Chasing Shadows: Mathematics, Astronomy, and the Early History of Eclipse Reckoning by Clemency Montelle

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Eclipses are the most dramatic of regular astronomical events. Temporarily removing one of the two most prominent objects from the heavens, they must have been terrifying to primitive observers; their universal interpretation as bad omens is no surprise. For cultures that studied the sky systematically, they posed some of the fiercest challenges to their predictive abilities. To handle an eclipse well, precise understanding of the motions of both the Sun and Moon is a necessity. Getting an eclipse prediction wrong would have been as public a failure as an astronomer could imagine.

Clemency Montelle's *Chasing Shadows* is a detailed technical study of the approaches of four different pre-modern cultures—Mesopotamian, Greek, Indian, and Islamic—to capturing these elusive phenomena. Eclipses are the obvious focus of discussion but the scope is actually much broader: eclipses are a well-chosen case study to observe historical astronomical practice in general. Although the four approaches are dealt with in separate chapters, the contrasts between them and their interactions are the highlight of the book. Montelle makes several telling cross-cultural observations and comparisons, while resisting the trap of engaging in philosophical or sociological exposition beyond the evidence. Much of the book may be a stiff challenge for the casual follower of the history of science; its heart is mathematical. But for those with a technical inclination and a bit of determination, *Chasing Shadows* rewards careful attention most richly.

The book opens with an inviting and accessible general introduction to the main actors, their perspectives, and their sources. Perhaps the most useful aspect of the first chapter is Montelle's discussion of the interplay between observation and theory. With limited apparatus and problematic effects

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such as parallax, ancient astronomers' observational data were necessarily limited in their dependability. Pre-modern astronomers often relied explicitly on shockingly few observations, and this contributed to their positing relationships between theory and observation that are foreign to a modern reader. Many misunderstandings of ancient astronomy derive from a failure to appreciate this and it is a credit to Montelle that she places the issue front and center.

The second chapter introduces the reader to the mathematical basics of eclipse theory that are needed to comprehend the more challenging discussions to come. These include notions such as the celestial sphere, the configuration of lunar and solar eclipses, and the measurement of eclipse magnitudes. Two aspects of eclipse theory are particularly important. The first is the identification of several types of lunar month (especially the synodic month or period of the Moon's phases and the draconitic month or period of the Moon's crossings of the ecliptic, the solar orbit on the celestial sphere). The second is the effect of parallax. Since we observe eclipses from the Earth's surface rather than from its center, different terrestrial observers see the Moon and Sun in slightly different places in the heavens. This has no effect on lunar eclipses (the Moon passes through the Earth's shadow, so everyone sees them simultaneously) but is crucial for solar eclipses, where a displacement of a few hundred kilometers can turn a total eclipse into a non-event. The concepts are beautifully depicted by diagrams from Charles Hutton's *Mathematical and Philosophical Dictionary* of 1795, which is a bit anachronistic for this book, perhaps, but still illustrative.

We begin with Mesopotamian eclipse reckoning. As the earliest substantial astronomical culture, the Mesopotamians had no choice but to make their own observations: there were no existing data on which to rely. The first fundamental record is *Enūma Anu Enlil*, an omen compendium from the second millennium BC comprising around 70 tablets. The omens contain no clear distinction between observations and predictions or even between events that are or are not predictable. Nevertheless it cannot be overlooked; traces of its content and structure may be found in surprisingly many places as late as medieval India.

The first millennium BC saw a recognition in Babylon of deeper patterns in the recurrences of eclipses, particularly the Saros cycle (223 synodic months = 242 draconitic months). One may wonder at the apparent incongruity between identifying and exploiting patterns in eclipse records, and considering eclipses to be portents of Earthly misfortunes. But modern notions of cause and effect were not present here, other than divine action. Indeed, Montelle frequently makes the point that Mesopotamian astronomers were interested solely in predictions of the heavens and appeared to have no interest whatever in underlying causes.

Babylonian eclipse reckoning reached its highest level of sophistication with the Astronomical Cuneiform Texts (319 BC–AD 42). Modeling various celestial motions using step and zigzag functions as building blocks, the authors of astronomical cuneiform texts were able to develop complicated arithmetic models to predict eclipses. Unfortunately, they were no more accurate than previous efforts had been. It would have been helpful to see relevant excerpts of some of the tables produced by these brilliant computational scientists, but Montelle's descriptions of the intricacies of the models in astronomical cuneiform texts and what is known of their motivations are nevertheless remarkably clear.

We turn next to eclipses in Greek astronomy. Montelle stresses the Greek desire for theoretical explanation, a need to begin with physical laws that govern the heavens and shape a resulting geometry that does what the heavens do. Of course, this feels much more familiar to us and more powerful. It was, in fact, partly through geometrical models that Greek astronomers first became aware of parallax and its importance. But without a sufficiently adequate number system and arithmetical apparatus, quantitative science was difficult or impossible. Transmission from Babylon, around the time of Hipparchus of Rhodes in the second century BC, brought both the number system and the observational data to allow geometry and arithmetic to merge into a system capable of both explanation and prediction (incidentally, giving birth to trigonometry).

Our knowledge of Hipparchus and his colleagues is sadly deficient because Claudius Ptolemy's *Almagest*, written almost three centuries later, achieved such dominance that it virtually obliterated all earlier texts. The *Almagest*'s clear mathematical exposition, carefully constructed in a precise logical order on a foundation of a small set of observations, became the archetype both in Greece and medieval Islam. Montelle's outline of the *Almagest*'s eclipse theory is typical of her coverage elsewhere in the book: a careful, step-by-step account of the mathematical arguments with occasional comments on transmission of parameters (mostly from Babylon) when something reliable can be said. Montelle also spends time on Ptolemy's *Handy Tables*, a manual deriving mostly from the *Almagest* but emphasizing computation and prediction rather than theoretical explanation.

At 130 pages, the chapter on India is almost as long as the chapters covering the other three cultures combined and its contents represent *Chasing Shadows*' most valuable contribution. At first read, Indian astronomy can seem almost incomprehensible. Part of the reason for this is the genre: since much the subject needed to be memorized as part of an oral tradition, it was composed in extremely concise verse, often with all explanations and commentary excised. Without Montelle's exegesis of the verses described in her chapter, deciphering these cryptic texts would seem nearly impossible.

Even when one understands the words, the texts cannot be read as one reads European astronomy or even the *Almagest*. Several times, concepts and methods from other cultures found their way into Indian astronomy and were modified heavily to fit their new context. There was almost no effort to reconcile contradictory approaches sitting side by side in a text or even intermingled into a single procedure. There was no need; logical consistency was not valued as dearly as in Greece or medieval Islam. Rather, Indian astronomers invented intensely clever computational schemes to predict eclipses and other phenomena (more or less inventing iteration to solve the difficult equations that arose), using received knowledge as helpful aids rather than as a foundation. It would be interesting to hear more on how Montelle coordinates this with her 'prediction *versus* theory' thesis of the previous two chapters. She makes the fascinating point that Indian astronomy was inherently conservative, unwilling to alter older approaches, due partly to their belief that the texts came from 'Gods and Sages' and were therefore inspired.

Indian astronomy is grouped into five schools or *pakṣas* defined mostly by geographical region rather than by chronology. The early works, called *siddhānta*s (astronomical treatises), show signs of transmission from both Babylon and Greece (this is contested by some) but with an entirely unique approach and a number of novelties. These include a streamlined trigonometry using the sine function rather than the chord, the use of iteration to solve the difficult problem of moving from true to apparent Sun-Moon conjunction, and the division of parallax into longitudinal and latitudinal components.

The nonagesimal, the point on the ecliptic 90° from the ascendant above the horizon, is an early Indian innovation; it played an important role in eclipse calculations and parallax, and found its way to Arabic astronomy as well.

Montelle outlines with care and precision the methods of a number of Indian astronomers, spending the most time with the two works, the *Brāhmasphuṭasiddhānta* and the *Khaṇḍakhādyaka* by Brahmagupta (seventh century AD), for whom the Brāhmapakṣa school is named. (Curiously, the latter work is in the Ārdharātrikapakṣa tradition; perhaps it is easier to outshine a rival by visiting his own house.) Brahmagupta often provides two methods to compute a given quantity: firstly in the traditional manner and secondly by his own more sophisticated approach. In both of these *pakṣas*, we find traces of a second episode of transmission of mathematical methods from Greece (particularly spherical trigonometry), although there is no evidence that Ptolemy's *Almagest* ever saw the light of day in medieval India. Montelle concludes her coverage of Indian eclipses with a jump forward from the 10th to the 15th century, with four treatises devoted exclusively to eclipses by Parameśvara, an astronomer of the Mādhava school in Kerala famous for its work with infinite series. We find here sophisticated methods of calculation, of course—although the astronomical approach to eclipses is not revolutionary—but we also find a new attitude of respect for the role of observations and a willingness to admit the possibility of future improvements.

Montelle's final visit is the astronomy of medieval Islam. Here the transmission story is also interesting and complex, although the evidence is easier to find. The early Islamic astronomers of the eighth and early ninth centuries worked mostly with Indian material, exemplified by al-Khwārizmī's *Zīj al-Sindhind* (a corruption of the word 'siddhānta'). A *zīj* was a comprehensive astronomical handbook filled with tables empowering the user to compute many astronomical phenomena, including eclipses. In their absence of theoretical discussions, *zīj*es resembled Ptolemy's *Handy Tables* more than the *Almagest*, although ironically they took inspiration more often from the latter. In al-Khwārizmī's eclipse parameters and calculations, Montelle finds evidence of Indian sources, although also a trace of the *Almagest*. The ninth century saw an increased presence of the Greek style of astronomy; by the time of al-Battānī's *zīj* (AD 900), the conversion to Ptolemy's way of thinking was complete. However, many of the mathematical methods that the Islamic astronomers exploited (such as trigonometric functions and iterative methods) were borrowed from India or, in the case of the late 10th-century revolution in spherical trigonometry, constructed by Islamic mathematicians themselves.

Montelle outlines the contributions of nine Islamic eclipse calculators, although mostly not in the depth of the previous chapter. One exception is al-Khāzinī, a 12th-century Iranian whose methods rely mostly on Ptolemy but with some Indian overtones. Two figures of particular interest are worth noting. Naṣīr al-Dīn al-Ṭūsī (13th century) played a major role in a movement to overturn the *Almagest* and propose new models of planetary motion—not to achieve a better fit to observations but to fit better certain cosmological constraints such as uniform circular motion. The *Tadhkira*, his book on the subject, nevertheless reveals Ptolemy's influence in its eclipse theory, although unlike those in the *Almagest* the parameters used by al-Ṭūsī permit the possibility of annular solar eclipses. Finally, Ibn al-Shāṭir (14th-century Damascus) not only developed complete alternate planetary models but actually constructed a *zīj* with them (the *Zīj al-Jadīd).* As revolutionary as this *zīj* was, Montelle shows that its eclipse theory contains traces of Greek, Indian, and earlier Islamic influence—exemplifying her larger point that eclipse theory was a grand collaboration between astronomers and cultures, a sometimes chaotic mixture of tradition and innovation, conservatism and revolution.

And this leads us to the chief value of the book. As a topic for a case study in the role of transmission of scientific knowledge between cultures, you cannot go wrong with eclipses. Our four cultures are, to some degree, incommensurable: the Babylonians cared only for arithmetic predictions, not geometric theories; the Greeks developed logical progressions from theory toward prediction; the Indians appropriated their heritage into systems of computational genius with not much concern for theoretical contradiction; and Islamic astronomers valued the primacy of cosmological theory even more rigidly than the Greeks. In these environments, what can be transmitted and what cannot may vary dramatically, depending on the situation. Montelle carefully, and appropriately, does not attempt grand philosophical conclusions, instead laying out the evidence and making observations pertinent to the data. Much more work (beyond eclipses) would need to be examined to make a larger case for the nature of scientific transmission; there is room here for several sequels.

The only substantial failing in *Chasing Shadows* that I can find to lament is its endpoint. If 'the primary purpose of this study was to determine the ways in which knowledge about eclipses was originated, developed, preserved, and transmitted' [325], it seems a bit arbitrary to stop just before the astronomy of Copernicus, Brahe, and Kepler. A rich discussion on these themes could have followed. Of course, full treatment of European eclipse theory may have required a second volume.

Overall, the book is splendid. It is a sophisticated scholarly work with important broader theses. It is technically accurate (with only a few trivial mistakes) and yet as clear as can be. Finally, it does not try to be more than it should be. *Chasing Shadows* will be a first contact for scholars on the history of eclipse theory for many years to come.