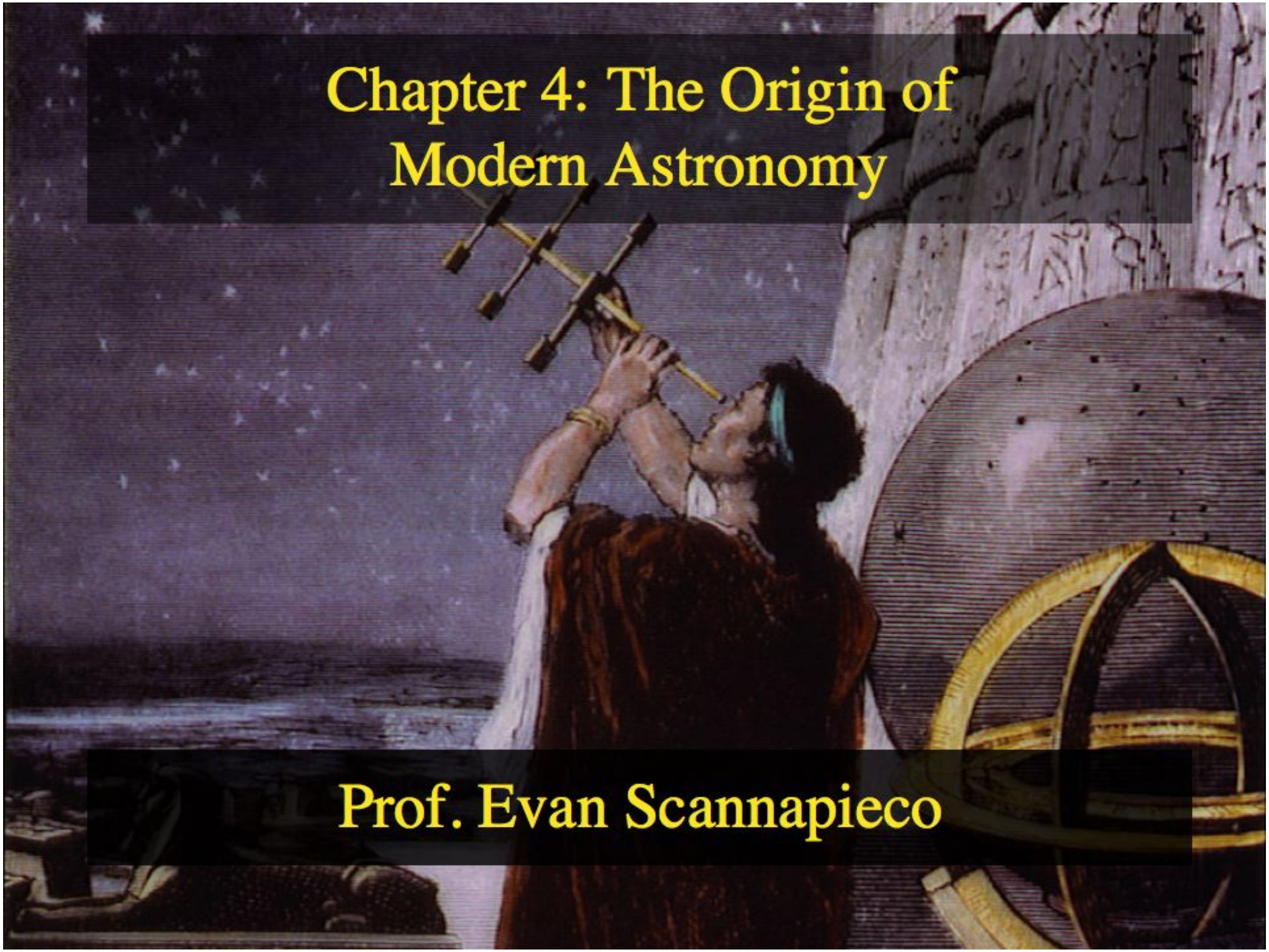


Chapter 4: The Origin of Modern Astronomy

Prof. Evan Scannapieco

2.4 The Ancient Mystery of the Planets

Object	*Teutonic Name*	*English*	*French*	*Spanish*
Sun	Sun	Sunday	dimanche	domingo
Moon	Moon	Monday	lundi	lunes
Mars	Tiw	Tuesday	mardi	martes
Mercury	Woden	Wednesday	mercredi	miércoles
Jupiter	Thor	Thursday	jeudi	jueves
Venus	Fria	Friday	vendredi	viernes
Saturn	Saturn	Saturday	samedi	sábado

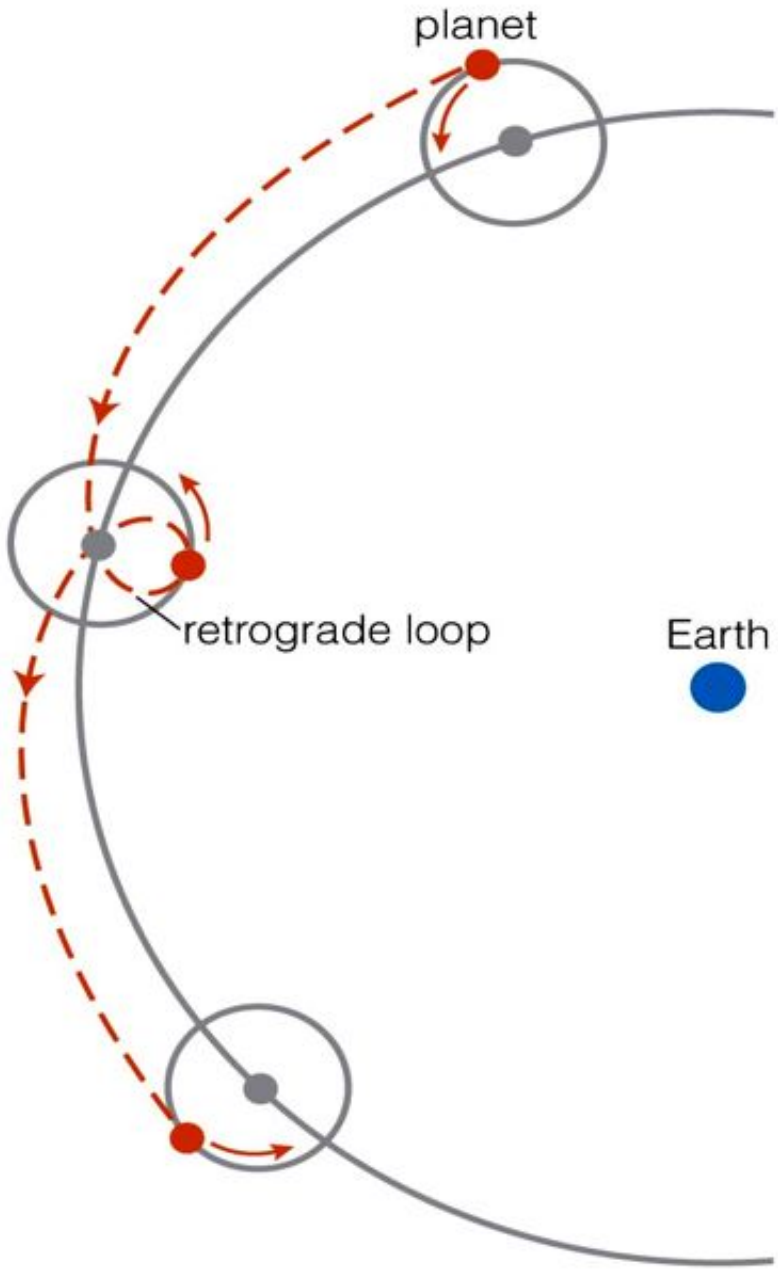
2.4 The Ancient Mystery of the Planets

- **Planets usually drift eastward relative to the stars from night to night; but sometimes, for a few weeks or few months, a planet turns westward in its apparent retrograde motion**

- **Most Greeks concluded that Earth must be stationary, because they thought the stars could not be so far away as to make parallax undetectable**

3.2 The Ptolemaic Model

Ptolemy (A.D. 100-170)



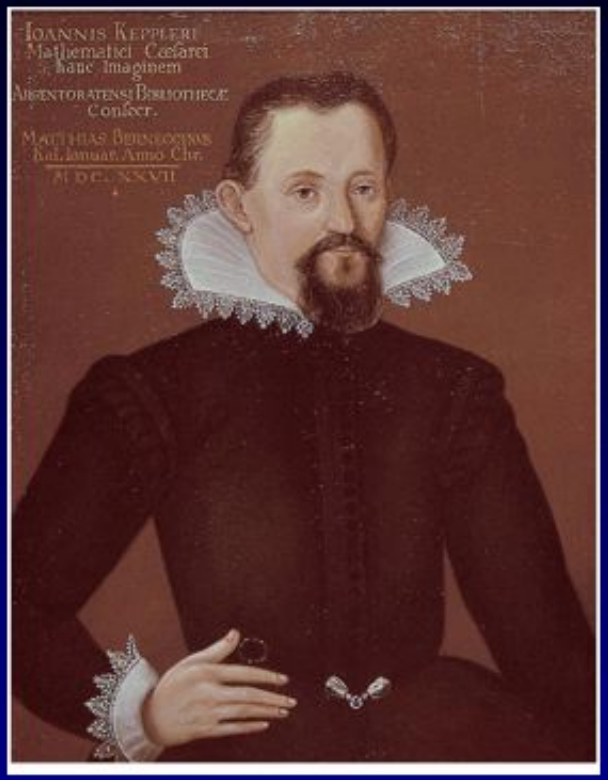
Copernicus (1473-1543):

- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)

Tycho Brahe (1546-1601)

- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- 
- Hired Kepler, who used Tycho's observations to discover the truth about planetary motion.

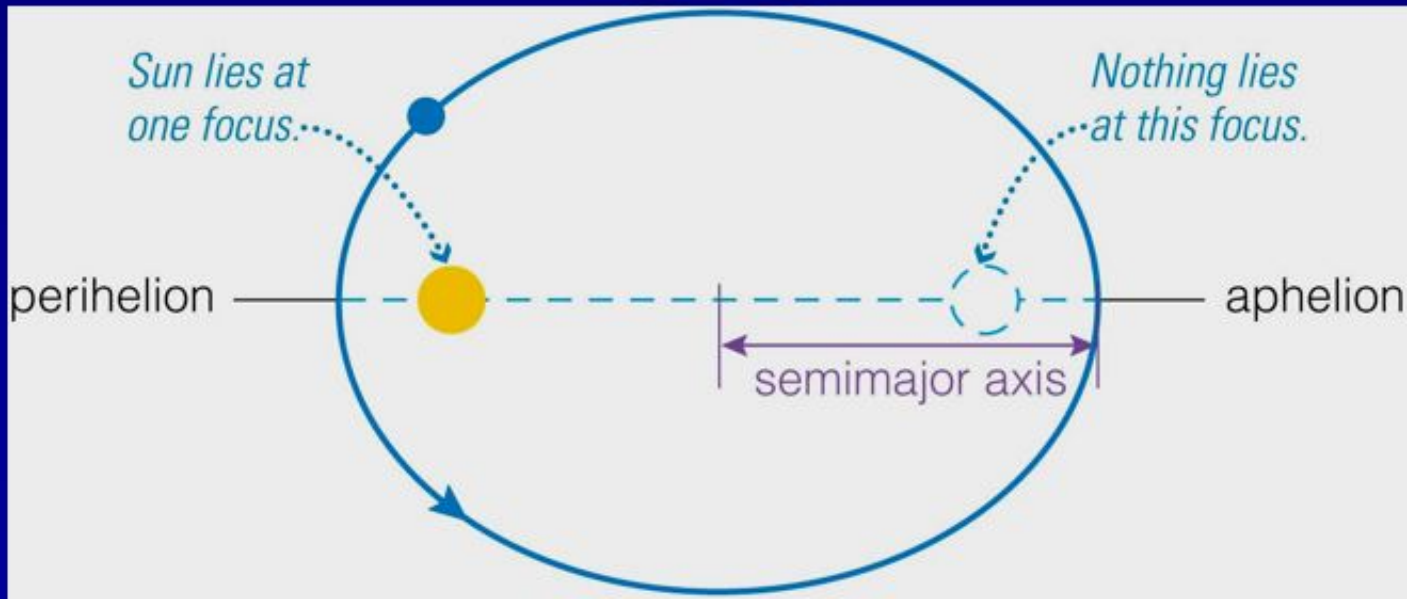
Johannes Kepler (1571-1630)



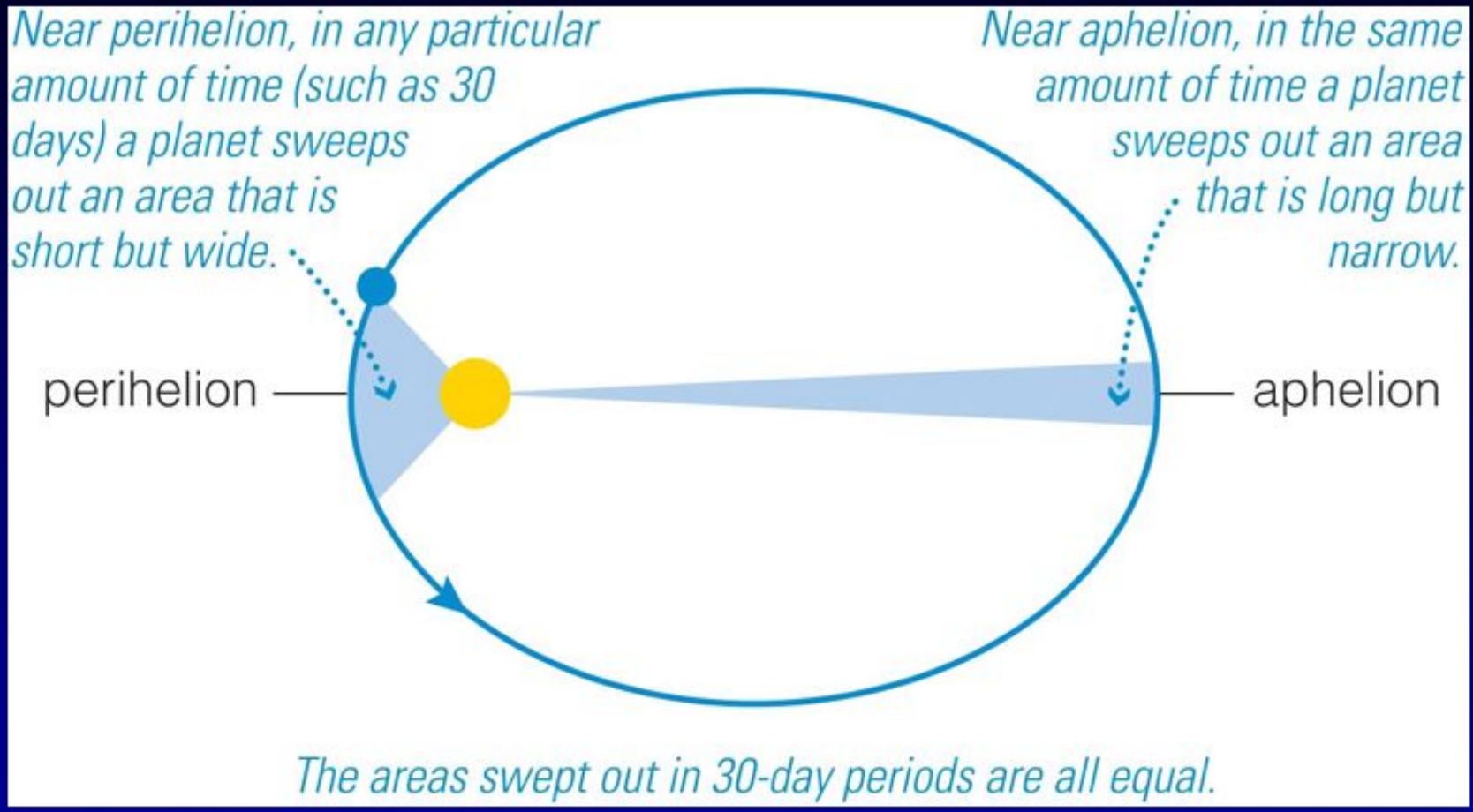
- Tries to match Tycho's observations with circular orbits, but 8-arcminute discrepancy led him to

KEPLER'S THREE LAWS:

Kepler's 1st Law: The orbit of each planet is an ***ellipse*** with the Sun at one focus.



Kepler's Second Law: As a planet moves around its orbit, it sweeps out **equal areas in equal times.**



⇒ means that a planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.

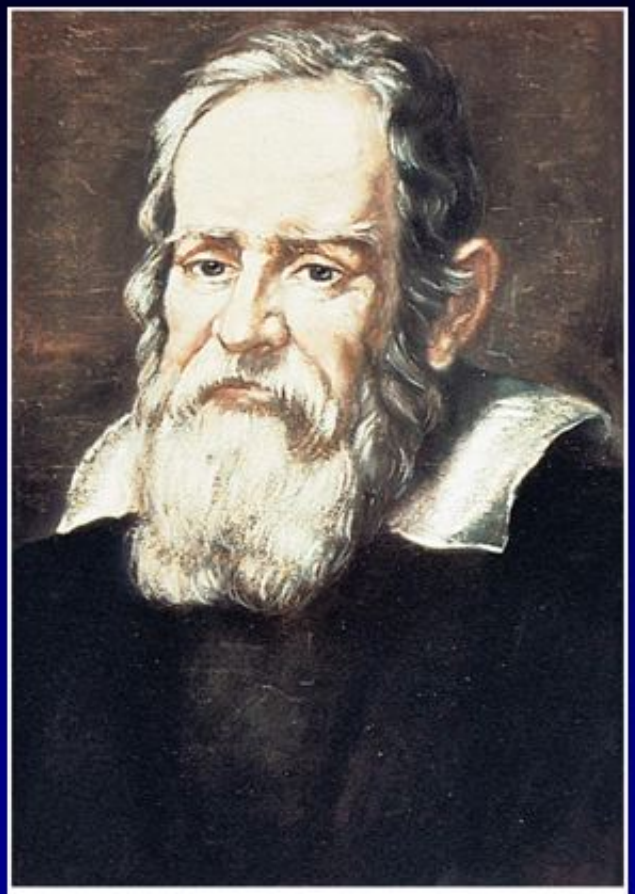
Kepler's Third Law

More distant planets orbit the Sun at slower average speeds, obeying the relationship

$$p^2 = a^3$$

p = orbital period in years
a = avg. distance from Sun in AU

How did Galileo solidify the Copernican revolution?



Galileo (1564–1642)

Galileo (1564-1642) overcame major objections to Copernican view. Three key objections rooted in Aristotelian view were:

1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not "perfect" as heavens should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

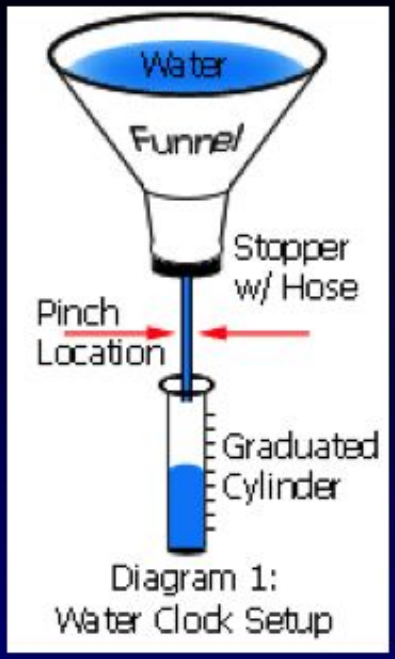
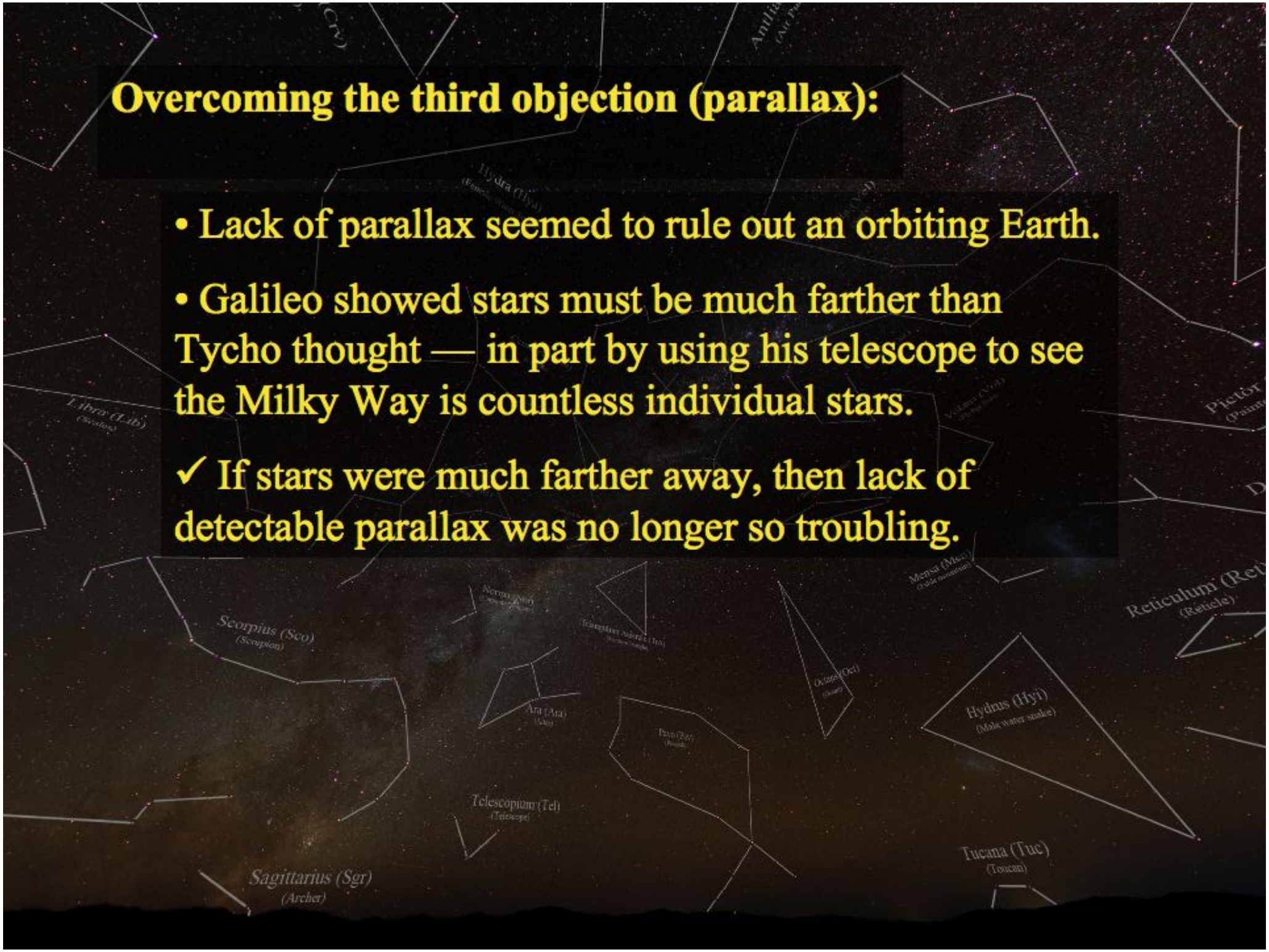
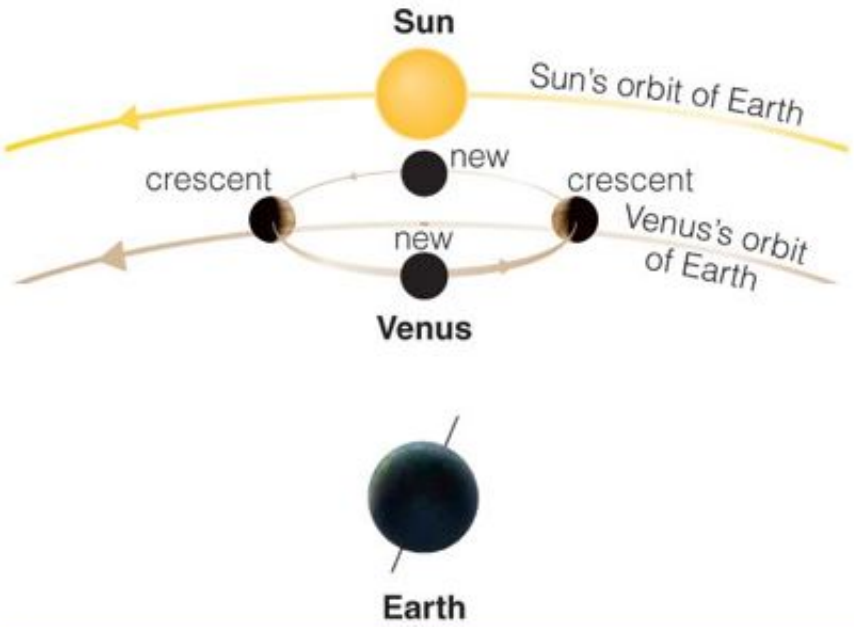


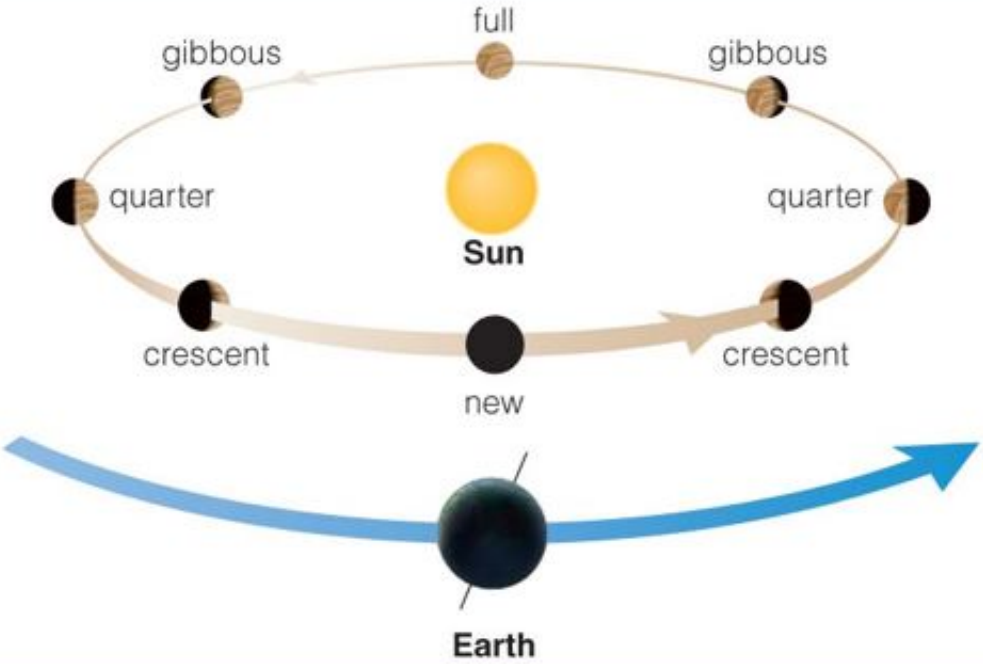
Diagram 1:
Water Clock Setup

Overcoming the second objection (heavenly perfection):

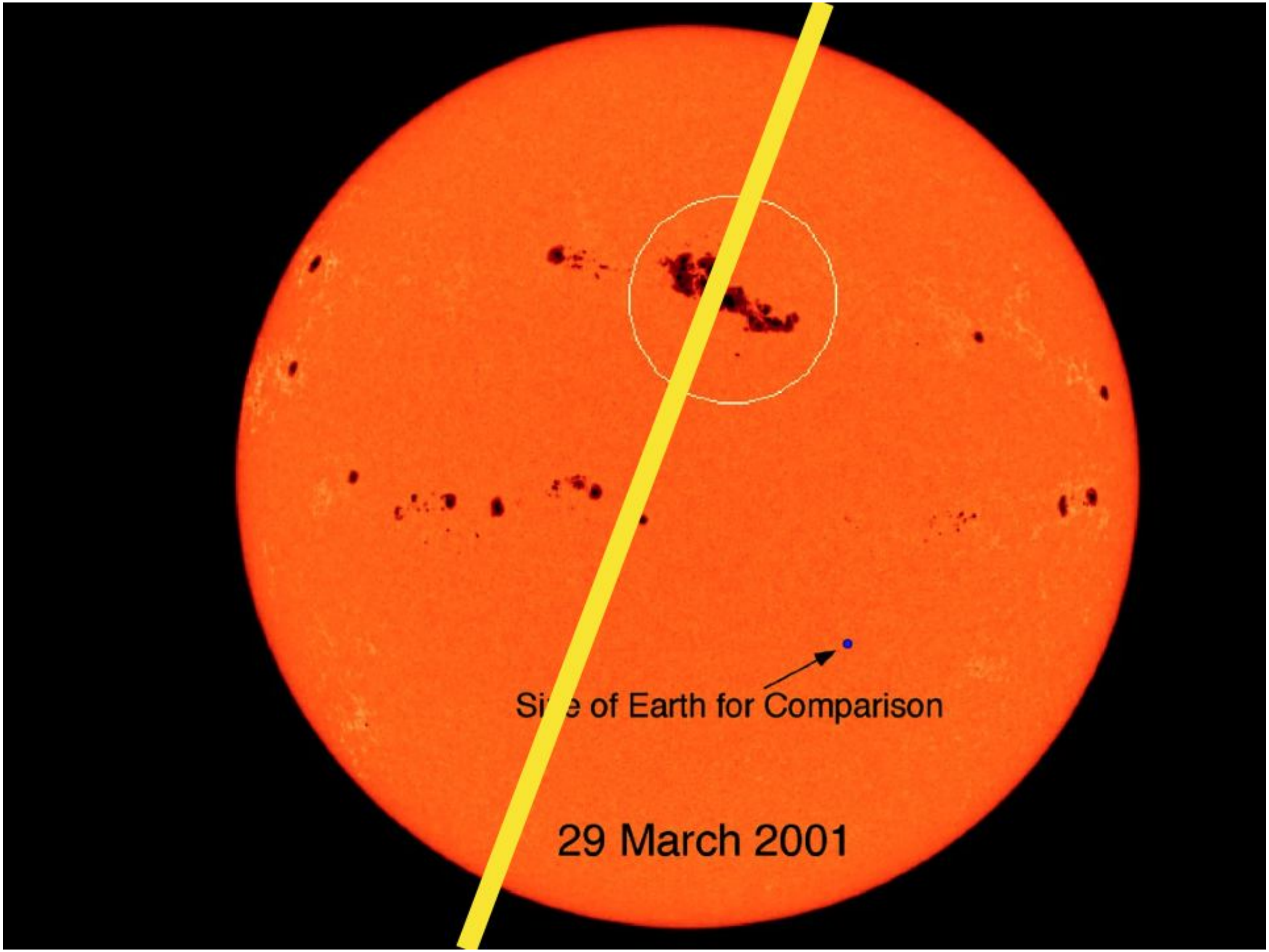
- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
  - Sunspots on Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)
  - Moons of Jupiter


Overcoming the third objection (parallax):
• Lack of parallax seemed to rule out an orbiting Earth.
• Galileo showed stars must be much farther than Tycho thought — in part by using his telescope to see the Milky Way is countless individual stars.
✓ If stars were much farther away, then lack of detectable parallax was no longer so troubling.
Scorpius (Sco)
(Scorpion)
Ara (Ara)
(Altar)
Telescopium (Tel)
(Telescope)
Sagittarius (Sgr)
(Archer)
Hydrus (Hyi)
(Male water snake)
Tucana (Tuc)
(Toucan)
Reticulum (Ret)
(Reticle)





Galileo's observations of phases of Venus proved that it orbits the Sun and not Earth.

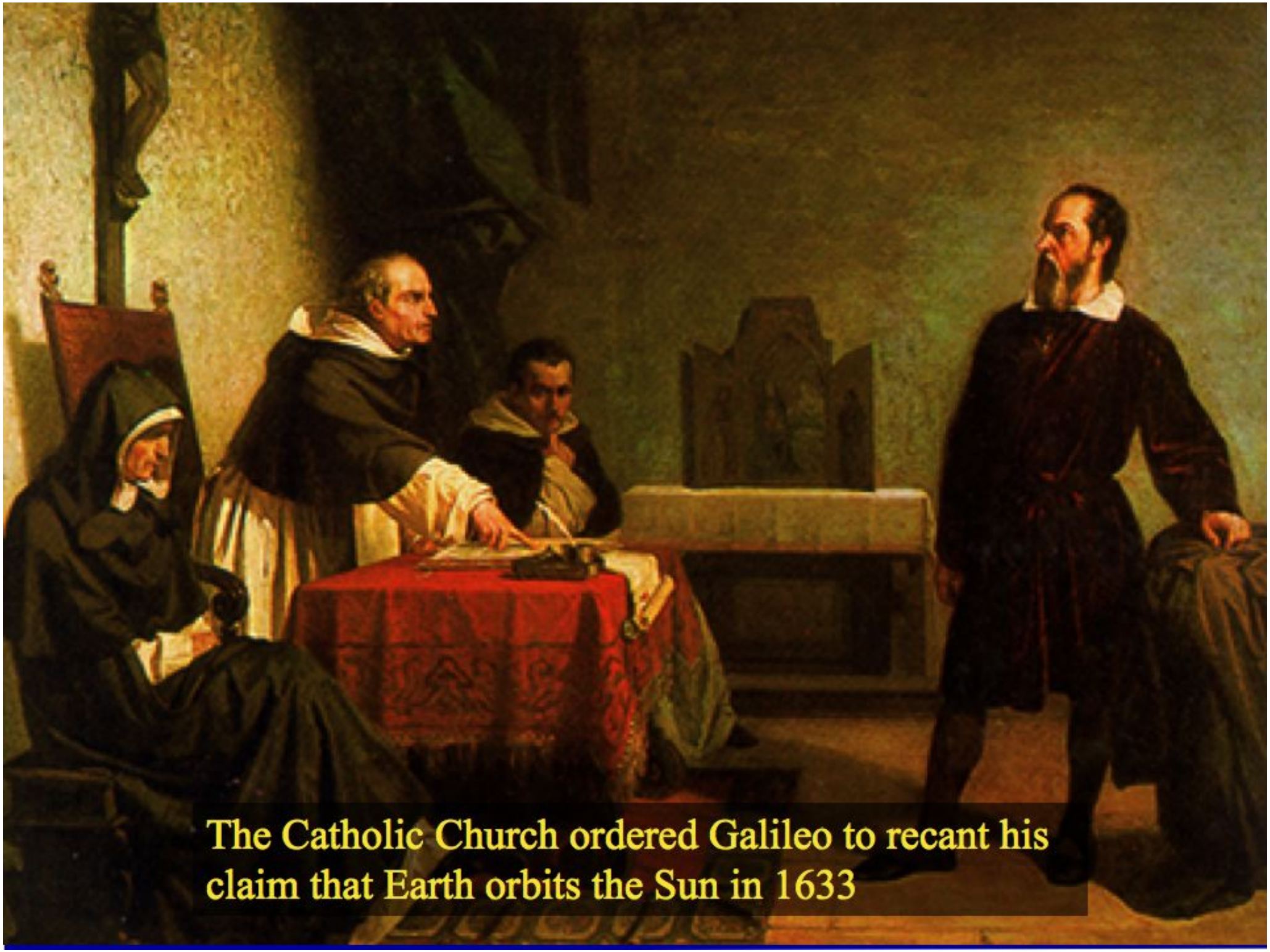

Size of Earth for Comparison
29 March 2001

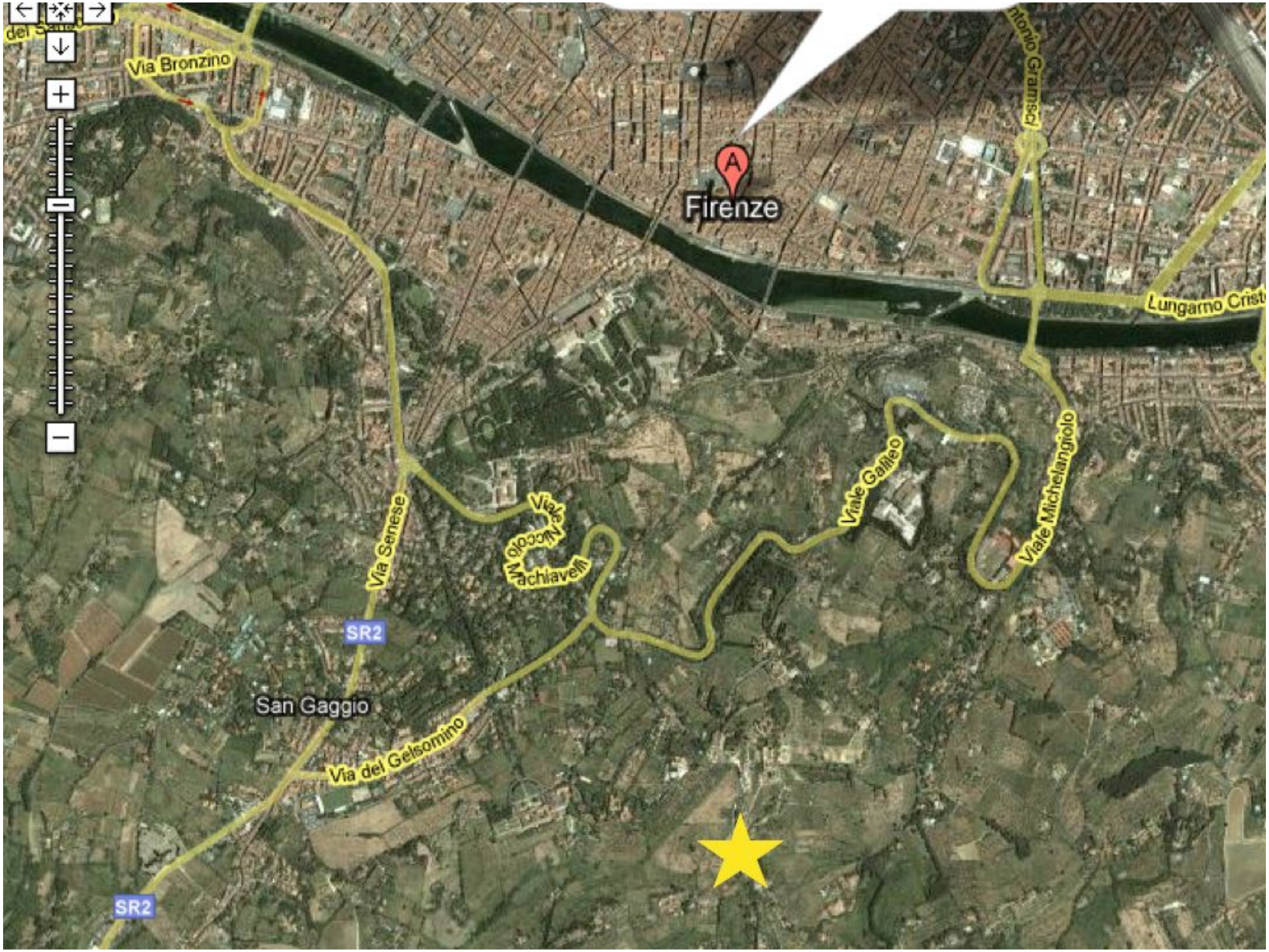
Pope Urban VIII (from 1623-1644)

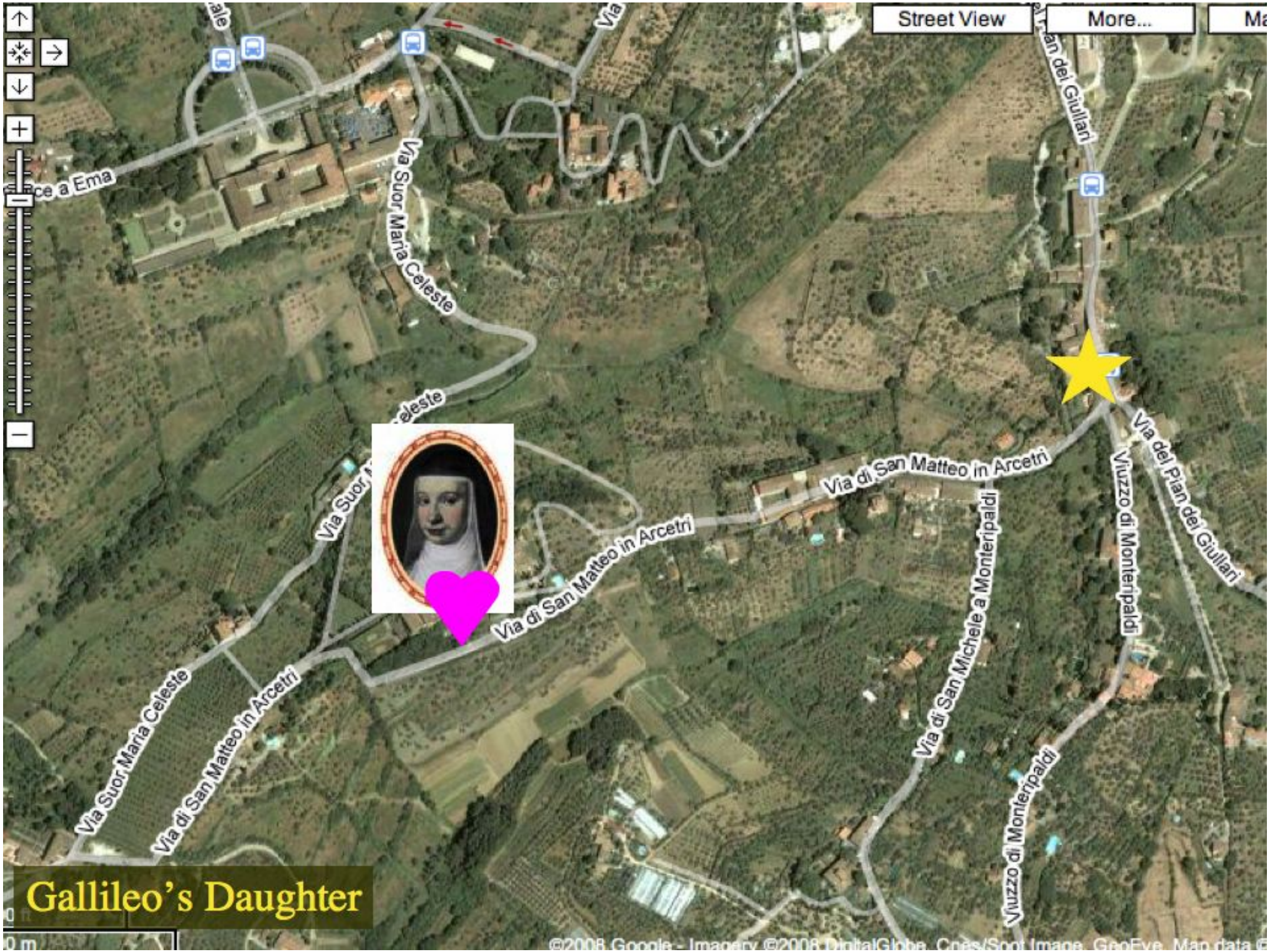
Cardinal Maffeo Barberini

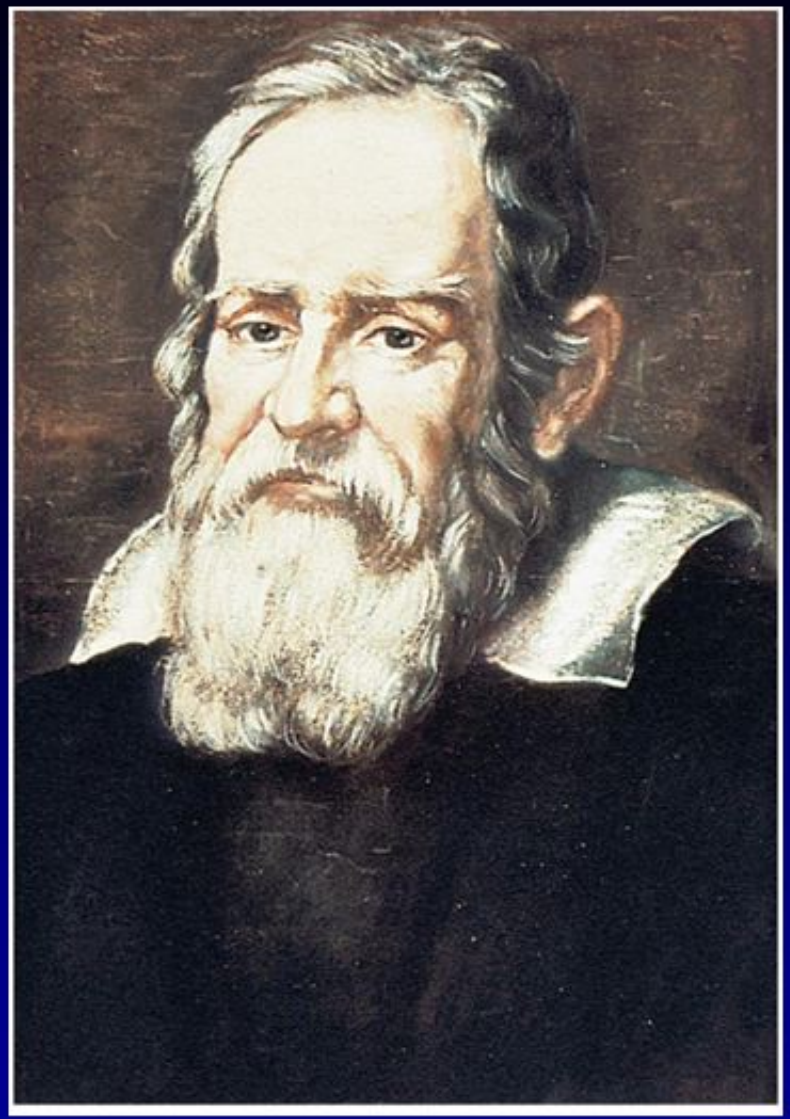
"Dialogue Concerning the Two Chief World Systems" published in 1632

Salviati argues for the Copernican system (Gallieo)
Sagredo is an intelligent layman
Simplicio a dedicated follower of Ptolemy (Urban VIII)


The Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun in 1633


Via Bronzino
Firenze
A
Lungarno Cristo
Viale Galileo
Viale Michelangiolo
Via Senese
Via Machiavelli
SR2
San Gaggio
Via del Gelsomino
SR2

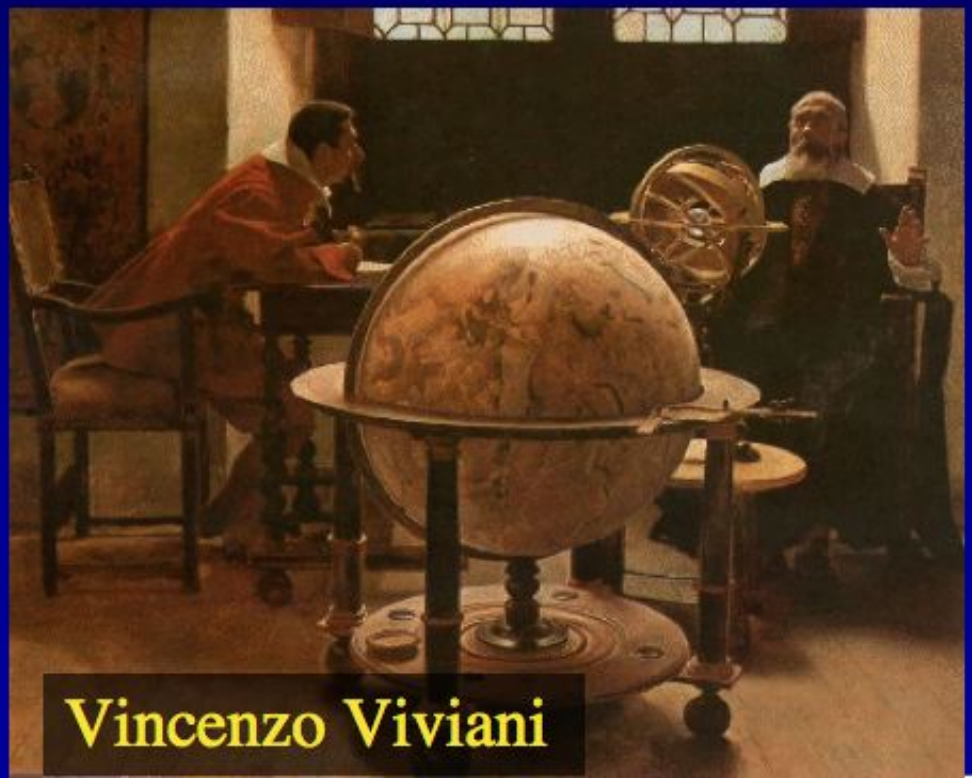

Street View
More...
Via del Pian dei Giullari
Via Suor Maria Celeste
Via di San Matteo in Arcetri
Via di San Michele a Monteripaldi
Viuzzo di Monteripaldi
Gallileo's Daughter
©2008 Google - Imagery ©2008 DigitalGlobe, Cnes/Spot Image, GeoEye, Map data ©



Galileo Galilei

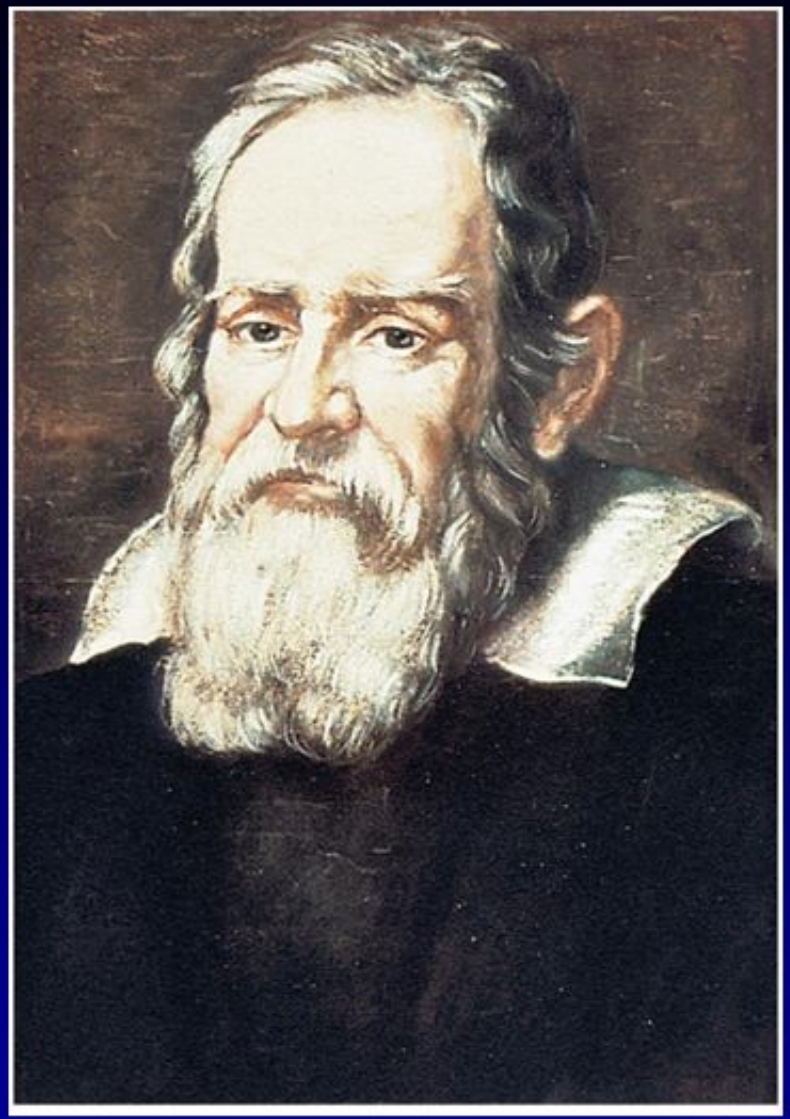
The Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun in 1633

He died at home in 1642



Vincenzo Viviani

He was reburied at Santa Croce, Florence in 1737



Galileo Galilei

In 1741, Pope Benedict XIV authorized publication of Galileo's complete works.

Question: Galileo was formally vindicated by the Church in:

A. 1750

B. 1825

C. 1925

D. 1992

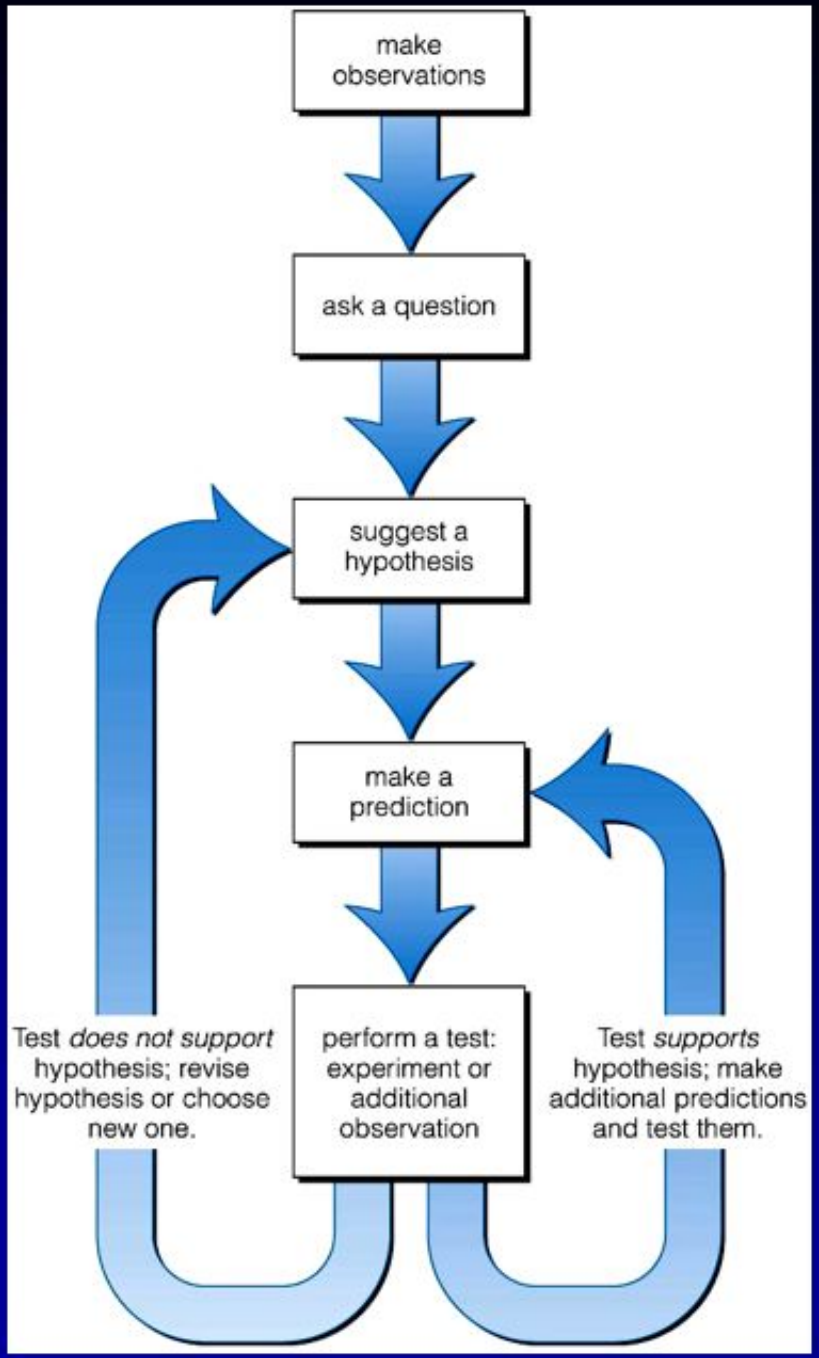
E. Never


The Vatican Advance
Technology Telescope

The Nature of Science

How can we distinguish science from non-science?

- Defining science can be surprisingly difficult.
- *Science* from the Latin *scientia*, meaning "knowledge."
- But not all knowledge comes from science…



The idealized scientific method

- Based on proposing and testing hypotheses
- **hypothesis** = educated guess

But science rarely proceeds in this idealized way… For example:

- Sometimes we start by "just looking" then coming up with possible explanations.

- Sometimes we follow our intuition rather than a particular line of evidence.

Hallmarks of Science: #1

Modern science seeks explanations for observed phenomena that rely solely on *observable and measurable* causes.

(A scientific model cannot include divine intervention, can not talk about what happen BEFORE the universe existed)

Hallmarks of Science: #2

Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

(Simplicity = "Occam's razor")

Hallmarks of Science: #3

A scientific model must make testable predictions about natural phenomena that would *force us to revise or abandon the model* if the predictions do not agree with observations.

What is a scientific theory?

- The word theory has a different meaning in science than in everyday life.
- In science, a theory is NOT the same as a hypothesis, rather:
- A ***scientific theory*** must:
  - —Explain a wide variety of observations with a few simple principles, AND
  - —Must be supported by a large, compelling body of evidence.
  - —Must NOT have failed any crucial test of its validity.

Thought Question

Darwin's theory of evolution meets all the criteria of a scientific theory. This means:

A. Scientific opinion is about evenly split as to whether evolution really happened.

B. Scientific opinion runs about 90% in favor of the theory of evolution and about 10% opposed.

C. After more than 100 years of testing, Darwin's theory stands has successfully met every scientific challenge to its validity.

D. There is no longer any doubt that the theory of evolution is absolutely true.

What is the difference between the word *theory* as used in everyday speech, and the word *theory* as used in science?

A. Theory, in common speech, is something uncertain ("It's just a theory")
B. A *scientific* theory is different. It has been thoroughly tested
C. A *scientific* theory must be discarded if it fails to explain what is observed in any experiment
D. All of the above

Do you think that science is a system of beliefs?

- **Yes**
- **No**

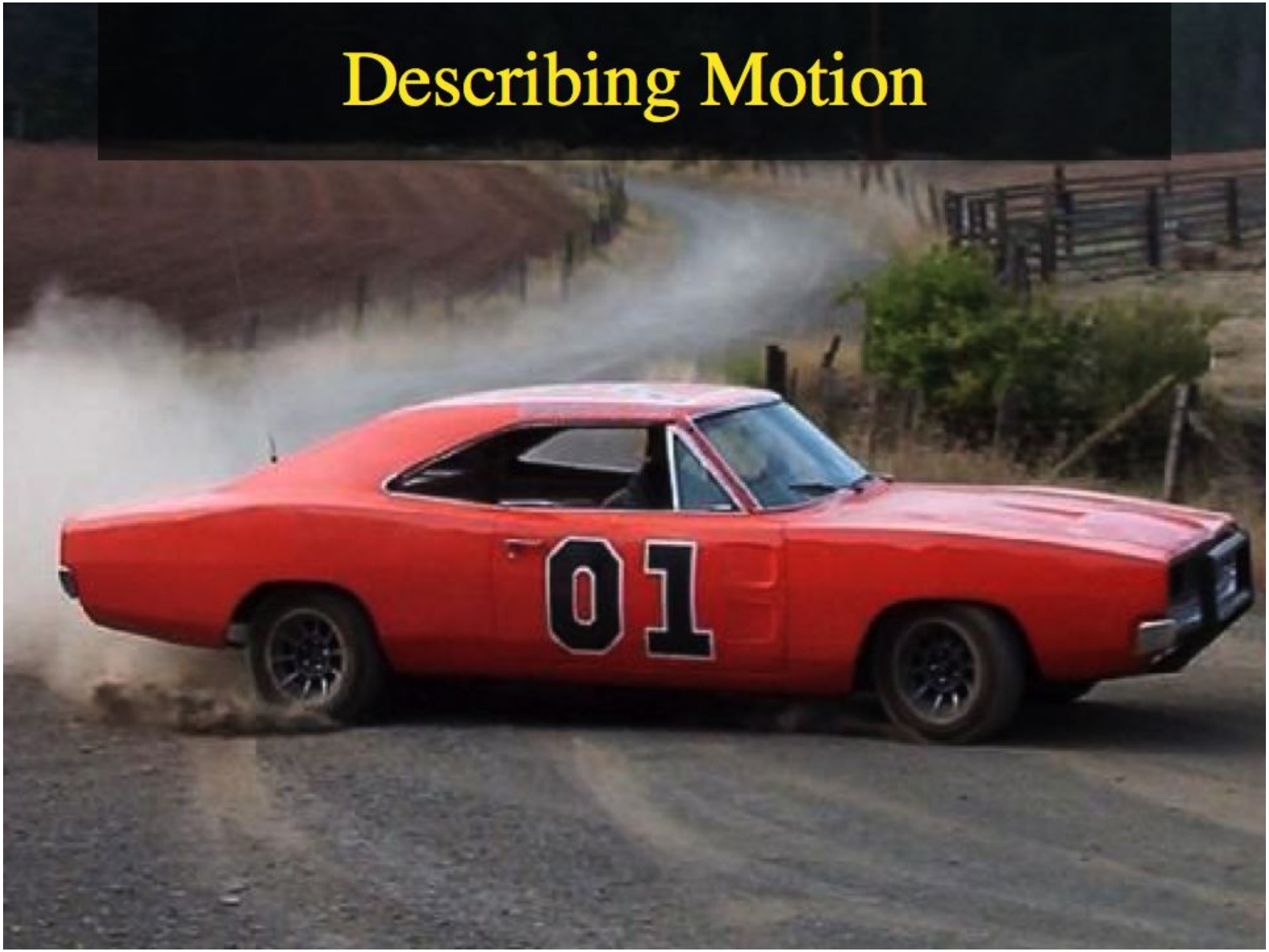
- [Science is based on evidence, experiment, predicting, and testing. A belief system is based on belief or faith.]

Are there ways of knowing other than scientific ones?

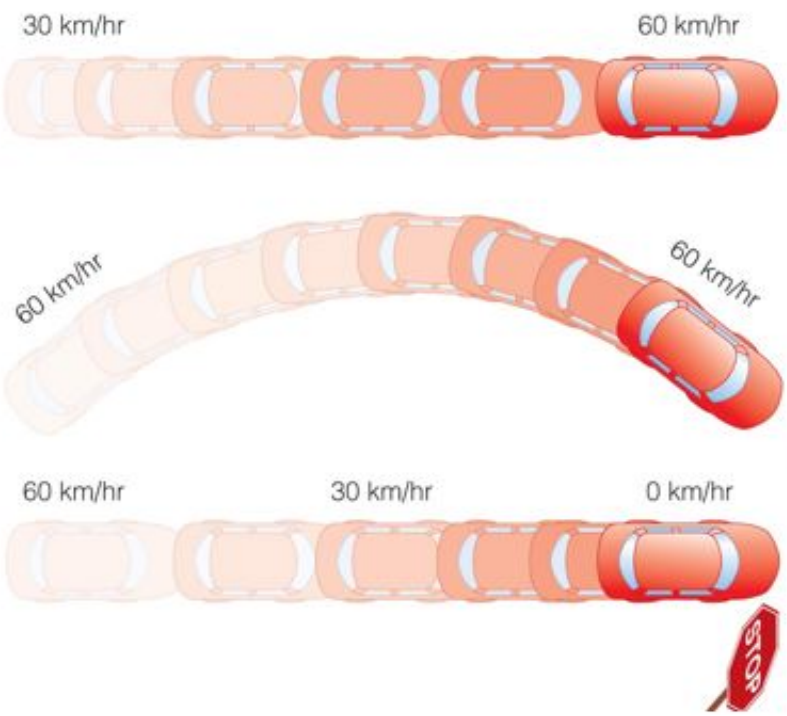
A. Yes
B. No
C. Not really

Chapter 5: Gravity

Describing Motion



How do we describe motion?



Precise definitions to describe motion:

- **Speed**: Rate at which object moves

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \left(\text{units of } \frac{\text{m}}{\text{s}}\right)$$

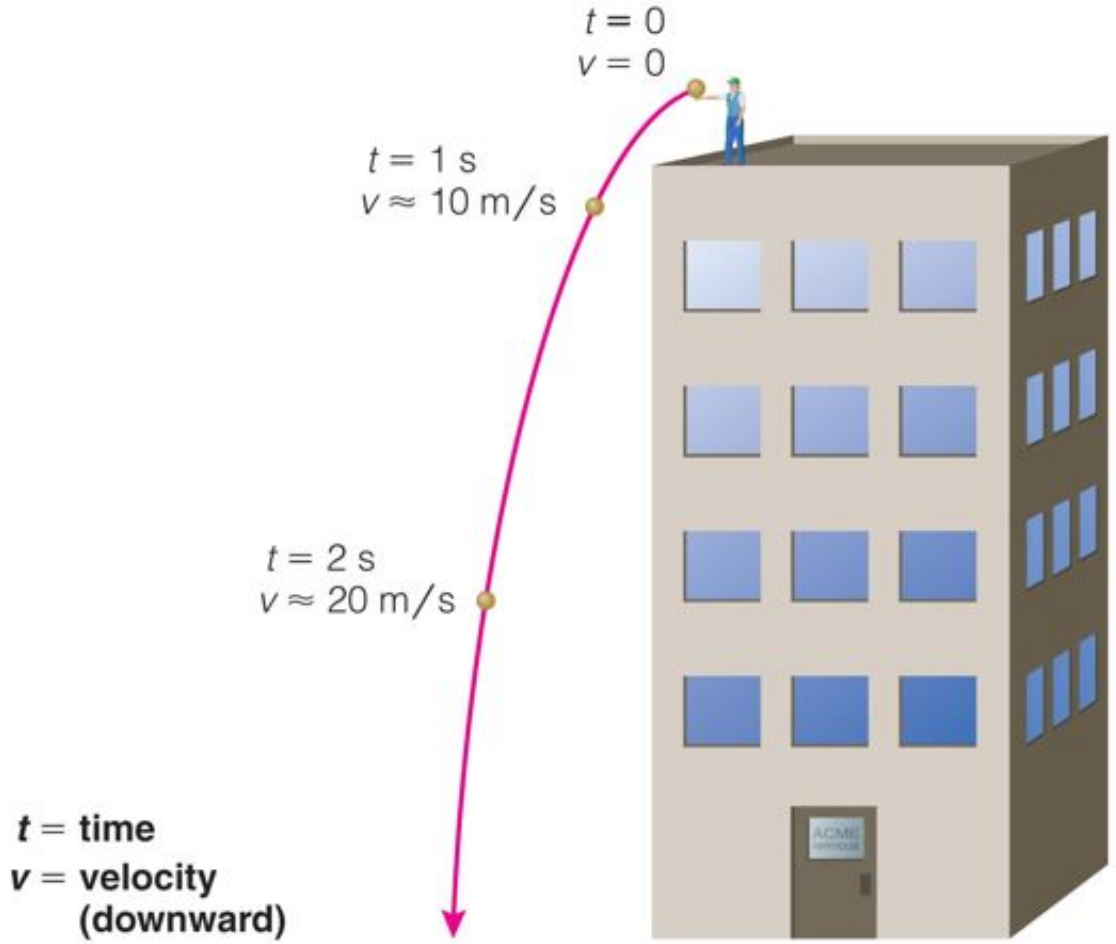
example: speed of 10 m/s

- **Velocity**: Speed and direction
  example: 10 m/s, due east

- **Acceleration**: Any change in velocity
  units of speed/time (m/s^2)

The Acceleration of Gravity

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, $g \approx 10$ m/s^2: speed increases 9.8 m/s with each second of falling.



The Acceleration of Gravity (g)

- Galileo showed that g is the *same* for all falling objects, regardless of their mass.

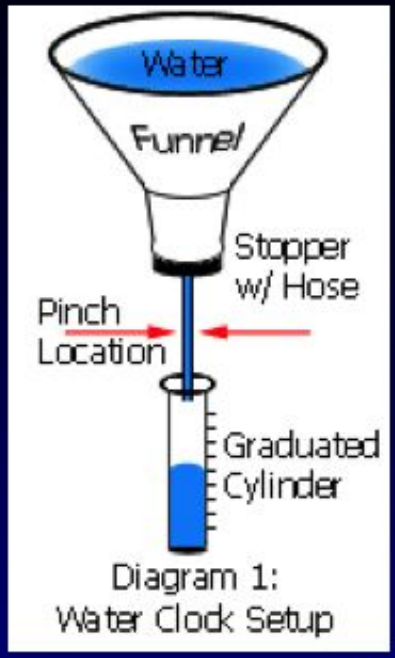


Diagram 1: Water Clock Setup

Momentum and Force

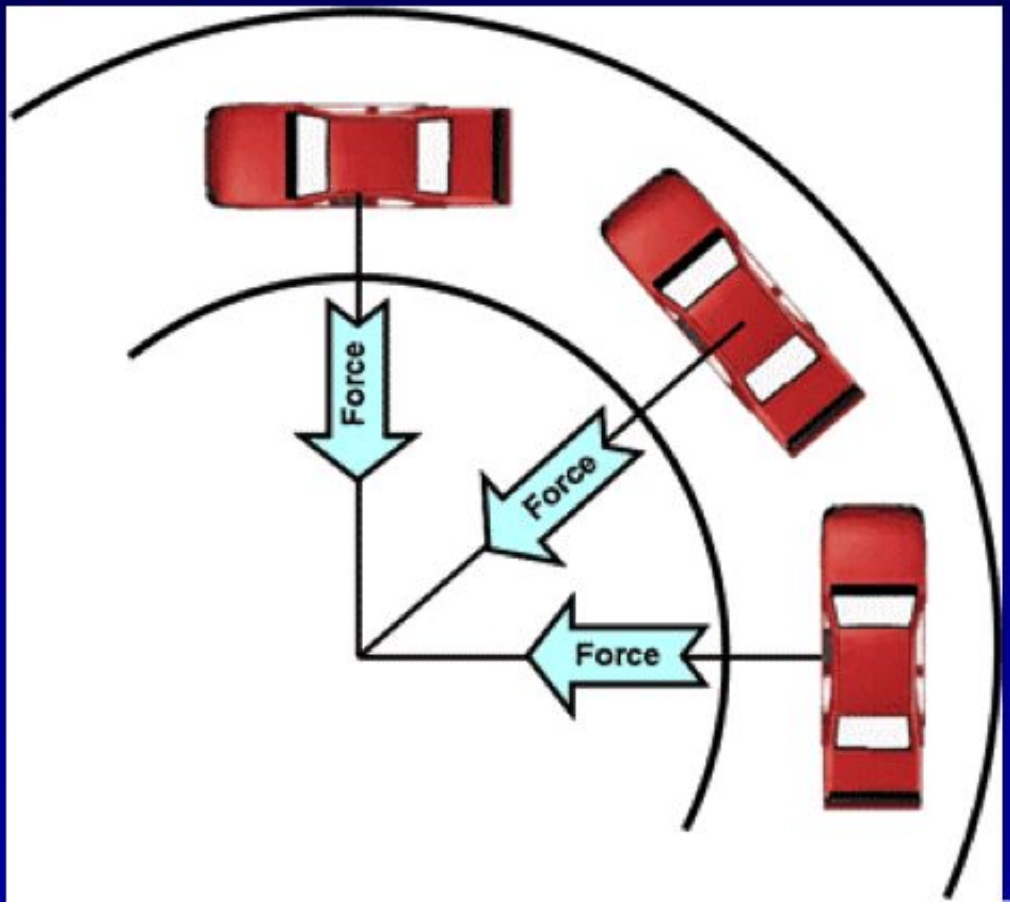
- Momentum = mass × velocity
- A **net force** changes momentum, which generally means an acceleration (change in velocity)
- Rotational momentum of a spinning or orbiting object is known as **angular momentum**

Thought Question:
Is there a net force? Y/N

1. An elevator moving up at constant speed.
   No

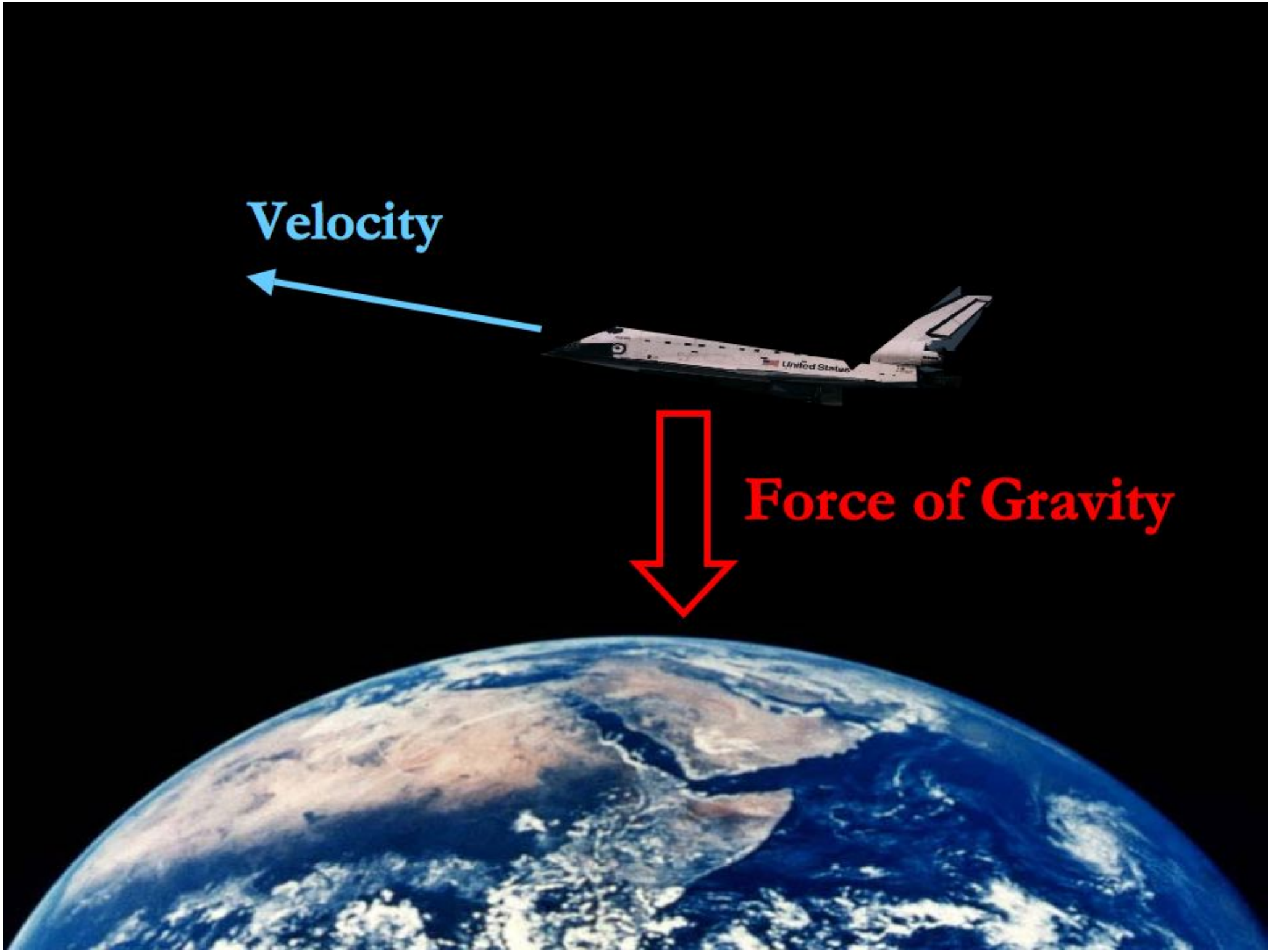
Thought Question:
Is there a net force? Y/N

2. A car going around a curve. Yes.



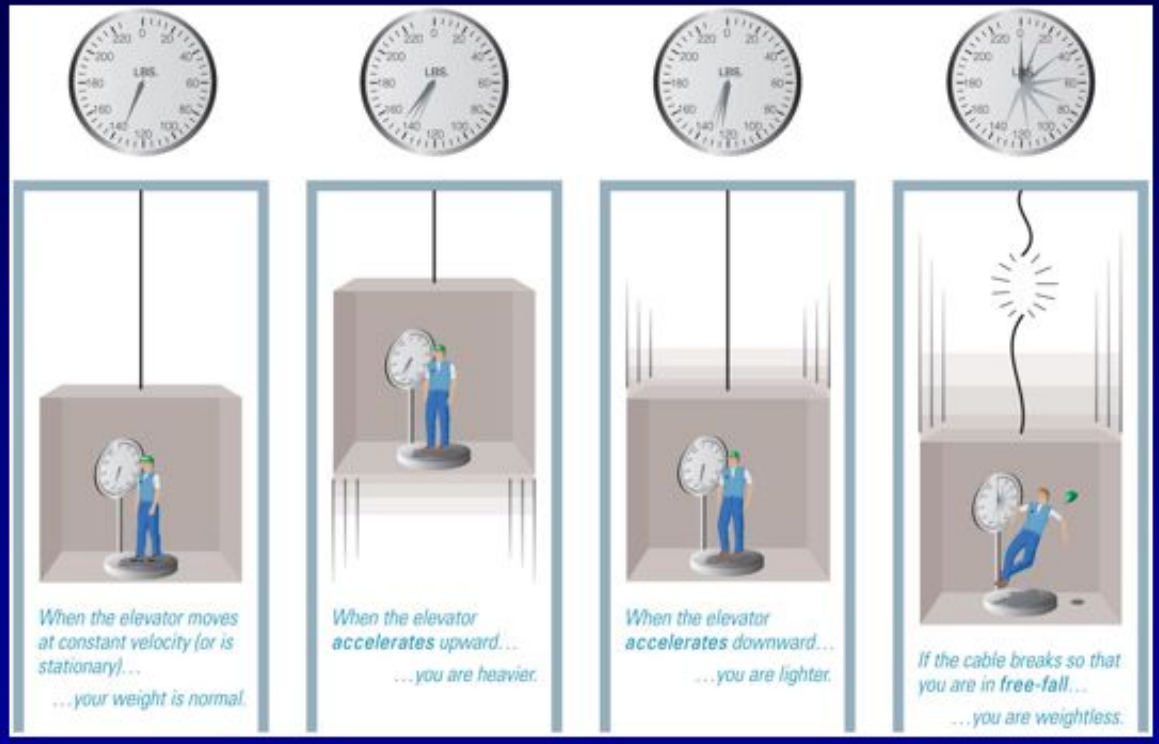
Thought Question:
Is there a net force? Y/N

3. The space shuttle orbiting earth. Yes


Velocity
Force of Gravity

How is mass different from weight?

- **Mass** – the amount of matter in an object
- **Weight** – the *force* that acts upon an object

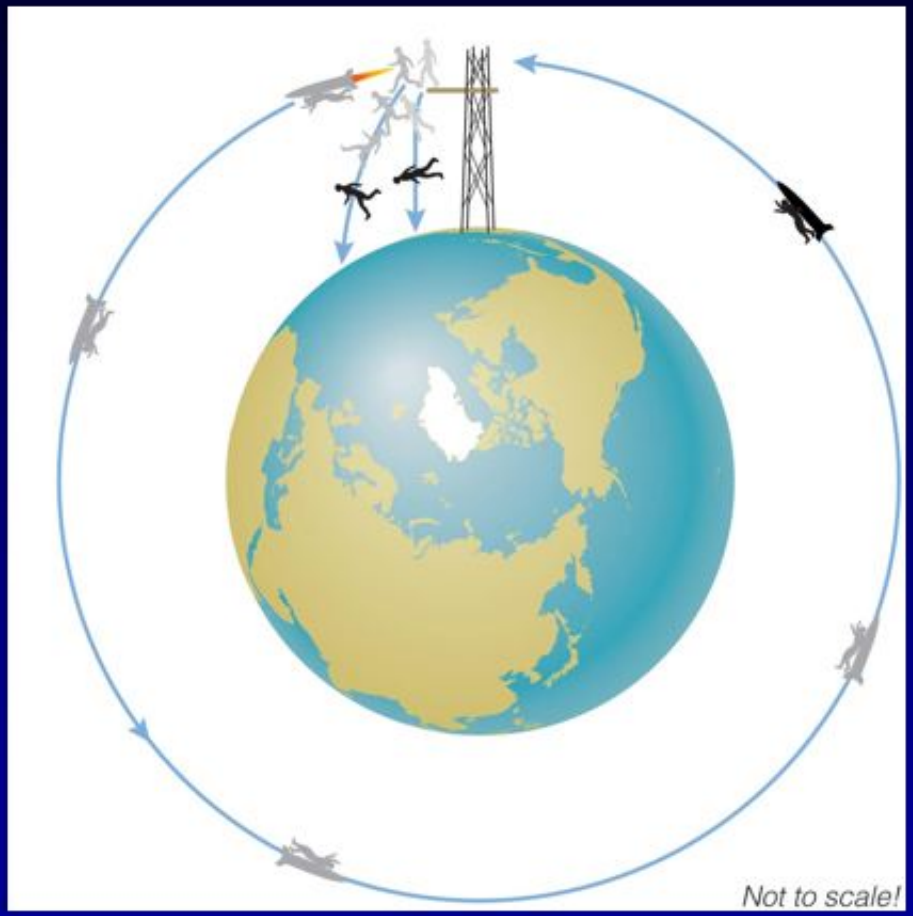


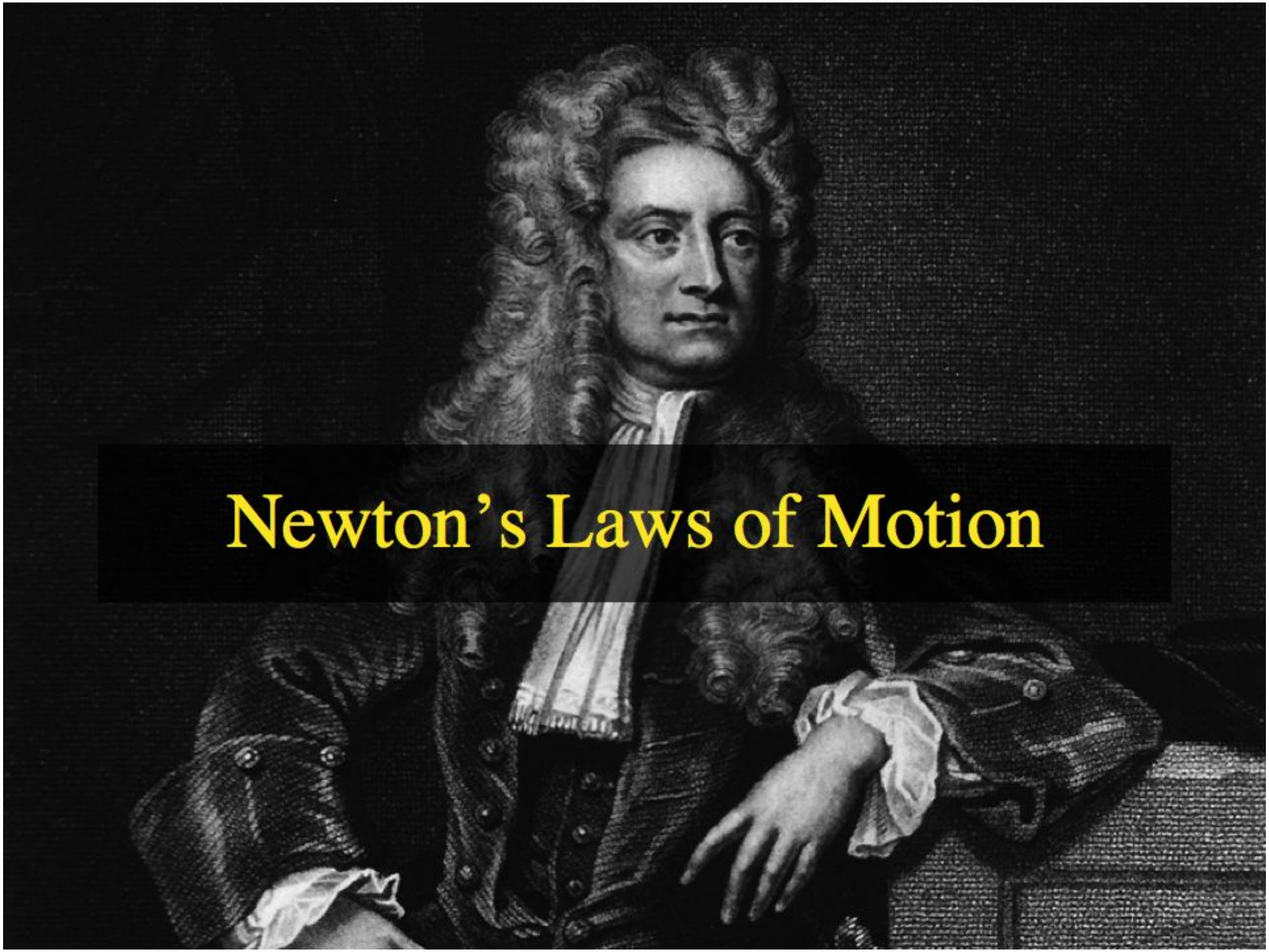
Interactive Figure

You are weightless in free-fall!

Why are astronauts weightless in space?

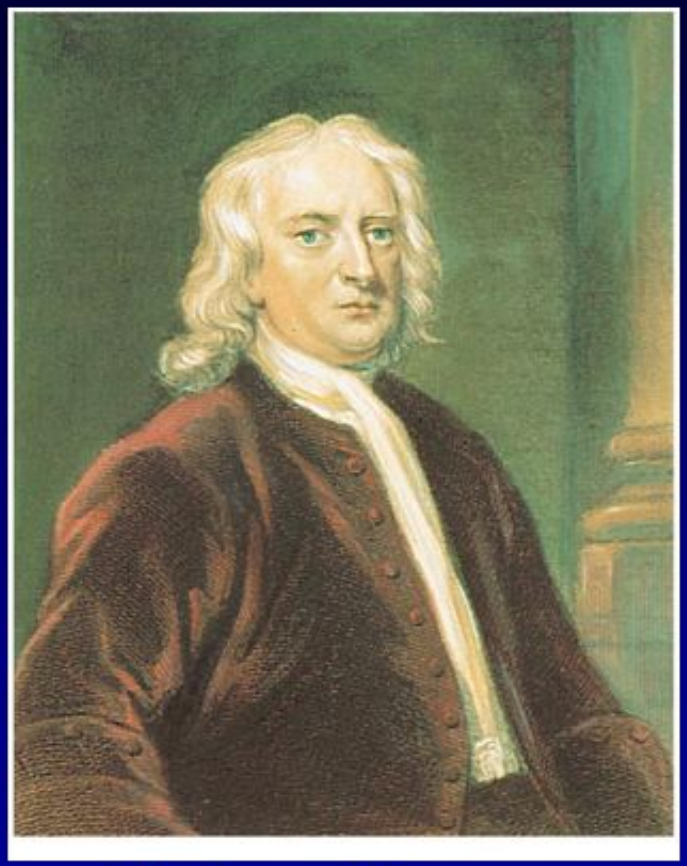
- There *is* gravity in space
- Weightlessness is due to a constant state of free-fall





Newton's Laws of Motion

How did Newton change our view of the universe?



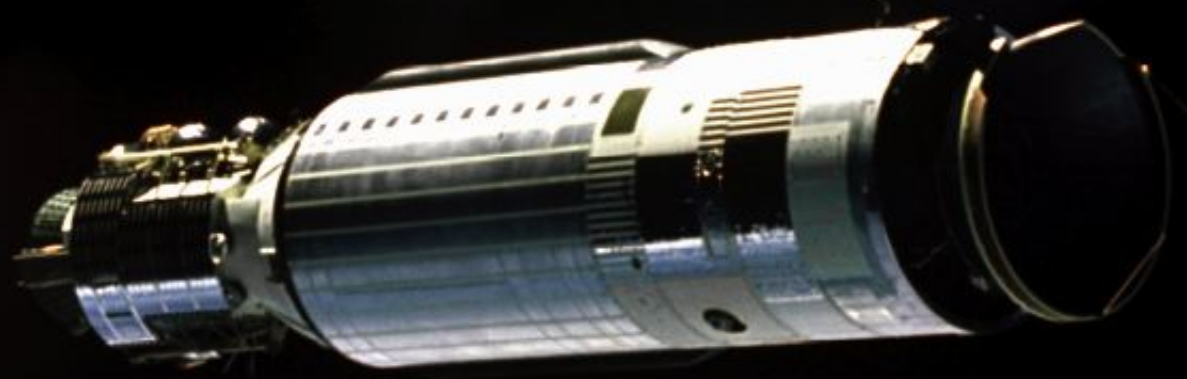
Sir Isaac Newton
(1642-1727)

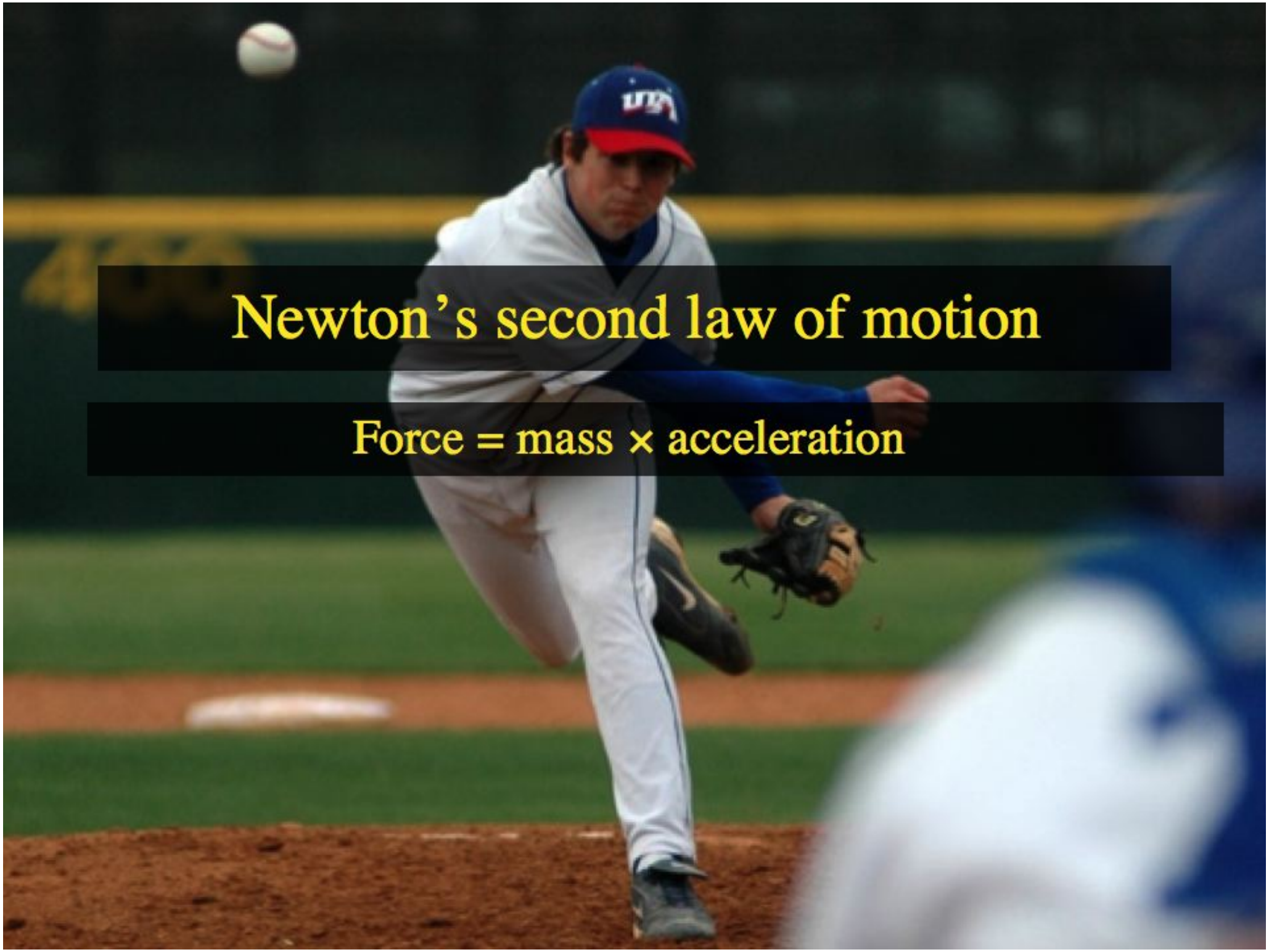
- Realized the same physical laws that operate on Earth also operate in the heavens
  ⇒ one *universe*
- Discovered laws of motion and gravity
- Much more: Experiments with light; first reflecting telescope, calculus…

What are Newton's three laws of motion?

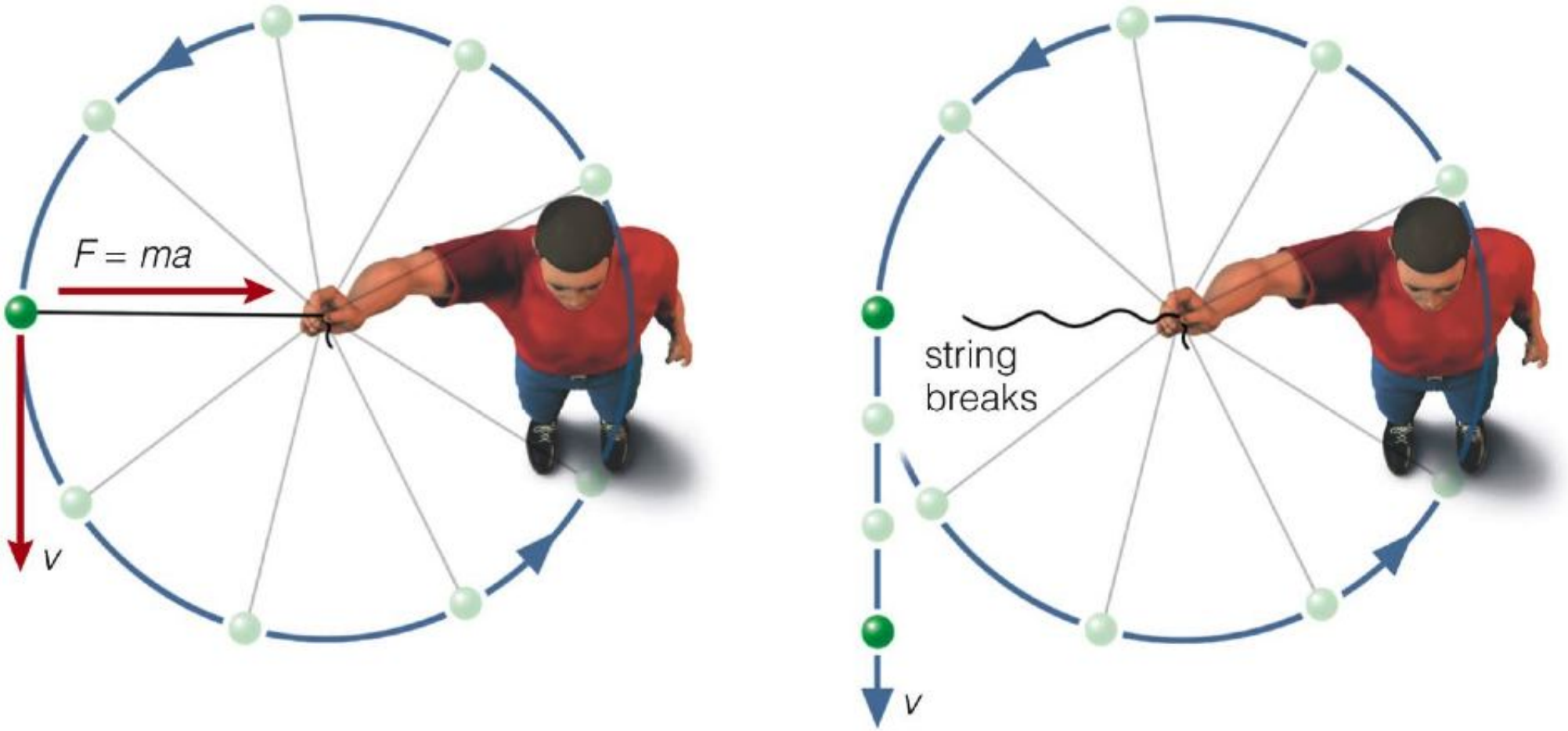
Newton's first law of motion:

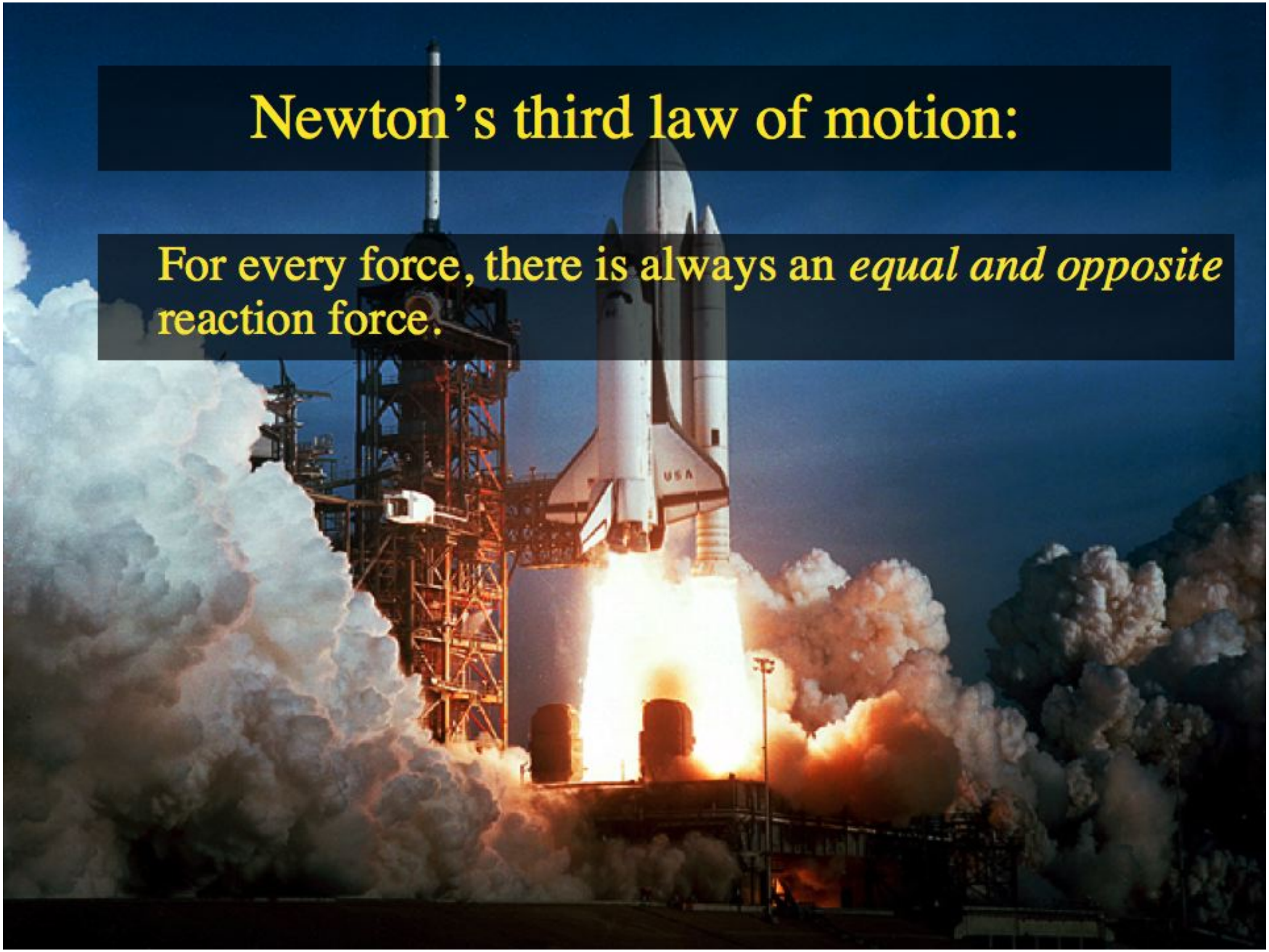
An object moves at constant velocity unless a net force acts to change its speed or direction.



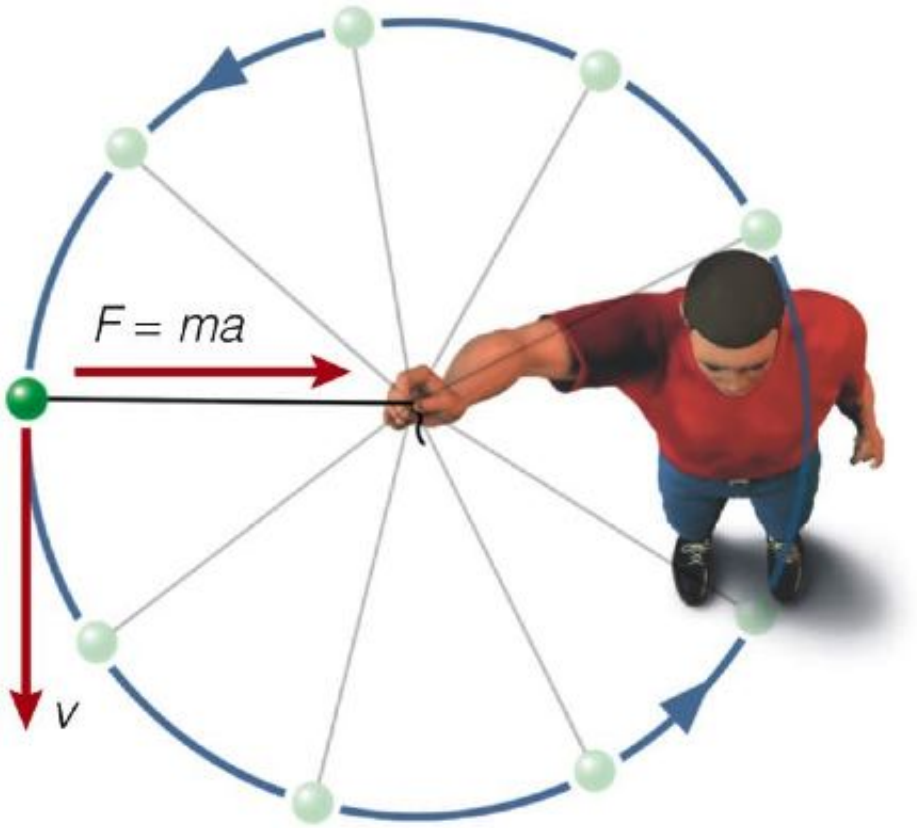

Newton's second law of motion
Force = mass × acceleration

Force = mass × acceleration

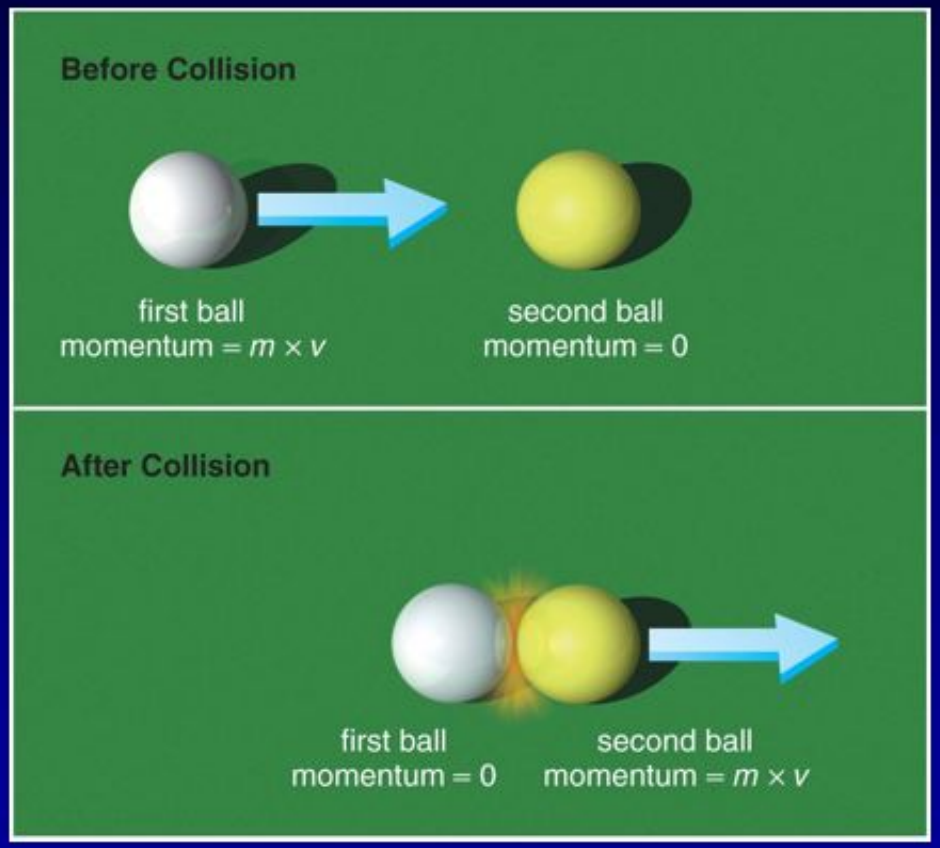



Newton's third law of motion:
For every force, there is always an *equal and opposite* reaction force.

Force = mass × acceleration



Conservation of Momentum



- The total momentum of interacting objects cannot change unless an external force is acting on them
- Interacting objects exchange momentum through equal and opposite forces

Conservation of Angular Momentum

angular momentum = mass x velocity x radius

- The angular momentum of an object cannot change unless an external twisting force (torque) is acting on it

- Earth experiences no twisting force as it orbits the Sun, so its rotation and orbit will continue indefinitely

Angular momentum conservation also explains why objects rotate faster as they shrink in radius:

Where do objects get their energy?

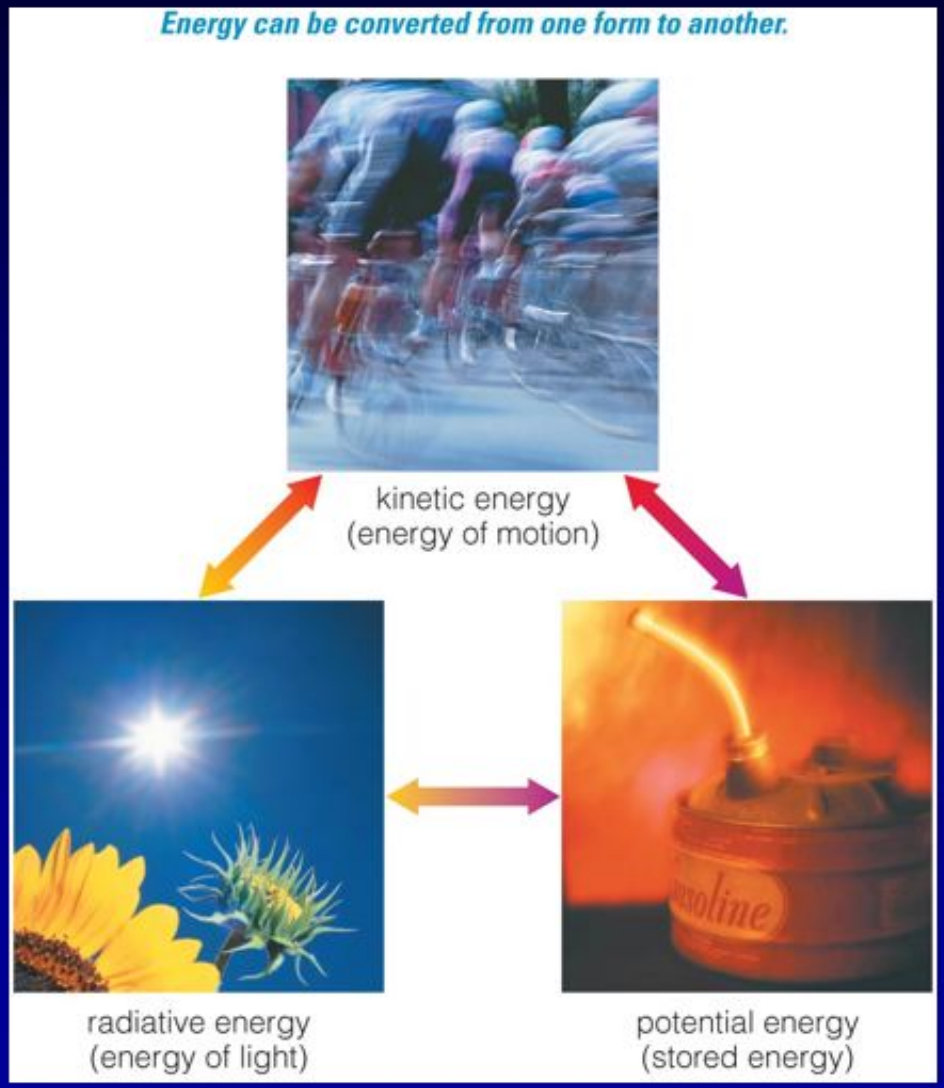
- Energy makes matter move.

- Energy is conserved, but it can:
  - Transfer from one object to another
  - Change in form

Basic Types of Energy

- Kinetic (motion)
- Radiative (light)
- Stored or potential

Energy can change type but cannot be destroyed.

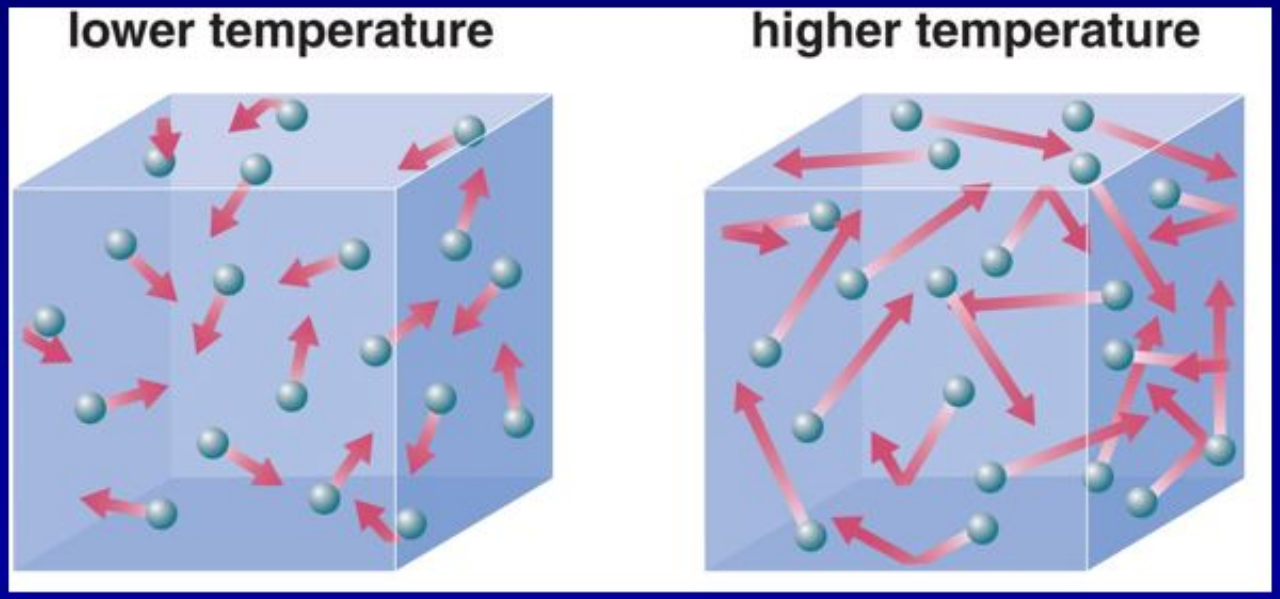


Thermal Energy:

the collective kinetic energy of many particles (for example, in a rock, in air, in water)

Thermal energy is related to temperature but it is NOT the same.

Temperature is the *average* kinetic energy of the many particles in a substance.



Gravitational Potential Energy

- On Earth, depends on:
  - object's mass (m)
  - strength of gravity (g)
  - distance object could potentially fall