Lecture 01

PY3109: Observational Astrophysics

Module Objective: To provide students with an overview of observational astrophysics.

Module Content: Magnitude brightness scale, optical telescopes, introduction to radio, IR, UV, X-ray astronomy, Hertzsprung-Russell diagram, stellar spectra & classification, variable and binary stars.

Learning Outcomes: On successful completion of this module, students should be able to:

1. Perform simple numerical calculations covering a wide range of astronomical topics, including magnitude brightness scale, radio, IR, UV and X-ray astronomy.
2. Explain the theory of star formation, stellar atmospheres and stellar structure.
3. Apply stellar structure theory to white dwarfs and neutron stars.
4. Demonstrate the ability to perform astronomical observations and gather astronomical data.

Assessment: Total Marks 100: Formal Written Examination 80 marks; Continuous Assessment 20 marks (10 assignments, 2 marks each).

Section 1: The Coordinate System

Relevant Literature: Chapter 1 of Ryden & Peterson

Key Question
How do we convey the positions of stars in the night sky to people who are observing from a different place on the Earths surface, or who live at different time to us (and make sense of observations taken thousands of years ago)? Defining a coordinate system which accounts for the tilt and precession of the Earths spin axis relative to the Sun-Earth orbital plane is non-trivial, and in order to understand it, we must go back to the ancient Greeks.

The evolution of the solar systems geometry - Geocentrism

Humans have a long history of studying the position of stars in the night sky. One of the oldest models is the geocentric model, proposed by Plato. In this model, the Earth lies at the centre of everything, and the stars and planets are on a celestial sphere which is rotating around us. There are a few useful definitions which come from this projection which we still use today. The projection of the Earth's equator onto the sphere is the **celestial equator**, while the projection of the poles onto the night sky gives us the **celestial poles**.
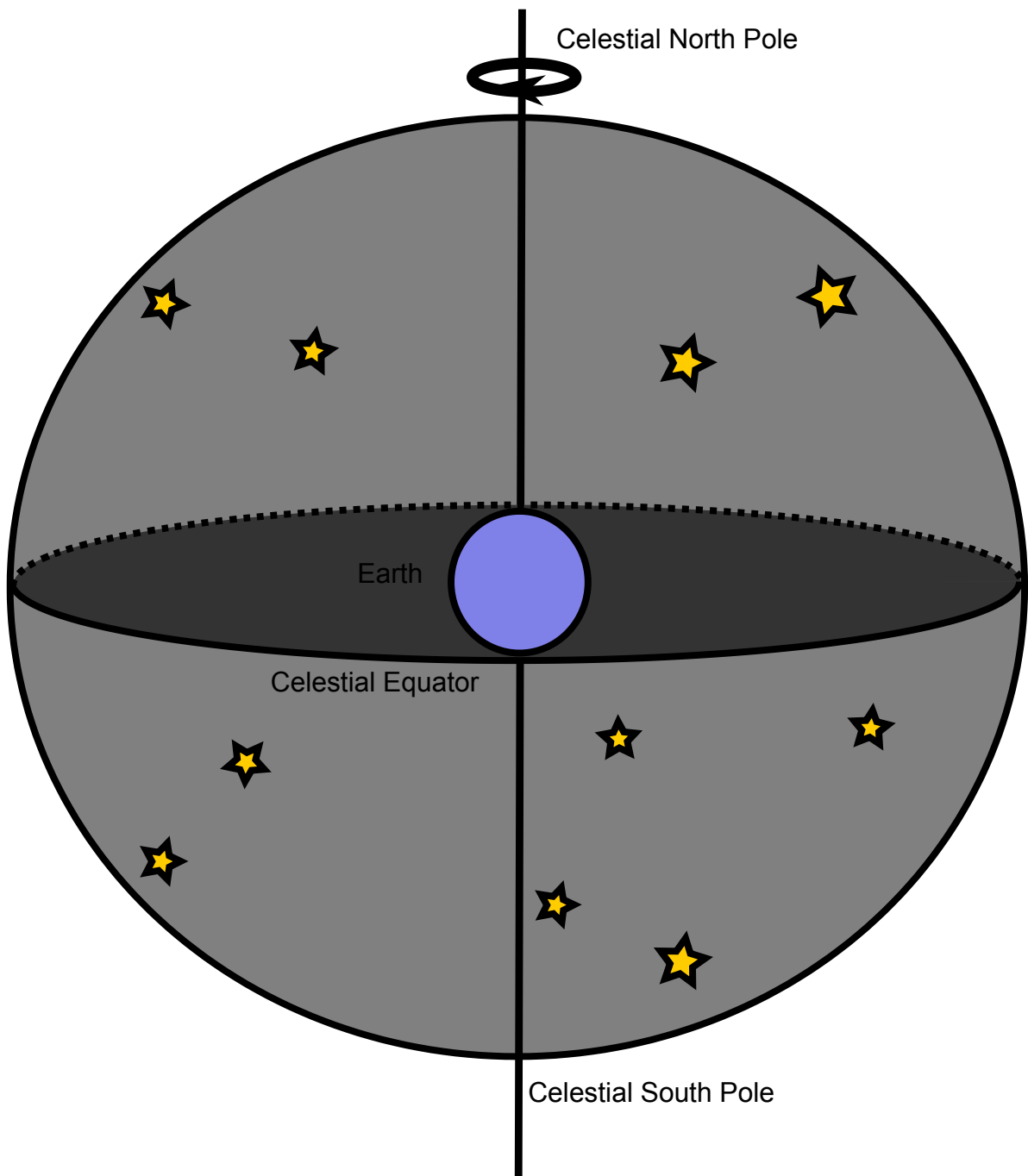
This model works well at explaining the diurnal (daily) motion of stars, but the "wandering stars", or planets, could not be. These planets would slowly move West to East with respect to the fixed background stars, but would occasionally reverse direction before reverting back to West to East. An example of this movement is shown below for Venus.
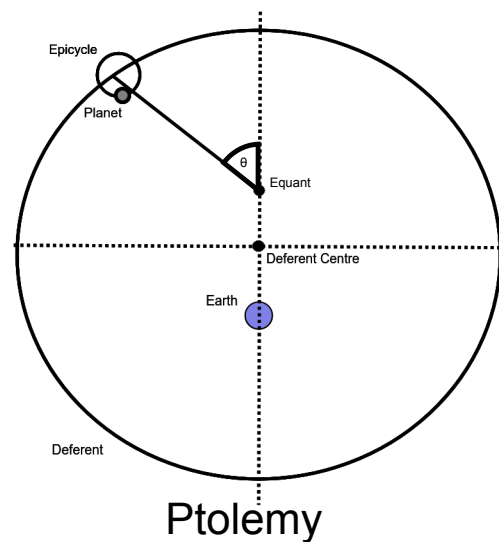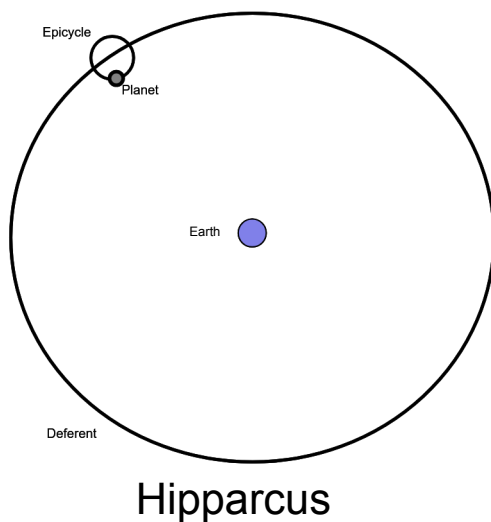
Location of Venus from 2015-06-19 to 2015-10-25
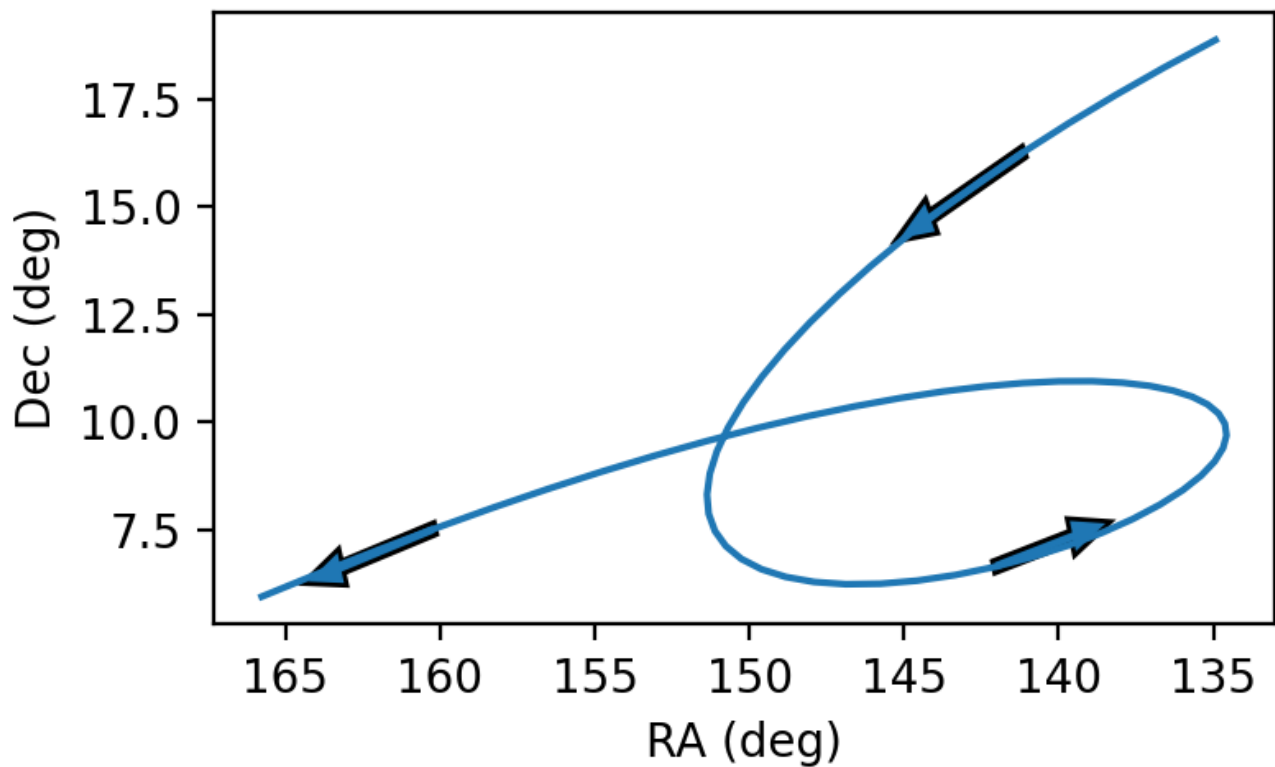
epicycle
deferent
equant

$$\frac{d\theta}{dt}$$

is constant, which allows for a circular orbit to give the same observed effects as a body which is following an elliptical orbit. While still not perfect at predicting the motions of the planets, it could easily be adapted to new observations by adding in new circles.


Hipparcus

Ptolemy

While these models were incredibly precise at predicting the positions of stars, the requirement to constantly add new circles to explain the complex motion of the planets suggested that something was wrong with them. One of the final versions of this model is shown below, and really hammers home how complicated the model had to be in order to explain the motion of *just Venus and Mercury*.
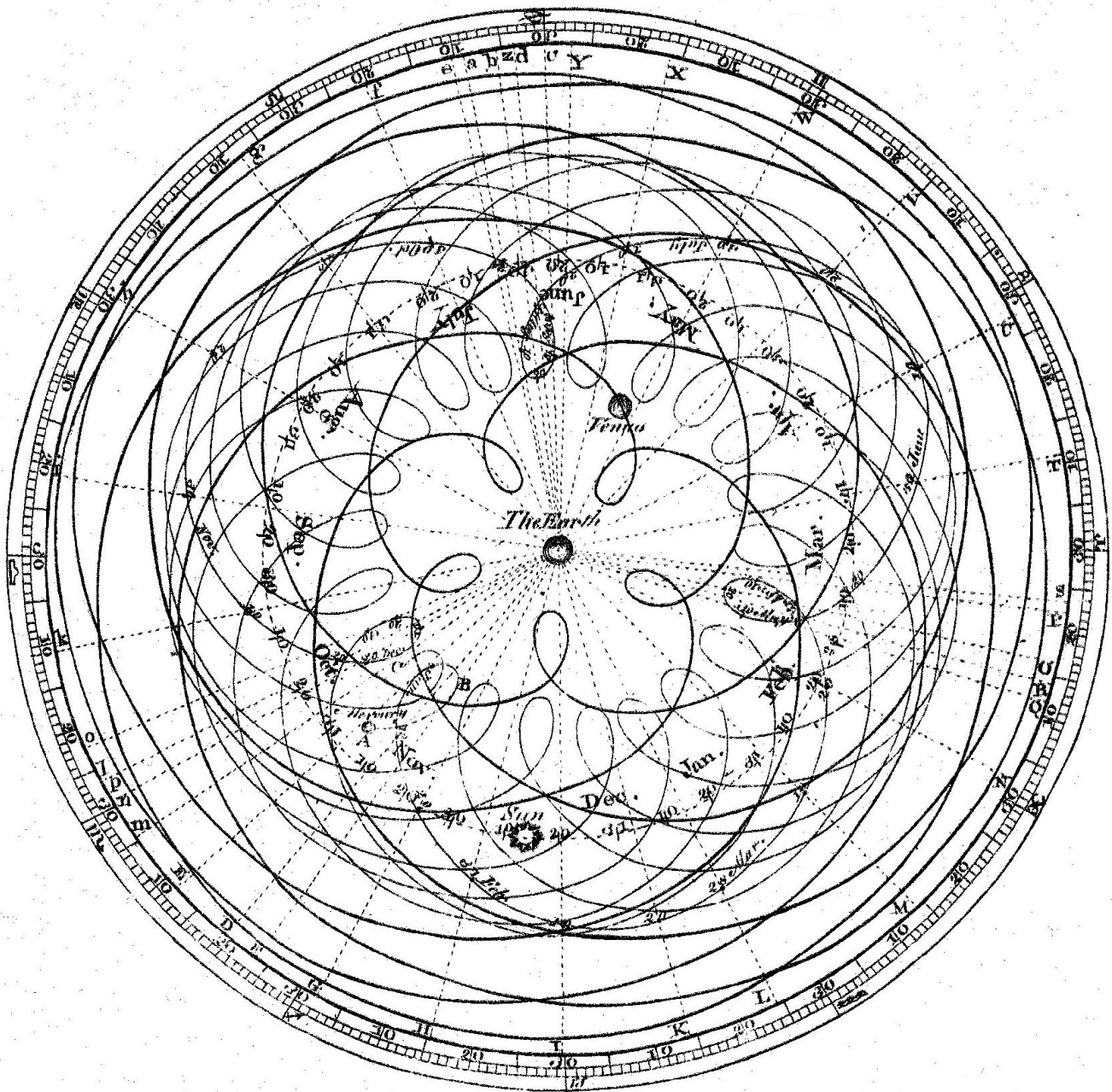
The evolution of the solar systems geometry - Heliocentrism

It took until the 15th century to move away from this geocentric view of the solar system, when Nicolaus Copernicus proposed a heliocentric model of the planets. One immediate consequence of this was that the maximum angular distance of both Venus (47°) and Mercury (28°) from the Sun meant that they had to lie within Earth's orbit, and that Mercury had to lie closest to the Sun.

Sun

Mercury

Venus

28°

47°

Earth

Sun
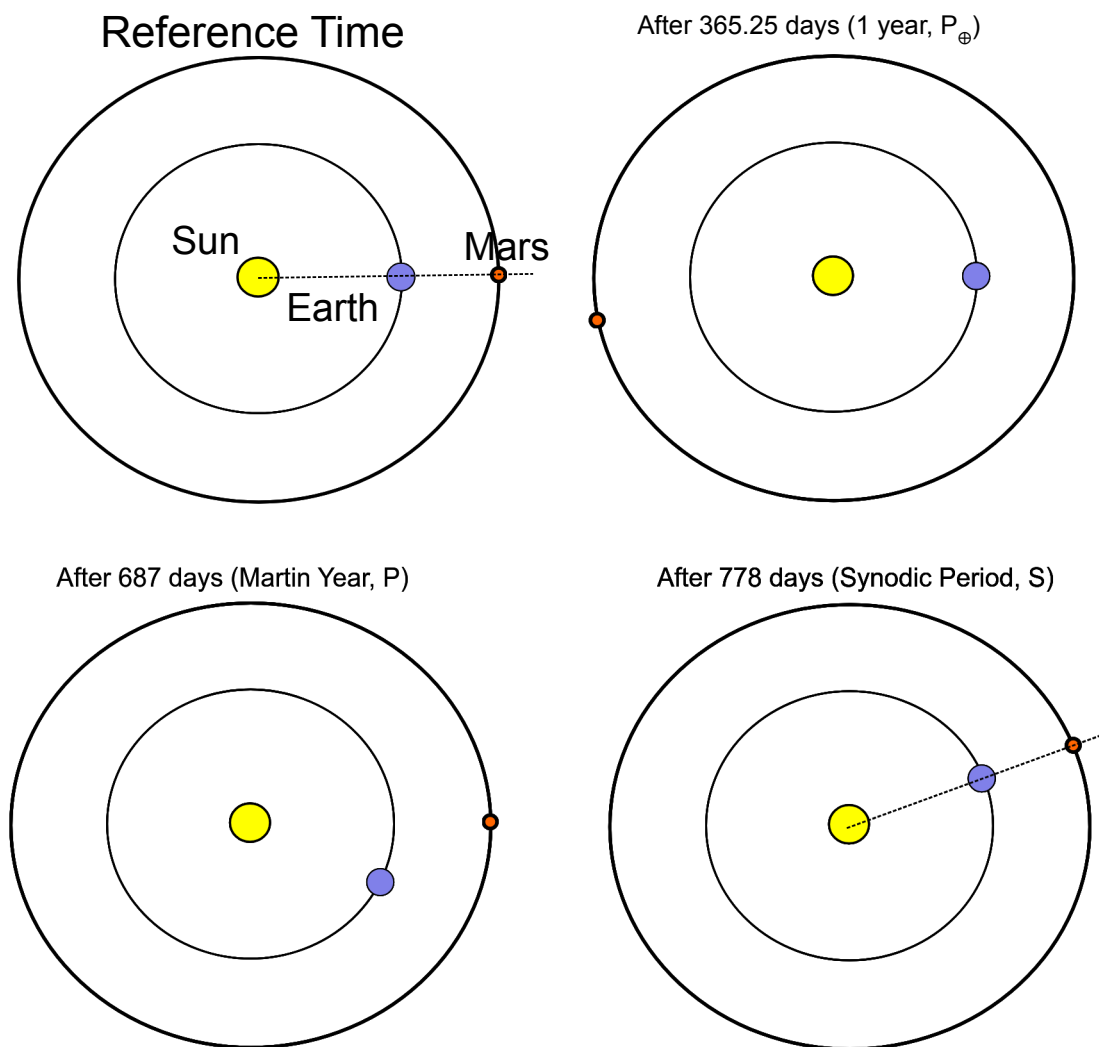
Earth

Mars

Fixed background stars
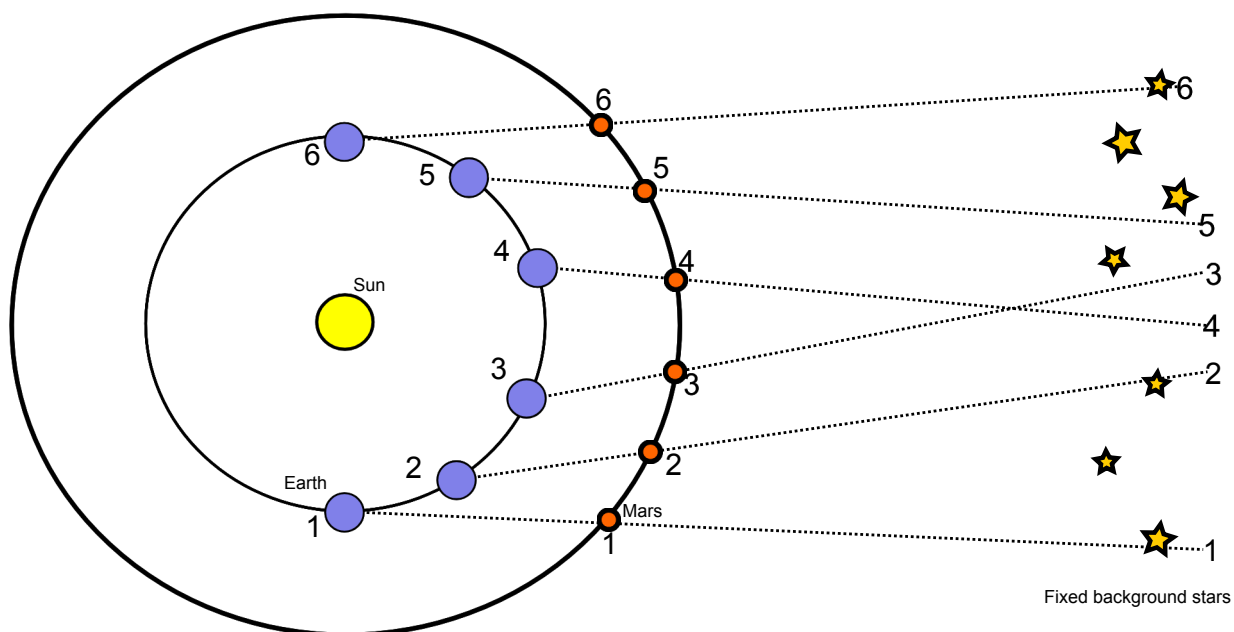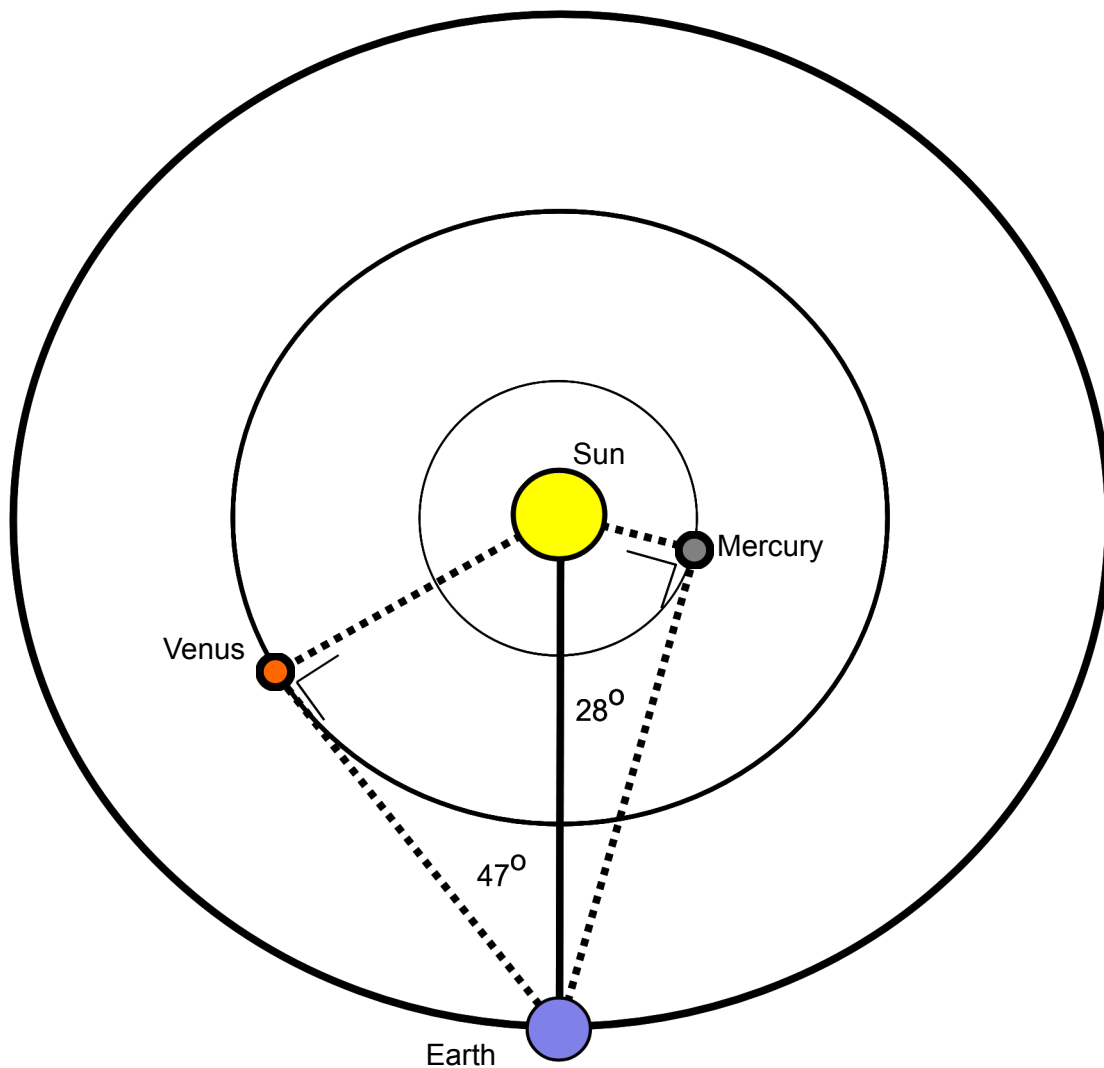
Heliocentrism also allows us to calculate the **true** (sidereal) orbital periods of the planets. Consider a planet which is further from Earth than the Sun. Conjunctions occur when all planets and the Sun lie on a straight line connecting their centres. In the below, when the Earth lies between the Sun and Mars, is called **opposition**. The time between successive oppositions is S, the synodic period. The sidereal period of the planet, P, can then be calculated using

$$\frac{1}{P_S} = \frac{1}{P_\oplus} - \frac{1}{P} \quad (P > P_\oplus)$$
$$\frac{1}{P_S} = \frac{1}{P} - \frac{1}{P_\oplus} \quad (P < P_\oplus)$$

where $P_\oplus$ is the Earth's period of 365.256308 days. Once P has been determined, Kepler's laws can then be used the separation between the Sun and the planet.

Reference Time

After 365.25 days (1 year, $P_\oplus$)

After 687 days (Martin Year, P)

After 778 days (Synodic Period, S)

While elegant in explaining the motion of the planets, the heliocentric model was as accurate as the geocentric model when it came to predicting the positions of bodies in the night sky - mainly because Copernicus still required that planets orbit in perfect circles. Epi-cycles were introduced into the Copernican model in order to have the predicted observations match positions.

It wasn't until Kepler derived his laws and incorporated eccentricities into the orbits of planets that the accuracy of positions increased by several orders of magnitudes, helping solidify the heliocentric model as the correct model.