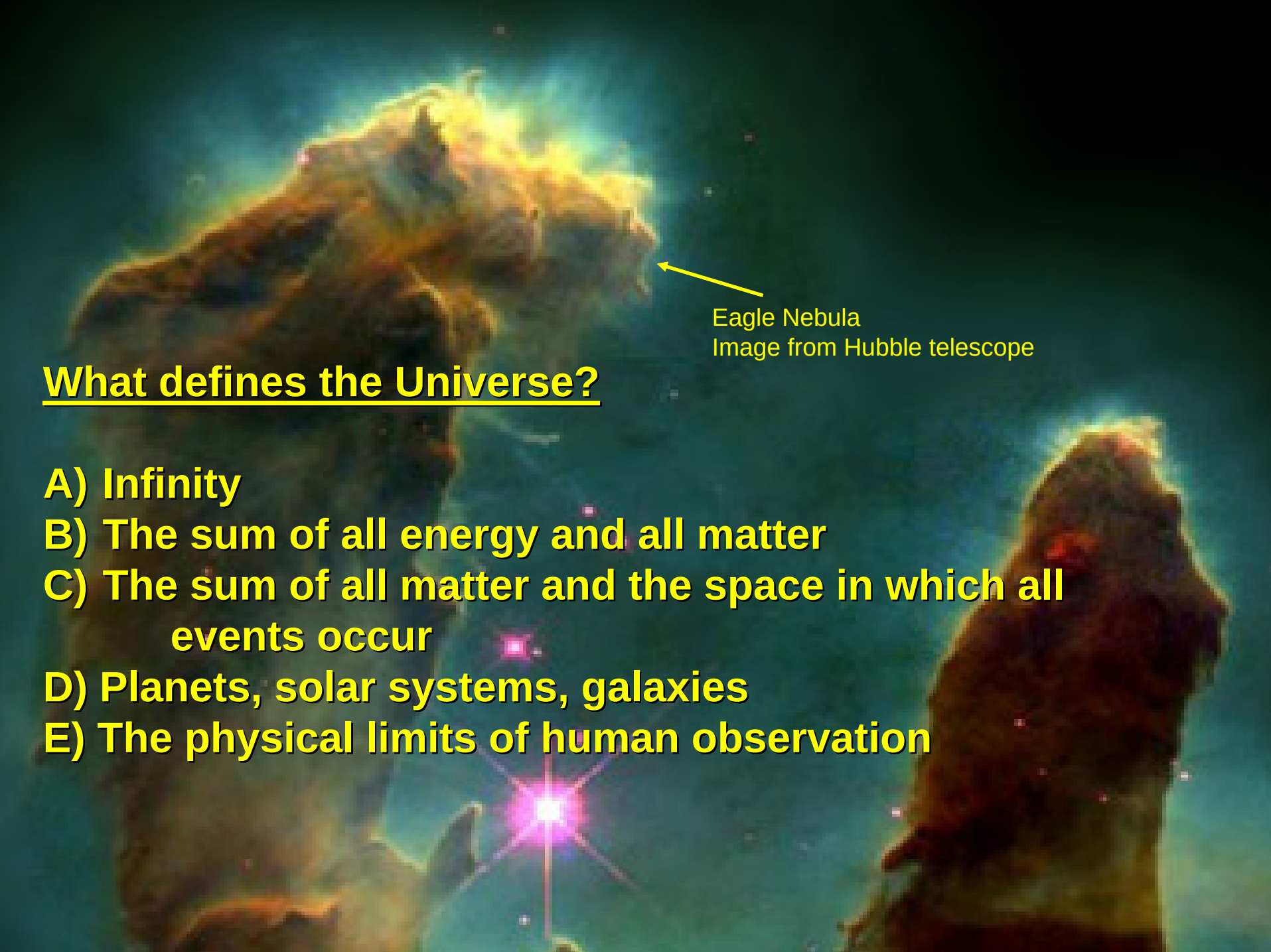
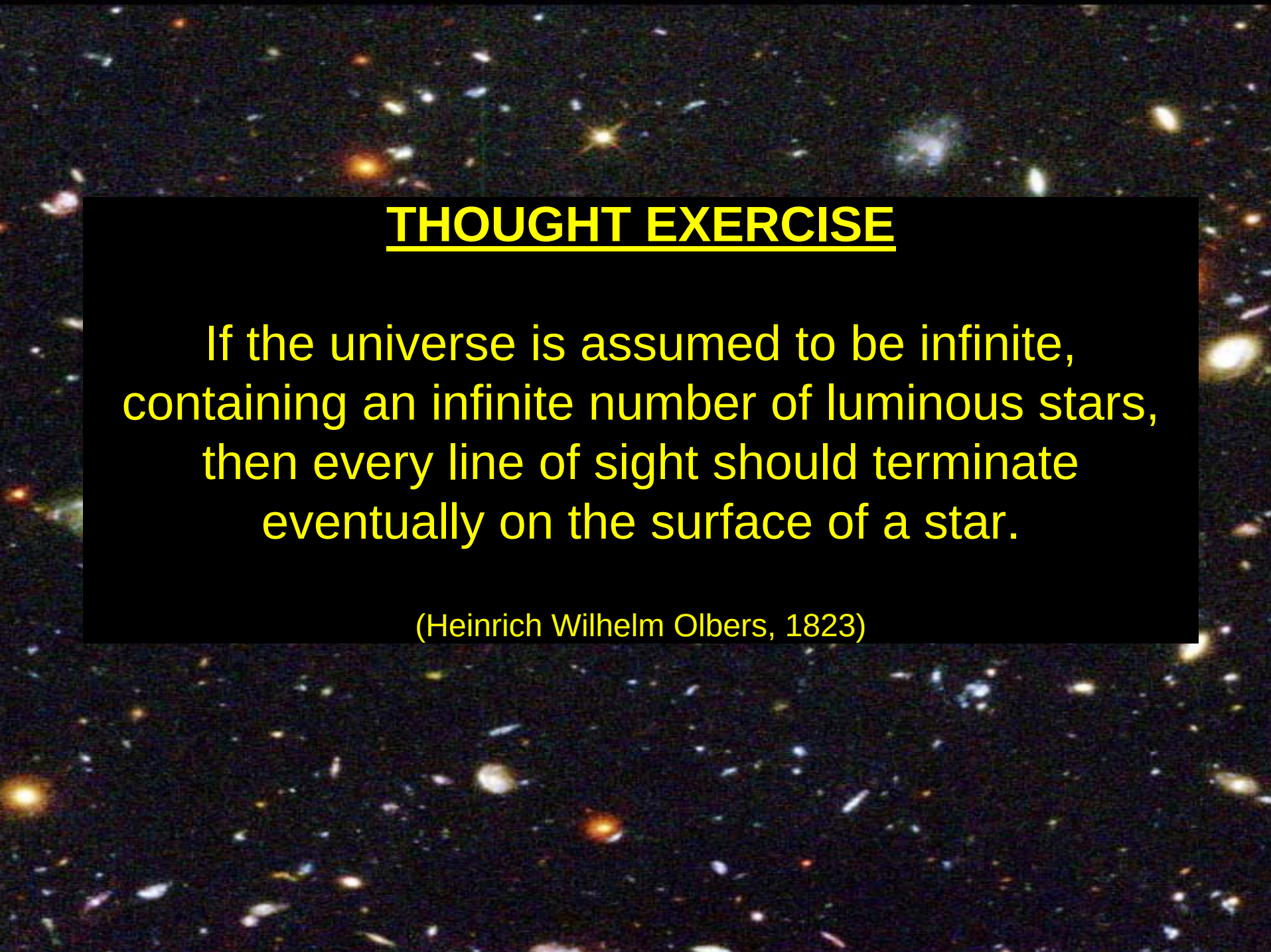


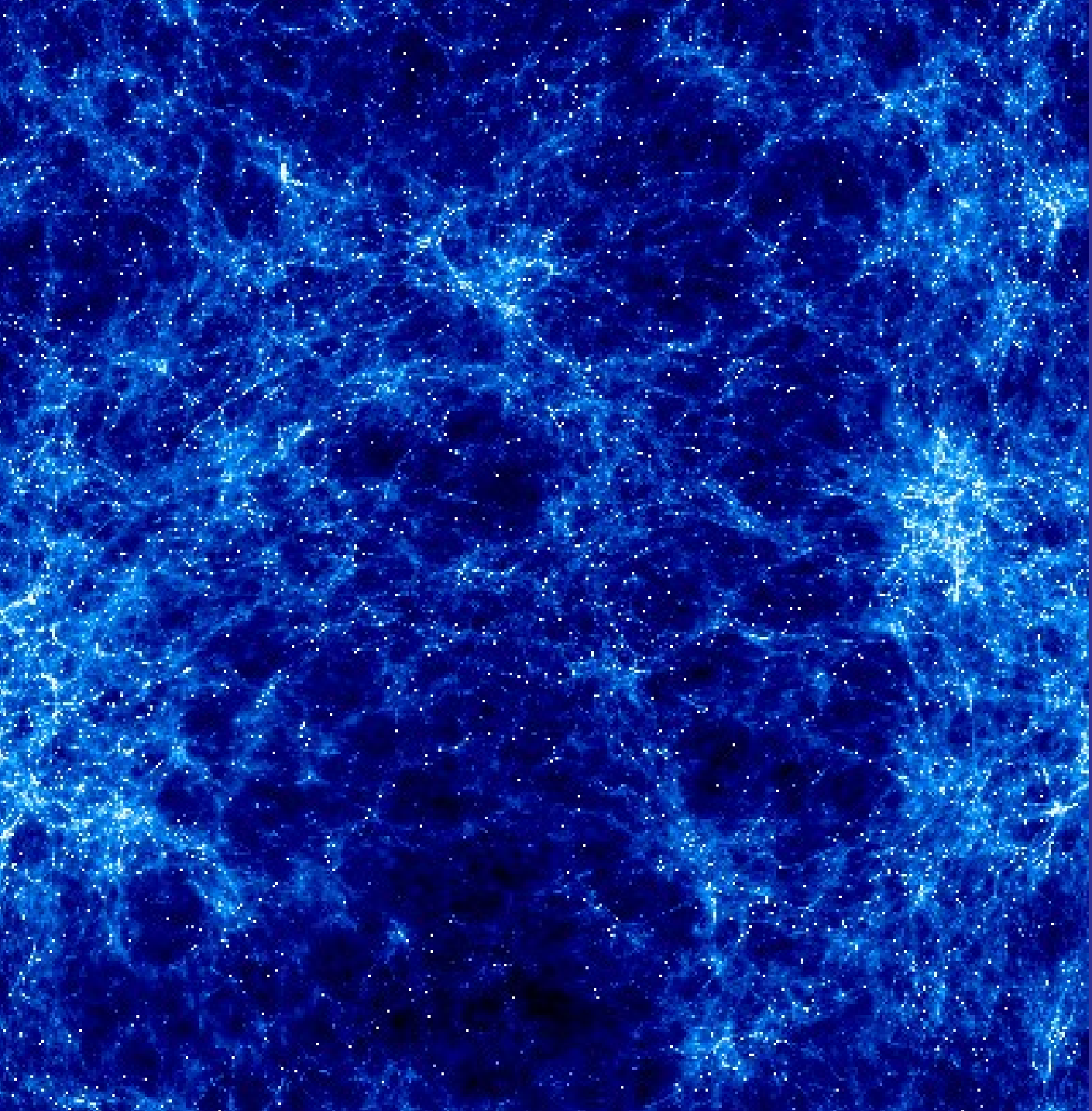
What defines the Universe?

A) Infinity
B) The sum of all energy and all matter
C) The sum of all matter and the space in which all events occur
D) Planets, solar systems, galaxies
E) The physical limits of human observation


Is the Universe infinitely large?


THOUGHT EXERCISE
If the universe is assumed to be infinite, containing an infinite number of luminous stars, then every line of sight should terminate eventually on the surface of a star.
(Heinrich Wilhelm Olbers, 1823)


Is the Universe infinitely old?



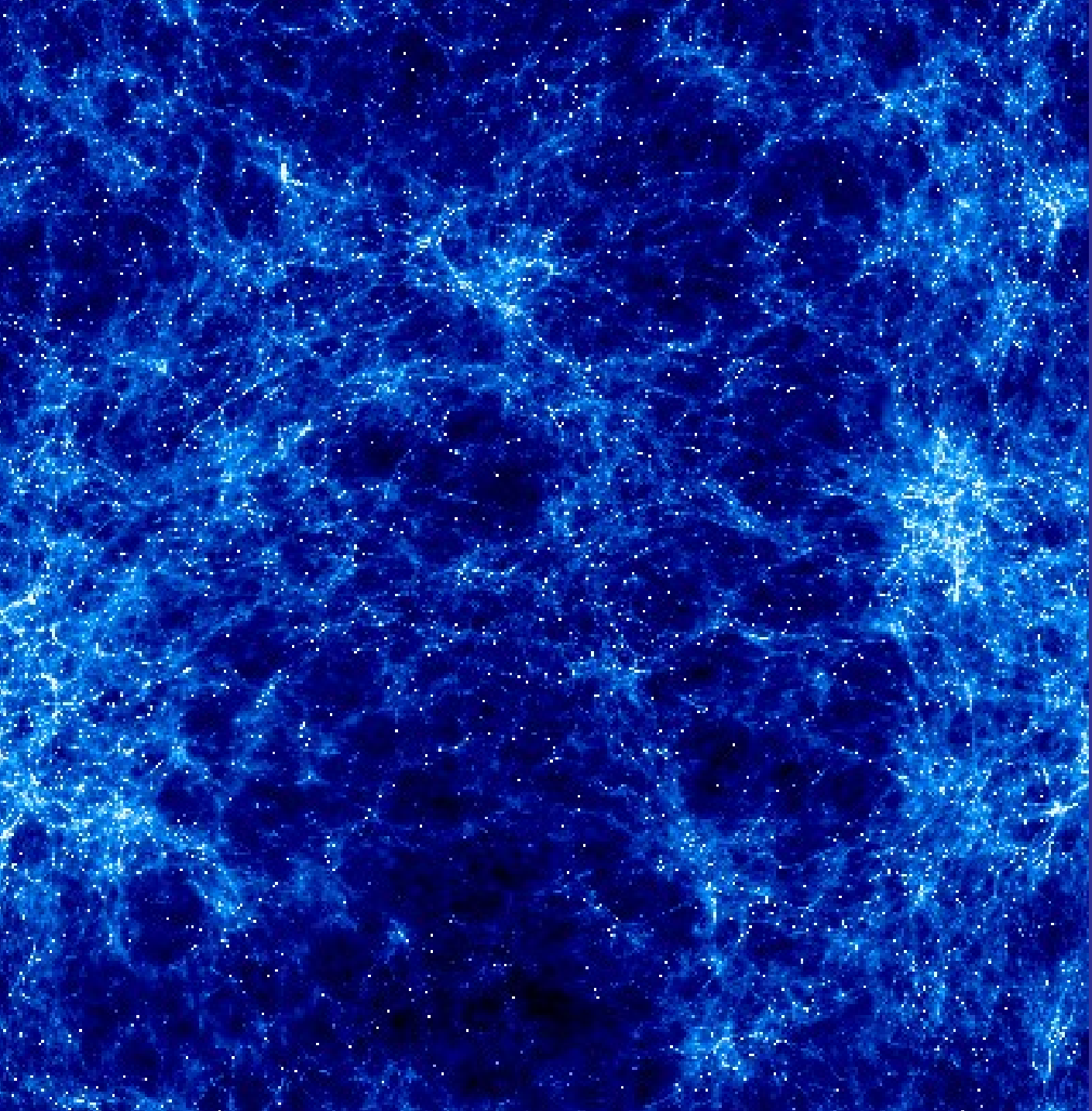
How are the

AGE

and the

SIZE

of the Universe related?



How are the

AGE

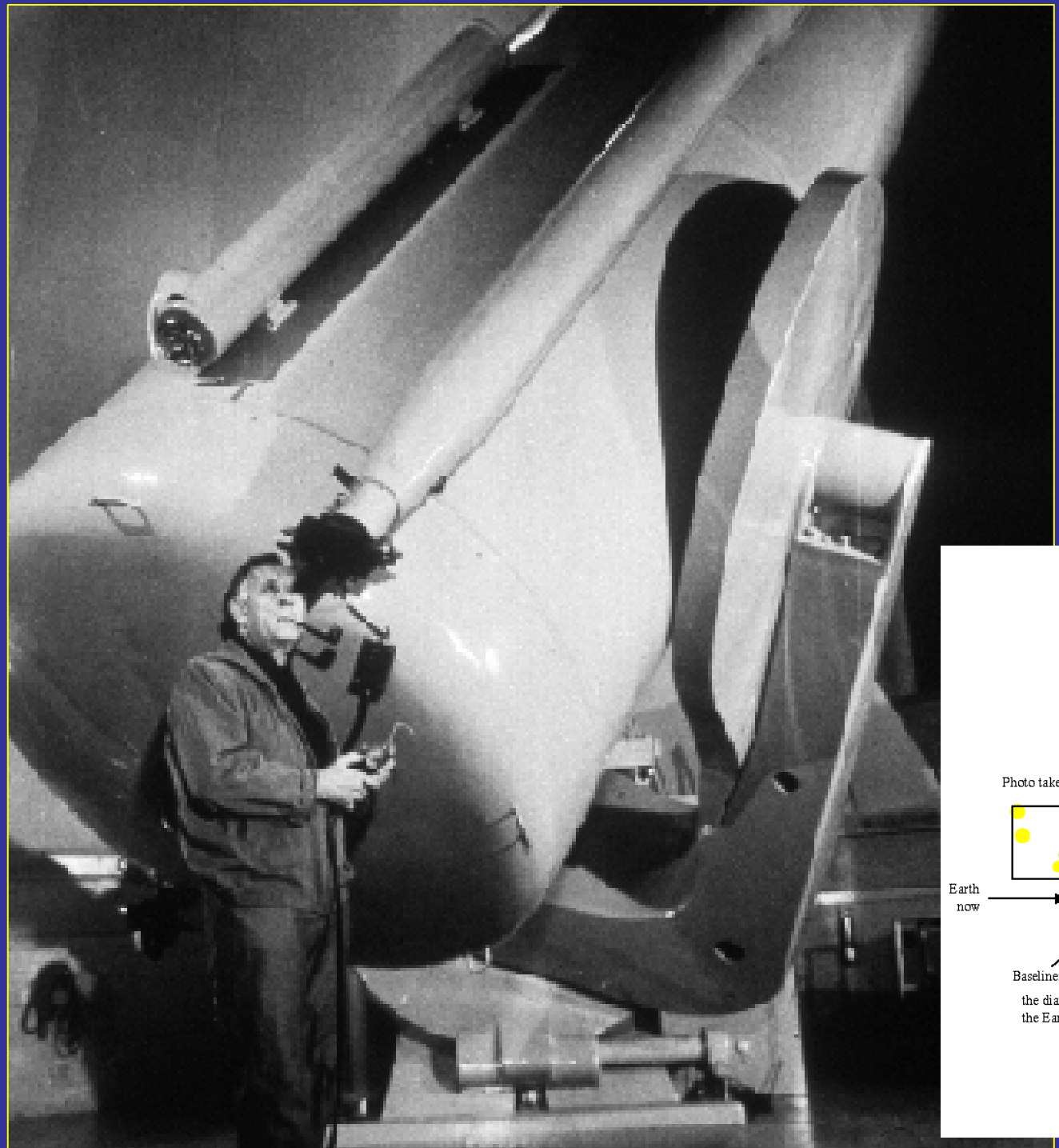
and the

SIZE

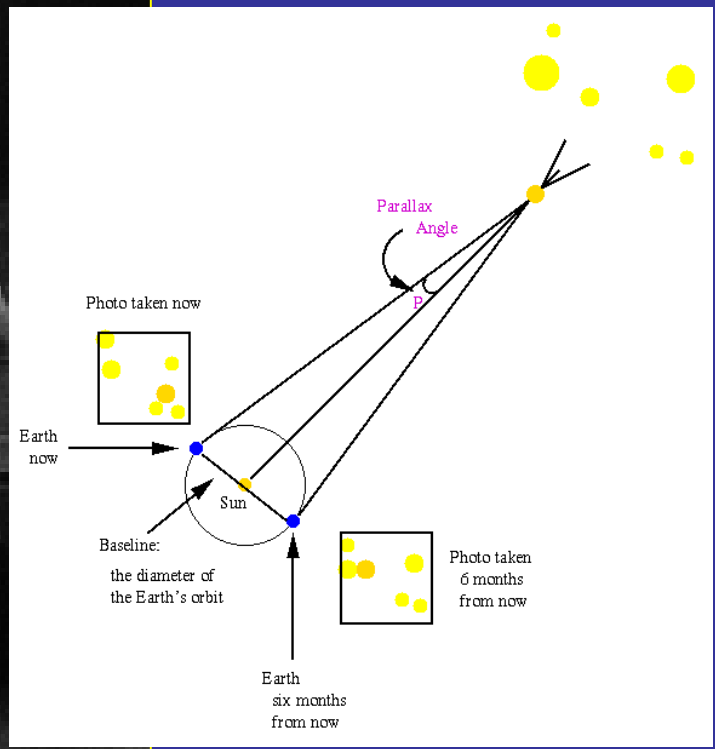
of the Universe related?

Light year:

Distance light travels in a vacuum in 1 yr
=
9,460,730,472,581 km



In the 1920s Edwin Hubble calculated distances to stars outside of the Milky Way galaxy



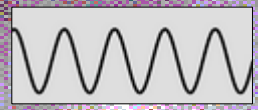
At the same time Vesto Melvin Slipher was calculating galactic **Red Shifts** *(like Doppler effect)*

Red Orange Yellow Green Blue Indigo Violet

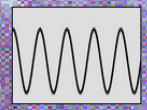
Retreating light source

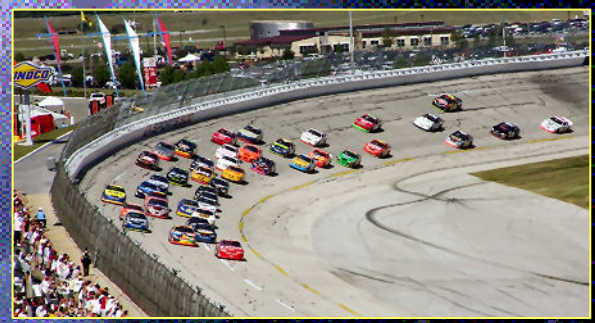


Stationary light source



Approaching light source





Most galaxies are red shifted

What Hubble noticed was that -

The further away a galaxy is from us,

the larger its Red Shift….

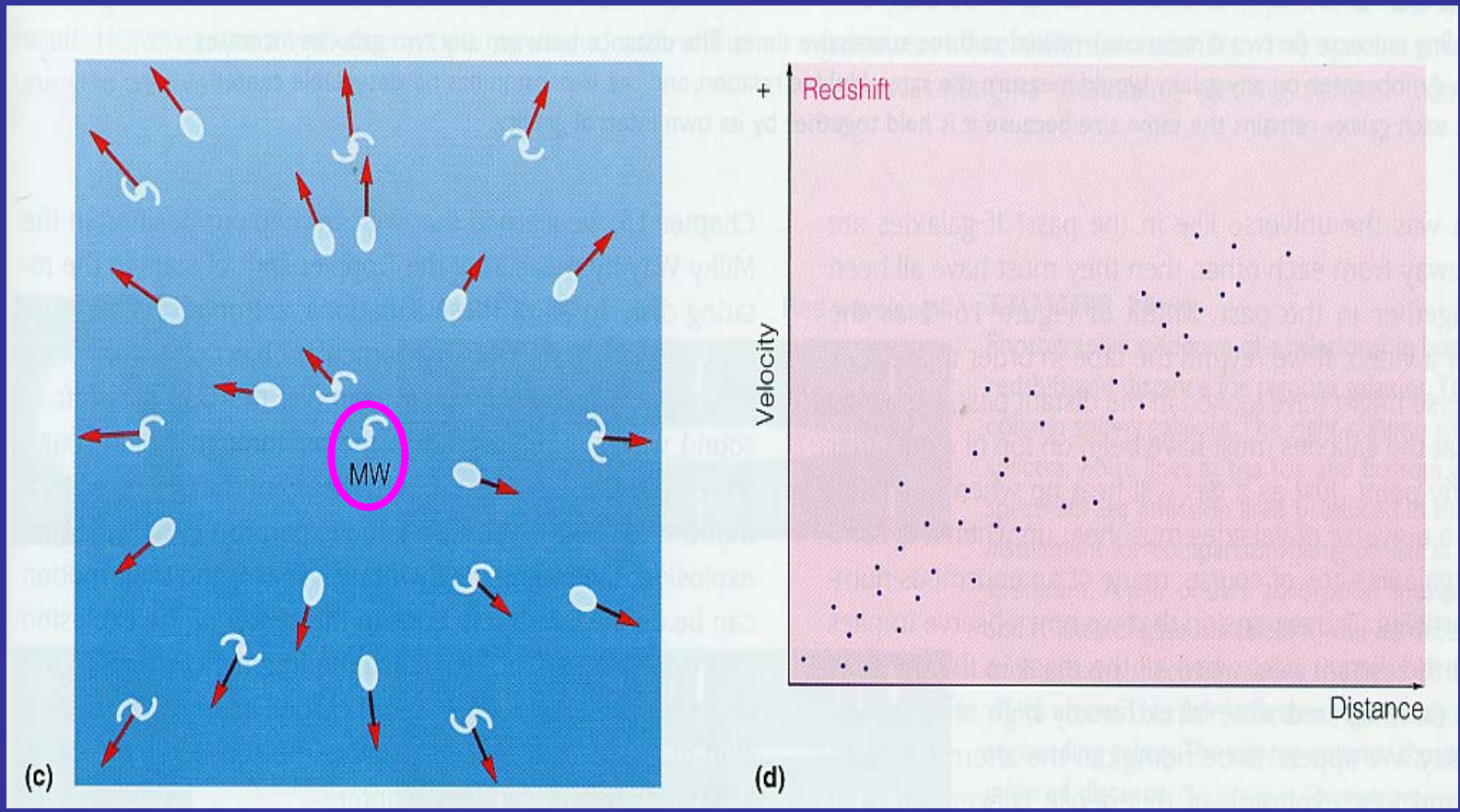
…what does this mean about its speed?

What Hubble noticed was that -

The further away a galaxy is from us,

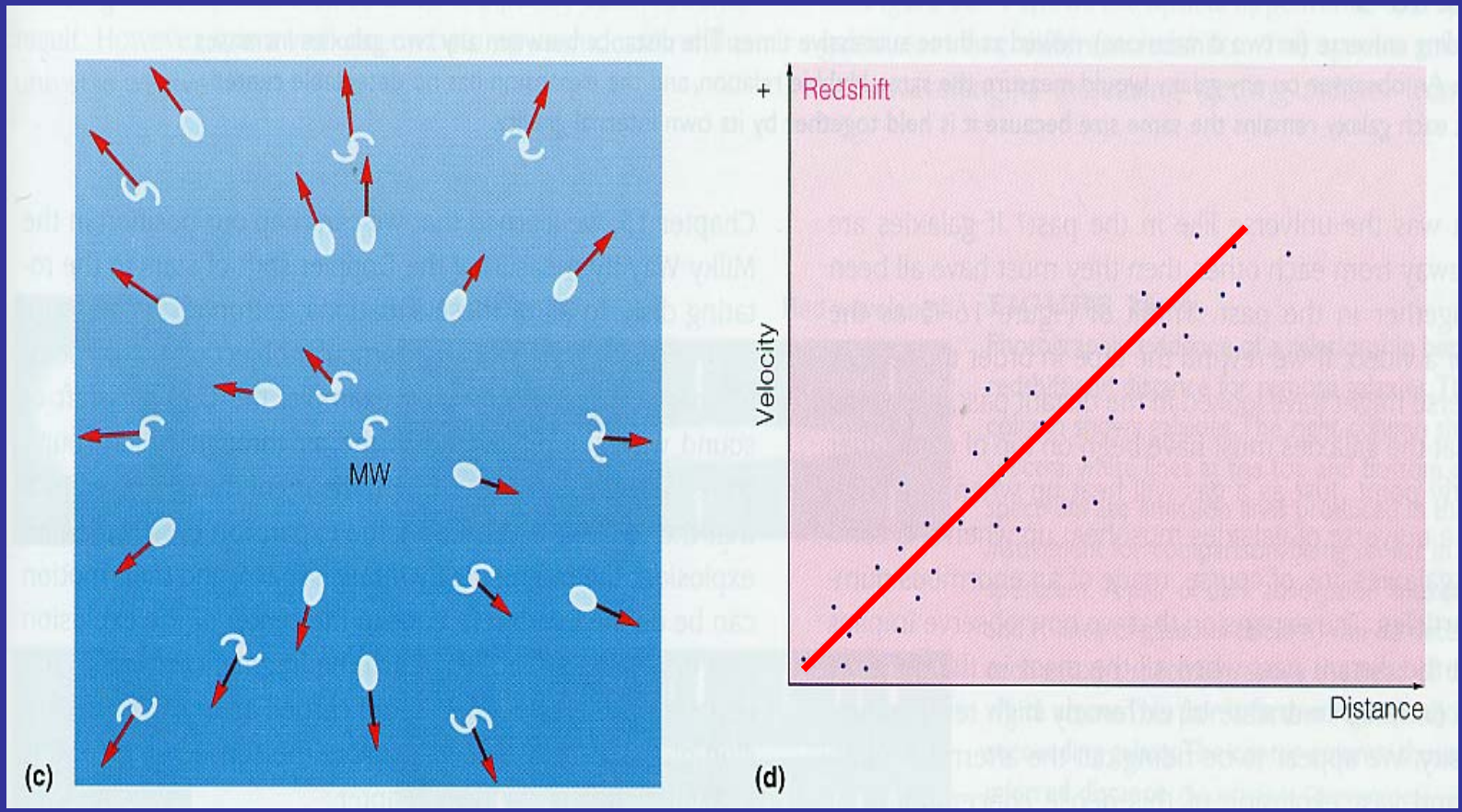
the larger its Red Shift….

….the faster it’s moving away from us.

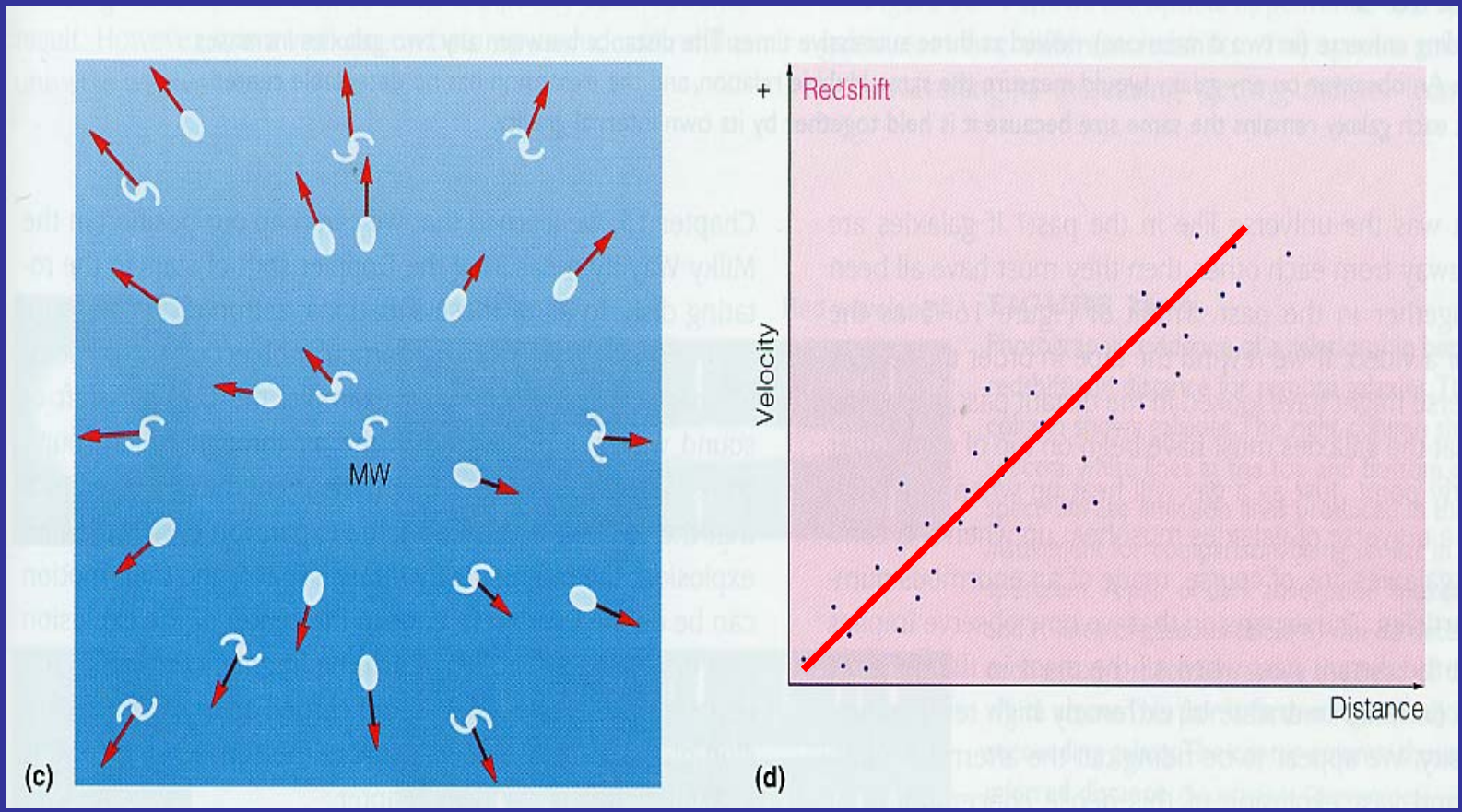


Galaxies close to us are moving away from us slowly

Galaxies that are farther away from us are moving away from us faster

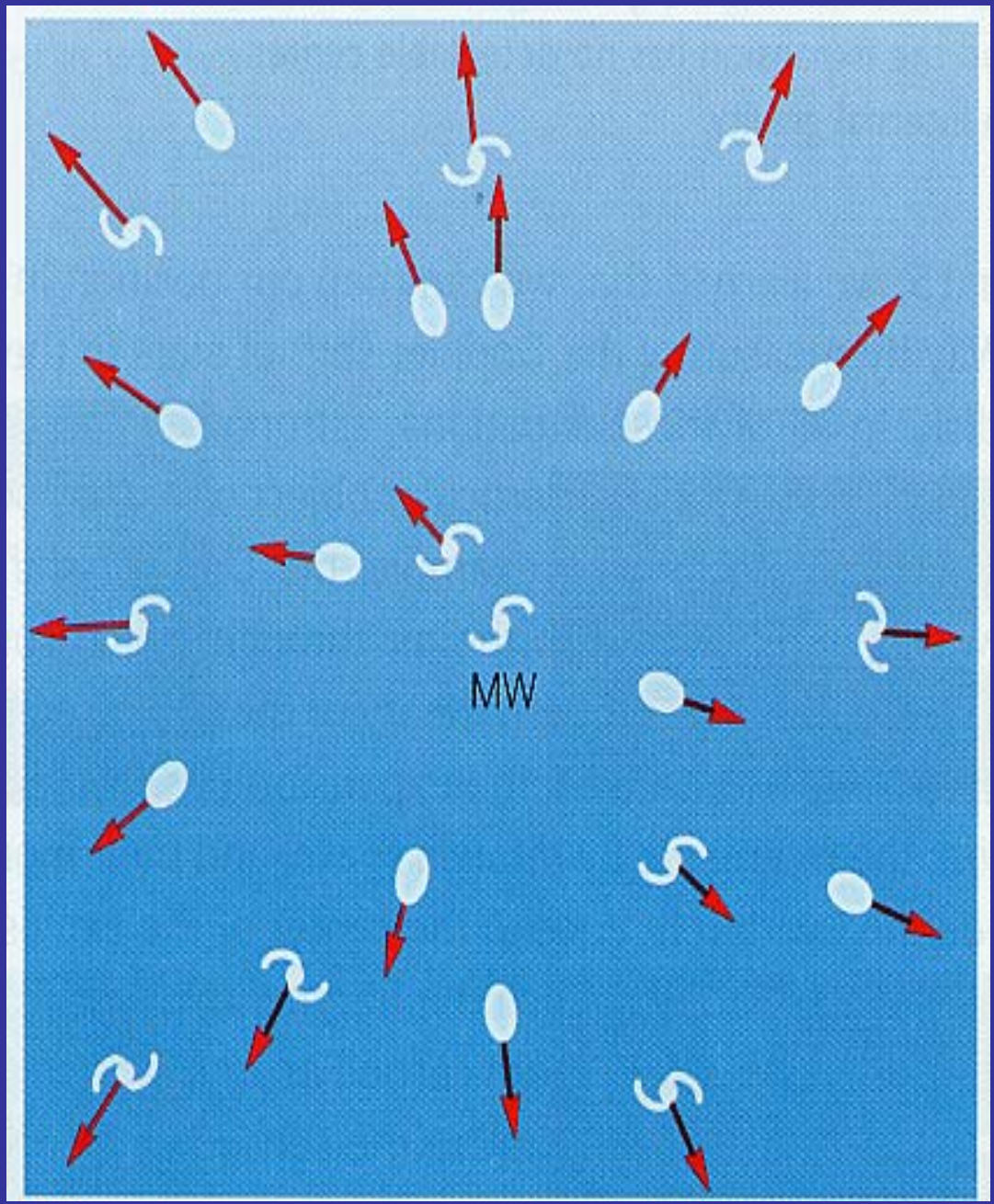


Straight line indicates that DISTANCE and SPEED of recession are…?



Straight line indicates that DISTANCE and SPEED of recession are…

PROPORTIONAL

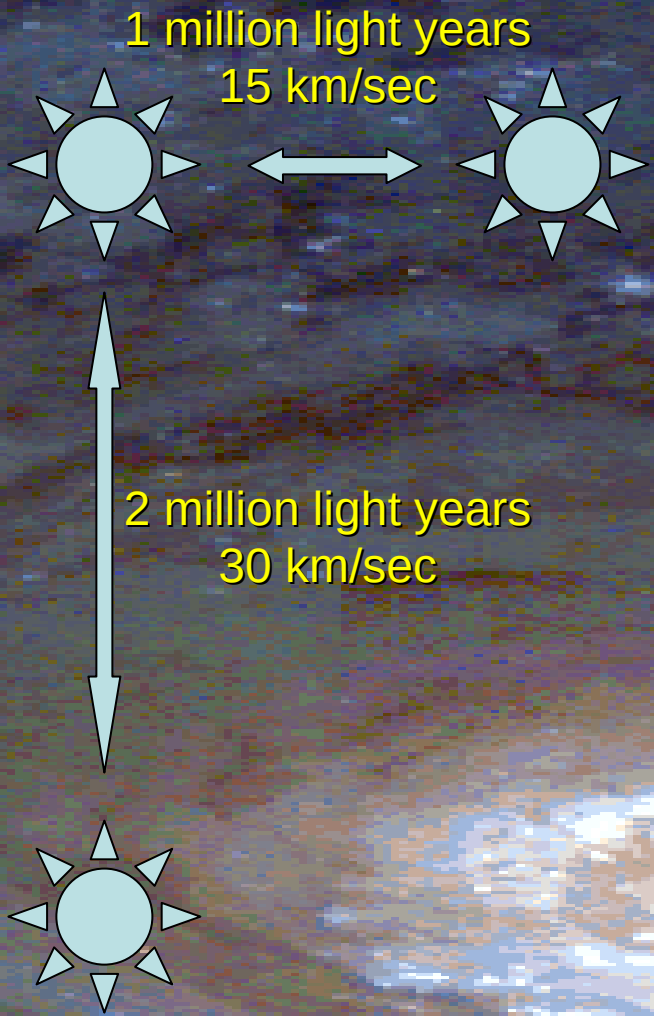


If all galaxies are moving away from each other…

what shape does the universe have to be?

A) Disc
B) Ellipse
C) Cone
D) Spiral
E) Sphere

What's wrong with this picture?



“Hubble’s Constant” for the cosmic rate of expansion

What does an expanding universe imply?




There was a beginning!
the “Big Bang”

Edwin Hubble calculated the rate (R) at which the universe is expanding

For two galaxies that are separated by a distance (D)

R= D/T

Rate of expansion = distance between two objects/time of expansion

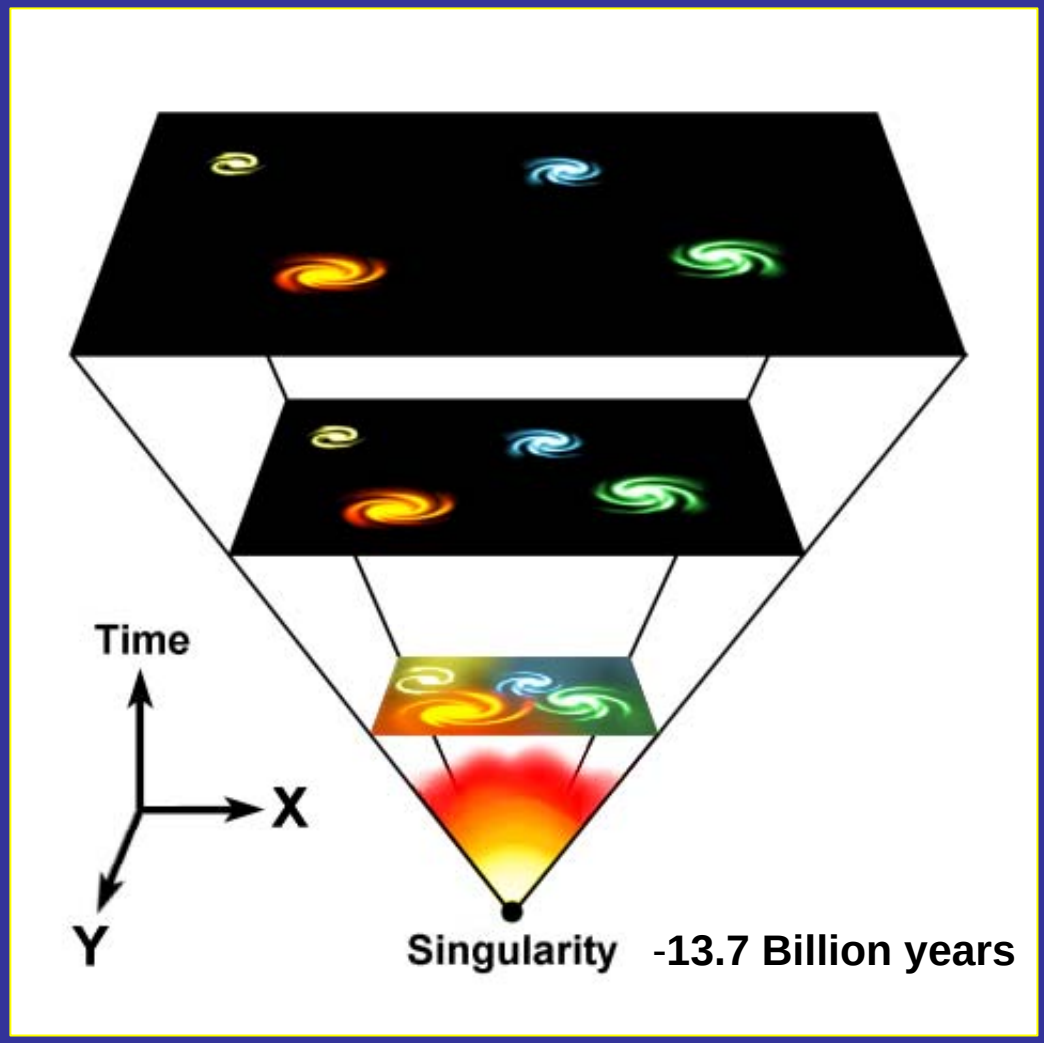
This can be reorganized to T = D/R.

T=age of the universe!

Hubble's calculation =
About 20 billion years

Improvements in estimating the rate of recession have lowered the probable **age of the Universe to ~13.7 billion years**

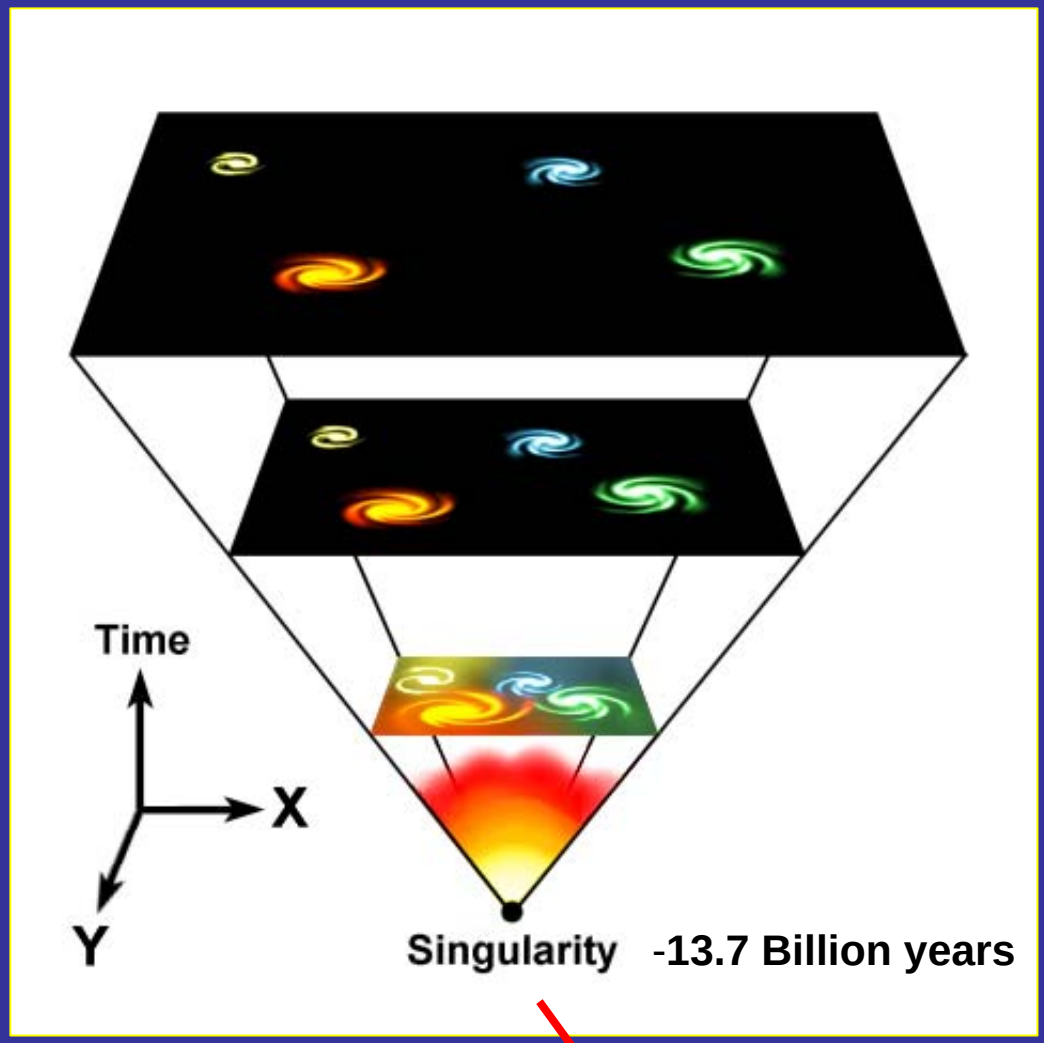
So how **BIG** is the Universe?



The Big Bang vs. Steady-State

1) Cosmic Red Shift

2) …?



The Big Bang vs. Steady-State

1) Cosmic Red Shift

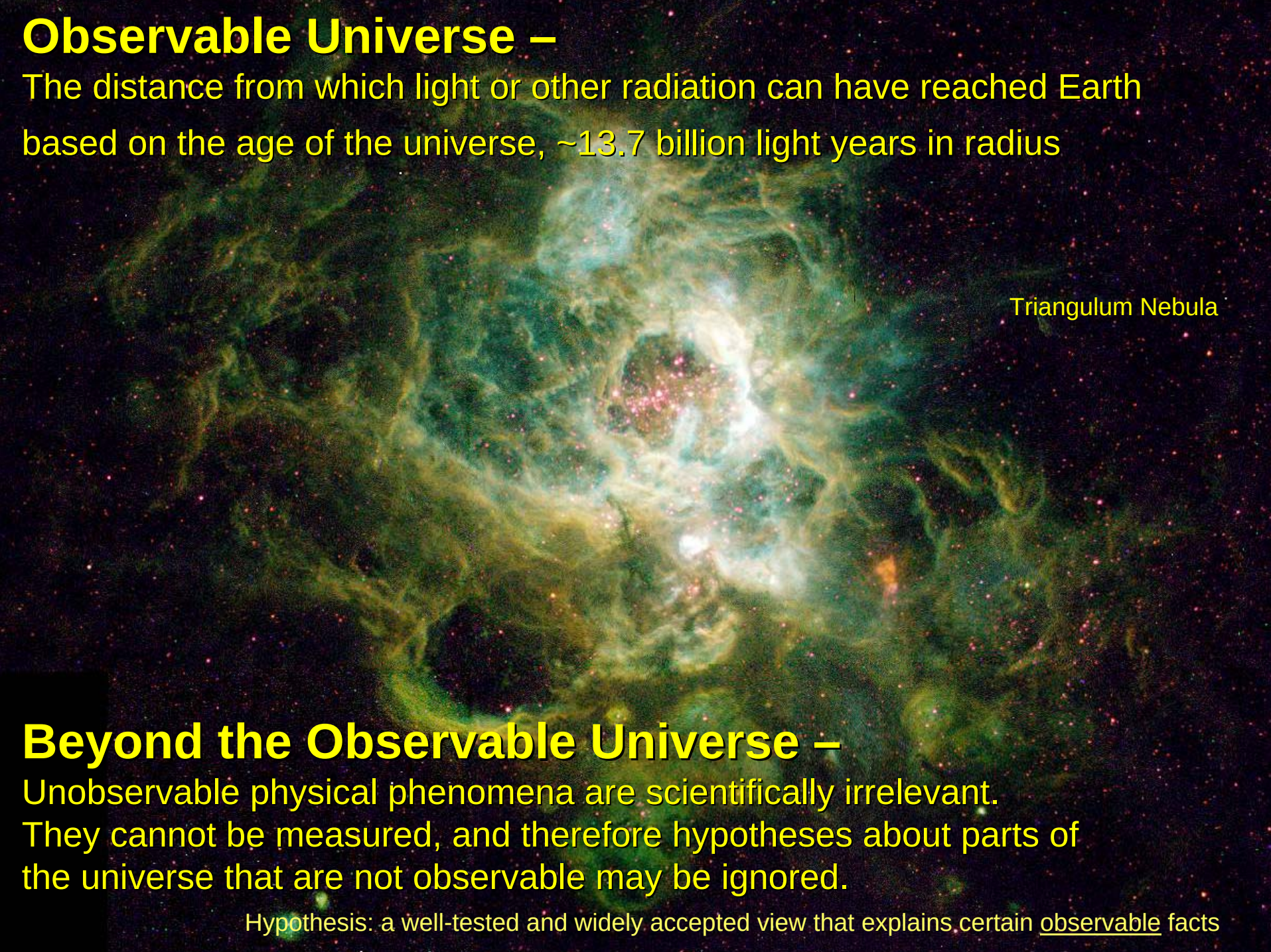
2) Cosmic Microwave Background Radiation

- 2.725° above absolute zero
- extremely uniform distribution
- microwave portion of EM spectrum

Gravitational singularity
Immensely hot and dense

Observable Universe –

The distance from which light or other radiation can have reached Earth based on the age of the universe, ~13.7 billion light years in radius



Triangulum Nebula

Beyond the Observable Universe –

Unobservable physical phenomena are scientifically irrelevant. They cannot be measured, and therefore hypotheses about parts of the universe that are not observable may be ignored.

Hypothesis: a well-tested and widely accepted view that explains certain observable facts

Universe summary:

1) **Universe has a finite size and a known shape**

(expanding sphere)

2) **Therefore, it must have a finite age**

(13.7 billion years)

3) **And therefore, there must have been a beginning**

(the “Big Bang”, *not Steady State system*)

4) **Evidence: galactic Red Shifts, CMBR**

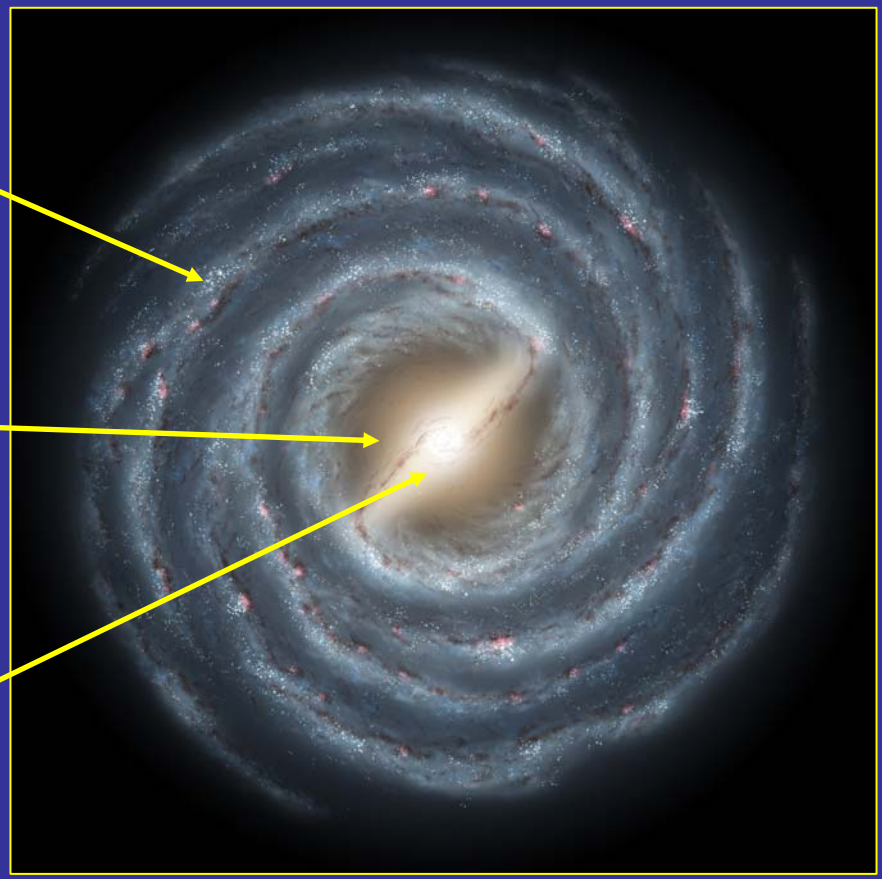


Milky Way Galaxy – barred spiral galaxy

Approximate location of our sun

Central bulge or nucleus

Supermassive black hole: 100,000s to 10s of billions of solar masses



The **Milky Way Galaxy**, one of billions of other galaxies in the universe, contains about 400 billion stars and countless other objects.

Democritus first suggested the Milky Way was made of stars about 400 BC

Width ~100,000 light years, thickness ~1,000 light years

(One light year = ~5,878,482,164,161 miles)
~979 x the world's population
65% of U.S. National Debt (~$9 trillion)

Solar Nebula Hypothesis

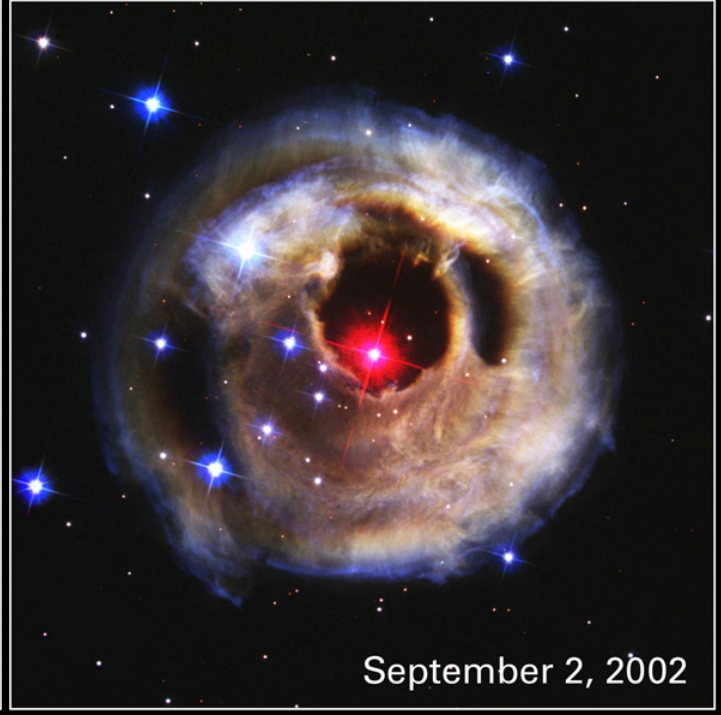
The beginning of the Solar System 6.9 billion years ago

Explosion of ancestral star creates giant cloud of cold interstellar gas

Composition same as our modern Sun
=
98% hydrogen and helium,
2% heavier elements
from previous
solar explosions











Formation of a nebula

.

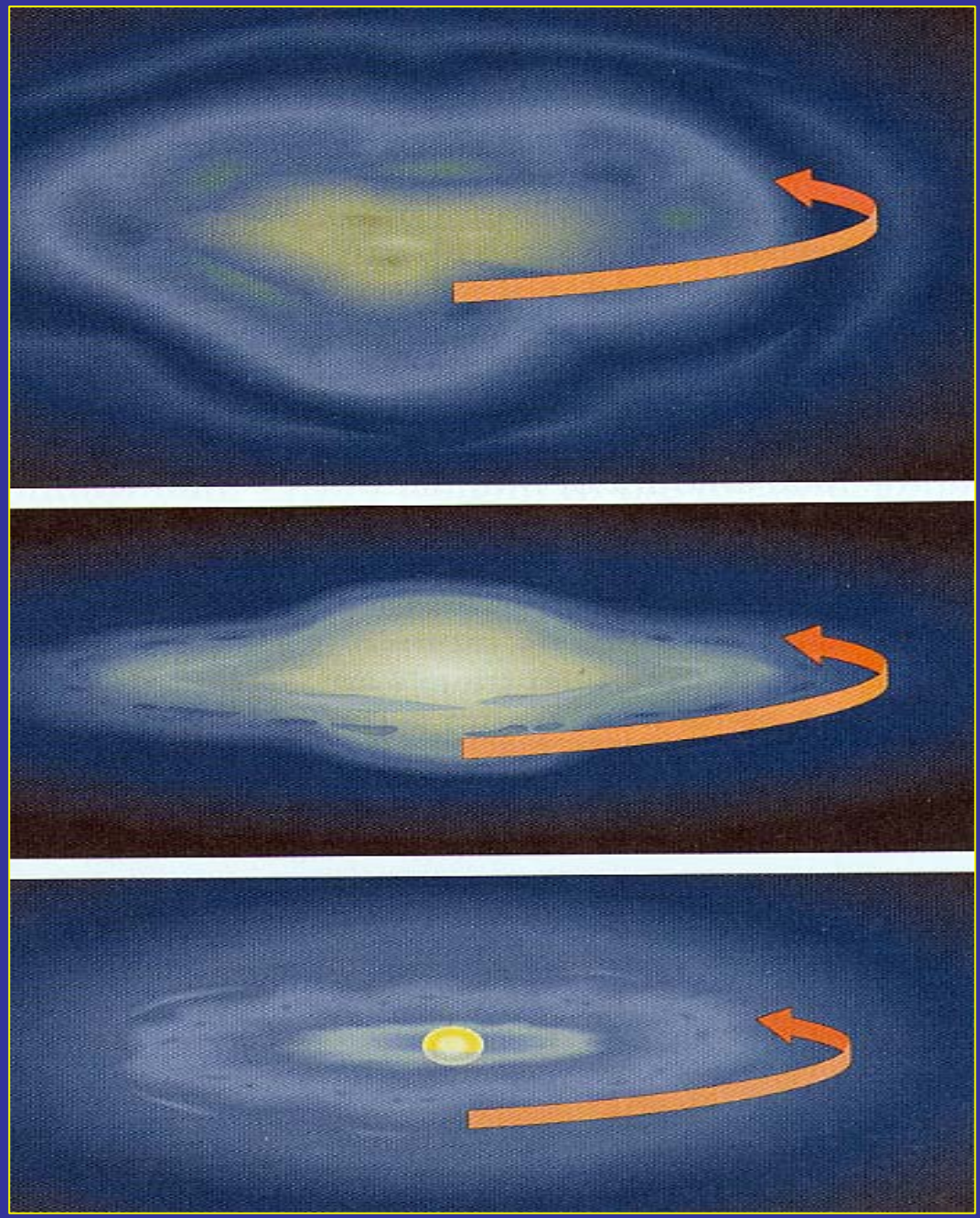
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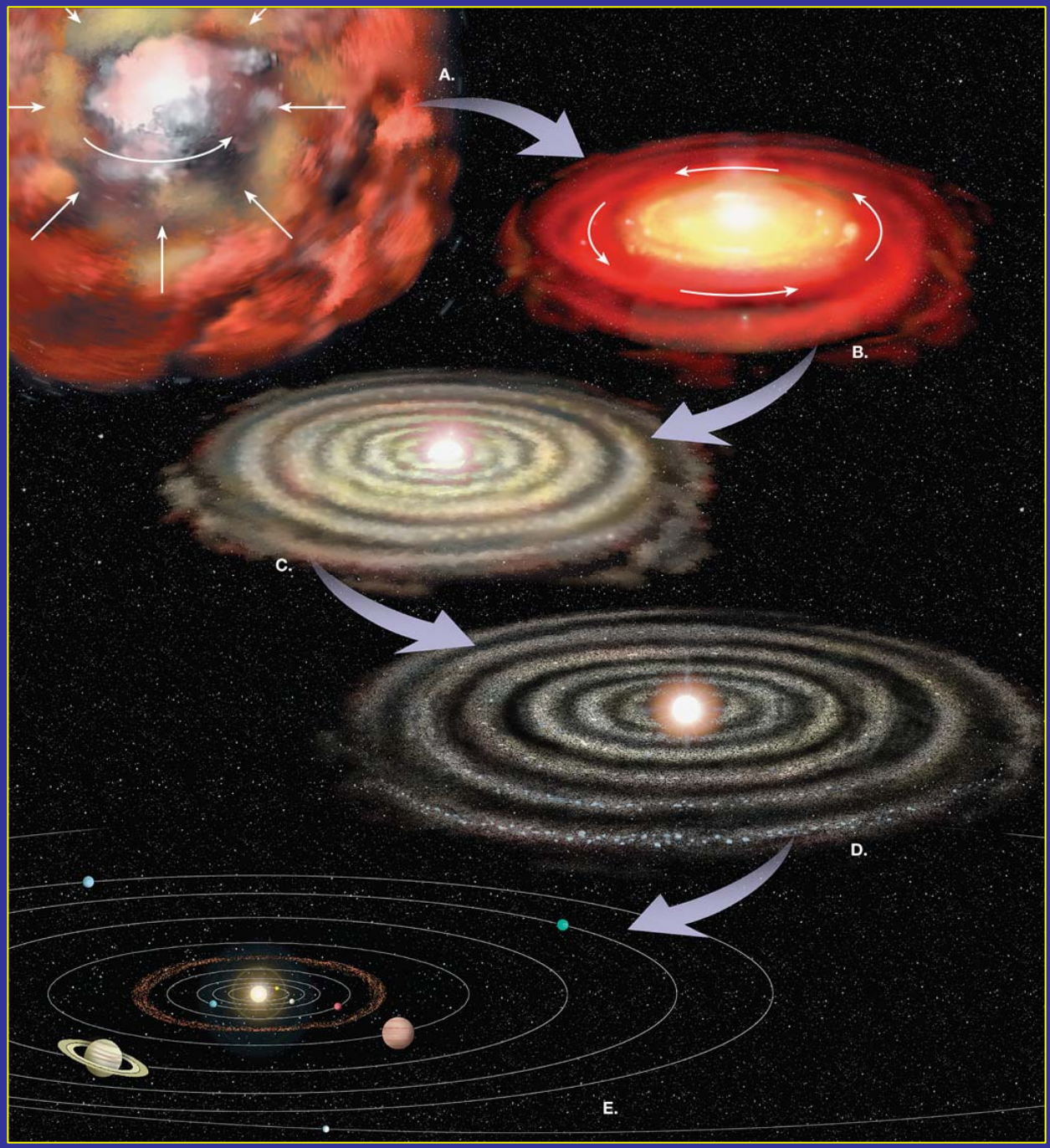
What causes this gas cloud to <u>stop</u> expanding?



1) Nebula collapses and condenses

2) Rotation started by shockwaves from a nearby explosion (?)

3) Because the solar nebula was rotating, it contracted into a disc, and the planets formed with orbits lying in nearly the same plane.



The spinning solar nebula segregated into:

1) the inner nebula core that was to become the Sun

2) a cooling outer accretion disc of rocky fragments and dust



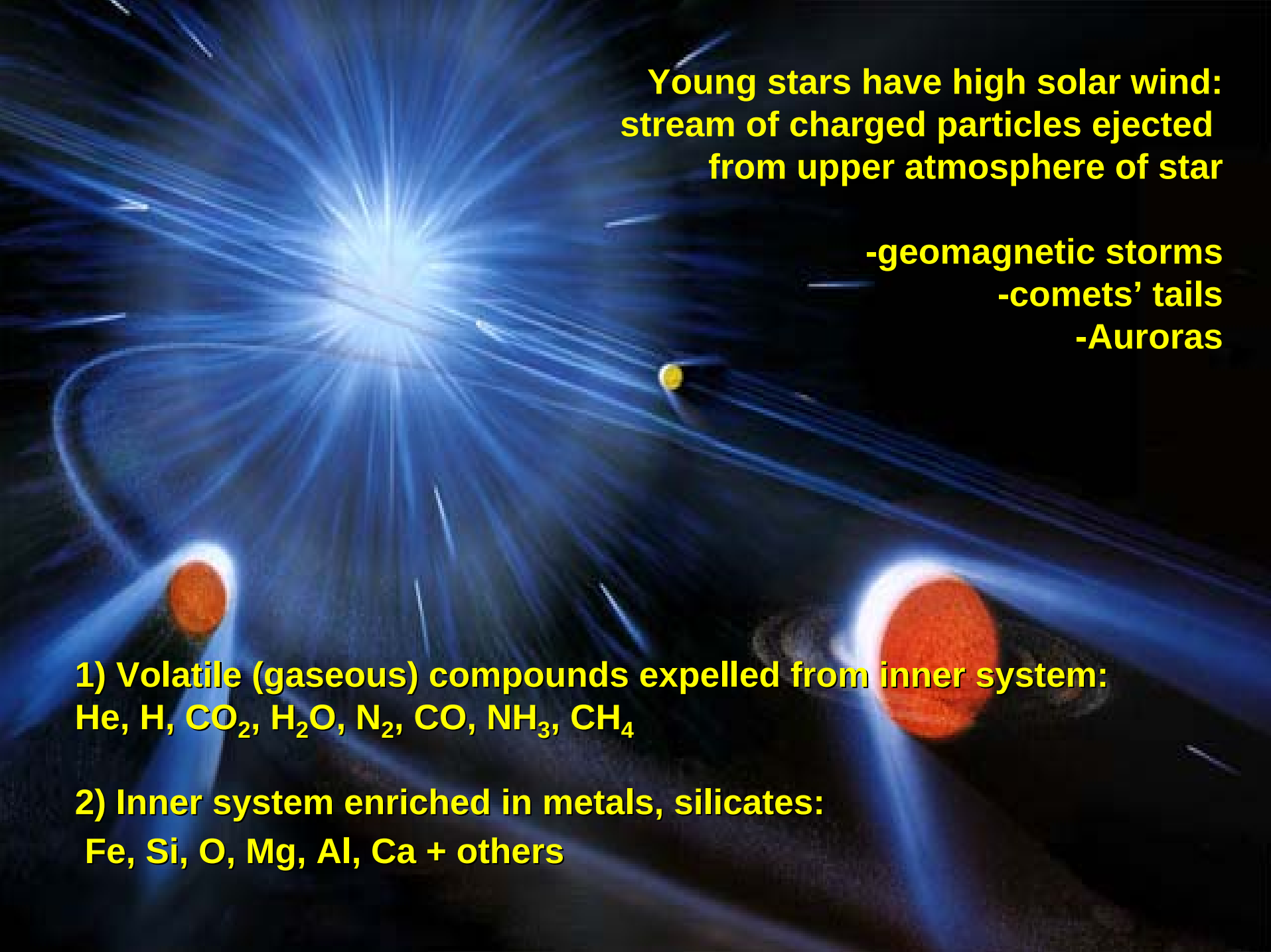
1) Formation of young sun

Nebula's gravity causes compaction

Core density increases

Hydrogen nuclear fusion starts

10-50 million years



Young stars have high solar wind:
stream of charged particles ejected
from upper atmosphere of star

-geomagnetic storms
-comets' tails
-Auroras

1) Volatile (gaseous) compounds expelled from inner system:
He, H, CO_2, H_2O, N_2, CO, NH_3, CH_4

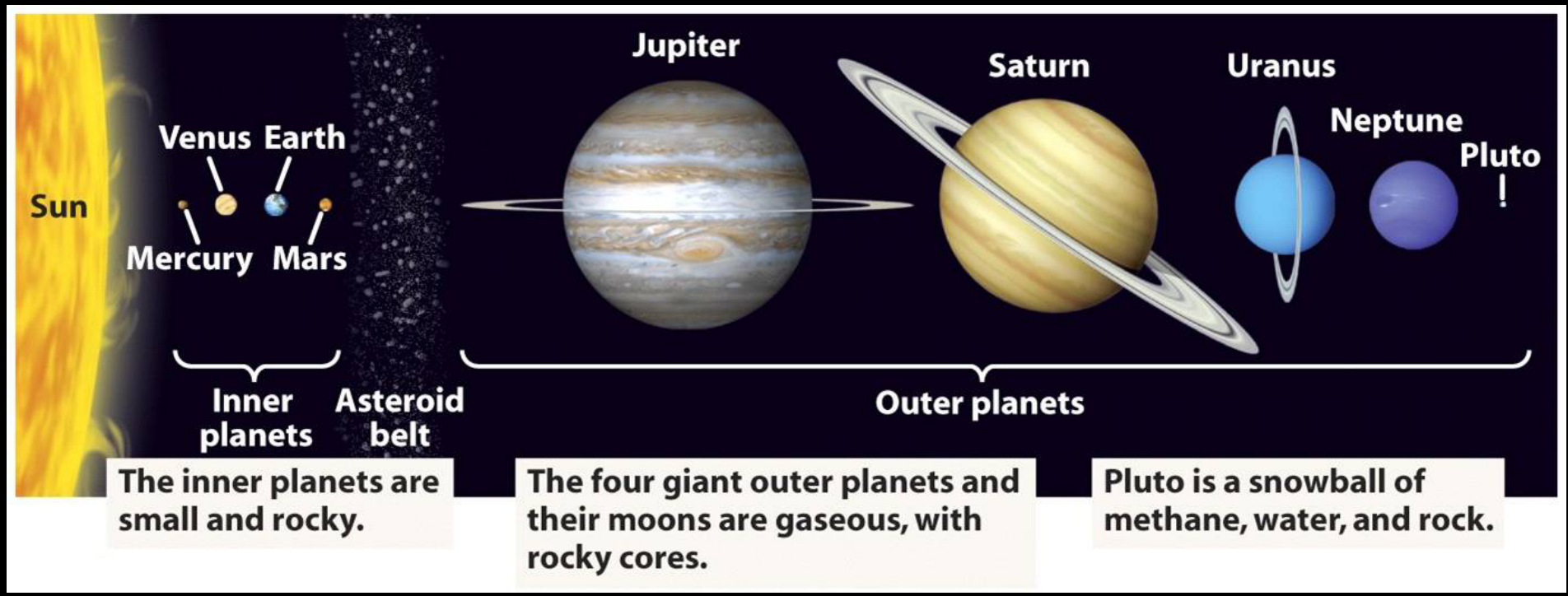
2) Inner system enriched in metals, silicates:
Fe, Si, O, Mg, Al, Ca + others



2) Planetesimal accretion

- Dust (metals and silicates)
- Ices (water, methane, ammonia)
- Grains condense, collide, accrete electrostatically
- Increasing gravity attracts more material

~5 to 4.6 billion yrs ago



1) Inner Rocky Planets – Fe, Mg, Si, O, Ca, Na, K, Al (nonvolatile)
Mercury, Venus, Earth, Mars

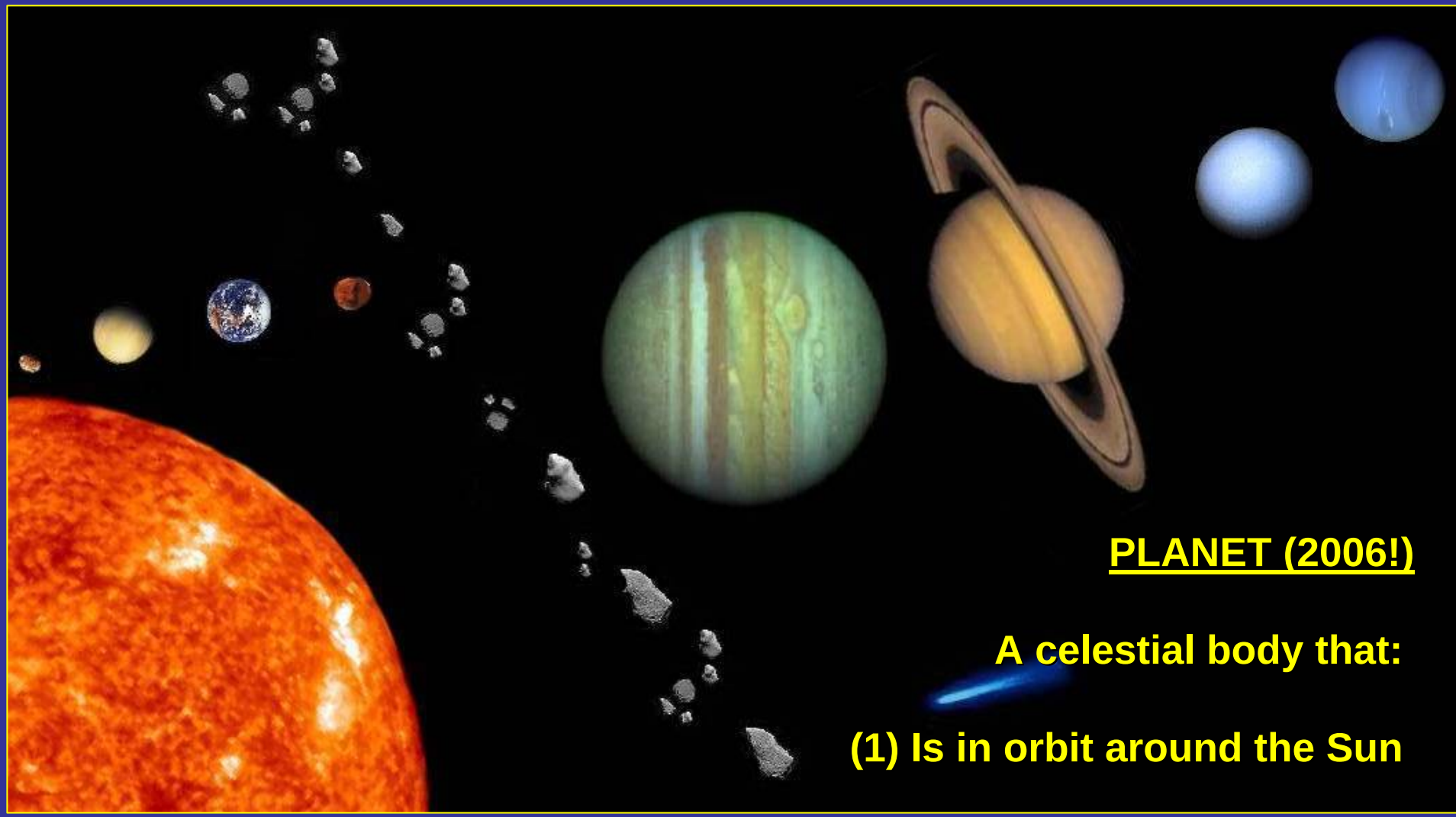
2) Outer Gas Giants – He, H, CO_2, H_2O, N_2, CO, NH_3, CH_4 (volatile)
Jupiter, Saturn, Uranus, Neptune

A rare image of tiny Pluto with its moon Charon, which is slightly smaller.

Pluto's surface is believed to reach temperatures as low as -240°C.

Why isn't Pluto a planet?

A) It doesn't have enough mass
B) It's too far from the Sun
C) It's gaseous instead of rocky
D) Its orbit does not track within the planetary disk
E) It's named after a dog



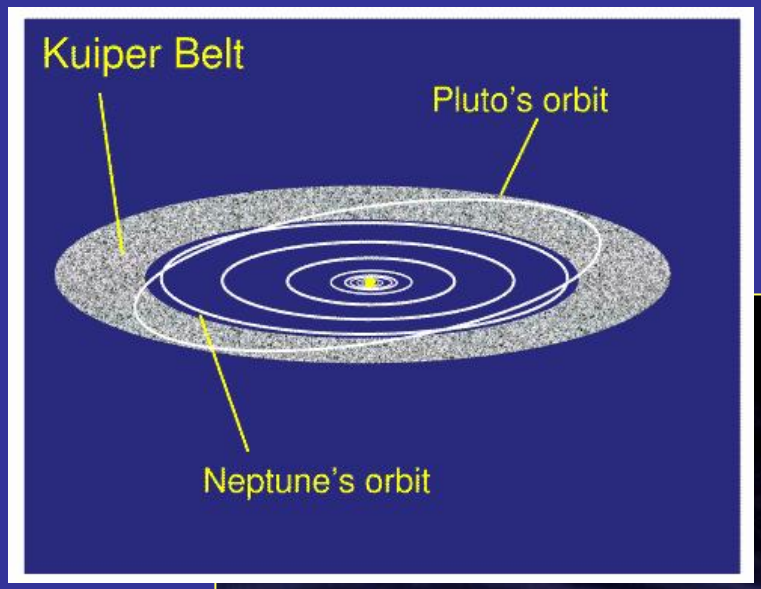
PLANET (2006!)

A celestial body that:

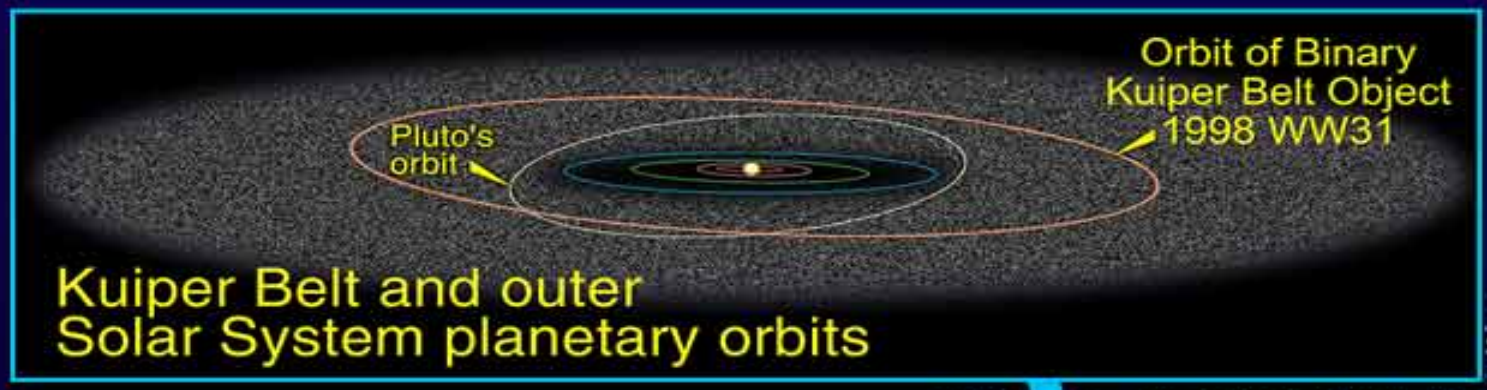
(1) Is in orbit around the Sun

(2) Has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape

(3) Has cleared the neighborhood around its orbit



Kuiper Belt Objects (KBOs) are usually icy planetoids native to the outer solar system



Kuiper Belt and Oort Cloud

The Oort Cloud (comprising many billions of comets)

Oort Cloud cutaway drawing adapted from Donald K. Yeoman's illustraton (NASA, JPL)

Early Earth



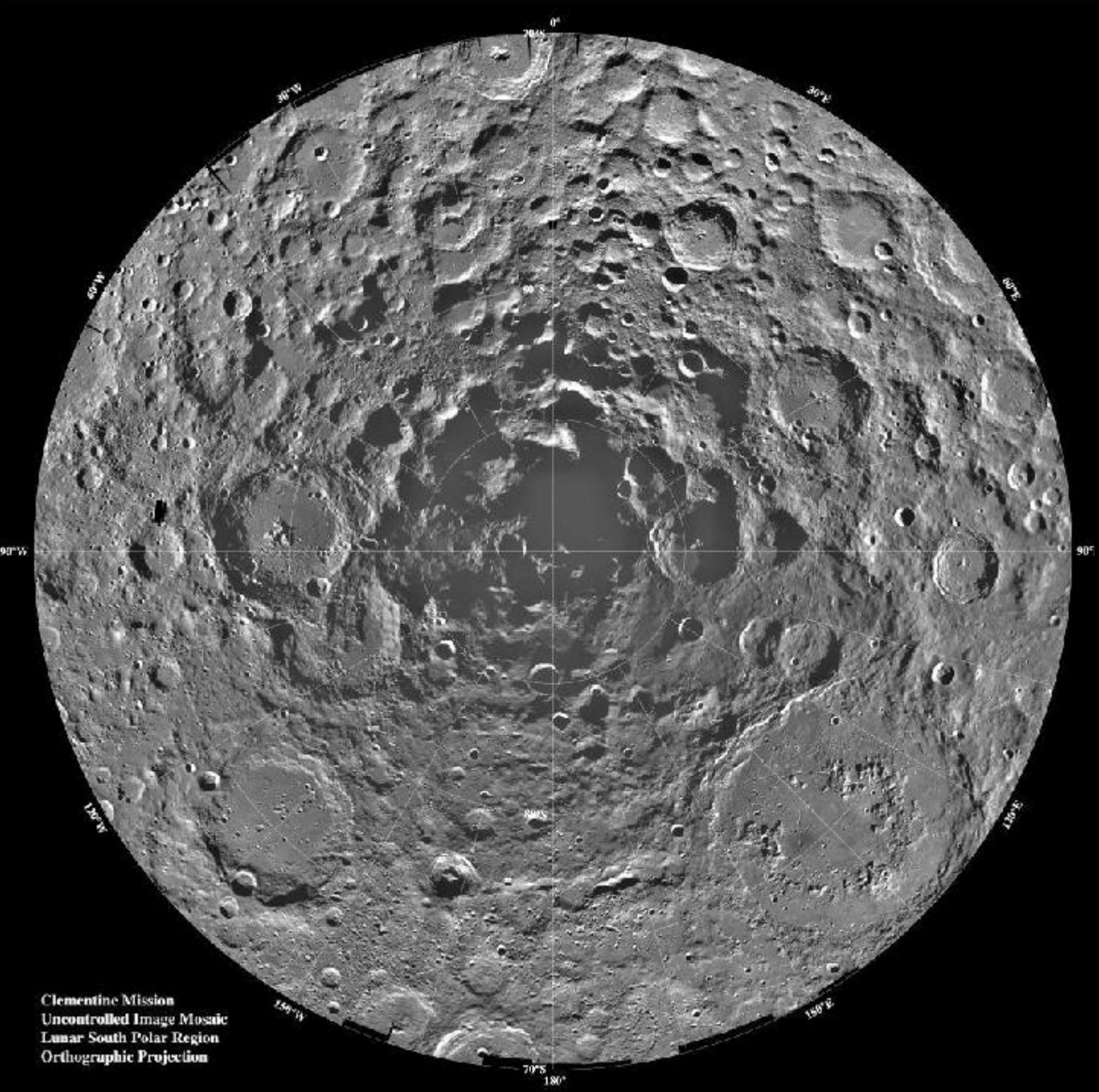


Planetesimal accretion ongoing….

Phase I:
Bombardment by planetoids/asteroids

(Earth is already a planet, but just a fraction of its current size)

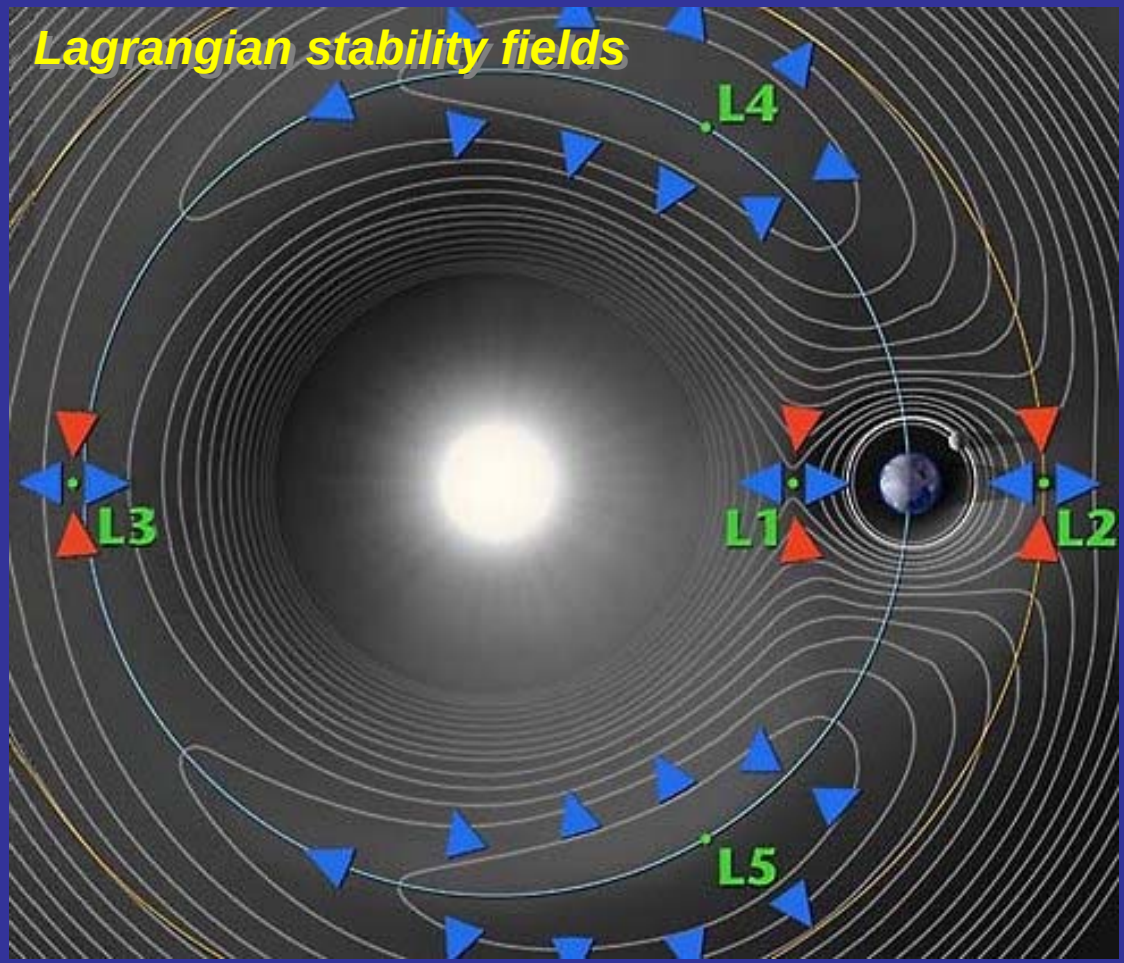
How do we know this was happening?

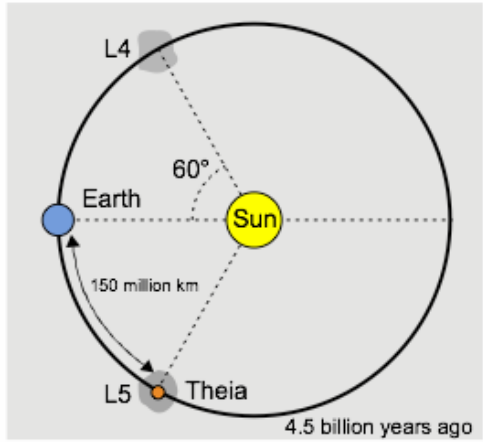


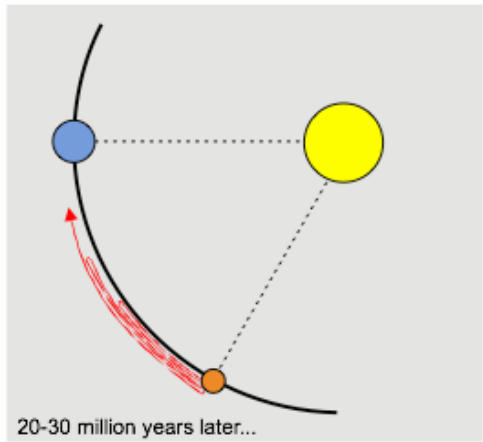
Early Bombardment

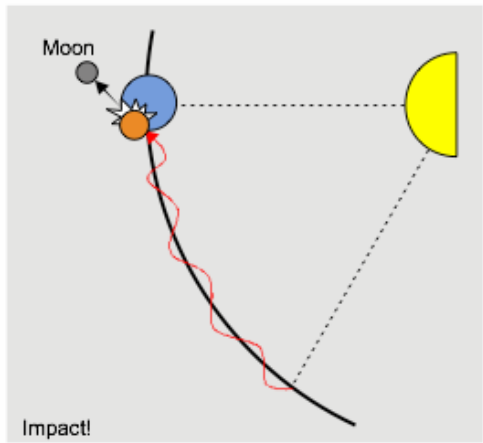
Craters preserved on surface of Moon

How was our Moon formed?









Giant Impact Hypothesis

Theia collides with Earth

~4.5 billion years ago

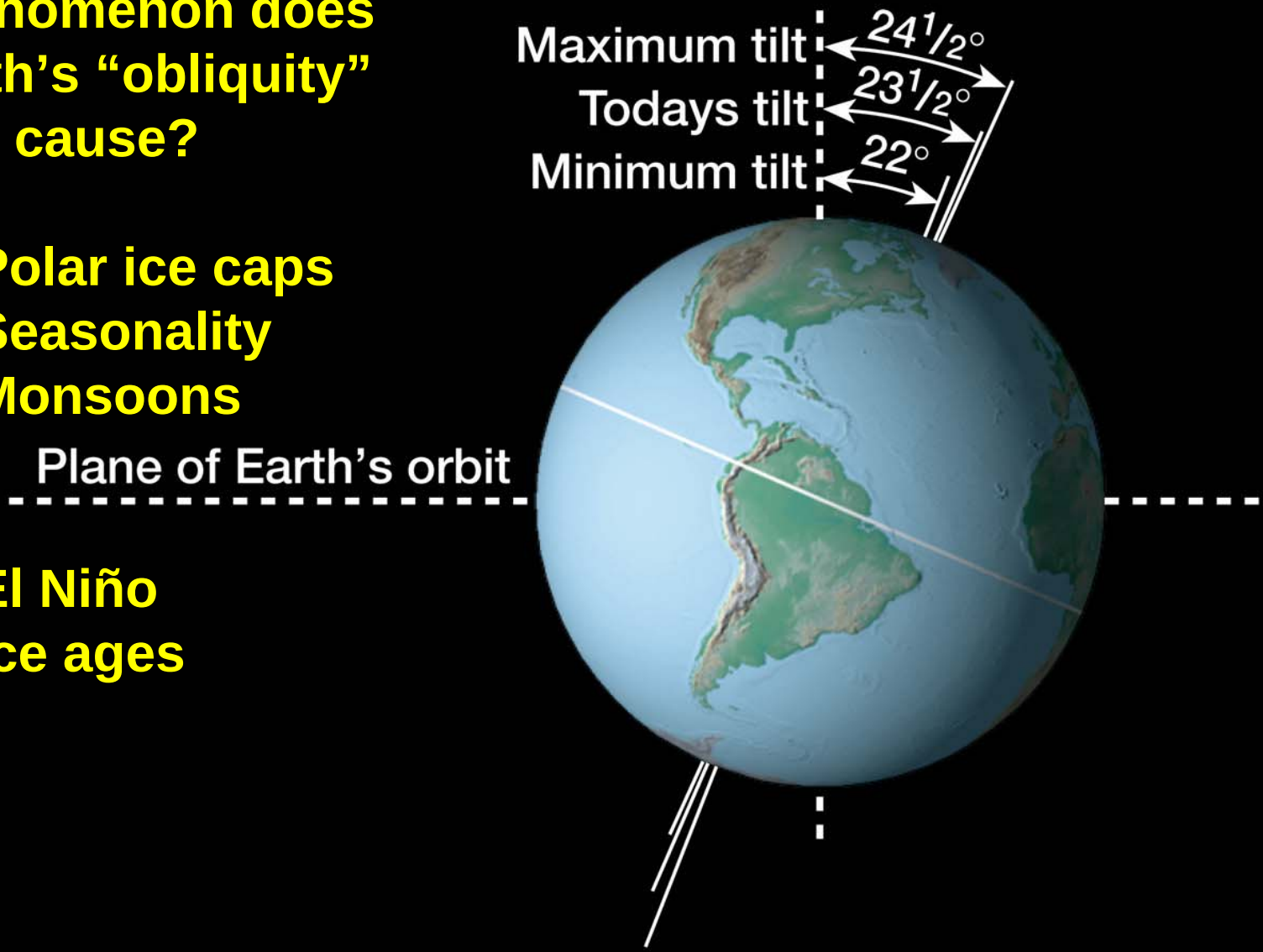




What happens to the impact debris?
What happens to Earth?

What familiar climate phenomenon does Earth's "obliquity" (tilt) cause?

A) Polar ice caps
B) Seasonality
C) Monsoons
D) El Niño
E) Ice ages





Seasonality results from Earth's obliquity

Phase II: Earth is molten planet

Rock is a good insulator – stores heat from…?

1. …
2. …
3. …
4. …

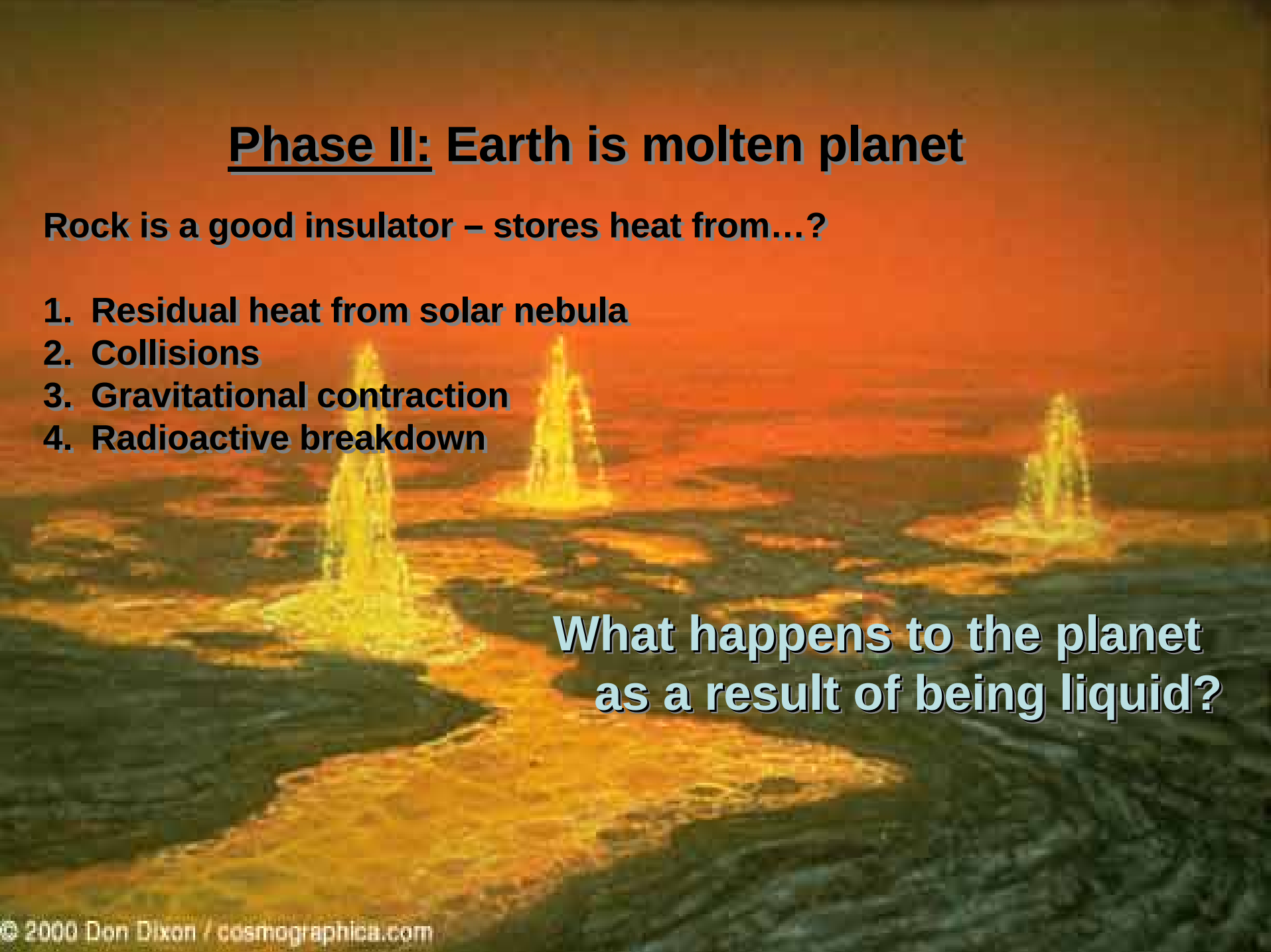


Phase II: Earth is molten planet

Rock is a good insulator – stores heat from…?

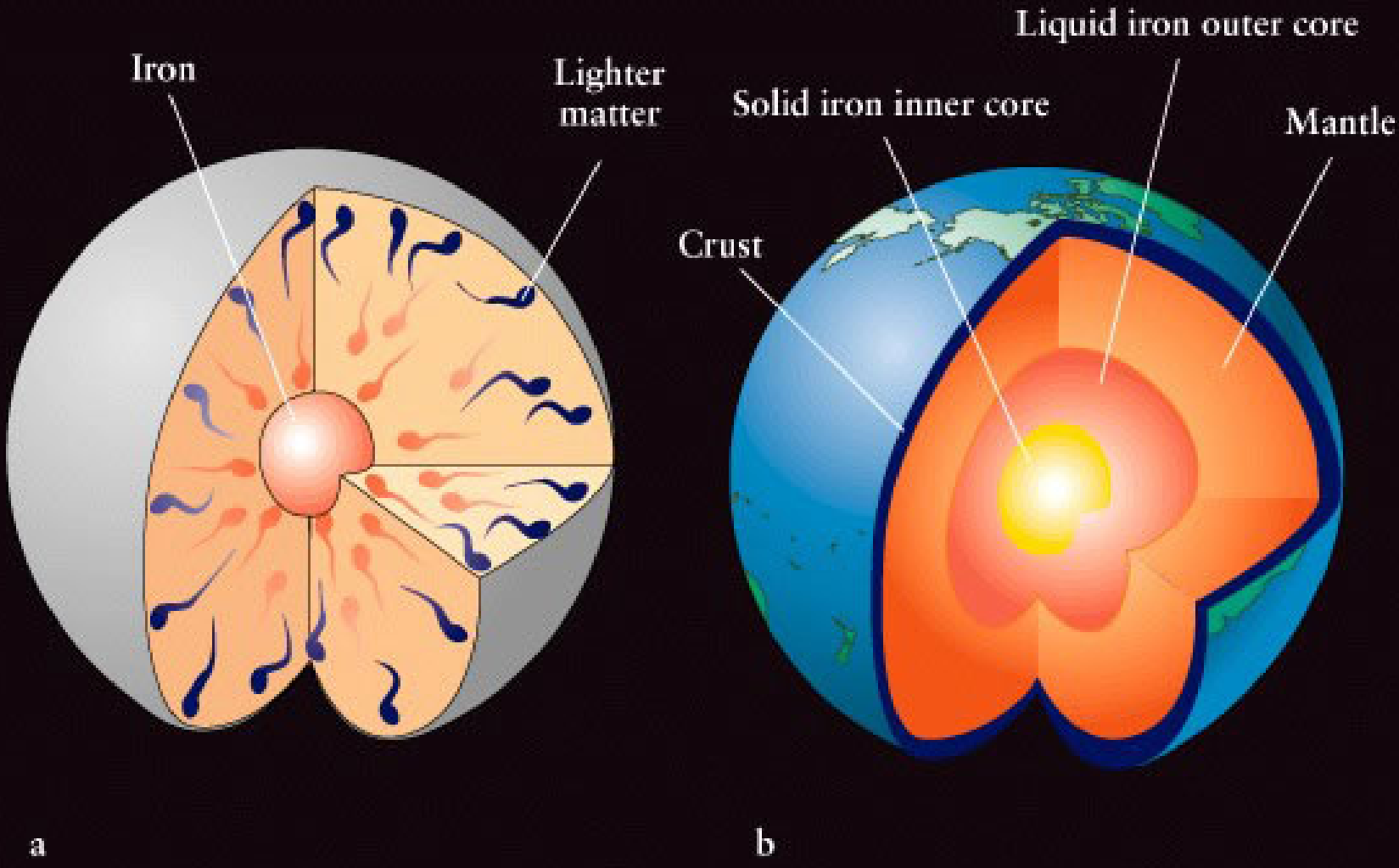
1. **Residual heat from solar nebula**
2. **Collisions**
3. **Gravitational contraction**
4. **Radioactive breakdown**

What happens to the planet as a result of being liquid?



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"Iron Catastrophe"



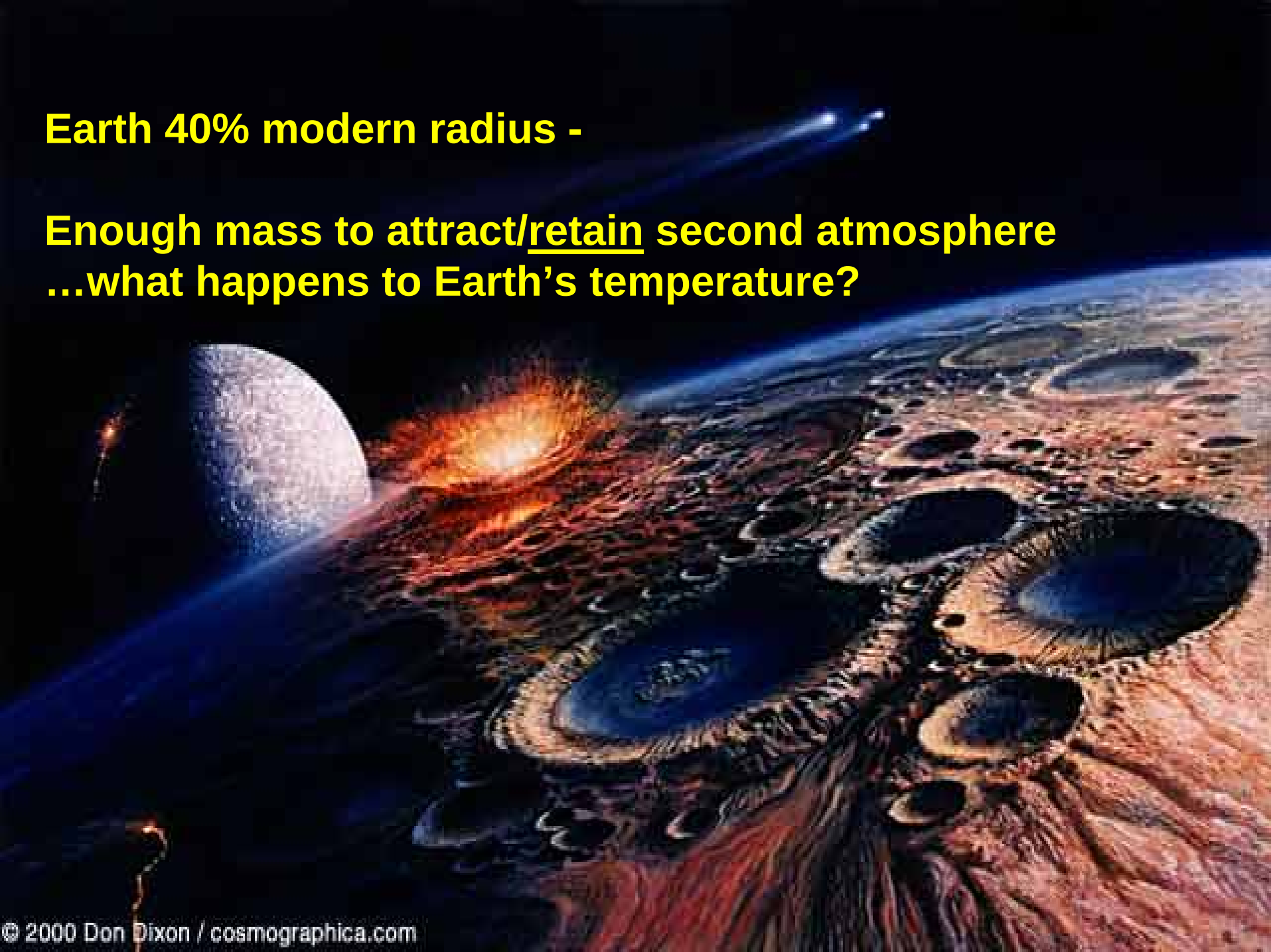
Density stratification: core → atmosphere


…but, Earth is still relatively small
so what happens to these
atmospheric gases…?


…Earth’s first atmosphere of H, He
blown away by solar wind
and Earth’s own heat.
nographica.com

Earth 40% modern radius -

Enough mass to attract/retain second atmosphere
…what happens to Earth's temperature?



Temperatures drop/stabilize…

…what happens to molten planet?




Outermost layer of molten planet begins to solidify
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