A bit about myself: I like both Astronomy and Philosophy

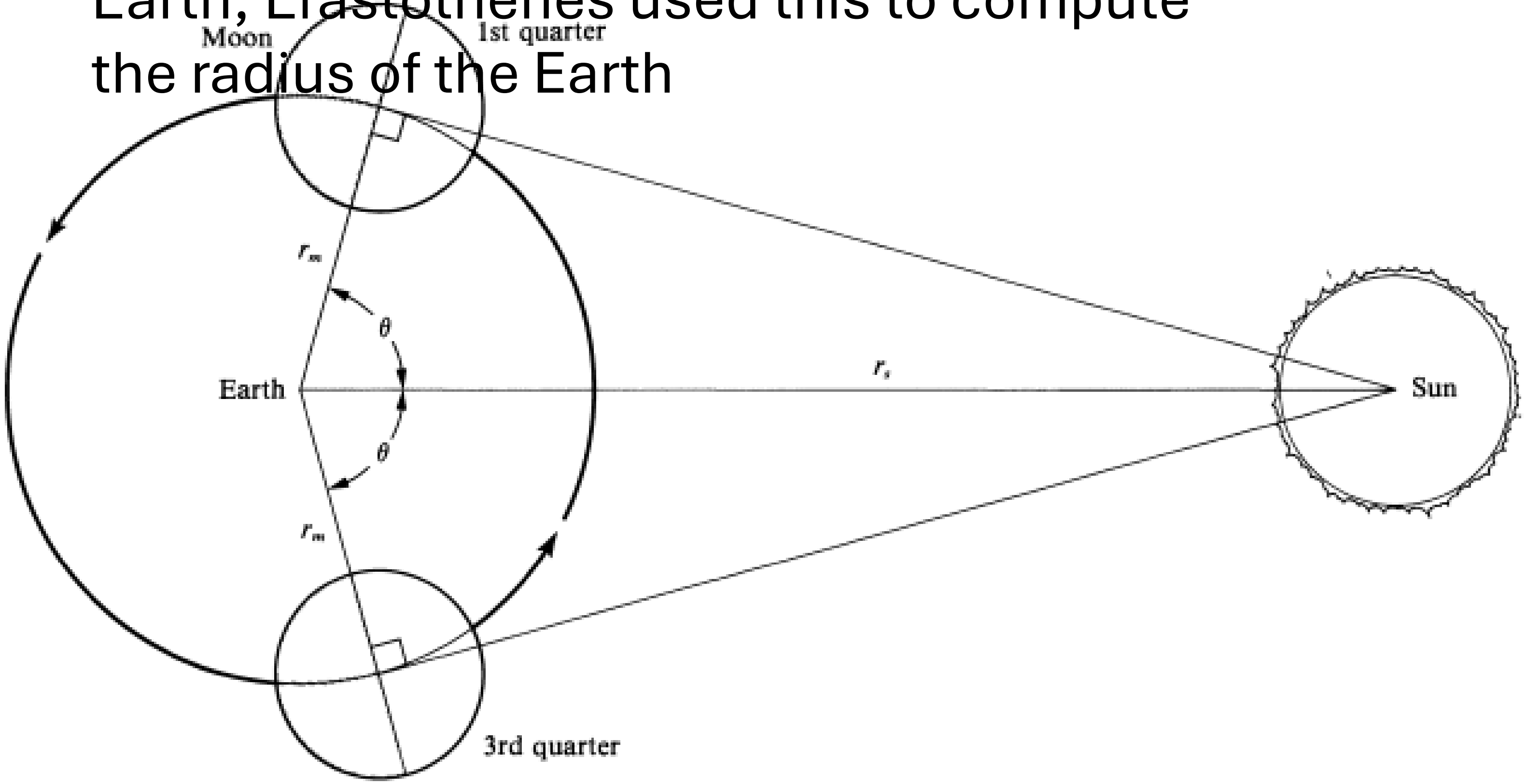
- Physics undergraduate studies mostly at Universidad de los Andes, Mérida
- Astronomy and **Philosophy** undergraduate studies in University of Central Florida
- Masters in **Philosophy** of Physics at University of Oxford
- Masters and Phd in Astrophysics at the University of Colorado, Boulder

At the end, one does not always need to choose

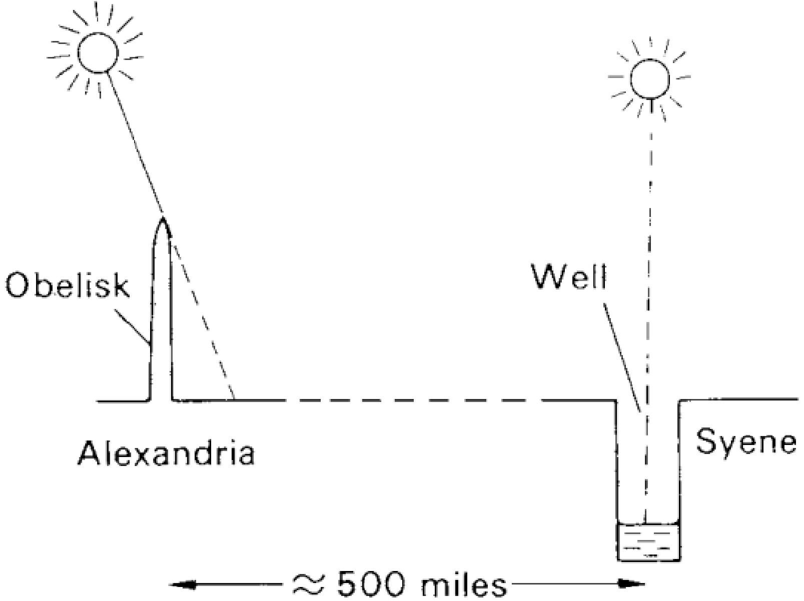
Period of the moon $\approx$ 29.5 days

Curvature of the Earth

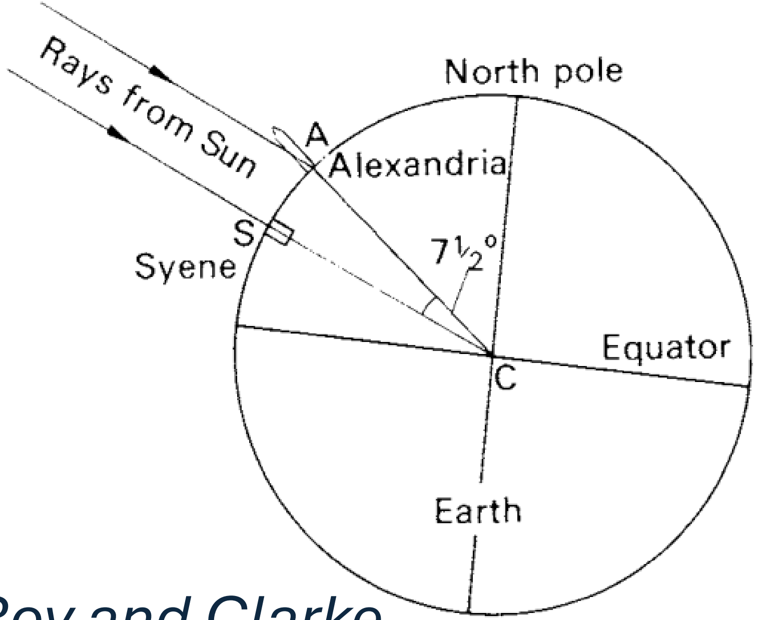
Aristarchus discovered the sun is very far away, and potentially huge compared to Earth, Erastothenes used this to compute the radius of the Earth



Aristarchus' argument, *From Shu, Intro. to Astronomy*



[redacted] The observations of Eratosthenes.



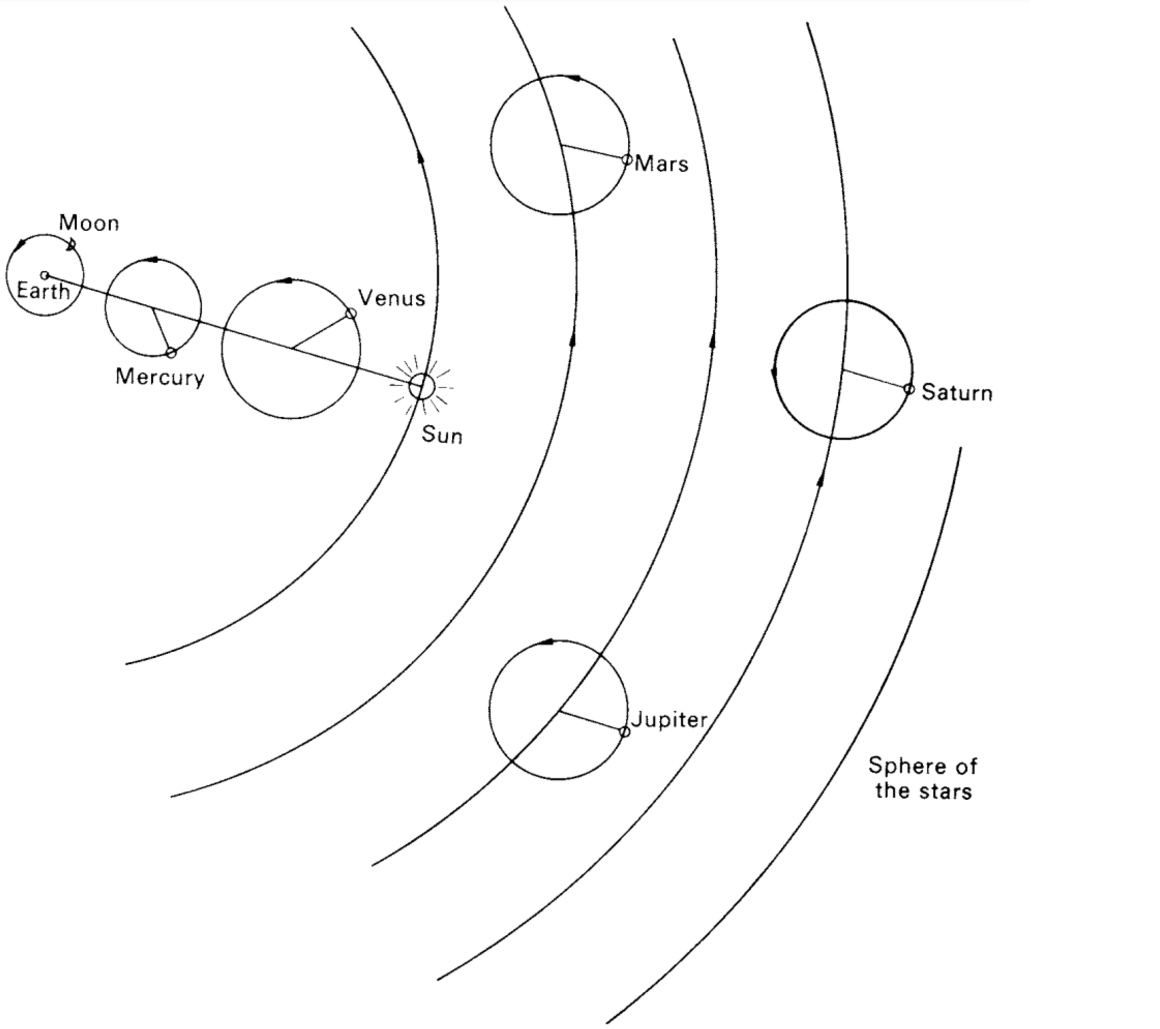
From Roy and Clarke

Ptolomy (~100 ac)

The Earth was the fixed at the center of the Universe.

The stars were fixed to the surface of a transparent sphere which rotated westwards in a period of one sidereal day.

The Sun and the Moon revolved about the Earth.



When the Arabian astronomer of the Middle Ages accumulated more accurate

From Roy and Clarke, under C

The first improvement to Ptolomy’s work. Hypatia (~300)

- Mathematician and Astronomer from Alexandria

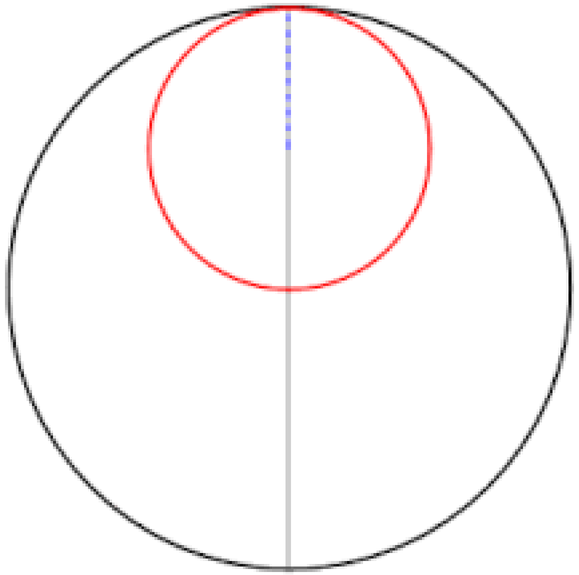
- Improved upon Ptolomy’s prediction by utilizing a novel long-division technique to obtain better planet positions.

Her edition was the version that went on the be re
by the Arab-Persians who continue to improve on
Ptolomy’s work

Hypatia

Nasir al-Din al-Tusi (1200)

He exposed problems present in Ptolemy's work. In 1261, he published his*Tadkhira*, which contained 16 fundamental problems he found with Ptolemaic astronomy.

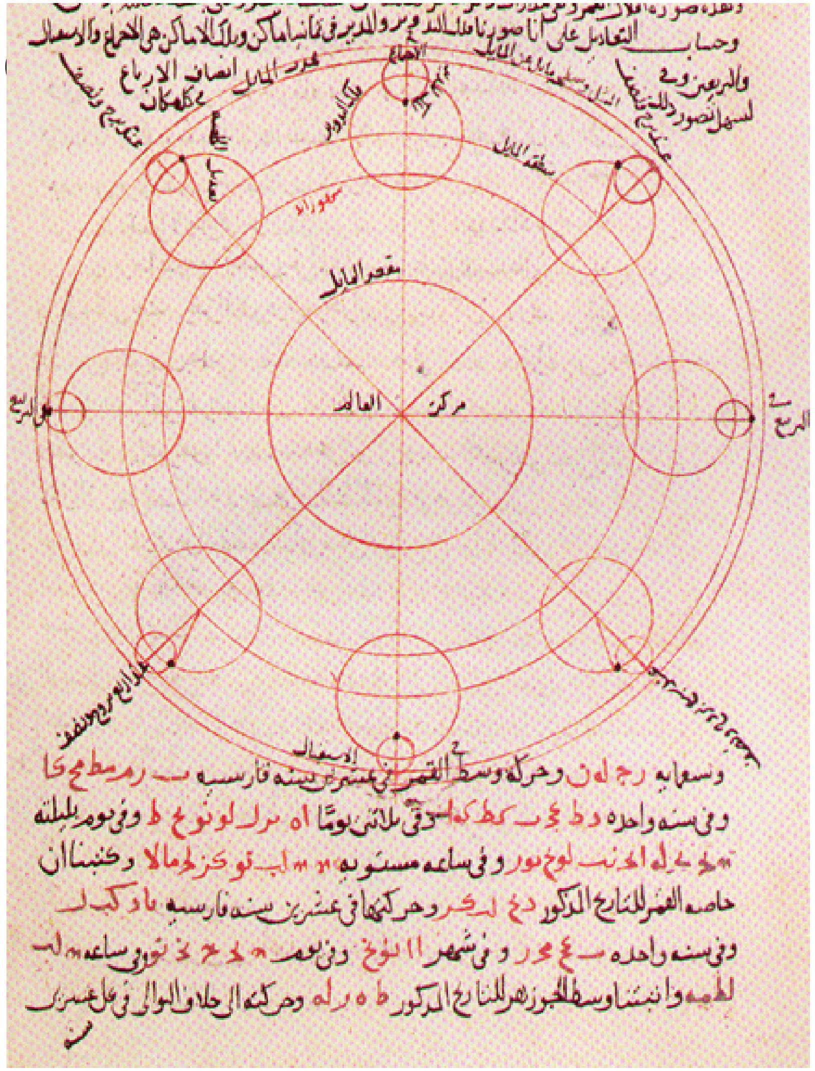


e changed how the epicycles work.

An uple. Made using Wolfram Mathematica. CC3.

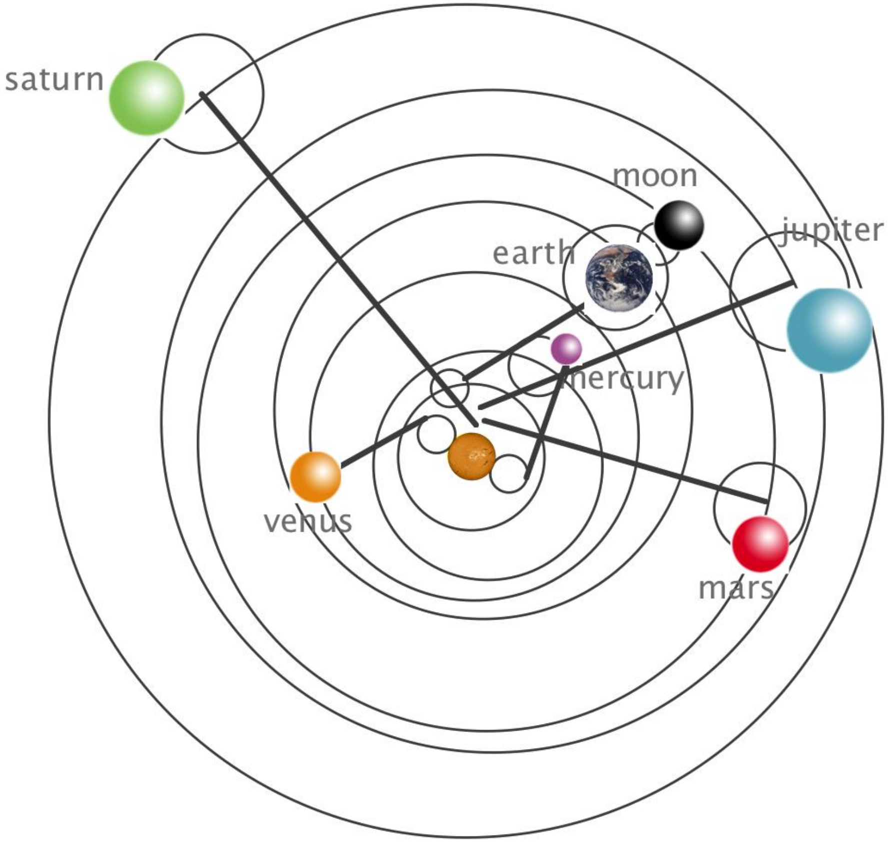
Ibn al-Shatir (1300)

Completes Ptolomy’s model by adding extra epi



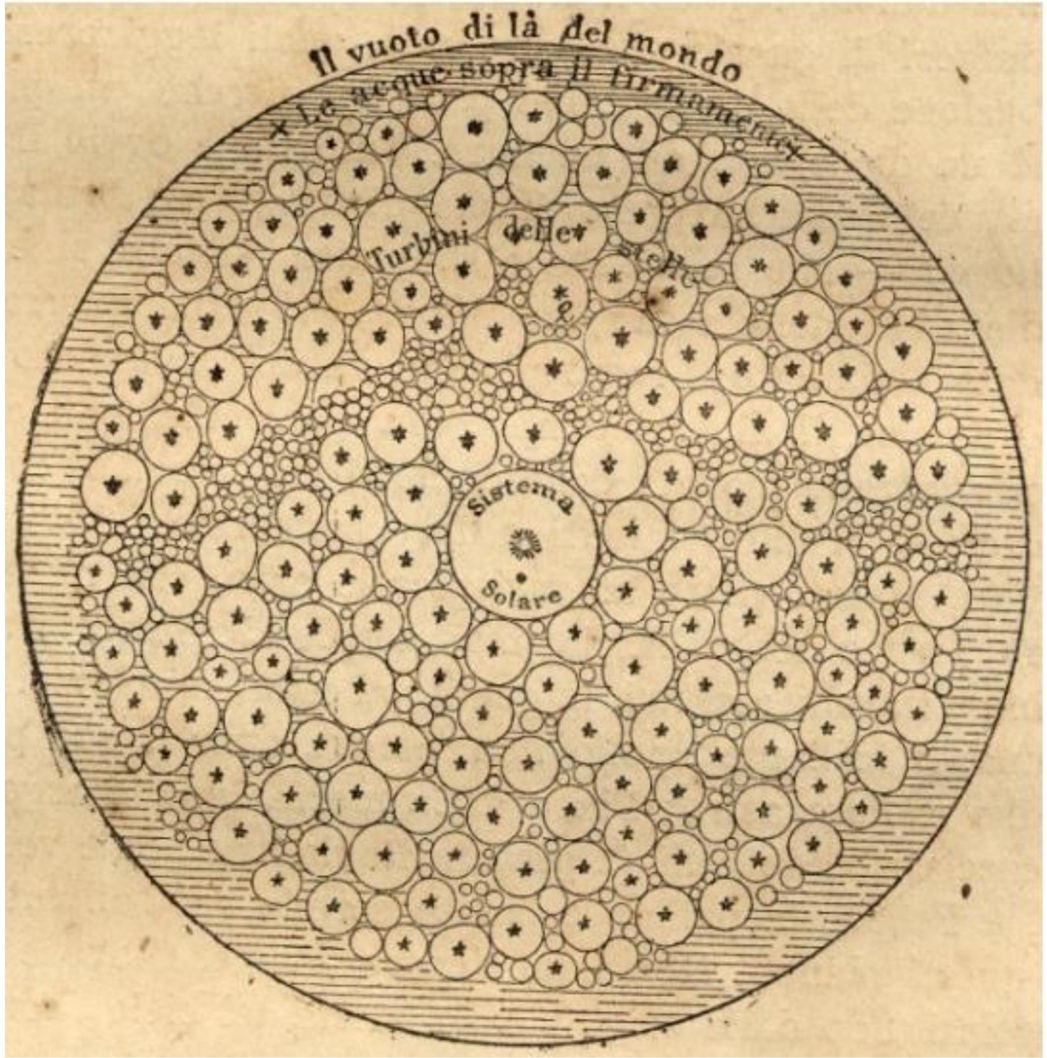
From his work: The New Planetary Handbook

A common misconception



Descartes Vortex theory

- There was no action at a distance, rather, gravity acted through contact with a vortex, which made all planets orbit the sun.



From Descartes, *A System of the World.*

Descartes had a second author: Elizabeth of Bohemia

They wrote dozens of letter, and Descartes will read to her his draft of books and discuss their id
He became his tutor in Philosophy and Morals.

She was interested in Natural Philosophy, and Astronomy in particular *(Ebbersmeyer, 2021).* Sh
was a patron of the Sciences (she will finance re

She focus was insisting in “efficient causal expla
of natural phenomena.” *(Shapiro, 2021)*

Descartes creates the 1st law of Newton

The claim that Descartes was the first to formulate the principle of inertia is based on the first two of his laws of nature, which read as follows: [2]

> *The First Law of Nature*: Each thing, insofar as in it lies, always perseveres in the same state, and when once moved, always continues to move.
>
> *The Second Law of Nature*: Every motion in itself is rectilinear, and therefore things which are moved circularly always tend to recede from the center of the circle which they describe.

Now compare this with Newton's first law of motion, which is the classic statement of the principle of inertia:

> Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.[3]

From Descartes' Laws of Motion, Richard J.

Sophia and Tycho Brahe

At the time, the debate between Heliocentric and Geocentric cosmologies was the biggest discussion between astronomers.
The offset between the real and predicted position of objects was measurable

Tycho and Sophia Brahe recorded the position of planets for decades. Their first recorded observation was done when he was 17 years old, and the last the year of his death, when we was 57.

Heliocentric and Ptolomeic model where at a draw

Tycho Brahe compared predictions from both, and while the Ptolomeic model did significantly better for predicting the motions of Venus, Mercury, and the Sun, the Heliocentric model did better predictions for Mars, Jupiter, and Saturn.

These are the name of ephemerides tables

Planet	Observed	Stadius	Carello
Venus	25°	22° 54′ (-3° 6′)	24° 3′ (-57′)
Mars	14°	12° 52′ (-1° 8′)	11° 20′ (-2° 40′)
Saturn	30°	27° 36′ (-2° 24′)	29° 53′ (-0° 7′)
Jupiter	3°	1° 30′ (-1° 30′)	0° 50′ (-2° 10′)

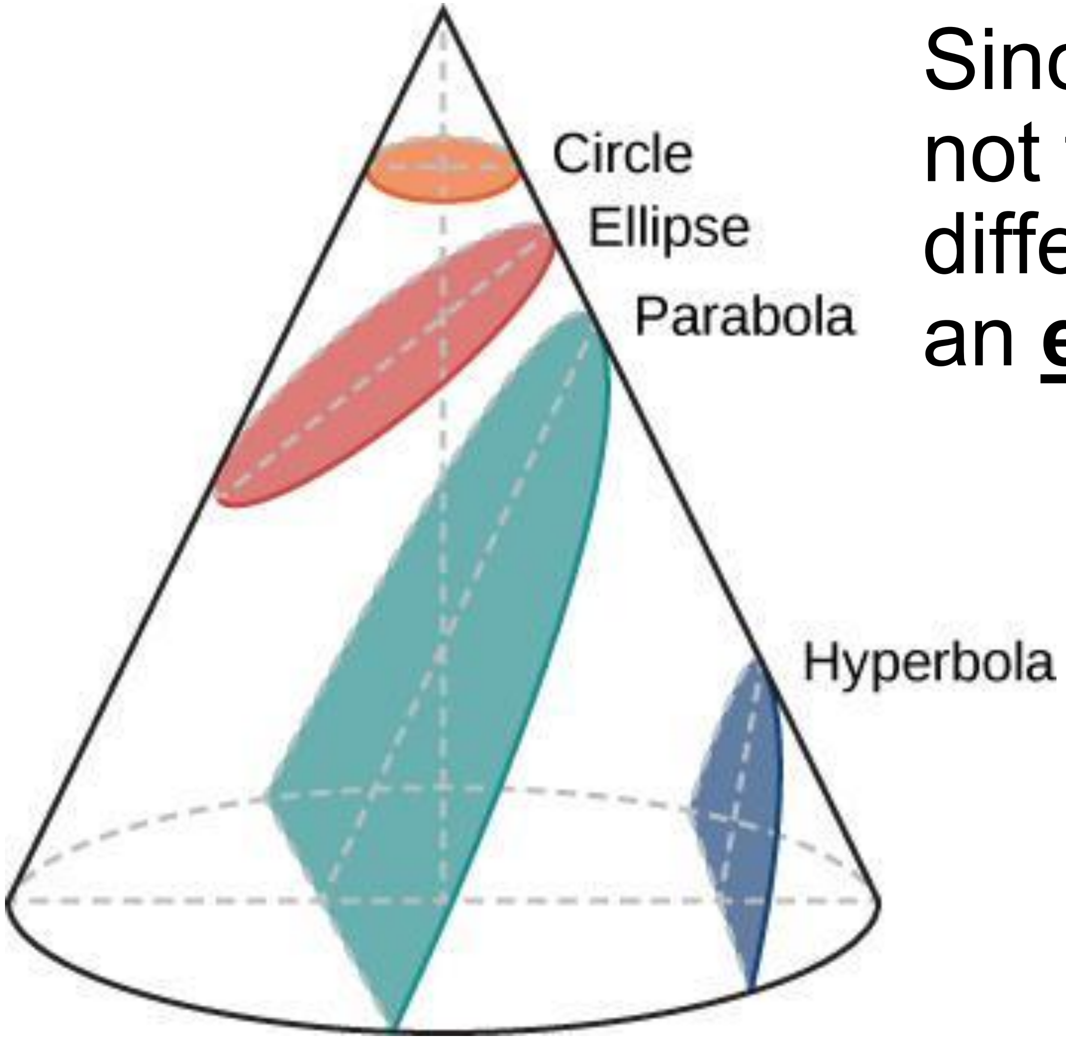
Ptolomeic astronomers, like John Dreyer, attributed the failing of the Ptolomeic model for certain objects to problems with the Carello tables. Clearly, the evidence was far from being strong to pierce through Geocentrism “protective belt.”

Johannes Kepler

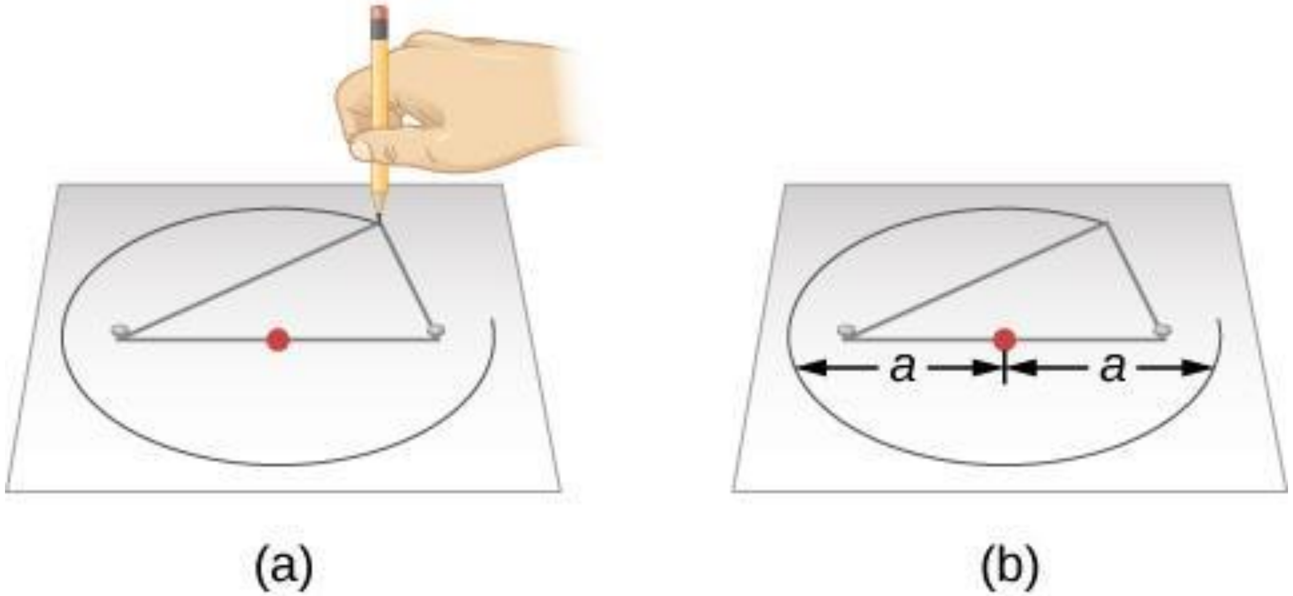
- Worked as a Clerk for Tycho. Wait until Tycho died and took his notebooks

- Finally resolved the discrepancy between both models

Kepler’s Laws of Planetary Motion



Since Kepler determined circles could not fit the orbital data, he tried a different “conic section” shape, called an **<u>ellipse</u>**.

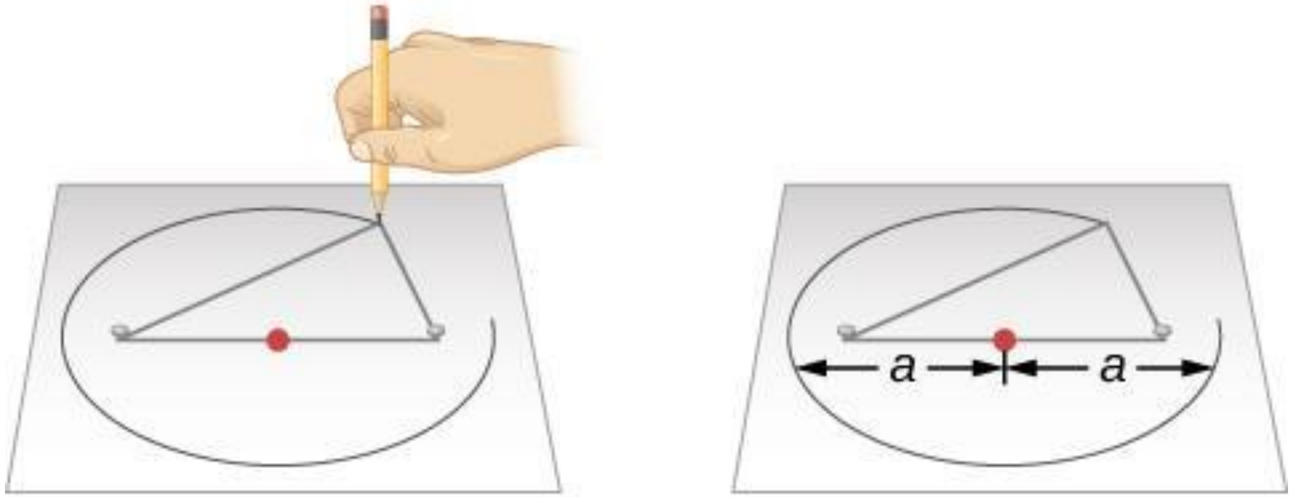


Kepler's First Law

Unlike a circle, an ellipse is not defined by a single central point, but rather two **foci** (singular: focus).

A circle has one radius that describes its size. An ellipse has a "long radius" called the **semi-major axis** (a) and a "short radius" called the semi-minor axis (b).

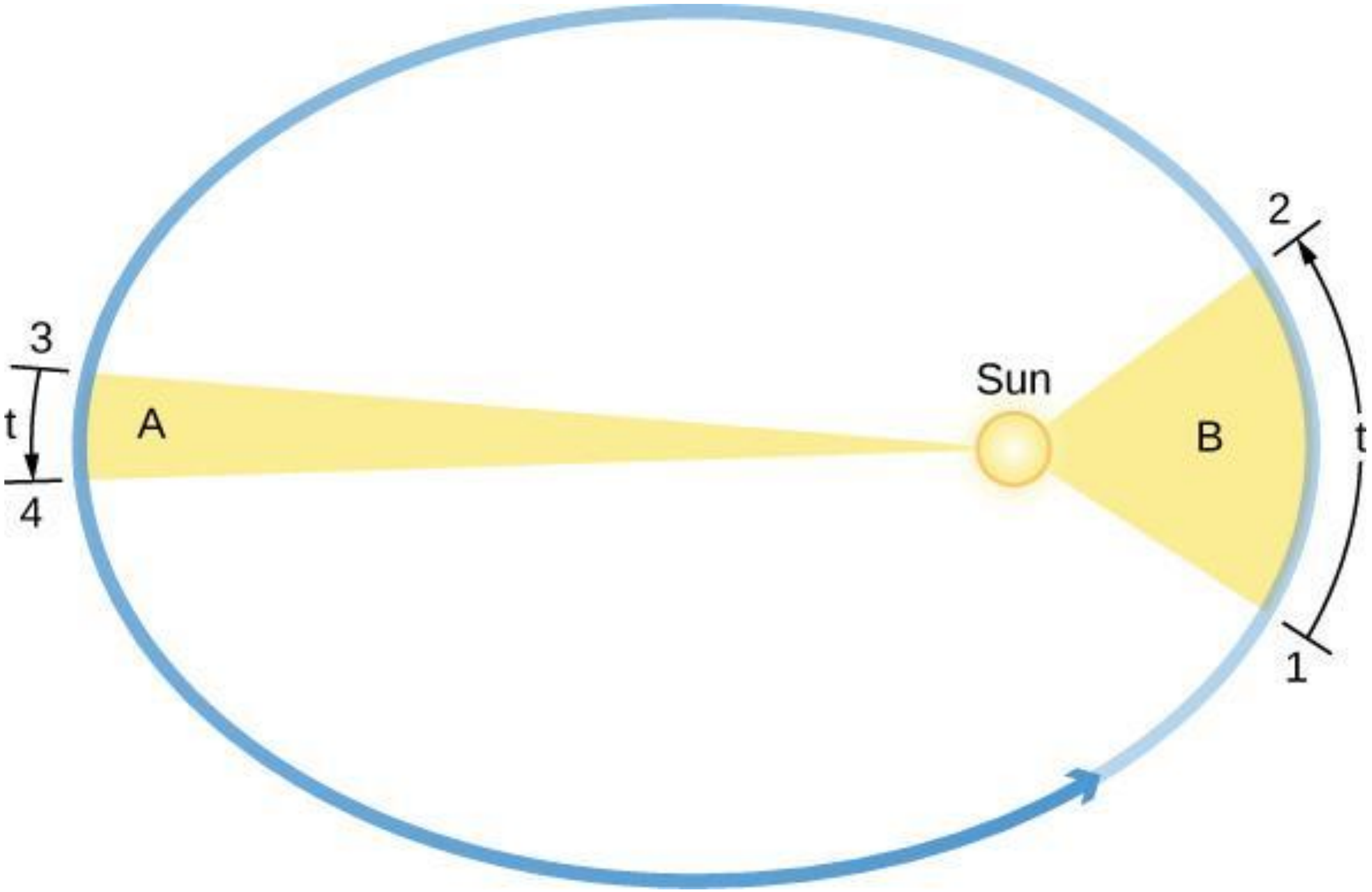
Kepler's First Law states that each planet moves around the Sun in an orbit that is an ellipse, with the Sun at one **focus** of the ellipse.



(a) (b)

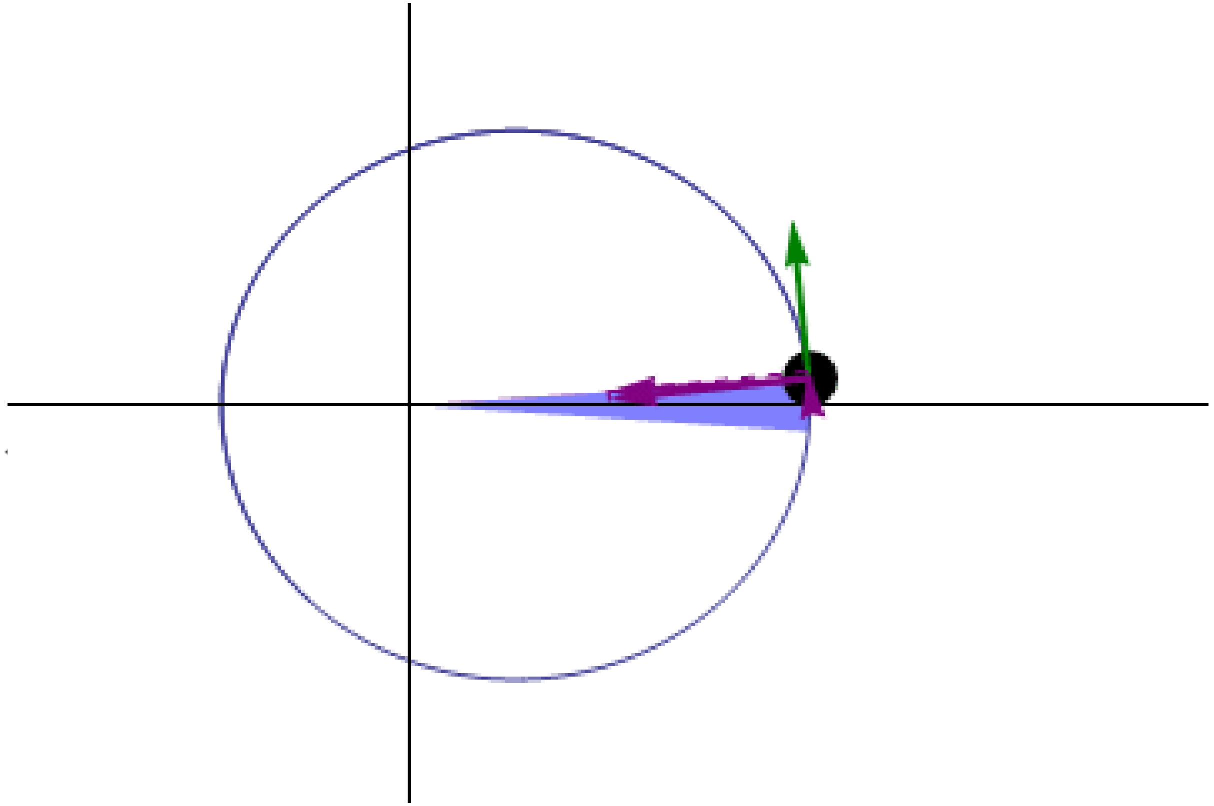
Kepler’s Second Law

Kepler’s Second Law states that the straight line joining a planet and the Sun sweeps out equal areas in space in equal intervals of time.



Kepler’s Second Law

- It states that equal areas are swiped in equal times



$$\frac{area\ SP_1P_2}{t_2 - t_1} = \frac{area\ SP_3P_4}{t_4 - t_3}$$

For $t_3 - t_2$ very small these Areas are triangles and:

$$area\ SP_3P_4 = \frac{1}{2} SP_3 * SP_4 * \sin(P_3SP_4) \approx \frac{1}{2} SP_3 * SP_4 * \theta$$

$$SP_4 = SP_4 \approx r$$

$$\frac{\theta_2}{\Delta t} = \omega_2$$

$$\frac{1}{2} r_1 * \frac{\theta_1}{\Delta t} = \frac{1}{2} r_2 * \frac{\theta_2}{\Delta t} = \text{constant}$$

Kepler's Third Law

Kepler's Third Law states that: $\frac{P^2}{a^3} = constant$

The square of a planet's orbital period is directly proportional to the cube of the semimajor axis of its orbit.

Kepler's Laws of Planetary Motion have stood up to all scientific evidence of the past 500 years.

Even though he didn't understand ***why*** the planets acted this way, he showed that they did.

Kepler's Laws of Planetary Motion

The ideas within Kepler's Laws are important but also quite difficult to understand without a mathematics background.

We will have further activities beyond this introductory lecture (worksheets, animations, etc) to practice these ideas.

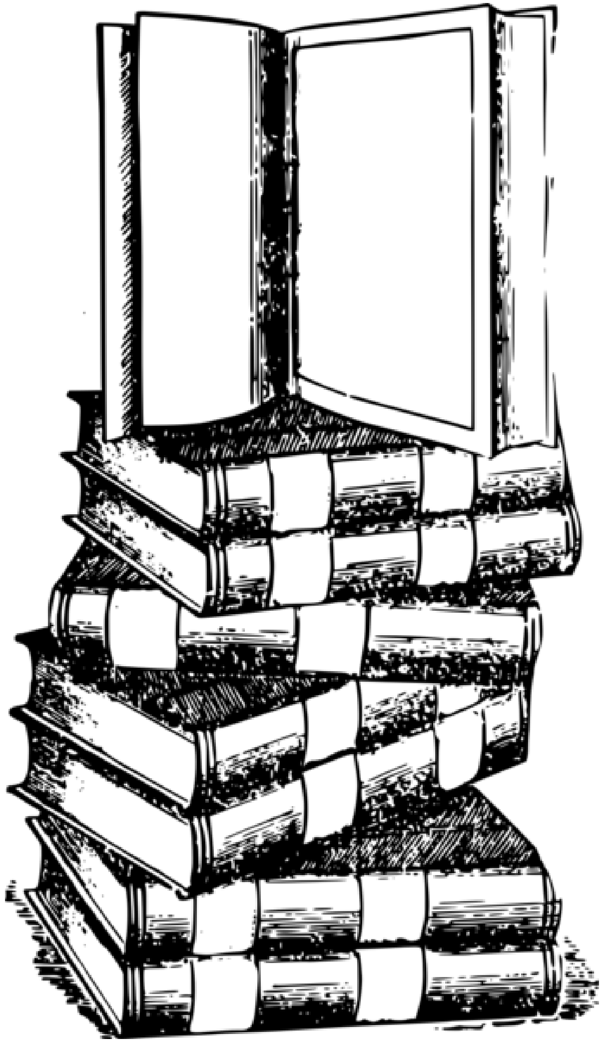
Supplemental Workbooks

- Lecture Tutorials for Introductory Astronomy, by Prather, Slater, et al:

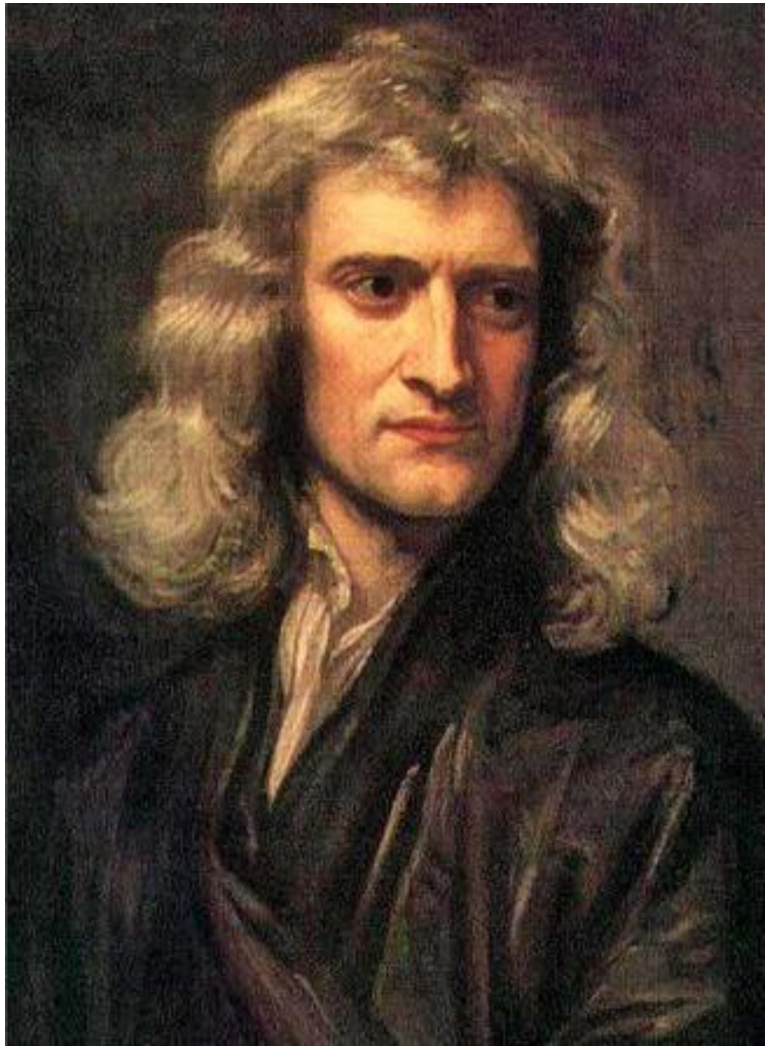
  "Kepler's Second Law" and "Kepler's Third Law"
- Learning Astronomy by Doing Astronomy, by Palen and Larson:

  "Activity 5: Working With Kepler's Laws" and "Activity 6: Extraterrestrial Tourism" (after Gravity)

Chapter 3: Orbits and Gravity



Isaac Newton and Orbital Motion

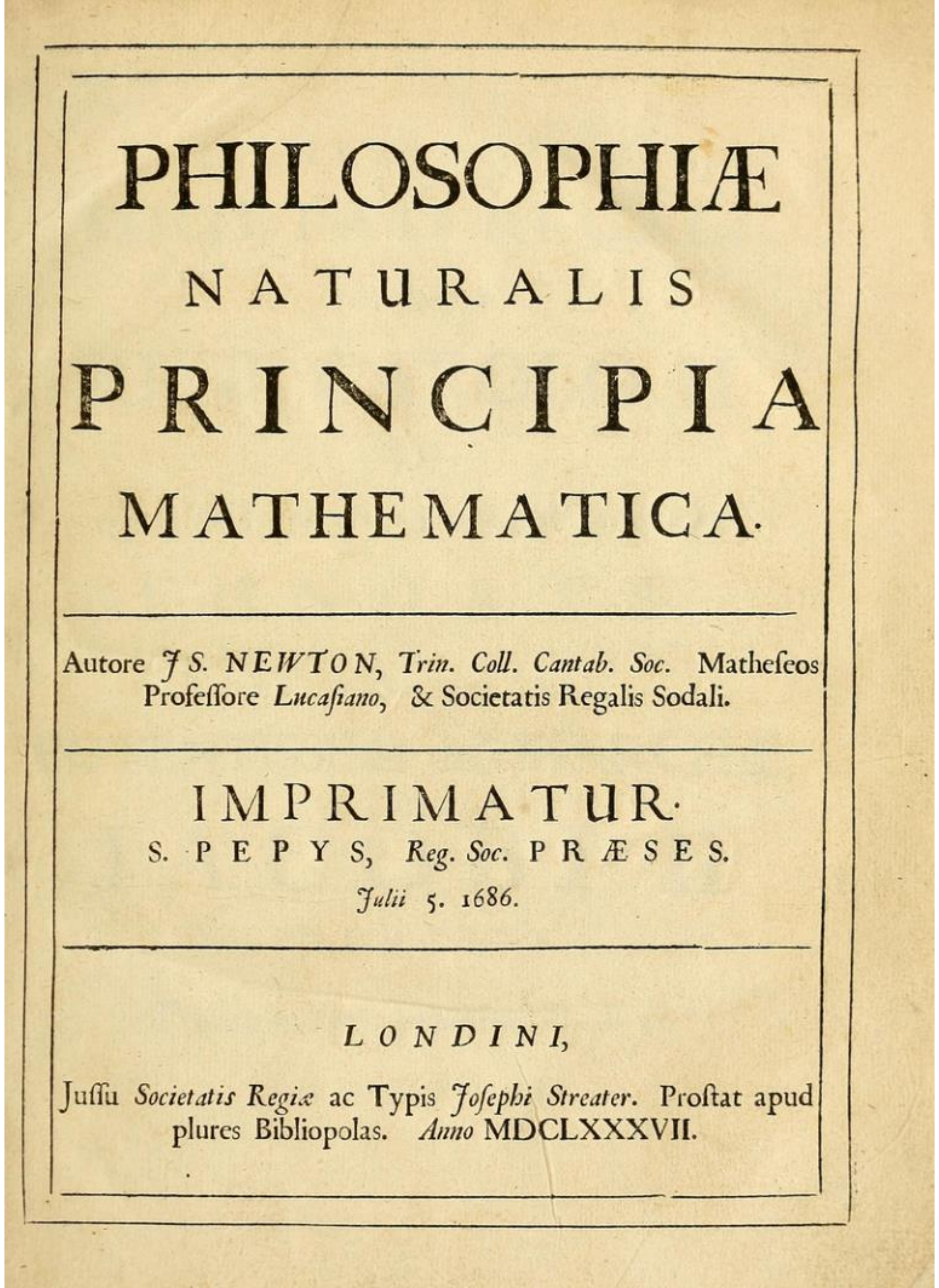


By the time Isaac Newton was born, modern astronomy had been 100 years in development, laying the foundations that we still use today.

Isaac Newton created new ***physical*** interpretations to the ***mathematical*** descriptions of astronomy made by Copernicus, Kepler, and Galileo.

Newton and “The Principia”

- Contains all 3 laws of motion, the law of gravity,
  and multiple concepts that
  will define physics for centuries
  to come, including today.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S.* NEWTON, *Trin. Coll. Cantab. Soc.* Mathefeos
Profeffore *Lucafiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juffu *Societatis Regiæ* ac Typis *Jofephi Streater*. Proftat apud
plures Bibliopolas. *Anno* MDCLXXXVII.

Newton in Inspired (triggered) by Descartes Philosophy

- A relatively recently translated to English work

De Gravitatione et aequipondio fluidorum ("On the gravity and equilibrium of fluids") was written two years before the Principia was written as a reply to Descartes.
Since Descartes formulated the law of inertia, the concept of Force as we know it is also due to him.

Rene Descartes, by Frans Hal

Isaac Newton and Orbital Motion

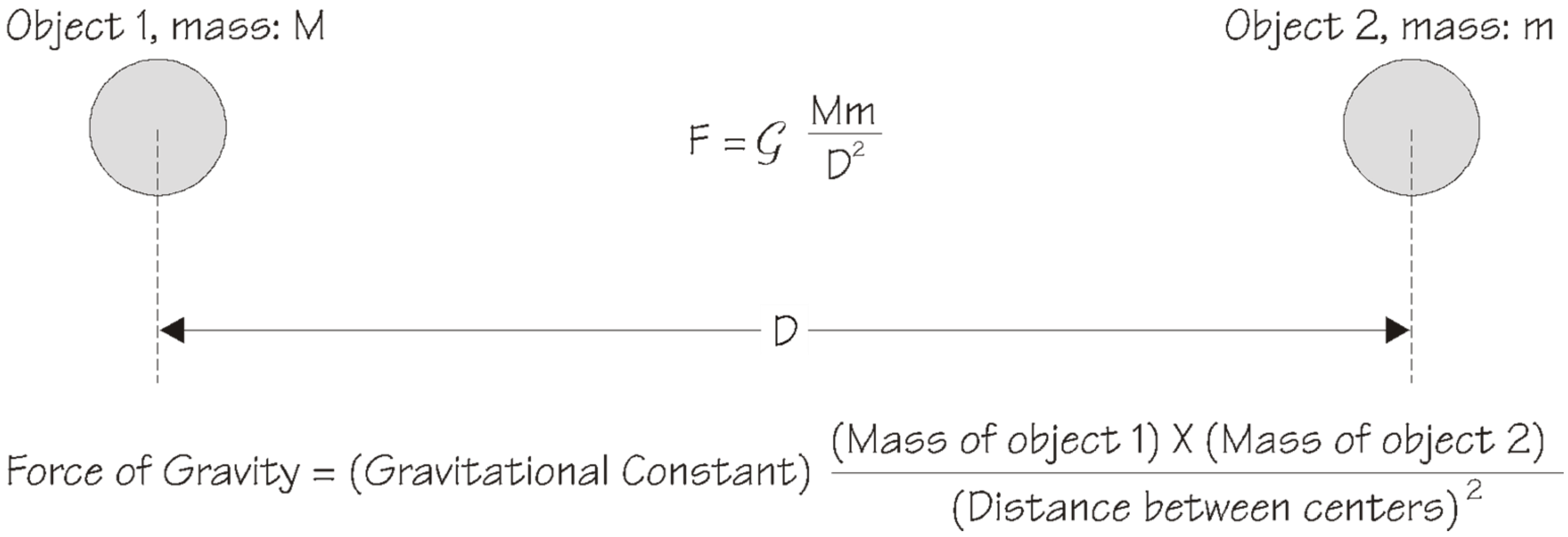
Newton developed the **universal law of gravitation**, a short equation (see right) which says that there is a force between any two masses.

$$F = G\frac{Mm}{r^2}$$

The **acceleration of gravity** of the Earth, Moon, or other astronomical body does not depend on the mass of the dropped object. Galileo had already determined that, and Apollo 15 showed it on the moon with a hammer and a feather!

Isaac Newton and Orbital Motion

The only requirement for gravity to act on an object is that it has mass (i.e. it physically exists) and there is another object with mass anywhere in the universe.



Pause-and-Think MC Question:

Which of the following would cause the force on the Moon by Earth to increase by the largest amount?

A) double the mass of the Moon.

B) double the mass of Earth.

C) move the moon two times closer to Earth.

D) None of the above would change the force.

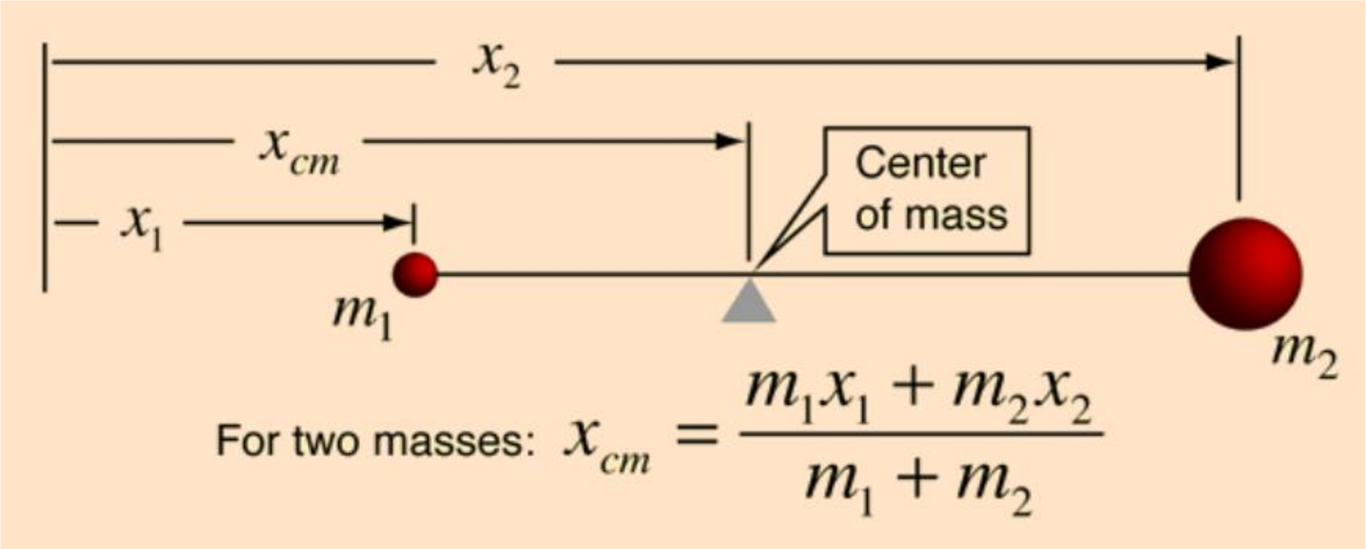
Center of Mass

- Gravitational Force

$$\vec{F} = -\frac{Gm_1m_2}{r^2}\hat{r}$$

- Center of Mass

$$\overrightarrow{R_{CM}} = \frac{m_1\overrightarrow{r_1} + \overrightarrow{m_2r_2}}{m_1 + m_2}$$



Newton's formulation of Kepler's 3rd law

We start by equating the gravitational specific force to the acceleration of the object (Newton invents the term "centripetal acceleration"):

$$\omega = \frac{v_t^2}{r} = \frac{\theta}{\Delta t}$$

$$\frac{Gm_1}{a^2} = a\omega^2$$

$$\frac{Gm_1}{a^3} = \omega^2$$

$$\frac{T^2}{(2\pi)^2} = \frac{a^3}{Gm_1}$$

Although, if we consider center of mass…

Conservation of Energy

2 In Fig. 8-22, a small, initially stationary block is released on a frictionless ramp at a height of 3.0 m. Hill heights along the ramp are as shown. The hills have identical circular tops, and the block does not fly off any hill. (a) Which hill is the first the block cannot cross? [redacted]

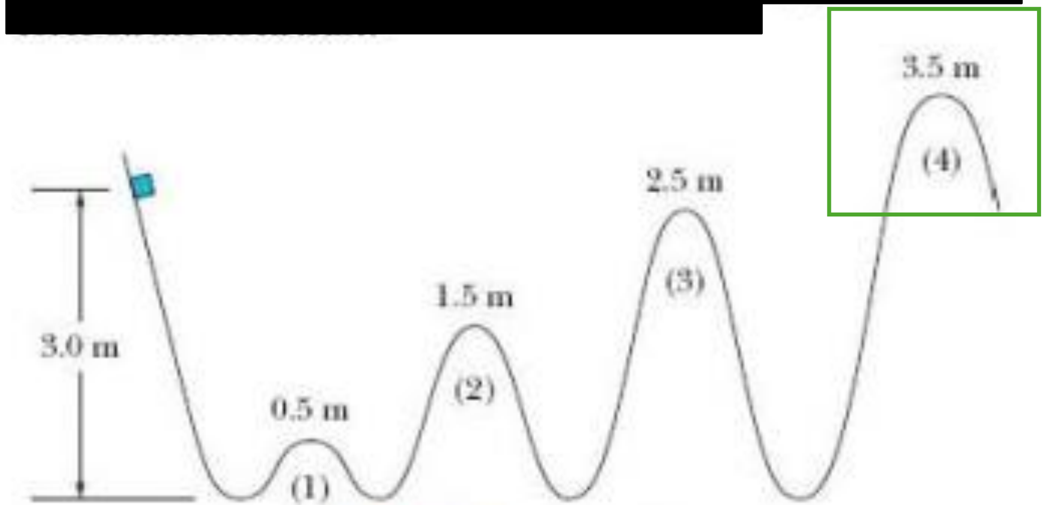


FIG. 8-22 Question 2.

Center of Mass

2 Figure 9-24 shows an overhead view of four particles of equal mass sliding over a frictionless surface at constant velocity. The directions of the velocities are indicated; their magnitudes are equal. Consider pairing the particles. Which pairs form a system with a center of mass that (a) is stationary, (b) is stationary and at the origin [redacted]

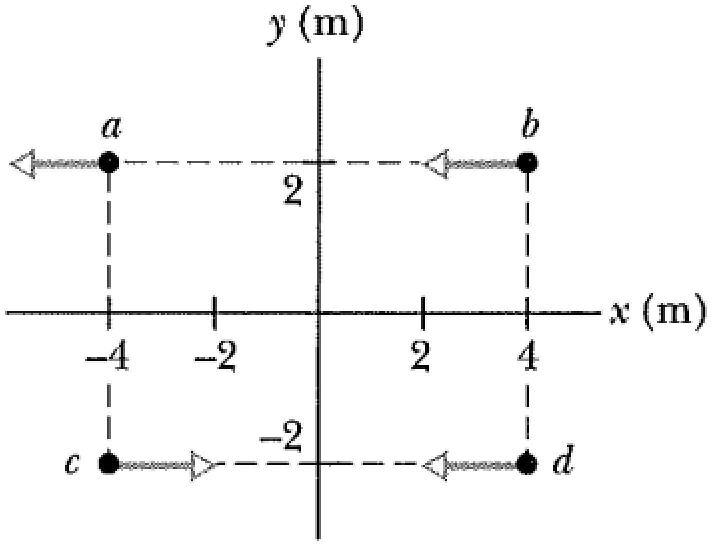
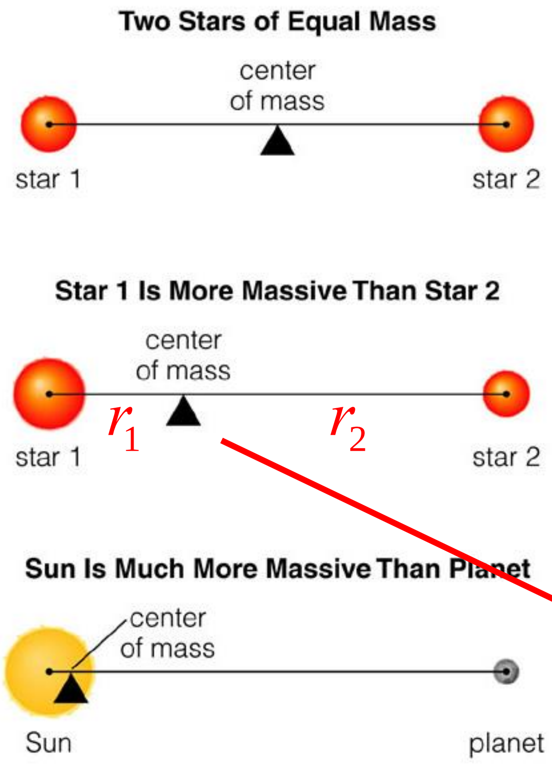
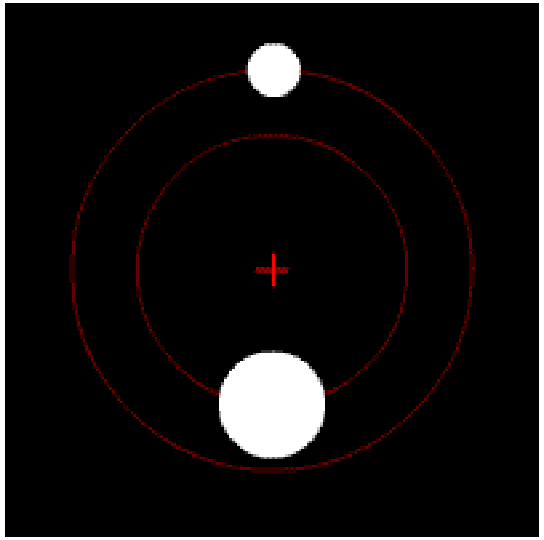
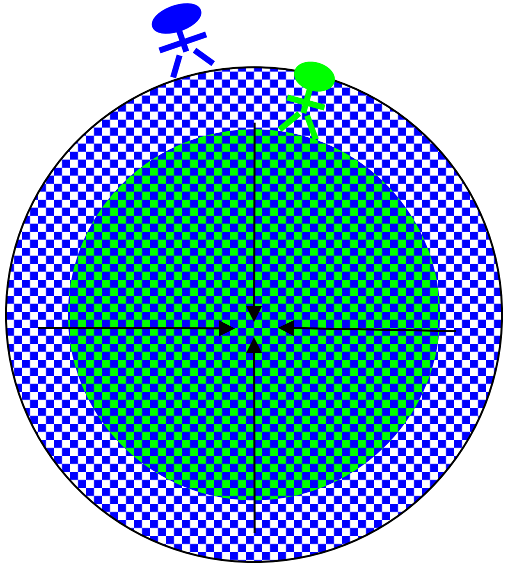


Fig. 9-24 Question 2.

a) a and c
b) a and d
c) b and c
d) b and d
e) c and d

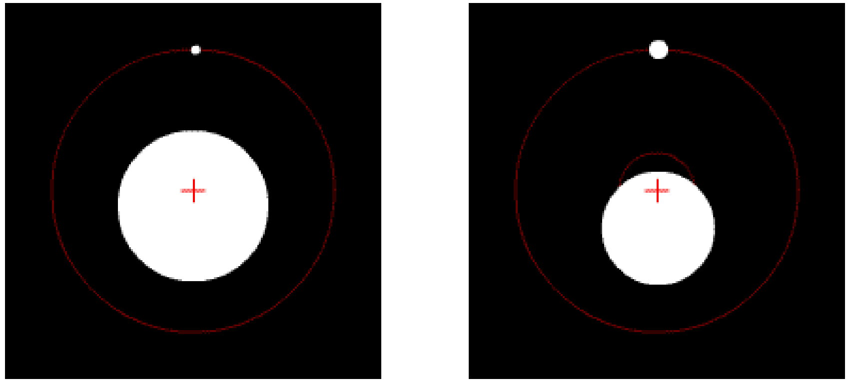

Two Stars of Equal Mass
center
of mass
star 1
star 2
Star 1 Is More Massive Than Star 2
center
of mass
r_1
r_2
star 1
star 2
Sun Is Much More Massive Than Planet
center
of mass
Sun
planet



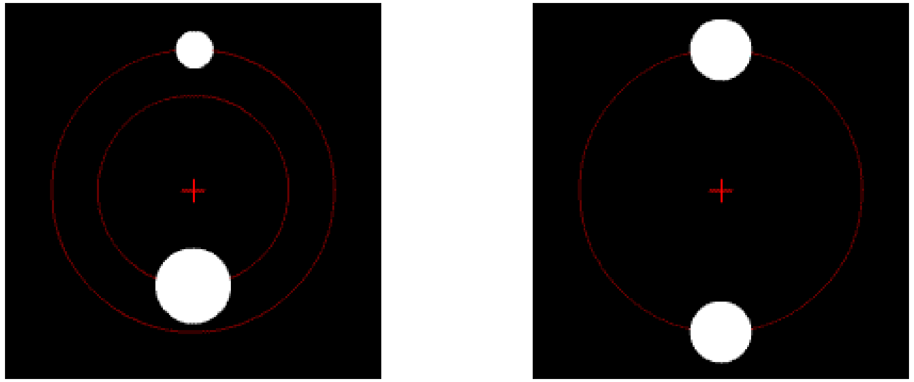


$$m_1 r_1 = m_2 r_2$$

Center-of-mass within more massive partner:



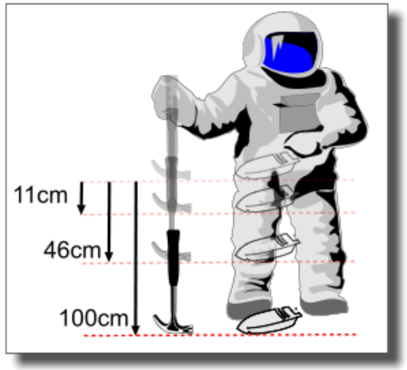
Center-of-mass outside of either object (mass of objects more nearly equal):

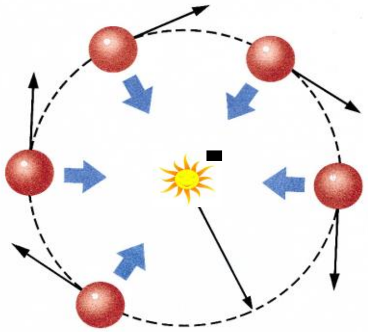


Clicker Question:

Clicker Question:

$$m\frac{v^2}{r} = \frac{GMm}{r^2} \quad \Rightarrow \quad v = \sqrt{\frac{GM}{r}}$$





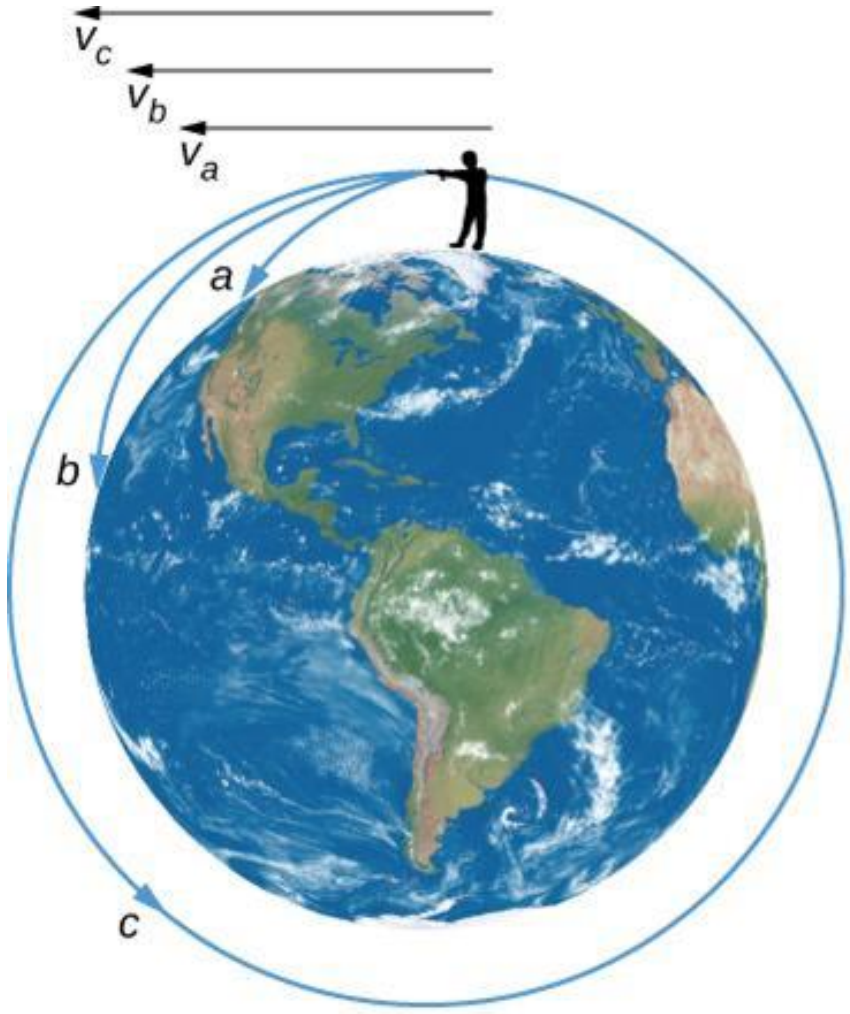
Newton's Law and Gravity

To be able to orbit something, we need the speed to be fast enough.

Too slow: object falls back to Earth

Too fast: object escapes Earth's gravity.

Just right: object is on a closed orbit. This "just right" speed for Earth is 17,500 miles per hour (8 km/s)!



Newton’s Law and Gravity

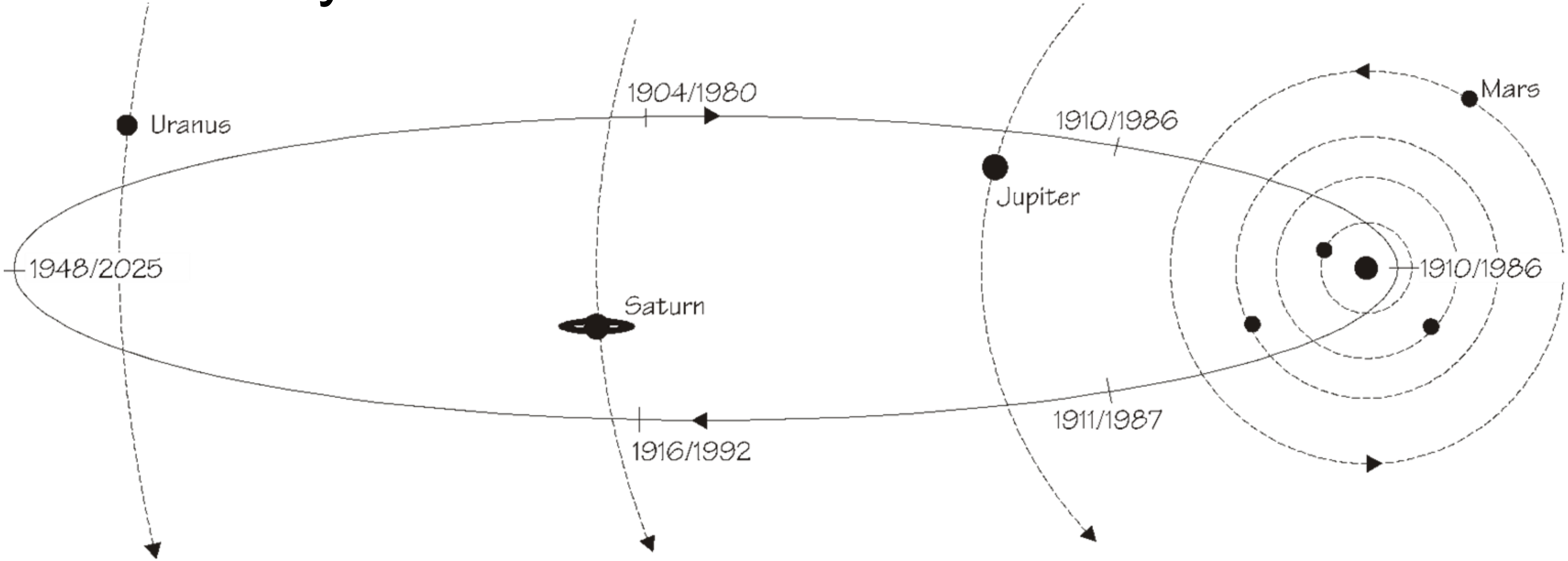
Newton’s theories were published in 1688 (“Principia”). His Universal Law of Gravity combined with the Laws of Motion explain all three of Kepler’s Laws of planetary motion.

These laws represent the “perfection” of the Copernican model. All planetary motions are explained with one equation, **gravity**. Geocentrism is finally wiped-out.

Can Newton’s ideas be tested further?

Newton’s Law and Gravity

Edmund Halley tracked part of the orbit of a comet, and predicted when it would return using Newton’s laws of motion. He was exactly correct!



Newton’s Law and Gravity

The planet Uranus discovered in 1781 by William Herschel. However, Uranus did not move according to predictions made with Newton’s laws.

The inconsistencies could be explained by another massive object that was pulling on Uranus’s orbit. Using Newton’s laws of motion, a new planet was predicted to exist further from the Sun than Uranus. Neptune was found in 1845, less than 1° away from its predicted position!

Newton’s laws are not only **testable and verifiable,** they are **fruitful**. The discovery of Neptune is one the great stories of the scientific method. “If I have seen farther than other men, it is because I stood upon the shoulders of giants.”