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# The Varying Agenda of the Study of the Heavens: Mesopotamia, Greece, China

Every student of early Chinese thought knows that the study of the heavens was divided into two main branches, *lifa* 曆法 and *tianwen* 天文. The ancient sources are not in serious disagreement about what each comprised, *lifa* covering "methods of making ephemerides and other computational tasks" and *tianwen* the "investigation of the 'patterns in the heavens,' including cosmography, observation and the interpretation of omens."[1] Many commentators, accordingly, propose a rough match between that pair and what *we* call "astronomy" on the one hand, and "astrology" on the other, though the fit is far from perfect, notably with regard to *tianwen*.

It is also well known that the Greeks' two terms, ἀστρονομία and ἀστρολογία were sometimes used interchangeably, and so also fail to match our distinction between astronomy and astrology, even though on occasion they drew a clear working distinction between predictions of celestial events on the one hand, and on the other predictions, on their basis, concerning what would happen on earth. Ptolemy, for one, does so in the opening chapter of the *Tetrabiblos*.[2]

What we call astrology is not so easily dismissed nowadays as it was when Otto Neugebauer, whose magnum opus was correctly titled *A History of Ancient Mathematical Astronomy,* said he would have nothing to do with Babylonian astrology.[3] Yet historians of astronomy, with

It is a great pleasure to offer this contribution to the collection of essays in honor of my friend and collaborator, Nathan Sivin, who has done more than any other living scholar to transform our understanding of Chinese science.

1 See Geoffrey E. R. Lloyd and Nathan Sivin, *The Way and the Word* (New Haven: Yale U.P., 2005).

2 I, 1, 13.32ff.

3 Otto Neugebauer, *A History of Ancient Mathematical Astronomy*, 3 vols. (Berlin: Springer, 1975).

some notable exceptions, to be sure, still devote the lion's share of their studies to ancient efforts in such matters as calendar regulation and eclipse prediction, where two prime topics of modern interest have been how accurate those efforts were, and who achieved which positive results first. The latter was, of course, a recurrent preoccupation throughout Joseph Needham's own volumes from 1954 in *Science and Civilisation in China*.[4]

My tactic in this paper is to take a step back and to ask what ancient inquiries in the matter of the study of the heavens were inquiries into. This is with a view to recovering some of the variety in the answers we can identify. What did ancient investigators believe were the main purposes of the work they undertook? The principal articulating framework I shall adopt for my discussion uses neither the contrast between astronomy and astrology, nor a taxonomy based on the different subject-matters. Rather, I start from broad distinctions between possible aims. Thus observing, recording, predicting, explaining, and understanding are divergent goals, though they are certainly not mutually exclusive ones, and indeed each comes in different modalities. To give the two most obvious examples, the modes of prediction attempted may vary, and ideas about what counts as understanding may be even more diverse. My argument will be that when we pay due attention to the divergences, shifts and transformations in the ancients' aims and goals, we can recover important, and still maybe rather neglected, aspects of the heterogeneity and pluralism of ancient work – against the tendency to write homogeneous "histories of ancient astronomy." This, I hope, will provide a convincing illustration of the benefit of comparing and contrasting divergent traditions of the study of the heavens in different ancient civilizations. This is to bring to light aspects of the aims and methods that ancient investigators used in different contexts, where such aspects may well be missed or underestimated by modern scholars working on just one ancient tradition. This was, of course, one of the guiding principles that motivated my collaborations with Nathan Sivin.

So let us start with Mesopotamia, a term of art that covers work done by Sumerians, Babylonians and Assyrians. This provides our earliest extensive evidence for detailed investigations of different types into the heavens, the subject of important new studies by scholars such

[4] Joseph Needham, *Science and Civilisation in China*, multiple volumes (Cambridge: Cambridge U.P., 1954–).

as Noel Swerdlow, Francesca Rochberg, and David Brown especially.[5] Sustained observations were evidently carried out at least from the early second millennium BC, even if, as is also well known, some of our evidence on this point has to be treated with caution. Thus many of the data associated with tables setting out the movements of different heavenly bodies are the result of calculation, not of observation. Again as I shall be remarking in a minute, in the omen literature some of the events set out in the protases of the conditional sentences in question were not merely never observed, they were not even observable (eclipses on impossible days in the month, when the moon was at quadrature, for instance). Nevertheless impressive sets of observations were undoubtedly made and carefully recorded, and the question this poses is, of course, what were the interests and aims of those responsible?

Now "those responsible" can be subdivided into those who did the actual work and the political authorities who used it – though their interests very largely coincided. Those who did the work were officials: we know of their titles and functions and quite a lot is known about their qualifications and how they were recruited.[6] They were based in palaces (or later, in Achaemenid times, after the fall of Babylonia, at temples, for example at Uruk) and they reported directly to the political authorities, indeed often to the kings in person. We have extensive personal Letters and Reports, the bulk of which date from 680 to 650 BC, in which both Assyrian and Babylonian officials write to the kings, sometimes in reply to direct questions that the kings have put to them about what they have observed.

So when we answer the question as to interests by referring first to certain practical matters, such as calendar regulation, and then to the use of the heavens as a source of signs about the future, *both* those aspects have a clear political dimension. It was in the state's interest that the calendar was in good order, and it was in the state's interest to know about the future, not just what was in store for the king himself

[5] Noel M. Swerdlow, *The Babylonian Planetary Theory* (Chicago: Chicago U.P., 1998); Francesca Rochberg, "Scribes and Scholars: The *ṭupšar Enūma Anu Enlil*," in Joachim Marzahn and Hans Neumann, eds., *Assyriologica et Semitica*, Alter Orient und Altes Testament 252 (Münster: Ugarit-Verlag, 2000), and idem, *The Heavenly Writing: Divination, Horoscopy and Astronomy in Mesopotamian Culture* (Cambridge: Cambridge U.P., 2004); David Brown, *Mesopotamian Planetary Astronomy-Astrology* (Groningen: Styx, 2000), idem, "Greek Astral Sciences," in David Brown, ed., *The Interactions of Ancient Astral Science*, Vergleichende Studien zu Antike und Orient 10 (Bremen: Hempen, forthcoming).

[6] There is a comprehensive and authoritative study of these issues in Rochberg, "Scribes and Scholars." Cf. Simo Parpola, *Letters from Assyrian and Babylonian Scholars*, State Archives of Assyria 10 (Helsinki: Helsinki U.P., 1993).

(and in Mesopotamia "king" and "state" were effectively synonymous) but also what was likely to happen in neighboring states, potential allies or enemies, though, as I shall be explaining in a moment, it was not as if events that took place in the heavens were thought to *cause* those on earth: rather they were (just) *signs* of the future.

We know, as I said, of various types of officials. The generic term for members of the learned elite was *ummânu*, "scholar," but there were several subcategories, men whose functions were usually clearly delimited, though these were not exclusive to one another. We hear, for example, of one scribe, Marduk-šāpik-zēri who says that he follows his father's calling, as *kalû*, or "lamentation singer," but who also claims knowledge of purificatory rituals and diseases and to have mastered bodies of canonical texts that include the *Šumma izbu* (anomaly series) and the *Šumma ālu* (terrestrial omen series).[7] Several kinds of specialists were concerned with divination in one or other of its forms. There were two kinds of medical specialists, the *āšipu* ("exorcist/magician") and the *asû* ("physician"), where the former especially went in for divination. In addition there were dream interpreters (*šā'ilu*), and those involved in haruspicy (*bārû*).

So far as the study of the heavens went, among the scribes (*ṭupšarru*), there were some, entitled *ṭupšarru Enūma Anu Enlil*, associated directly, as their name suggested, with the chief body of canonical texts setting out the lore of the heavens and providing the basis for the interpretation of its signs. This was the *Enūma Anu Enlil*, which was put together some time between 1500 and 1200 BC, although it incorporated material from even earlier periods. Mastery of that text was the chief qualification needed for astronomical prognostication, although entering the ranks of the *ṭupšarru Enūma Anu Enlil* could also involve initiation and purificatory rituals – and in many cases the title was, if not hereditary, at least often passed down from father to son. These were important officials, whose competence was under the closest scrutiny. There was evidently a good deal of rivalry among these scribes, some of whom accuse their colleagues of fraudulence as well as of incompetence. They were in positions of considerable influence, reporting, as I said, directly to the kings and on matters on which their advice was likely to count for a good deal.

Whatever the subject-matter involved, predictions in Mesopotamia generally took a standard form. The protases of conditional sentences set out the sign ("if so and so"), and the apodoses delivered the result

[7] Parpola, *Letters*, tablet 160: pp. 120ff. Cf. Rochberg, "Scribes and Scholars," p. 36.

or "verdict" ("then so and so"). Thus "if Jupiter approach the Crook [a particular asterism], the harvest at Akkad will prosper." "If a star flares up in the West and enters the Yoke, there will be a revolution."[8] What is included among the signs in the protases may, as that last example shows, be rather indeterminate. But the protases on occasion set out detailed and specific data. One famous tablet in the *Enūma Anu Enlil* series sets out a sequence concerning the appearances and disappearances of the planet Venus relating to the reign of Ammisaduqa around 1600 BC, linked, in this case, to various predictions of good and bad fortune for Babylonia and its neighbors. But that good or bad fortune was not thought of as predetermined. Steps could be taken, and usually were, to avert what the signs in the heavens foretold, as in the avoidance rituals known as *namburbû*.[9] One example of this was when a criminal who was thought to be dispensable was temporarily put on the throne as a substitute king so that whatever misfortune occurred would strike him, and the real king would remain unharmed.

Down to the eighth century the vast majority of the predictions made from the signs in the heavens related to matters of major or minor state importance, from the welfare of the king downwards. But then from that century or the next an increasing number of predictions take a different form, in that the apodoses do not talk about what is to happen on earth, but what is about to occur in the heavens themselves. Once again the Letters and Reports provide crucial evidence on the point. Many of the phenomena that had figured in the protases of earlier texts, such as *Enūma Anu Enlil*, came to be more rigorously classified and themselves predictable. They notably include: 1. the length of the month as determined by successive first visibilities of the moon; 2. the phases of the planets, that is first and last visibilities, conjunctions and oppositions with the sun, and stationary points; and 3. both lunar and, within limits, solar eclipses.

The importance of this shift in the agenda of one field of celestial predictions has been emphasized especially by Brown.[10] The scribes evidently became increasingly confident in predicting celestial events

8 I take these examples from Erica Reiner and David Pingree, *Babylonian Planetary Omens, Part 2: Enuma Anu Enlil Tablets 50–51*, Bibliotheca Mesopotamica 2.2 (Malibu: Undena Publications, 1975), p. 41, and Hermann Hunger and David Pingree, *MUL.APIN: An Astronomical Compendium in Cuneiform*, Archiv für Orientforschung, Beiheft 24 (Horn: Berger, 1989), p. 113.

9 See for example Jean Bottéro, *Mesopotamia: Writing, Reasoning and the Gods*, trans. Zainab Bahrani and Marc van de Mieroop (orig. title: *Mésopotamie: L'écriture, la raison et les dieux* [Paris: Gallimard, 1987]; Chicago: Chicago U.P., 1992), chap. 9.

10 See Brown, *Mesopotamian Planetary Astronomy-Astrology*, chap. 4.

that they understood would repeat themselves according to determinable cycles. Of course, *Enūma Anu Enlil* continued to be used to interpret signs that related to good and bad fortune for the state. There was no suggestion that that traditional program should be abandoned, for example that it was flawed or too conjectural to be worth pursuing. Quite the contrary. But it came to be realized that accurate predictions could be made of such a phenomenon as the first visibility of a planet after a period of invisibility – not that the *ṭupšarru* always agreed about what should be predicted, nor about whether a prediction that had been made had been fulfilled.

The requisite knowledge for this breakthrough to be made was no doubt only gradually acquired. It is likely, after all, that the appreciation that a lunar or solar eclipse was only possible at a full moon, or a new one, that is to say at a conjunction, antedated the drawing up of any detailed eclipse cycle. But the confidence the scribes felt in being able to deny that a eclipse would occur at a conjunction, when at least that was possible, is conveyed by one text where the writer proclaims: "I guarantee it seven times: the eclipse will not take place."[11] A clear difference thus opens up between a style of prediction that focuses on the good or bad fortune that will occur *if* a celestial phenomenon occurs, on the one hand, and, on the other, one that predicts such celestial phenomena themselves.

We have, however, to recognize two further points that show that the new knowledge was grafted onto the old, and did not supersede it. First the fact that lunar eclipses became reliably predictable did not mean that they were no longer considered ominous (interestingly enough in China interest in them as ominous did decline, once their predictability was understood).[12] Even though they followed a regular pattern, they could still be seen as signs. That may be less surprising if we reflect that we too know perfectly well that the 13th of the month will sometimes be a Friday, and yet some people in sophisticated modern societies continue to believe that Friday the 13th is an ill-omened day.

Secondly and this time more puzzlingly, even when the scribes were clear about the regular conditions of possibility of eclipses, namely that they could only happen at conjunctions, they still refer to eclipses

[11] See Hermann Hunger, *Astrological Reports to Assyrian Kings*, State Archives of Assyria 8 (Helsinki, Helsinki U.P., 1992), p. 251.

[12] See Nathan Sivin, "Cosmos and Computation in Early Chinese Mathematical Astronomy," in idem, *Science in Ancient China* (Aldershot: Ashgate, 1995; orig. published in *TP* 55 [1969]), chap. 2.

possibly occurring on other days. Modern commentators are divided in their interpretations of this. On one view the scribes refer to such eclipses merely out of deference to tradition – that such are mentioned in the canonical text, *Enūma Anu Enlil*. Alternatively the heavenly bodies were certainly thought of as divine, and some texts seem to indicate that the scribes believed that the gods could do anything, though without specifying everything that covers.[13]

Let me now take stock and put this shift in the Babylonian agenda into perspective. Four points stand out as fundamental.

1. Reliable predictions of certain celestial phenomena came to be within the grasp of the *ṭupšarru*, who were able to draw on records of sustained observations going back centuries.
2. This did not mean that the old program of attempts to predict good and bad fortune for the state was suspended. Not only did it continue: it is even possible that it was given a boost thanks to the new confidence the *ṭupšarru* could feel about some aspects of their own ability.
3. Neither program depended upon, neither implicated, any physical theory that set out to explain why either the celestial or the terrestrial events that were predicted took place. Nor was any attempt made to produce a geometrical model to represent the movements of the sun, moon and planets. Eventually, in the Seleucid period, there were highly sophisticated arithmetical models, incorporating step, or linear zig-zag, functions, to capture the regularities. But three-dimensional, geometrical, representations of bodies in space were at no stage part of the traditional Mesopotamian study of the heavens.
4. That entire study remained political, indeed religious, not secular in character. There was no suggestion that the heavens might be investigated merely to provide knowledge of the relevant phenomena themselves. They were studied because of their significance for the welfare of the state and king. Sun, moon, planets and constellations were all divine and sent signs to humans that it was then up to the humans to interpret.

I turn next to ancient Greece, where much of what was accepted as the standard view, over the last two or three decades, has recently been challenged in radical revisionist studies by Alan Bowen,[14] follow-

[13] *Enūma Eliš* IV 23ff. attests to the power of the god Marduk, who can not only create, but destroy, order in the heavens. Cf. other texts cited by Rochberg, *The Heavenly Writing*, that speak of angry gods destroying order.

[14] Alan C. Bowen, "La scienza del cielo nel periodo pretolemaico," in Sandro Petruciolli, ed., *Storia della scienza* (Rome: Istituto della Enciclopedia Italiana, 2001) 1, sect. 4, chap. 21, pp. 806–39; idem, "Simplicius and the Early History of Greek Planetary Theory," *Perspectives on Science* 10 (2002), pp. 155–67, and idem, "The Art of the Commander and the Emergence

ing up his earlier investigations with Bernard Goldstein.[15] Before I get to the main issue, namely fourth-century geometrical modeling, two preliminary remarks should be made concerning Greek interests and knowledge down to the mid-fifth century. First, the evidence for Greeks conducting astronomical observations during that period is thin. Various "discoveries" are attributed to different Presocratic philosophers, for example the identity of the Morning and the Evening Star, and the fact that the moon shines by reflected light. Anaximander in the sixth century is even said to have "invented" the gnomon, though the most that can be taken to mean is that he was the first Greek to use it.

But the first sign of a program that would have benefited from detailed observational data is that of Meton and Euctemon around 430 BC, in their work on the lengths of the solar year and lunar month. Even here the extent of their own first-hand observations is nowadays thought to have been extremely limited. Meton's so-called cycle, where 19 solar years equal 235 lunar months, may have been original: but it is possible, and maybe more likely, that it derives from Mesopotamia, where the Persians used those values already at the end of the sixth century.[16] Meton worked at Athens as a private individual. Although his investigations were certainly relevant to calendar reform, it took some time for them to have any impact there, and in general each Greek city-state persisted in using its own luni-solar calendar. It was up to untrained magistrates to determine the start of the new month and when an intercalation was needed. Even in the fourth century BC, where Aristotle, for one, does give circumstantial accounts of some of his personal observations of celestial phenomena, he neither dates nor locates the specific phenomena he mentions at all precisely, in the former case doing so just to the archon year and month, and in the latter using no coordinate system, whether ecliptic or equatorial.

My second preliminary remark concerns prediction. From Homer onwards there was certainly intense Greek interest in divination of different kinds, for example from the inspection of the entrails of sacrificial animals, from the flights of birds, and from meteorological phenomena.

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of Predictive Astronomy," in Christopher J. Tuplin and Tracey E. Rihll, eds., *Science and Mathematics in Ancient Greek Culture* (Oxford: Oxford U.P., 2002), pp. 76–111.

15 See Bernard R. Goldstein and Alan C. Bowen, "A New View of Early Greek Astronomy," *Isis* 74 (1983), pp. 330–40, and Alan C. Bowen and Bernard R. Goldstein, "Meton of Athens and Astronomy in the Late Fifth Century B.C.," in Erle Leichty, Maria deJong Ellis and Pamela Gerardi, eds., *A Scientific Humanist: Studies in Honor of Abraham Sachs* (Philadelphia: Occasional Papers of the Samuel Noah Kramer Fund, 1989), pp. 39–81.

16 This is discussed in Brown, "Greek Astral Sciences."

Hesiod in the *Works and Days* devotes a section to auspicious and inauspicious days, claiming that he has special knowledge on this subject, down to the particular types of activities that should be undertaken, or avoided, on particular days (this is comparable to the Babylonian *Iqqur īpuš* hemerological text). But there is nothing like the detailed analysis of what different celestial phenomena can be taken to signify that we have in such a text as *Enūma Anu Enlil.* The situation certainly changed, in Greece, once it came to be believed that a person's fortune could be predicted from the positions of the sun, moon and planets at birth, from their horoscope in other words. I shall be returning to that development later, but for now may note that it did not antedate the third or the second century BC at the earliest, and happened more or less simultaneously in mainland Greece and in Egypt, in circumstances that, as Alexander Jones has shown,[17] reflect an interaction of Mesopotamian, Egyptian, and Greek interests at that time. More on that later.

I turn now to the main issue in the controversy over fourth century BC Greek study of the heavens. Although the precise details of the system of homocentric spheres attributed to Eudoxus and Callippus were always a matter of dispute, it used to be generally agreed that the main problem that their theories addressed was the irregularities of the motions of the sun, moon and planets and especially the phenomena known as stations and retrogradations. That was certainly how Simplicius (in the sixth century AD) interpreted the brief reports of their theories in Aristotle's *Metaphysics* Λ. But Bowen has criticized Simplicius' view as deeply flawed and anachronistic, contaminated by Simplicius' own knowledge of much later developments, including the models of planetary motion in the *Almagest* of Ptolemy (in the second century AD).[18] No term for either "station" or "retrogradation" appears, Bowen points out, before the first century AD. When Aristotle ascribes to Eudoxus and Callippus complexes of three, four or five spheres to account for the movements of each of the planets, moon and sun, the original problems that may have exercised them could have been horizon phenomena, the displacements of the risings and settings of each of those heavenly bodies, rather than their stations and retrogradations.

This has usefully questioned just how robust the evidence for the various items in the standard view can be taken to be. Although it is recognized that Giovanni Schiaparelli's original reconstruction of Eudoxus was vastly overoptimistic, in ascribing to him accurate values

17 See Alexander Jones, *Astronomical Papyri from Oxyrhynchus*, 2 vols. (Philadelphia: American Philosophical Society, 1999).

18 See Bowen, "Simplicius."

for the retrograde arcs of each of the planets, it is now clear that we have to be much more cautious than the next generation of interpreters (such as Thomas Heath) was.[19] We must, in particular, distinguish firmly between what can be inferred on the basis of contemporary, fourth century BC, evidence on the one hand, and what derives from later, in some cases much later, interpretations.

So let me now summarize what can be put into the former category, and first in the matter of fourth-century Greek information about Babylonian work. Plato's *Timaeus*, the *Epinomis* (which may or may not be by him), and Aristotle all bear witness to some aspect of fourth-century Greek knowledge concerning the studies of the heavens that had been undertaken in Egypt, in Syria, and in Babylonia itself, but in every case their references are vague and general, to the effect for instance that those studies had shown that the heavens are unchanging (a dubious enough point, in all conscience). There is, for example, no direct evidence in those sources that any of them were aware of Mesopotamian values for the main periods of the planets, nor for their understanding of stations and retrogradations (the so-called Greek letter phenomena). So our most reliable evidence does nothing to confirm the idea that there was any detailed fourth-century Greek use of Mesopotamian studies.

Second of all, there is the question of whether, nevertheless, the Greeks appreciated the facts (at least) of stations and retrogradations. In Plato's *Timaeus* we have references to heavenly bodies overtaking and being overtaken by one another and to certain "backward turnings" (ἐπανακυκλήσεις) and "advances" (προχωρήσεις).[20] Bowen resists seeing these as definite references to direct motion and retrogradation, pointing out that the image of the race-track does not imply that at any point any runner, when being overtaken, actually moves backwards towards the starting-point. That is certainly true, but may be overcautious.[21] The direct and retrograde motions of a planet are only relative to the constellations through which it moves. The body that has the fastest easterly motion in relation to the constellations is the moon (which does not retrograde, of course) but it never has a net easterly motion, since the effect of the diurnal rotation is always more than enough to counterbalance that. The knowledge of the identity of the Morning and Evening Star, and the reference to both Venus and Mercury having

19 Thomas E. Heath, *Aristarchus of Samos* (Oxford: Oxford U.P., 1913).

20 See *Timaeus*, 38d and 40c, respectively.

21 Cf. Andrew Gregory, *Plato's Philosophy of Science* (London: Duckworth, 2000).

the same mean motion as the sun, show that at least in relation to the sun, those two planets are now west of it, now east, now west again, performing, in that regard, what can be called a retrogradation.

Moreover Plato does not just record the idea that the planets in general "wander," as their Greek name implies: in the *Timaeus* he draws back from a detailed account because of the "wondrous complexity" of their movements, remarking that only a very few individuals understand these.[22] Evidently *some* apparent irregularities are recognized, and this will turn out, in my view, to be crucial. It is true that when he came to write the *Laws*,[23] Plato insists that the planets, moon and sun, each move in a *single* circular motion. That has sometimes been taken to indicate that between the composition of those two works, Plato had learnt of Eudoxus' solution to planetary motion. Yet to that it has to be said that on Aristotle's report, Eudoxus did not assign just one circle to each of those heavenly bodies, but rather invoked a plurality of them in each case. The only "single" movement that could be in view is the resultant of the various components, and if that is what Plato had in mind, "circle" must be taken loosely, since that resultant motion takes the form of a spiral.

What finally can we say on the basis of Aristotle's evidence? The points that he bears witness to – independently of his commentators, that is – are that, first, each of the planets, moon and sun required, on Eudoxus' view, on that of Callippus, as on Aristotle's own, a plurality of concentric spheres, and second, that Callippus was dissatisfied with Eudoxus' solution with regard to the sun, moon and the three lower planets and introduced more spheres in order, Aristotle says, to "render the phenomena" (ἀποδώσειν τά φαινόμενα). He does not specify what those "phenomena" were, but there were clearly, in Callippus' view, inadequacies in the fit between Eudoxus' theory, and what could be observed, that called for modifications to that model.

Aristotle's account in the *Metaphysics* certainly does not, by itself, permit a detailed reconstruction of Eudoxus' or Callippus' theory. Indeed modern interpretations, such as those attempted by Erkka Maula, Ido Yavetz, and Henry Mendell,[24] in the latter two cases using sophisticated computer modeling, still exhibit startling divergences, reflect-

22 *Timaeus*, 39cd.

23 *Laws*, 822a.

24 See Erkka Maula, *Studies in Eudoxus' Homocentric Spheres* (Helsinki: Societas Scientiarum Fennica, 1974), Ido Yavetz, "On the Homocentric Spheres of Eudoxus," *Archive for History of Exact Sciences* 52 (1998), pp. 221–78, Henry Mendell, "Reflections on Eudoxus, Callippus and their Curves: Hippopedes and Callippopedes," *Centaurus* 40 (1998), pp. 177–275.

ing the indeterminacies of our evidence. Yet we have enough reliable fourth-century evidence to establish some points on the question that chiefly interests me in this study, namely determining what the agenda of these Greek studies of the heavens was. First it is clear that, unlike Mesopotamian arithmetical models, the theories reported by Aristotle were geometrical in character. They aimed to account for certain irregularities in the apparent motions of the sun, moon and planets in terms of combinations of regular circular motions – and this remains true, however those irregularities were described and indeed whether or not they included a well-defined understanding of planetary retrogradations.

That is the first positive point. But the second negative one is just as important. Until such time as they could assign specific values to each of the parameters involved (the speeds of rotation of the various spheres, and their angles of inclination to one another) the fourth-century astronomers were in no position to offer confident predictions, whether of planetary phenomena, or of lunar or solar eclipses.[25] Aristotle, of course, as I said, does not report such values. Although Simplicius does, the ones he gives suffer from serious inadequacies, as was already recognized by Heath, for instance (there is, for example, a wildly inaccurate value for the synodic period of Mars, namely 260 days, and if a more accurate one is substituted, Mars fails to go retrograde on the model).[26] As noted, Callippus reacted to some shortcomings, as he perceived them, whatever they were, in the fit between Eudoxus' theory and the phenomena, but it is pretty clear that, like Eudoxus, he too was some way away from providing a fully quantitative model, essential if it was to be the basis of predictions – as opposed to explanations showing qualitatively how irregularities could be reduced to regularities. Besides, Aristotle was in some doubt as to whether Callippus' modifications were an improvement on Eudoxus, since when he adapts the concentric spheres hypothesis for his own cosmological purposes by introducing retroactive spheres to unify the whole system, he hesitates on whether to accept some of Callippus' emendations.

But if astronomical prediction was well beyond the reach of these fourth-century theorists, and we can be confident that that was not their chief concern, we must next ask what their goal may have been.

25 Whatever lies behind the legend of Thales' predicting a solar eclipse "to within a year" (Herodotus I 74), we hear of no moves by his contemporaries or immediate successors to emulate his feat, although attributions of amazing predictions to wise men do continue (as in the story of Anaxagoras' foretelling the fall of a meteorite at Aegospotami in 467 BC).

26 See Heath, *Aristarchus*, p. 208.

If we stick to the contemporary evidence, we cannot, for Callippus, go beyond Aristotle's vague remark about "rendering the phenomena," but if that means, as I suggested, providing some fit between theory and data, that certainly suggests an aim of explaining or accounting for, rather than predicting, those phenomena. Of course another contested piece of information in Simplicius has it that Plato in particular set the astronomers that task of reducing apparently irregular motions to regular, circular ones.[27] Yet we do not have to go along with Simplicius here on Plato's role as catalyst in order to provide part at least of an answer to my primary question concerning the agenda of fourth-century study of the heavens, since we can base that part-answer on the clear evidence of Plato and Aristotle themselves. Plato, as we saw, is intent on accounting for the "wondrous complexity" of planetary motion, indeed on denying that they "wander" as he so emphatically does in the *Laws.* Aristotle too introduces his discussion of concentric spheres for the specific purpose of fixing on a determinate number of the Unmoved Movers needed to account for the hypothesized moved movers. Both of these fourth-century philosophers focus clearly on showing that – despite any appearances to the contrary – the motions of all the heavenly bodies are orderly. Both have, we may say, a *teleological* agenda, to show that the cosmos as a whole exhibits the good and the beautiful.

But the next question that arises is how typical such an agenda was for say the third or second century BC.[28] While geometrical model-building indeed continued, with the concentric spheres hypothesis being replaced by epicycles and eccentrics, down to Ptolemy in the second century AD at least, that was certainly not the only mode of the study of the heavens. Let me rehearse very briefly just some of this other work, which includes the construction of star catalogues, general observational work, an on-going interest in the problems of calendar reform, as well as the increasingly prominent practice of genethlialogy.

The first detailed Greek star catalog, for example, was the work of Hipparchus in the second century BC, the basis for Ptolemy's own catalog of more than 1,000 stars in Books 7 and 8 of the *Syntaxis.* We

[27] This comes in Simplicius' commentary on Aristotle's *On the Heavens*, 488.18ff., 492.31ff.

[28] The variety of Greek astronomical endeavours may be greater than the evidence from the Mediterranean area alone allows us to infer. In the *Yavanajātaka* (chap. 79), composed around the 3d c. AD by, or under the auspices of, Sphujidhvaja, a previously unknown mainly descriptive astronomy, with many otherwise unattested detailed parameters, is ascribed to the Yavana ("Greeks", "Westerners"). Brown, "Greek Astral Sciences," argues that this chapter reflects the nature of Greek astral sciences in the period before Hipparchus.

do not have Hipparchus' own book, nor indeed his more theoretical work dealing especially with the models of the sun and moon. The only book of his that is extant is his *Commentary of the Phainomena of Aratus*, from which it is clear, however, that both Aratus himself, and before him Eudoxus, had located stars only quite imprecisely – while Hipparchus himself was able to use a system of spherical coordinates with the ecliptic divided into $360^0$. We know from Ptolemy that Hipparchus conducted observations at Rhodes, and other Greeks were active at Cnidus (Eudoxus himself) and at Alexandria, where Ptolemy reports that there were a number of astronomical instruments in the city: he describes them as old and inaccurate. The astronomers came to use an Egyptian calendar of 365 days, each of twenty-four equinoctial hours, but individual city-states continued to use their own luni-solar calendars, with hours of variable length since an hour was defined as a proportion of sunlight. There are signs of some interest in calendar reform, but it took the Roman Julius Caesar to introduce a standard calendar for the lands ruled by Rome in the first century BC. Meanwhile so-called parapegmata were set up to help keep a record of the days of the month as they passed (these tables contained some meteorological as well as astronomical generalizations), but it is disputed when this tradition began and precisely what its function was.[29]

We may certainly assume that a number of Hellenistic rulers and rich individuals showed a certain interest in the study of the heavens. But not even in Alexandria was there a state supported institution sponsoring observers and overseeing the recording of their results. From Hipparchus onwards, Babylonian records provided one of the main sources of the data on which the Greeks relied, and some styles of Babylonian writing, including Tables and Almanacs of various types, find their parallels both in Greece and Egypt. By the end of the second century BC, if not before, there is evidence of a remarkable confluence or convergence of interests in the study of the heavens, particularly in Hellenistic Egypt, which had of course been under Persian control until the conquests of Alexander, and where indigenous traditions of star lore came to be amalgamated with Babylonian and then Greek ideas and knowledge.[30]

The first important conclusion we should draw from this evidence is that Babylonian linear arithmetical methods continued to be used,

29 See Goldstein and Bowen, "A New View"; Liba Taub, *Ancient Meteorology* (London: Routledge, 2003); Daryn Lehoux, *Astronomy, Weather, and Calendars* (Cambridge: Cambridge U.P., 2007).

30 See Jones, *Astronomical Papyri.*

including by Greeks, in the Hellenistic period, suggesting an important overlap between that Greek tradition and Mesopotamian work. Geometrical model-building of the type reported in Aristotle was far from setting the entire agenda of Greek studies of the heavens.

The second important feature of this confluence of traditions is, as I have already remarked, the growth of genethlialogy, where the prediction of the future now became an interest not just of the ruler or for the state, but also for many private individuals. Of course some horoscopes were much more elaborate than others: Jones calls them the deluxe models.[31] But at the cheaper end of the market, there are extant many relatively simple horoscopes, giving just the positions of the sun, moon and planets. The importance of this too is two-fold. First it meant that *some* knowledge of the heavens penetrated quite widely among ordinary citizens, and secondly it provided a livelihood for those who supplied their needs – a significant factor when students of the heavens generally had no prospect of state employment.

But if a variety of different ambitions for the study of the heavens can be attested in the Hellenistic Mediterranean world, attempts to explain the apparent irregularities of the movements of the planets also continued. Ptolemy in the second century AD conveniently demonstrates both the range of his interests, and his motivations for that elite mathematical study. His *Tetrabiblos* is a handbook for what we would call astrological prediction, the forecasting of events on earth on the basis of signs in the heavens, especially an individual's horoscope. But clearly distinguished from that is the study to which the *Syntaxis* is devoted, where drawing both on Babylonian data and on earlier Greek theories (especially Hipparchus) Ptolemy proposes what is in certain respects (notably in the introduction of the equant) an original solution to the major problems of the movements of the heavenly bodies. He acknowledges, in Book 13 especially, that many problems elude him. Yet his claim is that this study is *demonstrative*. This is in direct contrast to the merely conjectural discipline of astrological prediction. The mathematical study set out in the *Syntaxis* yields unshakeable knowledge, since it is based on the incontrovertible methods of arithmetic and geometry.[32] The teleological motive we noticed in Plato and Aristotle is here repeated in the best informed practitioner of his day. The study of the heavens is a study of the "sameness, good order, proportion and freedom from arrogance of divine things," a study that not only "makes

[31] See Jones, *Astronomical Papyri*, vol. 2, part 5.

[32] *Syntaxis* I 1, 6.17–21.

those who follow it lovers of this divine beauty" but also instils those same qualities in their souls.[33]

I turn now more briefly to my third ancient civilization, China, where the nature and development of mathematical astronomy have been the subject of pioneering and authoritative studies over the past forty years by Nathan Sivin.[34] Although the possibility of some external influences on Chinese work in this area during the period that chiefly concerns me, down to the end of the Han, cannot be ruled out, they are of only minor importance. Our starting-point should be the intense interest in divination of all kinds, going back to the Shang oracle bones in the twelfth century BC, used to foretell issues of state importance, and including the various techniques associated with the hexagrams set down in the *Yijing* 易經.

Neither of those two modes of prognostication depended on specifically astronomical data. But celestial phenomena certainly came to be a main source of portents – as they are already in the *Zuozhuan* 左傳, for instance. That sets out, as is well known, a continuous narrative of events from the late-eighth to the mid-fifth centuries BC, with a clear moralizing agenda that makes it an unreliable historical document. Moreover the astronomical events it refers to have in some cases clearly been contaminated. As Huang Yilong especially has shown,[35] some eclipses that were visible were ignored and not recorded (presumably because not politically or at least not symbolically acceptable) and conversely others are fabricated for the sake of the inauspicious portents they implied. Yet those interferences do not affect the value of this text as evidence of the assumption that the heavens carried messages for humans on earth.

As in Mesopotamia, cosmos and state were intimately, even indissolubly, linked. Indeed in China, as Sivin has shown,[36] state, cosmos and body all exhibit the same interacting processes. What we might take to be microcosm-macrocosm analogies were no mere analogies: heaven and earth, the state and the human body all exhibit the same reciprocal processes and form part of a single whole, where the ruler has a crucial role as responsible for mediating between heaven and earth and ensuring the harmony between them.

33 *Syntaxis* I 1, 7.17–24.

34 As noted, Sivin's "Cosmos and Computation" was first published in 1969.

35 See Huang Yilong, "Astronomia e astrologia," in Petruciolli, *Storia della Scienza* 2, sect. 1, chap. 13, pp. 167–70.

36 See Nathan Sivin, "State, Cosmos, and Body in the Last Three Centuries B.C.," *HJAS* 55 (1995), pp. 5–37, and Lloyd and Sivin, *The Way and the Word*, ch. 5.

As in Mesopotamia, again, the interest in celestial divination led to state support, indeed in China this was on a scale that was unequaled anywhere in the ancient world. In Han times the Astronomical Bureau was established that lasted all the way down to the Qing. At the top of the hierarchy were officials who reported direct to the emperor and advised him on how his Mandate stood. The duties of the *taishi ling* 太史令 are specified in the *Hou Hanshu* 後漢書 as: 1. being in charge of the calendar and ephemerides, 2. choosing auspicious dates and times for state business, and 3. recording propitious and unpropitious omens as they occurred.[37] But in the lower echelons there were considerable numbers of "expectant officials" (*daizhao* 待詔), "observers" (*wanglang* 望郎) and "clerks" (*zhanggu* 掌故) responsible for carrying out the necessary observations, producing, in the course of this, a data base that has continued to be used by modern astronomers.

While the chief work of those involved in *tianwen* was the interpretation of omens, the study of the heavens interacted, in China, unlike in Mesopotamia, with cosmography, for example the debate between the two main alternative models of the heavens, namely *gai tian* 蓋天 and *hun tian* 渾天, the first representing the heaven as a circular canopy over a central, square earth, the second treating the heavens as a sphere enveloping the earth. Interesting exchanges on this subject suggest that, already in the first century AD, observational data were invoked to the advantage of the *hun tian* view.[38] Yet on many occasions when we have evidence for opposing views on astronomical matters being the subject of explicit discussion, that evidence also shows the state's involvement in these matters, even though the point should not be exaggerated.[39] On the one hand, the main protagonists in such debates are specialists intent on bringing technical points to bear to see off their rivals. On the other, the discussions were often held at court, often in very formal circumstances, where the ultimate decision rested with the emperor or his representatives.

Yet the matters under discussion in Han times never included questions to do with the kinematics of the movements of the sun, moon,

[37] *Hou Hanshu* 25, p. 3572.

[38] Cf. Christopher Cullen, *Astronomy and Mathematics in Ancient China: The Zhou bi suan jing* (Cambridge: Cambridge U.P., 1996), pp. 56ff, on a fragment from the *Xin Lun* of Huan Tan preserved in the *Taiping yulan* 2, pp. 6b–7a.

[39] Contrast Christopher Cullen, "Seeing the Appearances: Ecliptic and Equator in the Eastern Han," *Studies in the History of Natural Sciences* 19 (2000), pp. 352–82, and "Actors, Networks and 'Disturbing Spectacles' in Institutional Science: 2d Century Chinese Debates on Astronomy," *Antiquorum Philosophia* 1 (forthcoming), with Lloyd and Sivin, *The Way and the Word*, pp. 78f.

and planets, nor, come to that, with the physics of their motions. As Sivin conclusively showed, the techniques used both in calendar studies and in determining eclipse cycles were arithmetical, not geometrical in character. While *lifa* and *tianwen* certainly had observation, recording, interpreting, and predicting on their agenda, there was no interest in developing geometrical models and no question that it was important to prove that the heavens were orderly. That, I argued, was the main driving force in Greek studies directed to solving the problems posed by the apparent irregularities in planetary motion. Neither that ambition, nor the program it generated, is to be found in either China or Mesopotamia.

I could go into much greater detail on the differences in the studies of the heavens in Mesopotamia, Greece and China, but I hope to have said enough for some provisional conclusions to be tentatively suggested. A first major differentiating factor relates to the degree and kind of the state's involvement, and a second to the way in which individuals exploited such room for maneuver as was open to them. The first evidently made a considerable difference to what we may call the job prospects of those entering the discipline. As a *ṭupšarru* in Mesopotamia or as a *taishi ling* in the Chinese Astronomical Bureau you had secure and well paid employment (though you always had to keep on the right side of your employers and while direct access to the ruler was a privilege, it also carried risks). In Greece you had to make your own way, looking for patronage from powerful individuals but falling back more often on developing a private clientele for your skills in casting horoscopes.

Obviously the state's involvement made a considerable difference to the conduct of the study of the heavens. But that was not the sole determining factor in what work was done and how it was done. Let me go back to the points Brown made about the Mesopotamian *ṭupšarru*. Evidently their first obligation was to carry out the work expected of them in that capacity, notably by interpreting the signs in the heavens according to the canonical *Enūma Anu Enlil*. But once it was realized that the phenomena in the protases were themselves predictable, *that* development was not determined by any part of the state's agenda: that breakthrough could not have been predicted. The interpretation of the omens was not abandoned. But the studies of the heavens produced an unexpected result that thereafter did affect the subsequent program.

Similarly in China, we should not underestimate the ongoing tension that existed between accepting the existing views and practices in use in the Astronomical Bureau and challenging them. Time and again the history of the development of Chinese studies provides examples of individuals starting from outside the Bureau and questioning the work within it, though if their challenge was successful, they quite often ended up in the Bureau themselves.

As for Greece, where private individuals were much more able to choose their own agenda, again we should not underestimate the constraints on that freedom. There was undoubtedly a premium on originality, and indeed many original and indeed counter-intuitive theories were proposed, models that suggested that the earth rotated on its axis every twenty-four hours, or that it was not at the centre of the cosmos,[40] even, in Aristarchus' theory, that the sun held that position. But there was also a price to be paid for that originality. You had, after all, to carry your contemporaries, or enough of them, to be taken seriously. Persuading an Assyrian king or a Chinese emperor posed one set of problems: persuading your fellow-Greeks and in the first instance your peer group was not without its difficulties, in overcoming their prejudices, either.[41] Proposed, inevitably, without any secure institutional backing, many ingenious ideas were stillborn.

So where does this leave our understanding of how to study these ancient studies? To try to bring all the complex factors in play under the single rubric of "the history of ancient astronomy" is bound to lead to distortions. Attempts to drive a wedge between what we call astronomy and what we think of astrology definitely tends to do so, for while certain distinctions were drawn between different modes of prediction, those modes were often run together. When we pay due attention to the different agendas to which different ancient investigators worked, several favorite kinds of direct comparison can be seen to be misleading. Of course, in a sense all the studies I have been discussing were studies of "the heavens," the movements of various heavenly bodies and how they should be interpreted. Yet we have seen how differently those studies were used in the societies in question, and how the ways

40 In the Pythagorean view, reported in Aristotle *On the Heavens* 293a17ff., there is an invisible fire at the center of the cosmos, and both the sun and the earth move around this like the planets.

41 The rejection of Aristarchus' heliocentric theory was, however, not simply a matter of prejudice. In the *Syntaxis* I ch. 7, Ptolemy sets out empirical arguments that suggested to him that it must be false. If the earth rotated on its axis every twenty-four hours, you would expect that to have marked effects on the movements of clouds near the earth and on those of solid objects dropping on to it. These are not observed: so one must rule out attributing any movement to the earth.

those studies related to the other learned disciplines that were cultivated were far from uniform. Many of those involved in the different modes of prediction in Mesopotamia were polymaths, not specialists in just one discipline. The role of a *taishi* 太史 in Han China was certainly not limited to observing and recording the movements of the heavenly bodies. It is obvious that the Greek teleological agenda of reducing apparent irregularities to regular motions was a concern of "philosophers" as much as those who considered themselves "mathematicians" or "astronomers."

Most importantly, our understanding the work of any one group in any one tradition depends on understanding what they were looking for, irrespective of whether they found it or not. They were not to know what later commentators would say they *should* have been looking for. They were not to know the comparison would be with Copernicus, or Kepler, or Newton. Their performance has to be judged by their criteria, their aims, their methods. With that in mind we have, it seems to me, to be particularly careful to pay due attention to the differences in the agendas to which they worked.