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A Technical Note on Epicyclical Interpretations of Pliny's Planetary Theory

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A Technical Note on Epicyclical Interpretations of Pliny's Planetary Theory

Irina Tupikova *

This technical note is a complement to P.D. Omodeo's article on "Erasmian Philology and Mathematical Astronomy: Jakob Ziegler and the Humanist Recovery of Pliny's Natural History*" in this issue of the* Journal of Interdisciplinary History of Ideas.

In his treatment of planetary motions, Pliny probably made no use of a system of deferents and epicycles, although this technical solution for planetary modeling predated his work, and although he hinted to the Greeks employing "circles" (*Natural History* II 13, 63). He also mentioned the fact that the circles of different planets have different centers (*Natural History* II 13,63), which can simply be a reference to their eccentricity with respect to the cosmological center. In this respect, however, it ought to be mentioned that, according to classical planetary theory, an eccentric motion can always be replaced by an equivalent epicyclical motion. As Otto Neugebauer correctly observed in his *History of Ancient Mathematical Astronomy*:

"All ancient and mediaeval astronomy under Greek influence made extensive use of this equivalence. The frequent shift from one cinematic model to the other is the best indication of the fact that none of these models implied that there existed in nature a corresponding mechanical structure. The constituent parts of any model are as unreal as

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the single terms in a modern series expansion, at least in principle when it is opportune to defend the purely mathematical aspect of the theory"[1].

Whether Pliny was aware of this equivalence principle cannot be said on the basis of the textual evidence we have. As a result, no conclusion can be drawn as far as his commitment for eccentric of epicyclical models is concerned.

This uncertainty and the lack of evidence did not hinder Renaissance scholars such as Jacob Ziegler, Jacob Milich and Erasmus Reinhold from interpreting Pliny's astronomical passages in the *Natural History* with the support of deferent-epicyclical planetary theory. Yet, their readings could descend from a later historical employment of the equivalence principle by Renaissance scholars trained in Ptolemaic astronomy. Thus, the modern reader should keep in mind that this perspective might have been anachronistic and remains at least controversial.

1. The Astronomical Background of Pliny's Treatment of Planetary Motions

In the second book of the *Natural History*, Pliny dealt extensively with the apparent motions of the planets, their stations and retrogradations, in connection to their relative positions to the Earth and the Sun, in conjunction, opposition and at quadrature. In order to make the astronomical problems and the meaning of the relevant termini (which are historically embedded in a geocentric framework) clear, a modern reader can also use a heliocentric visualization like the one given in *fig. 1*.

[1] Otto Neugebauer, *A History of Ancient Mathematical Astronomy* (Berlin, Heidelberg and New York: Springer, 1975), vol. 1, p. 57.

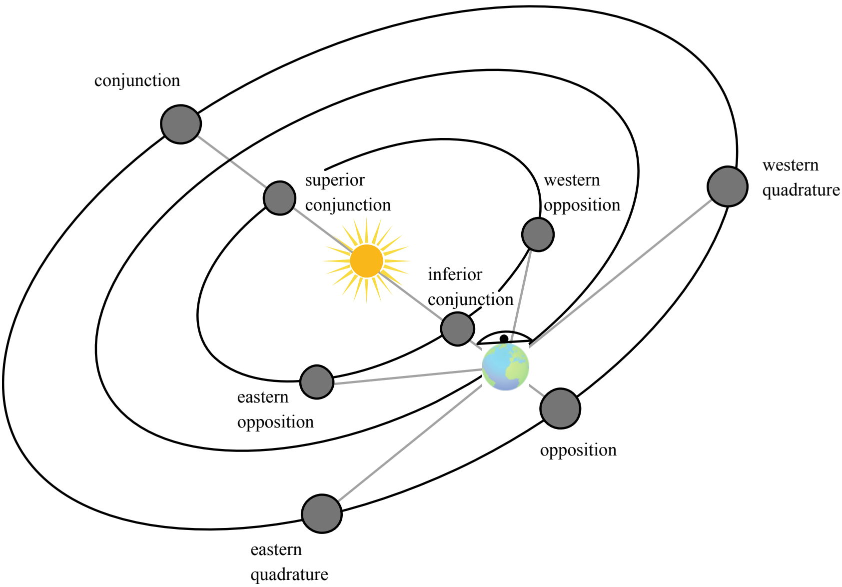


Figure 1: Planetary positions relative to the Earth and the Sun discussed by Pliny and his Renaissance commentators, in a modern heliocentric 'translation'.

When a superior planet travels eastward in relation to the stars, we call it *prograde*. When it travels westward in relation to the stars, its motion is called *retrograde*. This phenomenon is due to the fact that the Earth completes its orbit in a shorter period of time than the superior planets, and thus overtakes them in the course of its orbital motion. These planets' retrogradations occur near their opposition to the Sun (*fig. 2*). Moreover, the more distant a planet is, the more frequently retrograde motions appear, e.g. Mars retrogrades (approximately) for 72 days every 780 days, Jupiter for 121 days every 399 days and Saturn for 138 days every 378 days. The mean lengths of arcs of the retrograde motion attain about 15° for Mars, 10° for Jupiter and 7° for Saturn.

As to the inferior planets, Venus and Mercury, their retrogradations occur in connection with their inferior conjunctions with the Sun. At its maximal western elongation, an inner planet appears to be stationary and can be observed in the west soon after sunset. Moving from east to west, that is, in retrograde direction, the planet approaches the Sun and becomes invisible. After having been plunged into the Sun's rays, the planet becomes visible in the morning before sunrise. Its distance from the Sun increases until the planet reaches its maximal eastern elongation. In that point, after its second station, it again returns towards the Sun. In sum, it is between the western and eastern maximal elongations, that an inner planet shows an apparent retrograde motion (*fig. 3*). The retrograde motion of Mercury can be observed once in approximately 116 days and that of Venus once in approximately 584 days. The mean lengths of arcs of the retrograde motion attain about 12° for Mercury and 16° for Venus.

2. Pliny's Theory of the Inferior Planets in Ziegler's Interpretation

Renaissance scholars trained in Ptolemaic astronomy solved the challenging problem of the limited elongation of the (in their view) 'inferior' planets from the Sun in a quite ingenuous manner. Ziegler thoroughly discussed and illustrated this technical solution with the support of the diagram given in fig. 4, to the left. Here, D is the center of the zodiacal circle (and therefore of the finite cosmos of classical astronomy) where also the Earth was supposed to be

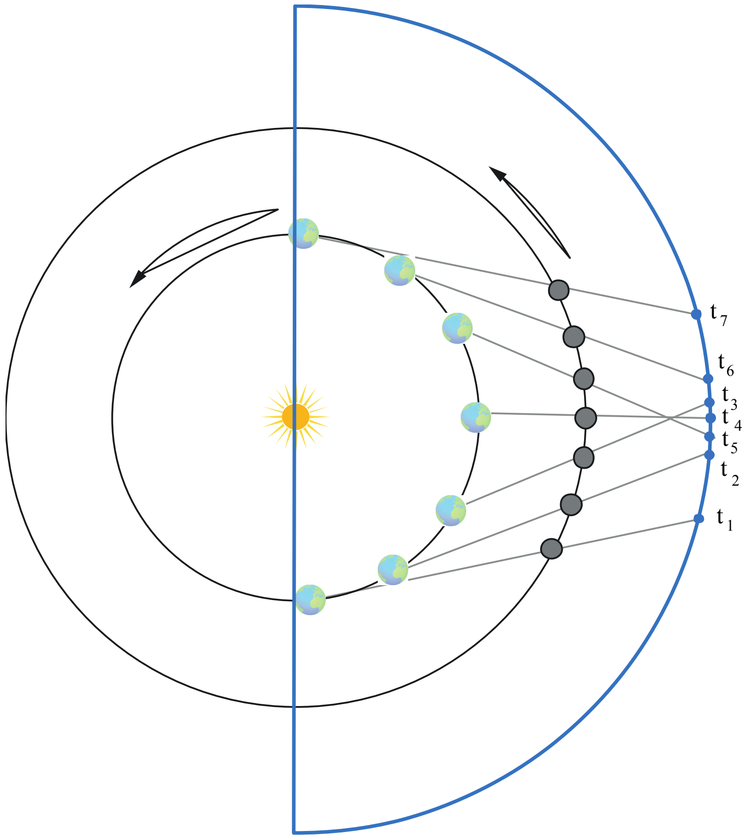


Figure 2: Retrogradation of a superior planet. The apparent positions of a superior planet are given as projections of its position relative to the celestial sphere (blue arc) for a sequence of time units marked with t_i.

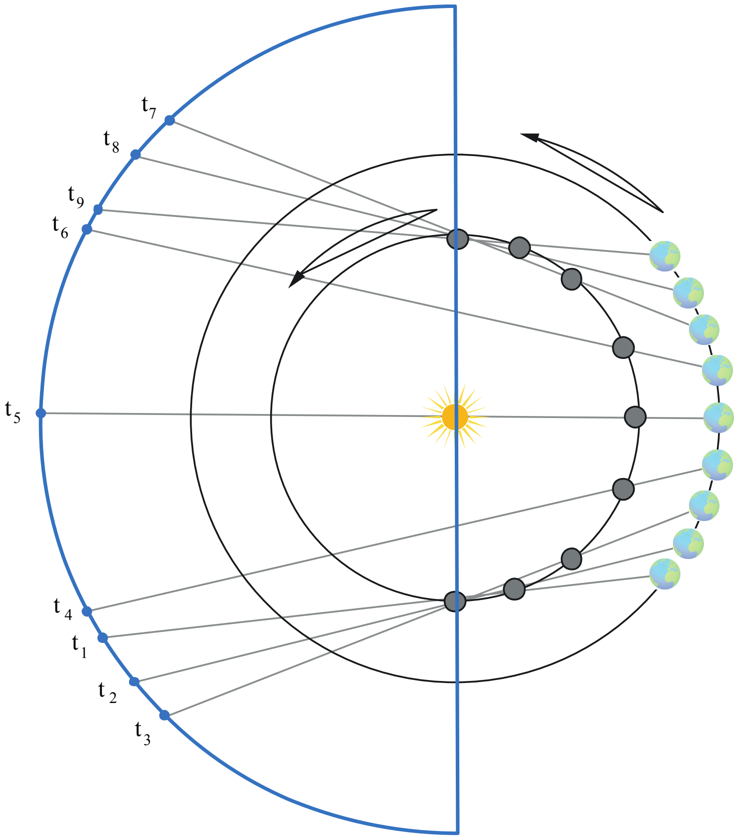


Figure 3: Retrogradation of an inferior planet. The apparent positions of an inferior planet are given as projections of its position with respect to the celestial sphere (blue arc) for a sequence of time units marked with t_i.

placed. Mercury's deferent AQBR is centered on the equant point H and Mercury's epicycle has its center in point A. Trying to make this epicycle more visible, Ziegler transposed it to the upper part of the diagram. The angles ADL correspond to the maximal elongation of Mercury as seen from the Earth, while EF is the line of the apses. The limited elongation of the inferior planets is the distinguishing feature of their motion relative to that of the superior planets. Ziegler accounts for it with the help of the Ptolemaic idea according to which the apsis of an inferior planet's epicycle is not fixed (as in the case of the superior planets) but rotates together with the line pointing towards the Sun (coinciding with the direction towards the mean Sun). A schematic illustration of this idea is given in fig. 4, to the right.

In order to understand the meaning of 'apses' in this context, it is expedient to recall the meaning that such an expression can assume in a Ptolemaic framework. A deferent is a circle and as such it has no apses meant as furthest and nearest points from the center. Therefore, the concepts of an apoapsis and of a periapsis can be used only if one assumes either an eccentric scheme, or epicyclical models. In the case of epicyclical modeling, as is the case for Ziegler, the line of the apsis connects the points of an epicycle transported along the deferent. *Fig. 5*, to the left, displays the 'epicyclical apses' for the superior planets, while *fig. 5*, to the right, shows the 'epicyclical apses' for the inferior planets.

The positioning of the superior planets on the epicycles merits special consideration. Already Ptolemy in the *Almagest* IX, 5 listed some arguments for the correct determination of the rotation of epicycles. As Reinhold in his *Commentary* on Pliny claimed, the epicycle moves along the series of the zodiacal signs in its superior part and in the opposite direction in the inferior one. His opinion was surely shared by Ziegler. Points A and A_1 in *fig. 5* (right) correspond to the superior conjunction (*fig. 4*), where no retrograde motion can be observed. Therefore, within an epicyclical framework, an inferior planet should be placed at the outer part of the epicycle with a prograde motion, i.e., at point A. The retrograde motion can be observed only in oppositions, i.e., at points C or C_1. In order to explain this motion by the rotation of the epicycle, the planet should be placed at the inner part of the epicycle where the motion goes in the opposite direction relative to the apparent motion of the Sun, i.e., at point C. It is easy to see now that between the positions at A and C the epicycle bearing a planet completed a full rotation, and only one (every additional rotation would

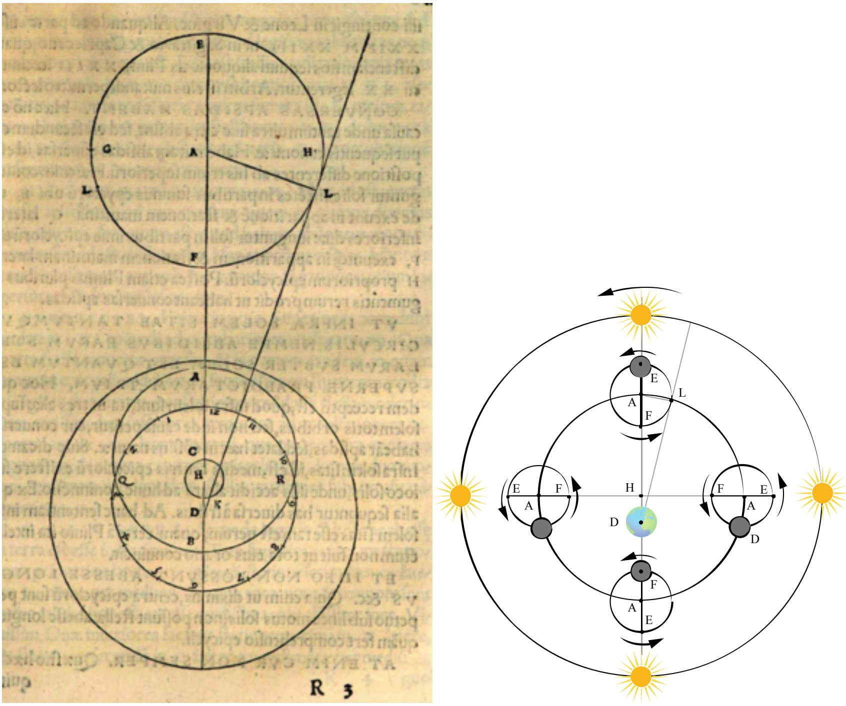


Figure 4: Ziegler's scheme for the maximal elongation of an inferior planet (left) and our reworking (right).

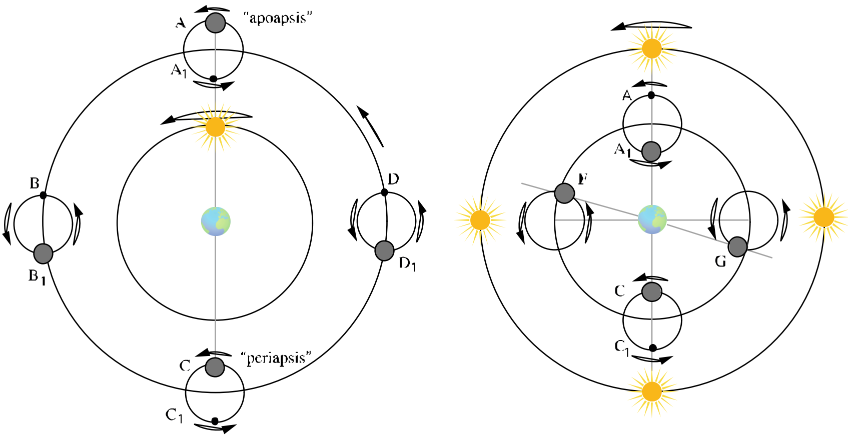
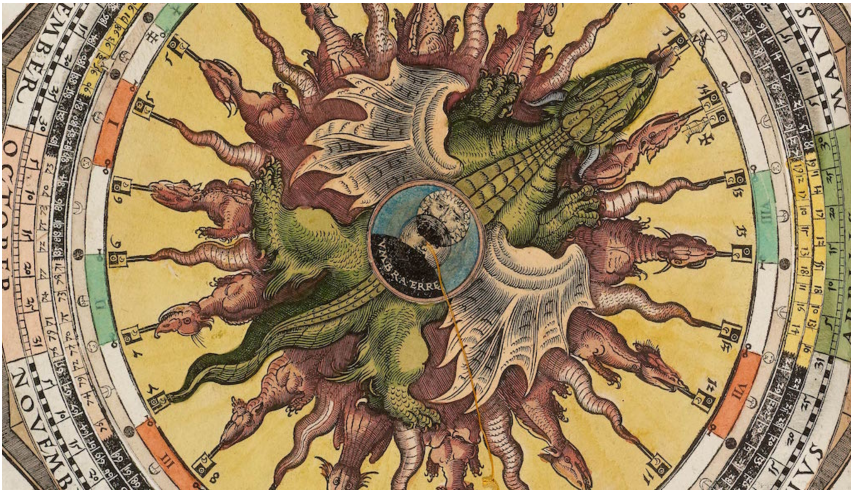


Figure 5: Epicyclical rendering of the line of the apses AC for inferior planets (left) and superior planets (right) in the Ptolemaic system.

produce an additional retrograde motion which is not observed). Since the motion of an epicycle is supposed to be uniform, at quadratures a planet should be placed at points B_1 and C_1 where the epicycle completes exactly the half of a rotational circle.

For an inferior planet the situation is more complicated. According to Ptolemy, the line connecting the equant point with the center of the epicycle of an inner planet should be approximately parallel to the line connecting Earth with the mean sun. As we have already mentioned, retrograde motion can only be observed at inferior conjunctions (*fig. 1*). In other words, whenever an inferior planet approaches this kind of conjunction, the retrograde motion should be observable. Within the framework of Ptolemaic modeling the planet should be placed at an inner part of the epicycle. This situation is displayed in *fig. 5*, left, where the positions of a planet in inferior conjunctions are marked with A_1 and C. The possible maxima of western and eastern elongations of a planet in this scheme correspond to the points F and G, respectively.



Peter Apian (Apianus), Astronomicum Caesareum, *Ingolstadii 1540.*
Titlepage, particular.