# Naked Eye Astronomy, Day 7: Planetary Theories

1. Review
   (a) Please ask questions at ANY TIME.
   (b) Web page with resources for the course: `https://osp.berry.edu/SeniorScholars`.
   (c) Recall our observations of the planets.
      i. All planets generally move eastward along the ecliptic, but occasionally stop and move westward for a bit before resuming their eastward motion.
      ii. The inferior planets (Mercury, Venus) are always near the Sun, with Venus straying farther then Mercury. Both retrograde in conjunction with the Sun. They both have tropical periods of one year, but have different synodic periods.
      iii. The superior planets (Mars, Jupiter, Saturn) do not stay close to the Sun but can be at any elongation from conjunction to opposition. They retrograde in opposition. Mars has the largest retrograde, then Jupiter, then Saturn. Meanwhile Saturn has the longest tropical period, then Jupiter, then Mars. These planets (but especially Mars) are brightest when they are in retrograde/opposition.
   (d) Now we will look at three historical theories to explain these planetary motions.
2. Eudoxus' Theory
   (a) Show simulation of Eudoxan theory. Explain the basic structure of nested spheres with Earth at the center, and how each sphere spins on an axis that is attached to the next sphere out. Turn on tracing, tilt sphere, play to show hippopede. Then turn on motion of orange sphere to show retrograde.
   (b) Criticisms: pattern repeats but that doesn't happen in real life, can't make numerical values work for some planets, no change in distance so no change in brightness.
3. Ptolemaic Theory
   (a) Inferior planets: show simulation and discuss basic deferent-epicycle idea with Earth at center of deferent. For inferior planets the motion along the deferent is linked to the Sun's motion so that the center of the epicycle is always on the Earth-Sun line. Thus the planets stay near the Sun and have a tropical period of 1 year on average. Motion on epicycle produces retrograde when the planet moves closer to Earth, which is when it is in conjunction.
   (b) Show full version of inferior theory, mention equant but don't discuss in detail.
   (c) Superior planets: show simulation. Same basic structure as before except now planet is beyond the Sun. For superior planets it is the motion on the epicycle that is linked to the Sun. Note how the line from the epicycle center to the planet is always parallel to the Earth-Sun line. This ensures that the planet can only retrograde in opposition, which will also be when the planet is closest to Earth and therefore brightest!
   (d) Show full version but don't say much about it.
   (e) Mention that the simulations only show motion along ecliptic. We can get motion above or below the ecliptic by tilting the epicycle and/or deferent.
   (f) These models worked very well quantitatively, giving predictions that were less than a degree off from the actual locations (at least for a while).

(g) Criticisms: why the mysterious connections to the Sun? Can't use these models to determine sizes of orbits (free to rescale deferent and epicycle by any factor as long as it is the same for both), so it can't even tell us the order of the planets (although Ptolemy assumed a specific order).

4. Copernican Model

   (a) Show simulation for Venus. Note that Venus moves faster than Earth along its orbit. Sky view shows general eastward motion but retrograde when Venus laps Earth on the inside. At this point Venus is between Earth and Sun and thus is seen in conjunction. Note that in some sense this is just a rearrangement of Ptolemy's deferent and epicycle (the Earth's orbit is the deferent, Venus' orbit is the epicycle). This model can be used (with some trigonometry) to find the SIZE of Venus orbit relative to Earth's.

   (b) Show full version but don't say much.

   (c) Show Mercury and note smaller orbit which results in Mercury staying closer to Sun.

   (d) Show simulation for Mars. Note that Mars moves slower than Earth. Mars seen to generally move eastward but retrogrades when Earth laps it on the inside. At this point Earth is between Mars and the Sun, so Mars is in opposition and closest to Earth (thus brightest). Again this is a rearrangement of Ptolemy's circles (Mars' orbit is deferent, Earth's orbit is epicycle). Once more we can find the size of Mars' orbit relative to Earth's.

   (e) Show full version quickly.

   (f) Show Jupiter and Saturn. Note decreasing size of retrograde arc as size of orbit increases relative to Earth's.

   (g) Copernicus provides a natural explanation for retrograde, explains the mysterious links with the Sun (they are really links with the Earth's motion!), and gives us a definite ordering and sizes for the planetary orbits.

   (h) Criticisms: what we have discussed previously about the moving Earth (contradicts Aristotle, Scripture, common sense, stars crazy far away, big gap between Saturn and stars, etc).

   (i) Copernicus' planetary theory was so beautiful that a few people like Johannes Kepler and Galileo Galilei thought it must be right. Kepler improved Copernicus' theory, Galileo argued for it using his new telescopic discoveries, and eventually it caught on. Then Newton (building on the work of others) explained the physics of how it all worked.

5. Questions and conversation