would take modern astronomy as the presumed standard of how to do astronomy or of what an astronomical system ought to look like. Other kinds of comparisons are almost inevitable. One kind of comparison notes that although two astronomical traditions may be dealing with similar problems, say, developing a calendar, they use different frameworks, concepts, or methods. Another kind of comparison notes that although two astronomical traditions may employ similar methods to approach a problem, one tradition may develop this method more elaborately while another system remains rudimentary. A third contrast would compare their value for a parameter, say, the velocity of the Moon, with an equivalent modern parameter.

In comparing the methods, concepts, or frameworks of different astronomical systems, there is little to be gained in ranking them in some way. Insofar as astronomies differ in their fundamental concepts, it may be difficult, if not meaningless, to judge one as superior to the other. Insofar as they use different approaches to different problems, the different techniques they employ are often more appropriate to those particular problems. For example, the kinematic models of geometric astronomies are well suited for the development of cosmological and physical interpretations, while the techniques of arithmetic astronomies are well suited to solving calendric problems.

In comparing the elaboration of an astronomical system, we are in exactly the same position as an anthropologist or historian who compares political or economic systems: some political systems lack an effective bureaucracy; some economic systems use currencies while others are based on exchange of services for goods or on barter. Comparisons may tempt us to rank these economic, political, or astronomical systems as superior or inferior in some sort of evolutionary schema, but such evaluation is not an essential result of comparison. Complexity does not always mean superiority.

In comparing astronomical parameters against modern theory, there is little to be gained in merely applauding a culture for having attained a certain level of precision or in condemning them for failing to do so. It is more appropriate to consider how a culture's astronomy led them to express parameters in a certain form, how a culture's observations could lead to the kind of precision found in their theory, and whether the precision they attained met, exceeded, or fell short of their specific requirements.

Time as the Measure of Motion

One of the fundamental astronomical problems from antiquity to the present has concerned the reckoning of time. The astronomies of different cultures employ different standards to mark and define the passage of time. Some take the motions of the Sun as marking the basic unit of time; some follow the motions or phases of the Moon; some note the changing seasonal appearances of the stars; while others use regular counts of successive days to reckon the passage of time. This choice is not just an incidental cultural phenomenon; the ways that different peoples have chosen to measure time have profound influences on the astronomical problems they formulate, on the kinds of solutions they obtain to those problems, and even, as we shall see, on the quantitative parameters they obtain to solve those problems.[2]

Relating the various units of time so that one could be measured against another was a central problem of early practical astronomies. Plato described, and condemned, this practice in his *Republic* (530^{a-b}):

> The true astronomer [Plato maintained] . . . will . . . think it absurd to suppose that there is an always constant and absolutely invariable relation of day to night, or of day and night to month, or month to year, or, again, of the periods of the stars to them and to each other.

Plato outlined here a fundamental problem of early astronomies: finding fixed relationships between the various periods of day and night, of month and year, and of the motions of the Sun, Moon, stars, and planets to each other. Plato's criticism took as its target the activities of Greek practical astronomers and calendar keepers, who sought to reconcile the Greek lunar calendar with the solstices and equinoxes, with the seasonal appearances of the stars, and with meteorological phenomena. Yet these concerns are central to Greek calendrical lore from the time of Hesiod around the eighth century B.C., through the creators of public calendars known as *parapegmata,* beginning with Meton of Athens in the fifth century B.C.

By presenting various examples of how people related the motions of the Moon to other units of time, this essay will illustrate the different ways people do astronomy. In these examples we will see the influence of various methods and concepts people employ, of the standards they choose for the measurement of time, and of the purposes which motivate their investigations of the Moon and its motions.

The earliest astronomies of this sort use simple observations of the Moon to reckon the passage of time. The problem of the lunisolar calendar has two aspects: relating the month to the day and relating the month to the year. The first aspect involves finding the specific day on which the lunar month begins; the second involves determining when an extra lunar month should be inserted to reconcile the motions of the Sun and the Moon.

The practice of watching the evening sky to determine the first appearance of the crescent moon is found in many different cultures, ranging from contemporary Islamic societies to a wide range of tribal societies. The changing phases of the Moon are one of the most noticeable of celestial phenomena. If we accept the Paleolithic bone markings analyzed by Alexander Marshak (1972) as representing tallies of lunar months, this becomes the earliest recorded kind of astronomical observation.

It is not a simple step from observing new moons to finding a pattern in these observations. A number of factors stand in the way: the average length of a month is not an integral number of days; the interval between true astronomical conjunctions is not constant but varies between about 29.3 and 29.8 days; and atmospheric conditions and the varying circumstances of the appearance of the crescent moon may delay the actual observation of the new moon by a day or two. Nonetheless, the general notion that two months equal somewhat more than 59 days, and certainly less than 60, appears in many cultures.

The second aspect of the lunar problem, relating the month to the year, relies on the fact that most years include twelve lunar months and only every two or three years does a thirteenth, intercalary month have to be inserted to keep the Moon synchronized with the seasonal appearances of the Sun or stars.

For some cultures, absolute synchronization of the Moon and the seasons was not perceived as essential. The Mursi of Ethiopia sought to reconcile a count of months to the Sun, the stars, and a range of other seasonal phenomena, but different individuals would give different values for the number of the current month in this count. In his fieldwork among the Mursi, David Turton (Turton and Ruggles 1978) found that identifying a person who could be taken as an authoritative source on the months was elusive. Rather than seeking agreement, there was a general consensus to leave disagreements about the current month unresolved.

While uncertainty among the Mursi about the place of the current month in the count of months tended to be between individuals, similar disagreements among the Hopi of northern Arizona also expressed rivalries between villages and disagreements about the proper month to celebrate religious rituals. The Hopi were clearly aware of this problem and of some of the principles behind it; one anonymous Hopi, as cited in Malotki (1983:368–369), described disputes about the calendar in these terms:

> When people get all confused about the Moon like that they are asking each other, "What month is this?" "This is Kyaamuya." [to which others reply] "It seems as if this is Pyamuya." "No it's not that [month] yet."[3]

This concern to establish a regular relationship between the Sun and the Moon for festivals following the winter and summer solstices elicited a practice of intercalating an extra month every two or three years (Malotki 1983:655; McCluskey 1977). Furthermore, in relating the Sun to the Moon, the Hopi expressed the late appearance of the solstice as the Sun "going slowly" in comparison to the Moon (Malotki 1983:36; Parsons 1933:58–59).

In the fifth century B.C., Herodotus (*Histories* 2.4.1) noted that "the Greeks add an intercalary month every other year, so that the seasons agree," reflecting a simple model of twelve lunar months with an occasional intercalary month. Within this general framework there was little uniformity, for most of the Greek city-states maintained local lunar calendars; at Athens both the length of individual months and the intercalation of a month could be altered, points criticized by the Greek playwright Aristophanes. The problem was so serious that some Athenian inscriptions from the second century B.C. give two dates, one civil date "according to the archon" and one astronomical date "according to the goddess," that is, according to the Moon (σεληʹνην). These two dates differ by as much as 20 days (van der Waerden 1984).

These variations were not due to ignorance of the underlying principles of a lunisolar calendar. As is widely known, in 432 B.C. the Greek astronomer Meton of Athens had established a regular cycle in which seven months would be intercalated every 19 years, making a period in which

$$19 \text{ years} = (19 \times 12) + 7 = 235 \text{ months.}$$

Meton is also said to have set up stelae containing calendric material. We know little about Meton's stelae, but texts and a few surviving fragments of later inscriptions suggest their contents.

These *parapegmata* listed the days not according to the lunar month, but following the entry of the Sun into each sign of the zodiac. Sockets were drilled into the stela for each day that the Sun takes to pass through a zodiacal sign (for example, the *parapegma* from Miletus has 30 sockets for the Sun to pass through Aquarius). Adjacent to many of the sockets are descriptions of solar, stellar, and meteorological phenomena, e.g., "The Sun in Aquarius," "first evening setting of Cygnus," or "Sagitta setting, season of continuous westerly wind." It is believed that pegs marking the beginning of the month, the phases of the Moon, or the current date in the lunisolar calendar were placed in the appropriate sockets (Diels and Rhem 1904).

As public presentations of calendric data, the *parapegmata* fit admirably within the Greek ideal of a civic society. The form that they take, however, reflects something of Greek conceptions of the heavens. It is eminently practical to engrave the manifold details of stellar, solar, and weather phenomena on a fixed tablet, while using movable markers to mark recurring lunar phenomena. Conceptually, however, the *parapegmata* tend to make seasonal phenomena primary, as they had been centuries earlier in Hesiod, and to measure variable lunar phenomena in terms of the unchanging stars.

The Babylonians also sought to relate solar and lunar phenomena, but left no ambiguity as to the primacy of the lunar calendar. Before Meton they had established a regular pattern of intercalating seven months every 19 years, which, unlike the Greeks, they employed consistently in civil records beginning in the reign of Darius around 498 B.C. As a consequence, the Babylonians used this regular 19-year scheme of intercalation to calculate the changing dates of the solstices and equinoxes, and of the heliacal rising, opposition, and heliacal setting of Sirius (Neugebauer 1975:354–366).

Before going deeper into Babylonian lunar theory, there is one more application of the Metonic 19-year intercalation schema to consider: its use in calculating the date of Easter. The Council of Nicea (A.D. 325) had decreed that Easter should fall on the Sunday following the full moon of the first month of spring (McCluskey 1998:77–87).

This decree, coupled with the earlier definition of the Julian calendar, was incorporated in medieval liturgical calendars, which also listed the solstices, the equinoxes, and the entrances of the Sun into each sign of the zodiac. The Easter calculations were not totally uniform; there were disputes over whether a 19-year or an 84-year cycle was the proper one. But the method itself was not questioned until astrological medicine provided a reason to know the exact time, rather than the correct day of the full moon, and observations of solar eclipses with the astrolabe demonstrated that the assumptions of uniform intervals between full moons was not valid (McCluskey 1998:180–182).

In the Greek, Babylonian, and medieval European cases we have astronomical calendars that share the same mathematical pattern and seem, at first glance, to be equivalent. However, they employ different units as their basic standard of time and, consequently, deal with different problems. Judging from our limited evidence of the Greek material, the Greek *parapegmata* took stellar phenomena as basic, and had to compute the day in a stellar framework when the lunar month began. A similar, and more firmly documented, situation appears in medieval Europe, where ecclesiastical calendars were fixed in the Julian calendar. Here the dates of the solstices and equinoxes were conventionally fixed and ceased to provide astronomical problems throughout the early Middle Ages, while the proper method to compute the Easter Full Moon remained a recurring matter of debate and discussion. In contrast, the Babylonians had taken the motions of the Moon as basic to their calendar, while the appearances of the Sun and stars needed to be computed. In each culture the motions of the body chosen to define the calendar's reference frame were not seen as problematic, but the motions of bodies measured against that frame continued to pose problems.

As is well known, the calendar was not the only astronomical problem dealt with by early astronomers; they had developed a range of systems for computing the times and places of a wide range of astronomical phenomena. In turning from calendric to more general astronomical problems, we find an even wider variation of astronomical methods serving a wide range of purposes, many of which center on various aspects of celestial divination. In discussing these more general problems I will consider a number of different lunar models, which will provide a further contrast with the calendric systems already studied.

The Babylonian case provides us with the best early evidence to connect astronomical observations, the calculations derived from those observations, the concepts embodied in those observations and calculations, the procedures employed in those calculations, and some of the uses to which those observations and calculations were put. The detail and scope of the extant astronomical and astrological texts have greatly enriched our understanding of the nature of Babylonian astronomical theory and the divinatory context of its development. The earliest astronomical records from Mesopotamia are collections of astronomical omens, detailing the significance of various celestial phenomena. In their current form they date to the beginning of the first millennium B.C., although elements contained in them are a full thousand years older. They are generally cast in the form, "If A happens, then B will follow." Beginning near the end of the eighth century B.C., prognostications drawn from this collection were sent regularly by professional scholars as formal advice to the king.

> If on the 14th day the Moon and Sun are seen together: the speech of the land will become happy; the king will become happy; the gods will remember Akkad favorably; there will be joy among people; the cattle of Akkad will lie in the steppe undisturbed.
> The Moon is seen on the 14th day: good for Akkad, bad for Elam and the Westland.
> The king my lord must not say as follows: "there were clouds; how did you see anything?" This night, when I saw the Moon's coming out, it came out when little of the day was left, it reached the region where it will be seen in opposition with the Sun. This is a sign that it is to be observed. In the morning, if the day is cloudless, the king will see: for one "double-hour" of daytime the Moon will stand there with the Sun [Hunger 1992:No. 294].

This letter indicates the king's concern with careful observations of celestial phenomena, a concern with quantitative measurements of the time between sunrise and moonset, and the ability of his astronomical experts to use evening observations of the Moon to forecast conditions on the following morning, all related to the significance of the appearance of the Sun and Moon together on the fourteenth day of the month as a favorable portent. The less frequent early or late appearances of the Sun and Moon on the twelfth, thirteenth, fifteenth, or sixteenth days were menacing portents, for example:

> If on the 15th day the Moon and Sun are seen together: a strong enemy will raise his weapons against the land; the enemy will tear down the city gates.
> If the Moon does not wait for the Sun but sets: raging of lion and wolf [Hunger 1992:No. 294].[4]

The final passage reflects the practice we have already seen of noting the portentous appearance of the Sun and Moon at dawn as the Sun was rising and the Moon setting. Dawn on the day that the

Moon and Sun face each other was also the proper time to perform an apotropaic ritual to turn away illness. In this ritual the patient faces north, makes offerings toward the places of sunset and sunrise, and then recites:

> To my left is Sîn, moon crescent of the great heavens, to my right the father of mankind, Šamaš [the Sun] the judge, . . . Sîn, light of heaven and earth, take away my sickness! . . . Šamaš, great judge, father of mankind, let the evil wind that has settled on me rise to heaven like smoke, and I will sing your praises [Reiner 1995:135–137; Scurlock 1988:238–240].

The time of this ritual has further significance. The interval between sunrise and moonset on the day after opposition is recorded in astronomical diaries, is an important result of lunar ephemerides, contributes to the development of precise Babylonian astronomical parameters, and is included in many Babylonian horoscopes.

Throughout this period, the astrologers report the ominous significance of particular events: new and full moons, eclipses, and significant planetary phenomena. The exact circumstances of these events could be calculated in advance with an aim of averting the evil. A new kind of Babylonian celestial divination, the birth horoscope, first appears around the fifth century B.C. These horoscopes generally present the positions of the Sun, Moon, and planets at or near the time of a person's birth, the circumstances of the full moon and of the first and last visibility of the lunar crescent in the month of the birth, and reports of eclipses when they occurred near the time of the birth. One early example reports:

> [The month] Nissanu, night of the 14th,
> son of Šumu-usur, son of Šumu-iddina,
> descendant of Dēkē, was born.
> At that time, the Moon was below the pincer of the Scorpion,
> Jupiter in Pisces, Venus in Taurus, Saturn in Cancer,
> Mars in Gemini, Mercury, which had set, was not visible. . . .
> Nissanu 1, duration of visibility of the new crescent was 28 time degrees,
> visibility of the Moon after sunrise on the 14th was 4,40 time degrees.
> The last visibility of the lunar crescent was the 27th [Rochberg 1998:39–46, 56–57].

Two elements are worth noting in these horoscopes. First, we see the recurrence of numerical values for the durations of visibility of the full moon and lunar crescent, which is an enduring concern of Babylonian lunar astronomy. Second, the positions of the planets at the time of birth, albeit usually only to the nearest zodiacal sign, called for different sources of astronomical data than did the ephemerides, which only provide positions at the time of specific occurrences.[5]

The earliest planetary ephemerides date from the end of the third century B.C., while a tablet calculating lunar eclipse possibilities was written shortly after 475 B.C. (Neugebauer 1955; Lis Brack-Bernsen, personal communication July 20, 1999). This is well after the first emergence of interest in celestial omens and the development of a professional "scribal" class reporting observations to the king, and after these observers had accumulated over four centuries of data in astronomical diaries (Sachs and Hunger 1988).

Several characteristics distinguish Babylonian astronomical calculations. First, the ephemerides compute the circumstances, the place, and exact time of specific astronomical phenomena such as a full moon or the beginning of a planet's retrograde motion. Second, the ephemerides do not assume uniform intervals between events, but use several mathematical techniques to account for the major sources of nonuniformity. Third, the dominance of the Babylonian lunar calendar is apparent in these computations, for the periods in lunar ephemerides are related to a lunar reference frame and sampled only once each lunar month, which leads to some uniquely Babylonian astronomical parameters.

Although there is a range of Babylonian lunar and planetary ephemerides, they all share a tabular layout similar to that familiar today from computer spreadsheets. As in a spreadsheet, the value in each cell of an ephemeris is calculated from values already computed in the same or preceding columns. I will briefly outline lunar system A using the ephemeris ACT 5 (Fig. 1), which computes the circumstances of a sequence of new moons in what Neugebauer (1955) described as the most complete surviving example of this type.

The longitude of the Moon (column B) is calculated from the position of the previous lunation on the basis of a nonuniform model of the Sun's motion (since the position of a new or full moon is fixed in relation to the Sun, computing the Sun's motion determines the position of the next new or full moon). The length of daylight (column C) and the correction for the solar velocity (column J) are then computed as functions of the longitude of the Moon (column B). The correction to the time of syzygy based on the change of length

No. 5

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T	Φ	B		C	E	F	G
XII₂	[1, 58, 27, 13, 20]	[27, 11, 15	Aries]	[3, 11, 27, 30]	+ 3, 12, 8, 39	[11, 1]3	4, 55, 34, 4,[26, 40]
2, 26 I	[2, 1, 13, 8, 53, 20]	[25, 18, 45	Taurus]	[3, 26, 7, 30]	+ 2, 45, 54	[11,]55	4, 44, 3[3, 20]
II	[2, 3, 59, 4, 26, 40]	[23, 26, 15	Gemini]	[3, 33, 47, 30]	− 3, 9, 22, 45	[12,]37	4, 18,[4]4, 41, 28,[53, 20]
III	[2, 6, 45]	[21, 33, 45	Cancer]	[3, 34, 27, 30]	− 5, 8, 8, 27	[13,]19	3, 52, 56, 2,[57, 46, 40]
IV	[2, 9, 30, 55, 33, 20]	[19, 41, 15	Leo]	[3, 28, 7, 30]	− 7, 6, 54, 9	[14,] 1	3, 27, 7, 24, 2[6, 4]0
V	[2, 12, 16, 51, 6, 4]0	18, 8	[Virgo]	[3, 14, 34, 40]	− 5, 17, 3, 9	[14,]43	3, [1,] 18, 4[5, 55, 33, 20]
VI	[2, 15, 2, 46, 4]0	18, 8	[Libra]	[2, 54, 34, 40]	− 3, 10, 47, 27	[15, 25]	[2, 41, 22, 46, 40]
VII	[2, 16, 20, 5]5, 33, 20	18, 8	Scorp[ius]	[2, 36, 44, 48]	+ 14, 56, 30	[15, 47]	[2, 40]
VIII	[2, 13, 35]	18, 8	Sagittar[ius]	[2, 26, 54, 56]	+ 3, 25, 43, 57	[15, 5]	[2, 40]
IX	[2, 10, 49,] 4, 26, 40	18, 8	Capri[corn]	[2, 25, 5, 4]	+ 5, 31, 59, 39	[14, 23]	[2, 51, 5]8, 20
X	[2, 8, 3,] 8, 53, 20	18, 8	[Aquarius]	[2, 31, 1]5,[12]	+ 6, 45, 44, 39	[13, 41]	[3, 1]7, 43, 57, 2, 13, 20
XI	[2, 5, 1]7, 13, 20	18, 8	[Pisces]	[2,]45, 25,[20]	+ 4, 39, 28, 57	[12,]59	3, 43, 32, 35, 33, 20
XII	[2, 2, 31, 1]7, 46, 40	[16, 48, 45	Aries]	3, 4, 32, 3[0]	+ 2, 38, 30, 15	[12,]17	4, 9, 21, 14, 4, 26, 40
2, 27 I	[1, 59, 45, 22, 13, 20]	[14, 56, 15]	Taurus	3, 21, 58,[30]	− 1, 4, 30, 54	[1]1, 35	4, 35, 9, 52, 35, 33, 20
II	[1, 58, 36, 2]8, 53, 20	[13,] 3, 45	Gemini	3, 32, 24,[30]	− 3, 43, 1, 9	[11, 15]	4, 56
III	[2, 1, 22, 2]4, 26, 40	11, 11, 15	Cancer	3, 35, 50,[30]	− 5, 41, 46, 51	[11, 5]7	4, 43, 6, 54, 48, 53, 20
IV	[2, 4, 8, 2]0	9, 18, 45	Leo	3, 32, [5, 30]	− 6, 43, 27, 27	[12,]39	4, 17, 18, 16, 17, 46, 40
V	[2, 6, 54, 15,] 33, 20	7, 26,[15	Virgo]	[3, 21, 1, 30]	− 4, 44, 41, 45	[13,]21	3, 51, 29, 37, 46, 40
VI	[2, 9, 40, 11, 6, 40]	[7, 4	Libra]	[3, 1, 57, 20]	− 2, 39, 55, 3	[14, 3]	3, 25, 41, 59, 15, 33, 20

J		C'		K	M				P		
[57, 3, 45	lal]	[9, 22, 30	lal]	[3, 49, 8]	[dirig	29	5, 29, 42	šú]	[bar	1	//////]
[57, 3, 45	lal]	[7, 20	lal]	[3, 40, 19]	[bar	28	1, 49, 23	šú]	[gu₄	1	//////]
[57, 3, 45	lal]	[3, 50	lal]	[3, 17, 50]	[gu₄	28	4, 31, 33	šú]	[sig	30	//////]
[57, 3, 45	lal]	[20	l]al	2,[55, 32]	[sig	28	1, 36, 1	šú]	[šu	1	//////]
[57, 3, 45	lal]	[3] 10	tab	2, 33, 13	[šu	28	5, 2, 48	šú]	[izi	30	//////]
[47, 17, 5]4, 30	l[al]	6, 46, 25	tab	2, 20, 46	[izi	28	2, 42, 2	šú]	[kin	30	//////]
		10 uš	tab	2, 51, 22	[kin	29	5, 50, 40	šú]	[du₆	1	//////]
		8, 54, 56	tab	2, 48, 5[5]	[du₆	28	3, 1, 45	šú]	[apin	30	//////]
		4, 54, 56	tab	2, 44, 5[5]	[apin	28	., 16, 5]0	š[ú]	[ga]n	30	14, 20
		54, 56	tab	2, 52, 5[3]	[g]an	29	3, 23, 57	šú	ab	1	23
		3, 5, 4	lal	3, 14,[3]8	ab	28	., 9, 19	šú	zíz	30	14, 10
		7, 5, 4	lal	3, 36, 27	zíz	29	2, 32, 52	šú	še	1	20
40,[1]1, 50, 3[0	lal]	9, 33, 35	lal	3, 19,[35]	še	29	5, 13, 17	šú	bar	1	ina ^{25}30-šú 10, 30
57, 3, 45	lal	[8, 4]3	lal	3, 29, 2[3]	bar	28	1, 43, 54	šú	gu₄	30	13, 20
57, 3, 45	lal	[5, 13]	lal	3, 53, 4[3]	gu₄	29	3, 50, 11	šú	sig	1	14, 10
57, 3,[45]	lal	1, 4[3]	lal	3, 44, 20	sig	28	., 5, 51	šú	šu	1	[//////]
57, [3, 45	lal]	1,[52,] 30	tab	3, 22, 7	šu	28	2, 53, 44	šú	[izi	30	//////]
57, [3, 45	lal]	[5, 32]	tab	2, 59, 58	[izi]	29	5,[43, 46	šú]	[kin	1	//////]
[11, 17,] 8, 30	lal	[9, 32,] 5	tab	3, 23, 5[5]	[kin	28	2, 19, 51	šú]	[du₆	30	//////]

Obv.

FIGURE 1. Babylonian Lunar Ephemeris ACT No. 5 (obverse). Shaded portions indicate reconstructed elements of the text (after Neugebauer 1955).

of daylight (column C') is then computed from the present and previous length of daylight (column C).

Two so-called zigzag functions, increasing or decreasing by a constant amount between each new moon, determine most of the remaining parameters. One such function (column E), with a period of 11.738 lunar months (which also equals 12.738 draconitic months), represents the latitude of the Moon. The other function, with a period of 13.944 lunar months (which also equals 14.944 anomalistic months), lies behind column Φ, closely related to the velocity of the Moon with respect to the Sun; column F, the velocity of the Moon; and column G, the approximate length of the month (Brack-Bernsen 1997; Brack-Bernsen and Schmidt 1994:207–208). Note that while both Babylonian periods accurately express lunar phenomena, there is no simple one-to-one correspondence between the periods of the Babylonian parameters and of the Ptolemaic and modern parameters that express the same phenomena. The idiosyncratic form in which the Babylonian parameters are expressed emerges as a consequence of their considering lunar latitude and "velocity" not as continuous functions, but sampling them discontinuously at intervals separated by a synodic month. This creates a problem often found in the analysis of sampled astronomical data, the occurrence of "aliasing" when periodic data are sampled using a different period.[6]

Despite their idiosyncratic "aliased" periods, the Babylonian parameters computed in the previous columns could be, and were, employed successfully to predict the true date and time of syzygy (column M), the date of first visibility of the crescent moon, and the interval from sunset to setting of the crescent moon (column P).

Although not displayed on this figure, the bottom edge of ACT 5 contains similar calculations of the time from moonrise to sunrise at the last visibility of the waning Moon. Similar ephemerides for full moons compute four intervals between sunrise or sunset and moonset or moonrise on the days immediately before and immediately after opposition, intervals known as the lunar four. Although the computed dates and times of first crescent were used to determine the beginning of the month, the lunar four had no such immediate calendric application.

These intervals between lunar and solar rise and set reflect an astronomical concept that plays a major, if not central, role in Babylonian astronomy. As observable intervals, these times were measured, apparently using a simple water clock, were recorded in the astronomical diaries, and provided a substitute for the precise time of syzygies, which cannot be directly observed except when the Sun or

Moon is eclipsed. More significantly, as has been recently demonstrated, they provided the means for determining the value of column F, which represents the lunar anomaly. Furthermore, they referred to ritually significant times: the days of full and new moon had long been noted for their divinatory significance, important apotropaic rituals were performed at these times, and three of these intervals appear regularly in Babylonian horoscopes. It appears that the ominous significance of these phenomena was the driving force behind column P, which far exceeded the practical needs of a lunar calendar.

These intervals are not considered in other astronomical traditions, but for the Babylonians they contribute to the ritual, observational, and theoretical aspects of astronomy. If we consider the recorded observations of these parameters in the astronomical diaries, their influence on the development of astronomical parameters and theory, and the precision with which they were calculated in the lunar ephemerides, the lunar four are at least as important as the time of a lunar syzygy and more important than the position of the Moon at syzygy. It is significant to our comparison of astronomical systems that an obscure element, found in no other astronomical system, should be central to the theoretical development and precision of Babylonian lunar astronomy.

Although most surviving Babylonian lunar ephemerides deal with separate computations of the time and place of new and full moons, ignoring the position of the Moon at intervening times, there are a few atypical Babylonian tablets from the second century B.C. that calculate the place of the Moon in the zodiac for each day during the course of a year. This is the kind of information required for personal horoscopes, rather than the ominous events calculated in the ephemerides. But like the ephemerides, these tablets take account of the variations of the Moon's motion. Specifically, they consider that the daily motion of the Moon through the zodiac oscillates with a linear zigzag function $\pm 2°4'$ around an average value of $13°10'35''$ per day (Neugebauer 1955:190–194). This daily motion is held to oscillate through its entire range nine times in 248 days. Unlike the uniquely Babylonian function tabulated in column Φ of the ephemerides, the period of this function is that of the Ptolemaic and modern anomalistic month.[7]

The anomalistic month appears again in Ptolemaic lunar theory, but Ptolemy expressed it in geometric terms as the consequence of the Moon being carried around on an epicycle. Unlike his Babylonian predecessors, for whom we have to infer how they related observations to theory, Ptolemy presents an explicit derivation of the size of the lunar epicycle and the rate of its rotation using Babylonian observations of three ancient lunar eclipses (720 B.C.) and three similar observations which he made between A.D. 133 and 136 (Neugebauer 1975:71–79).

The parameter Ptolemy derives for the rate of the lunar anomaly is directly comparable, both conceptually and in its quantitative result, to the modern value. If this reflects a departure from the general pattern of Babylonian ephemerides, a more significant departure from all the lunar theory we have seen thus far is Ptolemy's introduction of rigorously formulated, empirically based, quantitative geometric models of the motions of the Moon (Goldstein 1967). This merger of geometric models with quantitative precision would define and guide the mainstream of mathematical astronomy until the time of Kepler.

Unlike most of the astronomies we have seen heretofore, Ptolemy's provided techniques to compute the position of the Moon (as well as of the stars and other planets) at any arbitrarily chosen time. Significantly, Ptolemy's astronomy is not suited for simple direct calculations of the kind of ominous phenomena that had concerned the Babylonians. Babylonian ephemerides employ much more direct methods to compute lunar and planetary phenomena.

Ptolemy is clearly not doing calendric astronomy, and there is little doubt that, besides Ptolemy's clearly expressed desire to understand the motions of the divine heavens, the development of his theory responded to the contemporaneous rise of horoscopic astrology, on which Ptolemy himself had written.

The Maya eclipse table of Codex Dresden presents another purely arithmetic system for lunar predictions (Lounsbury 1970–1980).[8] The Maya material is much more limited than the Babylonian; we do not have any equivalents of the astronomical diaries and procedure texts, and only a few limited examples of Maya calculations. Insofar as inscriptions on Maya stelae incorporate both calculated celestial events and historical terrestrial events, we have something akin to the Babylonian horoscopes. These suggest that a leading motive for Maya astronomy is divinatory, determining the potential times when ominous events are likely to occur. However, the abundance of planetary phenomena in ominous inscriptions suggest that the Maya considered these more important than eclipses and other lunar phenomena (Aveni and Hotaling 1994).

Unlike the Babylonian texts, which keep the calculations of ephemerides separate from the prognostications of the omen literature and horoscopes, Codex Dresden includes augural glyphs and pictures depicting the eclipsed Sun and Moon gods.

The techniques employed in the Dresden eclipse table are closer in form to those used in relating calendric periods than to the techniques found in Babylonian ephemerides. Where lunisolar calendars related the periods of the Sun and the Moon, the Dresden eclipse table sought to relate the eclipse half-year (173.31 days), the lunar month (29.53 days), and the 260-day Maya sacred almanac (or *Tzol Kin*).

The solution was based on the interval between successive eclipses, which is usually six months, although sometimes eclipses are separated by only five months. Thus the table established a fixed pattern of 70 eclipse danger periods separated by 60 six-month intervals and 9 five-month intervals, which totaled 11,959 days, that is, 405 lunar months, and one day less than 46 cycles of the *Tzol Kin*. Interestingly, the Dresden eclipse table also incorporates exactly 434 anomalistic months, suggesting that the authors of the table may have chosen this interval in order to obtain a more precise value for the average length of the lunar month. If this is the case, there is no other indication that the lunar anomaly played any role in Maya astronomy. This is not an inadequacy in Maya theory. The lunar anomaly need only appear explicitly in lunar theory when one is concerned with the place of the Moon or the exact time of a lunar event; for computations of the day when an eclipse is possible, the introduction of the lunar anomaly would have been superfluous.

The second aspect of the eclipse problem concerned the alternation of 29- and 30-day months. The six-month intervals were generally 177 days long, reflecting a month length of 29 1/2 days, but seven of these intervals were lengthened to 178 days. The 9 five-month intervals were 148 days long, each of which adds a half day to the average month length of 29 1/2 days. The 11 1/2 days added over the 405 months of the lunar eclipse table yield an average month of 29.528 days.[9]

Conclusion

The lunar astronomies we have reviewed consider the Moon in many different ways. Some are based on simple observations, but most employ arithmetic or geometric schemes to predict future occurrences. With the sole exception of Ptolemaic geometrical astronomy, none of the predictive astronomies provide any indication that their predictions depend upon the structure of the universe. Arithmetical calculations, it seems, are not related to cosmology.

The second difference concerns the elements which are observed or predicted, and the level of precision of those observations or predictions. The observation or prediction of the day of specific lunar events does not require a subtle astronomical system; the Babylonian concern with the precise circumstances of those lunar events having special ominous or ritual importance led to calculations of exact times and intervals; the emergence of horoscopic astrology led to further techniques to calculate the position of the Moon at arbitrary times. Techniques were developed to deal with those questions that a culture perceives to be important.

The systems we have seen measure time against the varied units that define their calendars: the lunar month, the appearances of stars, the Julian Year, or the Maya *Tzol Kin*. This leads to different conceptual perceptions, and even to differences as to what is a problem; the dates of the solstices are not a problem in the Julian calendar, but they do pose a problem in the Babylonian calendar. Nonetheless, we would expect that we could easily convert parameters measured in lunar months to the same parameter measured in Julian Years, just as we can readily convert kilometers to miles or Celsius to Fahrenheit. In fact, as we have seen, this is not always the case.

The most surprising, and significant, result of this investigation of different astronomies is that the Babylonians' focus on discrete phenomena, and their use of the lunar month as the basis for reckoning, led them to express the periods of lunar latitude and lunar anomaly in terms that are not directly commensurable with the equivalent elements of modern astronomy. We are back at what philosophers of science have discussed as a translation problem (Kuhn 1970:202–204; Popper 1970:56–57). If we are to understand other astronomies, we not only need to translate their concepts, we may even need to translate their quantitative parameters. Translation is possible, but it does not involve one-to-one quantitative equivalency when the concepts that the parameters reflect are subtly different. Even precise quantitative data, the supposed epitome of scientific objectivity, can incorporate culturally based elements.

This provides an important lesson for those of us studying astronomies in cultures. We cannot assume that "they" were concerned with the same phenomena we are. We cannot even assume that their astronomies embody the same numerical parameters that ours do.

We can only try to identify the problems they were trying to solve, investigate why they considered those problems significant, and attempt to explain clearly how they came to their answers.

Notes

1. I am grateful to Dr. Lis Brack-Bernsen for her thoughtful comments on a previous draft of this paper. Any remaining misstatements are, of course, my own.

2. Aristotle (*Physics*, Δ14, 233^{b}, 15–19) had noted the arbitrary nature of the selection of a standard of time: "[M]otion and time mutually determine each other quantitatively; and . . . the standard of time established by the motion *we select* is the quantitative measure both of that motion and of time."

3. Note that the Hopi had specific terms, *muy-honaq-tot-e* (moon-crazy) and *muy-nanaywa* (moon-fight) to express the confusion and disagreement about the current month.

4. *Astrological Reports to Assyrian Kings*, no. 24; see also nos. 88, 267, 320, and passim. There are 71 reports of full moons on the fourteenth day; there are a total of 39 early and late full moons.

5. Rochberg (1998:8–9) suggests that this was not observational data but was either produced by some kind of interpolation scheme or extracted from "other records."

6. The period underlying the lunar latitude function (column E) corresponds to 12.738 draconitic months or to 19.613 revolutions of the lunar nodes; the period underlying the lunar velocity function (column Φ) corresponds to 14.944 anomalistic months or to 7.848 revolutions of the lunar perigee. Brack-Bernsen (1980:49) has derived the period of column Φ from the anomalistic month. Neugebauer (1955:30–32, 44, 55, 1975:485, 520) has extracted an underlying "true function" from column E with a period equal to the draconitic month.

7. The Babylonian period is 27.5556 days; the modern length of the anomalistic month is 27.5546 days.

8. I follow Lounsbury's emendations, which lengthen the eclipse table from 11,958 to 11,959 days.

9. These calculations follow the table as emended by Lounsbury; if we took the eclipse cycle as exactly 46 Maya sacred almanacs, or 11,960 days, the exact value for the length of the month would be 29.53086 days. Although the table provides no evidence for this relationship, and Maya inscriptions are not uniform, some inscriptions at Palenque indicate an equivalent identification of 81 lunar months (one-fifth the length of the Dresden eclipse table) with 2,392 days.

References

Aveni, Anthony F., and Lorren D. Hotaling

1994 Monumental Inscriptions and the Observational Basis of Maya Planetary Astronomy. *Journal for the History of Astronomy* 25 (*Archaeoastronomy* Supplement 19):S21–S54.

Brack-Bernsen, Lis

1980 Some Investigations on the Ephemerides of the Babylonian Moon Texts, System A. *Centaurus* 24:36–50.

1997 *Zur Entstehung der babylonischen Mondtheorie: Beobachtung und theoretische Berechnung von Mondphasen, Boethius 40.* Franz Steiner Verlag, Stuttgart.

Brack-Bernsen, Lis, and Olaf Schmidt

1994 On the Foundations of the Babylonian Column Φ: Astronomical Significance of Partial Sums of the Lunar Four. *Centaurus* 37:183–209.

Diels, Hermann, and Albert Rehm

1904 Parapegmenfragmente aus Milet. *Sitzungsberichte der königlich Preussischen Akademie der Wissenschaften. Philosophisch-historische Klasse,* 23:92–111.

Goldstein, Bernard

1967 Saving the Phenomena: The Background to Ptolemy's Planetary Theory. *Journal for the History of Astronomy* 28:1–12.

Hunger, Hermann (editor)

1992 *Astrological Reports to Assyrian Kings, State Archives of Assyria* No. 8. Helsinki University Press, Helsinki.

Kuhn, Thomas

1970 *The Structure of Scientific Revolutions.* 2nd. ed. University of Chicago Press, Chicago.

Lounsbury, Floyd

1970–1980 Maya Numeration, Computation, and Calendrical Astronomy. *Dictionary of Scientific Biography* 15:759–818.

Malotki, Ekkehart

1983 *Hopi Time: A Linguistic Analysis of Temporal Concepts in the Hopi Language*. Mouton, Berlin.

Marshak, Alexander

1972 *The Roots of Civilization*. McGraw Hill, New York.

McCluskey, Stephen C.

1977 The Astronomy of the Hopi Indians. *Journal for the History of Astronomy* 8:174–195.

1998 *Astronomies and Cultures in Early Medieval Europe*. Cambridge University Press, Cambridge.

Murray, William Breen

2000 The Contributions of the Ethnosciences to Archaeoastronomical Research. *Archaeoastronomy* 15(112–120).

Neugebauer, Otto

1955 *Astronomical Cuneiform Texts, Babylonian Ephemerides of the Seleucid Period for the Motion of the Sun, the Moon, and the Planets, (ACT)*. 3 vols. Institute for Advanced Study, Princeton, New Jersey.

1975 *History of Ancient Mathematical Astronomy (HAMA)*. 3 vols. Springer Verlag, New York.

Parsons, Elsie Clews

1933 *Hopi and Zuñi Ceremonialism, Memiors of the American Anthropological Association*, 39.

Popper, Karl

1970 Normal Science and Its Dangers. In *Criticism and the Growth of Knowledge*, edited by Imre Lakatos and Alan Musgrave, pp. 51–58. Cambridge University Press, Cambridge.

Reiner, Erica

1995 *Astral Magic in Babylonia, Transactions of the American Philosophical Society* 85(4).

Rochberg, Francesca

1998 *Babylonian Horoscopes, Transactions of the American Philosophical Society* 88(1).

Sachs, Abraham J., and Hermann Hunger

1988 *Astronomical Tables and Related Texts from Babylonia, Volume I, Diaries from 652 b.c. to 262 b.c. österreichische Akademie der Wissenschaften, philosophisch-historische Klasse, Denkschriften*. Vol. 195 and subsequent vols.

Scurlock, Jo Ann

1988 Magical Means of Dealing with Ghosts in Ancient Mesopotamia. Ph.D. dissertation, University of Chicago.

Turton, David, and Clive L. N. Ruggles

1978 Agreeing to Disagree: The Measurement of Duration in a Southwestern Ethiopian Community. *Current Anthropology* 19:585–600.

van der Waerden, Bartel L.

1984 Greek Astronomical Calendars I: The Parapegma of Euctmeon. *Archive for History of Exact Sciences* 29:102–114.