Geocentric and Heliocentric World Views

ABSTRACT

We explore in some detail how the geocentric cosmology worked, and what observations caused the adoption of the heliocentric view. For this lab, your writeup will consist only of these sheets plus separate sheets with the answers to the questions posed throughout the exercise.

1. The Motion of Mars

Stars appear to have a simple motion in the sky: they rise in the east, travel along a smooth arc, and set in the west. This motion was easily explained by early geocentric cosmologies that placed the earth at the center of the universe. However, a small group of objects, referred to as “wanderers” (or planets), did not share this motion, but drifted among the fixed stars. The rate that a wanderer moved among the stars varied, and (except for the moon and Sun) even the direction of their motion changed! This westward motion is referred to as **retrograde motion** (“normal” eastward motion is termed **prograde motion**).

In order to account for these oddities, astronomers had to modify their early Earth-centered model.

- Table 1 gives the celestial positions of Mars at two different times during 1992-1993, expressed in terms of right ascension and declination. These celestial coordinates are similar to longitude and latitude on the earth. Right ascension is analogous to longitude and measures positions in the sky in an east-west direction. It has units of hours, minutes, and seconds. Declination is analogous to latitude and measures positions in the sky in a north-south direction. It has units of degrees, arcminutes, and arcseconds. For this exercise it is adequate to express right ascension in units of hours and minutes and declination in units of degrees and arcminutes. A graph whose axes use these units is shown in Fig. 1. **Plot** the Table 1 positions on Fig 1. (Use pencil.)
- Assume that Mars moved through the sky in a *uniform* manner. Sketch on Fig. 1 the positions you would expect for Dec. 1, 1992 and Feb. 1, 1993 (one-third and two-thirds of the way to April 1, respectively.) Connect all four points with a single straight line.
- A sample of Mars’s actual positions during these months is given in Table 2. Plot *these* points on Fig. 1. Connect them smoothly with a dotted line.

- **Q1:** In your writeup, describe the actual motion of Mars and compare it with that predicted from bullet 2; uniform circular motion.

Table 1.

Date	Right Ascension	Declination
Oct 1, 1992	$6^h\ 44^m$	$23^\circ\ 25'$
April 1, 1993	$7^h\ 21^m$	$24^\circ\ 41'$

Table 2.

Date	Right Ascension	Declination
Oct. 1, 1992	$6^h\ 44^m$	$23^\circ\ 25'$
Nov. 1, 1992	$7^h\ 40^m$	$22^\circ\ 46'$
Dec. 1, 1992	$8^h\ 01^m$	$23^\circ\ 09'$
Jan. 1, 1993	$7^h\ 31^m$	$25^\circ\ 43'$
Feb. 1, 1993	$6^h\ 45^m$	$27^\circ\ 01'$
March 1, 1993	$6^h\ 44^m$	$26^\circ\ 21'$
April 1, 1993	$7^h\ 21^m$	$24^\circ\ 41'$

- Early geocentric models assumed everything revolved around the Earth in a it uniform, steady manner and on a perfect circle. Under these circumstances, Mars would cover the same arc distance along its orbit in equal amounts of time. For example, the amount of time Mars would need to move from position 1 to 2 in Fig. 2 would be the same as to move from position 2 to 3. Suppose that Mars moved in this fashion. On Fig. 2, draw a straight line from the Earth to each position of Mars, and extend it to just beyond that stars. At the end of each of these lines draw a small circle to represent Mars.

- Connect the predicted Mars positions with a line. **Q2:** Does the motion of Mars produced by the above figure agree with that predicted by uniform circular motion (bullet 2)? Why or why not?

- **Q3:** Is there any way to produce the *actual* motion of Mars with the Earth-centered, uniform motion model?

- In an attempt to explain the loop-like retrograde motion of Mars, an ingenious fix, the *epicycle*, was added to the geocentric model. This revised model is called the **Ptolemaic model** in honor of Claudius Ptolemy (c. 140 A.D.) who published big tables predicting future planetary positions based on this model. In this model, the orbit of Mars looks like Fig. 3.

  In such a model, Mars has two motions. Mars revolves on its epicycle, and the center of the epicycle revolves around earth. By assigning speeds to each of these motions, the observed retrograde motion of Mars could be produced.

  On Fig. 3, draw arrows to illustrate these motions.

- Let us visualize the motions produced by a model like Fig. 3, and draw them on Fig. 4.

  A. Assume Mars moved along its epicycle, but *did not* revolve around the earth. Illustrate how Mars would appear to move against star field A in Fig. 4. (Act it out: draw some stars on a blackboard, Joe student stands next to the board and holds up his fist to represent Mars; and spins around. How does Joe's fist move as seen by Jill and Jack?)

  B. Now let the epicycle move slowly around earth. Use star field B in Fig. 4 to show the path Mars would take among the distant stars. (Act it out: Joe walks past the board as he spins. Careful, Joe, don't get too dizzy.)

- **Q4:** Explain in words how the observed retrograde motion of Mars could be produced in this modified geocentric model.

- **Q5:** What observational data is needed to force a revision of the early uniform-motion geocentric model?
- **Q6:** Explain how the addition of the epicycle "fixed" the geocentric model.
- Make sure you can define the terms: retrograde motion, right ascension and declination, epicycle, and Ptolemaic model.

2. The Ptolemaic Model

During the time of Galileo Galilei (1564-1642), the Ptolemaic model, shown in Fig. 5, was widely accepted. It placed each planet on its own epicycle. Planets possessed two motions, one along its epicycle and the other around the Earth. This model agreed with the observational data of Ptolemy's era, and was able to predict the future positions of the planets (to within a few degrees, but this was considered "good enough.")

One of the Ptolemaic model's important properties was that the epicycles of Mercury and Venus were attached to a bar-like structure connecting the Earth and the Sun.

- In Fig. 5, locate Mercury and Venus, their respective epicycles, and the bar-like structure.
- **Q7:** How did the epicycle allow this model to explain retrograde motion?
- **Q8:** Why was this bar-like structure needed in the Ptolemaic model?
- **Q9:** Why was the epicycle of Mercury smaller than that of Venus?
- **Q10:** Why, in this model, are Mars, Jupiter, and Saturn *not* connected to the bar-like structure? That is, what observation requires these planets to be free?
- Figure 6 shows an enlarged view of the Ptolemaic model showing the Earth and Venus. On Fig. 6, shade the portion of Venus not illuminated by the Sun. **Q11:** Can a "full" Venus ever be seen from the Earth in this model? Why?
- **Q12:** What observational phenomena did the Ptolemaic model account for?
- **Q13:** What predictions did the Ptolemaic model make in regard to the phases of Venus?
- **Q14: Draw** a geocentric Ptolemaic cosmology. Label the objects in the figure. (Yes, this is just a re-sketch of Fig. 5.)

3. The Copernican Model

Sometimes a seemingly inconsequential observatoin has a profound implication. Individuals who first recognized the consequence of these observations stand out as the geniuses of their time. One such person was Galileo Galilei (1564-1642). Galileo was the first person to use a telescope to observe Venus. Over time, he noted that Venus, like the Moon, exhibited phases, changing from a small, disk-like object to a large crescent-shaped object. See panels a-e in Figure 7.

Galileo was aware of the recently published heliocentric model developed by Nicolaus Copernicus (1473-1543). This model was extremely controversial because it removed the Earth from its privileged position at the center of the Universe. Nevertheless, Galileo found that the heliocentric model was able to completely explain the observed phases of Venus.

- Drawing on Figure 8, place Venus in the positions needed to produce the phases seen in panels a and e of Fig. 7. Label these positions with the letters **a** and **e**.
- **Q15:** Explain how the heliocentric model accounts for the observed phases of Venus.
- **Q16:** Explain how the heliocentric model accounts for the observed sizes of the various images of Venus.
- Apparent size is related inversely to its distance. The farther away an object is, the smaller it will appear. At two distances, **a** and **e**, the apparent size changes as

$$\frac{\text{distance from us in panel a}}{\text{distance from us in panel e}} = \frac{\text{apparent angular size at e}}{\text{apparent angular size at a}}$$

or, with astronomical brevity,

$$\frac{D_a}{D_e} = \frac{\theta_e}{\theta_a}$$

Using a ruler, measure in millimeters the apparent size of the disk of Venus in panels **a** and **e**.

Q17: Record the two measurements (θ_e, θ_a, in mm) in your report.

Assume that Venus was located 1 unit from the Earth in panel **e**. Use the equation above to compute how far from Earth Venus is in panel **a**. **Q18:** Show your work.

- **Q19:** Why does this result seem reasonable?

- **Q20:** If the distance from Earth to the nearby Venus is 1 unit, and from the Earth to the far away Venus is 7 units, then how many units is Venus from the Sun? How many units is the Earth-Sun distance? See Fig. 9 if you need help visualizing this.

- **Q21:** If the Earth-Sun distance is defined as *one astronomical unit*, 1 A.U., what is the Venus-Sun distance in astronomical units?

- Now let's think again about Mars. In the heliocentric picture, Mars orbits around the sun in an orbit wider than that of Earth. See Fig. 10.

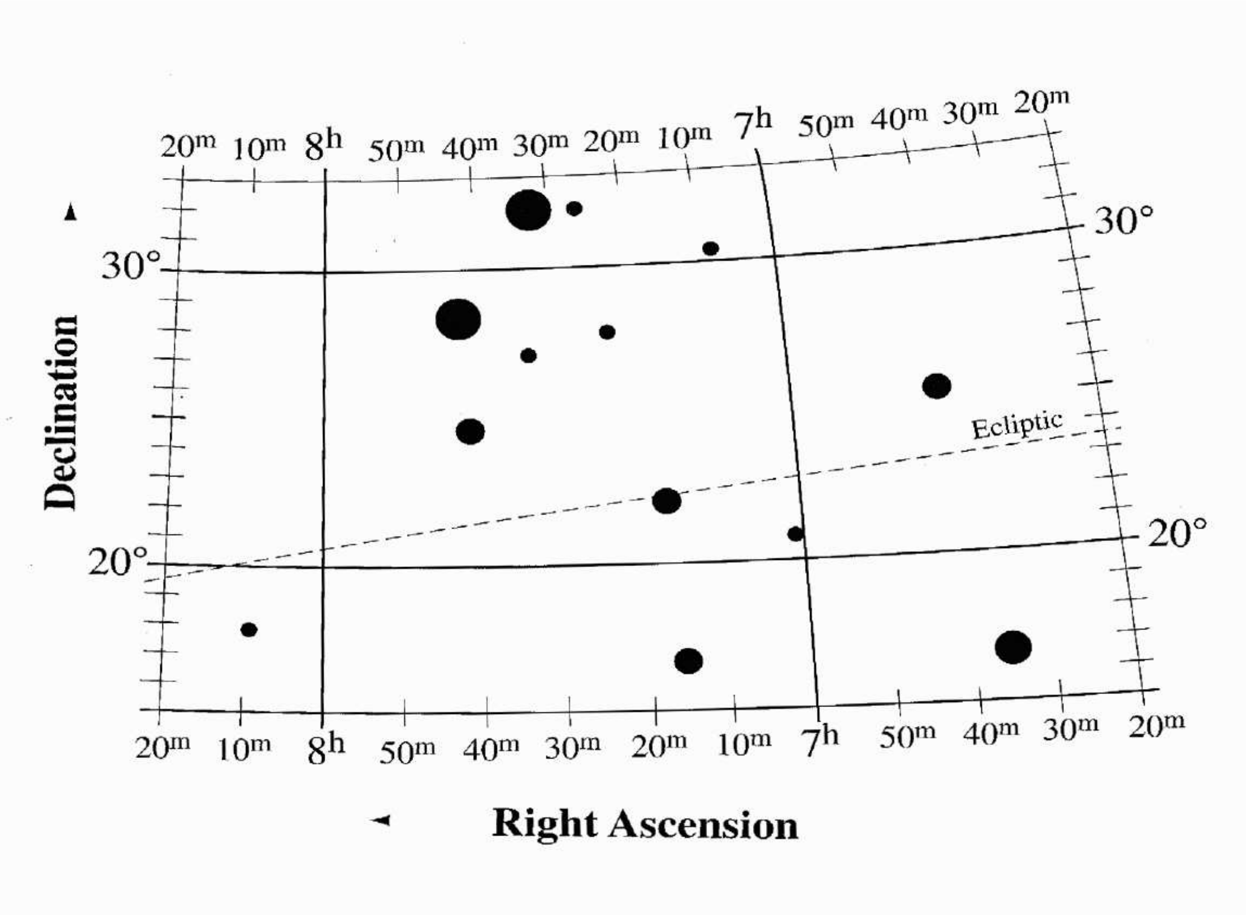
  Since Mars is located farther from the Sun than the Earth, it moves more slowly in its orbit. For instance (in Fig. 10) in the time it takes the Earth to move from its points 1 to 2, Mars will have moved only from its points 1 to 2.

  Using your ruler, connect the same-numbered points along the two orbits, and extend the line to the stars. Trick: extend each subsequent line a bit farther to the right — to avoid crossing your lines. Connect the end of each line to show the path that Mars would make among the stars.

- **Q22:** Explain how retrograde motion is produced in this model.

- **Q23:** Why couldn't the Ptolemaic model be modified to account for Galileo's observation that Venus exhibited a full phase?

- **Q24:** How is Venus's phasing behavior explained in the heliocentric model?


20m 10m 8h 50m 40m 30m 20m 10m 7h 50m 40m 30m 20m
30°
20°
Declination
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20m 10m 8h 50m 40m 30m 20m 10m 7h 50m 40m 30m 20m
Right Ascension

Fig. 1.—

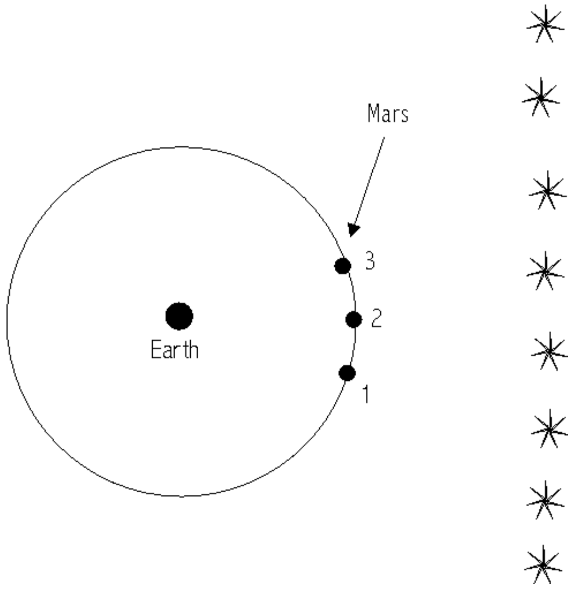

Fig. 2.—

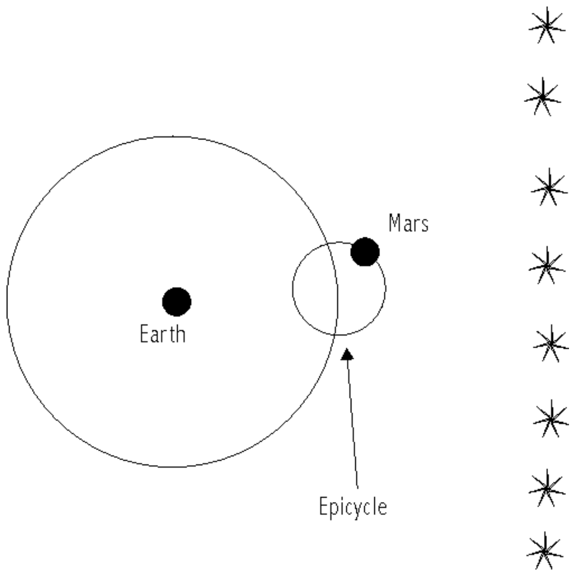

Fig. 3.—

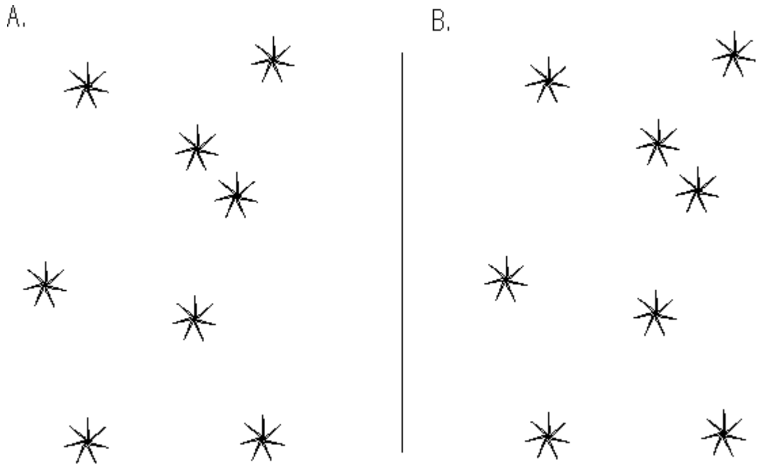

Fig. 4.—

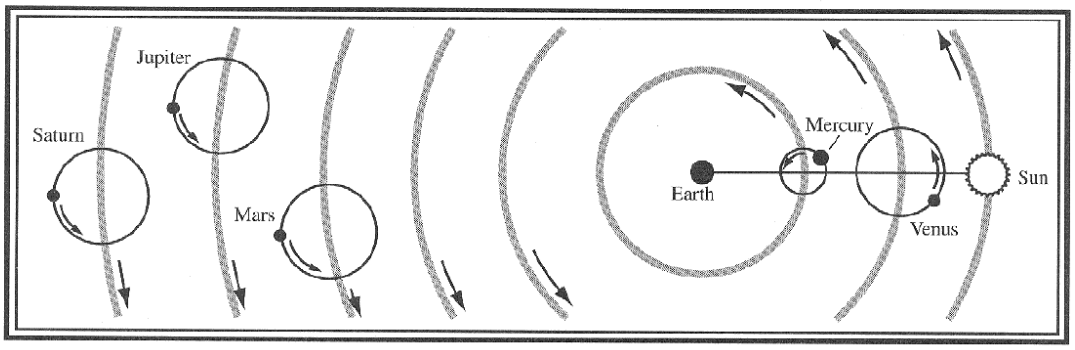

Fig. 5.—

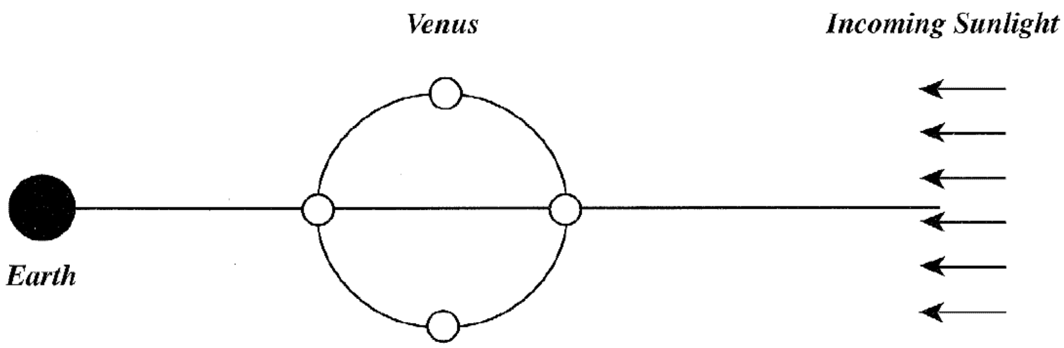

Fig. 6.—

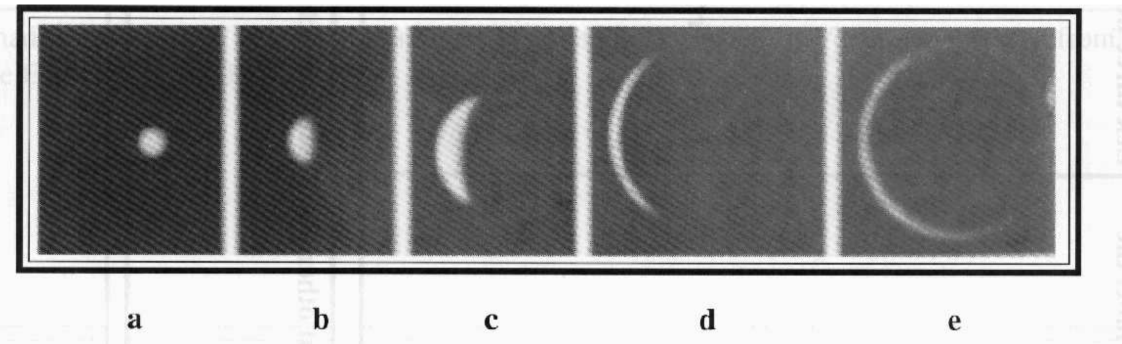

Fig. 7.—

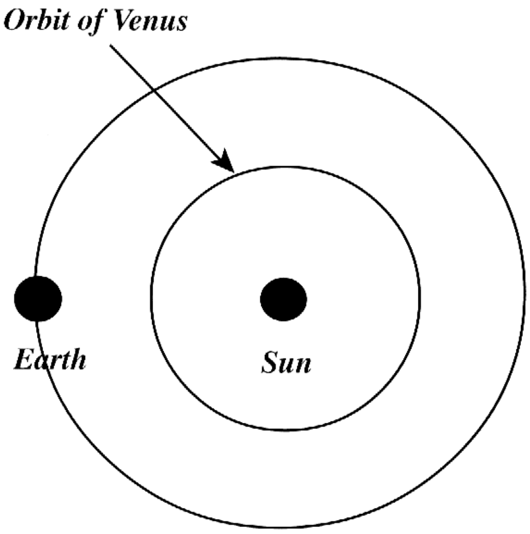

Fig. 8.—

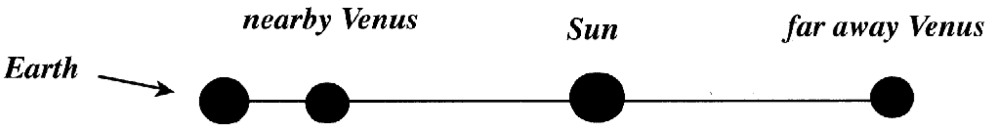

Fig. 9.—

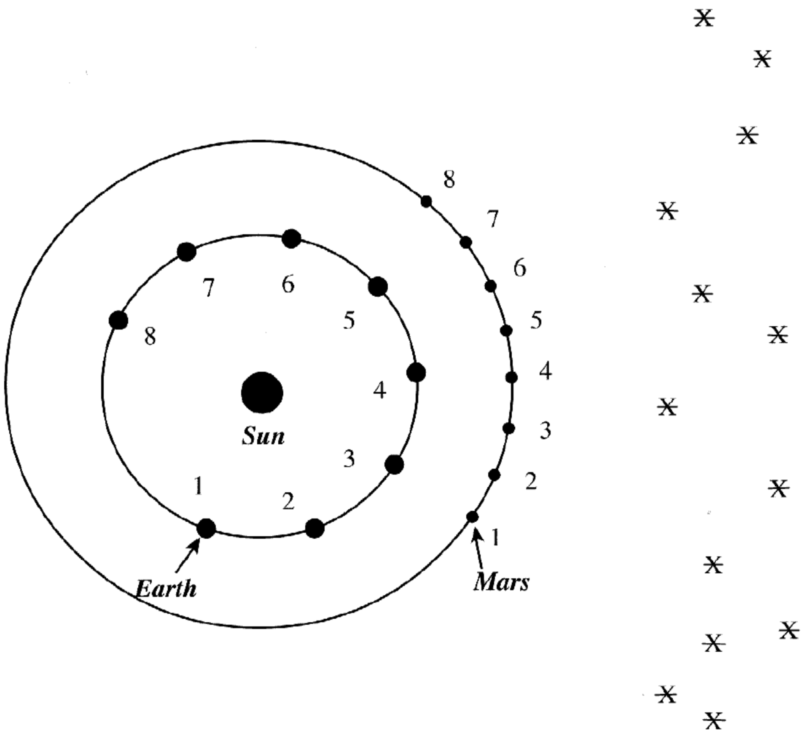

Fig. 10.—