c. A messy, unsuccessful account, largely developed around 1514 and then never improved

d. Kepler especially critical of this aspect of Copernicus

3. Does succeed in eliminating the implication that the moon comes much closer to the Earth than it obviously does by devising an alternative way to deal with the higher inequalities

   a. Basic model of moon like Ptolemy's -- minor epicycle

   b. But now adds, following Ibn al-Shāţir, an epicycle on top of this minor epicycle to account for anomalies Ptolemy discovered in the quadrants and octants

4. Copernicus apparently attempted to get better observations of Mercury, but failed, and hence ended up transporting Ptolemy's account of Mercury into his system with appropriate transformations

   a. Uses a minor epicycle to replace equant, but then adds epicycle on epicycle and has radius vectors vary in length to accomplish the same thing that Ptolemy's inner circle did

   b. Thus the worst "Rube Goldberg" aspects of Ptolemaic planetary theory – latitudes and the theory of Mercury -- carried over into Copernican, though in the form of Ibn al-Shāţir

5. One really must feel some sympathy for Copernicus, spending 30 years trying to achieve improved accuracy over Ptolemy, but having to introduce more and more complexity simply to match Ptolemy in accuracy

   a. Of course, what was really needed was a total reform of astronomy from the ground up

   b. With entirely new, highly reliable observations as a key element of that total reform

   c. Something Tycho came to realize in his early 20's, after finding that the Alfonsinetables mis-predicted the conjunction of Jupiter and Saturn in 1563 by around a month and the Prutenic tables mis-predicted it by several days

F. Copernicus's Triangulated Distances of the Planets

1. Where Ptolemy had used observations within retrograde loops and hence near opposition to determine his ratios of epicycle to deferent radii, Copernicus used observations away from opposition

   a. The observations in question allowed him to use triangulation to determine the ratios, in the process yielding distances, at the time of observation, of planets from both the sun and Earth

   b. Illustrated (see Appendix) by the triangle ELF with his first example, for Saturn

2. In his figure E represents the mean sun, L the Earth, F the planet, EL the radius of the Earth's circular orbit about the mean sun, AD=BD=CD the radius of the circular deferent of the planet, and AF= e/2 = ED/3 the radius of its minor eipicycle

   a. Observation gives the location of F along the zodiac as seen from L, i.e. the geocentric longitude of F; Copernicus's theory, with ED already established, gives him the location of F along the zodiac as seen from E, that is the heliocentric longitude of F with respect to the mean sun

   b. The difference between these two gives angle EFL; his heliocentric longitude for F together with the heliocentric longitude of L from his theory for the Earth gives him angle LEF

   c. Therefore observation plus his theoretical heliocentric longitudes determines the triangle ELF

3. From that Copernicus obtains the ratio of the mean distances of the planet and the Earth from the mean sun: 1090/10000 in the case of Saturn, "very little different" from Ptolemy's 0.1083
    a. Taking the Earth-Sun radius to be 1.0, it also gives him the distances of Saturn from the mean sun and the Earth at the time of observation: 9.601 and 9.254; and given the eccentricity of the true sun from the mean sun in the Earth orbit, the distance of Saturn from it as well
    b. Ptolemaic astronomy could obtain such a relative distance from the Earth, but had no means of obtaining a relative distance from the mean (or true) sun
4. Still, the comparatively good agreement with Ptolemy for the radius ratio for Saturn should not be surprising, for it was essentially built into Copernicus's theories of heliocentric longitudes
    a. The triangulation presupposes those theories, making them theory-mediated in a manner that comparison with Ptolemy amounts to just a check on Copernicus's transform of Ptolemy
    b. For that reason, even repeated triangulations with different observations, yielding a trajectory of Saturn around the sun, cannot show that Saturn, contrary to Ptolemy, describes a nearly circular orbit about the mean sun
    c. What the comparison with Ptolemy showed, therefore, was that the added complications still left the overall system observationally consistent with Ptolemy's
5. As the Copernican account of the distance to Saturn (in Appendix) displays, the combined orbits of the Earth and outer planets involved complications absent from Ptolemy's account
    a. These made Copernicus's account difficult to understand, witness whereunto is the struggle Kepler had in the 1590s, turning to his teacher Maestlin for help
    b. Maestlin's account, published as an Appendix to Kepler's first book, was likely the best explanation for Copernicus's individual orbital theories from the time, even though strictly speaking it was an exposition of Rheinhold's calculations for the Prutenic Tables
6. But what if there were some independent way of verifying Copernicus's theories of heliocentric longitudes, or even better some account of those longitudes that does not presuppose those theories
    a. Then any nearly circular trajectory for Saturn determined by triangulations using sequences of observations would be evidence that Saturn describes a nearly circular orbit around the mean sun, and not at all so around the Earth
    b. And observations of sufficient precision might even provide evidence deciding between his minor epicycle and a Ptolemaic equant for that heliocentric orbit

G. Philosophic Issue: Grounds for Preferring It?

1. Given all these features and shortcomings, the obvious question is why anyone ought to have preferred the Copernican system before, say, 1600
    a. Several key astronomers did, often with intensity, and they managed to persuade some of their best students to become Copernicans
    b. E.g. Rheticus, Digges, Reinhold, and most notably Mästlin, Kepler's teacher