Biographical Encyclopedia of Astronomers

Hipparchus of Nicaea

Born in Nicaea (Iznik, Turkey), circa 190 BCE

Died possibly in Rhodes (Greece), circa 120 BCE

Hipparchus is remembered chiefly for compiling a star catalog; measuring and attempting to explain what Nicolaus Copernicus later named "precession of the equinoxes," developing usefully predictive models for solar and lunar motions, and determining distances to the Sun and Moon. He compiled the first trigonometric table (giving the chord function) and may well have invented trigonometry. Hipparchus introduced the 360° angle measure and sexagesimal arithmetic from Babylon, invented a stellar magnitude scale that we still use (in updated form) today, and possibly invented the planar astrolabe. He applied astronomy to geography, particularly the use of gnomons for determining terrestrial latitudes. Hipparchus's most important influence, though, was to move Greek astronomy away from idealistic, theoretical, and qualitative geometry, toward precise, predictive, and empirically confirmed computation

Hipparchus "of Rhodes," as some moderns call him, was actually from Nicaea, the capital of Bithynia. Of Hipparchus's life and parentage, we know practically nothing. And though he is widely deemed the greatest of Greek astronomers, we know but little about his work—ancient writers credit Hipparchus with a dozen distinctive works in astronomy, but only his *Commentary on the Phenomena of Aratus and Eudoxus* survives intact. This commentary belongs to a long-standing discursive tradition concerned with constellations and astrological weather forecasting. In its third and final book, we find Hipparchus's own description of the constellations, plus the positions of 44 bright stars that he determined for telling time by night. Some of Hipparchus's later measurements are preserved in Ptolemy's *Almagest*, which is also our main source of information about Hipparchus's mathematical astronomy

Hipparchus's observations span the years 147–127 BCE and, though the evidence is not irrefutable, are thought to have been taken from Rhodes. The resulting star catalog was almost certainly not a systematic table of coordinates, but a mixture of notations: lists of stars that are collinear, distances between stars, and declinations. This odd mix facilitated Hipparchus's interest in detecting changes in the heavens. Pliny explains that Hipparchus noticed a "new star" that moved "in its line of radiance." Hipparchus thus wondered whether the fixed stars really were fixed. He therefore began to measure their positions and magnitudes with that question in mind. As for Hipparchus's new star, it remains mysterious. Some identify it with a comet in 134 BCE (that returned in 120 BCE); others with a nova in the Chinese records for 134 BCE The new star is not documented in the remains of Hipparchus's catalog, but we do find two "cloudy" stars: the Praesepe Cluster M44 (previously recorded by Aratus), and the Double Clusters h and chi Persei.

Precession of the equinoxes came to the fore while Hipparchus investigated the constancy of the year by timing successive equinoxes. These data, even when combined with those of

Timocharis and Aris-tyllus a century earlier, were recorded only to the nearest quarter day and proved insufficiently precise and spanned too short a time to yield a worthwhile estimate for the year. So Hipparchus worked instead from Babylonian data, concluding 365 + 1/4 + 1/144 days for the sidereal year and 365 + 1/4 - 1/300 days for the tropical year, well within what the limited range of observations could confirm. The difference between the sidereal and tropical years indicates equinoctial drift against the ecliptic of "no less than 1º per century," as Ptolemy put it. Though Hipparchus is commonly said to have explained this by adding a precessionary motion to the sphere of fixed stars, that credit actually belongs to Ptolemy's Islamic successors. Hipparchus himself seems undecided on what was happening, which is understandable given his apparent awareness of the limits inherent in the data available to him. He tentatively suggested that both equinoctial shift and mutation of the constellations occurred because stars near the ecliptic moved at a rate different from those near the poles.

Hipparchus accounted for the different lengths of seasons (as defined by the equinoxes and solstices) and annual variations in the apparent solar speed by assigning the Sun to a uniform circular orbit centered away from the Earth Finding the center of this orbit involved trigonometry, perhaps motivating the construction of his chord table—for without a tabulated trigonometric function, one must resort to first principles. The most important astronomical advance here lies in Hipparchus's approach: for the first time, a Greek geometrical model was fitted to precise observational data. The same is seen in Hipparchus's model of the Moon—he took the deferent-epicycle construction invented by Apollonius and adapted it to fit Babylonian data for the sidereal, anomalistic, and draconitic periods. The lunar model is accurate only when the Moon is near opposition and conjunction, as Hipparchus knew. But because eclipse prediction was his goal, these are precisely the times when accuracy was most needed.

Hipparchus's interest in eclipses also led him to determine the relative sizes and distances of the Sun and the Moon, using parameters from the long-established Babylonian observational tradition. But Hipparchus did not simply take the Babylonian parameters for granted; he computed a new eclipse period from them, which he then compared against available data from the several preceding centuries. Only a few suitable eclipse pairs could be found in the records, but they agreed well enough to confirm the Babylonian parameters. Hipparchus's appreciation for the limits of observational data is also evident in his calculated distance to the Moon. He gives only a lower bound, computed by assuming that the Sun is at infinity, and an upper bound, limited by the precision with which he could measure solar parallax

According to Ptolemy, Hipparchus failed to produce models for the motions of the other celestial bodies, though he did successfully refute earlier models. But clearly, Hipparchus's attempts provided the foundations for Ptolemy's own work, and hence for all mathematical astronomy up to the Copernican period

On the cosmological front, Hipparchus's epicycles and eccentric orbits spawned trouble; although observations *confirmed* the calculations, physics could not *explain* them. The absence of a suitable physics remained problematic well into the 17th century, since cosmologists naturally wanted to know why celestial bodies would move along such oddly compounded circular orbits. Hipparchus did produce some physics of his own, Philoponus, and Galileo Galilei later wielded Hipparchus's theory of projectile motion against Aristotle. Hipparchus

also seems to have written on how the celestial realm influences the terrestrial, but neither his nor any other physics ever succeeded in making the compounded off-center circles convincingly real. They were widely deemed a mere calculator's convenience. Mere convenience or not, Hipparchus sired an astronomy that was computational, predictive, and empirical, and which thrived well into the dawn of modernity

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Selected References

Aaboe, Asger (1955). "On the Babylonian Origin of Some Hipparchian Parameters." *Centaurus* 4: 122-125.

Fotheringham, J. K. (1919). "The New Star of Hipparchus and the Dates of Birth and Accession of Mithridates." *Monthly Notices of the Royal Astronomical Society* 79: 162-167.

Goldstein, Bernard R. and Alan C. Bowen (1995). "Pliny and Hipparchus's 600-Year Cycle." *Journal for the History of Astronomy* 26: 155-158.

Graßhoff, Gerd (1990). *The History of Ptolemy's Star Catalogue*. New York: Springer-Verlag

Hipparchus (1894). *Hipparchi in Arati et Eudoxi Phaenomena commentarium* (Commentary on the phenomena of Aratus and Eudoxus), edited by C. Manitius. Leipzig: Teubner. (German and Greek; Hipparchus's only extant work, still unavailable in English translation. The last of the three books contains Hipparchus's measurements of 44 stars. A Renaissance Greek edition in 80 pages, published in 1567 alongside another commentary by Achilles, was republished in 1972 in the Landmarks of Science microfiche series. English translations of some short passages are given by Graßhoff.)

—— (1960). *The Geographical Fragments of Hipparchus*, edited by D. R. Dicks. London: Athlone Press.

Irby-Massie, Georgia L. and Paul T. Keyser (2002). *Greek Science of the Hellenistic Era: A Sourcebook*. London: Routledge.

Jones, Alexander (1991). "The Adaptation of Babylonian Methods in Greek Numerical Astronomy." *Isis* 82: 441-453.

—— (1991). "Hipparchus's Computations of Solar Longitudes." *Journal for the History of Astronomy* 22: 101-125.

Maeyama, Y. (1984). "Ancient Stellar Observations: Timocharis, Aristyllus, Hipparchus, Ptolemy the Dates and Accuracies." *Centaurus* 27: 280-310.

Nadal, R. and J.-P. Brunet (1984). "Le 'Commentaire' d'Hipparque. I. La sphère mobile." *Archive for History of Exact Sciences* 29: 201-236

—— (1989). "Le'Commentaire'd'Hipparque. II. Position de 78 étoiles." *Archive for History Of Exact Sciences* 40: 305-354.

Neugebauer, Otto (1949). "The Early History of the Astrolabe." *Isis* 40: 240-256

Pliny the Elder (1938). *Natural History*, translated by H. Rackham. Loeb Classical Library, no. 330. Cambridge, Massachusetts: Harvard University Press. (Pliny tells the story of Hipparchus's star catalog in Book II, Chapter 24, where he also praises Hipparchus for his work on the astrological influence on humans and for showing that "our souls are part of heaven." Hipparchus's work on eclipses is mentioned in a brief but difficult passage in Book II, Chapter 9 [with further material in Chapter 10], on which see the article by Goldstein and Bowen. At Chapter 79, Hipparchus is said to have defined the day as the time between two successive midnights; at Chapter 112, he is said to have added 26,000 stadia to the circumference of the Earth as calculated by Eratosthenes.)

Ptolemy (1984). *Ptolemy's Almagest*, translated and annotated by G. J. Toomer. New York: Springer-Verlag. (Traces of Hipparchus's theoretical work are scattered throughout the Almagest. See in particular Book III, Chapter 1 on the length of the year; III.4 on solar motion; IV.2 on period relations; V.11 on the Hipparchan dioptra; V.14–15 on the distance to the Sun; VII.1 on fixed stars and constellations; and VII.3 for stellar declinations and the precession of the equinoxes. The commentaries on the Almagest by Pappus and Theon provide some further material on Hipparchus.)

Swerdlow, Noel M. (1980). "Hipparchus's Determination of the Length of the Tropical Year and the Rate of Precession." *Archive for History of Exact Sciences* 21: 291-309.

Toomer, G. J. (1973). "The Chord Table of Hipparchus and the Early History of Greek Trigonometry." *Centaurus* 18:6-28.

—— (1974). "Hipparchus on the Distances of the Sun and Moon." *Archive for History of Exact Sciences* 14: 126-142.

—— (1980). "Hipparchus' Empirical Basis for His Lunar Mean Motions." *Centaurus* 24:97-109

—— (1988). "Hipparchus and Babylonian Astronomy." In *A Scientific Humanist: Studies in Memory of Abraham Sachs*, edited by Erle Leichty, Maria de J. Ellis and Pamela Gerardi, pp. 353-362. Philadelphia: Occasional Publications of the Samuel Noah Kramer Fund 9.