Omens, Observations, Orbits
Steps towards Ptolemaic planetary theory

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Claudius Ptolemy's astronomical treatise, known to us as the *Almagest*, has a Janus-faced status in the history of celestial mechanics. For almost a millennium and a half after it was written (about A.D. 150) it defined for astronomers in the Greco-Roman world, medieval Islam, and Europe both the general character of the phenomena of planetary motion and the theoretical and empirical means of explaining these phenomena. At the same time, the *Almagest* was a witness of singular importance testifying to the course of earlier developments in its subject, because of the records of older observations and criticisms of the theoretical work of Ptolemy's predecessors that are embedded in it.

Aside from Ptolemy's writings, the medieval manuscript tradition preserved few original works of ancient astronomy, and practically the whole of this literature subsists at a didactic, nontechnical level. Modern accounts of the history of Greek astronomy began largely as exercises in reconstruction, extrapolating backward from Ptolemy along a course constrained only by other reports that are second-hand, vague, and often unverifiable.

Conditions began to change in the nineteenth century, as archeologically recovered documents emerged from the ancient Near East and Egypt. Excavations at the Assyrian capital Nineveh and at sites in Babylonia brought to light great numbers of cuneiform tablets that related to the observation, interpretation, and prediction of phenomena in the heavens. After the first decipherment of these texts, it became obvious that, notwithstanding the intervening centuries and the barrier of language, the Mesopotamian astral sciences were historically connected to Ptolemy's work. Rediscovering the channels of transmission is one of the challenging problems in contemporary research. Our greatest hopes of success lie in a second body of documents obtained through archeology, papyri from Greco-Roman Egypt. As we piece together the remains of a continuous astronomical tradition spanning two thousand years of Mesopotamian and Classical civilization, we are learning that the continuity of methods among the predecessors of Ptolemy cited in the *Almagest* belies profound changes in the rationale of their interest in the heavenly bodies.

Sightings of planets as omens

Excavations by Layard and Rassam at Kuyunjik (Nineveh) in the 1850s yielded two bodies of tablets from the late Assyrian empire: a palace library consisting largely of texts that were repeatedly copied and referred to as part of a scribal tradition and a royal archive containing correspondence, the great part of it addressed to the kings Esarhaddon (reigned 680–669 B.C.) and Ashurbanipal (668–627 B.C.). The two corpora complement each other, especially in their bearing on the interest of the Assyrian kings in divination by means of the observation and interpretation of omens. Collections of omen texts, providing the key to translating ominous terrestrial and celestial phenomena into forecasts, account for about one third of the extant tablets from the library, whilst much of the archive consists of letters and reports addressed by expert diviners to the kings concerning specific ominous occurrences. Astral omens involving sightings of the sun, moon, and planets as well as a range of meteorological and seismic phenomena represent a distinct category of omens, systematically interpreted in a vast compilation of about seventy tablets known as *Enūma Anu Enlil*. Each tablet contained a series of sentence pairings, often linked by an “if… then…” conjunction, associating an ominous event with an outcome. For the astral omens, the outcomes relate to the welfare of lands and their kings, as was suitable for phenomena that could be beheld over a large area.

The omens of *Enūma Anu Enlil* are believed to have been composed in large part several centuries earlier, and some elements go back about a thousand years to the Old Babylonian period. The planetary omens, however, are in no sense primitive. They recognize the five planets visible to the naked eye, Saturn, Jupiter, Mars, Venus, and Mercury, in full awareness that the morning and evening appearances of Venus and Mercury are alternating situations of a single object. They know the path traversed by the planets among the constellations, and distinguish the prevailing direction of their motion against the background of the stars from their retrogradations, which give rise to ominous reentries of a planet into a constellation that it has previously left. Of particular interest is a series of omens, concerning the alternating appearances and disappearances of Venus, that seems to be adapted from a record of Old Babylonian observations and reflects awareness of the periodic character of such events. The Assyrian diviners too paid special attention to the first sightings of the planets, and were confident that they could anticipate these dates at least roughly. Their observational practice reflects the omen texts in locating the planets only roughly in terms of constellations rather than relative to single stars.

Dated planetary observations from Babylon and Egypt.

The observations of the planets that Ptolemy uses in the *Almagest* fall chronologically into two groups: recent observations, mostly Ptolemy's own, that were made between A.D. 127 and 141, and observations made between 272 and 229 B.C. Most of the older observations are not attributed to any particular person or even geographically localized. Only since the decipherment of the cuneiform texts has it become possible to identify the precise source of one set of these reports.

We now know that in Babylon a group of scholars, probably associated with the Esagil temple, carried out an apparently unbroken programme of astronomical observation from the middle of the seventh century to the middle of the first century B.C.. The records of the programme, which had a longer life than any subsequent observatory can claim, are tablets known as Astronomical Diaries. More than 1200 fragments of Diary tablets are extant. In them the scribes recorded, night by night and day by day, a well defined selection of phenomena and measurements that hardly changed in character over six hundred years. In addition to the appearances, disappearances, and movements of the moon and planets, the Diaries report weather and prices of various commodities, the level of the Euphrates, and news that varied from trivial local reports to wars and other national events.

No document tells us what the purpose of the Diaries was, and the question is hotly disputed among historians. One hypothesis is that they were connected with astral divination of the kind familiar from *Enūma Anu Enlil*. A case for this can be made on the grounds that, broadly speaking, everything that is entered in the Diaries has some approximate counterpart in the astral omens, among either the ominous phenomena in the heavens or the outcomes for country and king. The planetary observations in the Diaries, however, do not closely match the expectations of the omen texts.

Nearly all the phenomena of the heavenly bodies in the Diaries repeat on a periodic basis. Was their object to lay the foundation of a predictive astronomy? Until about three centuries after the earliest Diaries we find little evidence in Babylonian astronomy of methods of prediction going beyond basic periodicities of recurrence, and one may reasonably doubt whether anyone would have shown such dedication in gathering data with a view to a scientific goal so far out of reach. Moreover, the Diaries assiduously recorded the same kinds of data long after Babylonian predictive astronomy had attained its most advanced level. Some texts contemporary with the Diaries speak of periodicities of economic data and weather tied to planetary motion, and perhaps these belong to a Babylonian theory relating mundane to celestial phenomena in a way distinct from the older omen lore, with emphasis on repeating rather than anomalous events.

The planetary observations in the Diaries include the dates of their first appearances, disappearances, and stations (reversals of direction), as well as their passing close to about thirty reference stars. These stellar passages contain the most precise positional information, with measurements of the distance between the star and the planet expressed in a unit called a “cubit” (equivalent to about 2 1/2 degrees). Three of the observations in the *Almagest* are recognizable as close translations of Diary reports of this kind.

The remaining anonymous planetary observations from the third century B.C. in the *Almagest* are quite similar to the Babylonian ones, but are believed to have been made in Hellenistic Egypt. They are also passages close to reference stars, but the unit of measurement here is the “moon's breadth” (ostensibly 1/2 degree) and planetary positions are often specified relative to imaginary lines drawn through two stars. The purpose of these observations is, if possible, even more of an enigma than the Diaries, because we have much less knowledge of the context of astronomical activity at this stage of Greek culture than in Mesopotamia. Babylonian influence is not out of the question.

Phenomena confronting models

In the fifth or fourth century B.C., the Babylonian scribes began to employ a new frame of reference for expressing planetary positions: the zodiac, divided into twelve equal parts named for but not exactly coinciding with constellations. The zodiac did not supersede the reference stars in observational reports, but became the foundation of new methods of predicting the phenomena of the planets using mathematical models. These models represented intervals of time and of distance along the zodiac as precise numbers, and prescribed algorithmic rules for the changing values of these numbers in such a way that both the short term variations and the long term periodicities were preserved. No attempt seems to have been made to explain these arithmetical models in terms of a geometrical or physical conception of planetary motion.

The inventors of these planetary models had gone well beyond the initial insight that planetary phenomena follow regular “synodic” cycles, and that these cycles are not all exactly equal. They had discovered that the variations in the cycles were dependent on the planet's location in the zodiac, determined approximately where the extremes were, and measured the extent of variations.

Roughly contemporary with the development of these predictive mathematical models in Babylonia, Plato's associate Eudoxus of Cnidos proposed a set of explanatory mathematical models according to which the apparently complex movements of the planets were produced by a combination of circular motions, all concentric with the earth but having different axes and different fixed rates of rotation. As they are described by the philosopher Simplicius (sixth century A.D.), Eudoxus' planetary models appear to be designed to generate the synodic cycles, probably including the retrogradations—though not all historians agree about this—but each cycle is identical.

Eudoxus' models reflect a stage of Greek astronomy when specific dated observations had no role in determining the patterns of planetary motion. We know practically nothing about subsequent developments in geometrical modelling until the second century B.C., when Hipparchus made extensive use of observations to calibrate his solar and lunar models. Hipparchus employed eccentric and epicyclic models, that is, simple combinations of circular motions that are not all concentric with the earth. Ptolemy reports that Hipparchus wrote a book in which he showed that the planetary models proposed up to his time were not viable, apparently because they failed to exhibit the zodiacal variations in the synodic cycles, the existence of which Hipparchus demonstrated from observations.

Hipparchus surely drew in this book on the same collections of Babylonian and Greco-Egyptian planetary observations that were the ultimate source of Ptolemy's reports. Scattered through his scientific work are numerous elements that we can recognize as Babylonian in origin, and it is not impossible that he learned much of this through direct contact with the scholars in Babylon; for evidence of familarity with some of Hipparchus' solar theory has also been discovered in a Babylonian tablet.

Harder to appraise is the possibility that the Babylonian arithmetical models influenced Greek geometrical planetary theory. If Hipparchus was familiar with these models—there is no proof that he was—he could have derived from them information about the zodiacal anomaly, which he then verified from specific observations. What we do know from recently discovered papyri is that practically the whole system of Babylonian mathematical astronomy was carried over into Hellenistic and Roman Egypt, where it supplied the basis for astrological computations. Opportunities for using the Babylonian models as a guide to the planetary phenomena continued as late as Ptolemy's time.

Another papyrus fragment, in this case from a Greek treatise on the motion of Jupiter composed about A.D. 105, has given us a rare glimpse of developments in planetary theory just a generation before Ptolemy. The author, who might be Menelaus of Alexandria, makes a systematic comparison of dated observations of Jupiter's position relative to reference stars made by himself and by an observer 344 years earlier. 344 years is an accurate recurrence period for Jupiter, so that the pattern of the planet's motion was almost identical over the two series of dates. The method of comparing observations separated by a recurrence period is reminiscent of Hipparchus' researches on the sun and moon, and quite different from Ptolemy's approach to the study of long-term aspects of planetary motion. Yet it is likely that Ptolemy read this work, and indeed borrowed from it one of the third century B.C. observation reports in the *Almagest*.

In Ptolemy's astronomy observations and theory are presented as tightly integrated, but he was well aware that this was not true in earlier times; thus he complains that most of the older planetary observations available to him were not amenable to his methods of analysis. His deductive method is not historiographical, but it relies on historical data, since even the ostensibly accurate theoretical results of Ptolemy's immediate predecessors had to be empirically verified (it was not, indeed, his practice to give other people credit for such results, but only for methodological principles). As we are gaining independent knowledge of the materials he had to work with, we must increasingly appreciate the combination of luck and clever manipulation latent in his planetary theory.

Further reading:

C. B. F. Walker, ed., *Astronomy Before the Telescope*, London (British Museum Press), 1996.

A. Jones, *Astronomical Papyri from Oxyrhynchus*, Philadelphia (American Philosophical Society), 1999.

(I don't know any good references in French for this material.)

Suggestions for illustrations:

Cuneiform tablet containing an Astronomical Diary from Babylon. Inquire if any colour photos are available from Dr. Christopher Walker, Department of Western Asiatic Antiquities, British Museum, London WC1B 3DG, Tel (011-44) 171 323-8382, Fax (011-44) 171 323-8489. He can tell you how to obtain permission to publish as well.

Papyrus fragment (*P. Oxy.* 4133) from a Greek treatise on the motion of Jupiter, containing observations made in 241 B.C. and A.D. 105. Image in digital form or as a glossy print may be obtained from Dr R. A. Coles, Papyrology, Ashmolean Museum, Oxford OX1 2PH, U.K., tel. 01865-278095. Permission to publish should be obtained from the Egypt Exploration Society, 3 Doughty Mews, London WC1N 2PG.