Models of the Solar System

Around 140 AD, a Greek astronomer named Ptolemy described a geometric model of the solar system, with the earth at rest in the center, and the moon, sun and planets orbiting around it. In order to match the model to the observations, the planets were also thought to move on epicycles, smaller circles centered on the circular orbits. For the planets Mercury and Venus, the center of the epicycle was thought to be fixed on a line between the sun and earth. A diagram of the earth-centered model is shown in Figure 1. The earth is in the center, the moon closest to the earth, then Mercury, Venus, the Sun, Mars, Jupiter and Saturn. This represents all the known objects in the solar system at Ptolemy's time.

Figure 1

1. Describe the motion of the moon and sun (as seen from earth) in this model. Does it agree with what we observe?

2. Describe the motions of Mercury and Venus in this model. Why do their epicycles need to be centered on a line between the sun and earth? Why is the epicycle for Mercury smaller than that of Venus?

3. Go to http://astro.unl.edu/naap/ssm/animations/ptolemaic.html. Set the planet to Venus (in the upper right corner) and start the simulation. Watch the path taken as Venus and the Sun move around the Earth. Does Venus move in a smooth circle around the Earth? Describe the path it takes.

4. In the bottom window (labeled "Zodiac Strip") it shows the apparent motion of Venus (labeled with a P) and the Sun across the constellations of the sky as seen from the Earth. Is Venus always on the same side of the Sun? How does the model explain this? Is this actually "retrograde motion" as defined in the textbook? Explain.
5. Now set the planet to Mars and watch the path taken. Describe its path, and how it differs from the path taken by Venus.

6. Look at Mars’ motion across the constellations (on the “Zodiac Strip”). Notice that it moves back and forth sometimes. Explain why it does this.

7. Run the simulation again with Mars, and with Venus. Both planets move around circles that themselves move around a circle nearly centered on the Earth. And yet, Mars exhibits retrograde motion while Venus does not. Explain why this happens in this model.

8. Figure 2 shows a part of the earth-centered model, including just the earth, sun and Venus. Recall that Venus moves around its epicycle as it and the sun move around the earth. Shade the portion of Venus not illuminated by the sun at each of the points on the diagram. Draw a line through Venus showing the half of the planet that faces Earth. What phases of Venus can be seen from the Earth in this model? (Phases are the shape of the planet that we can see from Earth -- the half of the planet that faces Earth.)
9. Figure 3a shows a sun-centered model of the solar system, where all the planets move around the sun. Figure 3b shows just part of the model; the Sun, Earth and Venus. From our point of view on the earth we see Venus move around the Sun as shown. **Shade** the portion of Venus not illuminated by the sun at each of the points on the diagram, and **draw** a line showing the half of Venus we can see from Earth. What phases of Venus can be seen from the Earth in this model?

![Figure 3a. Sun-centered Model](image1)

![Figure 3b.](image2)

10. The motion of Mars (and the other outer planets) is another observation which must be explained by a model of the solar system. Using the simulation, explain (in words and a sketch) how Mars appears to move as seen from the Earth in the Earth-centered model. (Describe the differences in the motion of Earth and Mars as seen from above, and also the motion of Mars against the constellations in the "Zodiac Strip"). This motion is called **retrograde motion**, and is actually the way Mars appears to move.

Retrograde motion of Mars and the other outer planets is easily explained by the earth-centered model, but it can also be explained by the sun-centered model. Due to the stronger gravitational attraction, planets closer to the sun move around it more quickly. So the Earth moves around the sun more quickly than Mars does.
11. Open the link: http://astro.unl.edu/naap/ssm/animations/configurationsSimulator.html. Set the Observer’s planet to be Earth, and the target planet to be Mars. Now run the animation. Describe the motion of Mars and the Earth. What is the difference between them? How does the motion of Mars in the “Zodiac Strip” compare to the motion seen in the Earth-centered model?

Figure 4 shows the position of the Earth and Mars at eight particular points in their orbits. The numbers 1 to 7 on each orbit mark the position of the Earth and Mars at the beginning of eight consecutive months. Since Mars moves more slowly, the distance it moves in one Earth month is less, so the numbers are closer together. A field of fixed background stars is shown on the right.

12. To see where Mars appears to be in the sky, as seen from Earth, draw a line connecting the Earth at point 1 and Mars at point 1, and extend the line to the vertical line near the stars. Label the number where each line hits the "stars". Do this for each month. Now draw a curve connecting the apparent position of Mars at each month, to show the apparent path that Mars takes across the sky.

13. Explain how retrograde motion is produced in this model.