AST 120 Activity 12
Copernicus' Theory of the Planets

Name	Full	Partial	None

We have examined how Copernicus explained the motion of the stars and the Sun. Copernicus deals with the motion of the Moon by having it orbit the Earth (like Ptolemy), but in a plane that is tilted relative to Earth's orbit. Because the Moon's speed along its orbit varies in a complicated way, Copernicus was forced to give the Moon two epicycles (an epicycle riding on another epicycle riding on the deferent). We won't go into the details. Instead we will move on to look at how Copernicus dealt with the five planets.

Run the `CopernicanSystem` program. Make sure the Use Simplified Orbits box is checked. From the Select Planet menu choose User Defined. In the control window that pops up, set the Orbit Radius to 0.7 and the Orbit ω (which controls the speed of the orbit) to 2. **Make sure to hit Enter after you type in each value**. Then play the simulation and answer the following questions. If you'd like you can adjust the Time Step to make the simulation run slower or faster.

1. The Orbit Frame shows a view of the orbits of Earth and the planet from "above" Sun (ie from the North Ecliptic Pole). Earth's orbit is shown in blue, the planet's orbit should be in yellow. A "line of sight" arrow shows where the planet would appear against the stars as seen from Earth (recall that the celestial sphere must be VASTLY larger than Earth's orbit). A planet whose orbit is larger than Earth's is called a *superior* planet. A planet whose orbit is smaller than Earth's is called an *inferior* planet. Is this planet inferior or superior?

2. The Sky View Frame shows the apparent motion of Sun and planet as seen from Earth. Watch the Sky View Frame for a while. Does the planet exhibit retrograde motion? If so, does this happen when the planet is in opposition, in conjunction, or at some other time?

3. Try to watch the Sky View Frame and the Orbit Frame. See if you can understand the relationship between the two different views. Can this planet EVER be in opposition? Or does it have a limited range of elongations? Explain the reasons for your answer.

4. What is happening in the Orbit Frame when the planet exhibits retrograde motion in the Sky View Frame?

5. Does the planet appear brightest when it is in retrograde motion? Why is it brightest at this time?

6. Based on what you know of the five visible planets, which of these planets must be inferior planets in the Copernican system?

7. Note that the planet is moving through its orbit faster than Earth (so it has a shorter period). Could we make this planet move through its orbit slower than Earth and still reproduce the same effects? Let's try. Pause the simulation, change the `Orbit` ω to 0.5, hit Enter, and then play the simulation. Watch for a while. What, if anything, is different about the apparent motion of this planet (as seen in the Sky View Frame) this time? Explain how we know that Mercury and Venus must have orbital periods that are shorter than Earth's in the Copernican System.

8. Now let's see what happens if we make the planet's orbit larger than Earth's. Pause the simulation, change the `Orbit Radius` to 1.5 (leave the `Orbit` ω at 0.5), hit Enter, and play the simulation again. Watch the simulation for a while. Is this planet inferior or superior?

9. Does this planet exhibit retrograde motion? If so does this occur when the planet is in conjunction, in opposition, or at some other time?

10. Can this planet EVER be in opposition, or does it have a limited range of elongations? Explain the reasons for your answer.

11. What is happening in the Orbit Frame when the planet exhibits retrograde motion in the Sky View Frame?

12. Does the planet appear brightest when it is in retrograde motion? Why?

13. Which of the five visible planets are superior planets?

14. Note that the planet is moving through its orbit slower than Earth. Could we make this planet move through its orbit faster than Earth and still reproduce the same effects? Let's try. Pause the simulation, change the `Orbit` ω to 1.5, and run the simulation. What is different this time? Is it possible that any of the planets you named as superior planets could have orbital periods SHORTER than Earth's?

15. Recall that Ptolemy's system was able to produce an orbit that made the following three things happen at the same time: retrograde, brightness, and conjunction/opposition. The brightness and retrograde motion *automatically* happened at the same time, but Ptolemy had to coordinate the orbits of the planets with that of the Sun to make these occur at conjunction/opposition. The point is that Ptolemy's system could easily be modified so that brightness/retrograde occurs at a time when the planet is *not* in conjunction or opposition. What about in Copernicus' system? Could the Copernican system be modified to separate brightness/retrograde from conjunction/opposition? Or *must* these three things occur at the same time in the Copernican system? Explain your answer.

16. Now let's try to figure out the period of the planetary orbits in the Copernican system. We'll start with Venus, so select Venus from the Select Planet menu.[1] Recall that with Ptolemy's system, with Earth at the center, we could measure the period of Venus' orbit directly. It was just the time it takes for Venus to go all the way around the celestial sphere (the zodiacal period). In Copernicus' system it is more complicated. This is because in the Copernican system we are watching Venus *from a moving platform*. Watch the simulation. Pay attention to how long it takes Venus to go all the way around the celestial sphere (as shown in the bottom window) and how long it takes Venus to go all the way around its orbit. Which period is longer?

    (a) Venus' zodiacal period is the same as its orbital period.

    (b) Venus' zodiacal period is longer than its orbital period.

    (c) Venus' orbital period is longer than its zodiacal period.

17. Play the simulation until Venus is exactly between the Earth and the Sun, then Pause the simulation. Sketch the arrangement of the Sun, Venus, and Earth in the space below. Label each object.

18. Now play the simulation again until Venus once again lies directly between the Earth and the Sun, then Pause the simulation. While the simulation is playing make sure to have one member of your group count how many full revolutions Venus goes through, and another member count how many full revolutions Earth goes through.

    Full Revolutions for Earth = ______________ Full Revolutions for Venus = ______________

19. Sketch the arrangement of the Sun, Venus, and Earth in the space below. Label each object.

[1] Copernicus' orbit for Venus is actually more complicated, with an eccentric circle whose center moves around on another small eccentric circle, but we will only consider a simplified version here.

20. You just watched the motion of Venus over the course of one synodic period (the time between retrograde arcs). The synodic period of Venus is measured to be 584 days. Recall that Earth completes a full revolution on its orbit in 365 days. How many revolutions has Earth completed in this time (note that your answer will not be a whole number).

21. How many revolutions has Venus completed in this time? Remember to account for any *extra* revolutions (i.e. additional full revolutions beyond those that Earth completed) that Venus completed during this time.

22. Now divide the time interval (the synodic period of 584 days) by the number of revolutions Venus completed in that time to find the time it takes for Venus to complete a single revolution. This is the period of Venus' orbit.

    $$T_{♀} = \underline{\hspace{6cm}}$$

23. You can calculate the period of an inferior planet's orbit (T_{ip}) from the planet's synodic period (T_s) using the following formula:

    $$T_{ip} = \frac{T_E T_s}{T_E + T_s},$$

    where $T_E = 365$ days is the period of Earth's orbit. Use this formula to calculate the period of Venus' orbit and show that you get the same result you found above.

24. That's enough for Venus. Copernicus' orbit for Mercury is actually much more complicated because he did not have good observational data for Mercury (it is hard to see because it is always so close to the Sun). He tried to fit his model to the bad data and the result was a bit of a mess. We'll skip over the details, but we can use the same formula as above to find the period of Mercury's orbit. Mercury's synodic period is 116 days. Use the formula above to find the period of Mercury and record your answer below.

    $$T_{☿} = \underline{\hspace{6cm}}$$

25. Now let's move on to the superior planets, which will be represented by Mars. Select Mars from the Select Planet menu.[2] Play the simulation until Earth is exactly between the Mars and the Sun (i.e. Mars is in opposition), then Pause the simulation. Sketch the arrangement of the Sun, Mars, and Earth in the space below. Label each object.

26. Now play the simulation again until Mars is once again in opposition, then Pause the simulation. While the simulation is playing make sure to have one member of your group count how many full revolutions Mars goes through, and another member count how many full revolutions Earth goes through.

    Full Revolutions for Earth = ______________ Full Revolutions for Mars = ______________

27. Sketch the arrangement of the Sun, Mars, and Earth in the space below. Label each object.

28. The synodic period of Mars is measured to be 780 days. How many revolutions has Earth completed in this time.

29. How many revolutions has Mars completed in this time? Make sure to account for any difference between the number of full revolutions completed by Earth and Mars.

30. Now divide the time interval (the synodic period of 780 days) by the number of revolutions Mars completed in that time to find the time it takes for Mars to complete a single revolution. This is the period of Mars' orbit.

    $T_{\mars} =$ ____

[2]In the full version has a small epicycle that spins in the same direction as the deferent. Also, as with all the planets, the plane of Mars' orbit is tilted relative to the plane of Earth's orbit to produce variations in ecliptic latitude.

31. You can calculate the period of a superior planet's orbit (T_{sp}) from the synodic period (T_s) using the following formula:

$$T_{sp} = \frac{T_E T_s}{T_s - T_E}.$$

Use this formula to calculate the period of Mars' orbit and show that you get the same result you found above.

32. Now use the same formula to find the period of Jupiter's orbit. Jupiter has a synodic period of 399 days. Record Jupiter's period below.

$$T_{♃} = \underline{\hspace{8cm}}$$

33. Now determine the period of Saturn's orbit. Saturn has a synodic period of 378 days. Record your answer below.

$$T_{♄} = \underline{\hspace{8cm}}$$

34. In the table below order the planets by increasing period (shortest period at the top of the table, longest period at the bottom). Write in the name of each planet and its period *in years*. Note that there are *six* spaces. Remember that in Copernicus' system the Earth is "just another planet."

Planet	**Orbital Period** (in years)