

# Biographical Encyclopedia of Astronomers

© 2007 Springer

Eudoxus

Born Knidos (Tekir, Turkey), circa 390 BCE

Died Knidos (Tekir, Turkey), circa 338 BCE

Eudoxus offered the first fully worked-out model of planetary motion

Eudoxus was the son of Aiskhines of Knidos; he was probably born around 390 BCE, when Knidos was a Spartan ally and a closed oligarchy. Eudoxus was married and had three daughters, Aktis, Delphis, and Philtis; he died at the age of 52.

Eudoxus studied mathematics under Archytas of Taras and medicine under Philistion of Lokroi in southern Italy. He made astronomical observations there and in Sicily—perhaps around 361/360 BCE—when he may have been in Sicily

Diogenes reports that Eudoxus came to Athens with little money at the age of 23, accompanied by his patron, the physician Theomedon. He lived in the port city of Piraeus for two months, walking to Athens daily for lectures at the academy. Around 366/365 BCE, he sailed from Knidos to Egypt with Chrysippus, having been introduced by a letter from Agesilaus II of Sparta to Pharaoh Nectanebo I. For over a year, Eudoxus remained in Heliopolis, near Cairo, studying language and religion with the priest Chonouphis and making astronomical observations at nearby Kerkesoura. He also visited Memphis, where the priests predicted that his life would be short but famous (*endoxos*).

Geminus reports that Eudoxus wrote on the calendar, and some sources state that he wrote an *Octaeteris* (probably circa 365/364 BCE), which treated the 8-year cycle of the calendar, over which he perhaps distributed 49 months of 30 days and 50 months of 29 days in 8 Egyptian 365-day years. He is reported to have set the interval between the autumnal equinox and the winter solstice as 92 days, and that from the winter solstice to the spring equinox as 91 days; the other two intervals are not known but must sum to 182 days, and both were most likely 91 days (since Eudoxus later assumed uniform solar motion). This means that he ignored the earlier work of Eudoxus and Meton on the inequality of the seasons and on the 19-year luni-solar cycle. Eudoxus also gave seasonal weather and star-appearance data, preserved in the calendar appended to Geminus. It may also be at this time that he wrote *Disappearances*, which apparently dealt with the seasonal visibilities of stars. Eudoxus seems to have been the first to estimate the relative size of the Sun as many times larger than the Moon. (Archimedes records that he said "nine.")

Eudoxus visited Mausolus of Halicarnassus (modern Bodrum) around 364/363 BCE, and probably also visited his birthplace at this time. Knidos had relocated its site (from modern Datça to the better harbor at modern Tekir) around 365-360 BCE, and changed its constitution from oligarchic to democratic. Strabo records that Poseidonius claimed to have seen an observatory used by Eudoxus in new Knidos, but excavators have not identified it

Then, around 363–357 BCE, Eudoxus taught at Cyzicus (modern Belkis), where his students included the mathematician brothers Menaechmus and Dinostratus of Prokonessos, and three natives of Cyzicus: Athenaius (not the much later mechanic), Polemarchus (the astronomer and teacher of Callippus), and perhaps Helicon. Besides mathematics and astronomy, he taught geography, metaphysics, and ethics. Probably during this period, Eudoxus composed his *Survey of Earth*, the astronomical works *Mirror* and *Phainomena*, as well as a work of mathematics

Eudoxus's geography was the earliest to employ mathematical methods and the spherical Earth model. He covered "Asia" (the East), including Egypt, in Books 1-3, and "Europe" (the West), including Libya, in Books 4-6, with Islands (including Sicily and its Pythagoreans) in Book 7, telling ethnographic stories similar to those of Herodotus. He may be the author of the earliest extant estimate of the circumference of the Earth, 40 myriad stades (approximately 75,000 km), in Aristotle's *On Heaven*

The two works of descriptive astronomy, almost identical according to Hipparchus, were apparently based on observations made from a latitude where the longest day was about 15 hours (about 42° 2' N), probably Cyzicus. They were the earliest systematic analysis of the sky, describing the constellations located along the celestial circles. Eudoxus's work was the foundation of Aratus's poem *Phainomena*, and is described in Hipparchus's commentary thereon. Eudoxus located stars relative to parts of their figures, and sometimes clarified placements with geometry. He placed the solstitial and equinoctial points at the middle of the constellations Aries, Cancer, Libra, and Capricorn, possibly following the similar Babylonian practice, but he rejected their claims of predictive astrology. Vitruvius credits him with the invention of a type of sundial called the *arachnê* ("spider-web")

Eudoxus's mathematical work developed the theory of proportion presented in Euclid, Books 5 and 6, and the method of "exhaustion" (approach to the limit) presented in Euclid, Book 12. The former provided a definition of proportion applicable to both rational and irrational numbers (which D. Fowler suggests arose from his calendaric work); the latter provided a means to prove formulae for the area or volume of figures not tractable by Greek geometrical methods, such as the volume of the cone or pyramid

Some years before 348 BCE, Eudoxus returned to Athens, accompanied by many students, and continued his research and teaching. (He did not join the academy.) He published his greatest astronomical contribution, the theory of concentric spheres, in *On Speeds*, probably after Plato's death, perhaps around 345–340 BCE. Attempts to reconstruct the lost work are rife with ambiguity, because we depend entirely on a brief report in Aristotle's *Metaphysics*, and a longer report in *Simplicius* that depends on the lost work *On Counter-rotating Spheres* by the second-century astronomer Sosigenes, itself dependent on Eudoxus's lost *History of Astronomy*, Book 2. Eudoxus's books may not have survived the Roman conquest of Egypt

The theory was a geocentric model of planetary motion, attempting to explain the movements of the seven planets (Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn) on a common basis. Although probably not predictive, it contained numerical parameters based on observation. Each of the seven planets had three or four concentric rotating spheres whose axes

were tilted with respect to one another, and whose compound motions explained the observed motion of the respective planet.

The outermost sphere of each planet moved with the same rotational velocity as the sphere of the fixed stars, i.e., with a 1-day period, rotating from east to west. The second sphere rotated with its equator in the plane bisecting the band of the zodiac, from west to east, with "zodiacal" periods preserved by Simplicius (corresponding modern periods are given in the third column):

Saturn	30 years	29.45 years
Jupiter	12 years	11.86 years
Mars	2 years	1.88 years

(The periods of Venus and Mercury are not comparable.)

The Sun and Moon each had one more sphere, which rotated very slowly (the solar one east to west, and the lunar one west to east), with its equator sufficiently inclined to the center of the band of the zodiac to explain the deviation of the Sun or Moon from that circle. Modern scholars usually suggest that Eudoxus must have intended a period of 1 month for the third lunar sphere, the second sphere being the very slow one (period about 18 or 19 years). A similar correction is often applied to the solar spheres, the third requiring a 1-year period, and the second a long period

(Eudoxus did consider the Sun to have the small motion explained by the third sphere, as Hipparchus reports, quoting the *Mirror*: "the Sun differs in where it appears at the solstices." This geocentrically reasonable view was held by other Greek astronomers, but Hipparchus defined the center of the zodiac band as the ecliptic circle, on which the Sun traveled, thus rendering Eudoxus's third solar sphere otiose.)

Eudoxus took no account, and maybe had no knowledge, of the longitudinal variation in lunar velocity, and ignored the annual variation in solar velocity. (See above.)

Each of the other five planets had a total of four spheres, either to explain retrograde motion or the varying intervals of their phases of visibility. The poles of the third sphere lay on the equators of the second spheres, those of Mercury and Venus coinciding, the others differing. These spheres rotated with synodic periods (the interval between corresponding positions with respect to the Sun), evidently given to an accuracy of 1/3 of a month. Preserved by Simplicius, they are as shown below:

Saturn	"close to 13 months"	378 days
Jupiter	"close to 13 months"	399 days
Mars	"8 months and 20 days"	780 days
Mercury	"110 days"	116 days
Venus	"19 months"	584 days

(The third column gives the corresponding modern average periods; the value for Mars is so discordant that scholars often amend the Greek to "8 months and 20.")

The fourth sphere carried the planet (on or near its equator) and rotated with the same period as, but oppositely and at an individual small inclination to, the third sphere. Their combined motion produced a figure-eight-shaped curve called by Eudoxus a hippopedê, and was carried along the zodiac by the motion of the second sphere.

There were ancient objections to the theory's predictions of planetary latitude, and Polemarchus noted that it could not explain the variations in apparent lunar size or in the apparent brightness of Mars and Venus. Giovanni Schiaparelli's reconstruction of Eudoxus' model could not match the observed retrograde motion of Venus or Mars (with either period), but our evidence possesses enough gaps to allow various interpretations, some of which generate motions very close to the observed ones

Eudoxus' planetary theory, which accounted for most of the easily observed phenomena of all seven planets, and though modified by Callippus, Aristotle, and Autolycus, was not superseded for almost four generations (by Apollonius). The qualitative nature of the model colored astronomical thinking through Ptolemy (who spoke of planets as carried-on segments of spheres), and thus through the era of Johannes Kepler. When ancient or medieval astronomers wrote of the harmony of the spheres, it was to these spheres that they referred (though Eudoxus himself did not subscribe to the notion).

*Paul T. Keyser*

### **Selected References**

Aristotle. *Metaphysics*. 12.8.1073b17-1074a15.

Dicks, D. R. (1970). *Early Greek Astronomy to Aristotle*. Ithaca, New York: Cornell University Press, pp. 151-189.

Diogenes Laertius. *Lives of Eminent Philosophers*. 8.86-90

Evans, James (1998). *The History and Practice of Ancient Astronomy*. New York: Oxford University Press, pp. 305–312

Folkerts, Menso (1998). "Eudoxos [1]." In *Der neue Pauly: Encyclopädie der Antike*, edited by Hubert Cancik and Helmuth Schneider. Vol. 4, cols. 223-225. Stuttgart: J. B. Metzler.

Fowler, David. "Eudoxus: *Parapegmata* and Proportionality." In Suppes *et al.*, pp. 33-48.

Geminus (1975). *Introduction aux Phénomènes*, edited by Germaine Aujac, pp. 98-108. Paris: Belle Lettres. (Eudoxus' calendar.)

Guthrie, W. K. C. (1978). "Eudoxus." In *A History of Greek Philosophy*. Vol. 5, pp. 447-457. *The Later Plato and the Academy*. Cambridge: Cambridge University Press

Huxley, G. L. (1971). "Eudoxus of Cnidus." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie. Vol. 4, pp. 465-467. New York: Charles Scribner's Sons.

Lasserre, François (1966). *The Fragments of Eudoxus of Cnidus*. Berlin: W. de Gruyter. (See critical review by G. J. Toomer (1968). *Gnomon* 40: 334-337.)

Mendell, Henry. "The Trouble with Eudoxus." In Suppes et al., pp. 59-138.

Neugebauer, Otto (1975). *A History of Ancient Mathematical Astronomy*. 3 pts. New York: Springer-Verlag, pt. 2, pp. 674-683

Santillana, Giorgio de (1940). "Eudoxus and Plato: A Study in Chronology." *Isis* 32: 248-262.

Simplicius. *Commentary on Aristotle, On the Heavens*. 2.12.221a. Suppes, Patrick et al. (eds.) (2000). *Ancient and Medieval Traditions in the Exact Sciences*. Stanford: Center for the Study of Language and Information.

Toomer, G. J. (1996). "Eudoxus of Cnidus." In *Oxford Classical Dictionary*, edited by Simon Hornblower and Antony Spawforth, pp. 565-566. 3rd ed. Oxford: Oxford University Press.

Yavetz, Ido (1998). "On the Homocentric Spheres of Eudoxus." *Archive for History of Exact Sciences* 52: 221-278.