AST 120 Activity 11
The Motion of the Earth

Name	Full	Partial	None

Copernicus imparted four motions to the Earth in his new system. The fourth of these motions (to account for a changing rate of the precession of equinoxes) turns out to be fictitious (it was based on bad data). This activity will focus on the first two motions: the rotation of the Earth on its axis, and the revolution of the Earth around the Sun. The activity also includes some discussion of the motivations for the third movement.

1. Run the program `DailyRotation`. This program shows a schematic simulation of how the motion of the stars is reproduced in Ptolemaic and Copernican systems. The Earth is represented by the blue circle at the center (in Copernicus' system the Earth is not *at* the center, but it is still *near* the center of the Celestial Sphere). The green line shows the horizon of an observer on the Equator of Earth. The magenta dot represents a particular star fixed to the Celestial Sphere (the sphere itself is shown as a circle of small stars). All of this is pictured from above the North Pole of Earth. Also shown is a view from the perspective of an observer on Earth. Let's first investigate the Ptolemaic version. Click the Rotating Stars radio button and then play the simulation. Does the Celestial Sphere rotate in this simulation? If so, does it rotate clockwise or counterclockwise?

2. Does the Earth rotate in this simulation? If so, does it rotate clockwise or counterclockwise?

3. From the perspective of the observer at the Equator, in what direction will the star move across the sky during the night? Make sure you see how the two parts of the simulation correlate with each other.

4. If we viewed this simulation from below the South Pole of Earth, in what direction (CW or CCW) would the Celestial Sphere appear to be spinning?

5. Now let's look at the Copernican version. Click the Rotating Earth radio button and play the simulation. Does the Celestial Sphere rotate in this simulation? If so, does it rotate clockwise or counterclockwise?

6. Does the Earth rotate in this simulation? If so, does it rotate clockwise or counterclockwise?

7. From the perspective of the observer at the Equator, in what direction will the star move across the sky during the night? Make sure you see how the two parts of the simulation correlate with each other.

8. In what direction is a point on Earth's surface moving as the Earth spins?

   (a) North

   (b) South

   (c) East

   (d) West

9. If we viewed this simulation from below the South Pole of Earth, in what direction (CW or CCW) would the Earth appear to be spinning?

10. What we have seen is that the rotation of the Earth can reproduce all of the visual effects in the night sky that we have previously attributed to the rotation of the Celestial Sphere. What, then, is the period of Earth's rotation? Be as precise as possible. Does the Earth rotate around the same axis about which we thought the Celestial Sphere rotated? Does it rotate in the same direction or the opposite direction, as compared to how we thought the Celestial Sphere rotated?

11. That's it for the daily motion, now we need to consider the annual motion. Run the `EarthOrbit` program. This simulation shows a 3D view of the Earth orbiting the Sun (as it does in Copernicus' system). The Sun is represented by a yellow ball at the center[1] of the Celestial Sphere (shown as a blue wire mesh with white stars). Earth is a blue ball and the axis of Earth's rotation is shown by a green line running through the Earth. Six stars (Regulus, Procyon, Pollux, Betelgeuse, Aldebaran, and Antares) are highlighted in color. Also shown is the view from the perspective of an observer on Earth. If you look at the simulation from directly above the sun, is the Earth orbiting clockwise or counterclockwise?

[1] Actually Copernicus placed the Sun a bit off the center of the Celestial Sphere, as we will see later.

12. The yellow line running from Earth, through the Sun, to the CS traces out the path of the Sun against the stars. From above the Sun the path of the Sun seems to go ______________ around the CS.
    (a) clockwise
    (b) counterclockwise

13. What direction does the Sun *appear* to move relative to the stars? Make sure you see how the two parts of the simulation correlate with each other.

14. The apparent path of the sun on the Celestial Sphere is the _______.
    (a) celestial equator
    (b) ecliptic
    (c) meridian
    (d) horizon

15. Keep running the simulation and pay close attention to the orientation of the Earth's axis. Does the orientation of the axis change *relative to the Sun*? You may need to click and drag to get a better view.

16. Does the orientation of the Earth's axis change *relative to the stars*? Keep in mind that although the Celestial Sphere shown in the simulation isn't much farther away from Earth than the Sun, in Copernicus' system the CS was MUCH farther away (so far away that the entire orbit of Earth would look like a point in comparison to the CS).

17. Note that the axis of rotation for the Earth is not perpendicular to the plane of Earth's orbit around the sun. Instead it is tilted at a certain angle. Using what you know about astronomy, what is the value of this angle?

18. Pause the simulation. Under Select Day, choose Summer Solstice. Is the north pole of Earth (indicated by a red dot on the green axis) tilted toward the sun, away from the sun, or neither on this day? For an observer in the northern hemisphere, will the sun be relatively high in the sky at noon, relatively low in the sky, or neither? In other words, will the northern hemisphere experience greater than average, less than average, or average sunlight on this day?

19. Now choose Winter Solstice and answer the same questions as before.

20. Do the same thing for the Vernal Equinox.

21. Does Copernicus' theory explain the seasonal variations in sunlight? How so?

22. We have already seen that Ptolemy's system can also reproduce these seasonal changes. In Ptolemy's system, what two things are tilted relative to each other to produce this effect?

23. Copernicus thought the Earth was carried around its orbit by a sphere, much like the spheres of Eudoxus. Grab a meter stick. Hold the stick straight out in front of you with the stick pointing straight up and down. Now tilt the stick (by 23.5° if you can). Turn around in a circle, keeping the meter stick held out in front of you (you are now playing the role of the sphere that carries Earth, while the meter stick is the Earth's axis). Does the orientation of the meter stick remain fixed *relative to the room*?

24. Copernicus' system combines the rotation of Earth (which reproduces the daily motion of the stars, etc Westward across the sky) and the revolution of the Earth around the Sun (which reproduces the Sun's annual motion Eastward along the ecliptic). A third motion was used to keep the Earth's axis fixed relative to the stars (because otherwise it would change orientation as Earth was carried around its orbit - or so Copernicus thought), and also to reproduce the precession of the equinoxes. Only one more element is needed to take care of the apparent motion of the stars and the Sun. We know that the Sun doesn't move at a constant speed along the ecliptic, but in the simulation you just looked at it did. We saw that to solve this problem in the geocentric system, Hipparchos moved the center of the Sun's orbit away from the Earth. Copernicus also made use of an eccentric orbit, shifting the center of Earth's orbit away from the Sun. But Copernicus kept the center of Earth's orbit at the center of the CS, and instead *moved the Sun away from the center.* In Activity 10 we found that in Hipparchos' model the Sun appears to move fastest on the ecliptic (as it does in early January) when it is closest to Earth and slowest (as in early July) when it is farthest from Earth. So in Copernicus' system the Sun needs to be moved away from the center of the CS in the direction of which zodiacal constellation? (You may want to refer back to the fourth question of A10.)

25. Consider what you have seen so far of the Copernican system and what you know of the Ptolemaic system. Based on *astronomical* data alone, can we tell whether Copernicus or Ptolemy is correct? Explain your answer.

26. Now we need to consider a major astronomical problem with the Copernican theory. Under Display Options select Trace Motion of Celestial Poles and run the simluation. This will trace out the motion of the north and south celestial poles along the celestial sphere. What do you notice about the location of the celestial poles as the Earth completes its annual orbit around the sun? Does this match your observations of, for example, Polaris?

27. If Copernicus' theory disagrees with your observations, is there some way we can fix the problem? Try changing the radius of Earth's orbit (you'll need to pause the simulation first). Can we solve the problem this way? If so, what must be true about the size of Earth's orbit relative to the Celestial Sphere if Copernicus' theory is correct?

28. Most astronomers of Copernicus' day subscribed to Aristotelian physics. What are some arguments they might have made against Copernicus' system.

29. Given the available astronomical evidence at the time, if you were an astronomer in Copernicus' day (trained in Ptolemaic astronomy and Aristotelian physics) would you have found Copernicus' ideas plausible?