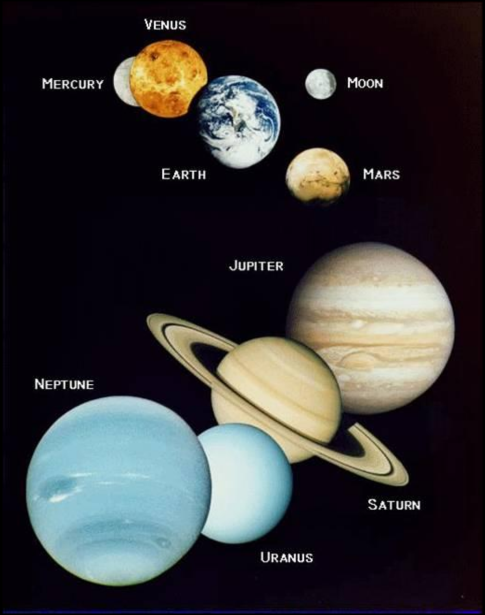
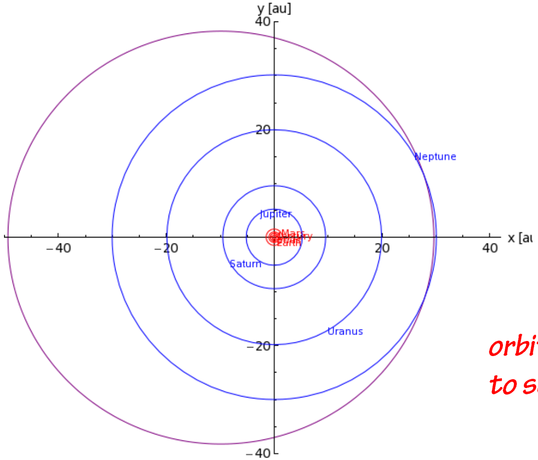
The Solar System



Collage of the planets; not to scale

The solar system

(Pluto)
Neptune
Uranus
Saturn
Jupiter
Mars
Earth
Venus
Mercury
Sun



Sun
Planets
Asteroids
Comets

orbits drawn to scale

Historical figures in the Copernican Revolution

Ptolemy – the geocentric model, that the Earth is at rest at the center of the Universe (...lived in Egypt, 90 – 168 AD)

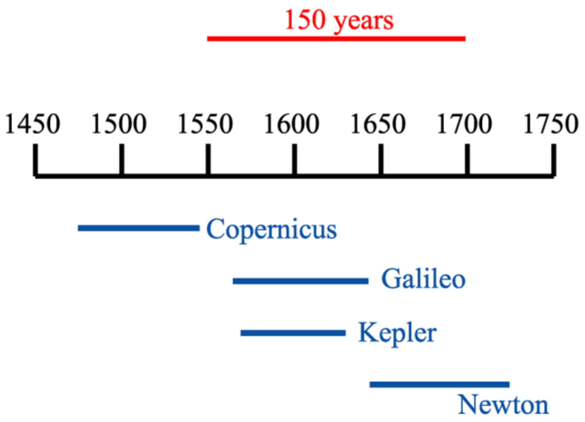
Copernicus – published the heliocentric model.

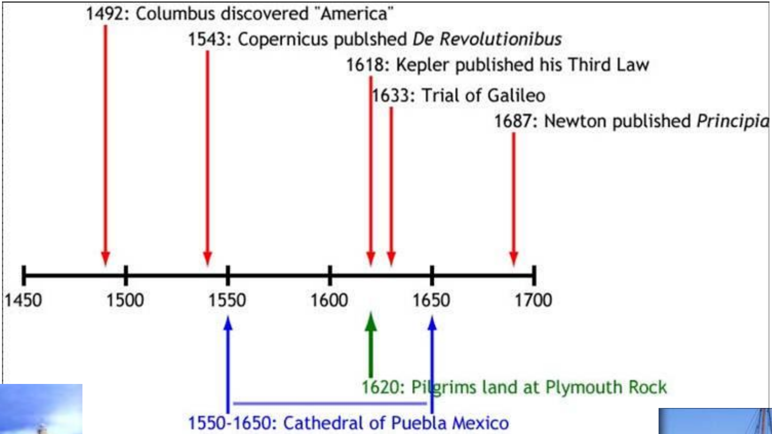
Galileo – his observations by telescope verified the heliocentric model.

Kepler – deduced empirical laws of planetary motion from Tycho's observations of planetary positions.

Newton – developed the full theory of planetary orbits.

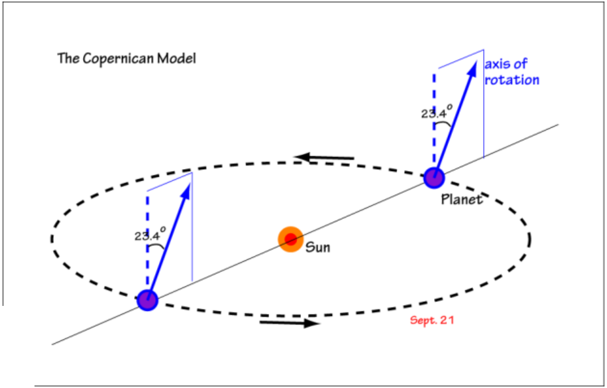
The Copernican Revolution




1492: Columbus discovered "America"
1543: Copernicus publshed *De Revolutionibus*
1618: Kepler published his Third Law
1633: Trial of Galileo
1687: Newton published *Principia*
1450
1500
1550
1600
1650
1700
1620: Pilgrims land at Plymouth Rock
1550-1650: Cathedral of Puebla Mexico

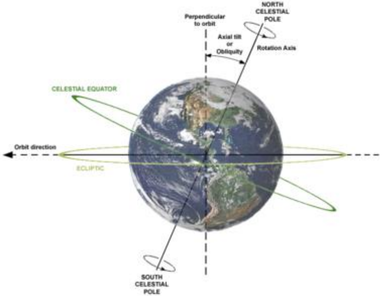
Nicolaus Copernicus

Nicolaus Copernicus



The Earth moves, in two ways:

- It rotates around a fixed axis (period = 1 day).
- It revolves around the sun (period = 1 year).

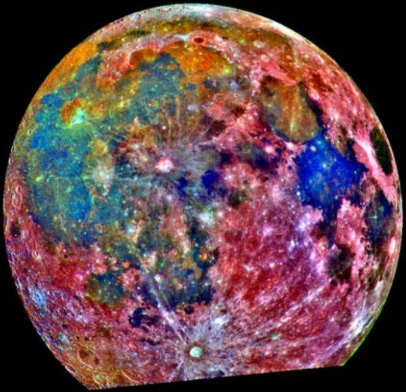


Galileo Galilei

Galileo's sketch of the moon as seen from his telescope

A photograph of the moon

"What do you think of the foremost philosophers of this university? In spite of my oft repeated efforts and invitations, they have refused, with the obstinacy of a glutted adder, to look at the planets or Moon or my telescope." (letter to Kepler)



False Color Image

The exaggerated color helps determine surface composition (blue is titanium-rich, orange lower titanium, purple pyroclastic, red iron and titanium poor).

The surface of the Moon

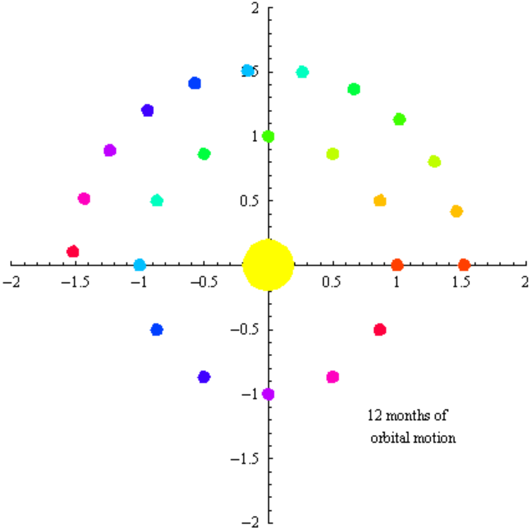
Johannes Kepler (1571 – 1630)

… discovered three empirical laws of planetary motion in the heliocentric solar system

1. A planet moves on an elliptical orbit, with the sun at one focal point.
2. The radial vector sweeps out equal areas in equal times.
3. The square of the period is proportional to the cube of the radius.

(needed for the CAPA)

How did Kepler determine the planetary orbits?



pare the heliocentric model to naked-
astronomy

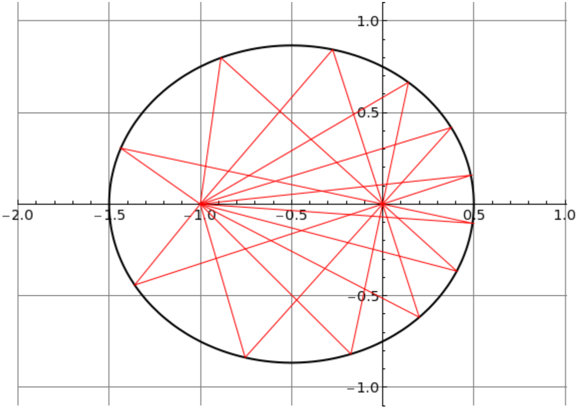
The inner planet is Earth; the outer one is Mars. Plot their positions every month. Mars lags behind the Earth so its appearance with respect to the Zodiac is shifting.

The most complete data had been collected over a period of many years by Kepler's predecessor, Tycho Brahe of Denmark.

Ellipse Geometry

To draw an ellipse: Take a string. Tack down the two ends. Put a pencil in the string and pull the string taut. Move the pencil around keeping the string taut.

An ellipse is the locus of points for which the sum of the distances to two fixed points is fixed.



The two fixed points are called the *focal points* of the ellipse.

Parameters of an elliptical orbit *(a,e)*

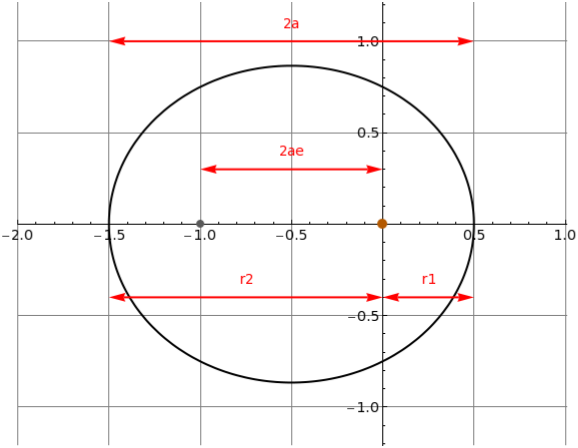
Semi-major axis = *a* = one half the largest diameter

- Eccentricity = *e* = ratio of the distance between the focal points to the major diameter

For example, this ellipse has a = 1 and e = 0.5.

- Perihelion and aphelion

Perihelion = $r_1 = 0.5$
Aphelion = $r_2 = 1.5$

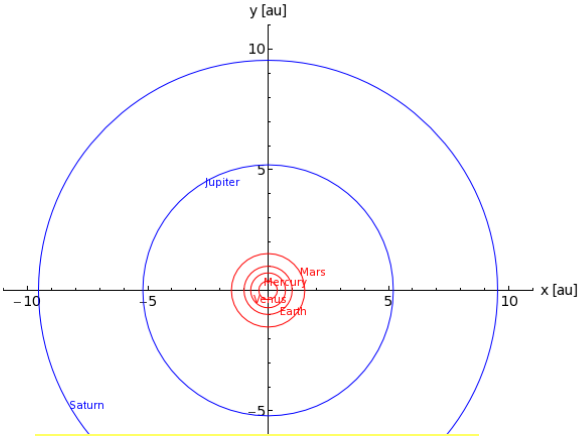


Isaac Newton

The observed solar system at the time of Newton:

Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn

(all except Earth are named after Roman gods, because astrology was practiced in ancient Rome)



Three outer planets discovered later…
Uranus (1781, Wm Herschel)
Neptune (1846 Adams; LeVerrier)
Pluto (1930, Tombaugh)

Isaac Newton

Newton solved the premier scientific problem of his time --- to explain the motion of the planets.

To explain the motion of the planets, Newton developed three ideas:

1. The laws of motion
2. The theory of universal gravitation
3. Calculus, a new branch of mathematics

$$\vec{\mathbf{a}} = \frac{\vec{\mathbf{F}}}{m}$$

$$\vec{\mathbf{F}} = \frac{G m_1 m_2}{r^2} \hat{\mathbf{n}}$$

"If I have been able to see farther than others it is because I stood on the shoulders of giants."

--- Newton's letter to Robert Hooke,
probably referring to Galileo and Kepler

Circular Orbits

(a pretty good approximation for all the planets because $e \ll 1$.)

$$a_r = -\frac{v^2}{r}$$

$$F_r = -\frac{GMm}{r^2}$$

[There is a subtle approximation here: we are approximating the center of mass position by the position of the sun. This is a good approximation because $M_{sun} \gg M_{planet}$.]

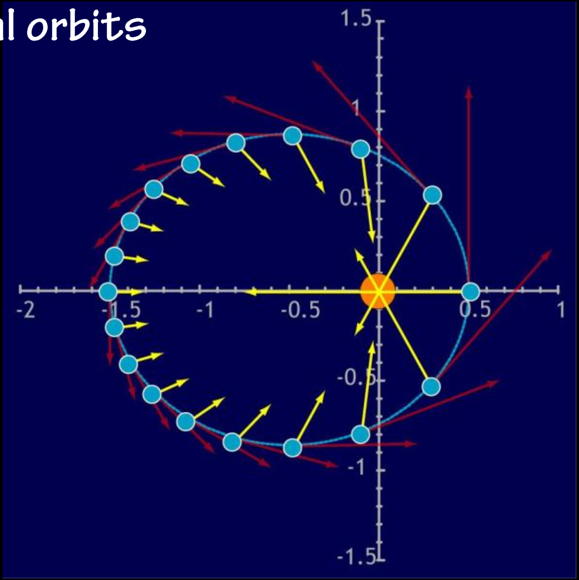
$$\vec{\mathbf{a}} = \frac{\vec{\mathbf{F}}}{m} \quad \text{implies} \quad \frac{v^2}{r} = \frac{GM}{r^2}$$

The mass of the planet cancels out!

Speed

$$v = \sqrt{\frac{GM}{r}}$$

Generalization to elliptical orbits



Velocity vectors in RED

Force vectors in YELLOW

Generalization to elliptical orbits

(and the true center of mass!)

$$T^2 = \frac{4\pi^2 a^3}{G(M+m)} \approx \frac{4\pi^2 a^3}{GM}$$

where a is the semi-major axis of the ellipse

The calculation of *elliptical orbits* is difficult mathematics.

The story of Newton and Halley

Many applications ...

END