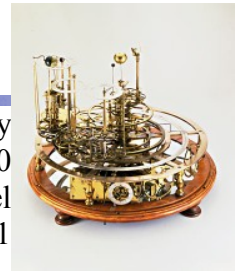


Astronomy 211 - Project: Frames Of Reference

Grand Orrery
England, ca. 1780
Yew, brass, ivory, steel
Adler Planetarium A-61



<http://www.adlerplanetarium.org/research/collections/instruments-of-time/index.shtml> (accessed 12/20/08)

Geocentrism vs. Heliocentrism - Rediscovering the Insights of Copernicus

The obvious tension between the geocentric world model of Ptolemy and the heliocentric counterparts posed by Aristarchus and Copernicus highlights at least two fundamental issues in attempting to make sense of the motion of heavenly bodies:

- which celestial body dominates the cosmos, and
- what frame of reference for viewing the motion of celestial bodies is most revealing?

This project makes it possible for you to experience some measure of the nearly 2000-year frustration generated by grappling with the problem of discovering the Cosmic Mechanism.

Part I (15 points)

Thought question: If we consider the Moon and Earth an isolated system within the sphere of stars (pretend there is no Sun or planets other than the Earth), is it possible to tell whether the Moon orbits the Earth, or the Earth orbits the Moon?

Start with the diagram, Fig. 2 page 5, which depicts our looking down from "above" the Earth - Moon system, that is, from the north celestial pole, with the Earth stationary at the center; that is, seen from a reference frame tied to the Earth (a geostatic frame). This represents a view seen by a remote observer who is not moving relative to the Earth. The diagram assumes uniform, circular motion concentric with the Earth. Each position is labeled with the day of observation. The task has been made easier by assuming that the sidereal (with respect to the stars) orbital period is 27 days rather than the 27.321582¹ days it actually is (27 d 7 h 43.1 min). <<http://incompetech.com/graphpaper/polar/> used to generate the polar graph.>

A. (5 pts) You should now make a similar diagram showing the position of the Earth in orbit around the Moon, a lunarstatic frame seen from a remote observer who is not moving relative to the Moon. Use these same days. (A template is included here, see **Fig. 3**, page 7. If you use a tracing-paper overlay, this step may be a bit harder but the shift in reference frame is more apparent.) Be sure to number the positions on each diagram so that the shift in the frames is apparent; in other words, the position of the Moon on the geostatic diagram and the position of Earth on the lunarstatic diagram must show the different reference frames.

¹ Wikipedia: <http://en.wikipedia.org/wiki/Moon> accessed 12/20/08

01. (5 pts) Are these two diagrams different? Are there any observations that could be made by either an Earth-bound observer, or a Moon-bound one to enable that observer to distinguish whether the Earth "actually" orbits the Moon or the Moon "actually" orbits the Earth? Explain your answer.

02. (5 pts) What about the Earth-Sun system in isolation? Is the answer to the previous question about the Earth-Moon system any different when phrased to apply to the Earth-Sun system? Explain the similarities or differences.

Answer these questions explicitly (state "Part I" and number your answers corresponding to the above questions), giving details as to how you constructed the second diagram, and supporting your answers with references if needed. (Be sure to footnote your references!) See the bottom of the last page of this project for more instructions.

Part II (65 points)

Now, consider in detail the relative (sidereal) motion of more than just two bodies. Start with a heliocentric picture in which Venus, the Earth, Mars, and Jupiter orbit the Sun at the distances and with the sidereal periods listed below. Again, as an approximation, assume uniform, circular motion. You may also assume that there are 360 days in a year, making exactly 12 Earth months, and letting the Earth move 1 degree per day (30 degrees per month). This approximation will not detract from your final result and will make the graphing a lot easier. The sidereal periods are not precisely stated, but are good enough for this project.

Orbital radius	Sidereal period	Degrees per month
Venus 0.7 AU	0.6 yrs = 7.2 mo	$360^\circ / 7.2 \text{ mo} = \underline{\hspace{1cm}}^\circ / \text{mo}$
Earth 1.0 AU	1.0 yrs = 12 mo	$360^\circ / 12 \text{ mo} = \underline{30^\circ} / \text{mo}$
Mars 1.5 AU	1.9 yrs = <u> </u> mo	
Jupiter 5.2 AU	12 yrs = <u> </u> mo	

B. (10 points) Carefully draw a scale diagram that shows the position relative to the background of stars of each of these bodies at nominal one-month intervals (1/12 year) for **two** Earth years as they orbit the Sun. Start with all planets in a straight line, moving counter clockwise with the Sun at the left. This is a diagram of a heliocentric cosmos shown in a heliostatic frame of reference. [Hint: Don't make the planets themselves too large. Be sure to number each planet each month; for example, t = 0, t = 1, t = 2, ... t = 24. Use different colors for each planet.] See Fig. 1 for suggested starting positions and **Fig. 4** on page 9 may be used as a pattern.

C. (10 points) Now, using these positions, make a second diagram showing the positions of Venus, the Sun, Mars, and Jupiter relative to the Earth. The Earth is to be fixed at the center of this (heliocentric) **geostatic** diagram. After you have completed this diagram, connect the dots for each planet. (Don't forget to put in the Sun's apparent orbit around the Earth.) The easiest way to do this is to use a large sheet of tracing paper; your instructor will show you how. Initial instructions are on the next page.

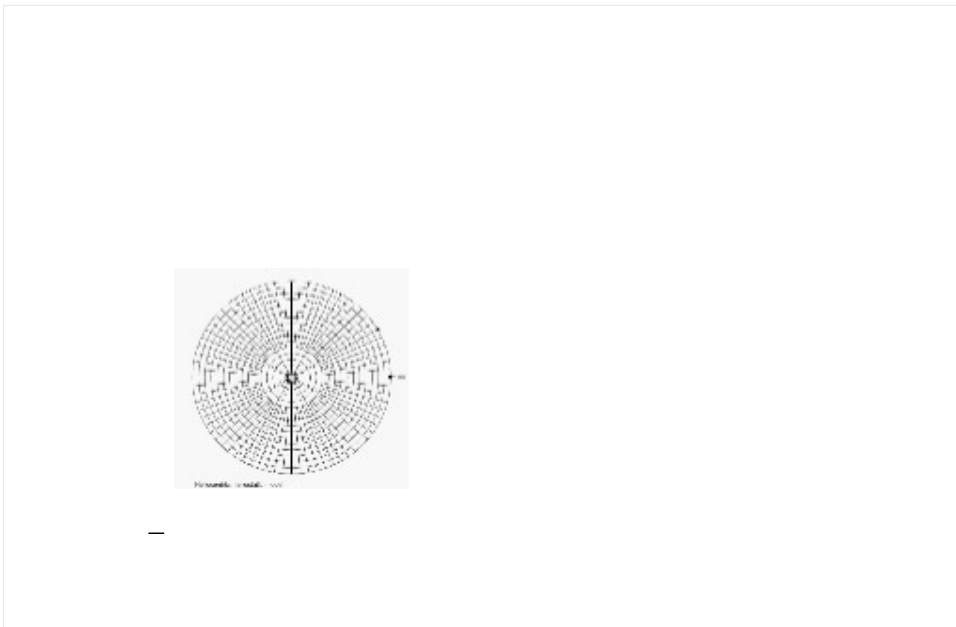


Fig. 1

Once you have the planets laid out in their positions on a monthly basis over a 2-year time period, take your large sheet of tracing paper and lay it over this diagram. On the overlay, there will be just 1 Earth since you are creating a geostatic frame of reference. Mark the Earth. Now, mark each of the other planets using their respective colors for $t = 0$ locations. Move the overlay so that the Earth on it is over Earth at $t = 1$ on the original diagram.

YOU MUST NOT TWIST OR TURN THE OVERLAY! KEEP SIDES PARALLEL. THIS REPRESENTS THE UNCHANGING CELESTIAL SPHERE OF STARS.

On the overlay, mark the positions of the rest of the planets at their $t = 1$ positions. Continue this until you get to the $t = 24$ positions.

01. (5 pts) What is the planetary motion suggested by the second diagram? The motion we are interested in is that relative to the background of stars as viewed from the Earth. Compare the motion predicted by this second diagram to the motion that could have been predicted by Ptolemy based on a simplified epicyclic model; that is, one using epicycles only, with no equants or eccentrics. This is the simplistic Ptolemaic model.
02. (7 pts) Pertaining to the motions predicted by your second diagram and the motions that could have been predicted by Ptolemy based on a simplified epicyclic model: Are these motions qualitatively similar? Are they quantitatively similar? What are the important differences between your diagram and a hypothetical diagram based on this simplified epicyclic model?
03. (5 pts) What have you done in making your diagram that the Greeks could not have done? In addition to rounding off the orbital periods, months, and distances, what assumptions have you used? Specifically, what two phenomena have you "explained"?

04. (5 pts) Examine especially the path of the inner planet, Venus. How does the character of its apparent motion, as seen from the Earth, differ from that of the outer planets? Being an inner rather than an outer planet, why might we predict that its apparent motion would be different?

05. (3 pts) If you remembered to "connect the dots" for each planet, you should be able to roughly measure the size of the retrograde orbits (epicycle) of Mars and Jupiter. Measuring across the longest part of each loop, are they about the same size? Should they be? What relationship do you find. How could this information be used to determine the relative distances to these planets? (Note: This will work only if you've done an accurate job!)

06. (5 pts) Galileo claimed to have observational proof that the Earth orbited the Sun thereby directly challenging the classical and Hellenistic Greek assumption that the Sun orbited the Earth, as well as the received wisdom passed on through medieval times. From your pondering over the Earth-Sun-Venus-Mars-Jupiter system, and your conclusions from Part I of this project, do you think he was speaking the truth or overstating his case in support of the Copernican model? Why might he choose to overstate or understate his case? Support your answers with logic or references.

07. (10 pts) How does the choice between these two frames of reference (geostatic and heliostatic) and two models (geocentric and heliocentric) relate to developing a concept of gravity? To address this last question adequately, you will need to make sure that you have understood the difference between "frames of reference" and "models." You should also relate this exercise to what is meant by the "insights of Copernicus" as mentioned in the title. Galileo was a Copernican. How did he use Copernicus's work in convincing himself so absolutely that the Sun was the center of the cosmos that he was willing to meet his church head-on? How, then, did Galileo's work on the orbits of planets lead Sir Isaac Newton to formulate his laws of gravity?

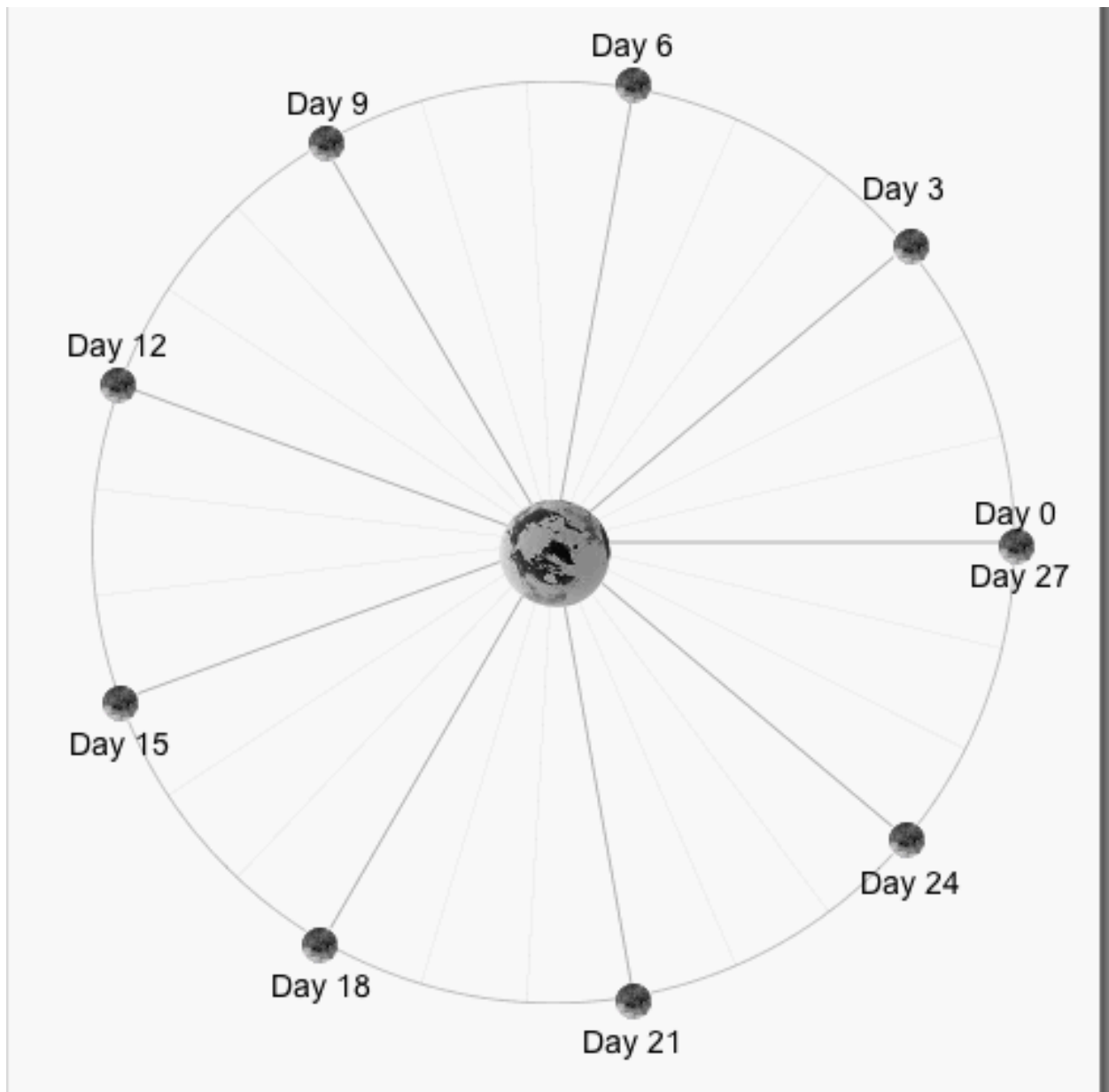
08. (5 pts) Finally, summarize what you personally pulled out of this assignment. What did you learn? Did the assignment change your view of how our current knowledge of the Universe developed? Add additional comments as you see fit.

Please complete this assignment by carefully constructing precisely drawn diagrams made with compass (if needed), protractor (if needed), and straight edge, filling a sheet of paper at least 11" x 17" in size. Your diagrams are to be accompanied by an itemized (Part II, 1, 2, 7) description of the process by which you have constructed and interpreted these diagrams (data tables may be included on the diagrams themselves) in order to answer the questions posed here.

The point structure itemized for each question is for marking/checking purposes, what your work will be checked against. This is also a writing exercise, aim your prose at a fellow student who is not taking this course. Explain to her/him what it is that you have done, and please do so in no more than three typewritten pages. You will have no room in which to ramble.

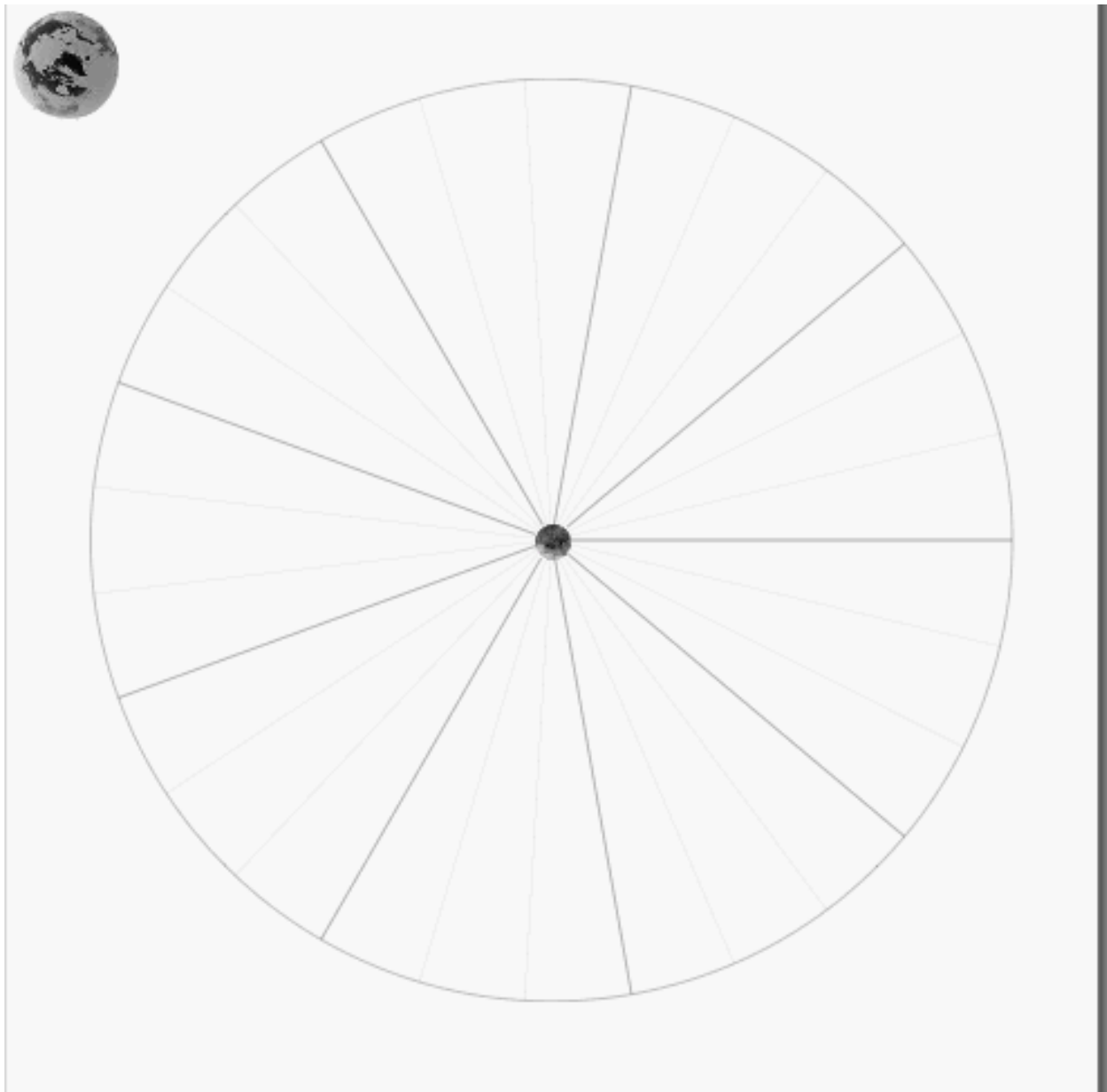
Font: no smaller than 11 pt; margins: no narrower than 1 inch; use single spacing, with double spaces in between paragraphs.

Figure 2



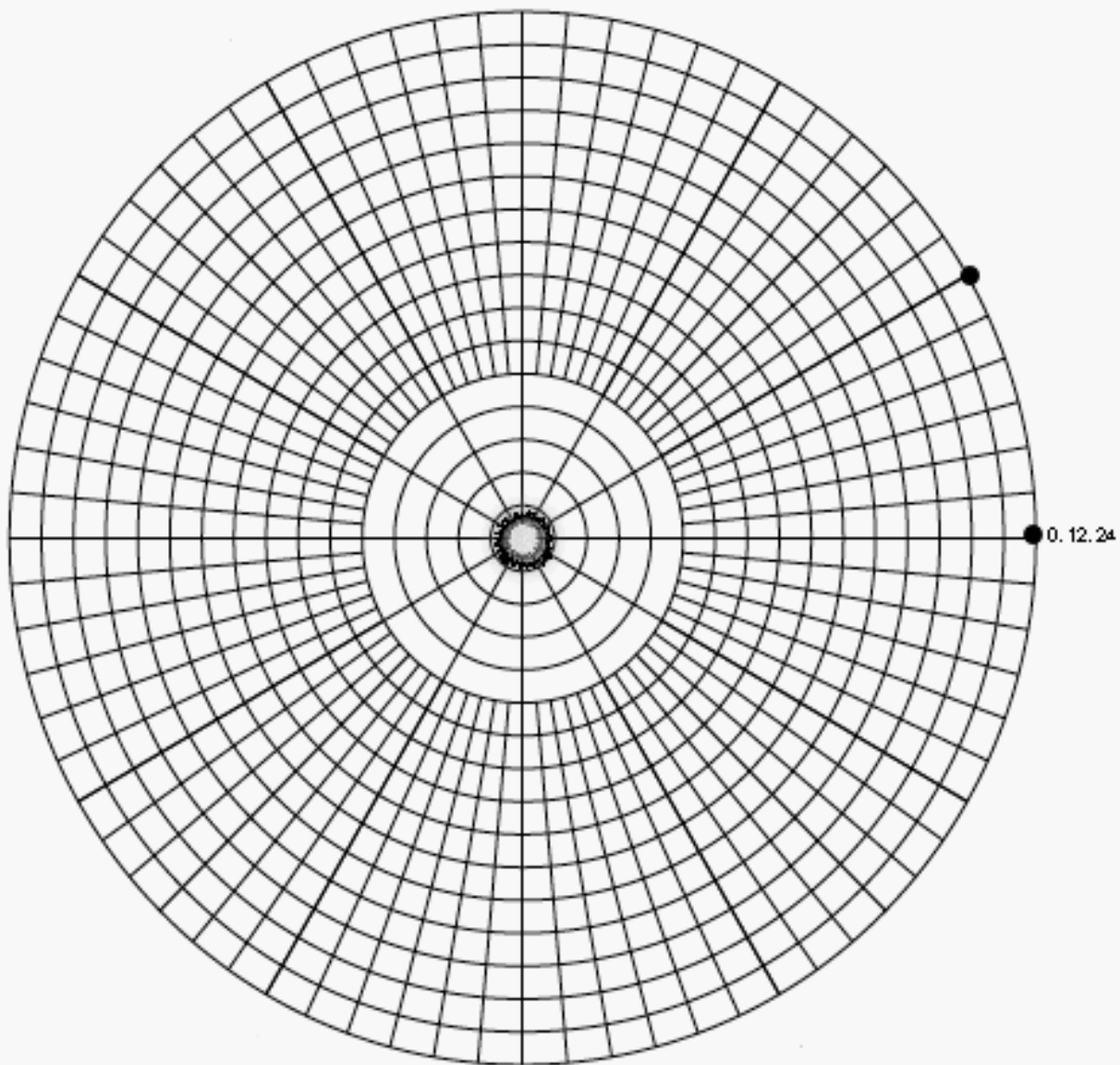
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Figure 3



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Figure 4



Heliocentric, heliostatic model

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