AST 120 Activity 14
The Tychonic System

Name	Full	Partial	None

In this activity we will look at a few final details from the Copernican theory. Then we will consider the system of the world introduced by Tycho Brahe in his 1588 *De mundi aetheri recentioribus phaenomenis* (On very recent phenomena in the aetherial realm), some 45 years after the publication of Copernicus' *De revolutionibus*.

1. Run the `CopernicanSystem` program. Select Mars from the Select Planet menu. To see the full set of motions for Mars as described in the *De revolutionibus*, uncheck the Use Simplified Orbits box. Note that here the center of Mars' deferent is eccentric to the Sun as well as to the center of Earth's orbit (Copernicus used eccentrics just as Ptolemy did). But the most interesting new feature is that Mars now has an epicycle! Play the simulation and note that one effect of the epicycle is that it shifts the orbit.[1] How does this affect the eccentricity of Mars' orbit (as compared to the center of Earth's orbit or to the Sun)?

   (a) The orbit is more eccentric than Mars' deferent.

   (b) The orbit is less eccentric than Mars' deferent.

   (c) The orbit has the same eccentricity as Mars' deferent (it is shifted, but not along the *line of nodes*).

2. Of course, this epicycle must do something more than just change the eccentricity. Otherwise Copernicus would have just moved the deferent circle. To see what the epicycle does, consider the motion of the planet on the epicycle, independent of the epicycle's motion along the deferent, and how it is related to the motion along the deferent. When Mars is on the inside of its deferent the direction of its motion on the epicycle is _____ the direction of the epicycle's motion along the deferent.

   (a) the same as

   (b) opposite to

   (c) perpendicular to

3. When Mars is on the outside of its deferent the direction of its motion on the epicycle is _____ the direction of the epicycle's motion along the deferent.

   (a) the same as

   (b) opposite to

   (c) perpendicular to

[1] Actually, the resulting orbit is note quite circular but is "bowed out" a bit at the top and bottom of the simulation.

4. Considering that the motion of each circle is uniform, we can conclude that Mars moves fastest on the _____ of its deferent and slowest on the _____ of its deferent.

5. Which device from Ptolemy's system do you think is most closely related to this epicycle in Copernicus' system? Explain your reasonong.

6. Watch the simulation again. How many times does the epicycle go around during the time it takes the deferent to make on complete revolution?

7. Recall that Copernicus thought of the planets as being carried by solid celestial spheres. Because of this the epicycle would make one full revolution as it went all the way around the deferent, even if it were not rotating itself (because it gets turned around by the turning of the celestial sphere). Given this point of view, how is the period of the epicycle's own revolution related to that of the deferent?

8. This gives you the basic structure that Copernicus used for the orbits of Mars, Jupiter, and Saturn. He found that it worked best to have the radius of the epicycle be exactly one third of the eccentricity of the deferent (although he then deviates from this slightly). His orbit for Venus is actually a bit more complicated because the center of Venus' deferent actually moves around on a small circle (so that in a sense the deferent becomes an epicycle and the regular epicycle becomes a second epicycle). The orbit for Mercury uses even more complicated devices (Mercury moves back and forth along a line as it orbits!). Considering all of this, would you say that Copernicus' system is much simpler than Ptolemy's?

9. Now let's make a more detailed comparison of the Ptolemaic and Copernican systems, as well as the newer system of Tycho Brahe. You are already familiar with the Ptolemaic and Copernican systems. The Tychonic system was basically a compromise between Copernican astronomy and Aristotelian physics.[2] In the Tychonic system the planets are arranged exactly as in the Copernican system, but the Earth remains at rest. The five planets orbit the Sun while the Moon and Sun orbit the Earth. Let's take a look at all three systems side by side. Download and run `PtolemyCopernicusTycho`. The simulation shows the Earth (blue), the Sun (orange), Venus (yellow), and Mars (red) from the perspectives of all three systems. It also shows the apparent motion of the planets and Sun against the background stars as in the other simulations. I've taken some liberties with the scaling of the Ptolemaic system. In particular, the deferent of Venus' orbit is scaled so that it exactly matches _____.

   (a) the Earth's orbit

   (b) the deferent of Mars

   (c) the Sun's orbit

[2]Tycho was also concerned that Copernicus' system seemed to contradict passages in the Bible, and his system was designed to remove these contradictions.

10. I have also scaled the Ptolemaic deferent for Mars to a specific size (more on that later). Note that this is permissible in Ptolemy's mathematical system. Ptolemy specifies the size of the epicycle *relative to* the size of the deferent, but doesn't say anything about the absolute sizes of any part of the orbit. So we can rescale things all we want, as long as we scale the deferent and epicycle by the same factor. With that said, what objections do you think Ptolemy might have had to presenting his system in this way?

11. When the Ptolemaic system is scaled this way, one interesting effect is that Venus orbits the Sun (which is something Ptolemy never proposed). Another interesting feature is that the epicycle of Mars is exactly the same size as _____.

    (a) the deferent of Mars

    (b) the epicycle of Venus

    (c) the Sun's orbit

12. I should now point out that I've also greatly simplified the presentation of these systems. I've left out the eccentrics and equants of Ptolemy's system (but kept the epicycles, without which the motion is not even qualitatively correct). I've also left out the eccentrics and epicycles from the Copernican and Tychonic systems. These devices do make a difference in the detailed predictions of the system, but to compare the basic structures of the three systems they can be safely ignored. Play the simulation and pay close attention to the relative locations of Earth, Sun, Venus, and Mars. In particular, look closely at the lines connecting Earth and Sun (orange), Earth and Venus (yellow), and Earth and Mars (red). What do you notice about the appearance of these lines in the three systems?

13. Note that the path of the planets through space in the Tychonic system is the same as their path in the Ptolemaic system. In fact, the construction for Venus' orbit is exactly the same in both systems (once we rescale the Ptolemaic orbit as described above). What, if anything, is different about the construction for Mars' orbit in these two system?

14. Watch the simulation of the Tychonic system. Does this system make sense if the planets are carried around in their orbits by solid celestial spheres (as both Copernicus and Ptolemy thought)? Why or why not?

15. It should be pretty obvious that the relative positions of the Earth, Sun, Venus, and Mars *must* always be the same in the Copernican and Tychonic systems. After all, Tycho's system *is* the Copernican system but with the Earth fixed in place. In fact, Tycho never bothered to work out the mathematical details of his system (he wasn't much of a mathematician anyway) because Copernicus had already done the work. There was no need to redo it because the predictions for the Tychonic system had to match those of the Copernican system, by definition. But what about the Ptolemaic system? We can rescale the sizes of the orbits, which will certainly affect the distance from Earth to the Sun, etc. But if we make sure to scale epicycles and deferents by the same factor will any of the angles changes? (Note that it is only the angle of the line that determines where the object appears to be relative to the stars.)

16. This rescaling of the Ptolemaic system and its comparison with the Tychonic system can help us see how certain features in Ptolemy are related to features of the Copernican system. The table below lists certain features of the Ptolemaic system. Write in the feature on the Copernican system to which each of these corresponds.

Ptolemaic Feature	Corresponding Copernican Feature
Deferent of a Superior Planet	
Epicycle of a Superior Planet	
Deferent of an Inferior Planet	
Epicycle of an Inferior Planet	
Orbit of the Sun	

17. Does the Tychonic system share the advantages of the Copernican system? Explain.

18. Does the Tychonic system share the disadvantages of the Copernican system? Explain.

19. Given that the simplified versions of the three systems produced exactly the same *relative* motions, and relative motion is all we can actually *observe*, which system do you think is best? Why?

20. Which system would a 16th century astronomer have thought was best. Why?