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## The Copernican System: A Detailed Synopsis

John Cramer Dr.  
jcramer@oglethorpe.edu

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## The Copernican System: A Detailed Synopsis

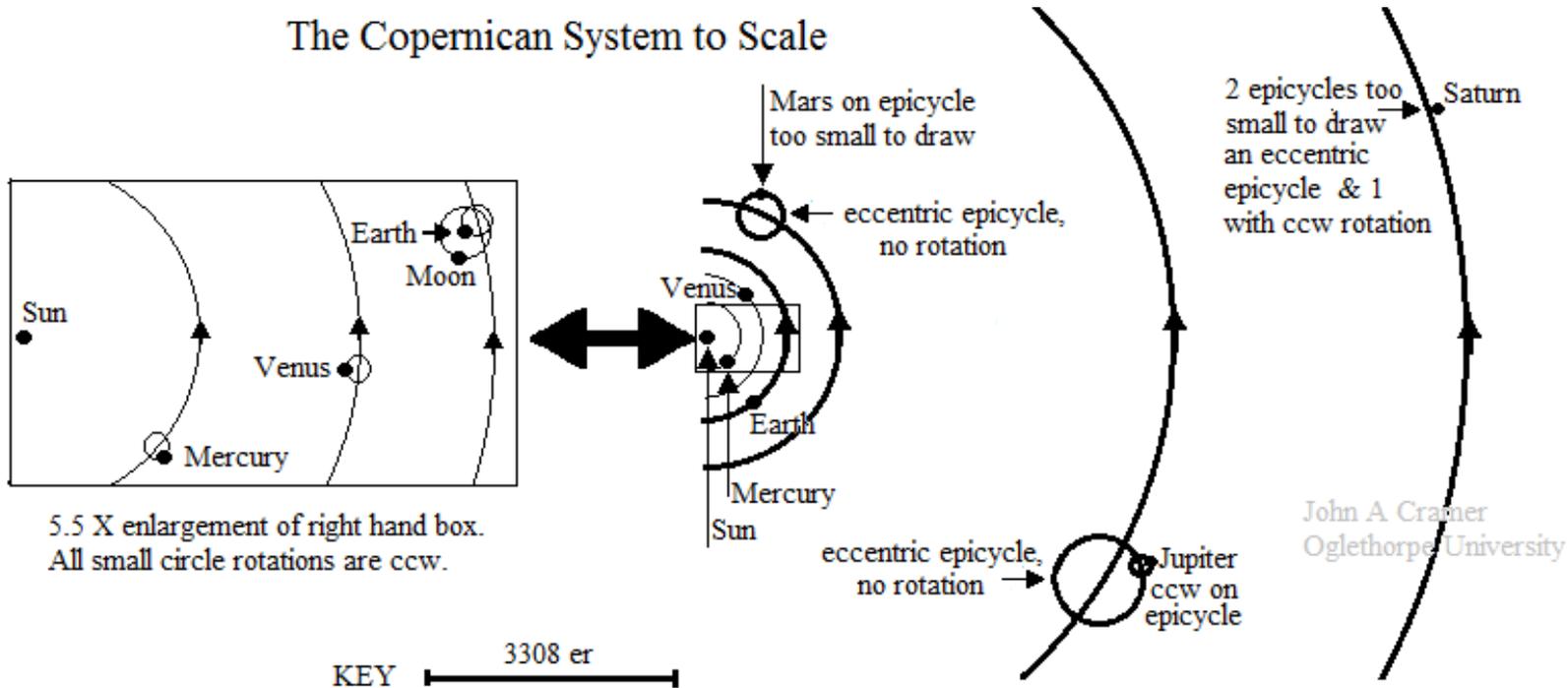
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Dissatisfied with the problems of the geocentric system inherited from Claudius Ptolemy, Nicholas Copernicus began the change from geocentrism to heliocentrism. His eponymous system was expounded first in the Commentariolus (written about 1508 and circulated privately in manuscript form) and then more fully and finally in his book, De Revolutionibus Orbium Coelestium (On the Revolutions of the Celestial Orbs) published as he lay dying in 1543.

Recognizing three motions of the Earth where Ptolemy, following Aristotle, could admit none, he claimed to then be able to greatly simplify the heavenly motions. The motion of the stars, he said, is only apparent and is occasioned by the daily rotation of Earth on its north/south axis. The Earth also revolves about the Sun annually causing the 7 wanderers (“planets”) to seem to move around the Zodiac. More subtly, he reinterpreted the “precession of the equinoxes,” discovered by Hipparchus about 150 B.C. and thought by Ptolemy to rotate the plane of the “motion” of the Sun about  $1^0$  per century. Copernicus recognized this appearance as the consequence of a precession (a rotating tipping) of the axis of rotation of the Earth revolving about once every 26,000 years.

In the figure below, note immediately that the Copernican system is a *good bit smaller* than the Ptolemaic System by about a factor of 26% as measured by Saturn’s orbit. Since the stars do not rotate in the new system, there is no need to place them on a fixed sphere and Copernicus has

### The Copernican System to Scale



absolutely nothing to say as to the distance to the stars. His system contains no sphere of the stars. The implicit, possibly unintentional, message was *that the distances to stars is not a*

*constant* and cannot, in general, be computed, thus opening the way to a much larger universe with a smaller solar system!

The Copernican system is also more open. Unlike the Ptolemaic System which was quite deliberately stuffed full of circles, here there is considerable empty space between planets. The second implicit message of the new system is *that nature may not, after all, “abhor a vacuum.”* The system thereby quietly laid siege to Aristotelian science!

A primary motivation for Copernicus was the elimination of equants which he called “unesthetical.” He meant they violated the “rule” of what he called “regular” motion by which he meant constant angular speed. Heliocentrism was his desperation move where equants had been Ptolemy’s. Both were forced by the fact that the planets, as Johannes Kepler eventually showed, simply do not have “regular” motion but travel on ellipses at varying speeds.

Basic numbers for the Copernican System are listed in the following table. An er is an Earth radius and a yr is an Earth year (which equals a solar year). Like Ptolemy, Copernicus used an “Egyptian year,” of just 365 days, in his calculations. His distance from the Earth to the Sun, like Ptolemy’s, is badly in error, about 21 X too small and he uses the same radius of the Earth as did Ptolemy, incurring a further error of as much as 18% in all distances. Nevertheless, his periods for the deferents in column five compare quite favorably with a modern list of planetary periods.

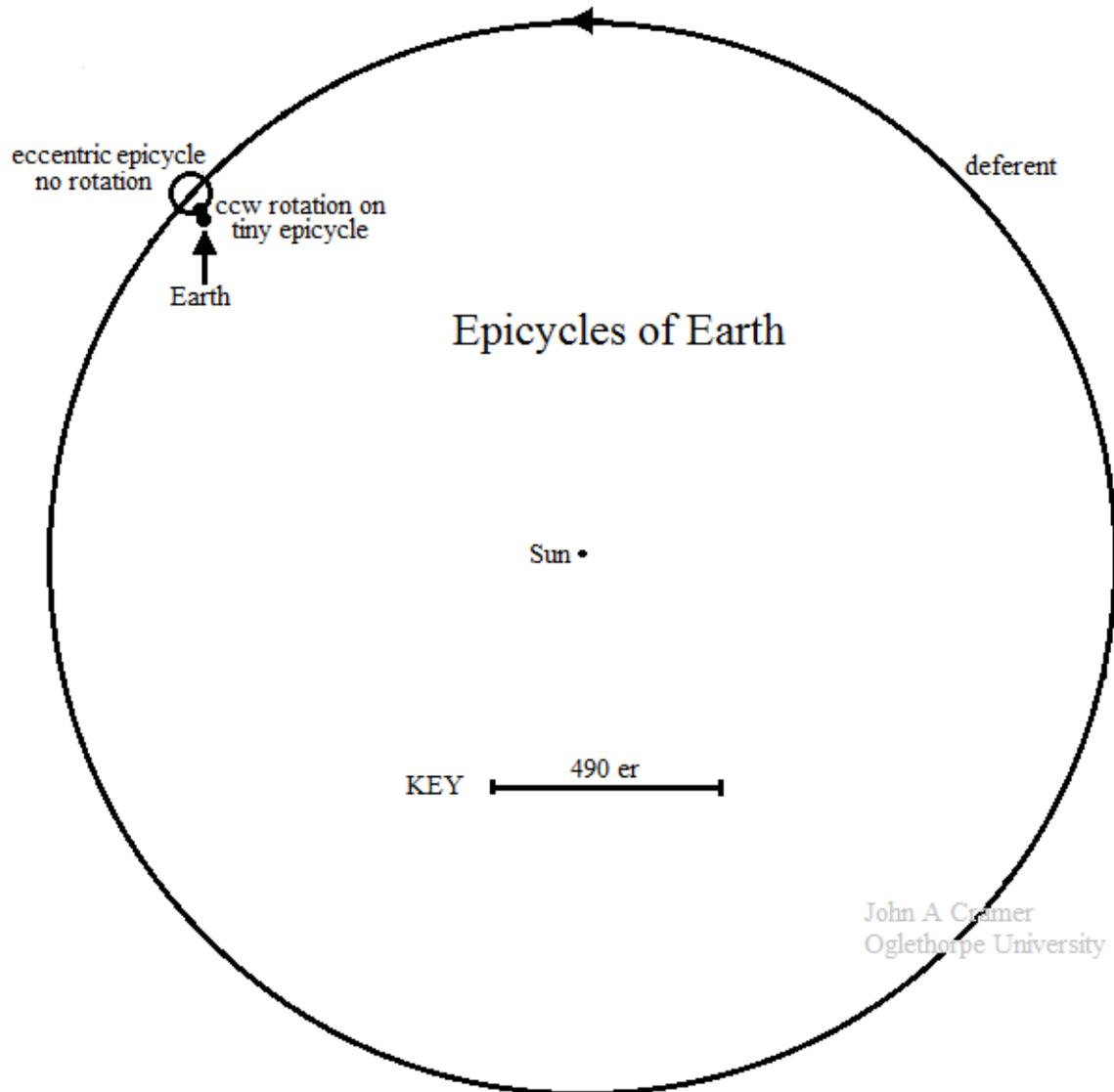
Planet Name	deferent radius (er)	1st epicycle radius (er)	2nd epicycle radius (er)	deferent period (yr)	1st epicycle period (yr)	2nd epicycle period (yr)
Moon	60.32	6.617	1.4295	0.081	0.073	0.04
Mercury	429.6	24.153	21.7	0.241	0.5	0.5
Venus	28.09	11.8768	821.44	0.625	0.5	0.625
Earth	1142	42.1398	5.4816	1	0	1
Mars	1888	275.62	94.39	1.882	0	2.137
Jupiter	6255	574	143.25	11.87	0	1.099
Saturn	10478	89.48	29.862	29.48	0	0.954

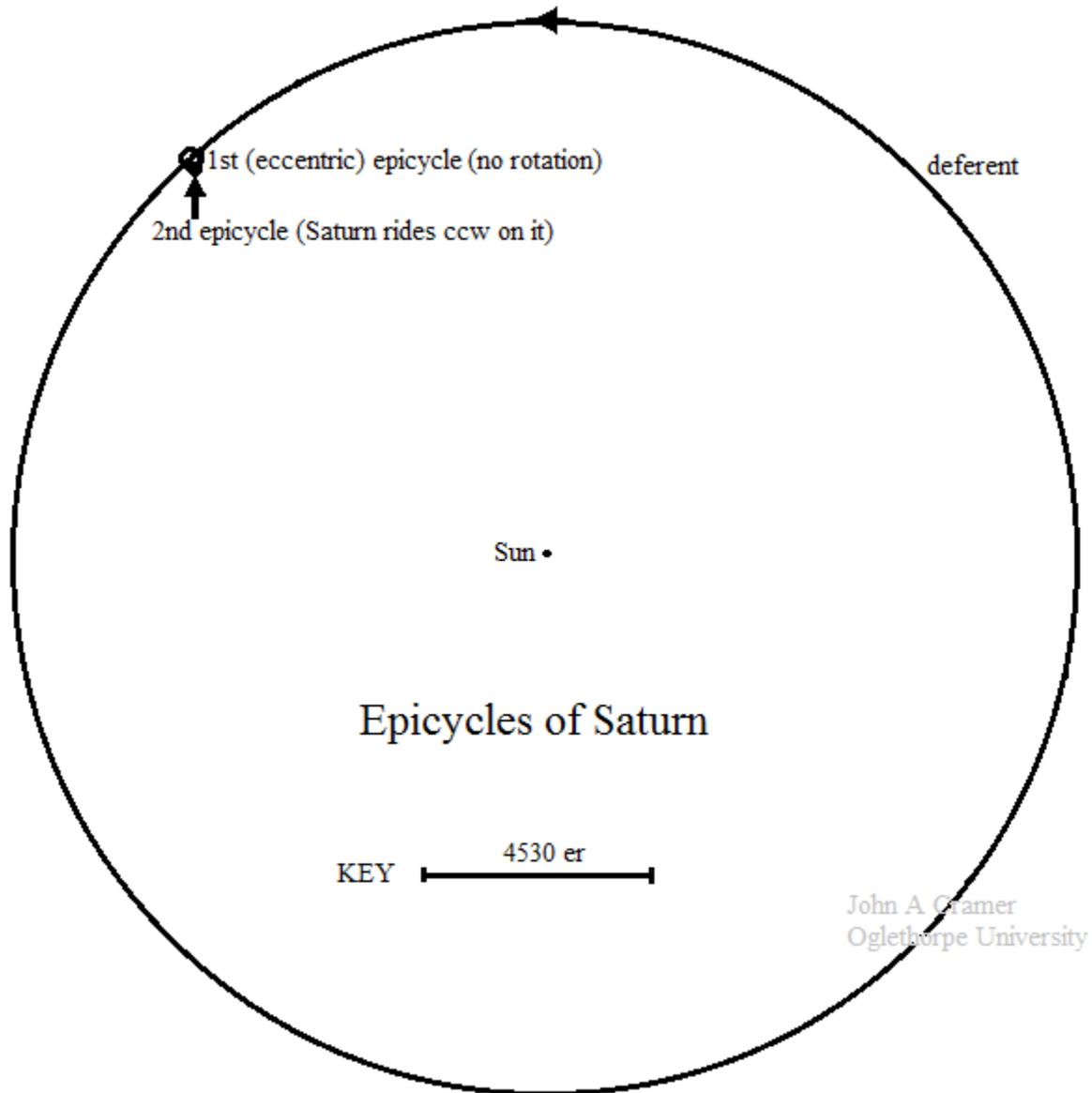
With the motion of the Earth eliminated from other motions, the large epicycles needed by Ptolemy are greatly reduced in size relative to the deferent. That explains why the figure above contains so few epicycles; the others are too small to show up! Although Copernicus never cited this as a point in favor of his system, he should have. The small epicycles are a consequence of describing the planetary motions more accurately. Of course, had he used ellipses rather than circles the fit to orbit shape (but not timing) would have been even better.

A further oddity worth noting is that Mercury, a problem for Ptolemy, remained problematic. Copernicus retained Ptolemy’s bizarre eccentric rotating on a small circle and added the additional peculiarity of Mercury vibrating on a diameter of an epicycle! Both moves were forced by the unusually great eccentricity of Mercury’s (actually elliptical) orbit as well as by bad data occasioned by the difficulties in observing an object permanently near the Sun.

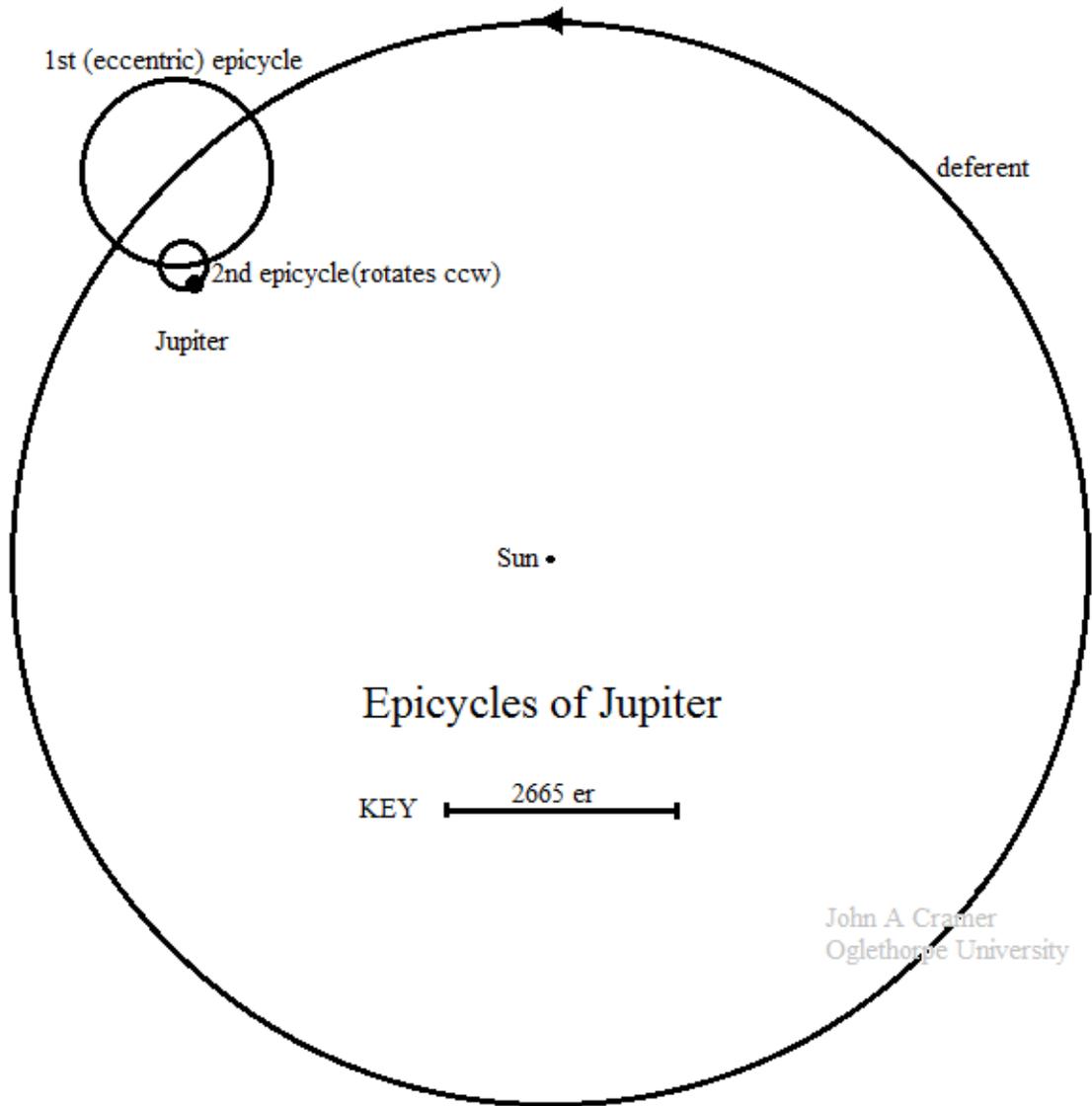
Starting with the simplest models the Earth, Saturn, Jupiter and Mars all require only an epicycle on an eccentric. I draw each one as an epicycle on an epicycle rather than an epicycle on an eccentric. Both Ptolemy and Copernicus recognized the interchangeability of the two models. Copernicus explicitly points out that this fact implies that we cannot decide which

model actually describes celestial motions, undermining any attempt to think of the “spheres” as real, solid objects moving the planets. However, Copernicus dispensed with equants and his epicycles are noticeably smaller relative to the deferent. Saturn’s epicycles are almost miniscule as the second figure below demonstrates. I present these four models with little further comment.

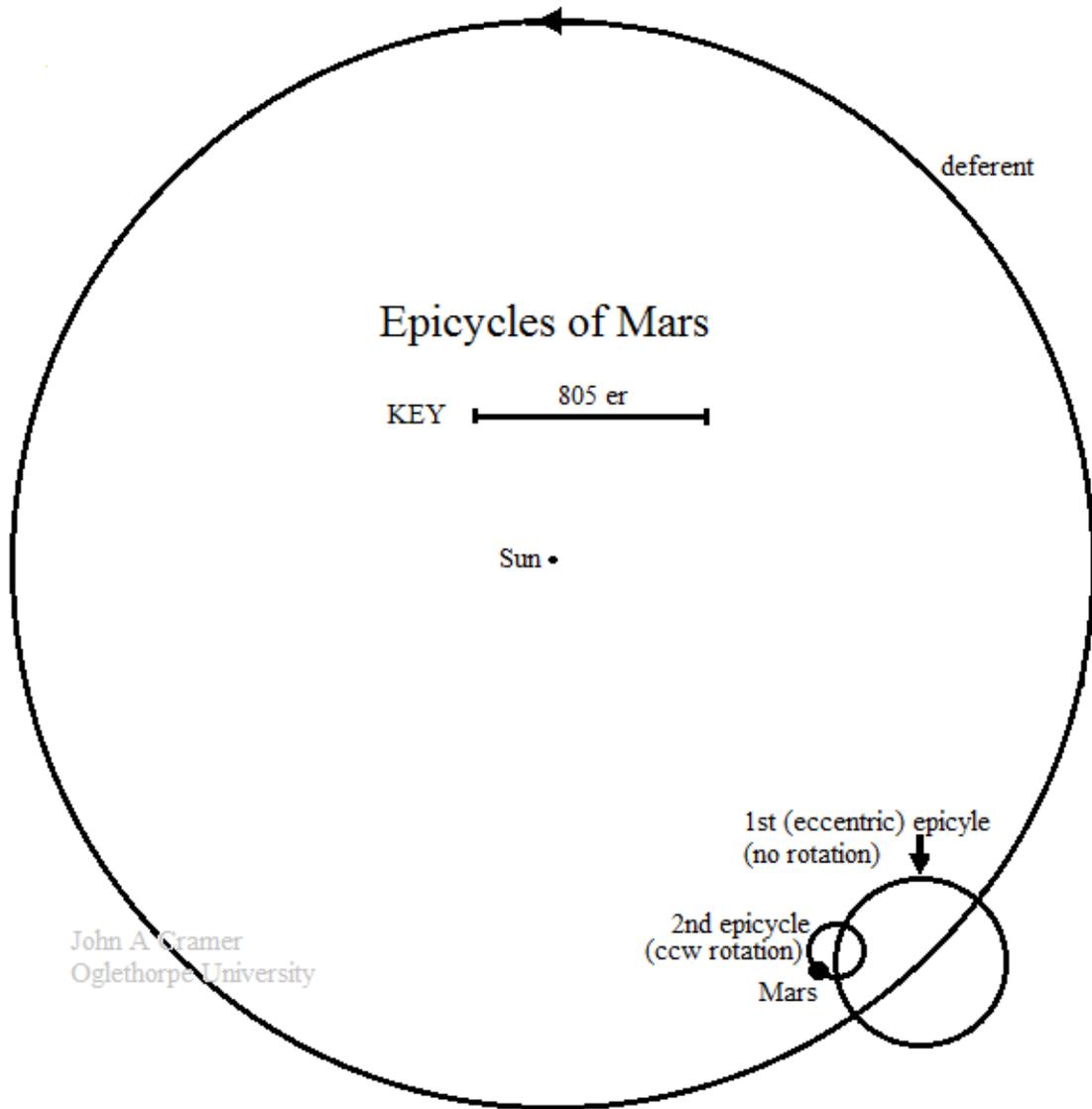




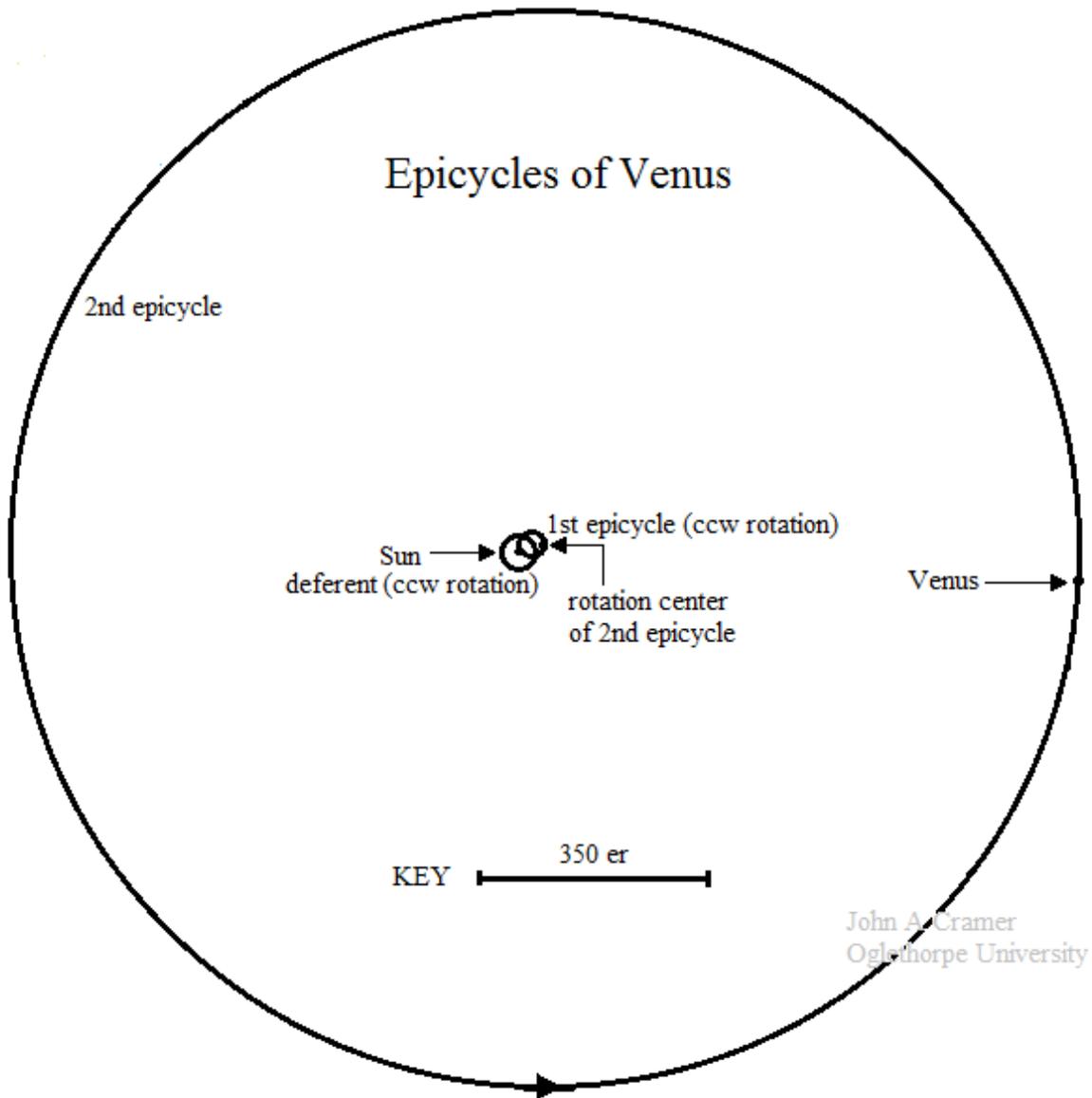
Just as in the Ptolemaic System, the epicycles of Jupiter in the Copernican System appear to be a good bit bigger than those of Saturn but, again, the effect, though present, is exaggerated by the smaller size of the deferent for Jupiter.



John A Cramer  
Oglethorpe University



The next simplest model is for Venus with an epicycle on an epicycle. Copernicus was following Ptolemy closely which may explain why the second epicycle is huge because it was also very large in the Ptolemaic system. It is nevertheless surprising that Copernicus seems not to have realized that he would have had the exactly same result had he arranged the circles in order of decreasing size with a huge deferent and two tiny epicycles. I have taken that route in the figure of the whole system in order to show the Copernican System in the most uniform possible way but, for the large scale diagram of Venus I think it best to show it as did Copernicus himself, bizarre as it seems.

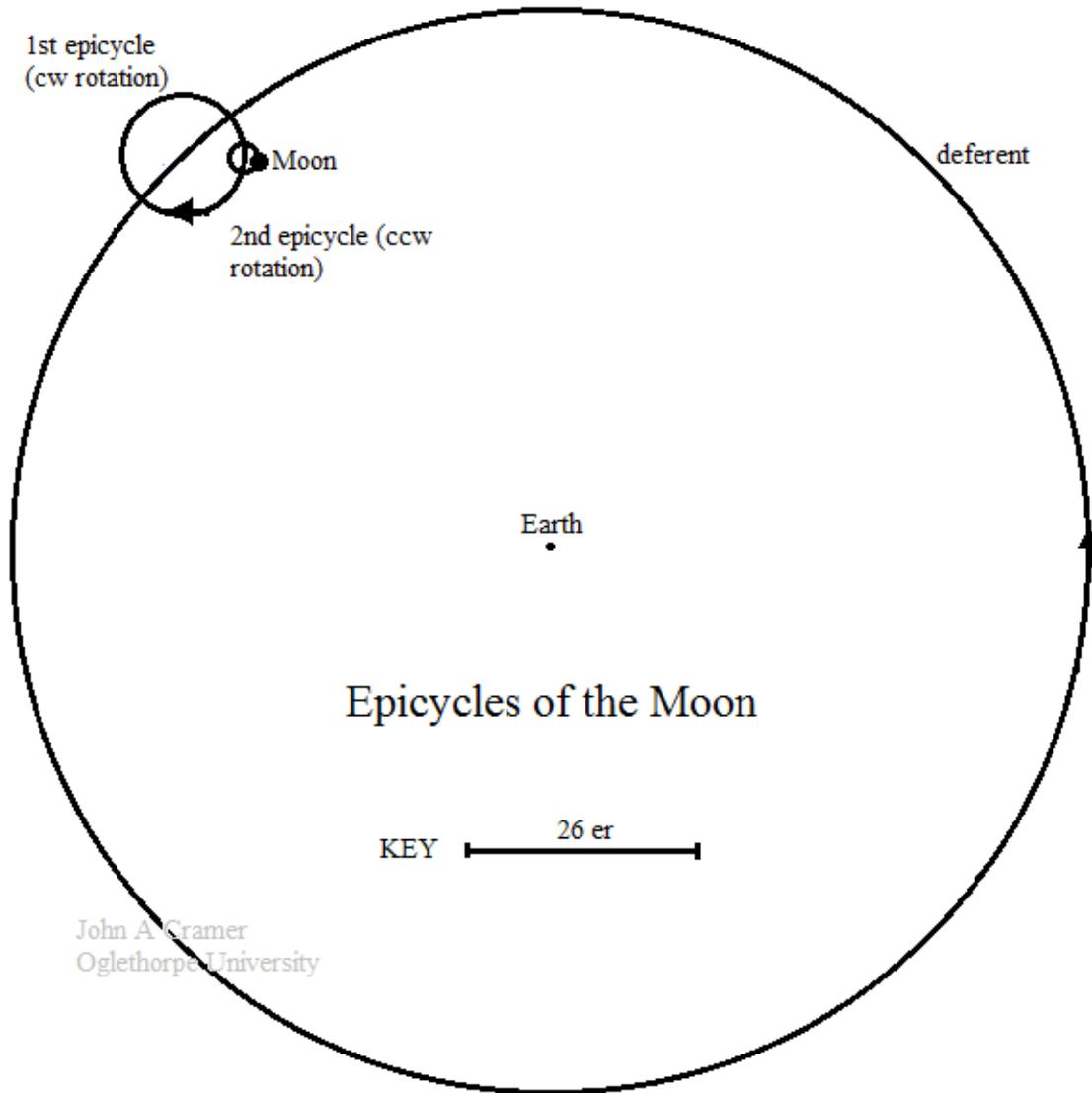


Mercury and the Moon yet remain. As their strange figures in both systems show, these last two “planets” were easily the most troubling. The standard model works for neither “planet” in either system and both Ptolemy and Copernicus had to stretch their ingenuity and inventiveness a great deal in what became never quite successful attempts to replicate the motions.

Since the Moon actually does simply orbit the Earth, Copernicus had no special advantage over Ptolemy. It is a testimony to his analytical abilities that his value for the mean distance of the Moon is far better than that of Ptolemy.

Also, Copernicus *almost* made the simple epicycle model work. The only deviation from the basic scheme he required meant that his model cannot be reduced to an epicycle on an eccentric.

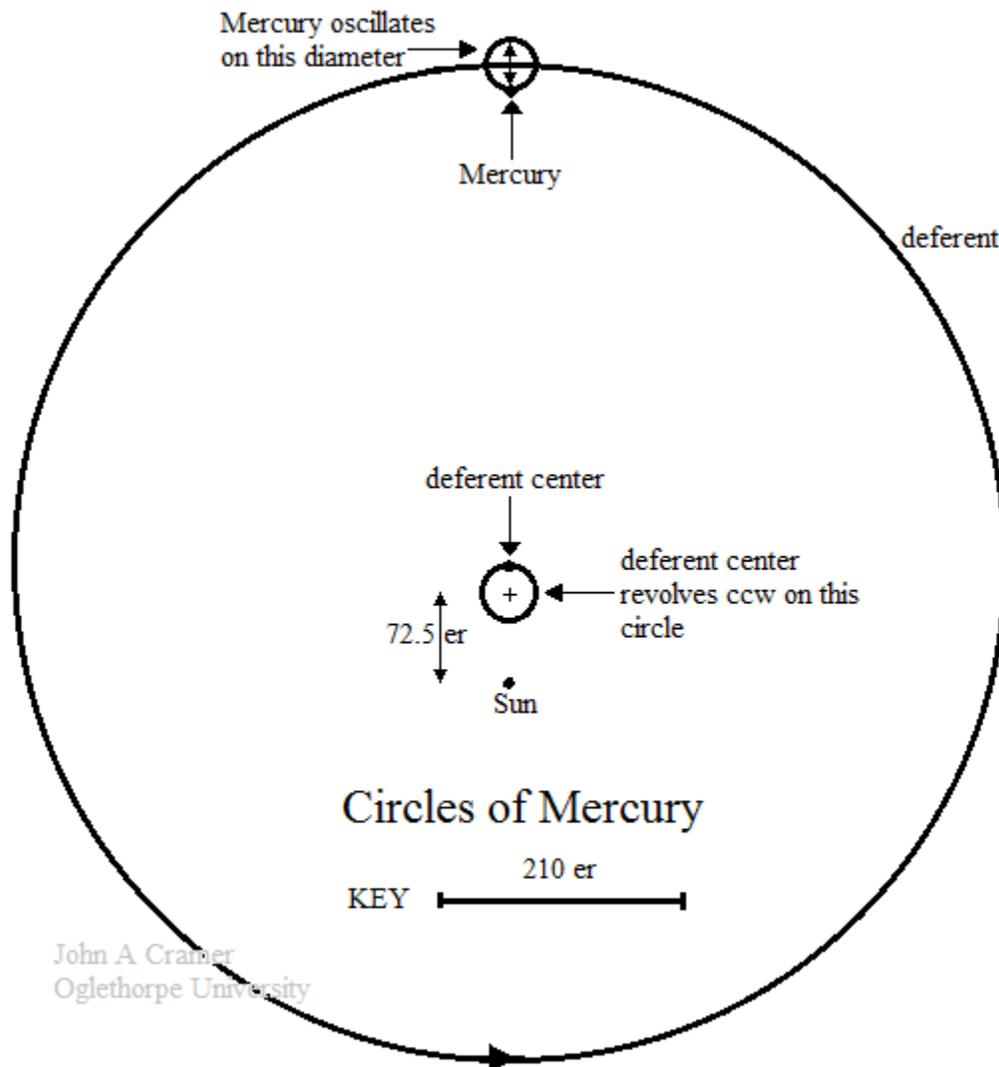
That is because he was forced to make the first epicycle rotate clockwise at a slightly faster pace than the motion on the deferent. In the eccentric, the first epicycle does not rotate with respect to the stars (although it seems Copernicus saw it as rotating counter to the deferent at exactly the same period).



Note that the Copernican system has much improved the Ptolemaic problem of the size changes of the circling Moon. Here the Moon changes size by no more than about a factor of 1.3 where the change was about a factor of 2 in the Ptolemaic System. This is far more realistic a result and another point in favor of the Copernican System.

As in the Ptolemaic System so too in the Copernican System and for all of the same reasons, Mercury's is far and away the most peculiar of all the models. Copernicus felt it necessary to retain the Ptolemaic feature of a deferent center revolving on a small circle eccentric to the Sun (rather than the Earth). Most peculiar of all, he also felt he needed to introduce what we today call Simple Harmonic Motion (SHM). His defense of this choice is that it is the combination of two circular motions of identical periods and radii but of opposite sense. That is, the SHM actually involves simultaneous motions of the planet on two epicycles that are identical except the motion on one is ccw but cw on the other. Thus, Copernicus thought he was still "playing the game" fairly, using only "regular" motion on circles to describe the planetary motions in contrast to Ptolemy's "cheating" in using equants.

An addition number required for Mercury is that the Sun is offset from the center of the circle on which the center of the deferent rotates by 72.46 er.



John A Cramer  
Oglethorpe University

Copernicus was, of course, well aware that the planets move on different planes but, like Ptolemy, he handled that without adding circles to the system. Thus, the count of circles in the Copernican system is three for each of six objects plus five for Mercury with three for the eccentric deferent and two for the SHM. The total then stands at 23. However, that does not include the precession of the equinoxes, a motion exclusive to the Earth in the Copernican System. The final total then stands at 24. Since the Ptolemaic System weighed in at perhaps 27 and possibly 31 (if we agree with Copernicus that the equants count as circles) we see that even on this basis, Copernicus was justified in claiming a simpler system than that of Ptolemy.