

The Copernican Model (1543)

The Copernican Model is Heliocentric and Geodynamic

Heliocentric = “Sun Centered”

Geodynamic = “Earth in motion”

(The Ptolemaic Cosmology was Geocentric and Geostatic.)

The Earth rotates eastward about its axis.

The rotation period with respect to the stars is the Sidereal Day.

The Sidereal Day is 23^h 56^m 04^s

The Earth, like all other planets, revolves about the Sun.

The Earth orbits the Sun with an orbital period of one year.

The Sidereal Year is 365.256.. Sidereal Days

Its Rotation Axis is Inclined with respect to its Orbital Axis

The inclination angle remains (essentially) fixed

The “Obliquity of the Ecliptic” is 27.45°

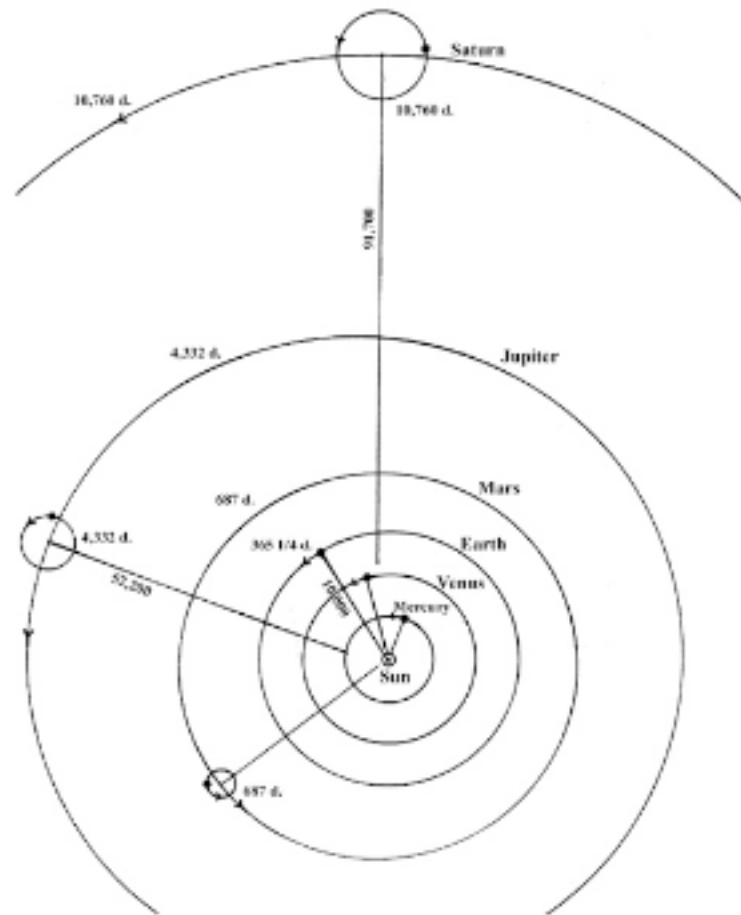
.....and this gives rise to the seasons.

The inclination direction slowly changes

The Precession Period is about 25,700 years (*cf.* Hipparchus)

The Copernican System (1543 CE)

The Sun and Celestial Sphere are fixed. The Earth, Moon, and Planets all move.



Note that the deferent circles and epicycles can have central offsets and tilts.
Only the epicycles associated with Mars, Jupiter, and Saturn are indicated.

Digression: Orbital Periods and Synodic Periods

- The time required for a planet (or other object) to complete an orbit about the Sun with respect to the **stars** is its **Sidereal Period**
(... sometimes called its orbital period)
- The Earth's orbital period is the **Sidereal Year** of 365.26 days.
(This is therefore the time required for the Sun, as seen from the Earth, to appear to complete a full circuit of the celestial sphere.)
- The **Synodic Period** of an object is the time required for it to make a complete circuit of its motions with respect to the **Sun** as seen from some other object (usually the Earth).
- The Sidereal and Synodic periods of two objects are related by
$$1/P_{\text{synodic}} = 1/P_{\text{shorter}} - 1/P_{\text{longer}}$$

Example: The Synodic Period of Mars as seen from the Earth (or *vice versa*) is observed to be **2.135** years. The orbital period of the Earth (which is shorter than that of Mars) is **1** year. The orbital (sidereal) period of Mars, in years, is therefore given by

$$1/2.35 = 1/1 - 1/P_{\text{Mars}} \quad \text{or} \quad P_{\text{Mars}} = 1.881 \text{ years}$$

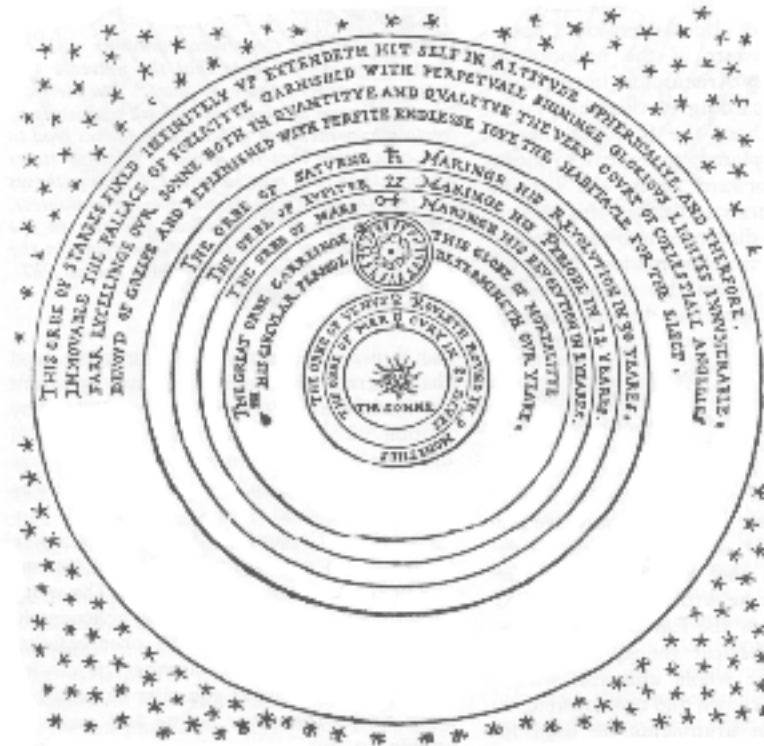
Completing the Copernican Revolution

Thomas Digges (1546-1595)

A Perfit Description of the Caelestiall Orbes... (1576)

A Heliocentric System - but not a Heliocentric Universe
(*cf.* Democritus & Aristarchus)

Tycho's Observations indicate that the stars are at $>1,700$ the Sun's distance



Completing the Copernican Revolution

Johannes Kepler (1571-1630)

Astronomia Nova (1609) & *Harmonice Mundi* (1619)

also, *The Optical Part of Astronomy* (1604)

Kepler and Tycho: Observations of Planetary Motions

Kepler's Determination of the Martian Orbit: Method

Kepler's Empirical Laws of Planetary Motion

I. The orbits of the planets are ellipses with the Sun located at a focus of the ellipse.

(Motions are neither circular nor combinations thereof. Not really heliocentric.)

II. The line joining planet to Sun line sweeps out equal areas in equal intervals of time.

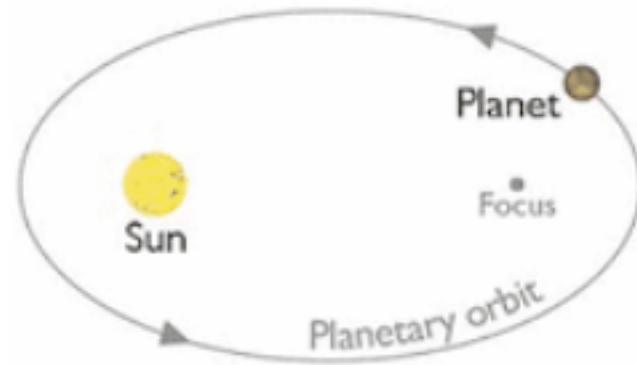
("Law of Areas" - Motions are nonuniform.)

III. The square of the orbital period is proportional to the cube of the length of the orbit's semi-major axis.

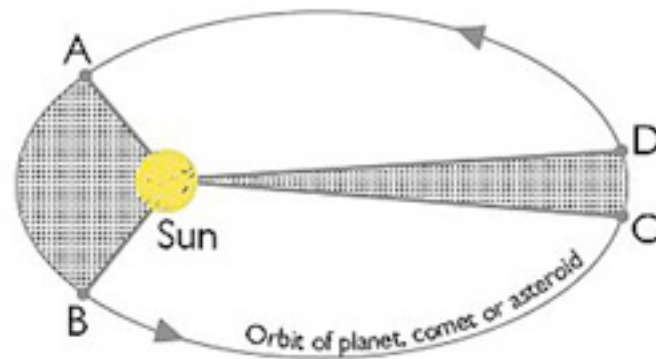
("Harmonic Law" - The constant of proportionality is the same for all planets.)
....again, a "not quite" heliocentric system.

Kepler's Laws:

Kepler I:



Kepler II:



Kepler III:

$$P^2 = Ka^3 \quad \text{where } \mathbf{K} \text{ is a constant.}$$

Testing the Copernican Model (and the “falsification” of the Ptolemaic Model)

Galileo Galilei (1564 - 1642)

Sidereus Nuncius (1610)

Dialogue Concerning the Two Chief World Systems (1632)

Aristotelian Physics Falsified

Observational and experimental verification of assumptions

Introduction of the idea of experimental and observational verification!

Experiments with falling objects

The acceleration of falling objects: $v = gt$ independent of m !
(also $d = (v/2)t$ implying constant acceleration, g .)

The Law of Inertia

The ideas of inertia, mass, and momentum

“Gravitational Mass” and “Inertial Mass”

Abolishing the need for a “Prime Mover”

The Leaning Tower



The Cathedral of Pisa



Galileo's Laboratories?

Galileo's Astronomical Observations

New Technology: The Telescope (....and the microscope)

Sidereus Nuncius (1610) - “The Sidereal Messenger”

- **Lunar topography** (Mountains, valleys, craters, and “seas”)
- **The Milky Way - stars!** (*cf.* Democritus)
- **Sunspots** (and Solar rotation)
- **Planetary markings** (and rotation)
- **Saturn's rings** (a puzzlement!)
- **Spherical planets shining by reflected sunlight** (*cf.* the brightness problem)
- **The Galilean Satellites of Jupiter** (“Medicean Stars”) and **Jovicentric motion.**
and especially

The gibbous phases of Venus!

A clear falsification of the Ptolemaic Model - (but not of Tycho's Construction)

History: Galileo & The Inquisition

Orders from the Inquisition (Decree of 1616)

The *Dialogue*.. (1632) and the Index of Proscribed Works

The Trial and Conviction of Galileo (1633)

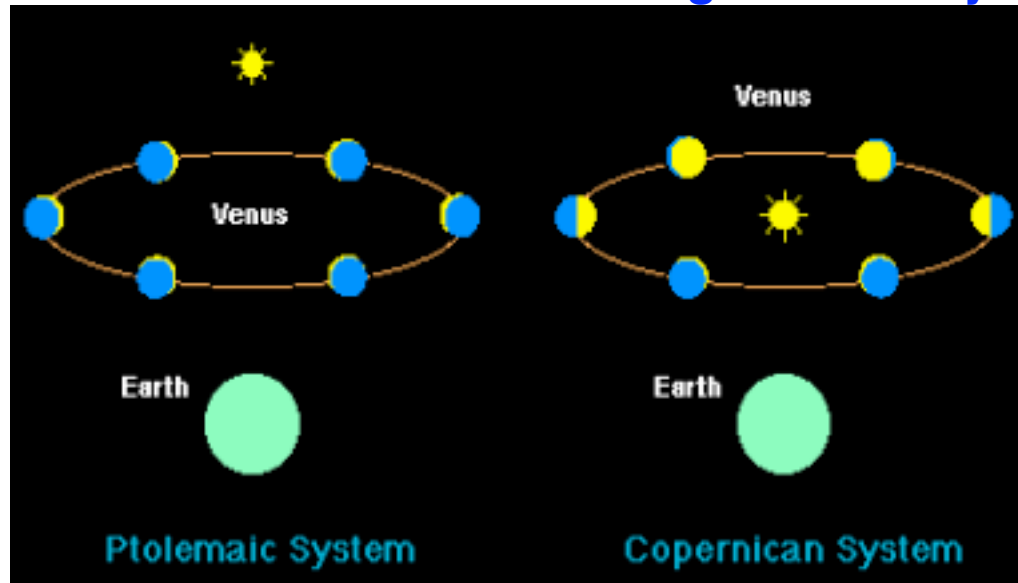
“Epur si muove”

Rehabilitation of the *Dialogue* and Galileo (1741, Benedict XIV)

Heliocentrism officially accepted by the church (1748)

Galileo exonerated (1992, John Paul II)

Predictions: The Phases of Venus according to Ptolemy and Copernicus



Observations: Galileo's observations of planets - and the phases of Venus

