Newton's First Law states that the product of a body's mass times its velocity is a constant if no forces are applied to it.

With no force on it, a body in motion would go in a straight line forever.

Newton's Second Law - Force

This law deals with changes of momentum

It states that if a force acts on a body, it produces a change in momentum of the body in the direction of the applied force.

It states that the change in momentum with respect to time is equal to the applied force.

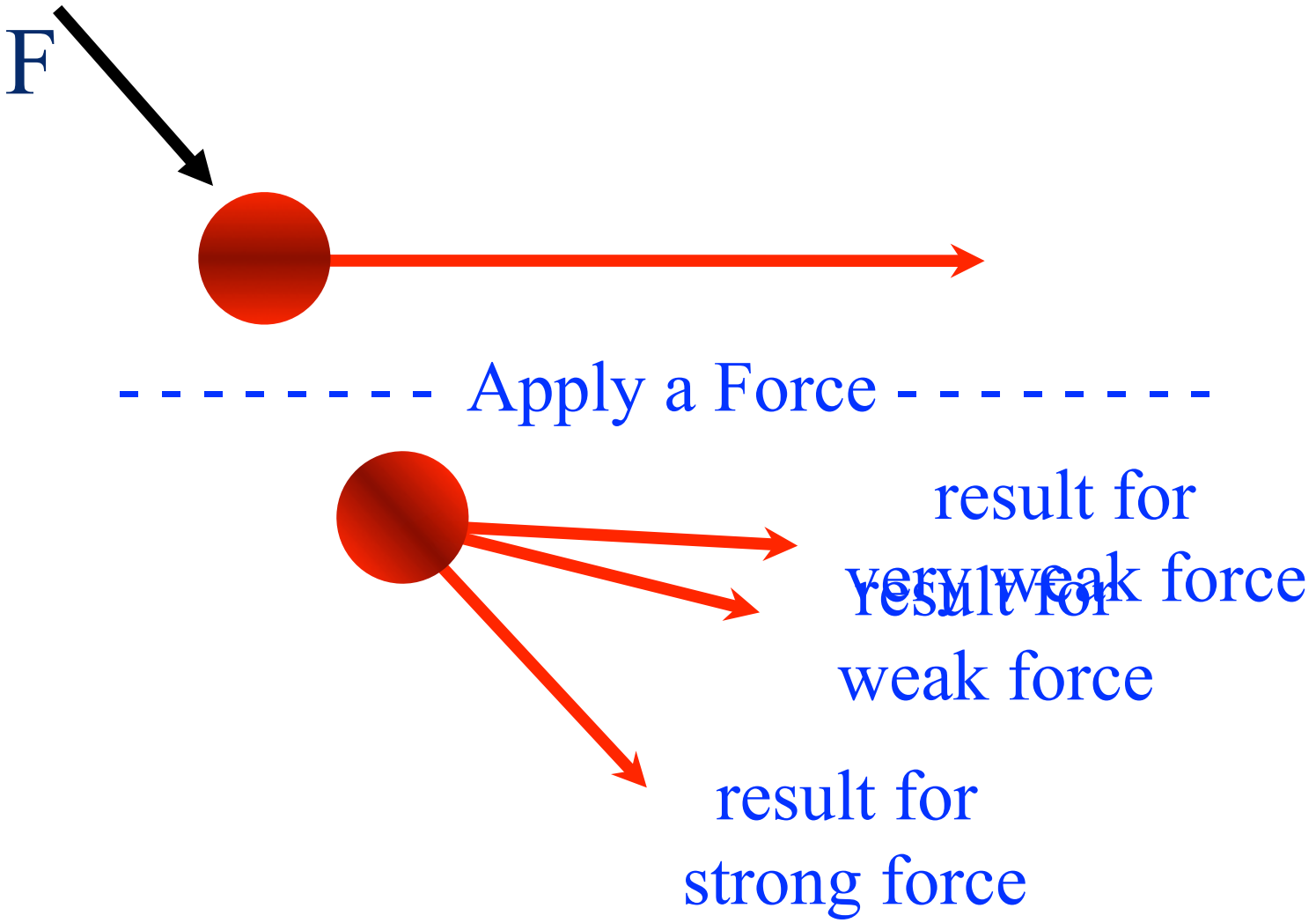
How momentum changes

$$F = \frac{dp}{dt}$$

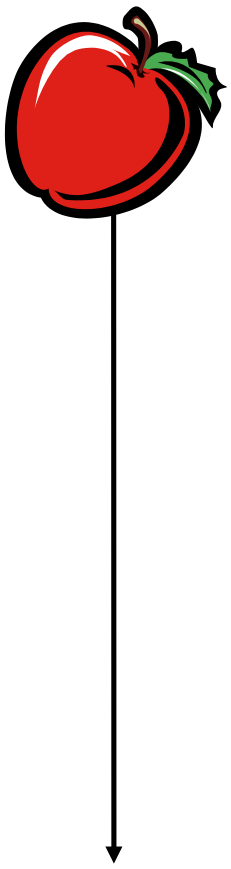
as time changes

$$\sum F = ma$$

The sum of all forces acting on a body produce the acceleration

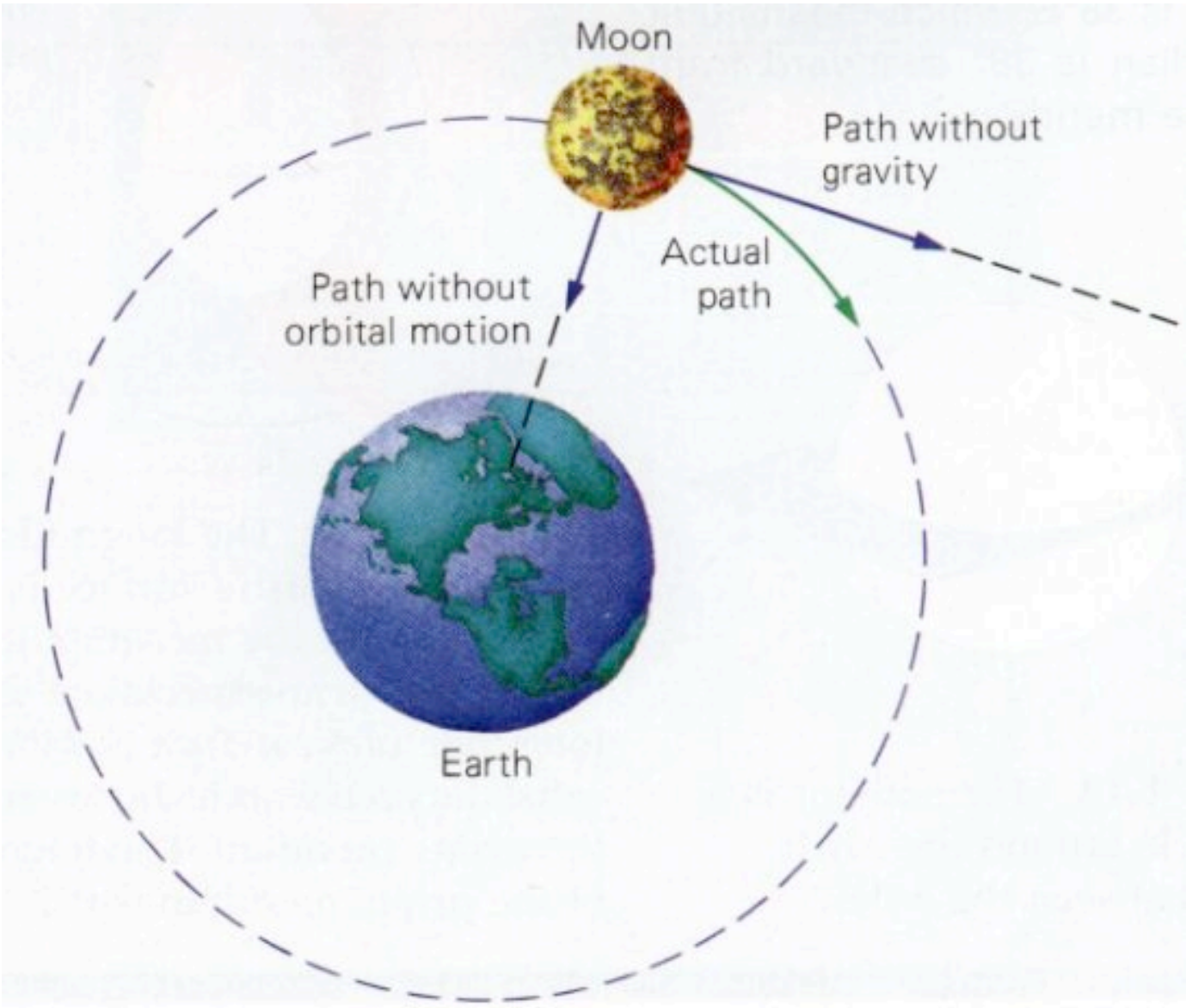

F
Apply a Force
result for
very weak force
result for
weak force
result for
strong force

$F = ma$

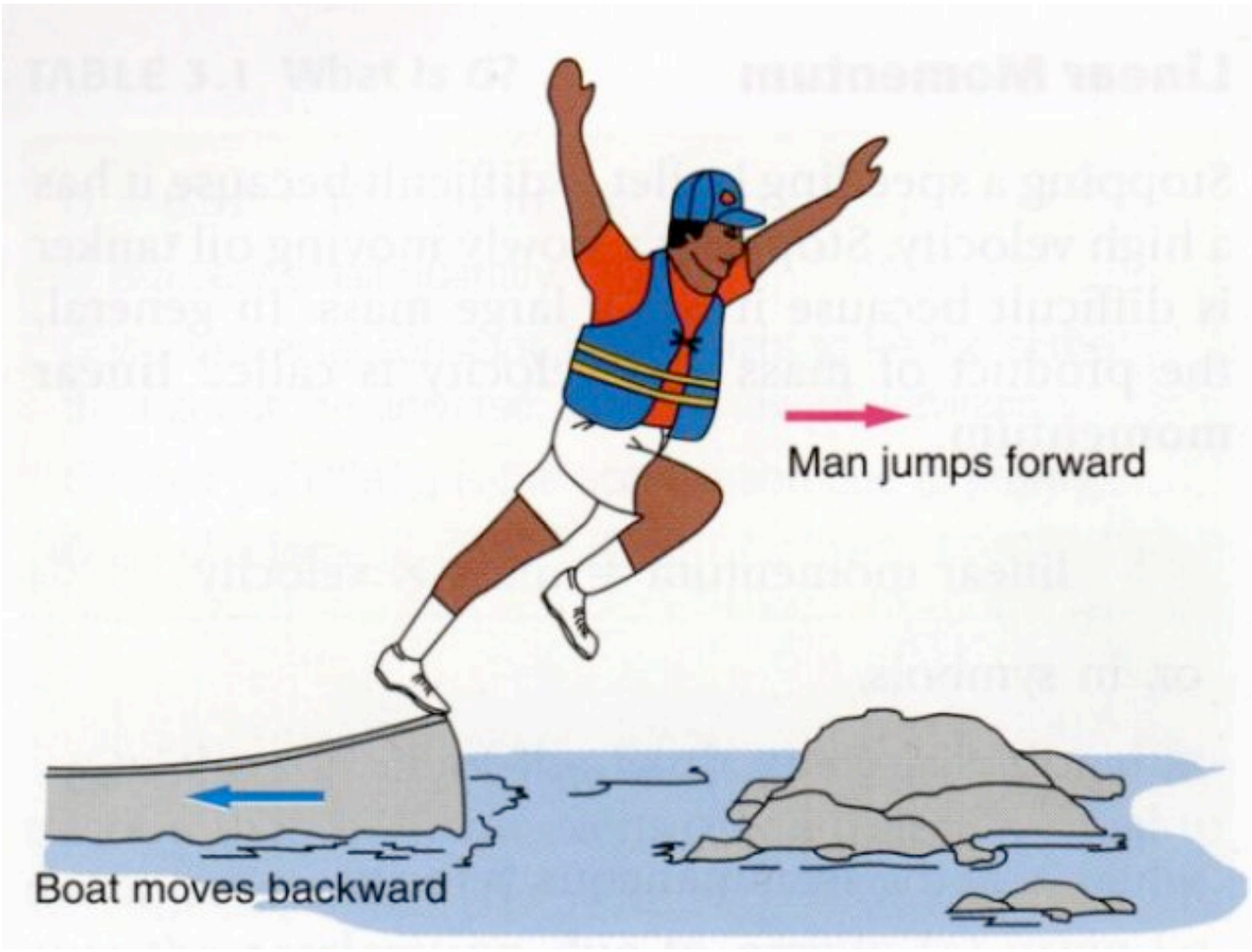


An apple falls to the ground due to the force of gravity.

The acceleration due to gravity is 9.81 m/s^2.


Moon
Path without gravity
Actual path
Path without orbital motion
Earth

Conservation of linear momentum



Conservation of Angular Momentum

http://news.nationalgeographic.com/news/2010/03/100302-chile-earthquake-earth-axis-shortened-day/

Chile Earthquake Altered Earth Axis, Shortened Day

Earthquake sped Earth's spin, figure skater style.

by Ker Than,for National Geographic News

Published March 2, 2010

By speeding up Earth's rotation, the magnitude 8.8 earthquake —the fifth strongest ever recorded, according to the USGS— should have shortened an Earth day by 1.26 millionths of a second, according to new computer-model calculations by geophysicist Richard Gross of NASA's Jet Propulsion Laboratory in California.

Gross also estimates that the Chile earthquake shifted Earth's figure axis by about three inches (eight centimeters).

Newton's Third Law - Reaction

This law was a new idea. It states that all forces occur in pairs of forces that are mutually equal and opposite to each other.

If a force is exerted on an object the object will exert an equal and opposite force on that something.

Some examples

Some examples - recoil

When a rifle is discharged the force pushing the bullet out of the muzzle is equal to the force pushing backward on the gun and marksman – called recoil.

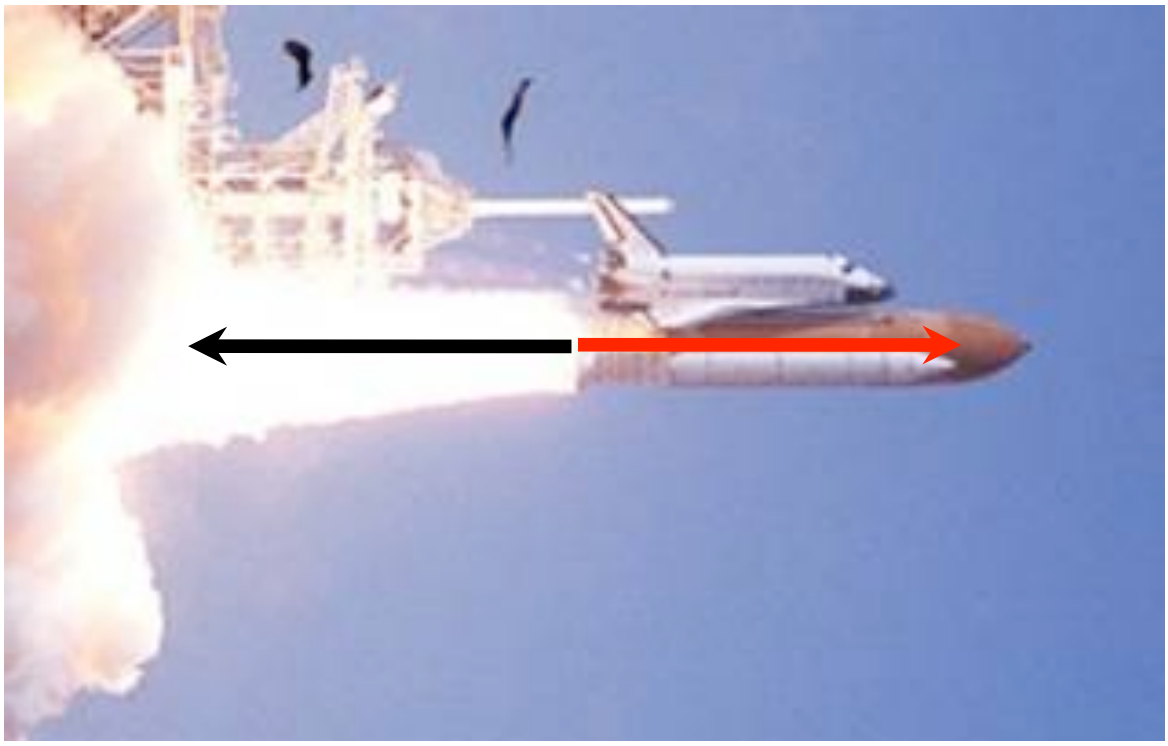
momentum balance !!!

What if the bullet weighed as much as you do?

Inertia

Some examples

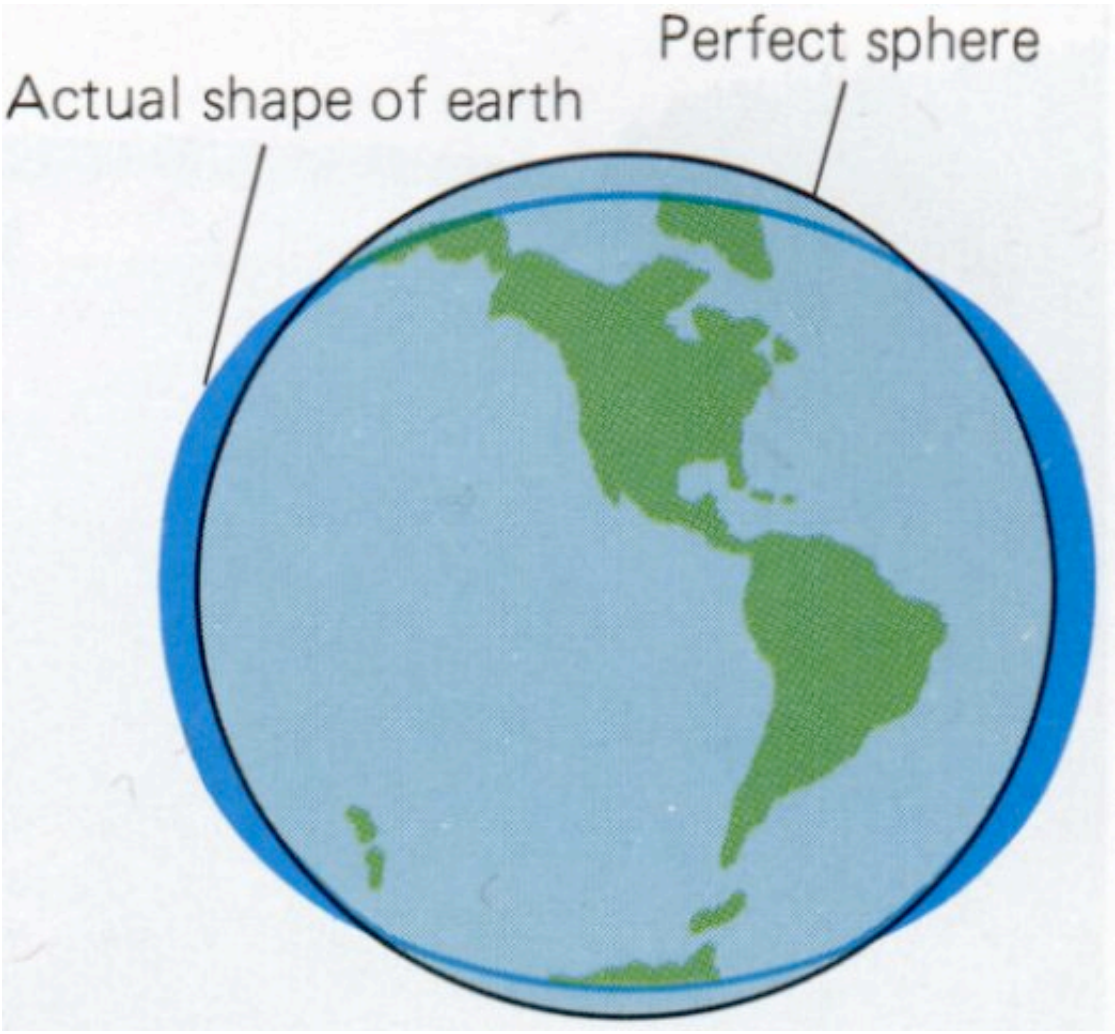
Rockets – the force that discharges the exhaust gases from the rear of the rocket is accompanied by a force that pushes the rocket forward.



The exhaust gases need not push against air or the earth;

In fact a rocket operates best in a vacuum – that's why they work in outer space!

Bulge of the Earth



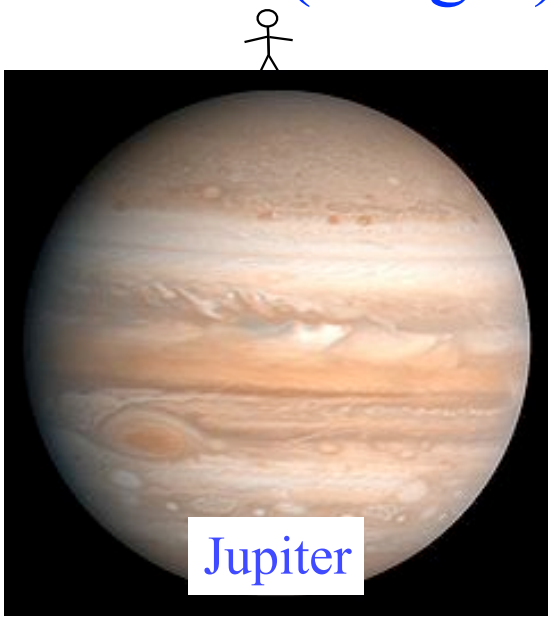
150 lb person

68 kg (mass)

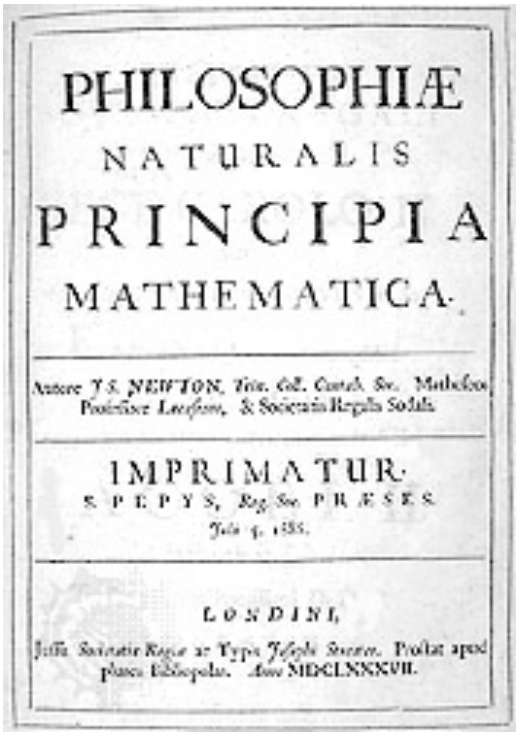
667 N (weight)

68 kg (mass)

1 688 N (weight)



Equivalent mass on Earth 406 lb



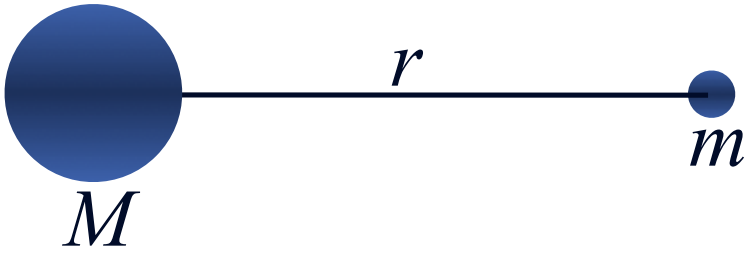
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *I.S. NEWTON*, Trin. Col. Cantab. Soc. Mathesos Professore Lucasiano, & Societatis Regalis Sodali.

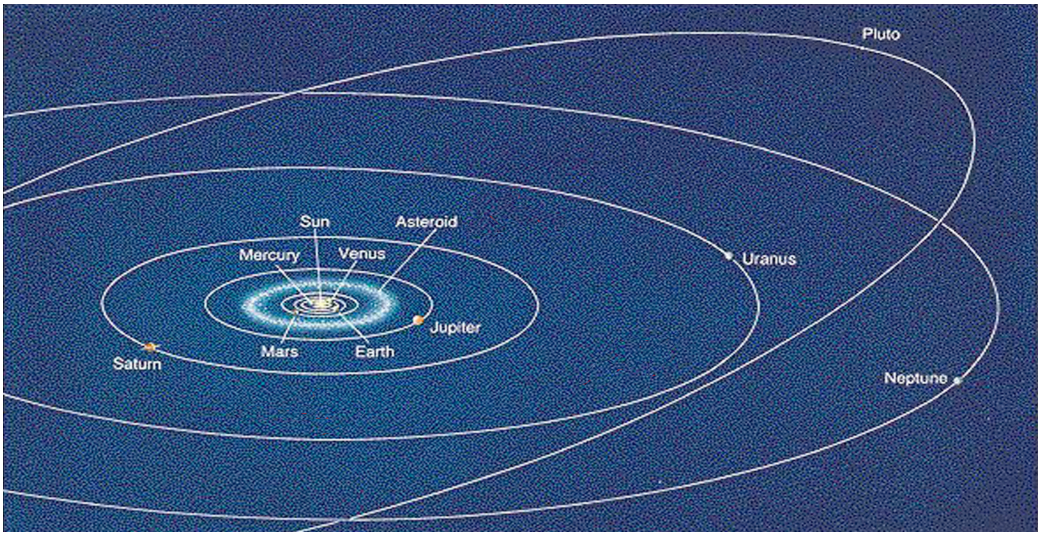
IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

In the Principia (1687), Newton states: "***there is a power of gravity pertaining to all bodies,*** proportional to the … quantities of matter which they contain."


r
m
M

$$F = G \frac{M \ m}{r^2}$$

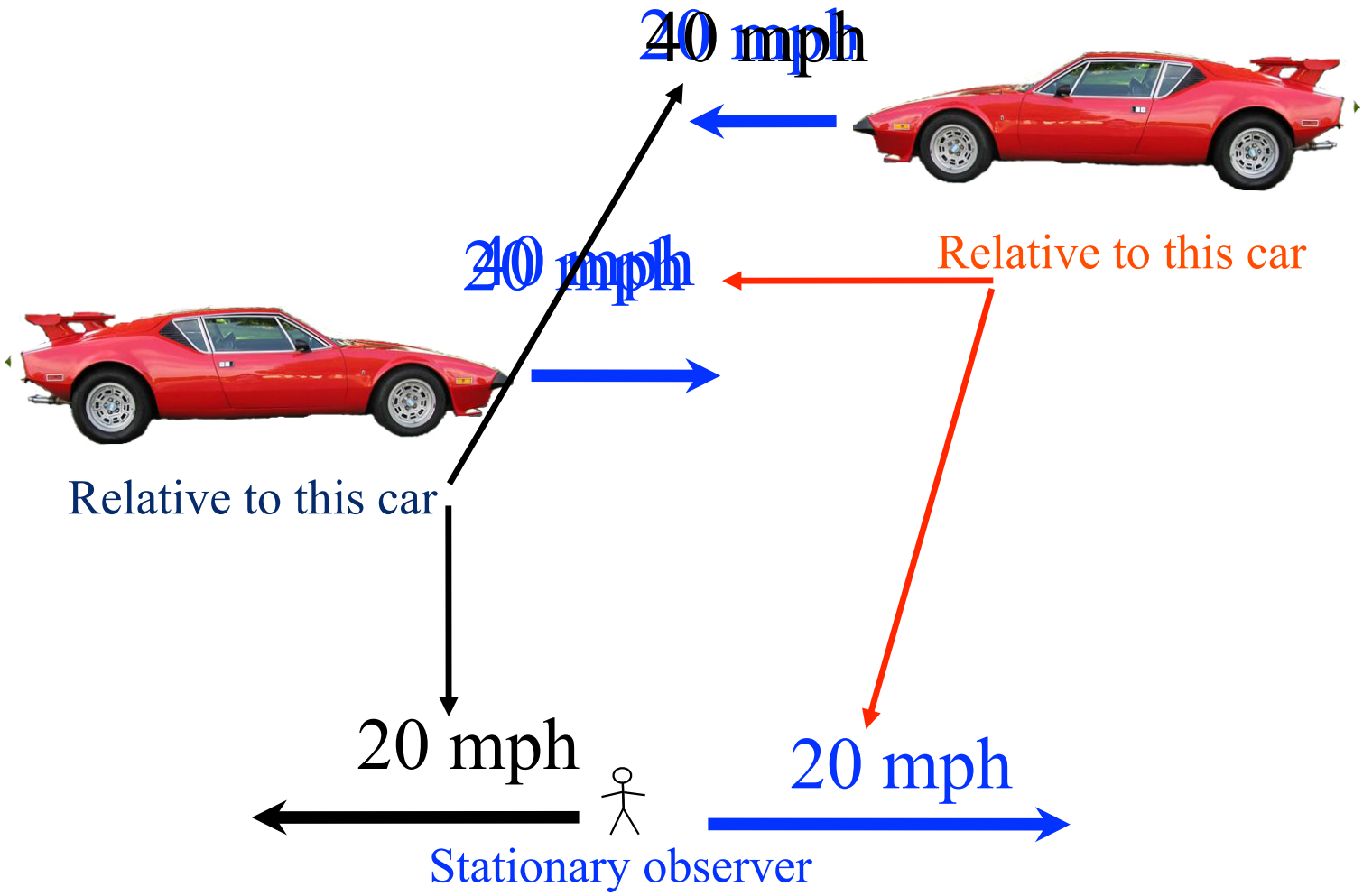

Pluto
Sun
Asteroid
Mercury
Venus
Uranus
Jupiter
Saturn
Mars
Earth
Neptune

Frame of reference

Ever sit in a car at a stop light with another car on the side of you. The other car starts rolling backwards slowly and you think you are moving forward so you quickly hit the brakes!

Newton gave us laws that explain why the celestial bodies (and all other macroscopic objects) move the way they do --

Independent of the reference frame.


40 mph
40 mph
Relative to this car
40 mph
40 mph
Relative to this car
20 mph
20 mph
Stationary observer

Frame of reference

Newton's equations work no matter what reference frame you want to use.
You need to rewrite the equations for the frame you are in, but the physics does not change.

For almost 200 years Newton's Laws of Motion were almost perfect predictors of planetary motion.

As instruments got better there were a few finer details that were not predicted.

Always small but always there.

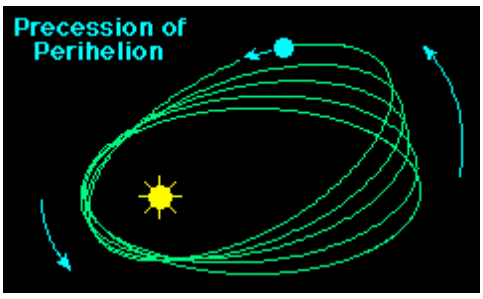
Examples

Mercury's orbit is observed to move in space (*precess*) at a rate that is larger than that predicted by Newtonian mechanics.

Mercury's "extra" precession

Newton - 531 arcsecs

Actual - 574 arcsecs

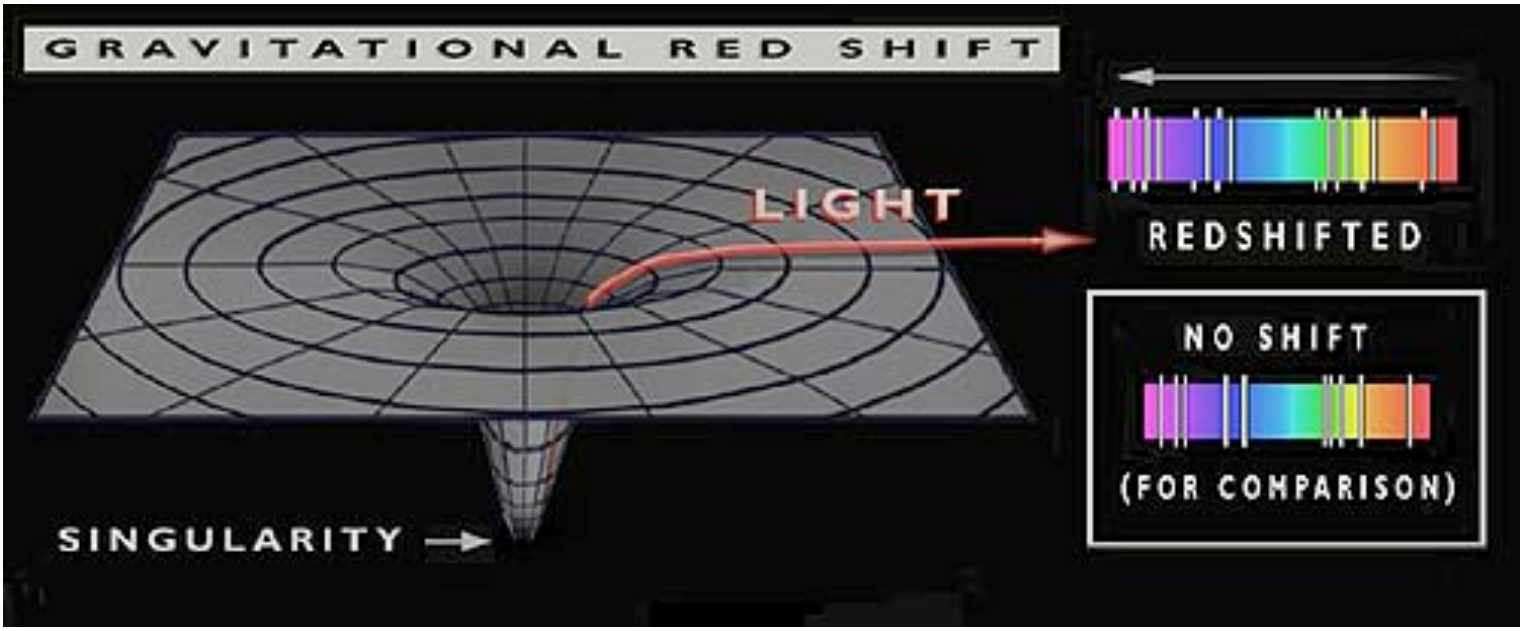


Examples

Bending of light rays by the sun.

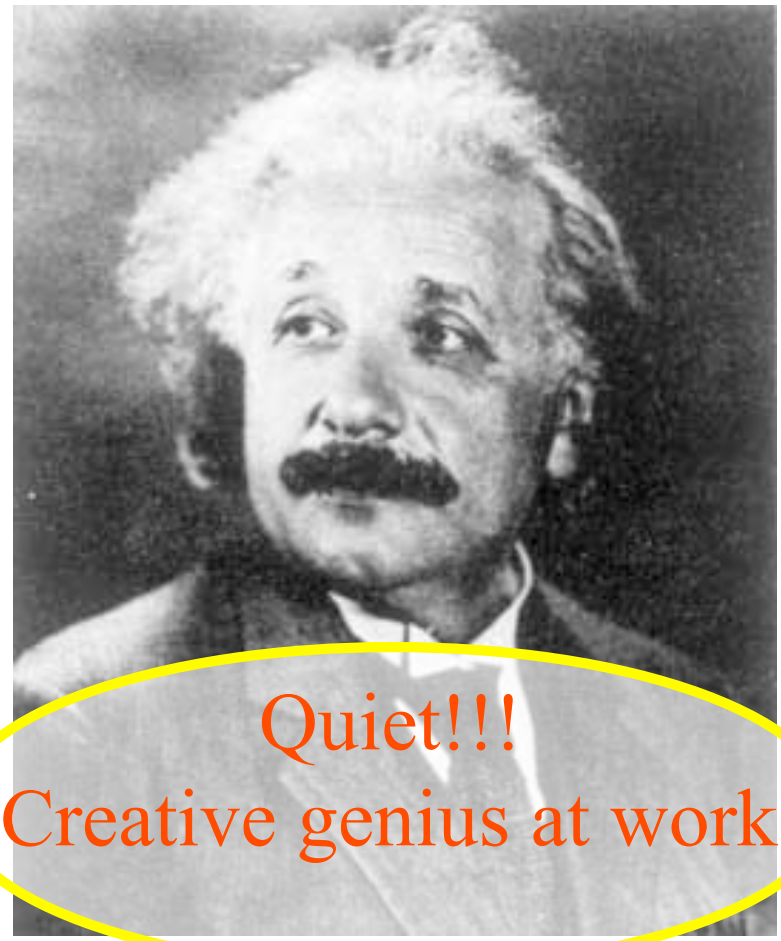
Examples

Gravitational red shift – light accelerated by gravity can only gain energy by increasing its frequency



http://archive.ncsa.illinois.edu/Cyberia/NumRel/Images/redshift.jpeg

Albert Einstein (1879-1955)



Theory of relativity

Einstein was not trying to solve the problem with Newton's Equations, but he was using some of what the equations tell us.

Physics must be independent of the frame of reference

Newton's Equations did this for mechanics.

Einstein looked at Maxwell's equations for electromagnetic radiation. And said they must also be independent of reference frame.

Maxwell's Equations

Coulomb's law: $\nabla \bullet D = 4\pi\rho$

Ampère's law: $\nabla \times H = \frac{4\pi}{c} J$

Speed of light

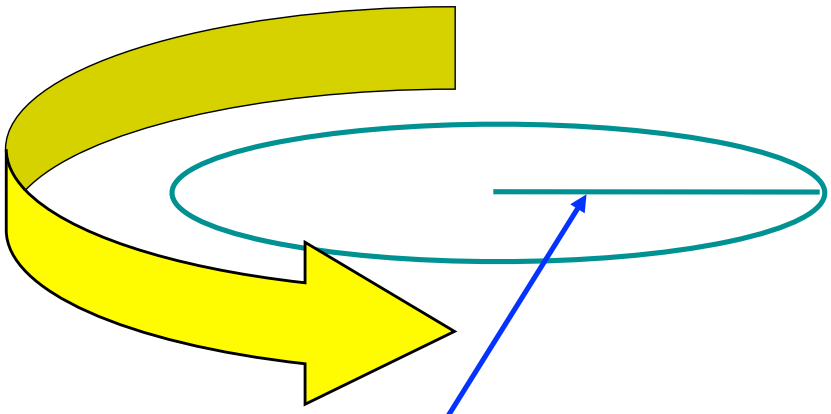
Faraday's law: $\nabla \times E + \frac{1}{c}\frac{\partial B}{\partial t} = 0$

Absence of free magnetic poles: $\nabla \bullet B = 0$

Speed of Light

$2.99\ 792\ 458 \times 10^{8}$ m/s

7 ½ times per second

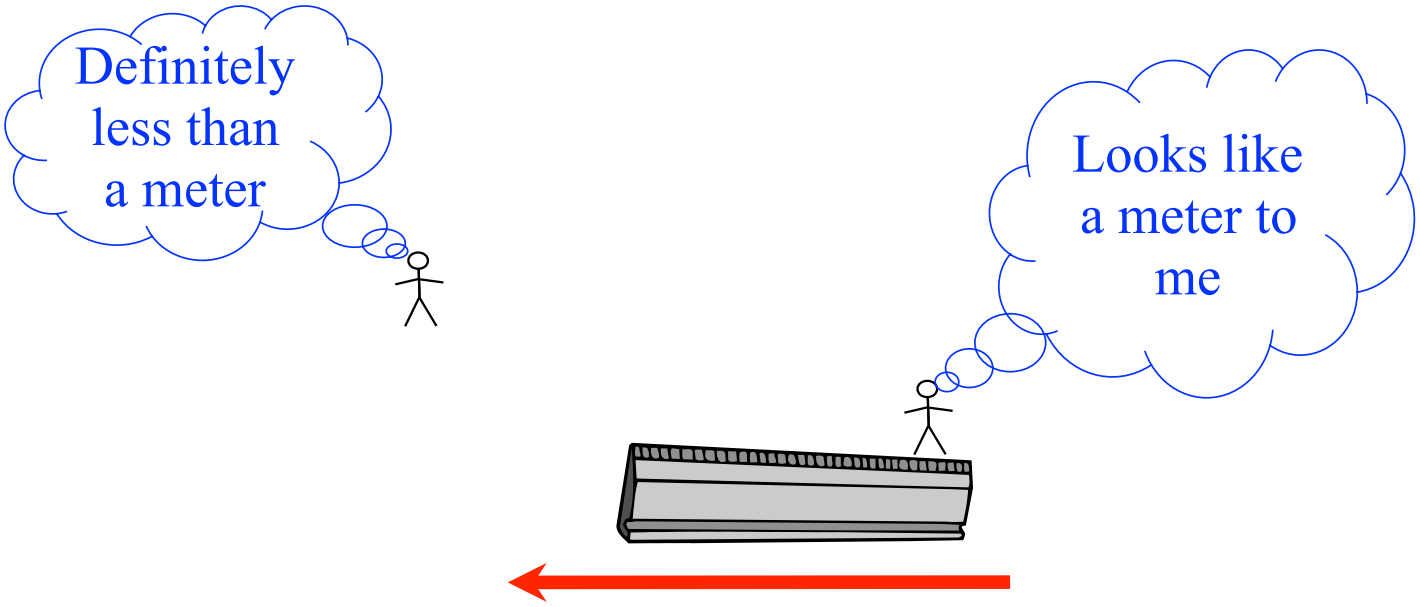


Earth $= 6.38 \times 10^{6}$ m

Einstein formulated the

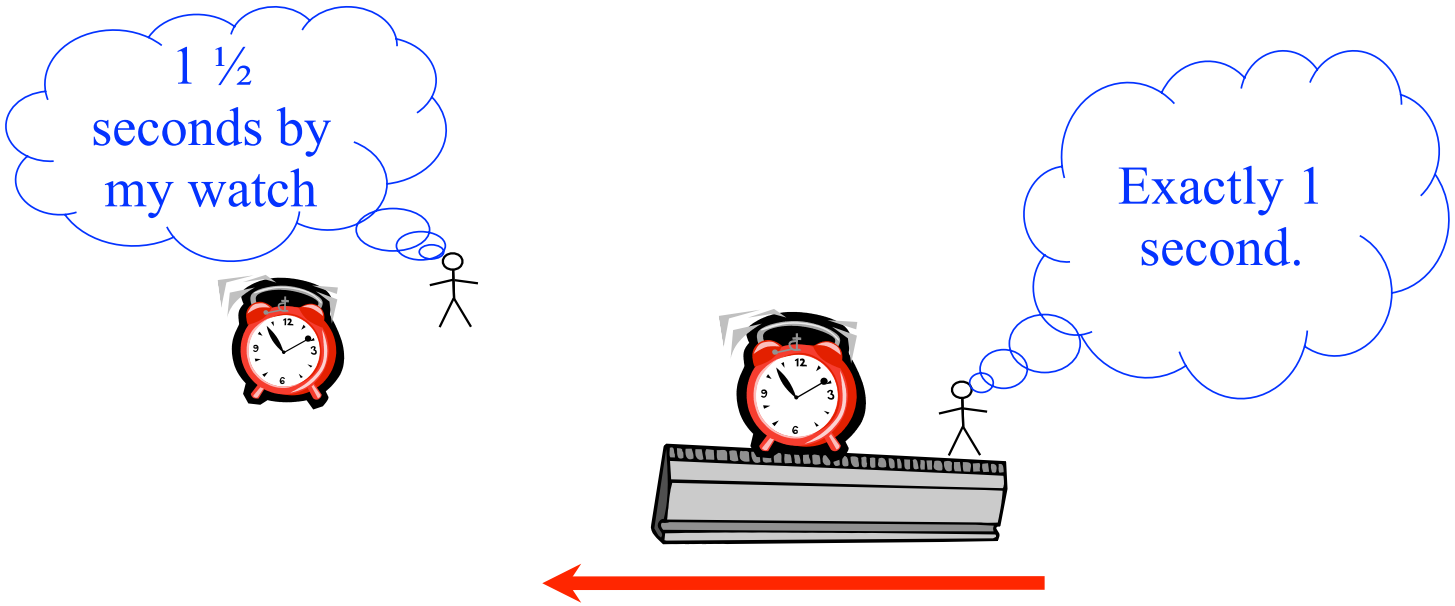
Special theory of relativity - 1905
General theory of relativity - 1915

At very high speeds



Distances seem shorter to stationary observer

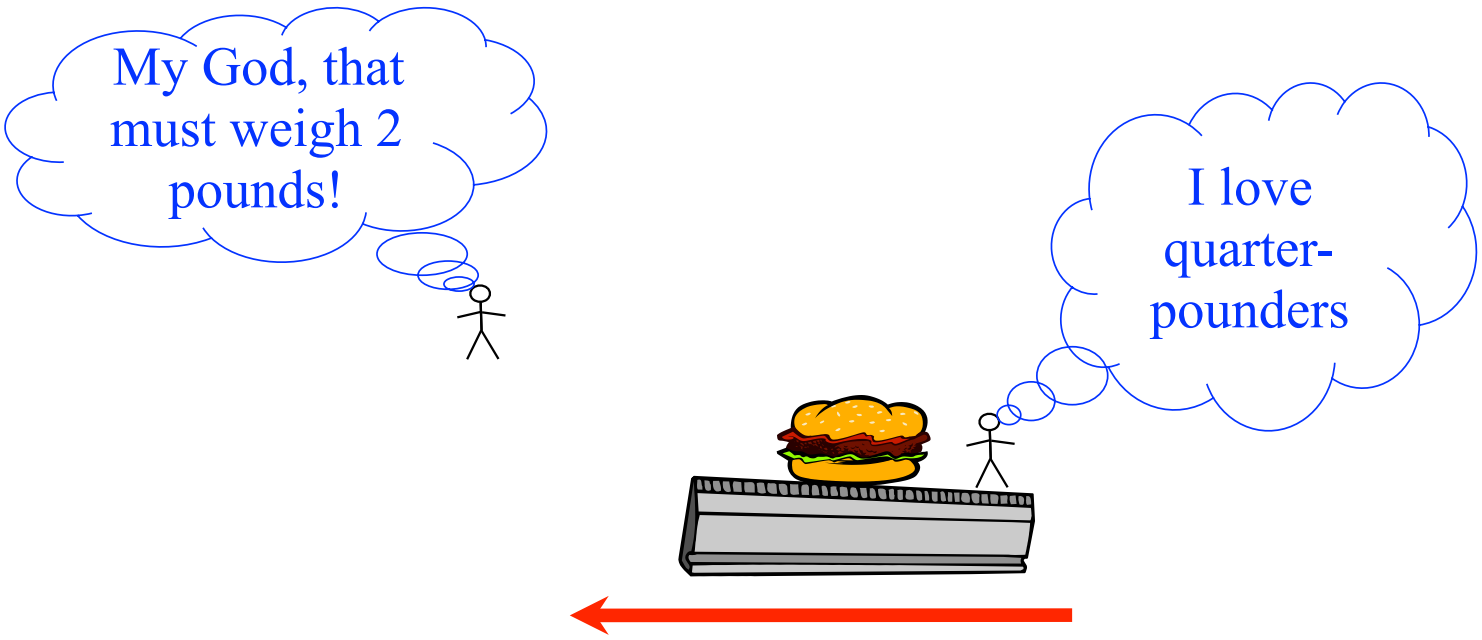
At very high speeds



time seems lengthened to stationary observer

It looks like the moving clock runs slow

At very high speeds



mass seems greater to stationary observer

Gravity

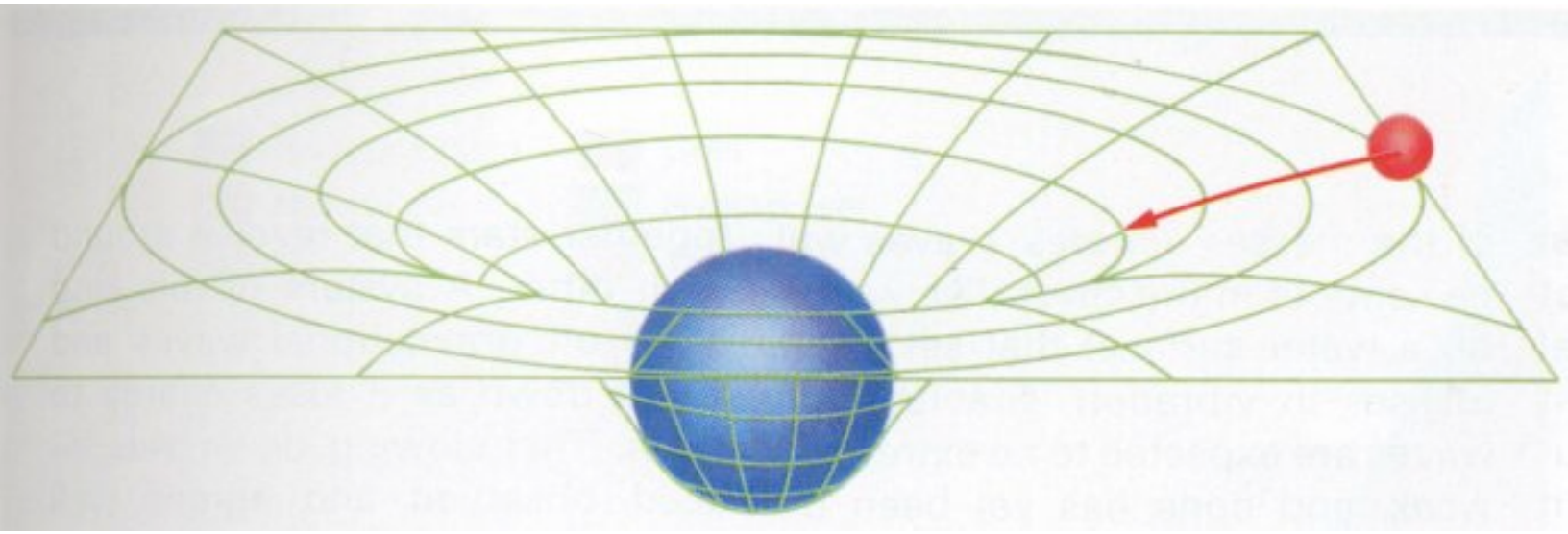
How fast is gravity?

"instant propagation" (Newton)

or

"delayed information" (Einstein)

Time-Space is warped by gravity



Einstein's theory of relativity

Correctly predicts all observed phenomena – planetary motion, bending of light, etc.

How long will the theory go unchallenged?

1971

Joseph Hafele and Richard Keating flew state-of-the-art cesium-beam atomic clocks around the world on a commercial Pan Am jet.

When the clocks on the plane were compared with other clocks that remained on the ground they found less time had elapsed on the clocks that were moving. The difference was in agreement with theory.

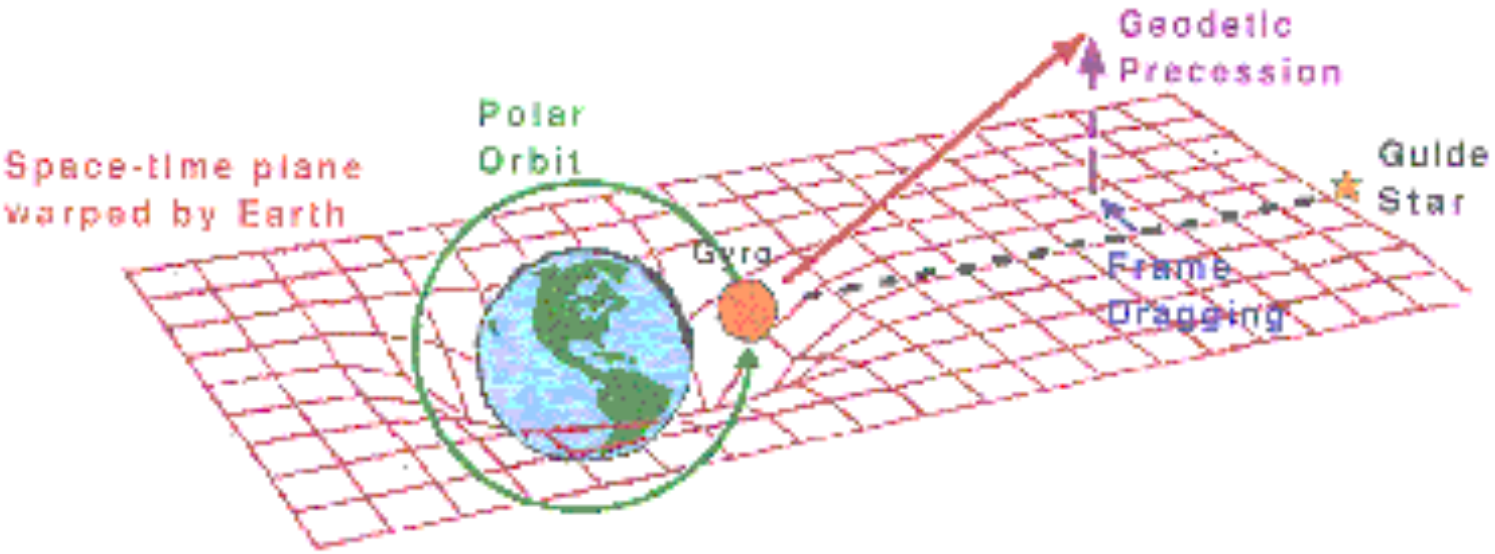
Gravity Probe A - 1976

→verified that the flow of time is slowed near a large body.

→A rocket carried an extremely precise atomic clock to an altitude of about 6,200 miles.

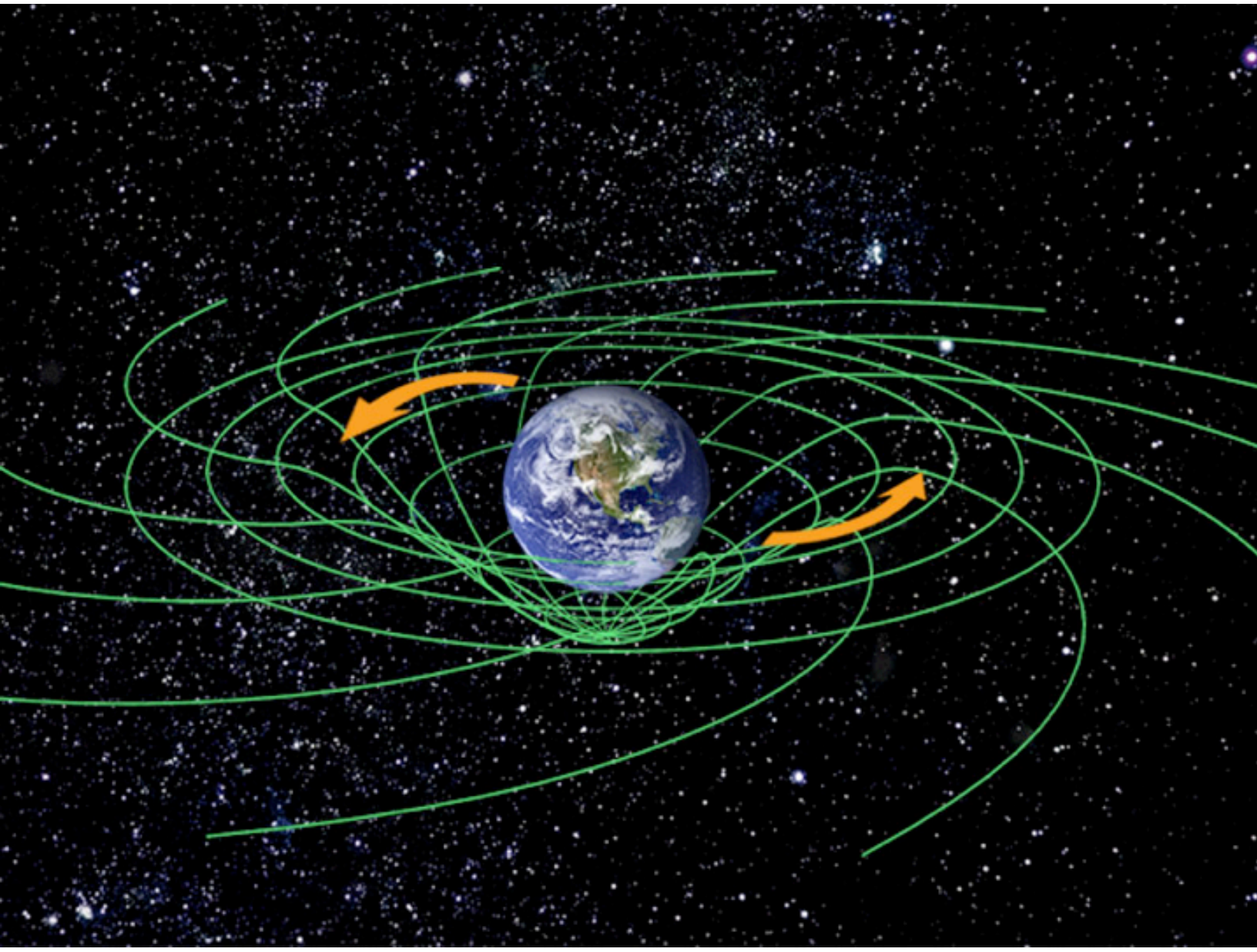
→As the Earth's gravitational pull weakened, the instrument showed that time speeded up almost imperceptibly - by about 1 part in 10 billion compared to the rate on Earth demonstrating that gravity slows the flow of time.


Gravity Probe B
http://einstein.stanford.edu



The rubber-sheet analogy is the best way to envision how mass curves space and time; the Earth is like a marble denting the smooth surface (Jupiter would be like a bowling ball). Frame-dragging will act as if there's just a trace of friction between the Earth and the rubber sheet so that the Earth's rotation twists the sheet just a little in one direction, while geodetic precession pulls a little at a right angle. Credit: UAH

http://spacescience.com/headlines/y2000/ast24may_1m.htm?list



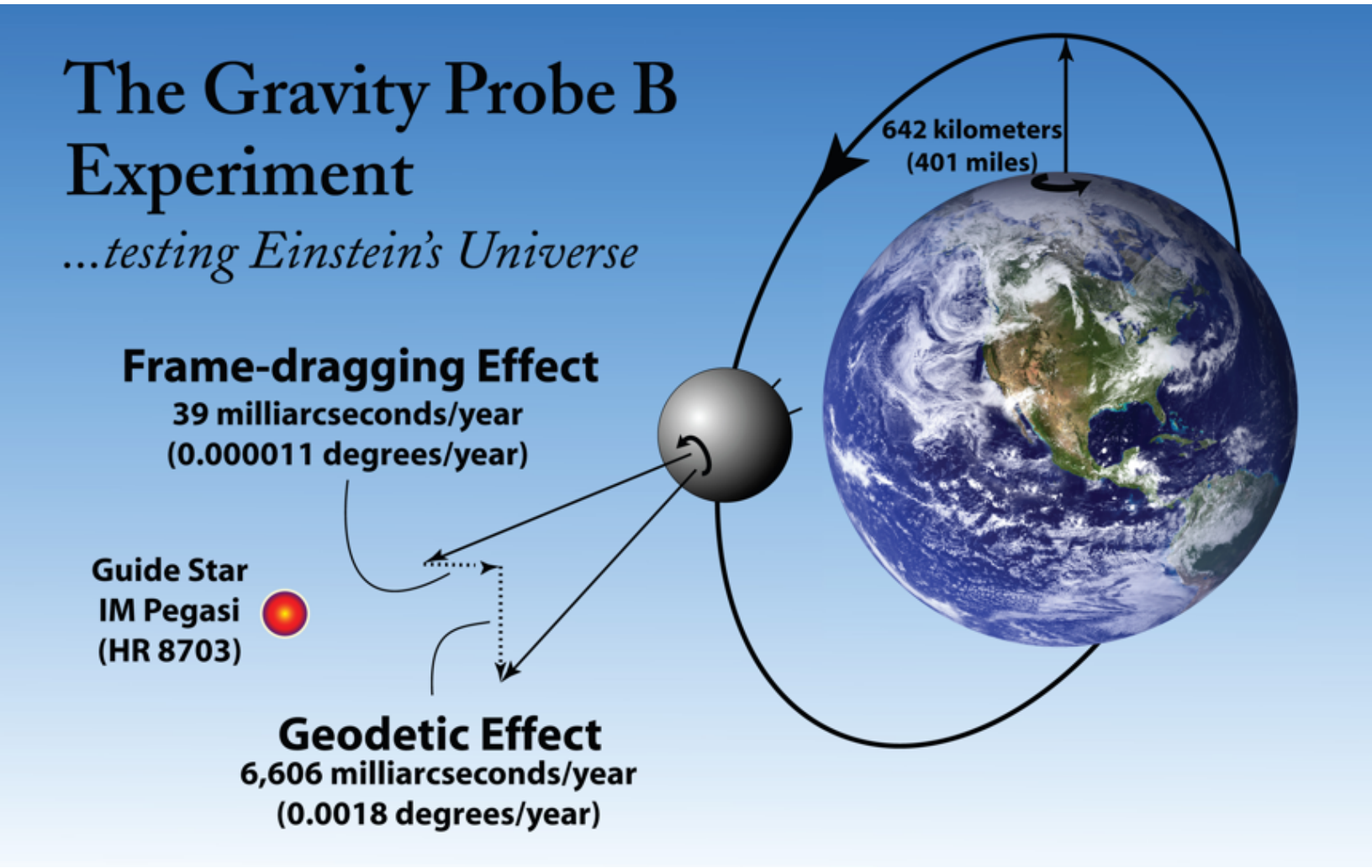
The principle behind the Gravity Probe B instrument is straightforward.

Newton’s first law: Free of disturbing forces, a gyroscope pointed at a star should stay aligned indefinitely.

However, Einstein's theory says the spin axis and orientation of the gyroscope should change ever so slightly due to the warping and dragging effects of Earth's gravitational mass on local space-time.

The Gravity Probe B Experiment

...testing Einstein's Universe



Gravity Probe B

Why is it important?

Major aspects of modern cosmology depend on the integrity of Einstein's theory.

1st presentation of results APS April 2007

Warping of space confirmed.

February 2010

Frame Dragging Clearly Visible

(Statistical uncertainty ~ 14%)

4000 years of theory

2000 BC: Egyptians: sun is a boat sailed by the gods

400 BC: Eudoxus: Earth fixed, planets roll on spheres. Aristotle constructs the model with 55 crystal spheres

100 AD: Ptolemy: modified Eudoxus's model to account for apparent direction reversals

1543 AD:	Copernicus postulated that Earth was one of the planets, all of which revolved around the sun.
1609 AD:	Kepler postulates elliptical rather than circular orbits, 3 laws
1632 AD:	Galileo confirms Kepler's laws
1666 AD:	Newton: universal law of gravitation
1904 AD:	Einstein: special relativity
1917 AD:	Einstein: general relativity

It doesn't stop here.

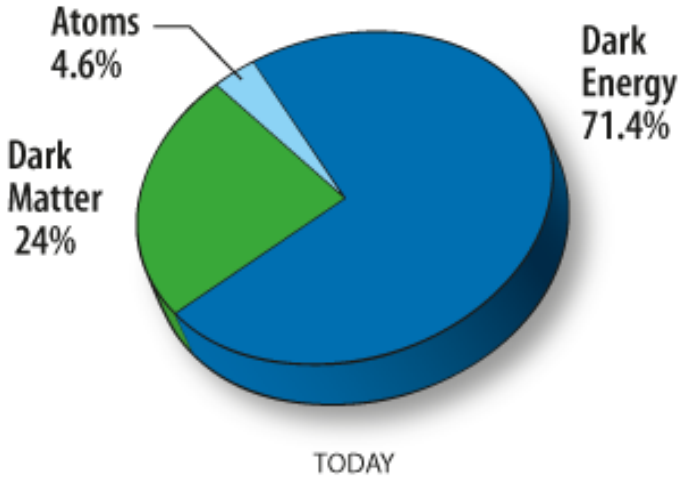
Inflationary universe

The origin of mass

String theory – the fabric of space-time

Digital space? – Planck length (10^{-33} cm) and Planck time (10^{-43}s) (Greek Atomism???)

Dark matter and energy



The universe comprises only 4.6% atoms. A much greater fraction, 24% of the universe, is a different kind of matter that has gravity but does not emit any light --- called "dark matter". The biggest fraction of the current composition of the universe, 71%, is a source of anti-gravity (sometimes called "dark energy") that is driving an acceleration of the expansion of the universe.

"IN MONTH XI, 15th day, Venus in the west disappeared, 3 days in the sky it stayed away. In month XI, 18th day, Venus in the east became visible."

What's remarkable about these observations of Venus is that they were made about 3500 years ago, by Babylonian astrologers. We know about them because a clay tablet bearing a record of these ancient observations, called the Venus Tablet of Ammisaduqa, was made 1000 years later and has survived largely intact. Today, it can be viewed at the British Museum in London.

http://www.newscientist.com/article/mg20527451.300-digital-doomsday-the-end-of-knowledge.html

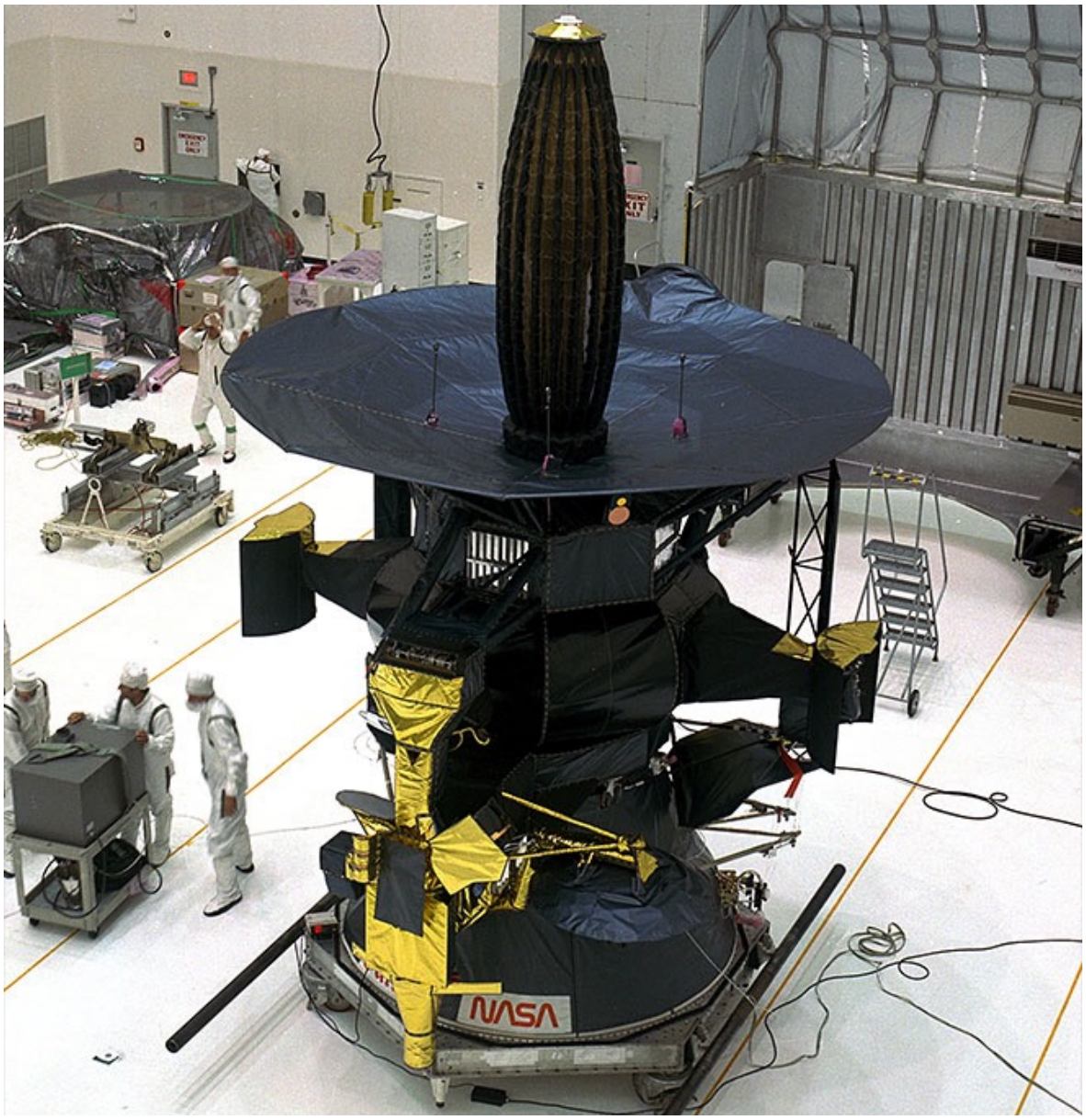
What can we do with Mechanics?

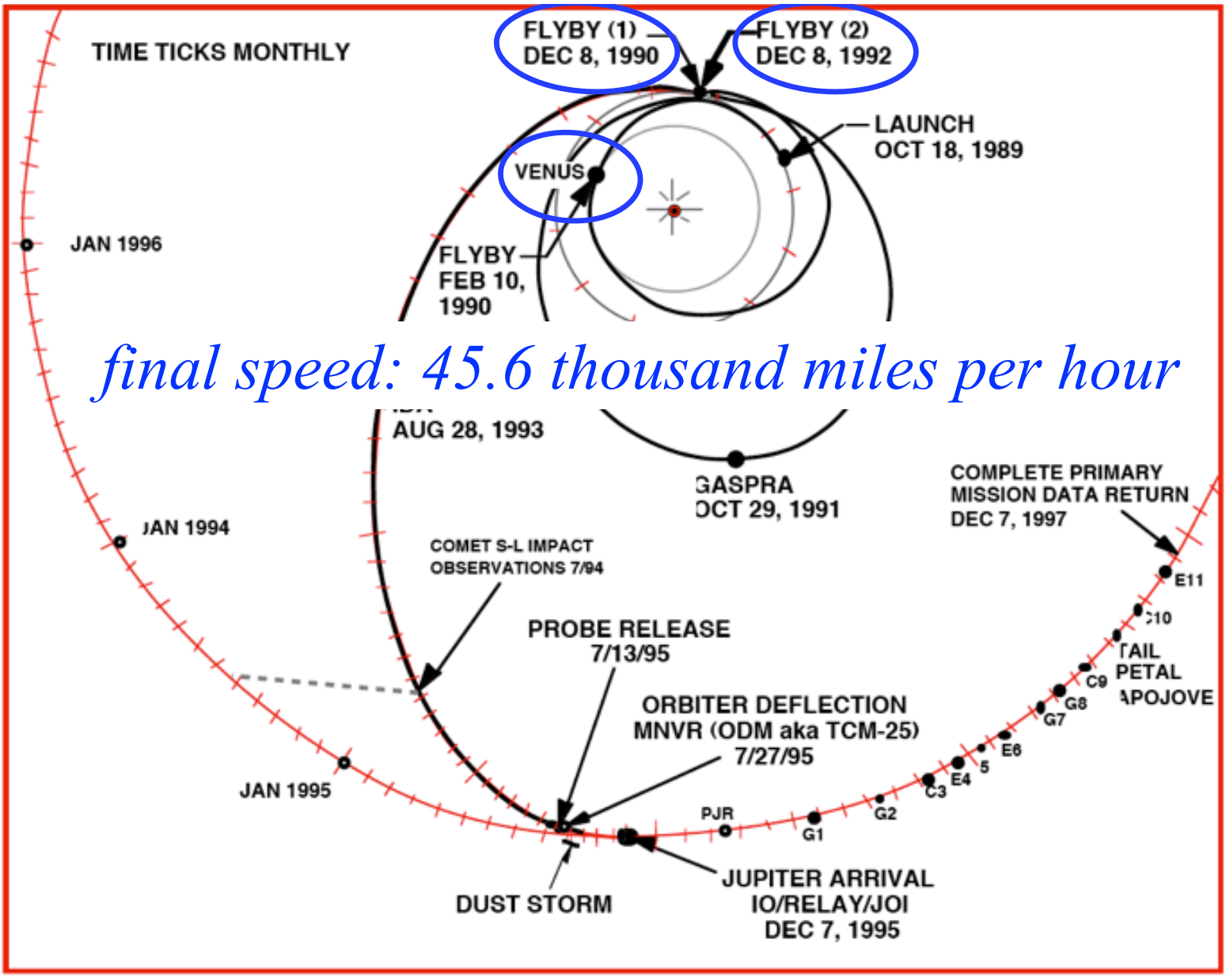
Consider the Galileo Mission

launched from the space shuttle Atlantis in October 1989 on a 6 year 2.4 billion mile journey to Jupiter

Lets say you build it really efficient and get 500 miles/gallon.

What size gas tank do you need?


NASA



final speed: 45.6 thousand miles per hour

in situ measurements

December 7, 1995 the probe from Galileo was released into the atmosphere of Jupiter

Mechanics: The Galileo Mission

The probe entered the atmosphere at a speed of 106, 000 mph. The entry time and angle were critical.

Mechanics: The Galileo Mission

In order to ensure a radio link to the orbiter the entry time needed to be known within 8 minutes in 167 days (0.0033%)

The actual time occurred 14 seconds earlier than target time, 0.0001% error.

Mechanics: The Galileo Mission

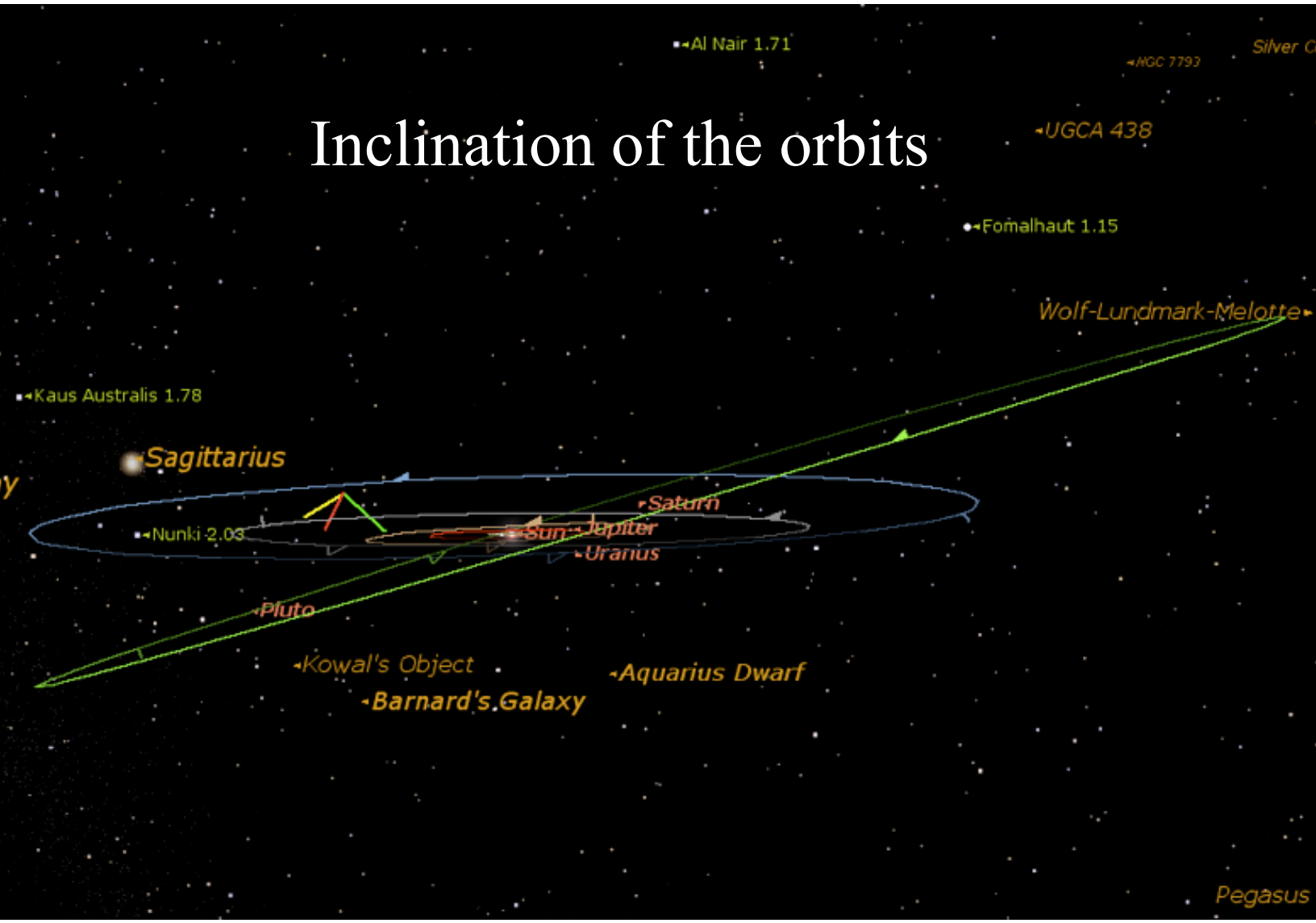
Getting the probe there and at the correct angle has been compared to shooting an arrow from New York trying to hit a bull's eye in Los Angeles.

Mechanics: The Galileo Mission

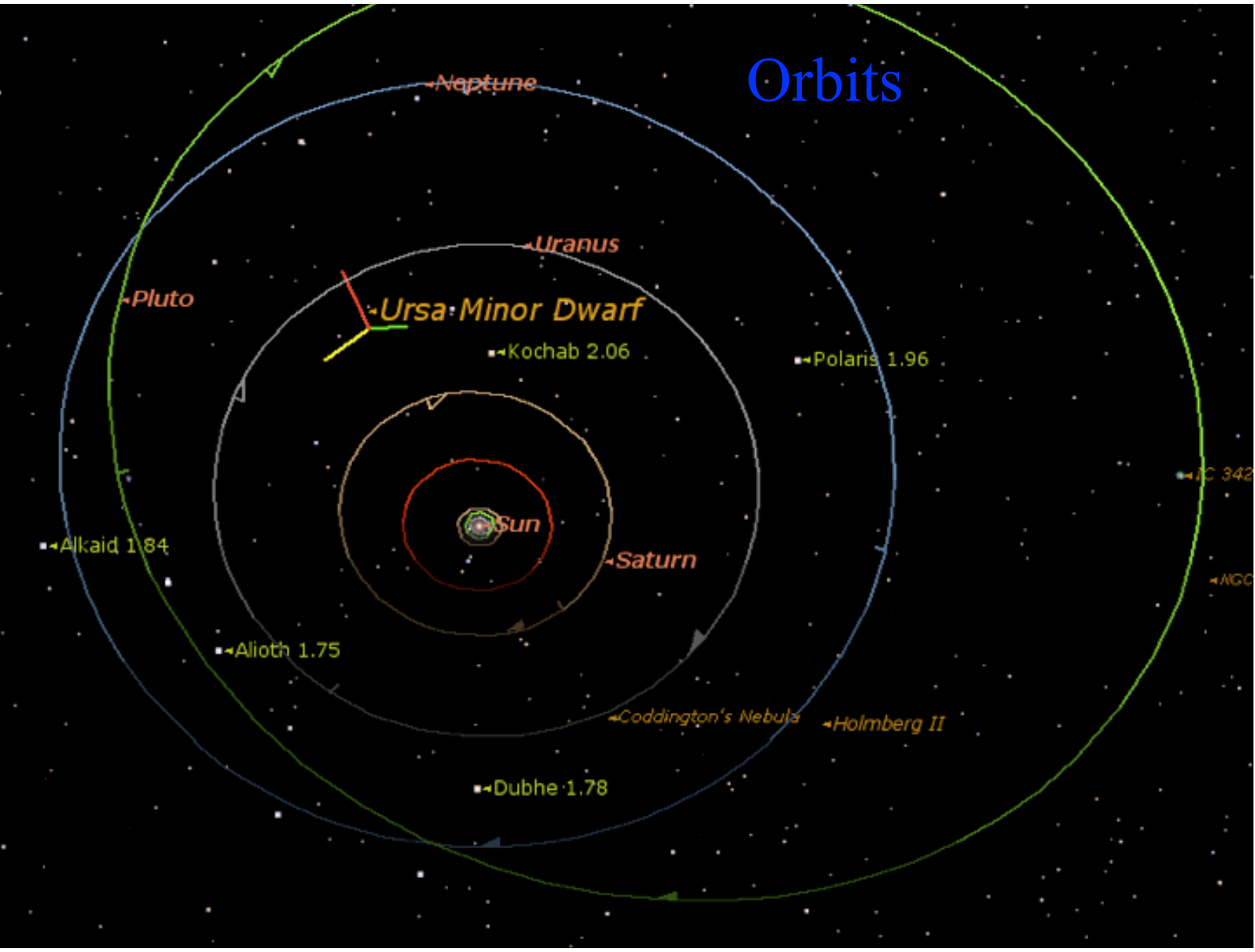
Usi ts to
obse
chal he
Goo aw
fron in a
car

Our Universe – what have we learned?

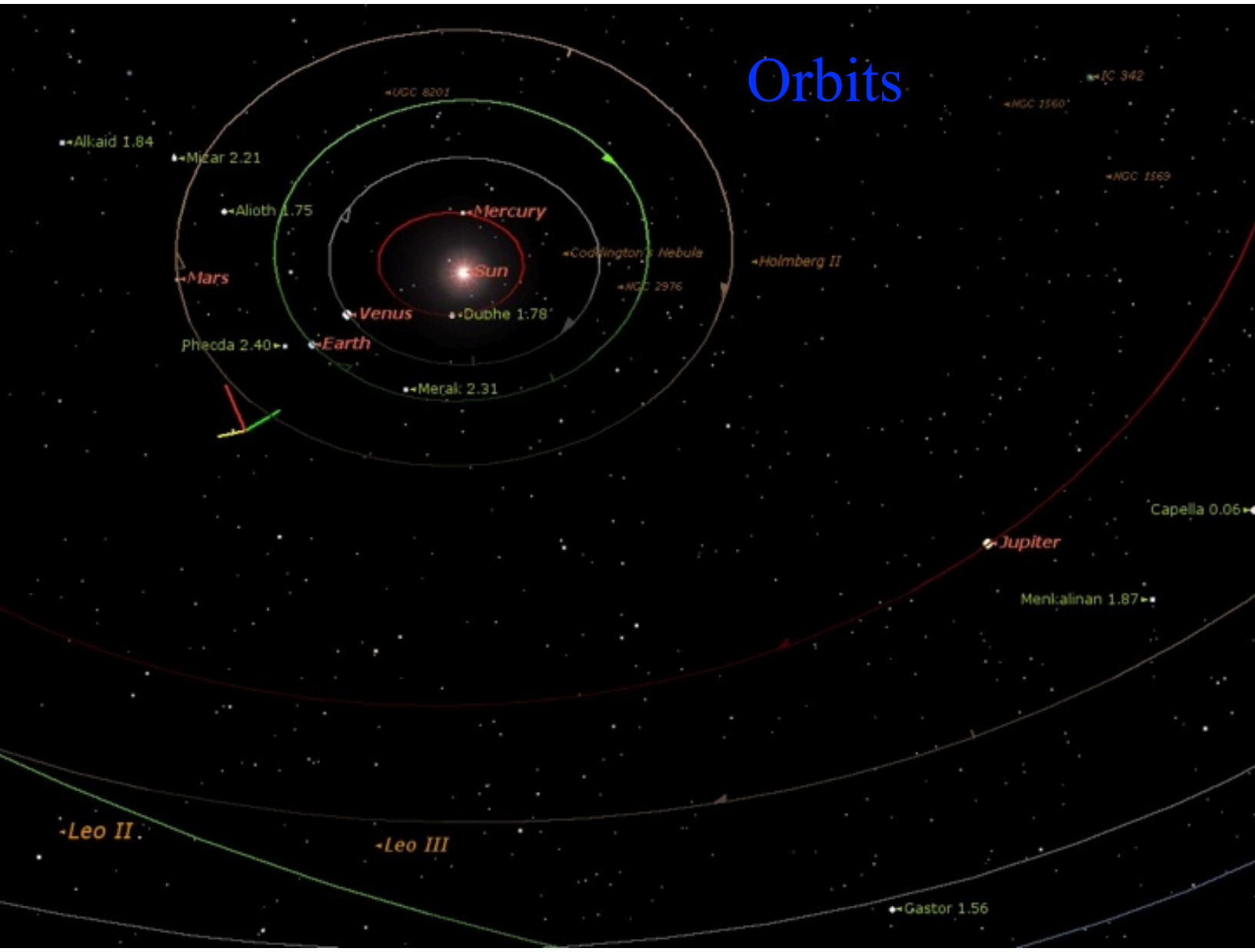
Inclination of the orbits

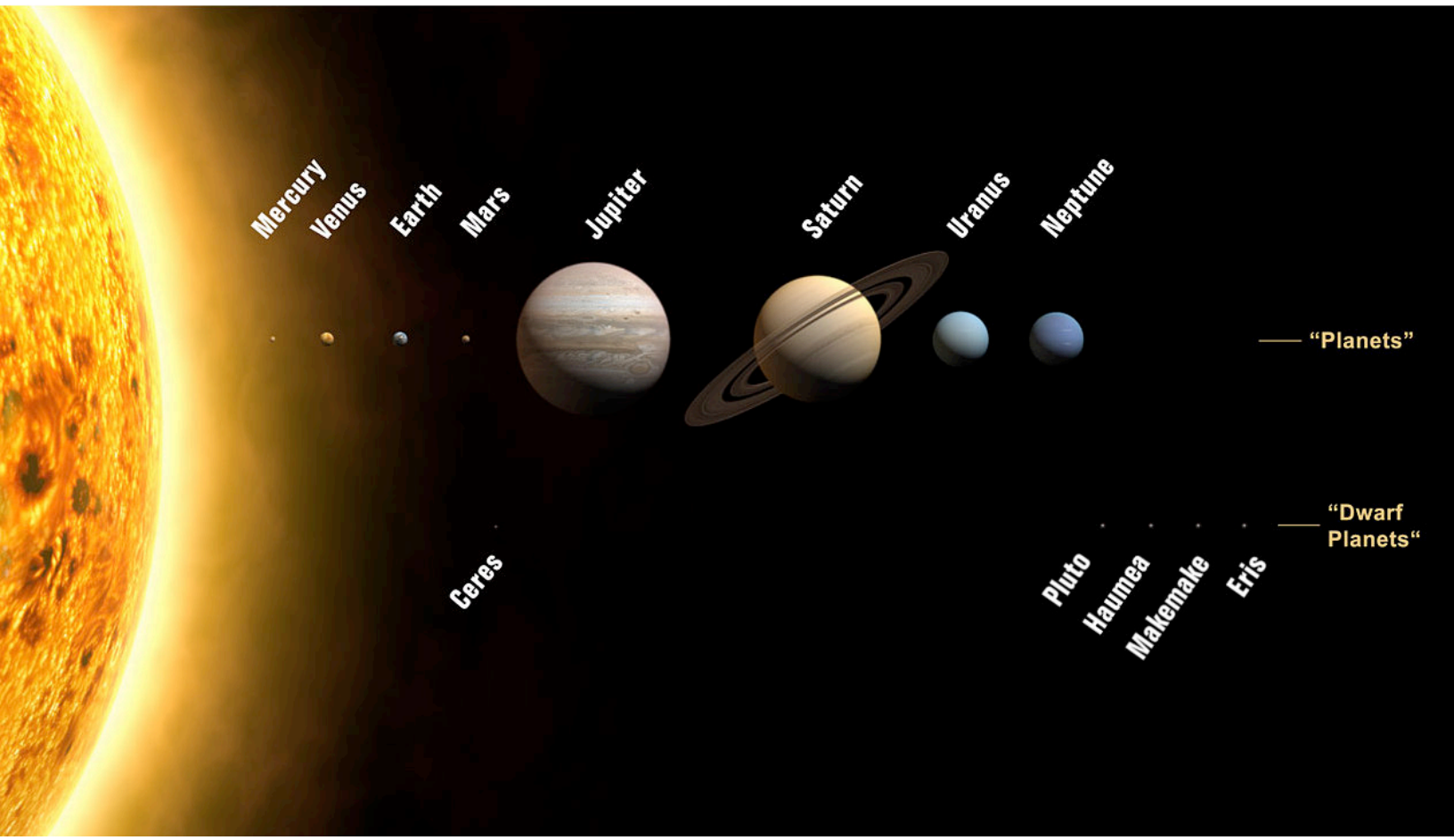


Orbits

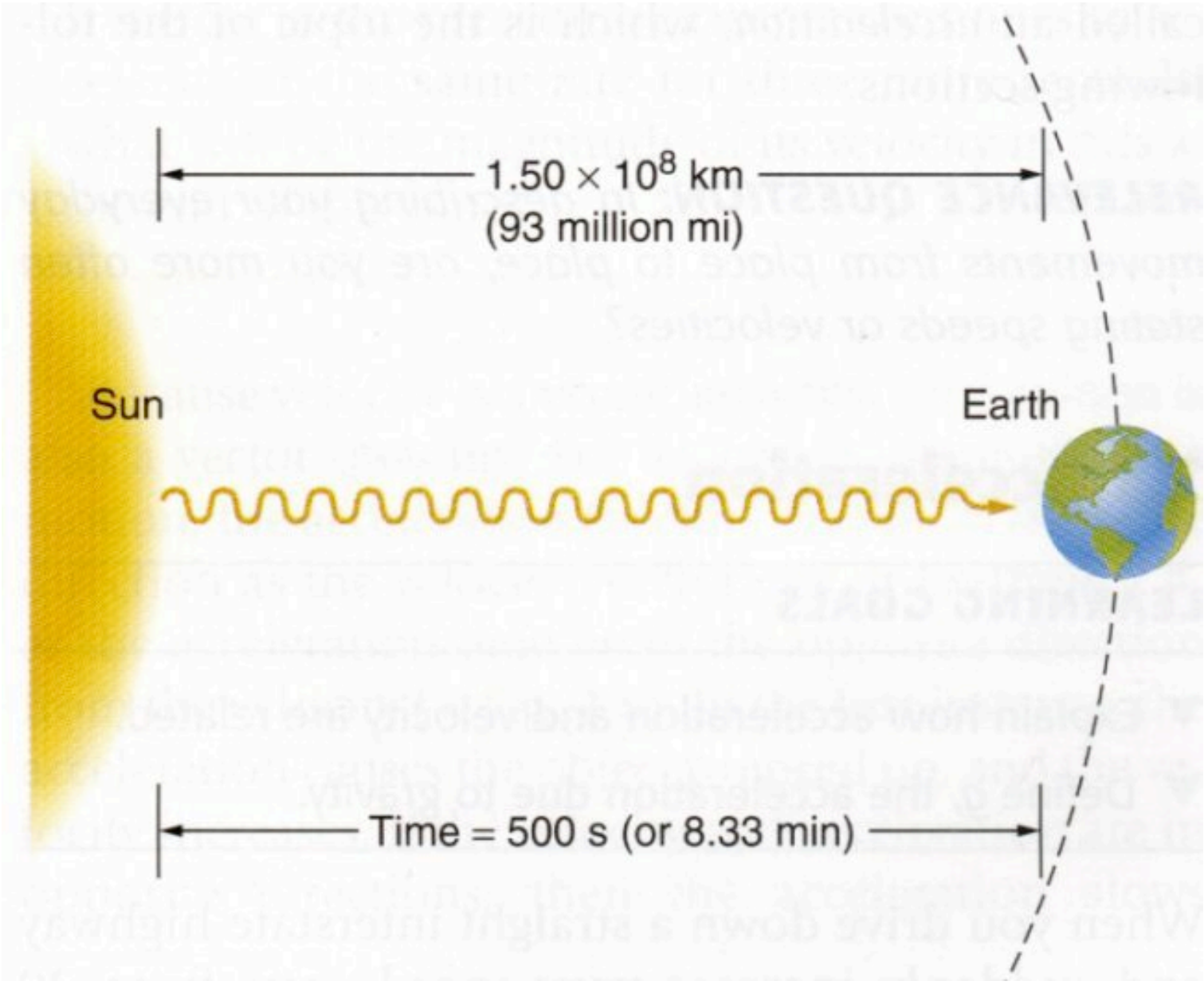

Neptune
Uranus
Pluto
Ursa Minor Dwarf
Kochab 2.06
Polaris 1.96
IC 342
Sun
Saturn
Alkaid 1.84
Alioth 1.75
Coddington's Nebula
Holmberg II
Dubhe 1.78

Orbits

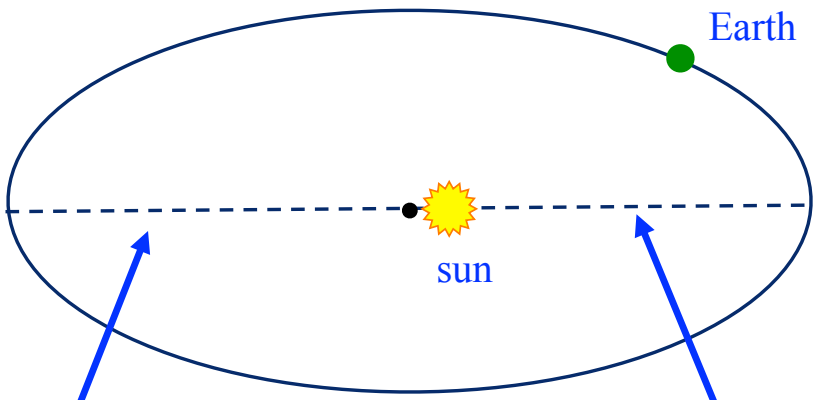

UGC 8201
IC 342
NGC 1560
Alkaid 1.84
Mizar 2.21
NGC 1569
Alioth 1.75
Mercury
Coddington's Nebula
Holmberg II
Mars
Sun
NGC 2976
Venus
Dubhe 1.78
Phecda 2.40
Earth
Merak 2.31
Capella 0.06
Jupiter
Menkalinan 1.87
Leo II
Leo III
Gastor 1.56



http://upload.wikimedia.org/wikipedia/commons/c/c4/Planets2008.jpg


1.50 × 10^8 km
(93 million mi)
Sun
Earth
Time = 500 s (or 8.33 min)

Elliptical orbit – 365.2422 days



aphelion

further away

perihelion

closer

What causes the seasons?

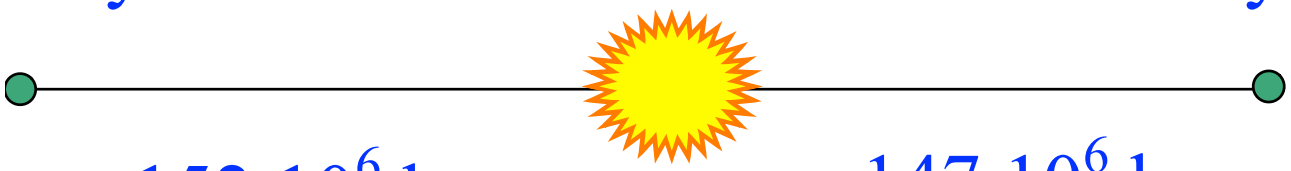
Winter, Spring, Summer, Fall

- 4 gods, who each share governing Earth 25% of the year (ancient Egyptians)

- when the earth is closest to the sun it is summer, furthest it is winter (graduating Harvard University student)

July 4

January 3



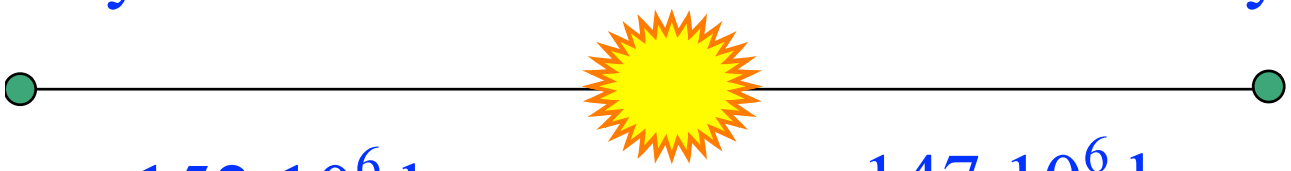
152 10^6 km
aphelion

147 10^6 km
perihelion

Only a 3% difference in distance!!!

500-700% T difference

July 4 January 3



$152\ 10^6$ km
aphelion

$147\ 10^6$ km
perihelion

Even worse for hypothesis #2 we (NH) are closest to the sun in January.

The 4-god hypothesis is looking better.

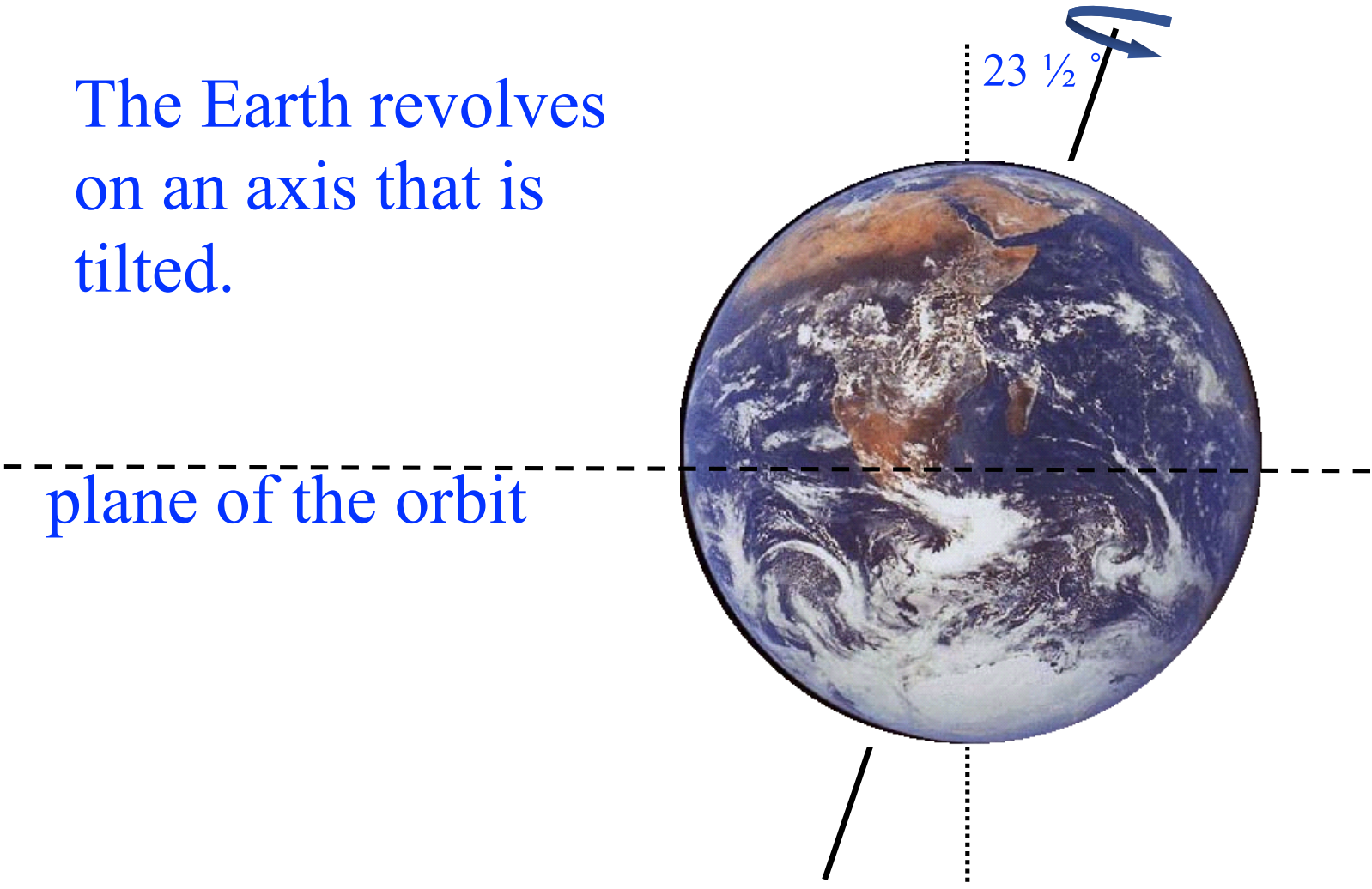
What does the data tell us?

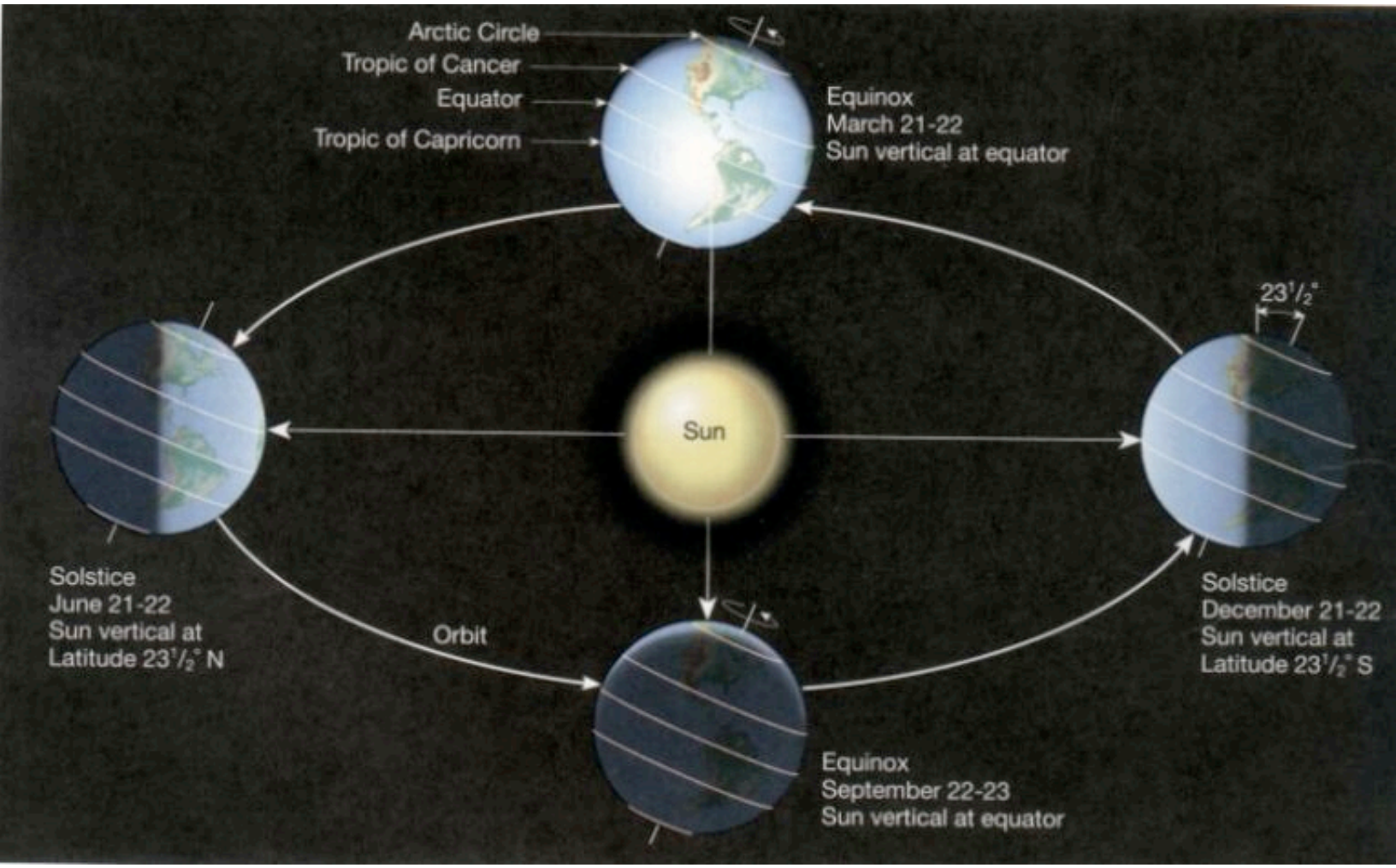
Northern and Southern Hemispheres winter in Boston, Paris, Moscow, (NH cities) corresponds to summer in Buenos Aries, Cape Town, Melbourne, (SH cities) and vice versa.

→ It cannot be related to the distance to the sun.

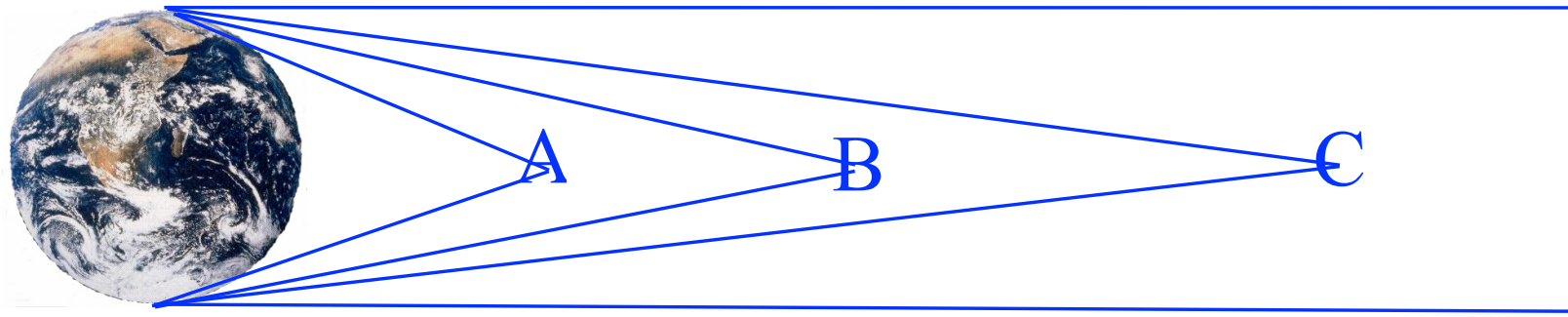
What else could it be?

The Earth revolves on an axis that is tilted.




Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Equinox
March 21-22
Sun vertical at equator
23 1/2°
Sun
Solstice
June 21-22
Sun vertical at
Latitude 23 1/2° N
Orbit
Solstice
December 21-22
Sun vertical at
Latitude 23 1/2° S
Equinox
September 22-23
Sun vertical at equator

Recall, the rays of the sun arrive parallel

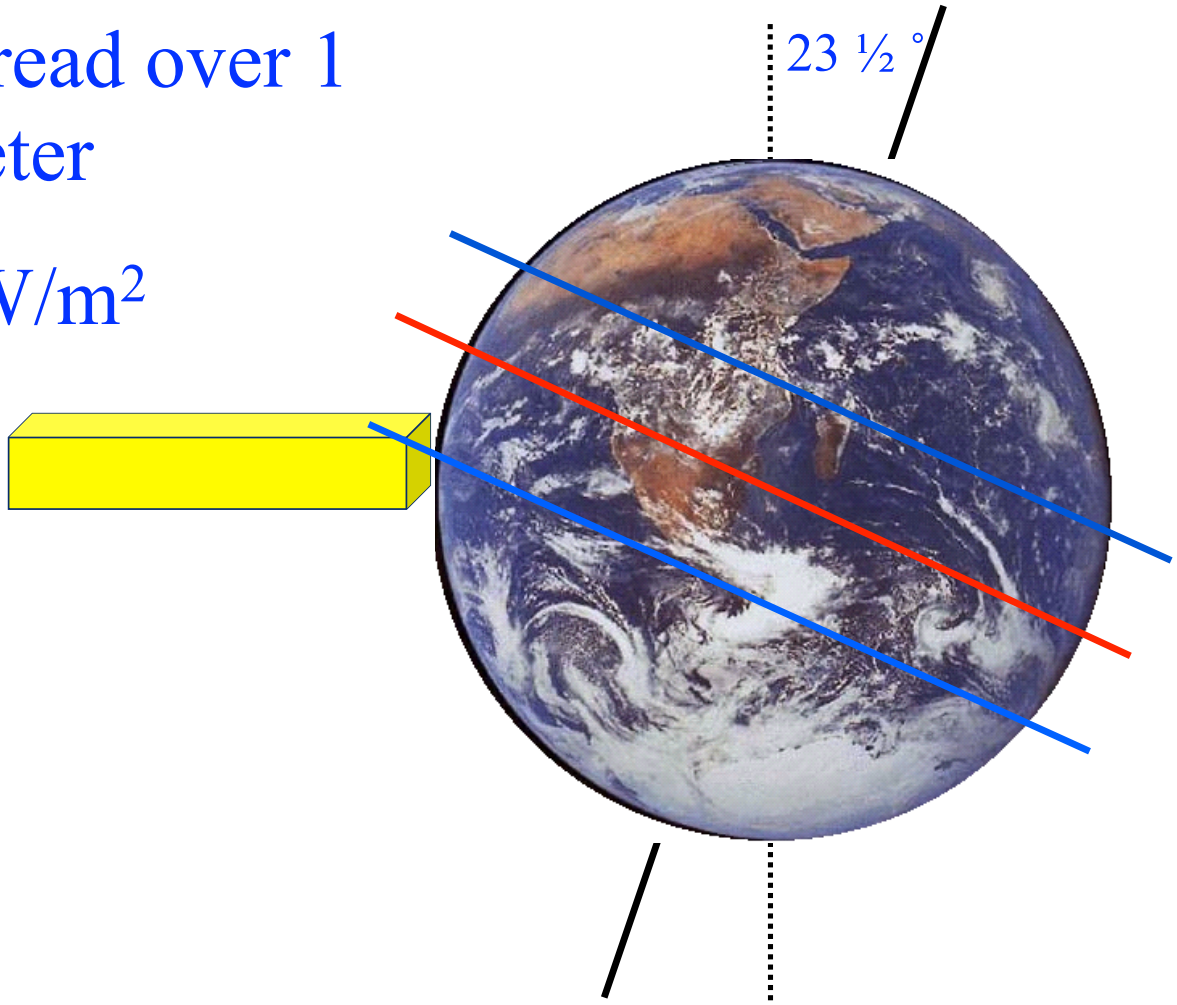


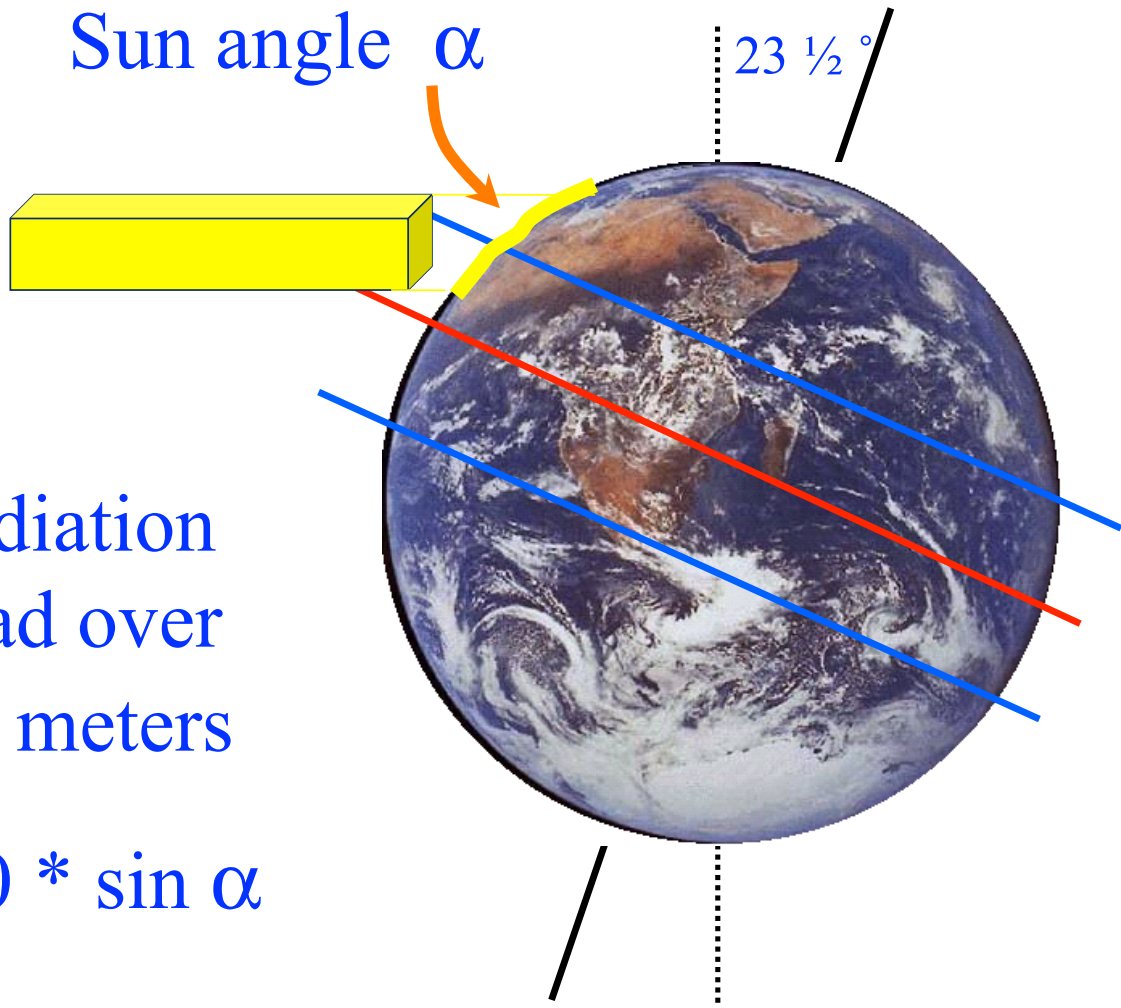
To the sun →

Can we explain the consequence of the tilt

Intensity of radiation is 100 W spread over 1 square meter

$I_0 = 100\ W/m^2$

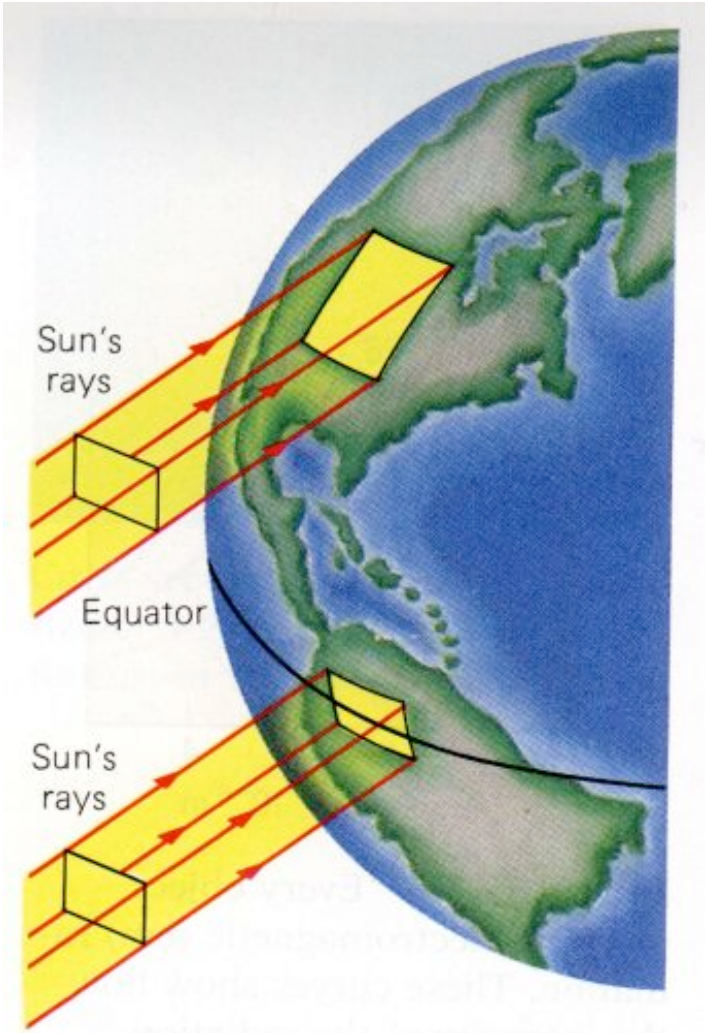




Intensity of radiation is 100 W spread over $1/\sin \alpha$ square meters

$I\ (W/m^2) = 100 * \sin \alpha$

Effect of sun angle



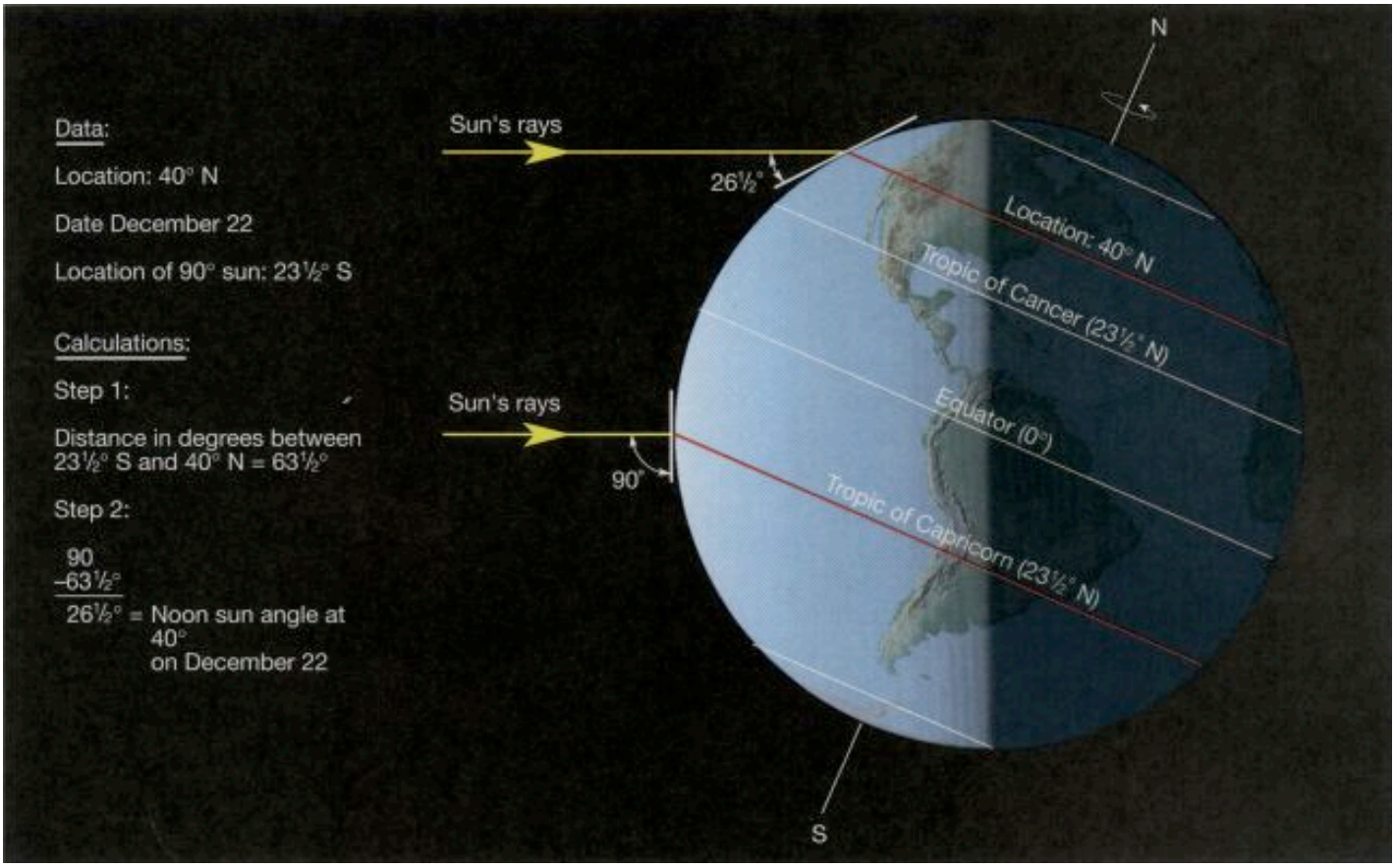
The consequence of the tilt

The part that is tilted toward the sun receives more direct sunshine and heats more (summer) than when it is tilted away (winter)

α	Intensity hitting surface
90	100
75	96.6
60	86.6
45	70.7
30	50
23.5	40

Lowell on the winter solstice

We only receive 41.5% of the sun's energy



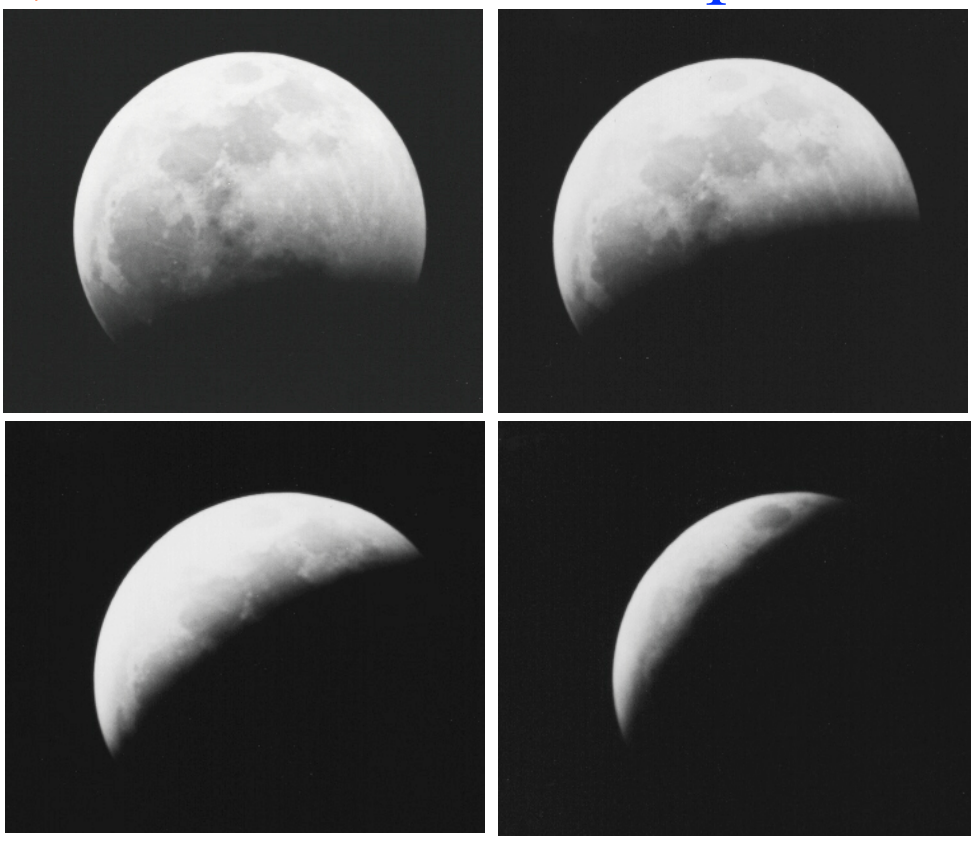
Phases of the moon

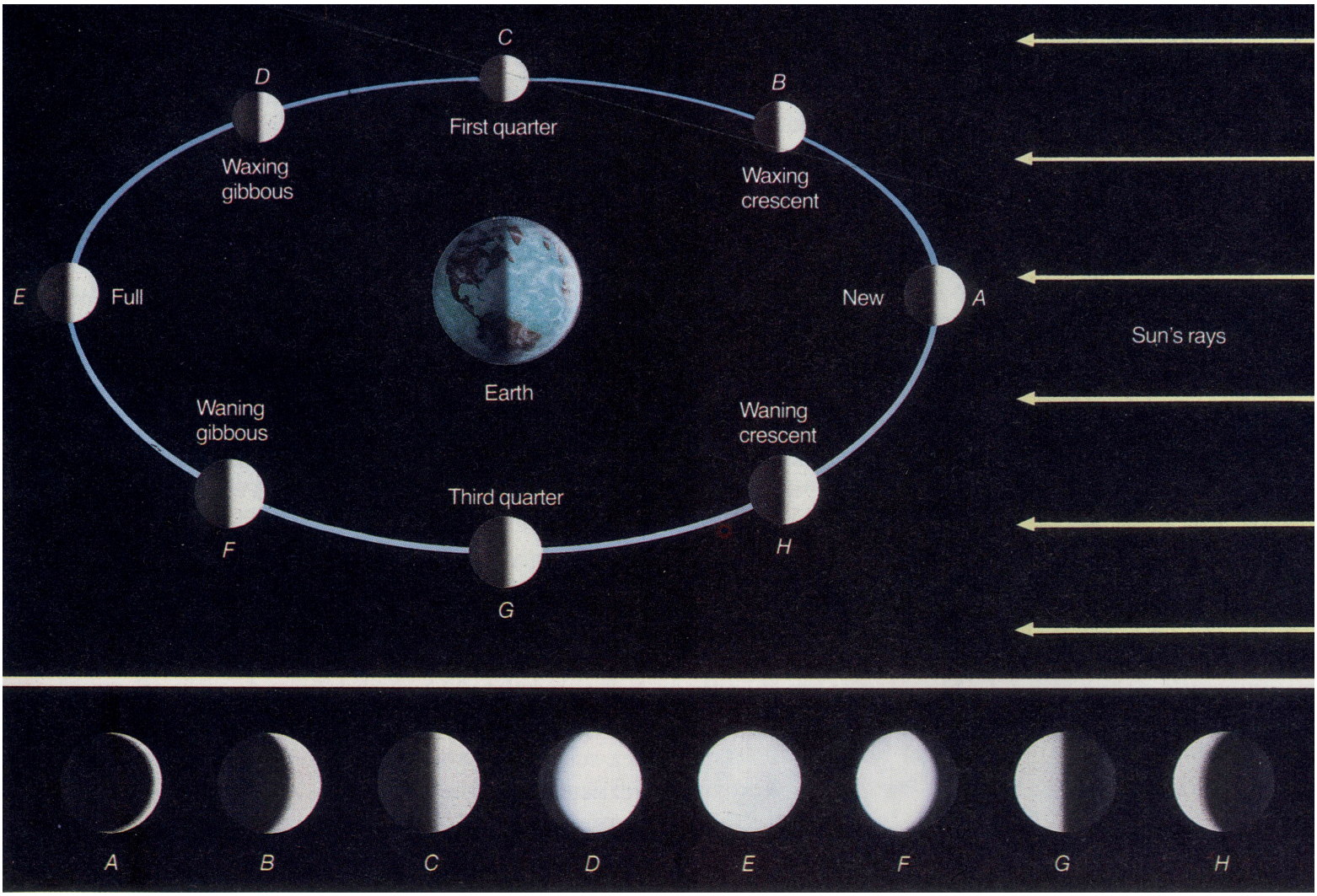
Why do we see different phases of the moon?

What causes the shadow?

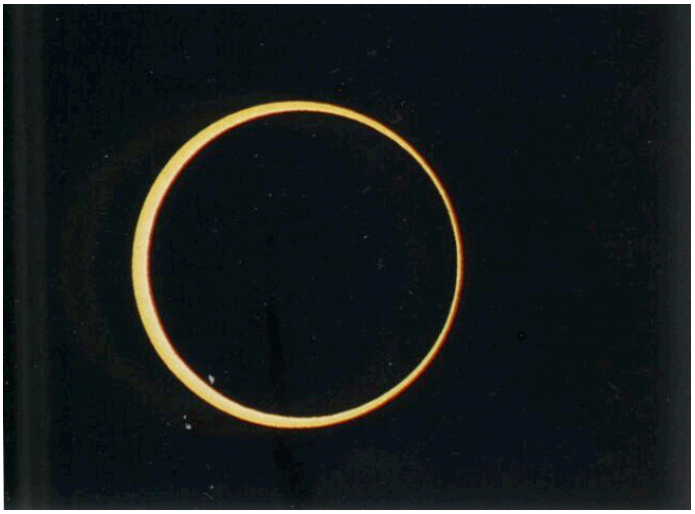
Could it be the shadow of the Earth?

→ No, There are lunar eclipses

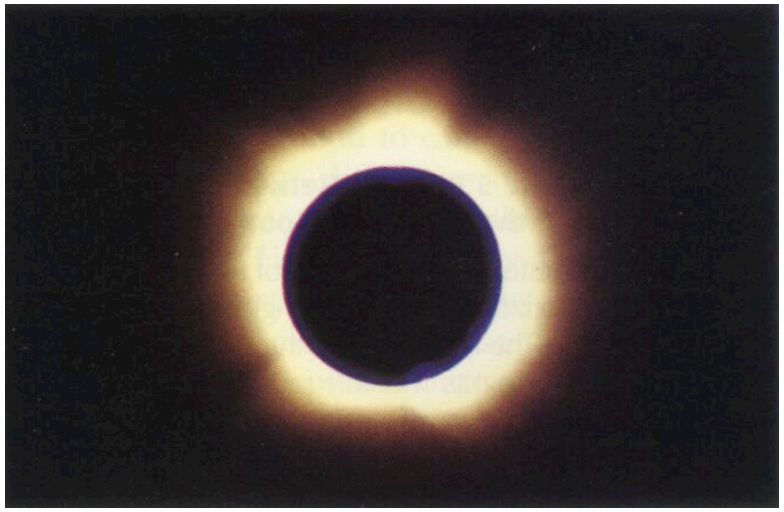



C
D
First quarter
B
Waxing gibbous
Waxing crescent
E
Full
New
A
Sun's rays
Earth
Waning gibbous
Waning crescent
Third quarter
F
H
G
A
B
C
D
E
F
G
H

Solar Eclipse

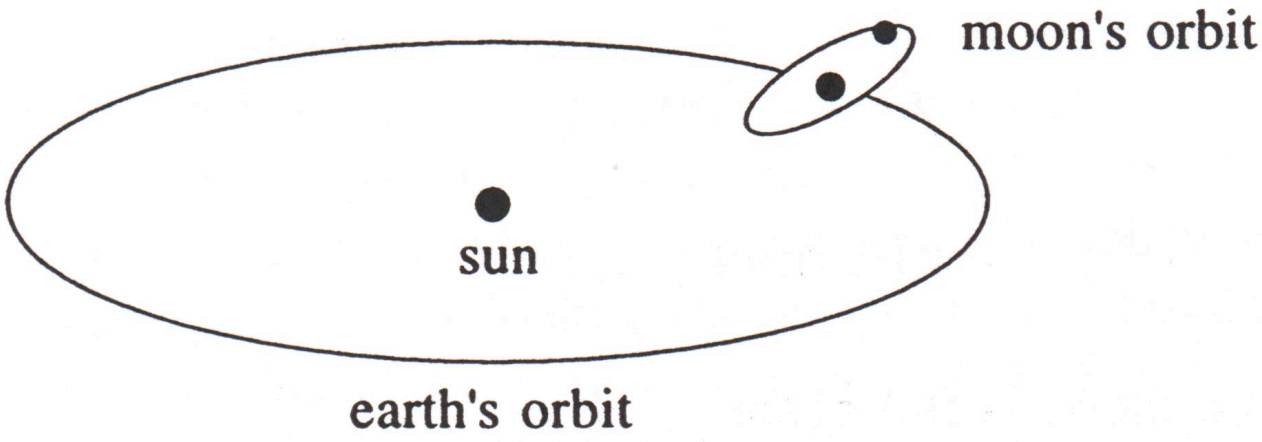


Annular Eclipse of the sun

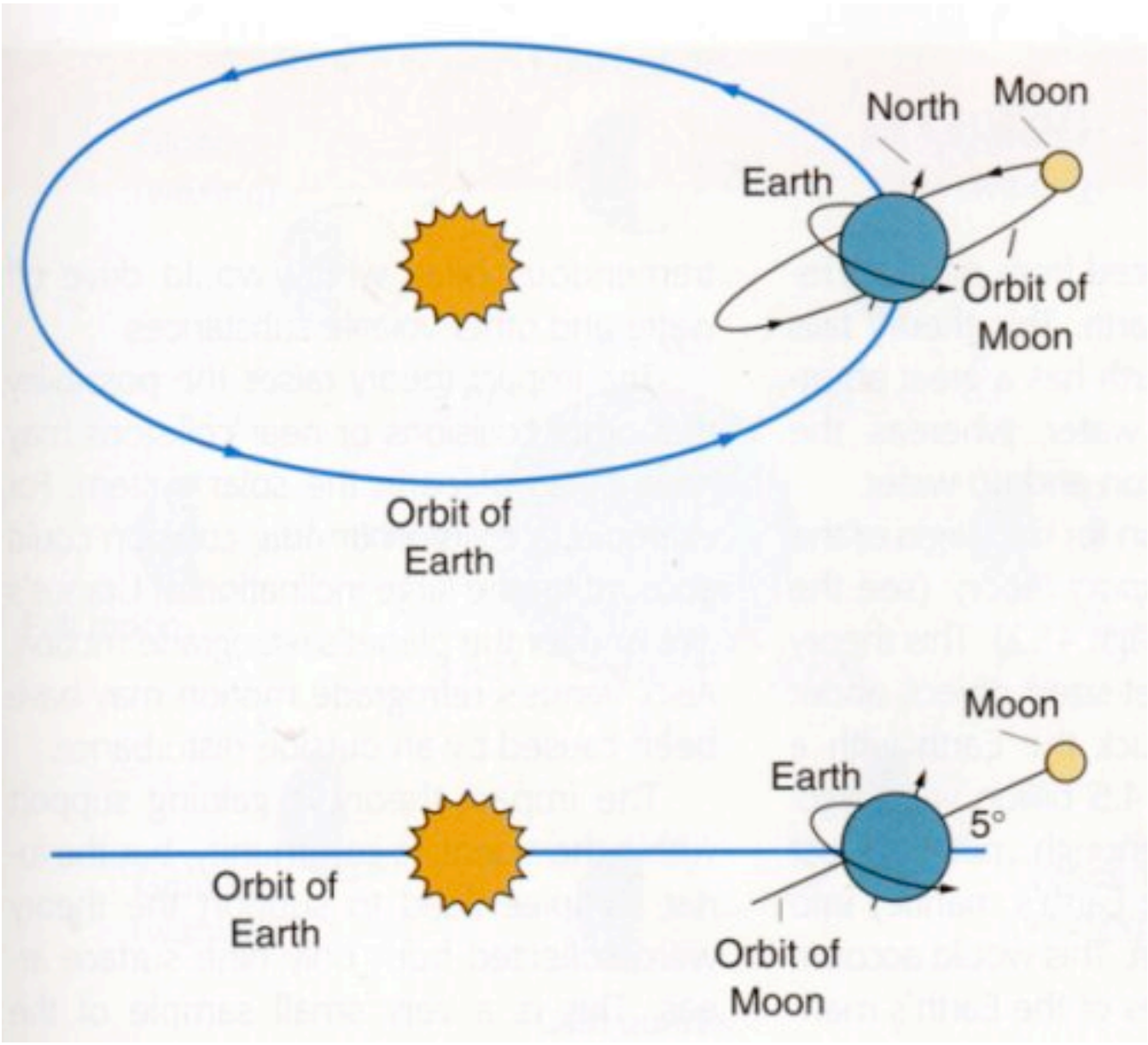


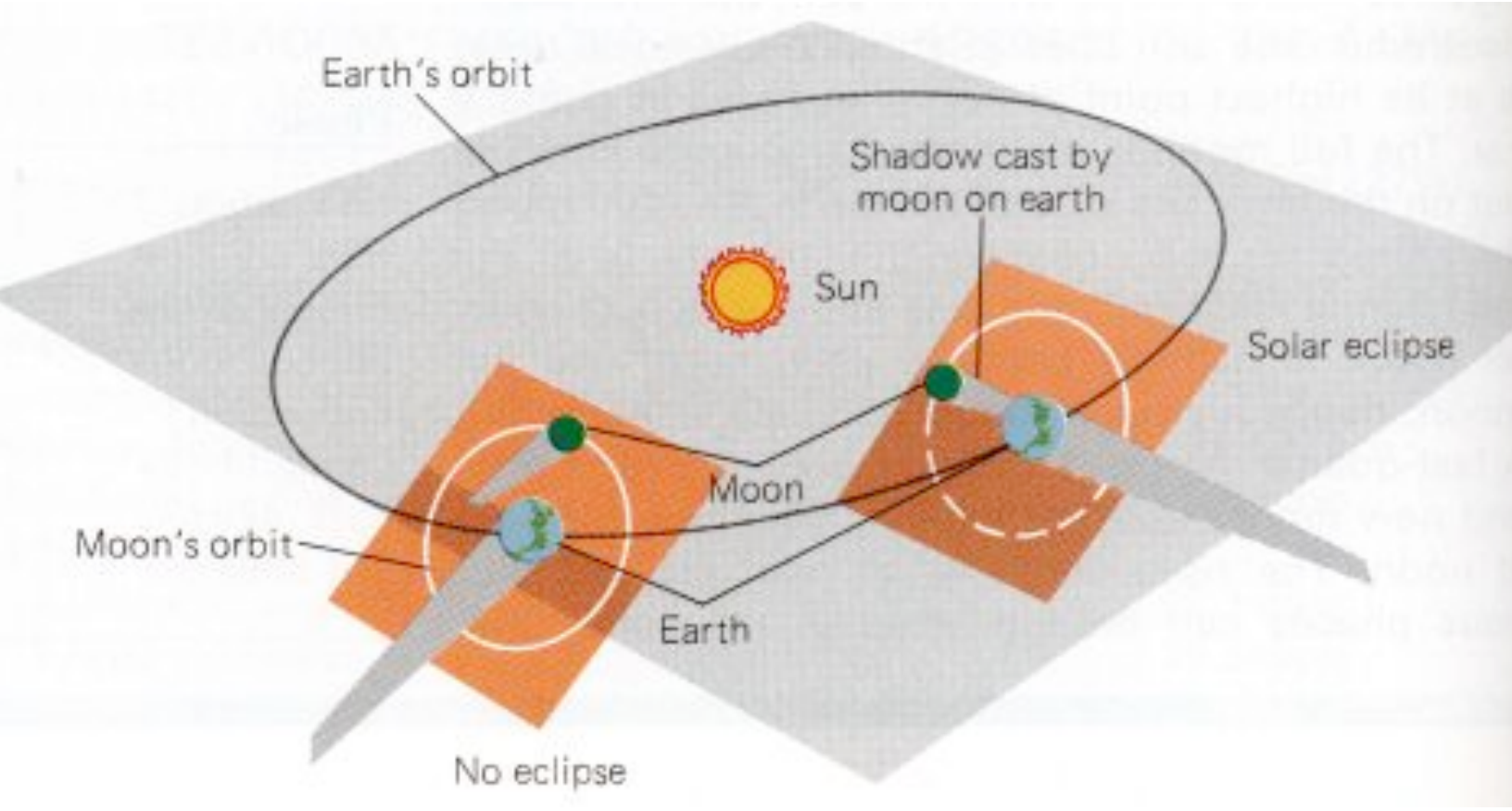
Total Solar Eclipse

Why don’t we have a solar eclipse every month?



Eclipses do not occur every month.


North
Moon
Earth
Orbit of
Moon
Orbit of
Earth
Moon
Earth
5°
Orbit of
Earth
Orbit of
Moon


Earth's orbit
Shadow cast by moon on earth
Sun
Solar eclipse
Moon
Moon's orbit
Earth
No eclipse

The Stuff of the Universe

Atoms and Molecules

How many of you believe in atoms and molecules?

How many of you have ever seen an atom or a molecule?

The Elements

Hinduism: “five great elements” earth, water, fire, wind, aether.

Buddhism: earth, water, fire, and air - a basis for understanding suffering and for liberating oneself from suffering.

Ancient Tibetan philosophy: five elemental processes of earth, water, fire, air, and space - essential materials of all phenomena or aggregates. basis of the calendar, astrology, medicine, psychology, and spiritual traditions.

The Elements

Chinese: fire, earth, water, metal, and wood - understood as different types of energy in a state of constant interaction and flux.

Japanese: earth, water, fire, wind, void - came from Buddhist belief.

All rooted in mythology.

Empedocles (490-430 BC)

"Nothing can come from nothing nor be destroyed into nothing" - to explain reality he states

"There must be assumed to exist something eternal and unchanging beneath the constant change, growth and decay of the visible world."

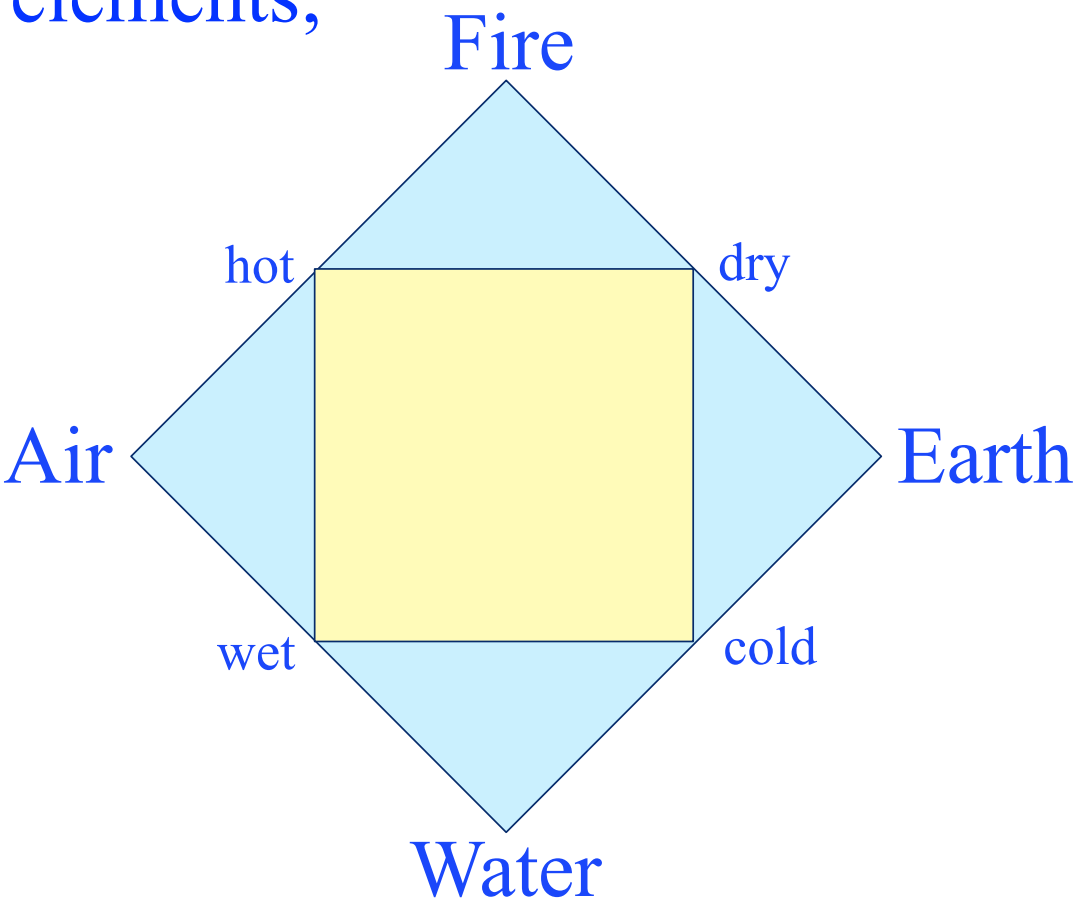
Earth, Air, Fire, and Water

Empedocles (490-430 BC)

Earth, Air, Fire, and Water

According to the different proportions in which these four indestructible and unchangeable elements are combined with each other the difference of the structure is produced.

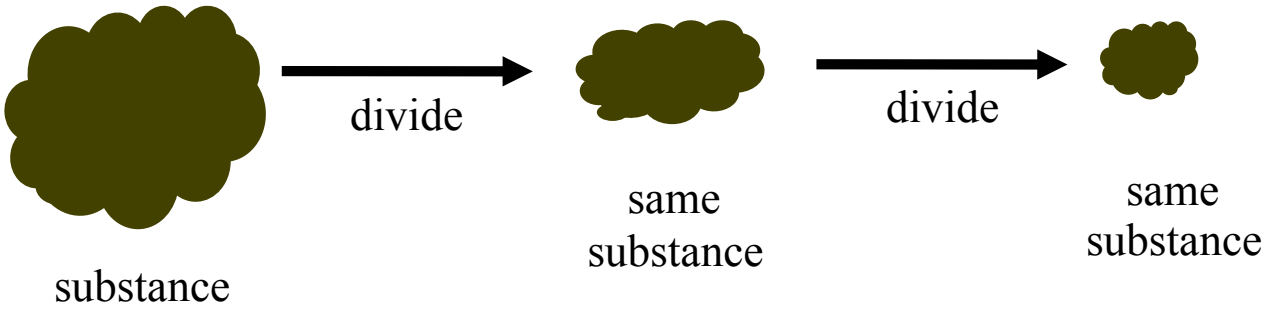
The Greeks, in the teaching of Aristotle, believed everything is made of the four basic elements;

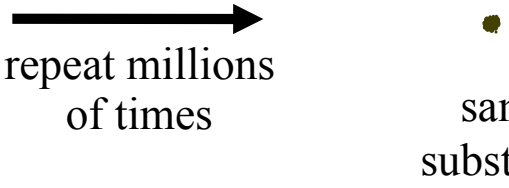


Do an experiment where you burn wood in a scale. Fire, smoke, the scale tips as the burning side gets lighter.

What can you conclude?

Substances made of the four basic elements





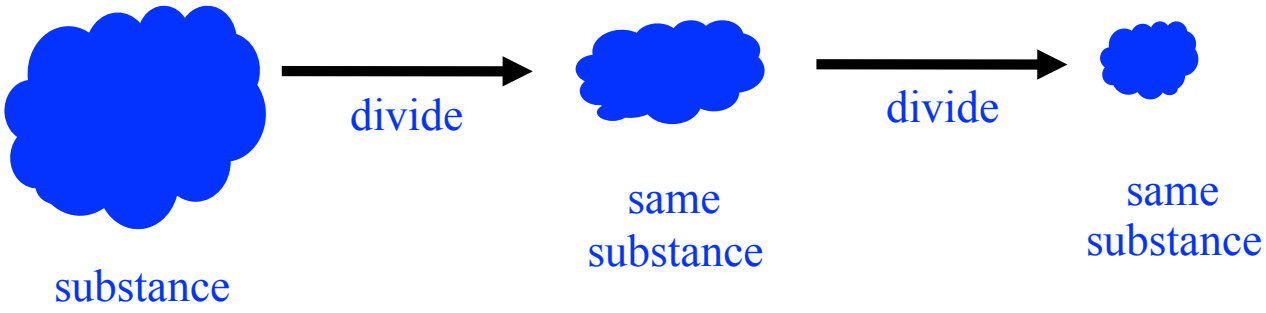
Greek Atomism

Leucippus was the founder of Atomism.

Democritus (460 - 370 BCE) expanded the atomic theory of Leucippus.

He maintained the impossibility of dividing things *ad infinitum*.

Substances made of the four basic elements



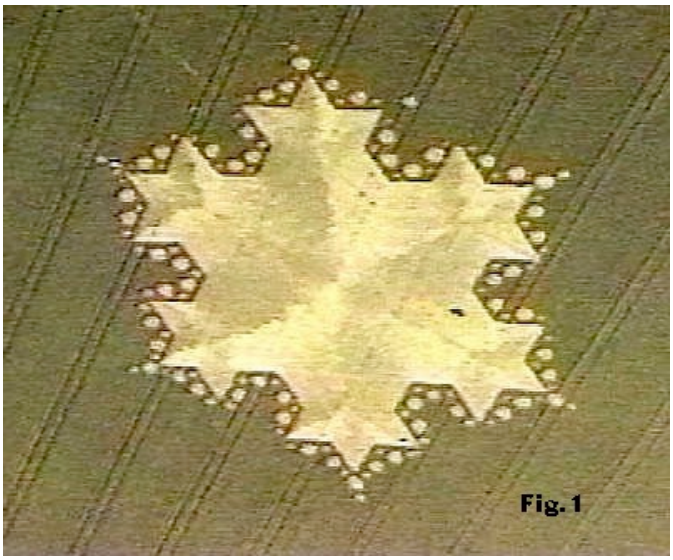
After some time you cannot go further

Fundamental piece of matter – the atom

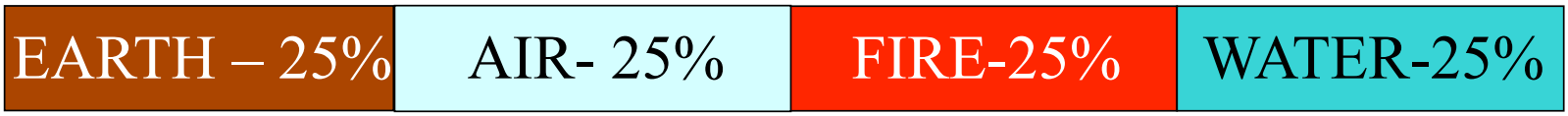
Fast Forward to after the first millennium

Alchemy ≈ 1200 – 1700 A.D

The Philosopher's Stone to medieval alchemist was the catalyst in the long sought after magical process that could transmute lead into gold.



Example: 4-element Earth



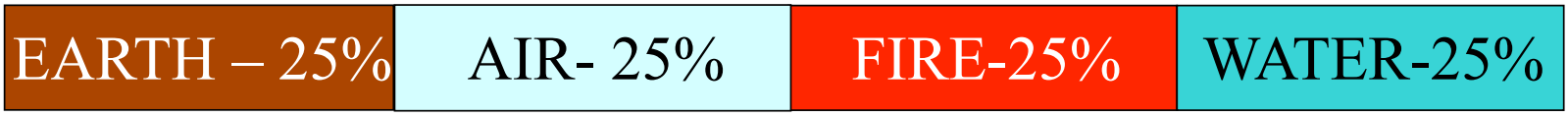
Substance 1

What is the difference between two similar substances?

Proportions of the elements. One might have slightly more earth and a little less fire.

Vastly different substances obviously have large differences in the amount of Earth, Air, Fire, and Water.

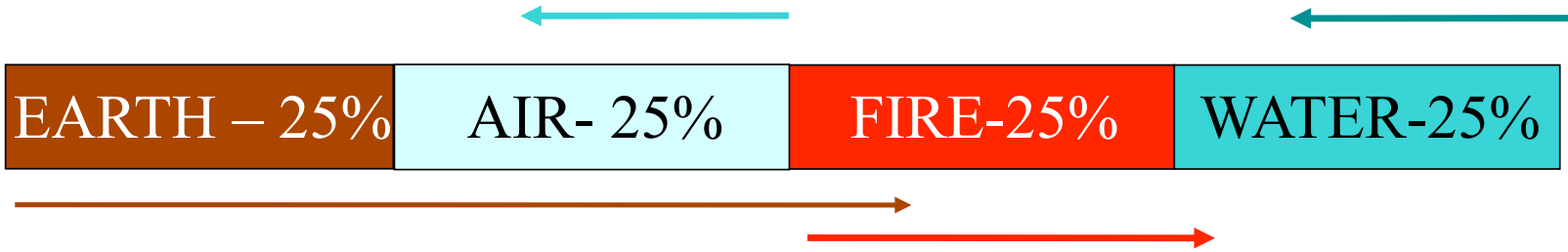
4 - element Earth



Substance 1

earth air fire water

gold

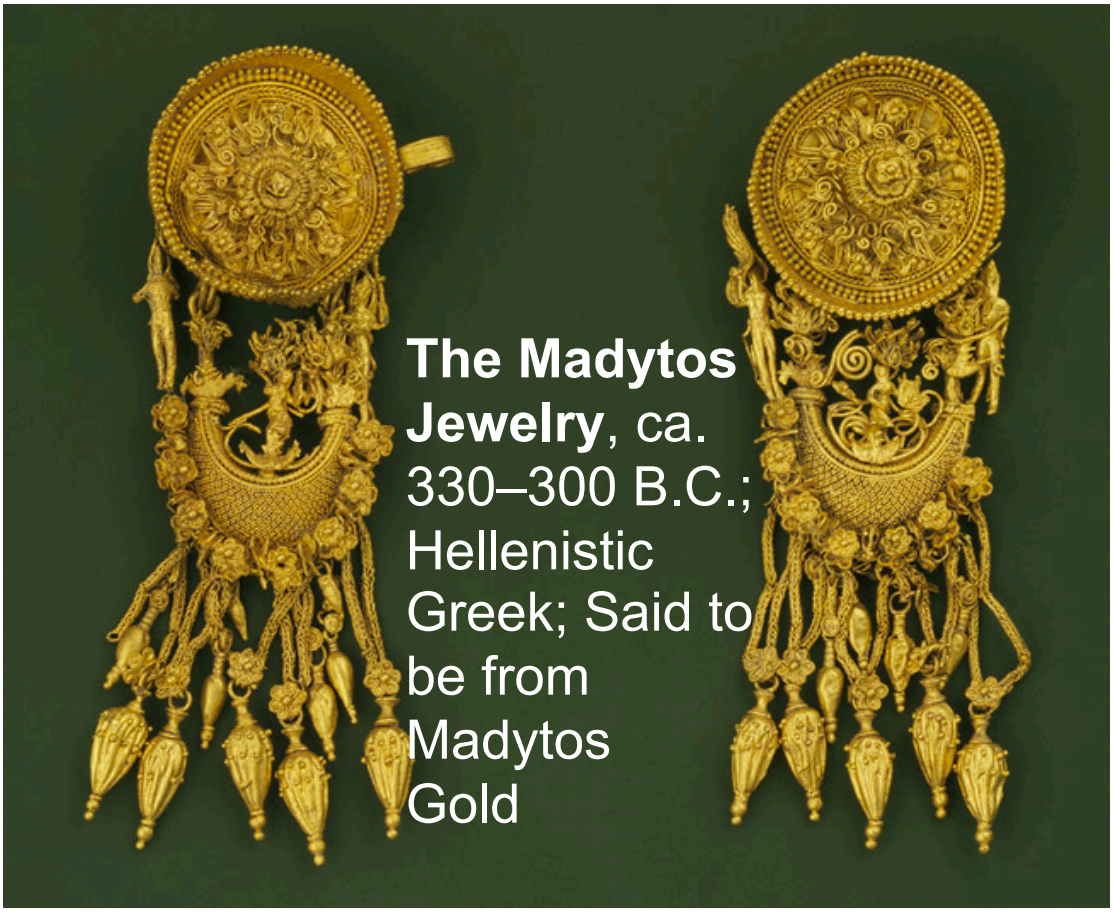


substance 1 → gold

What transmutations are needed to change the elemental proportions of substance 1 to make it gold?

What are the properties of gold?

http://www.metmuseum.org/toah/works-of-art/06.1217.1-.13



Headdress with leaf-shaped ornaments, 2600–2500 B.C.;
Early Dynastic period IIIa; Sumerian style
Excavated at "King's Grave," Ur, Mesopotamia

http://www.metmuseum.org/toah/works-of-art/33.35.3

Vessel terminating in the forepart of a lion, Achaemenid, 5th century B.C. **Iran Gold**

http://www.metmuseum.org/toah/works-of-art/54.3.3

Lead is a metal having a number of properties similar to gold

heavy, soft, easy to work, not a great amount of heat to melt, etc.

→ If it is so similar, it should have close to the proportions of Earth, Air, Fire, and Water as does gold. Thus, transmutation should be easier than starting with rock.

Nuclear Chemistry = Alchemy ???

Bombard Mercury 201 (^{201}Hg) with electrons → process known as electron capture occurs.

In the process Hg, an element with 80 protons, is transmuted in to element number 79 – Gold (Au)

Things change

A new way of thinking

FRANCIS BACON
(1561-1626)

A new method of investigation.

"We are not to imagine or suppose , but to discover, what Nature does or be made to do."

--- Let the results tell you what is going on. ---

What else changed?

instrumentation

measurement

experiments

There now is quantitative chemistry and physics being practiced.

Chemistry

What can we say about the stuff everything is made of?

Induction →

Law of Conservation of Mass

Law of Constant Composition

Law of Definite Proportions

Atomic Theory

http://www.guardian.co.uk/science/2012/feb/29/gene-therapy-cures-lung-infection

Gene therapy cures life-threatening lung infection in teenage boy

Doctors used the new technique to temporarily boost the immune system of the boy, who has an inherited condition. Remy Halbawi had been ill for two years with the fungal infection and would not have survived without radical treatment, doctors said.

Remy was born with a genetic condition called x-CGD (Chronic Granulomatous Disorder) that affects boys.

His condition was so serious that in June last year they decided to use an experimental gene therapy technique to replace the faulty gene with a working copy.

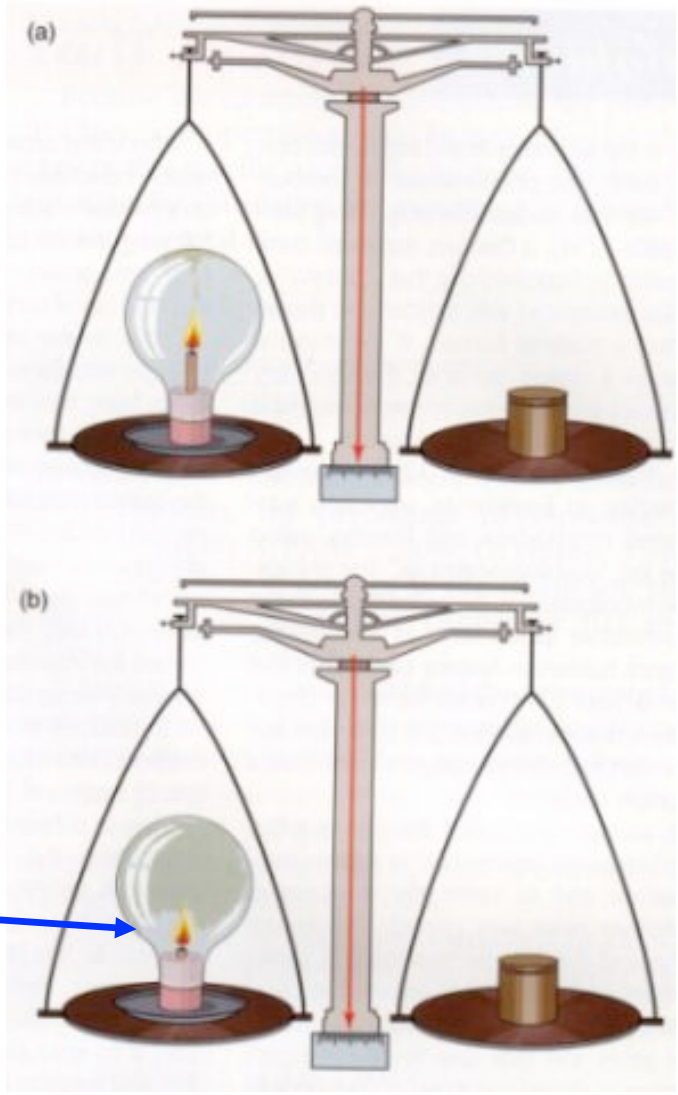
Law of Conservation of Mass

The mass of substances present after a chemical reaction is the same as the mass of the substances entering into the reaction.

→Matter can neither be created nor destroyed in a chemical reaction.

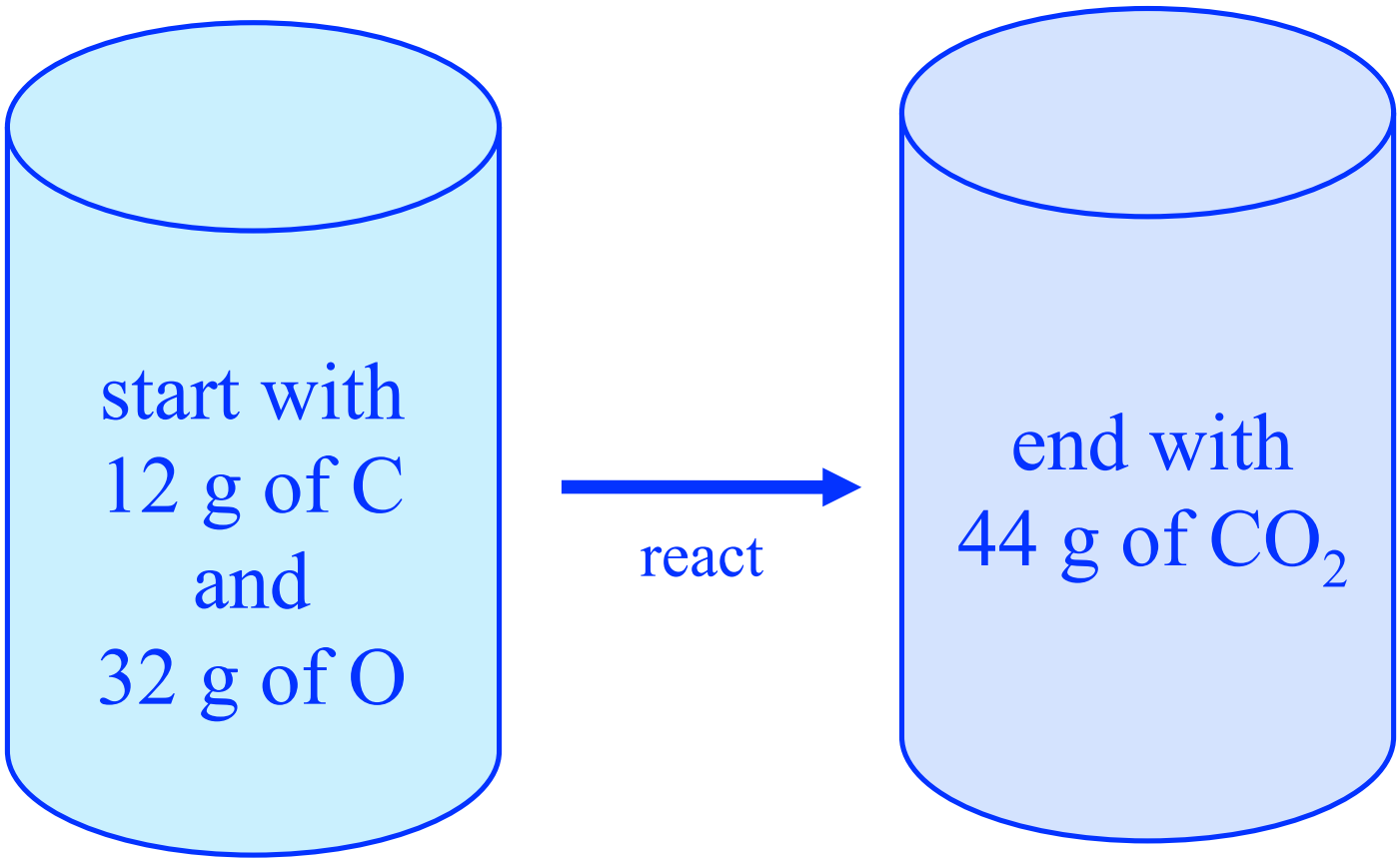
Something else is going on!

Law of Conservation of Mass



Candle burned away

Law of Conservation of Mass



Law of Constant Composition

All samples of a given compound have the same composition, that is, the same proportions by mass of the constituent elements.

new words are being used

No longer a sliding scale of Earth, Air, Fire, and Water. Compounds are made of *elements*.

Law of Constant Composition

The relative amount of each *element* in a particular compound is always the same, regardless of preparation or source.

Not the elements as we now know them, but we are getting there.