Epicycles Dome

Teaching the Geocentric Model

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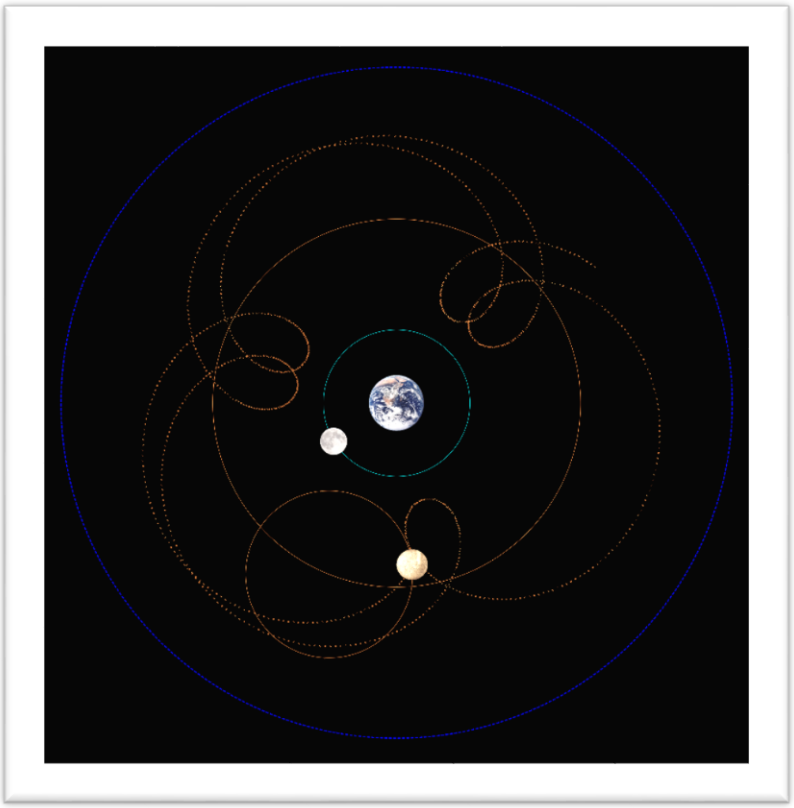

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This presentation offers details on how to use the "**Epicycles Dome**" program to teach your students the fundamentals of the Ptolemaic Geocentric Model and to help them discover the *a priori* systemic oddities which are red flags to a bad theory.

Introduction

I spend a fair amount of time, especially in my Honors Cosmology course, going through ancient cosmologies and explaining why our ancestors believed what they believed about the workings of the heavens. These were highly intelligent people and they came up with ingenious methods to model what they perceived to be reality in the skies. Unfortunately, they came at many of these observations with deep-rooted prejudices and *a priori* (preconceived) beliefs which shackled their creativity.

The most prevalent and far-reaching of these beliefs were that the Earth was immovable and at the center of the entire universe. Although of course we now know this to be preposterous to the extreme (even to the point that there is no such thing as a center to the universe), it is still a useful exercise to challenge students to prove, without leaving the Earth or using satellites, that the Earth does indeed rotate and that it revolves about the Sun. (Jean Bernard Léon Foucault proved its rotation only in 1851 using a large pendulum in the Panthéon in Paris, and James Bradley accidently discovered the aberration of starlight in 1729 while searching for stellar parallax which proved that the Earth was indeed moving around the Sun as well as giving us a method for determining the speed of light.)

The **Epicycles Dome** program graphically illustrates the main characteristics of the Ptolemaic Geocentric Model. Its many features will be described via the teaching pedagogy that I use in helping students to discover the systemics of the model which can only be explained as "it just has to be that way to match the observations." Whenever ***that*** is the reasoning, it signals a problem with the theory/model that needs to be improved or discarded in favor of a theory that explains the phenomena. This will become obvious as we go through the lesson.

It is ***critical*** that you have demonstrated the celestial motions of the planets in the planetarium prior to investigating this geocentric model! You must especially point out the various retrograde paths of the planets and how Mercury and Venus seem to hover around the Sun, never straying from it more than 27 degrees for Mercury or 47 degrees for Venus. Without this background your audience will have no understanding as to why the epicyclical model was devised in order to mimic the motions of the celestial bodies while keeping the Earth stationary.

Teaching with the Program

For simplification purposes, let's turn off all the bodies beyond the Sun for now. Uncheck the boxes so that your Control Panel display appears as in Figure 1.

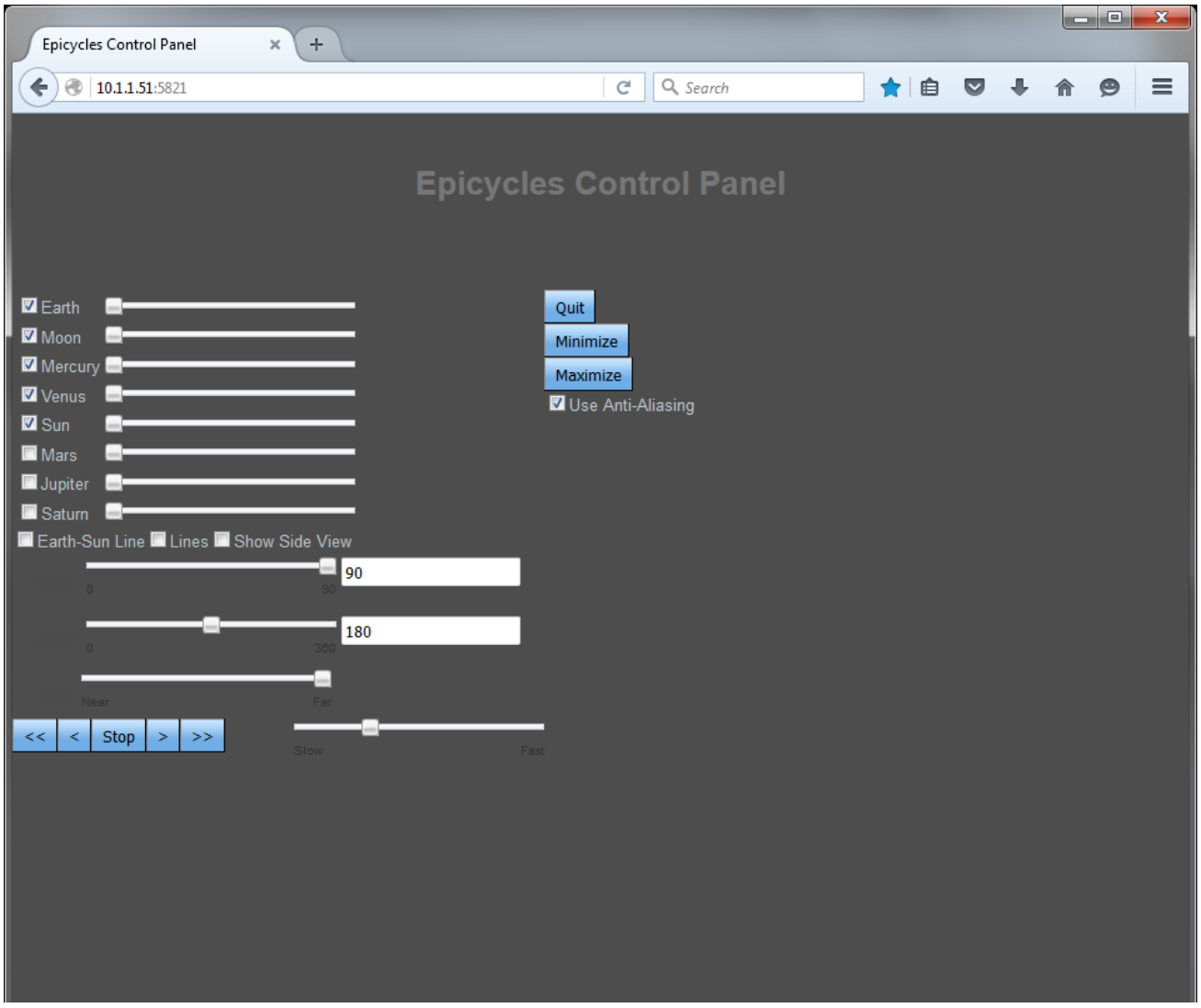

Figure 1 – Superior Planets off

You dome display should now appear as shown in Figure 2.

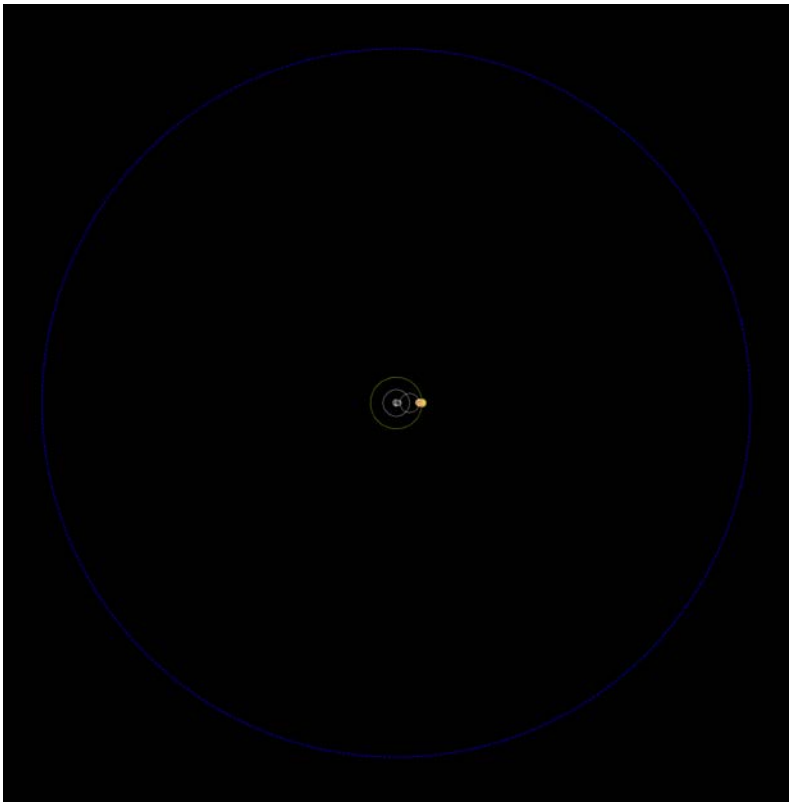

Figure 2 – Outer planets beyond the Sun turned off

Let's zoom in to the central part of the model such that we can see the bodies closest to the Earth out to the Sun. Move the scaling slider (see Figure 3) on the Control Panel until you see the dome display as shown in Figure 4.

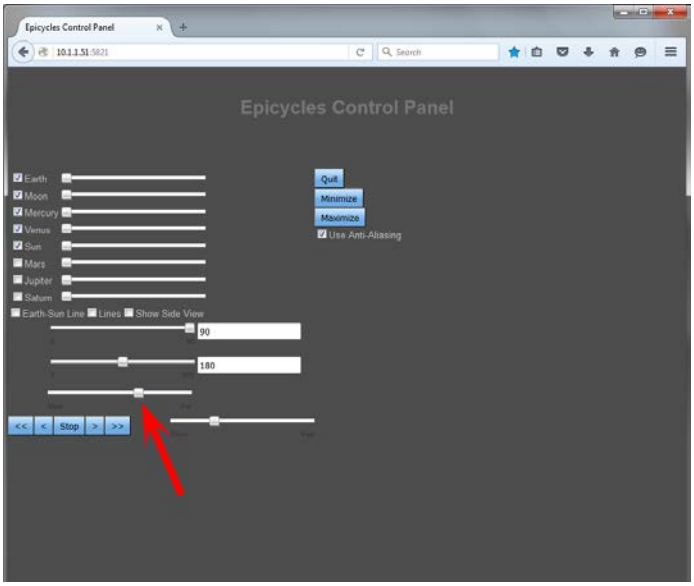

Figure 3 – Scale slider zoomed in to inner part of geocentric system

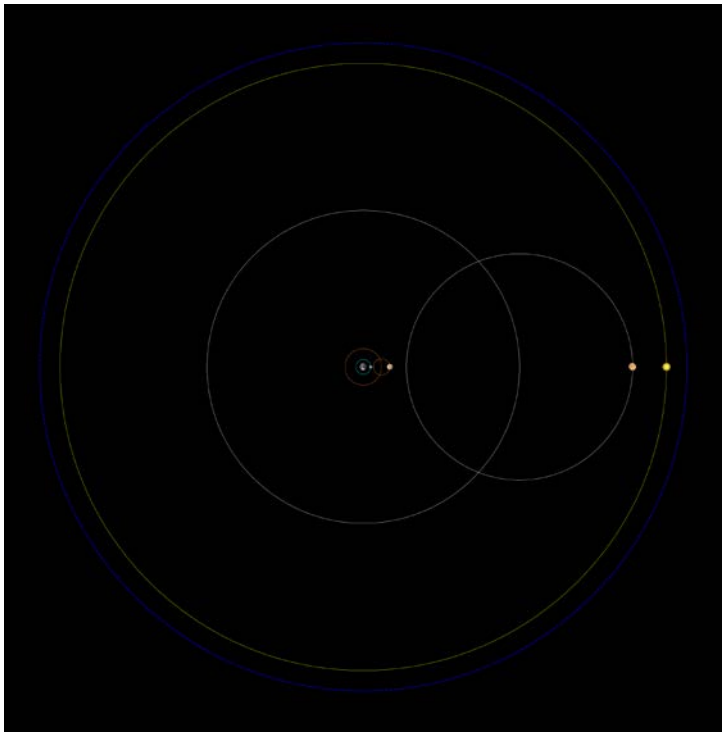

Figure 4 – Zoomed in to the inner part of the geocentric system out to the Sun

I first emphasize that this diagram is not to any scale, but that's okay for teaching purposes. (Besides, the scale of the geocentric system was unknown! It wasn't until Copernicus postulated his heliocentric model that he demonstrated for the first time using straightforward geometry that a definite scale size was imposed upon his solar system. His values for distances from the Sun to the planets (out to Saturn at that time) in astronomical units were amazingly close to the modern ones!)

Click on the "Show Side View" radio box to turn on the display of the Sun, Moon, Mercury and Venus below the dashed circle near the edge of the dome. Emphasize to your audience that this view will show them the appearance of the planets relative to each other as they appear from the stationary Earth.

Press the continuous time step button 

and let the bodies move a little. You can adjust the speed at which they move by adjusting the time flow slider  back and forth.

Ask your audience to discuss approximately how much time is passing and how do they know? [Each time the Moon revolves around the Earth is approximately a month, and the Sun revolves in one year.]

Ask them to describe the motions that they see. Also point out the motions of the planets and Moon in the narrow display at the bottom of the dome. Ask if the audience can see how the motions that they're seeing within the model spheres correspond to the dance of the planets and Moon that they see in the narrow strip beneath the dashed circle along the periphery of the dome. You will at some point probably want to zoom in closer to the Earth to better display the Moon's and Mercury's orbits as shown in Figure 5.

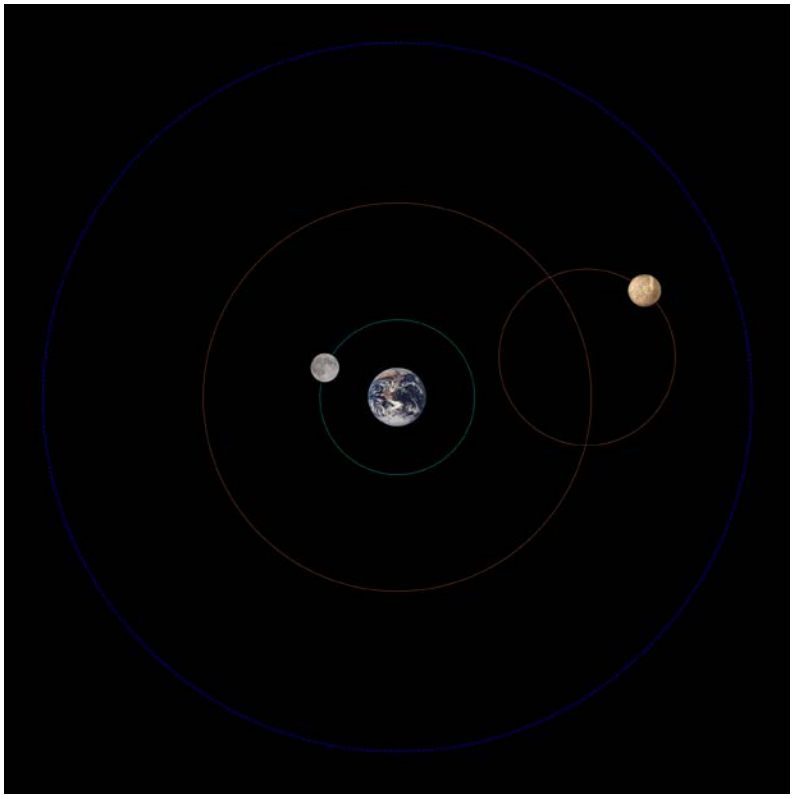

Figure 5 – Zoomed in to see the Moon and Mercury's orbits

Do they see any systematic motions going on? Do they understand why Mercury's epicycle has to be smaller than the one for Venus? [The celestial motions of Mercury made it appear to go back and forth by the Sun in smaller arcs (26 degrees on either side of the Sun) compared to 46 degrees on either side of the Sun for Venus.]

Why is there no epicycle for the Moon or the Sun? [Neither displayed retrograde motion.]

Usually someone in the audience will note that the center of the epicycles of Mercury and Venus are always lined up with the Sun. **This is a critical and key observation.** If the audience doesn't remark on this fact, then you must point it out. The question now is ***why*** do these epicycles always stay centered on the position of the Sun? The answer is "because they must in order for this model to work!" The center of the epicyclic motion of Mercury and Venus is the Sun; therefore their epicycles are locked on the Earth-Sun line. Turn on the Earth-Sun line in the upper left menu where it says "Earth-Sun line" as shown in Figure 6 to emphasize this fact.

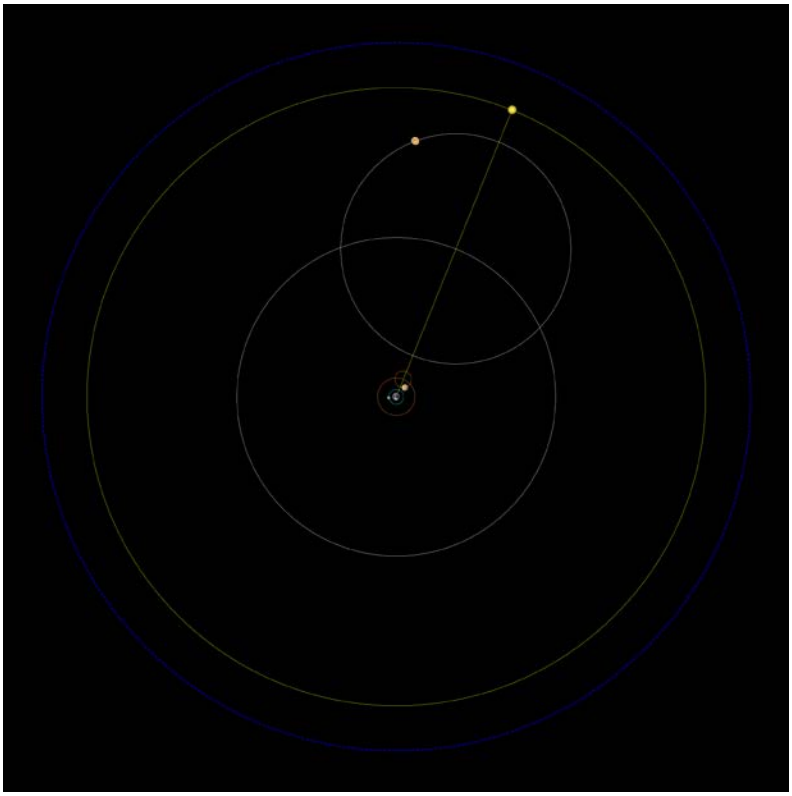

Figure 6 – The Earth-Sun Line displayed

Here we have stumbled upon a "red flag" in the model/theory. If you cannot explain ***why*** the epicycles ***must*** be centered on the Sun other than "it must be so to explain the phenomenon," then your theory is flawed if not out and out wrong. These "red flags" should always be emphasized because they stand out as flaws which must eventually be explained or the theory rejected.

Of course we know that in the Copernican heliocentric model we don't need epicycles to cause Mercury and Venus to wobble back and forth around the Sun because they are simply closer to the Sun than Earth and they orbit the Sun. In fact, Copernicus was the first to completely untangle the motions of Mercury and Venus from the Sun's motion. In the geocentric model, the relative distances of the bodies from the Earth was simply one of relative motions, *i.e.,* the bodies which appeared to move the fastest were deemed to be the closest to the Earth. However, in carefully inspecting the motions of Mercury, Venus and the Sun, we see that all three orbit around the Earth in one year! So which one is closest to Earth? This was a hotly debated subject within the geocentric proponents, and the major view which we depict here was arrived at because Mercury moves the fastest in its epicycle while it's moving around the Earth, Venus next fastest, and the Sun doesn't retrograde at all, and hence the order we have in this model. This confusion is one rarely discussed reason why the Copernican heliocentric model was so appealing. It unambiguously separated the motions of Mercury and Venus and even established, for the first time, their orbital periods around the Sun (88 days and 225 days, respectively). [See the lessons on Synodic Periods in Volume 3 of the Fulldome Curriculum.]

In addition to watching the motions of the closer bodies to Earth, the Control Panel has sliders which, when slid to the right, will reveal a plot of the position of the planets' motions showing their retrograde loops. The further the slider is moved to the right, the more of the past history of the motion is displayed, as shown in Figures 7 and 8 for Mercury and Venus, respectively.

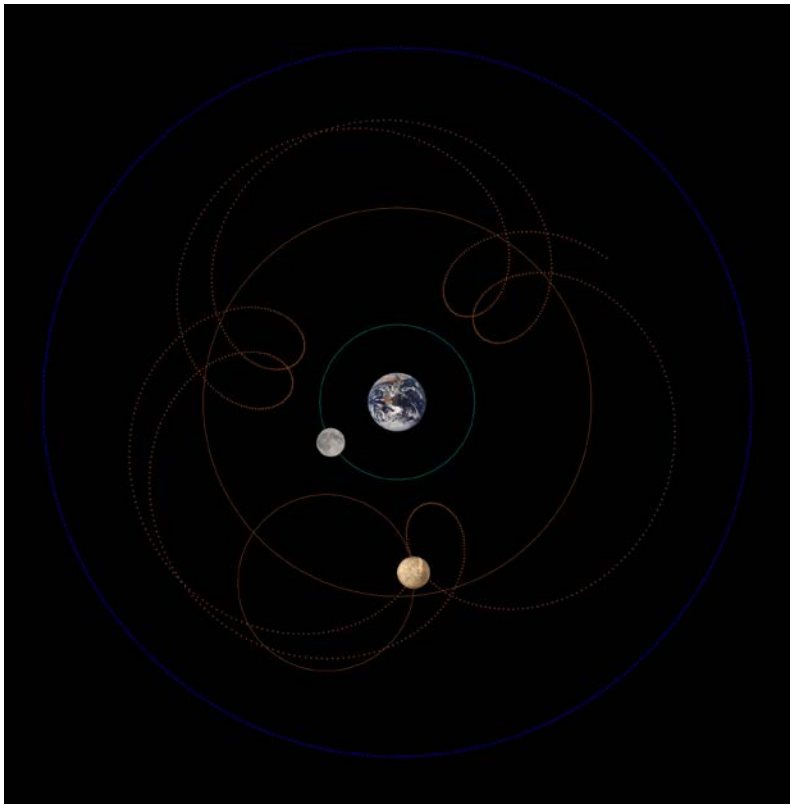

Figure 7 – Mercury’s retrograde loops displayed

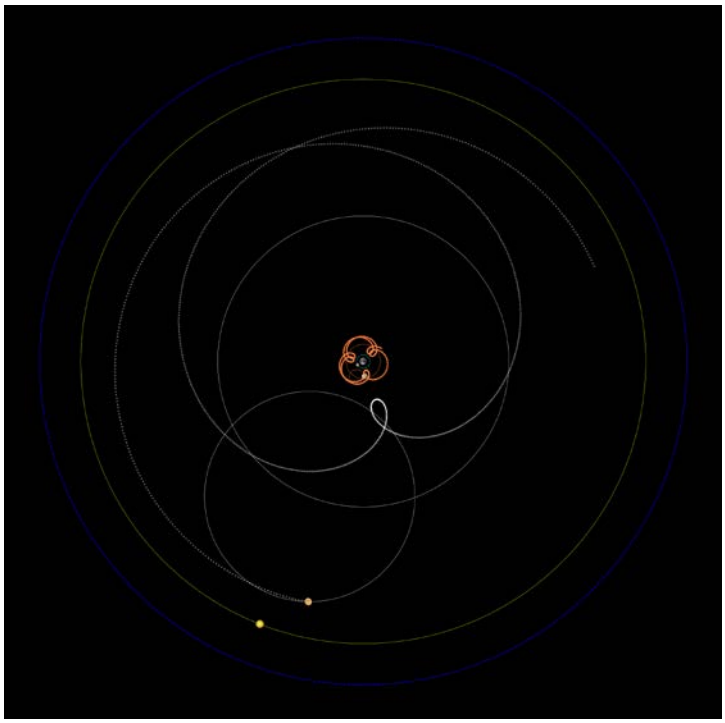

Figure 8 – Venus’ retrograde loop displayed

Now let's zoom out and concentrate on the planets beyond the Sun. Turn on all the planets in the upper left hand menu and move all the sliders to the far left. Zoom all the way out so that you can see all the planets, and then play time and have the audience carefully watch the motions of the more distant planets. Do they see anything systematic in the way that they move? I suspect that they will not, as the systematics of their motion are a bit more subtle than Mercury and Venus' epicycles moving in lock step with the Sun.

To help visualize the systematics, turn on the Lines function as shown in Figure 9 and the display will look something like Figure 10.

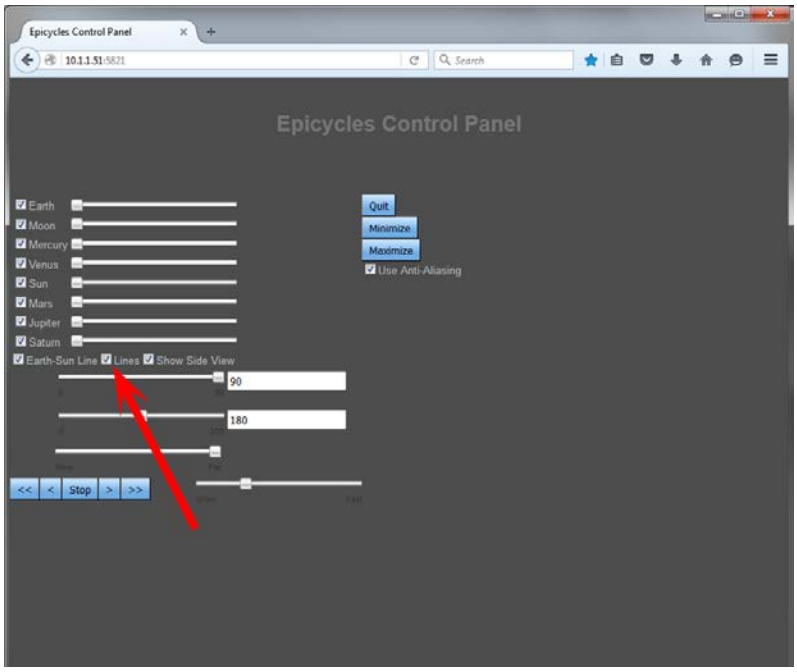

Figure 9 – Lines turned on via the Control Panel

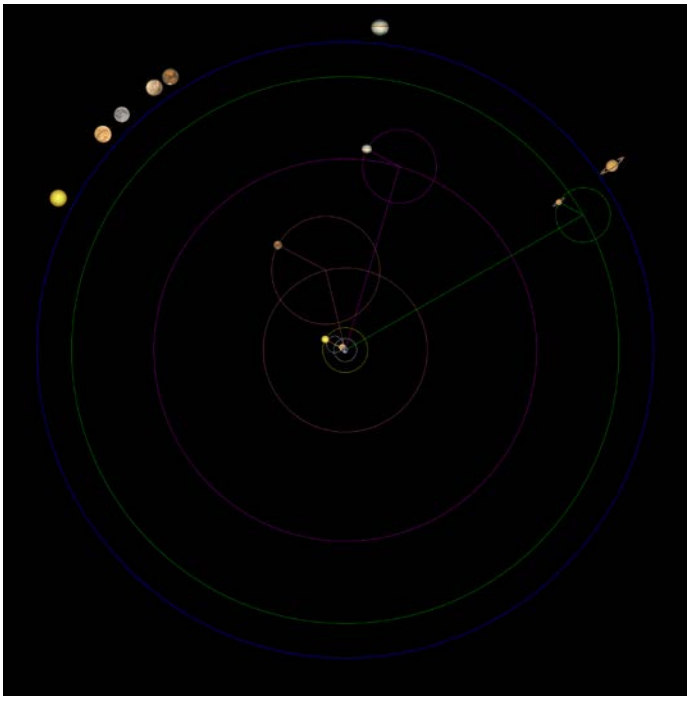

Figure 10 – Epicycle radii Lines turned on

The Lines drawn are the lines from the Earth to the center of the epicycle for each planet as well as the radius of each planet's epicycle to the planet itself. Make sure that the Earth-Sun Line is also displayed.

Play time again and see if this helps. If no one picks it up, then you will have to point out that the Earth-Sun Line is always parallel to the planet's epicycle radius. Again, the ancients noted this "coincidence" but could never explain it other than "it has to be this way for the model to work." Another "red flag" has raised itself in the flawed Ptolemaic model! The basic reason for this "coincidence" is because the retrograde motion of each planet is a function of its position relative to the Earth in its own orbit. Since we're locking down the Earth and moving the Sun, it's the orientation of the Earth-Sun line that is the determining factor as to when planets exhibit their retrograde motions.

You can now move the sliders for the outer planets to the right and continue time moving forward to display their retrograding loops, as shown in Figure 11.

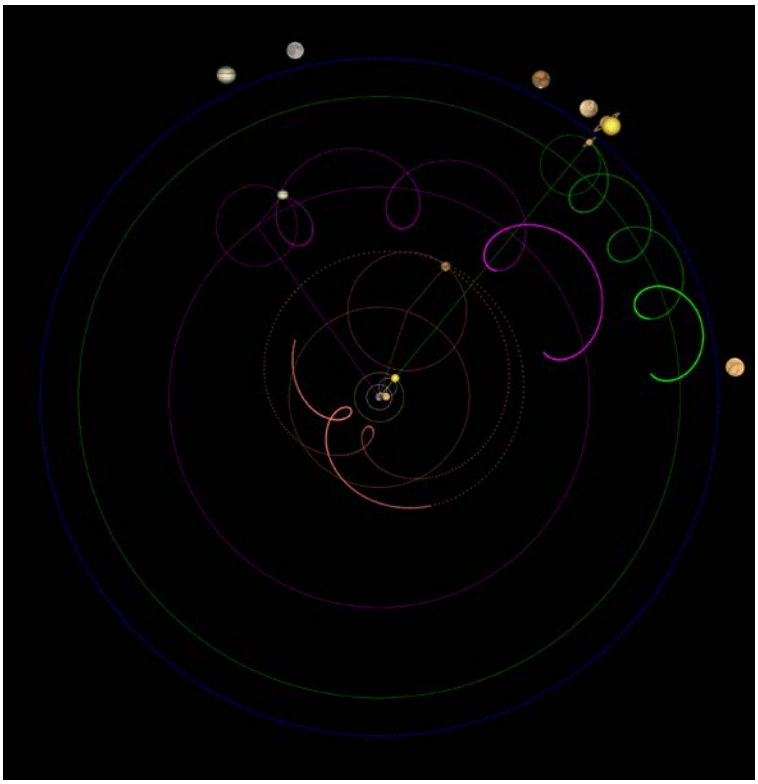

Figure 11 – Outer planets orbits displayed with their retrograde loops

Other questions you could ask your audience might be why Jupiter's retrograde loops are more spread out than Saturn's [because Jupiter moves faster and therefore farther in its orbit than Saturn in the time that the Earth-Sun line sweeps by and signals a retrograde loop]. You could also ask why Mars has only one loop in the time that Jupiter and Saturn have nearly two [because Mars moves so quickly it takes nearly two years in between retrograde loops as the Earth has to catch up with it (or the Earth-Sun line in this case)].

Don't be afraid to experiment with the program! My main purposes in using this teaching tool are to demonstrate how ingenious the system is in reproducing complicated celestial motions, but also to emphasize that preconceived notions can severely hamper scientific progress and that we often tremendously complicate a model in order to save it rather than objectively examine it and propose a newer, simpler one to replace it if the newer model works more simply at explaining the phenomena. But having the Earth move was a huge paradigm shift, and it took over 1500 years to overthrow it!