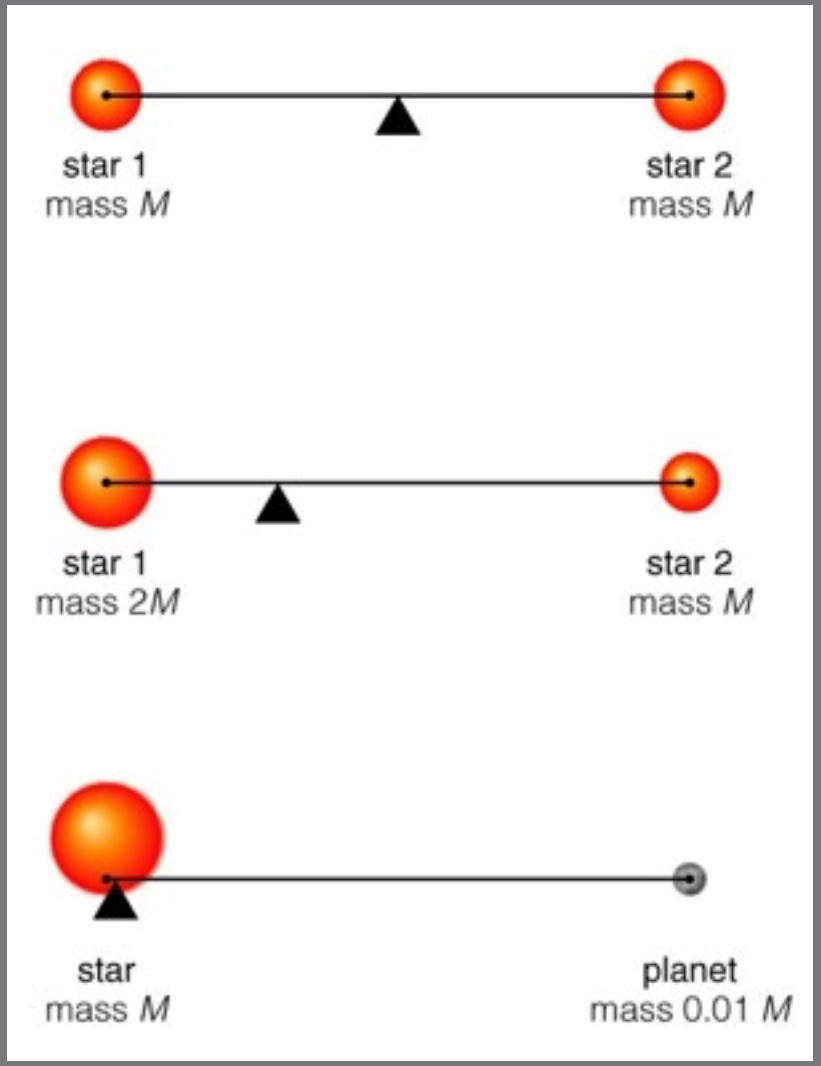
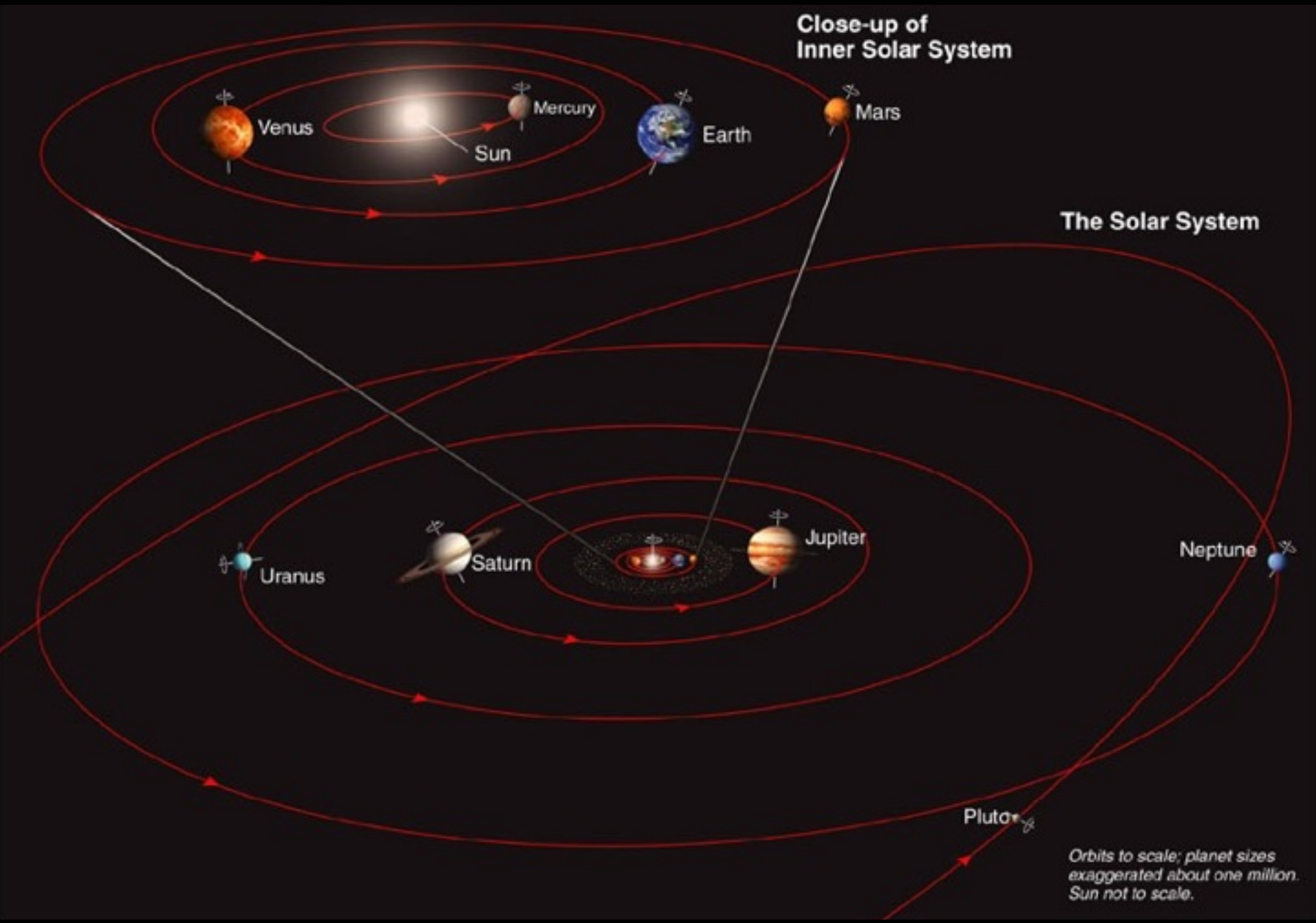
Our Solar System

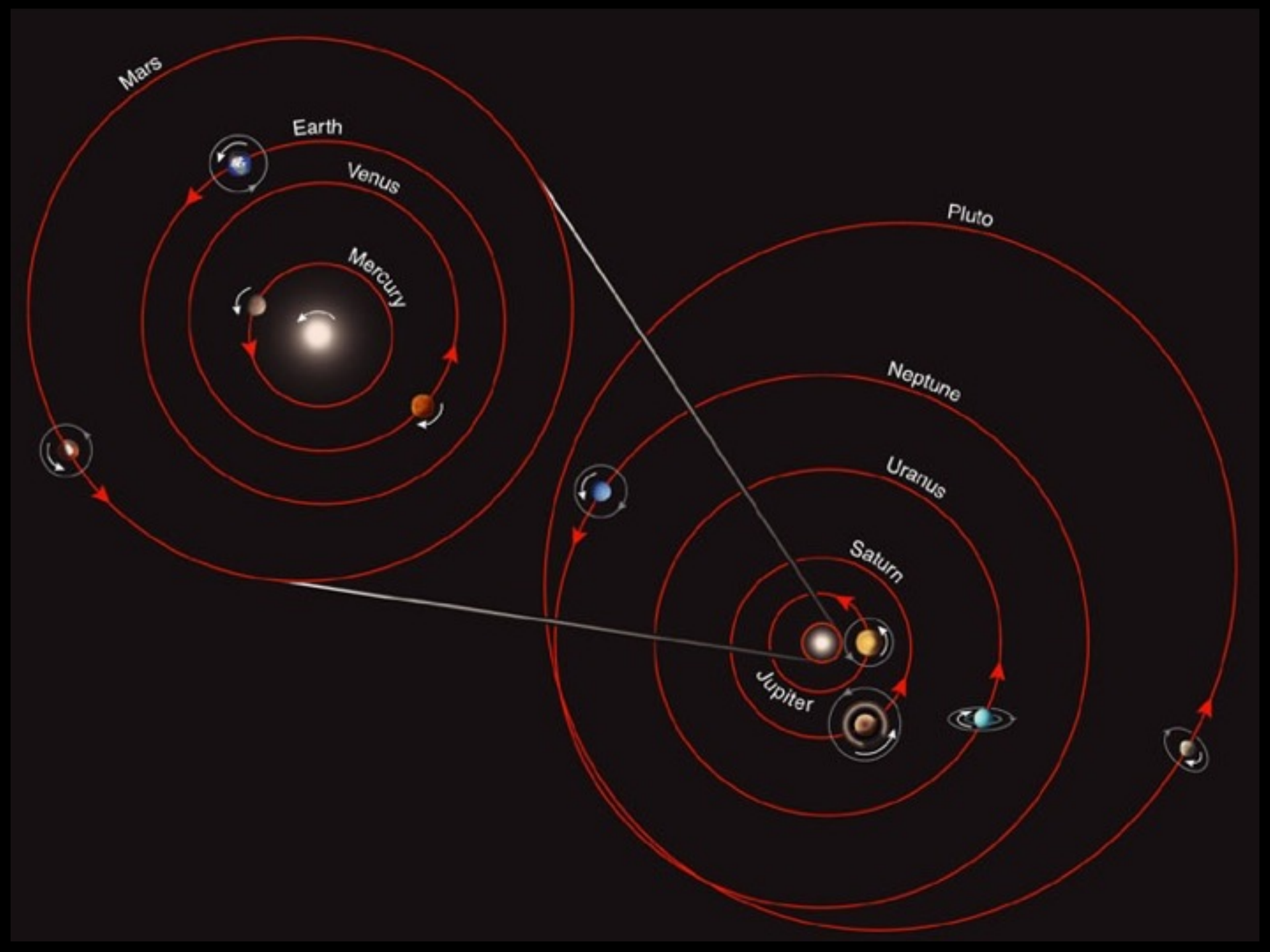
- Studying The Solar System
- What's in it?
  - Sun
  - Mercury
  - Venus
  - Earth
  - Mars
  - Jupiter
  - Saturn
  - Uranus
  - Neptune
  - Pluto and The Kuiper Belt
  - The Oort Cloud
- How do we know how big it is?
- Space Exploration

Objects Orbit The "Center of Mass"



- Because of momentum conservation, objects orbit around the center of mass of the system


Close-up of
Inner Solar System
Venus
Mercury
Sun
Earth
Mars
The Solar System
Uranus
Saturn
Jupiter
Neptune
Pluto
Orbits to scale; planet sizes
exaggerated about one million.
Sun not to scale.


Mars
Earth
Venus
Mercury
Pluto
Neptune
Uranus
Saturn
Jupiter

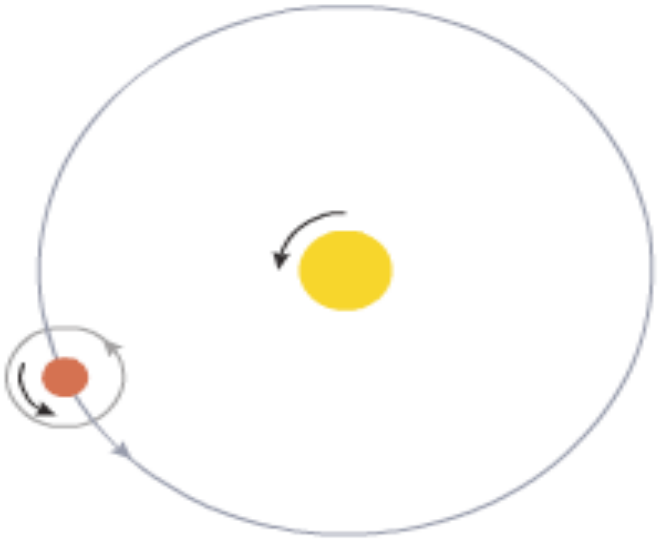
Four Patterns in the Solar System

1. Orderly motions
2. Two kinds of planets
3. Two kinds of small bodies
4. Exceptions to the rules

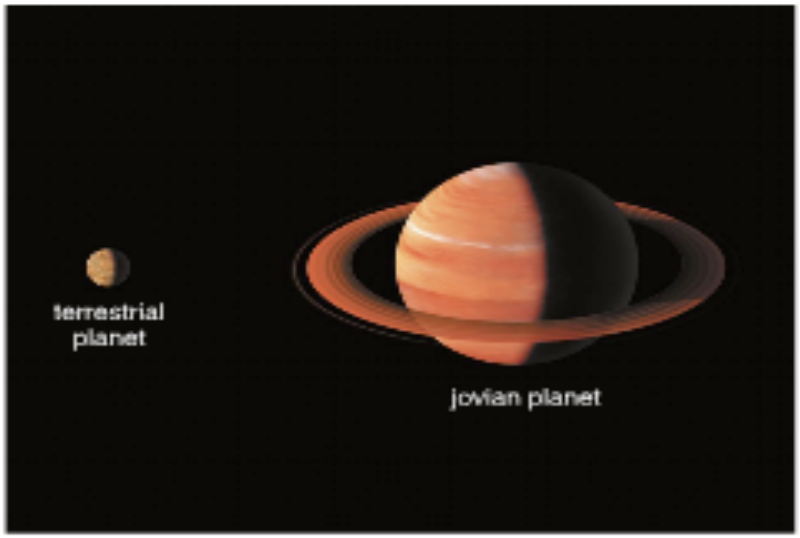
Patterns in the Solar System

Orderly Motions

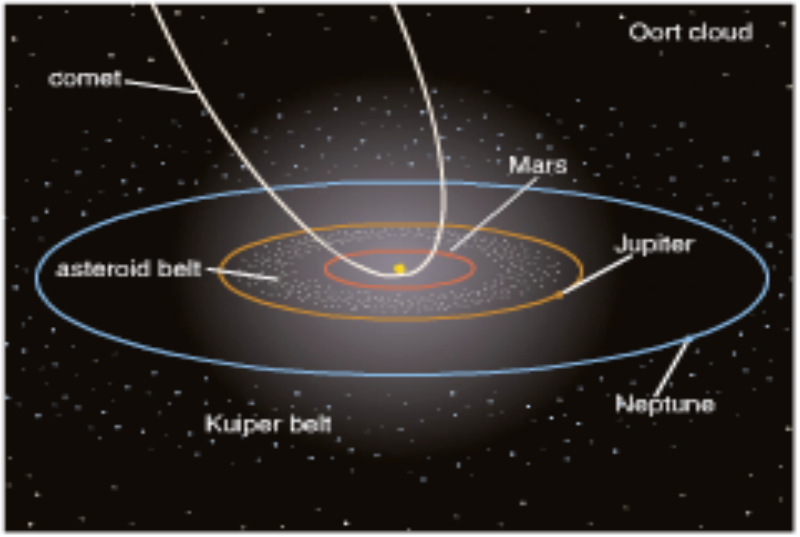
- Almost every body orbits & spins in the same direction.
  - Counterclockwise from above
- Planetary orbits nearly circular, lie in nearly the same plane.
  - Large moons tend to exhibit the same properties.



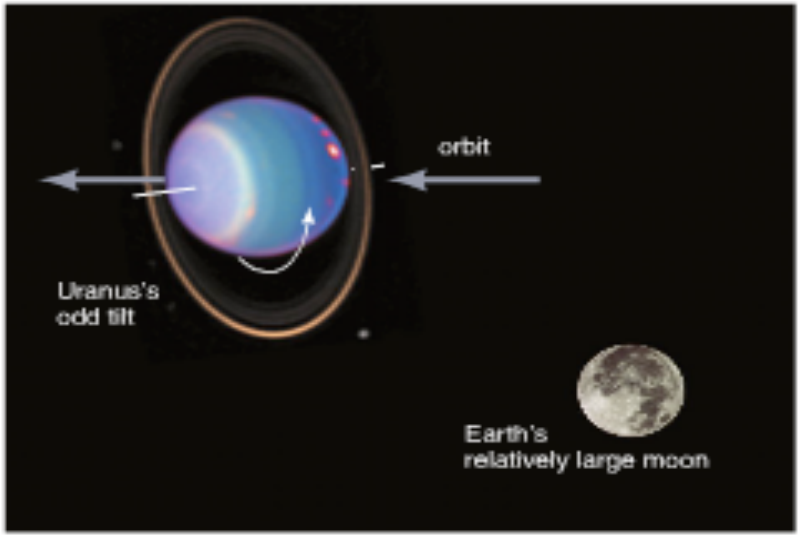
1. Large bodies in the solar system have orderly motions. All planets and most satellites have nearly circular orbits going in the same direction in nearly the same plane. The Sun and most of the planets rotate in this same direction as well.



2. The first eight planets fall into two major categories: small, rocky terrestrial planets near the Sun and large, hydrogen-rich jovian planets farther out. The jovian planets have many moons and rings made of rock and ice.



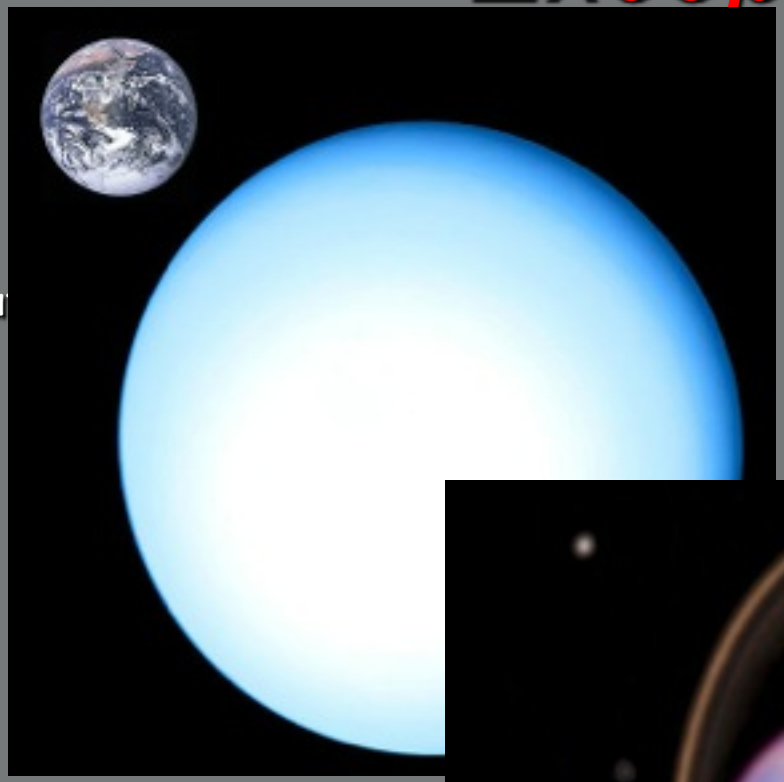
3. Swarms of asteroids and comets populate the solar system. Asteroids are concentrated in the asteroid belt, and comets populate the regions known as the Kuiper belt and the Oort cloud.

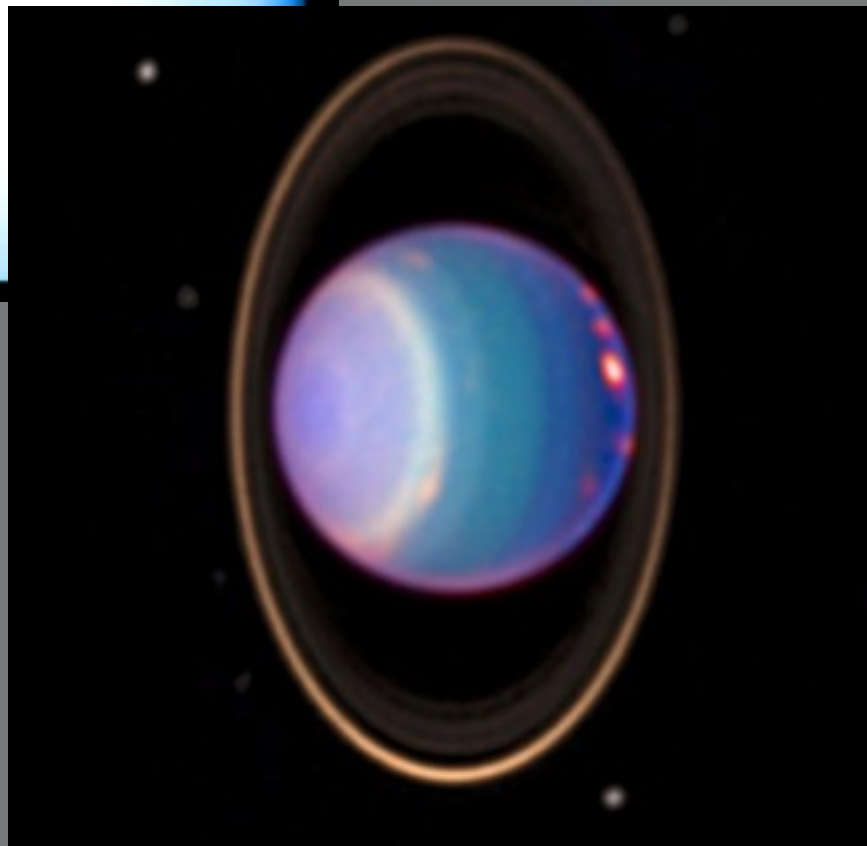


4. Several notable exceptions to these general trends stand out, such as planets with unusual axis tilts or surprisingly large moons, and moons with unusual orbits.

Exceptions

- Uranus rotates on its side
- Venus Rotates backwards
- Questions
  - What does this say about the seasons on these planets?
  - Venus may have been whacked by something, how did Uranus get this way?





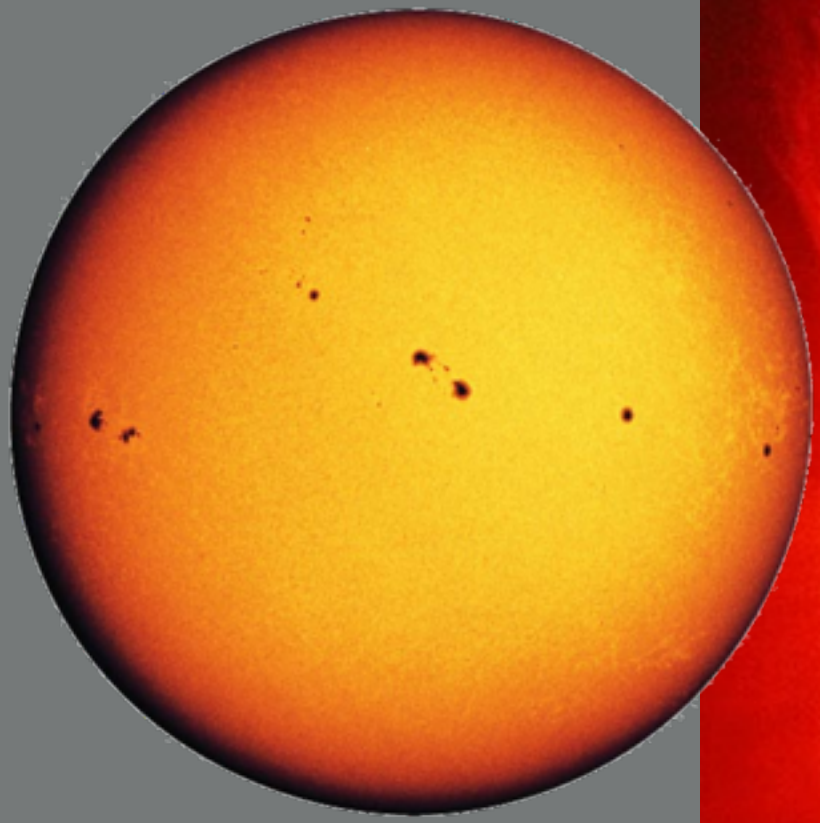
Comparative Planetology

- We can learn more about a world like our Earth by studying it in context with other worlds in the solar system.
- Stay focused on processes and trends common to multiple worlds instead of individual facts specific to a particular world.

1. Large bodies in the solar system have orderly motions
2. Planets fall into two (three?) main categories
3. Swarms of asteroids and comets populate the rest of the solar system
4. Several notable exceptions to these general trends stand out

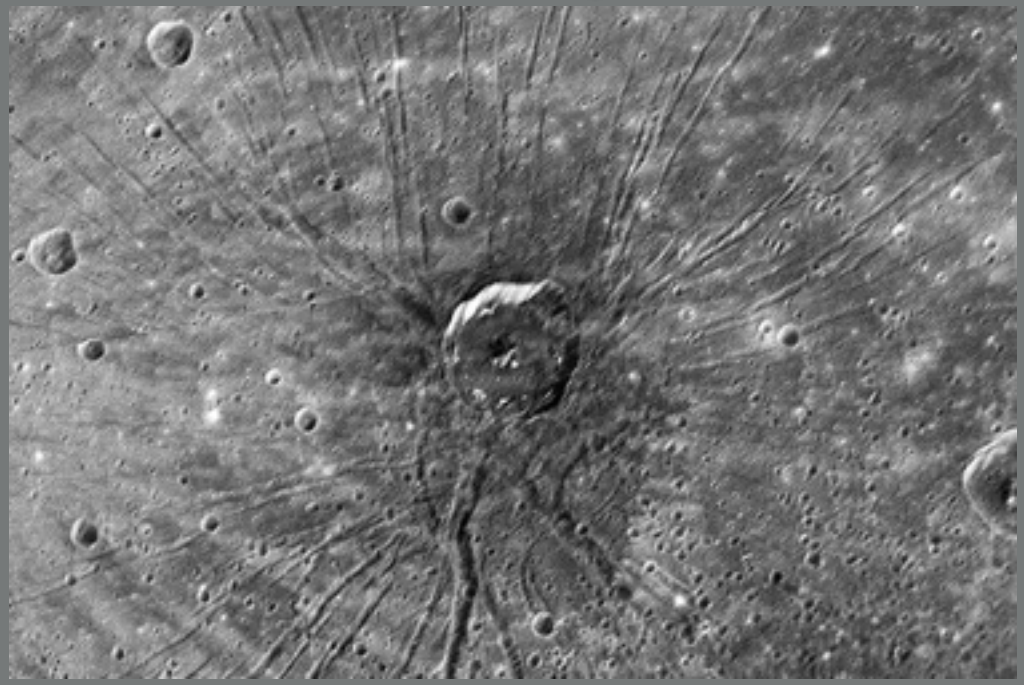
These are all facts we need to explain!

Sun



- Over 99.9% of solar system's mass
- Made mostly of H/He plasma
  - Trace amounts of other elements

Mercury

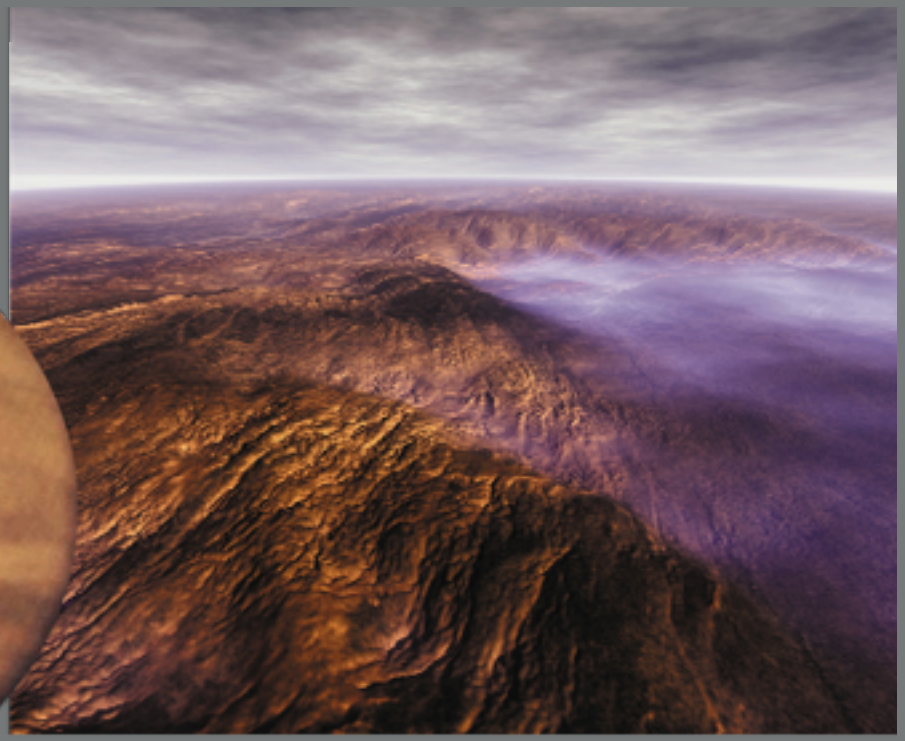


- Made of metal and rock; large iron core
- Desolate, cratered; long, tall, steep cliffs
- Rotates three times for every two orbits

(resonance, like pushing someone on swing)

- Very hot and very cold: 425°C (day), –170°C (night)

Venus



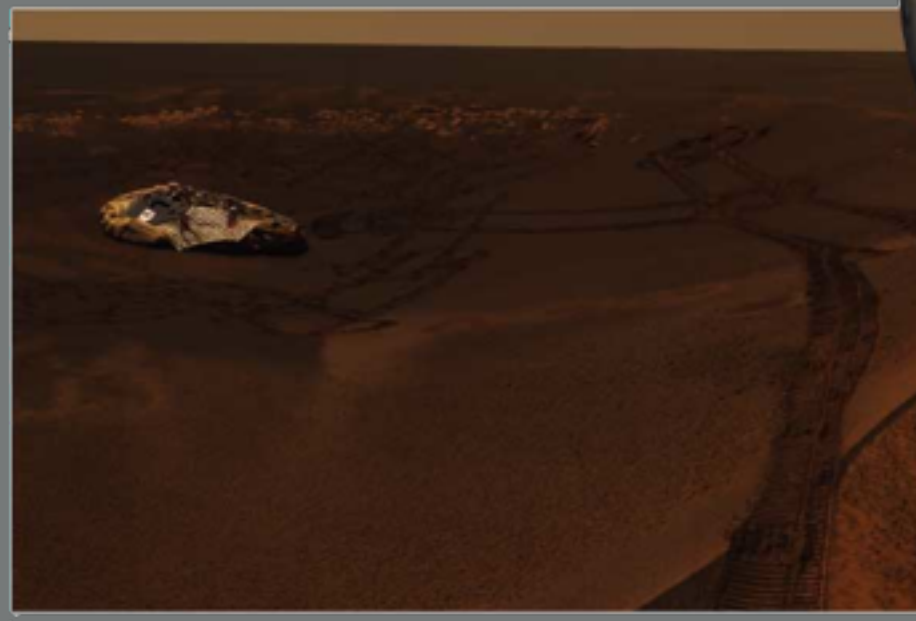
- Nearly identical in size to Earth; surface hidden by clouds
  - Hard to observe until invention of radar
- Spins backwards (clockwise from above)
- Hellish conditions due to an extreme **greenhouse effect**
  - Even hotter than Mercury: 470°C, day and night

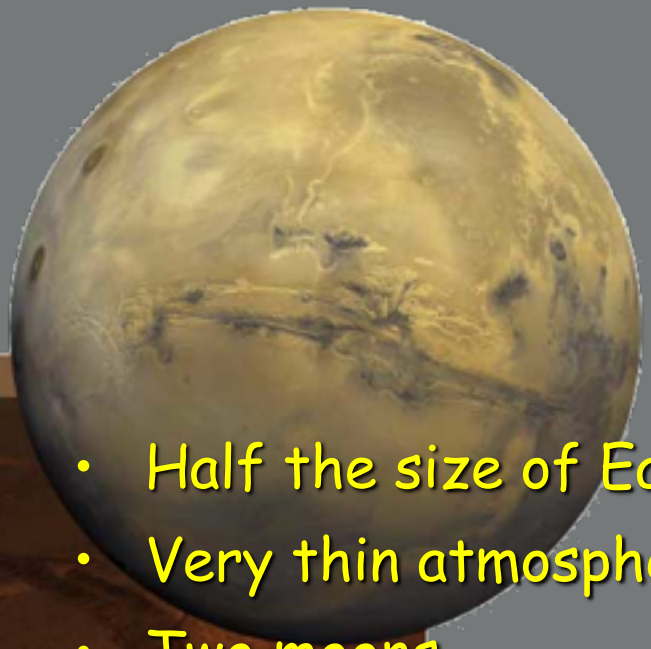
Earth

Earth and Moon to scale (size only, not distance)

- The only surface liquid water in the solar system
- An oasis of life (only life that we know of)
- A surprisingly large moon

Mars

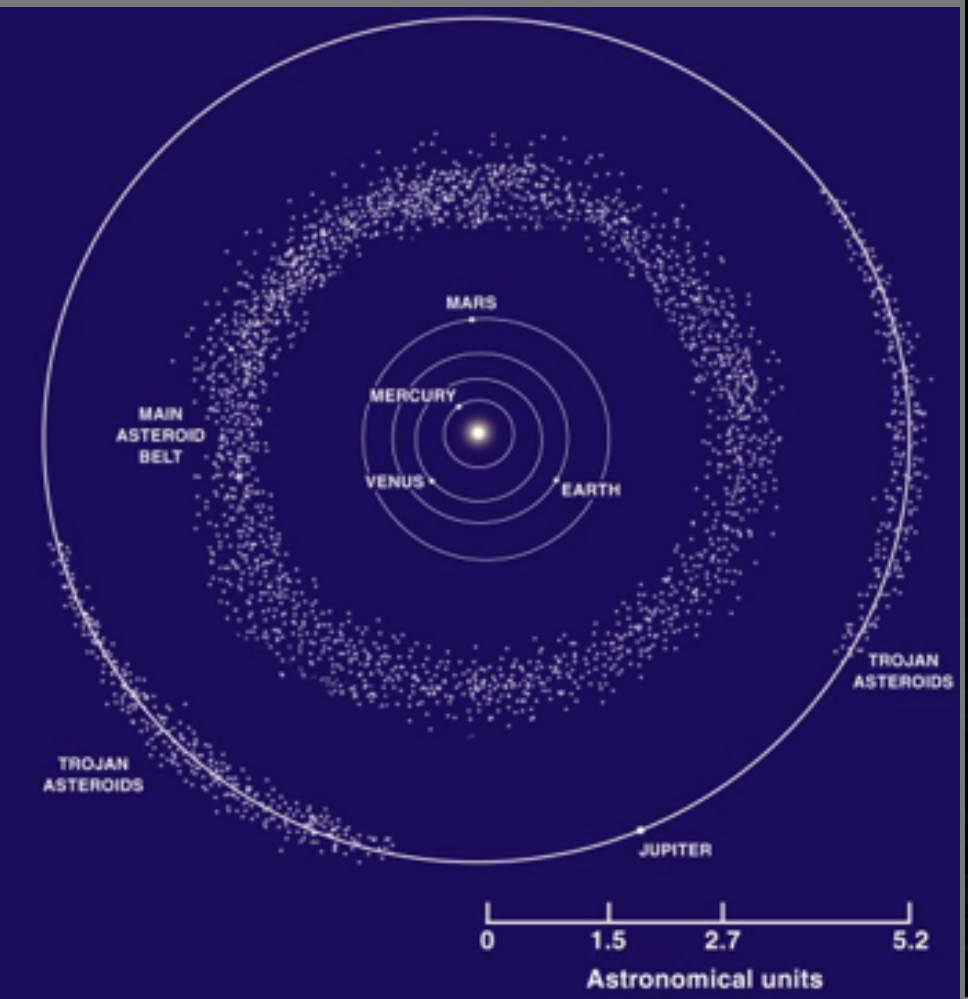


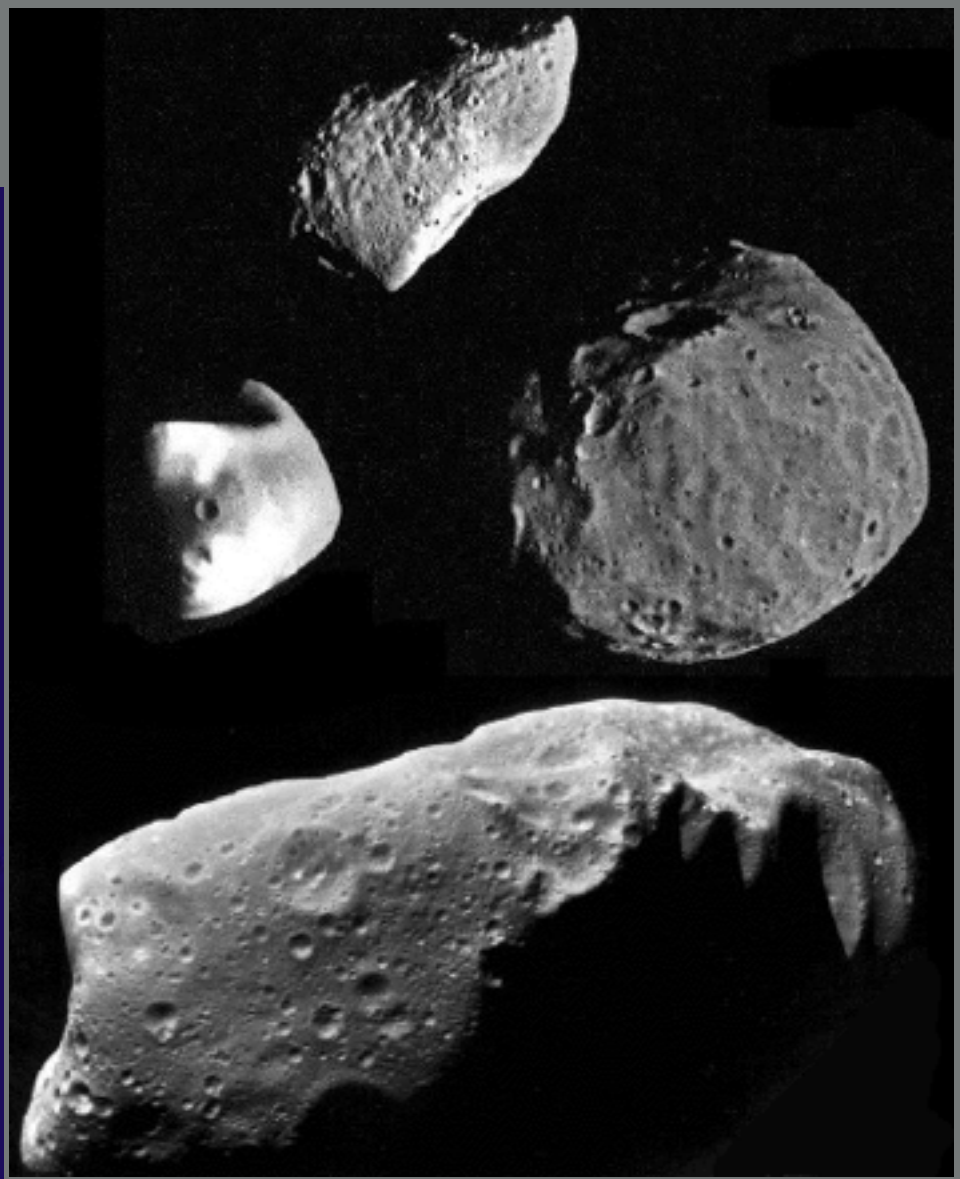


- Half the size of Earth
- Very thin atmosphere
- Two moons
  - Captured asteroids?
- Polar caps, river valleys
  - Once had liquid water
    - Life??
- Most-studied planet
  - 5 current missions!

Asteroid Belt

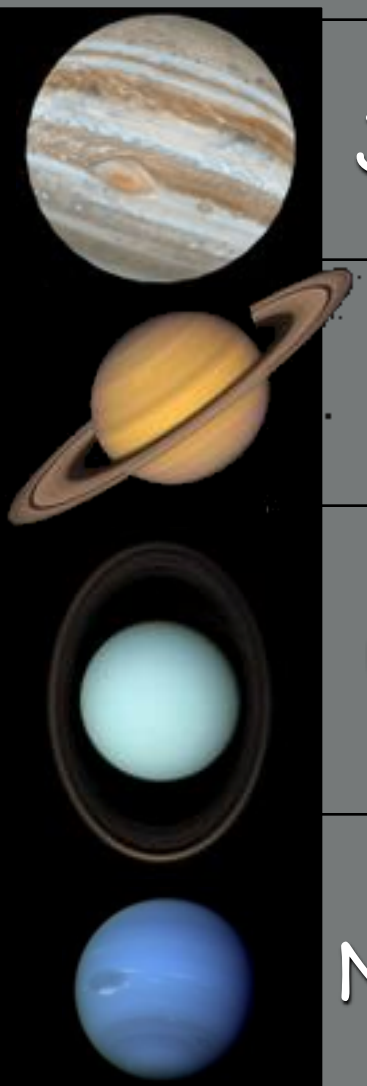
- A failed planet?
  - Bullied around by Jupiter





Jovian Planets

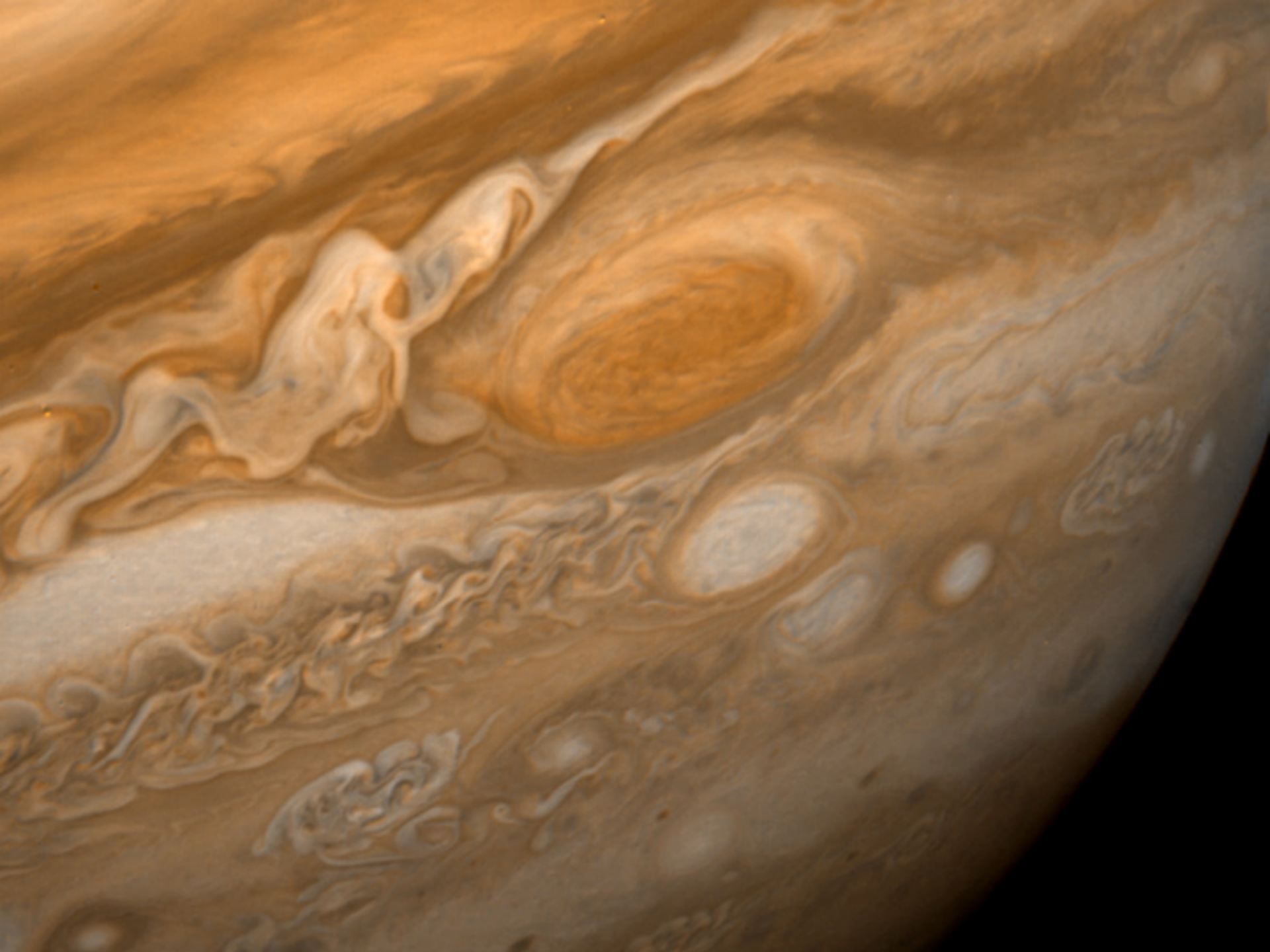
DON'T COPY!!

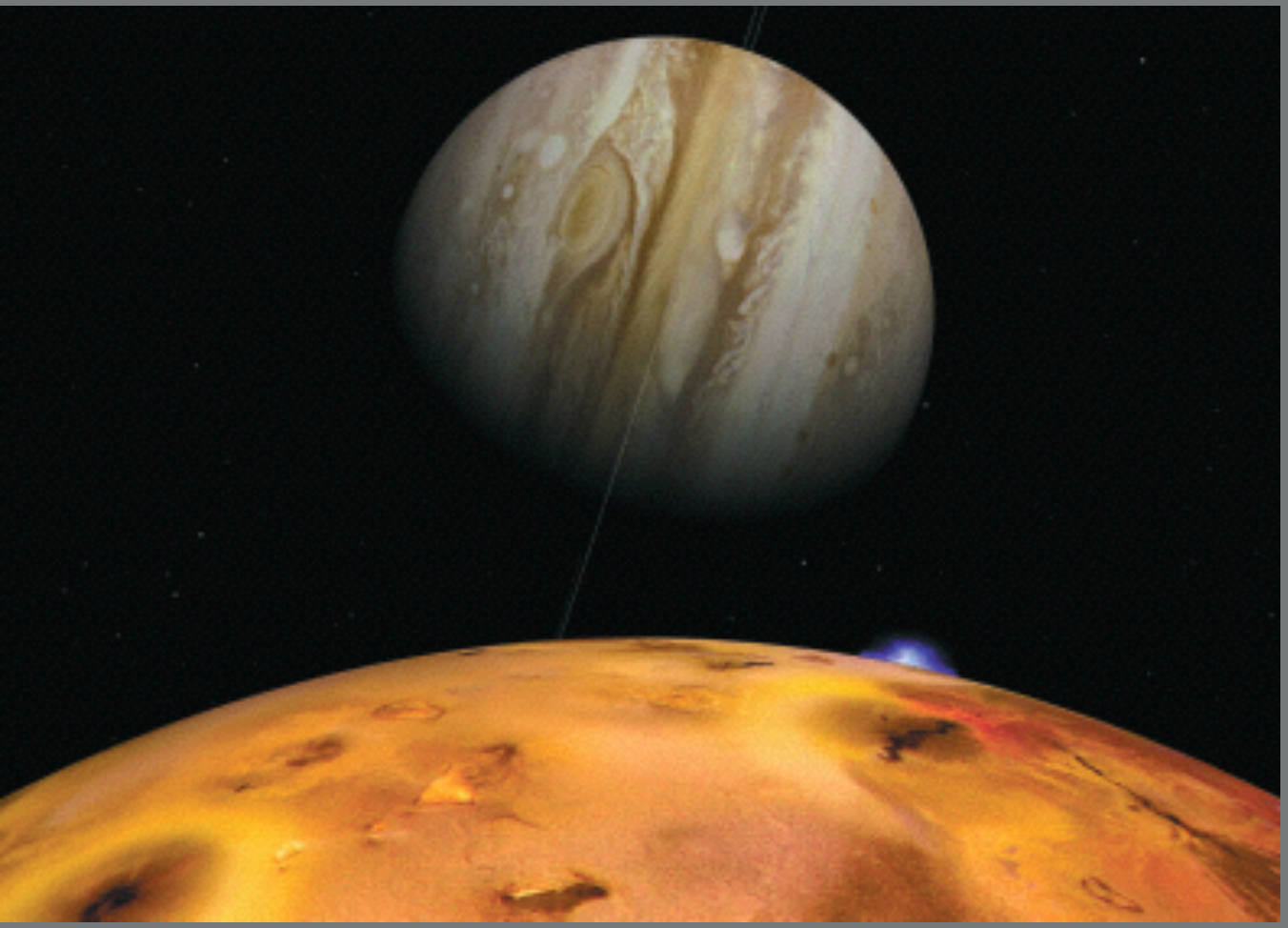


	Distance AU	Mass Earth	Radius Earth	Density g/cm (1=water)	Composition (primarily)
Jupiter	5.20	318	11.2	1.33	H, He
Saturn	9.54	95	9.46	0.71	H, He
Uranus	19.2	14	3.98	1.24	H,He W A M
Neptune	30.1	17	3.81	1.67	H,He W A M

Jupiter

- Much farther from Sun than inner planets
- Mostly H/He; no solid surface
- 300 times more massive than Earth
- Many moons, AND rings …



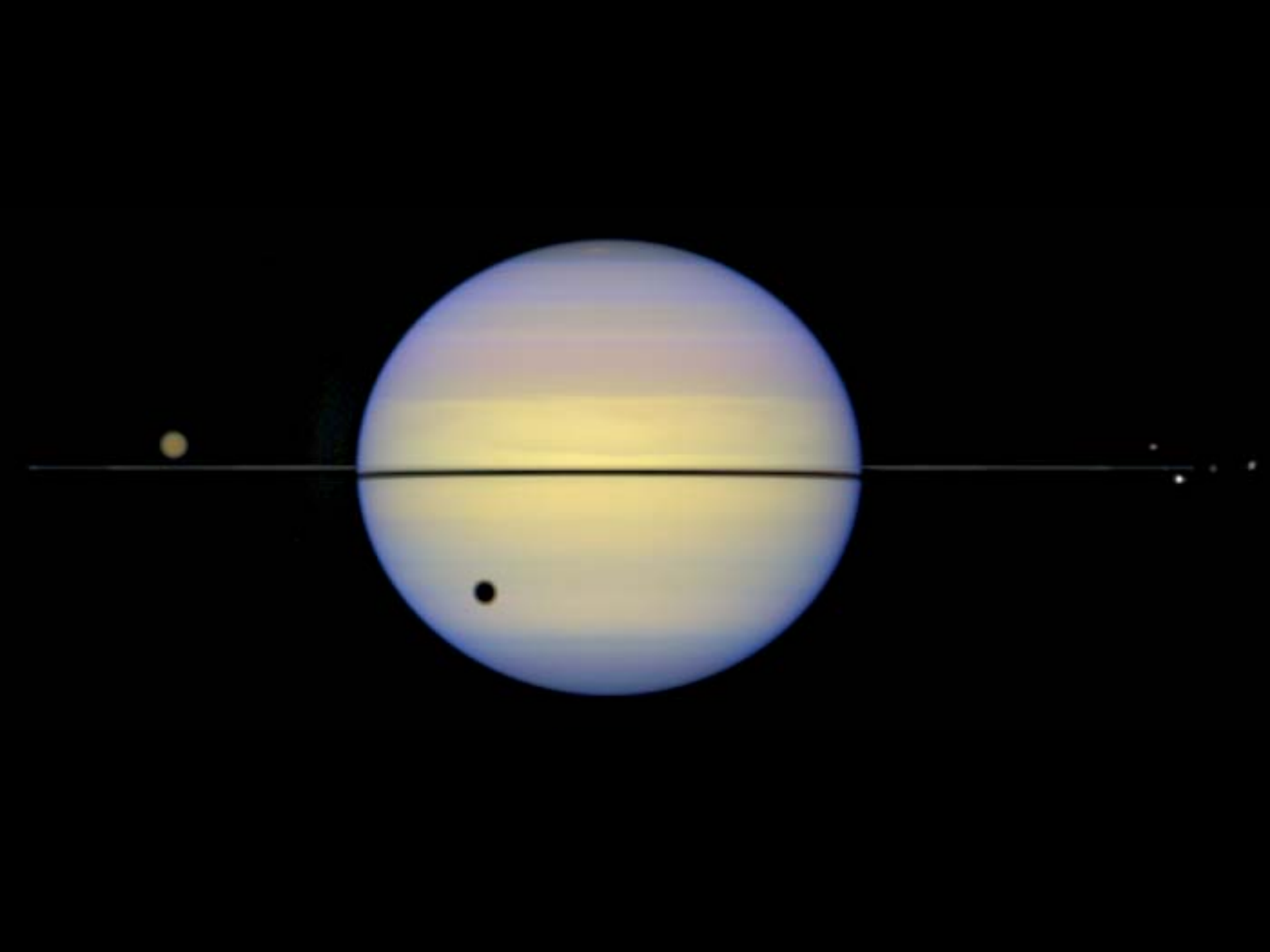


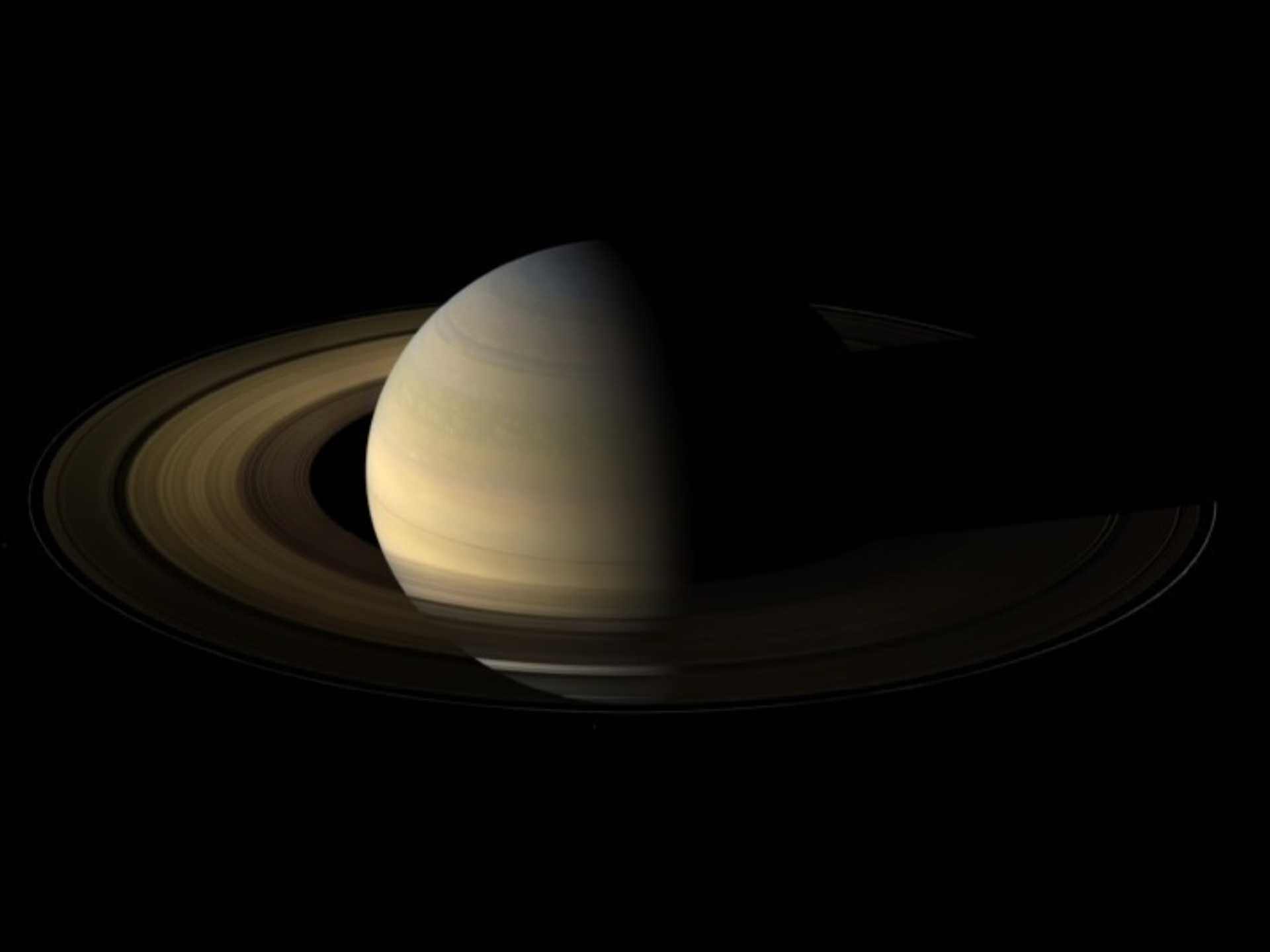
Jupiter's moons can be as interesting as planets themselves, especially Jupiter's four Galilean moons

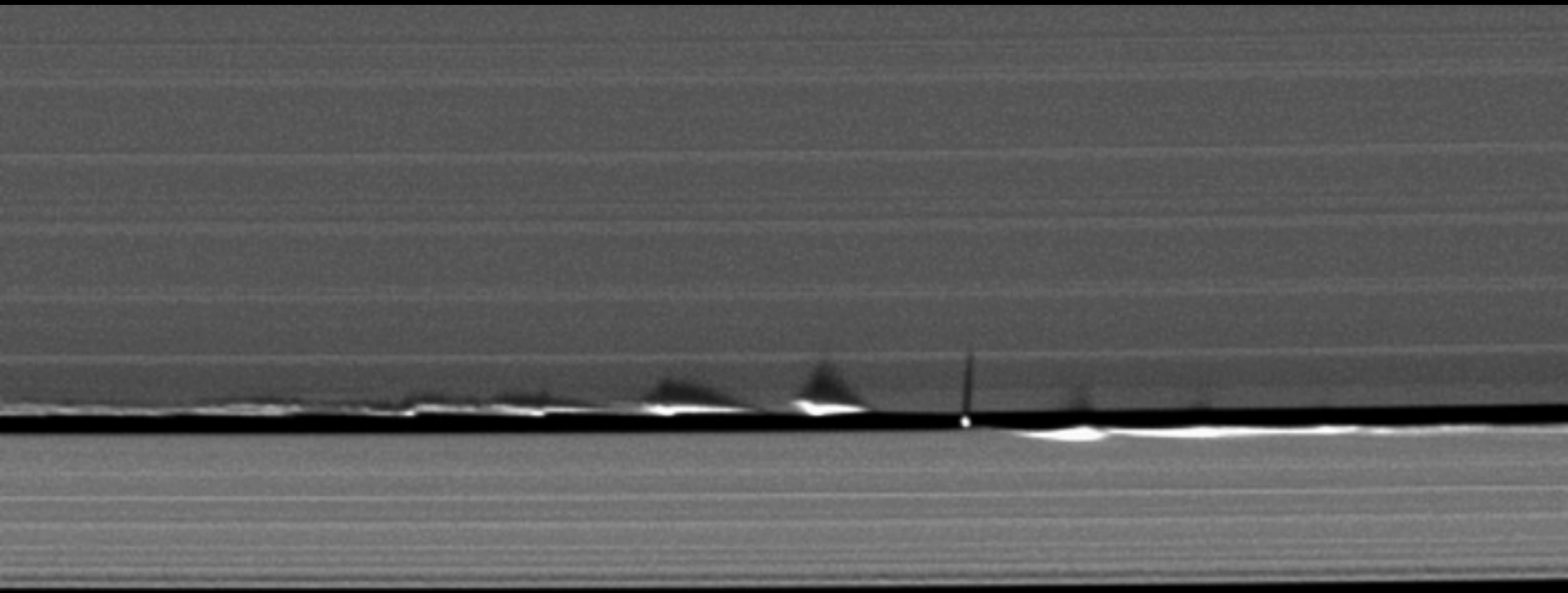
- Io (shown here): Active volcanoes all over
- Europa: Possible subsurface ocean
- Ganymede: Largest moon in solar system
- Callisto: A large, cratered "ice ball"

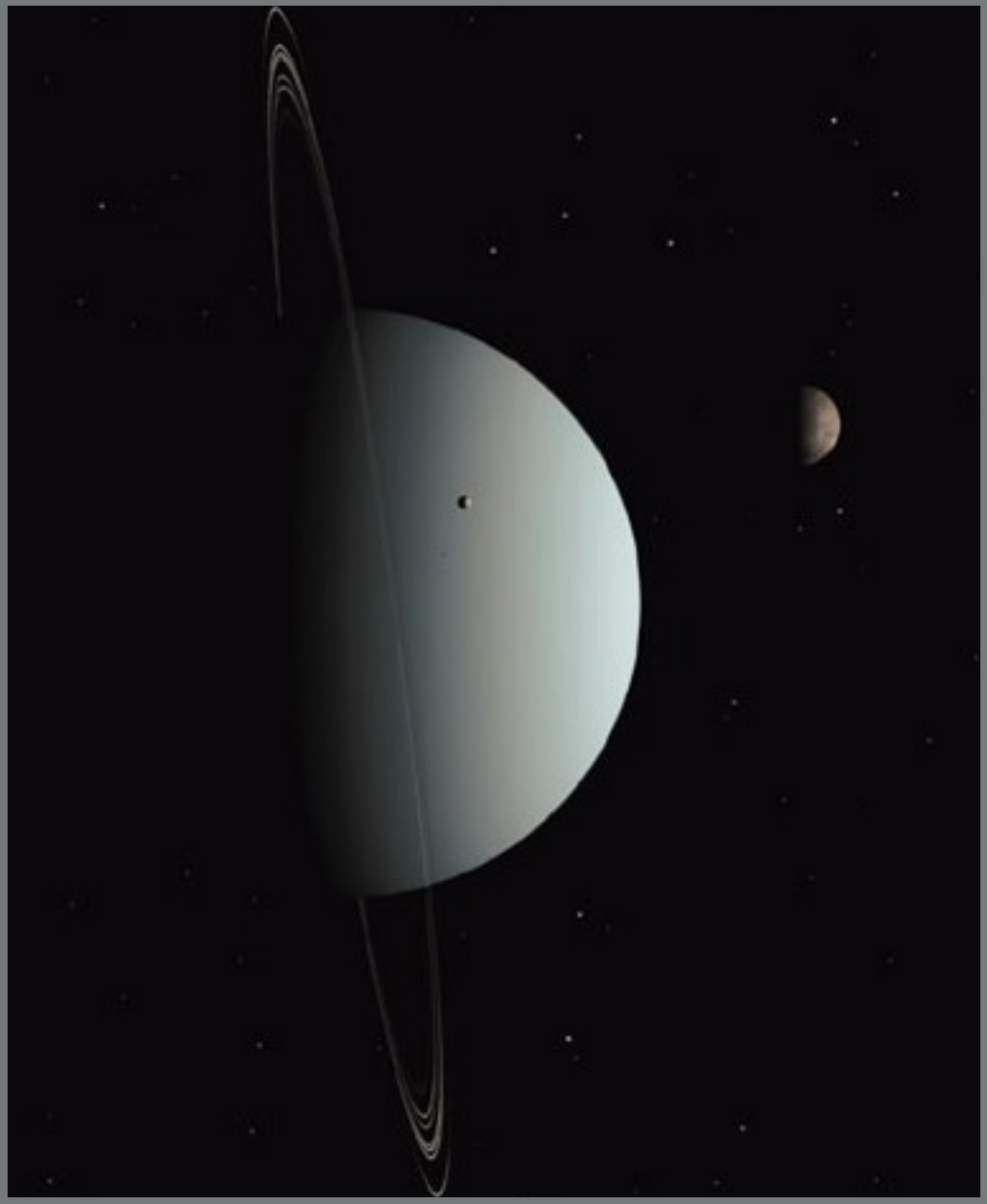
Saturn

- Giant and gaseous like Jupiter
- Spectacular rings
- Most moons in the Solar System
  - Including cloudy Titan (only moon with an atmosphere)
- Cassini spacecraft currently studying it



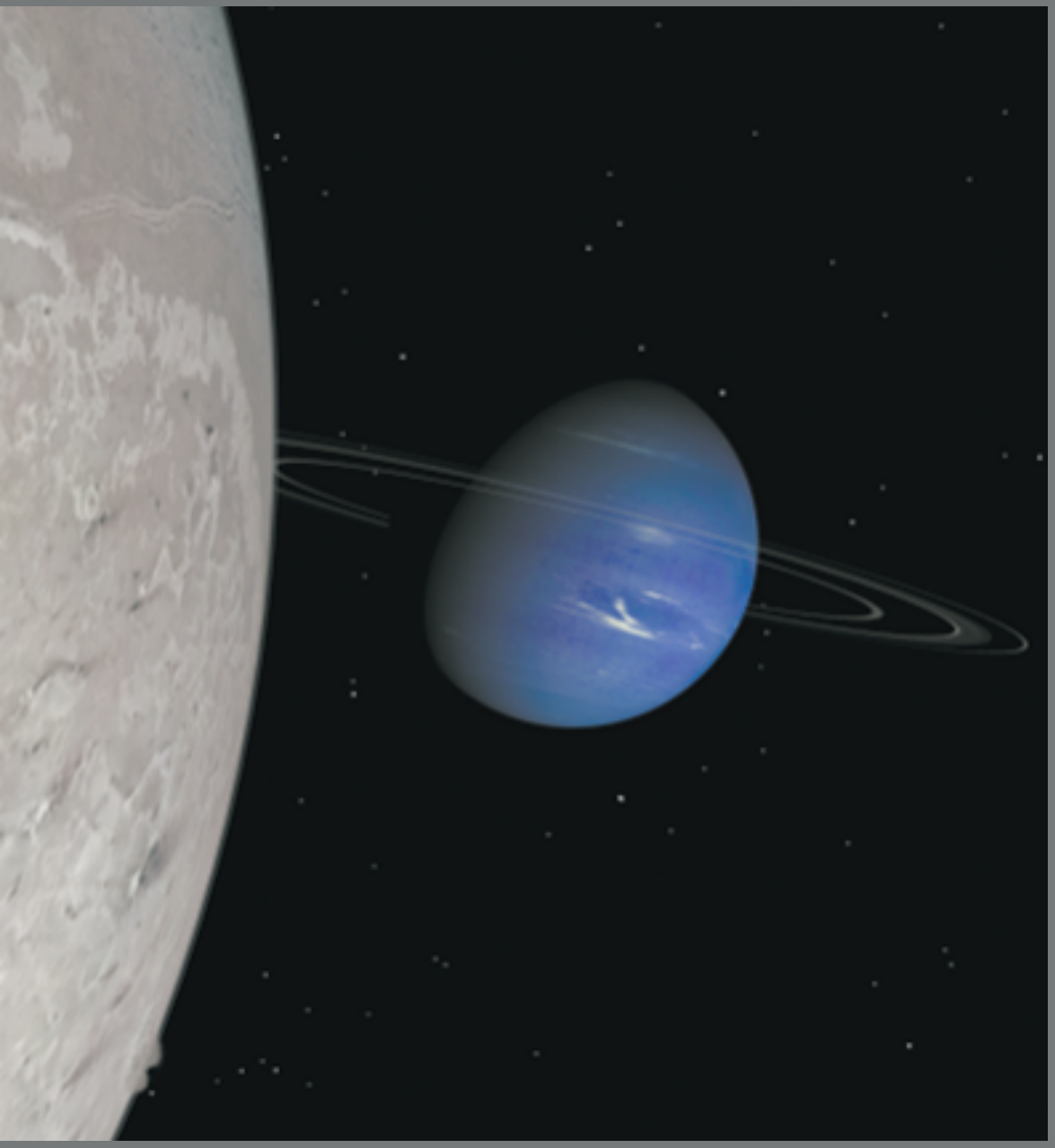






Uranus

- Smaller than Jupiter/Saturn; much larger than Earth
- Made of H/He gas & hydrogen compounds (H_2O, NH_3, CH_4)
- Extreme axis tilt
- Moons & rings



Neptune

- Similar to Uranus (except for axis tilt)
- Many moons (including Triton)

Thought Question

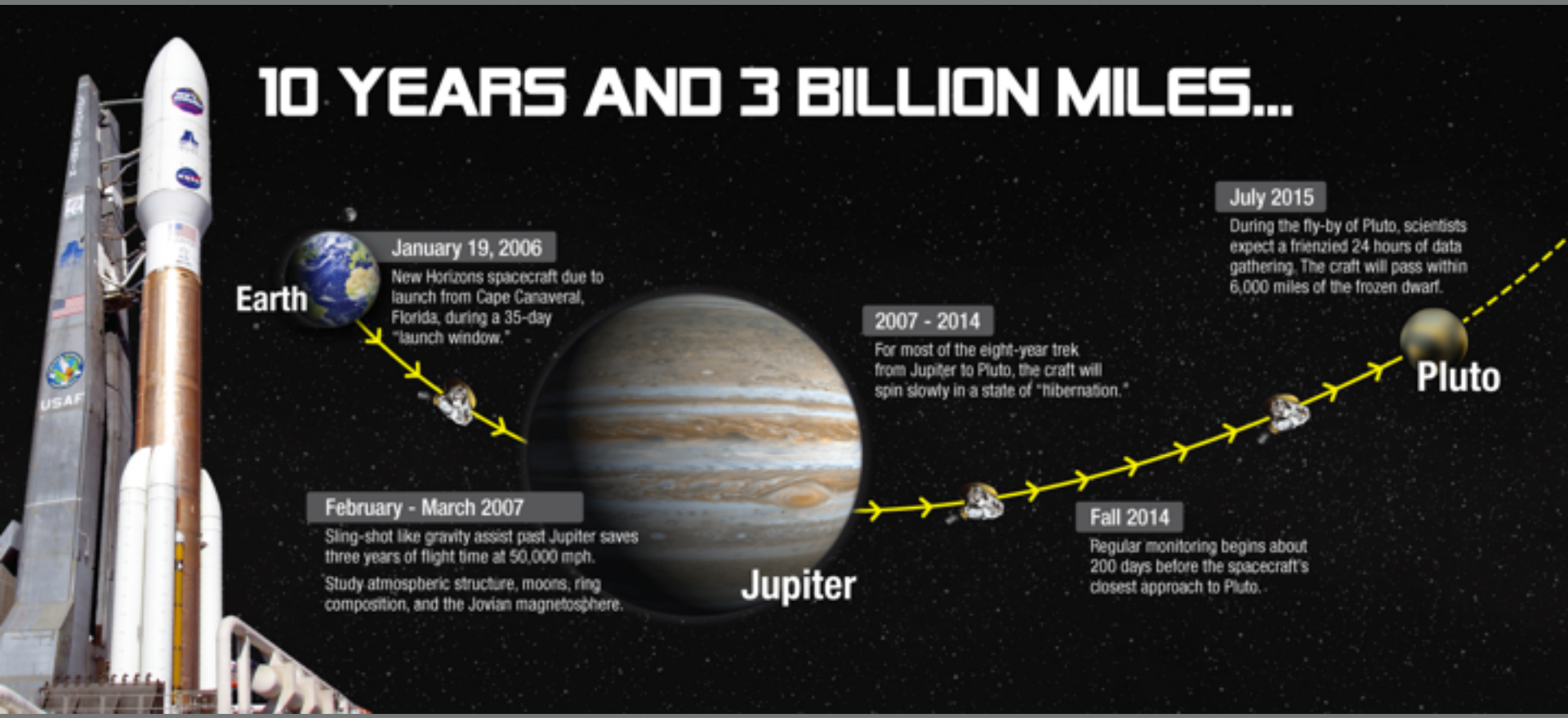
HOW can we know the masses of planets?

A. Measure the orbital period & distance of the planet from the Sun
B. Measure acceleration of an object falling on the planet
C. Measure the orbital period & distance of a moon
D. Measure their size, use density of Earth to get mass.
E. Measure the orbital period & distance of a spacecraft orbiting around them

Pluto (R.I.P)

- Much smaller than other planets
- Icy, comet-like composition
- Its moon Charon is similar in size
- Astronomers using HST recently (2007) found two other moons

New Horizons




Before
After

Survey Question

In YOUR opinion, should Pluto have remained a classical planet?

A. Yes

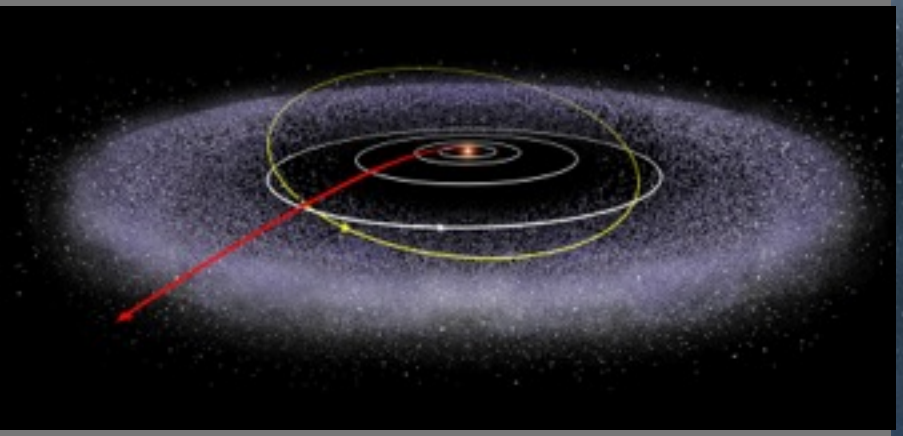
B. No

Survey Question

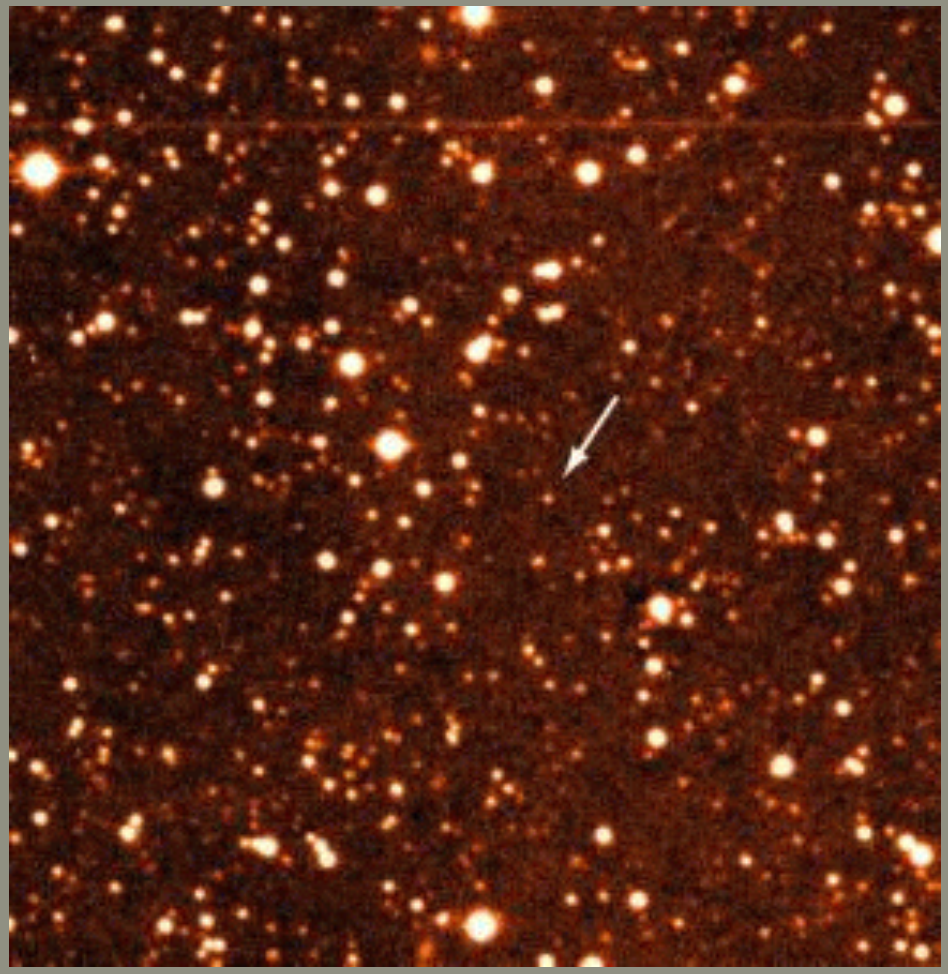
What was the main reason Pluto was declassified?

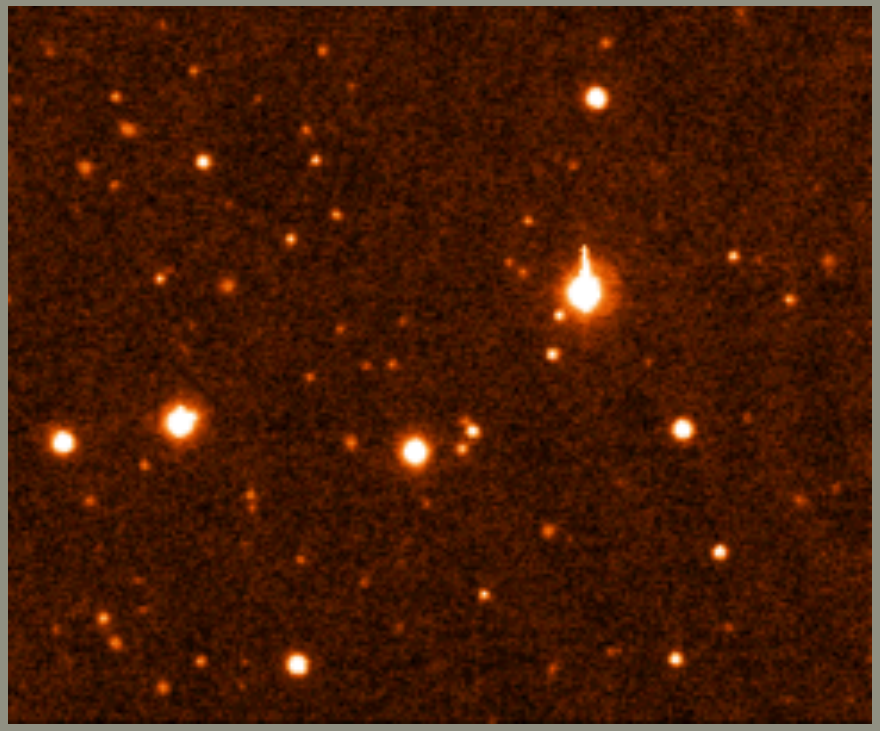
A. It is too small
B. It is too far out in the SS
C. It is made of different materials than the rest of the planets
D. Its orbit is tilted

Pluto is just one of thousands of objects in *The Kuiper Belt*



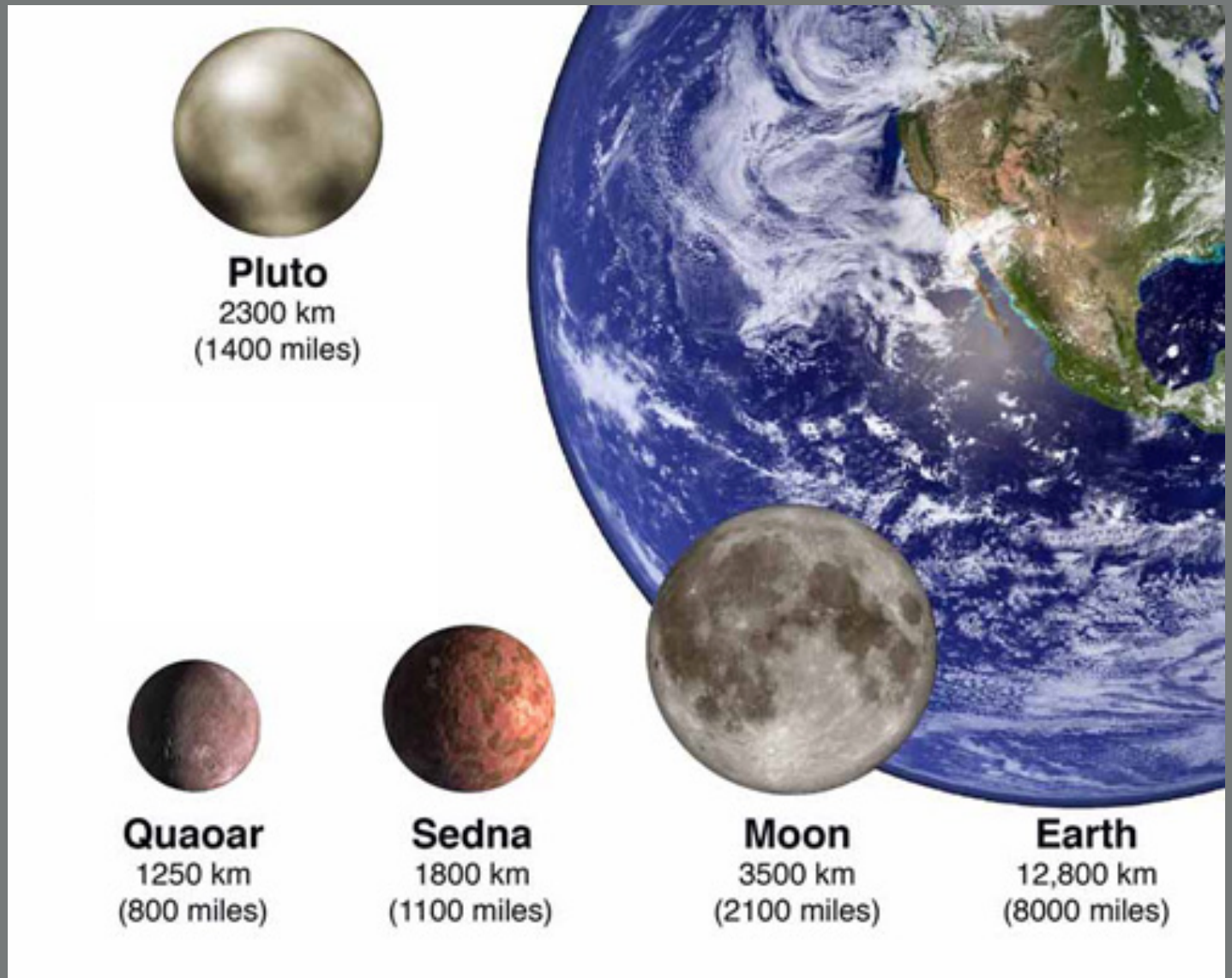
Kuiper Belt Object Detection



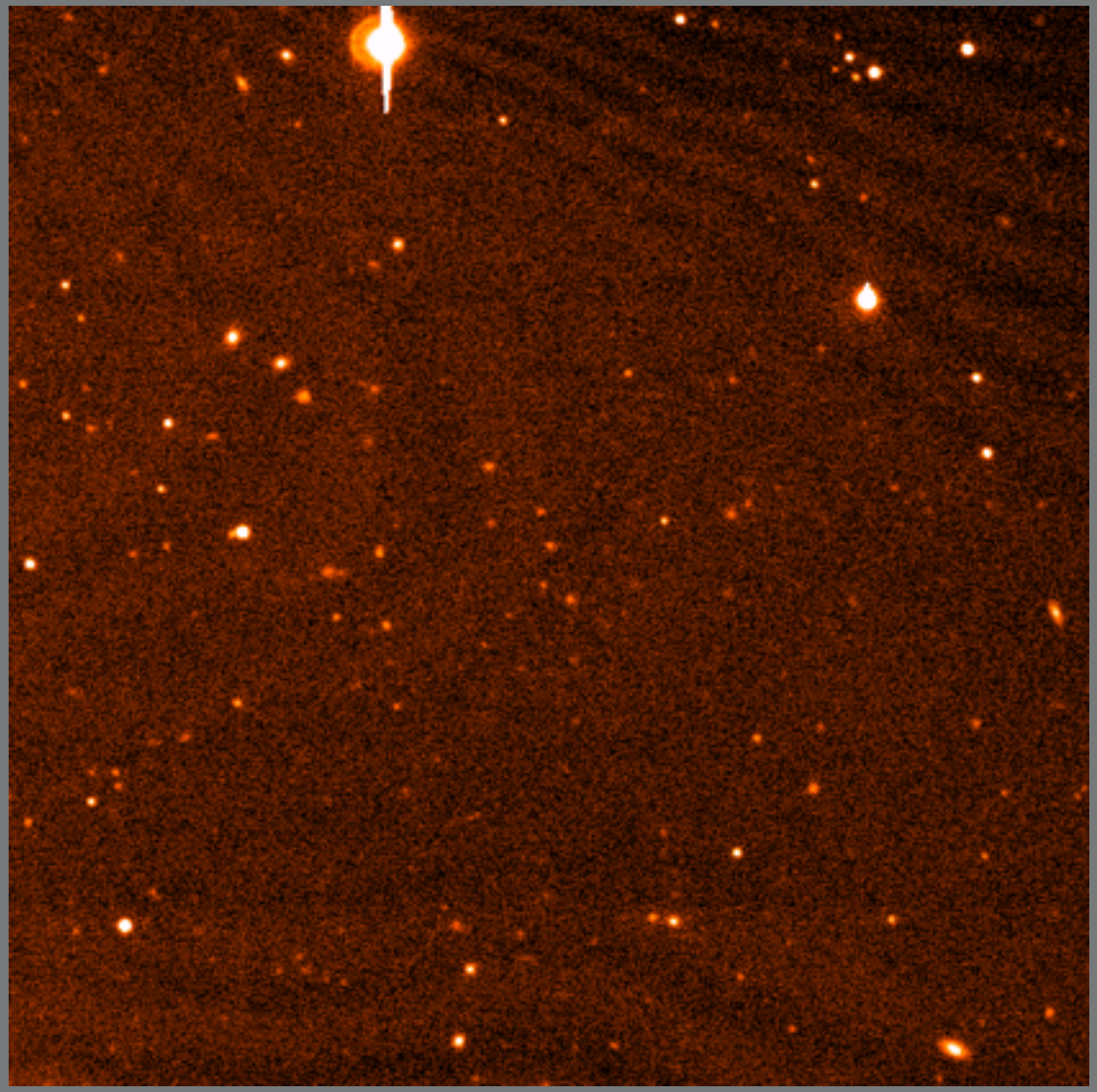


Planet hunting team of M. Brown, C. Trujillo, & D. Rabinowitz @Caltech

At first, Kuiper Belt objects were no real threat to Pluto



But it was only a matter of time …



Largest known Kuiper Belt objects

What is the definition of a planet?

Is Pluto a planet?

Proposed Definition:

A Planet…

1. orbits the Sun (rather than a moon that orbits a planet)
2. Is big
3. is big enough so that its own gravity pulls it together into a sphere

Official Word from the International Astronomical Union (IAU)

http://www.iau.org/IAU/Organization/divcom/div3.html

(1) A planet[1] is a celestial body that

(a) is in orbit around the Sun,

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

(c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that

(a) is in orbit around the Sun,

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

(c) has not cleared the neighbourhood around its orbit, and

(d) is not a satellite.

(3) All other objects[3], except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

Reading Question

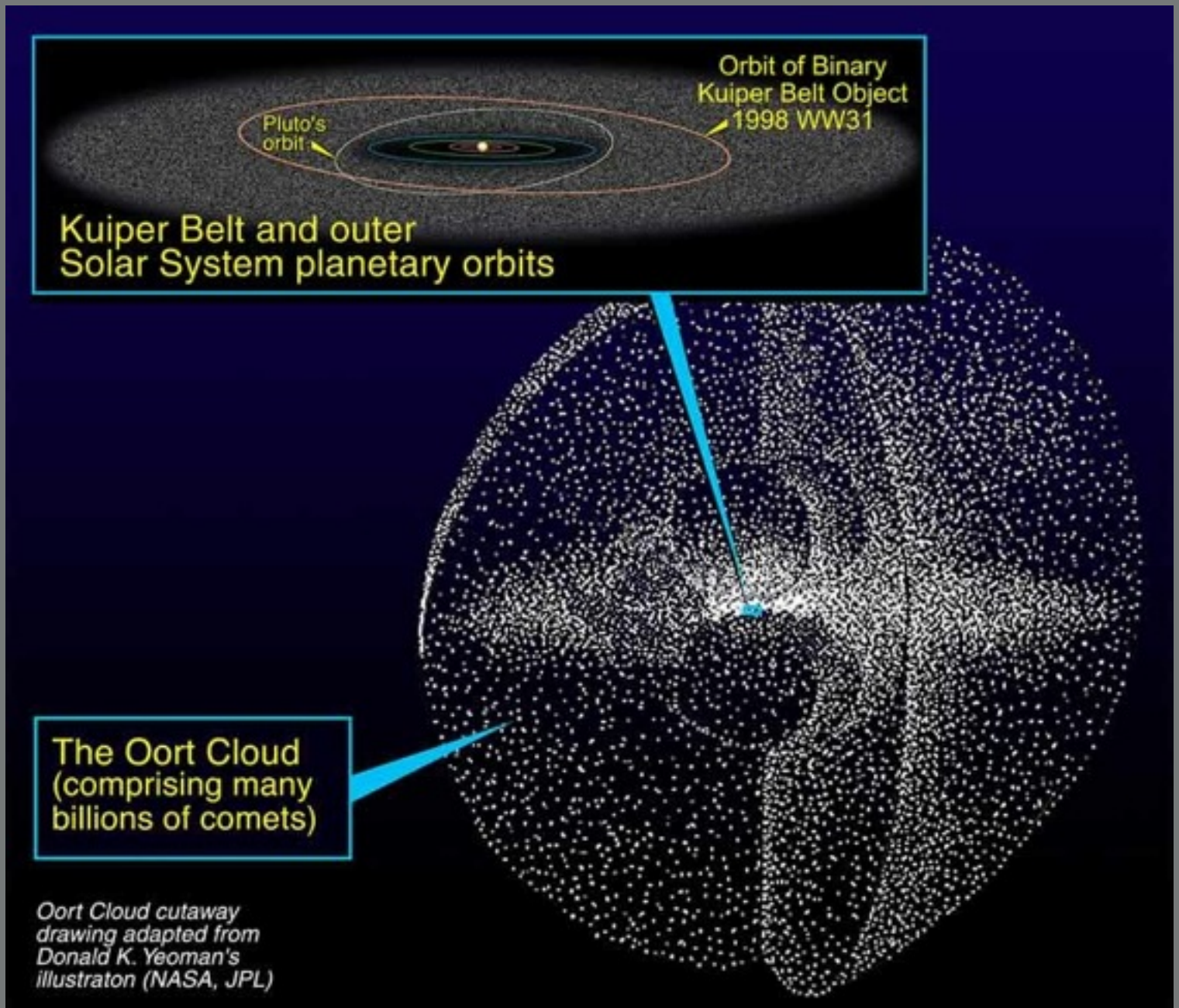
Consider the following 'rules for planets':

- Planets orbit the Sun in the same direction
- Planets rotate in the same direction (CCW from above)
- Planets have with small axial tilts (less than 30°)
- Moons orbit the same direction planets rotate
- Moons are small compared with their host planet

How many of the 'rules' above are broken in our Solar System?

A) 1 *B) 2* *C) 3* *D) 4* *E) 5*

Oort Cloud

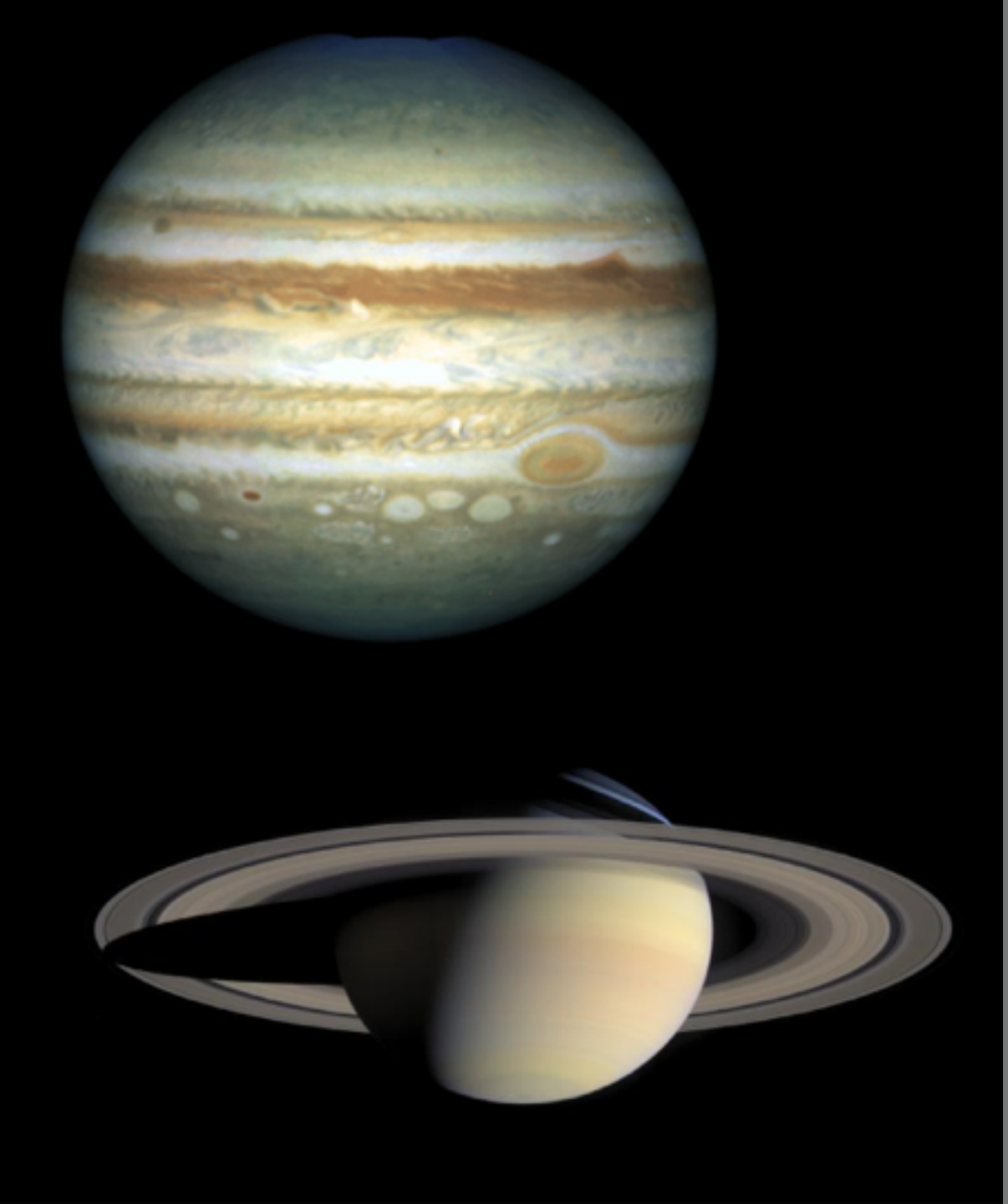

Orbit of Binary
Kuiper Belt Object
1998 WW31
Pluto's
orbit
Kuiper Belt and outer
Solar System planetary orbits
The Oort Cloud
(comprising many
billions of comets)
Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
illustraton (NASA, JPL)

Mercury

Venus

Earth

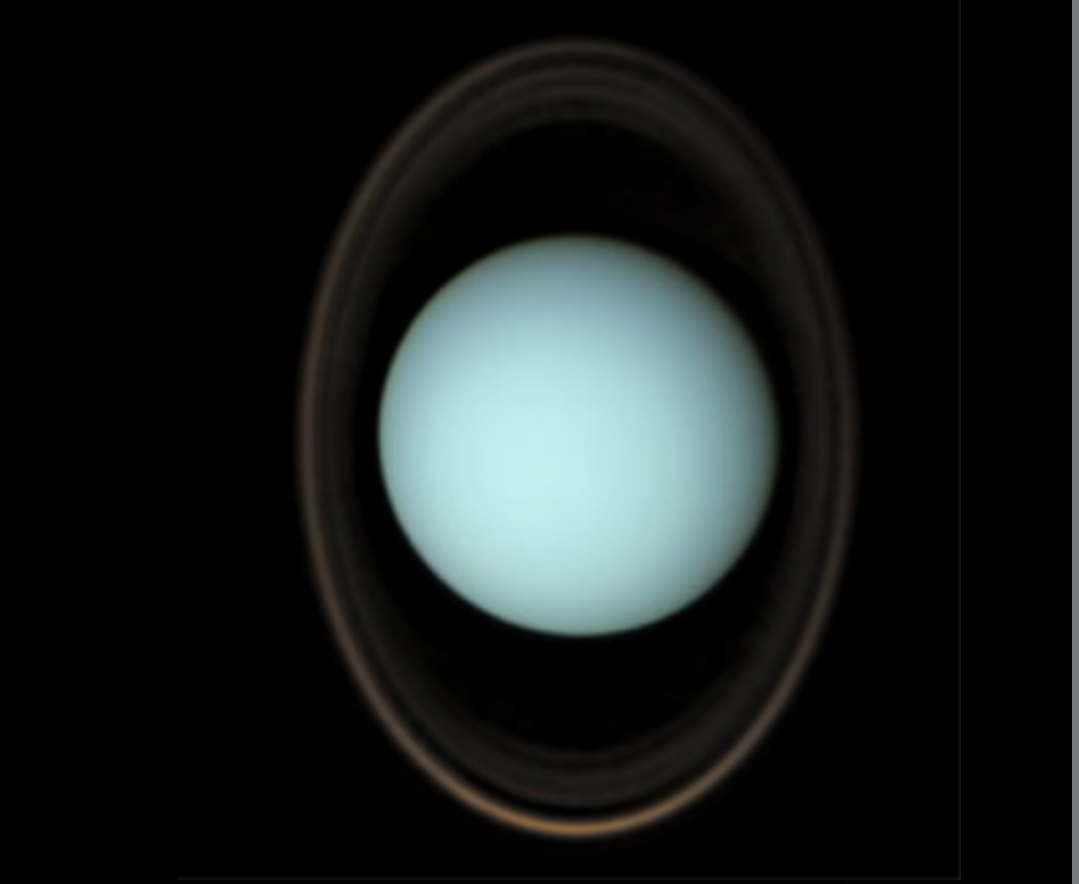
Mars



REVIEW

Gas Giants

- Much farther from Sun than inner planets
- Mostly H/He;
- Hundreds of times more massive than Earth
- Many moons, AND rings



REVIEW

Icy Giants

- Smaller than Jupiter/Saturn; still much larger than Earth (only ~16x Earth's mass)
- Made of H/He gas & ices/hydrogen compounds (H_2O, NH_3, CH_4)

Mnemonics

- Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto
  - My Very Excellent Mother Just Served Us Nine Pizzas

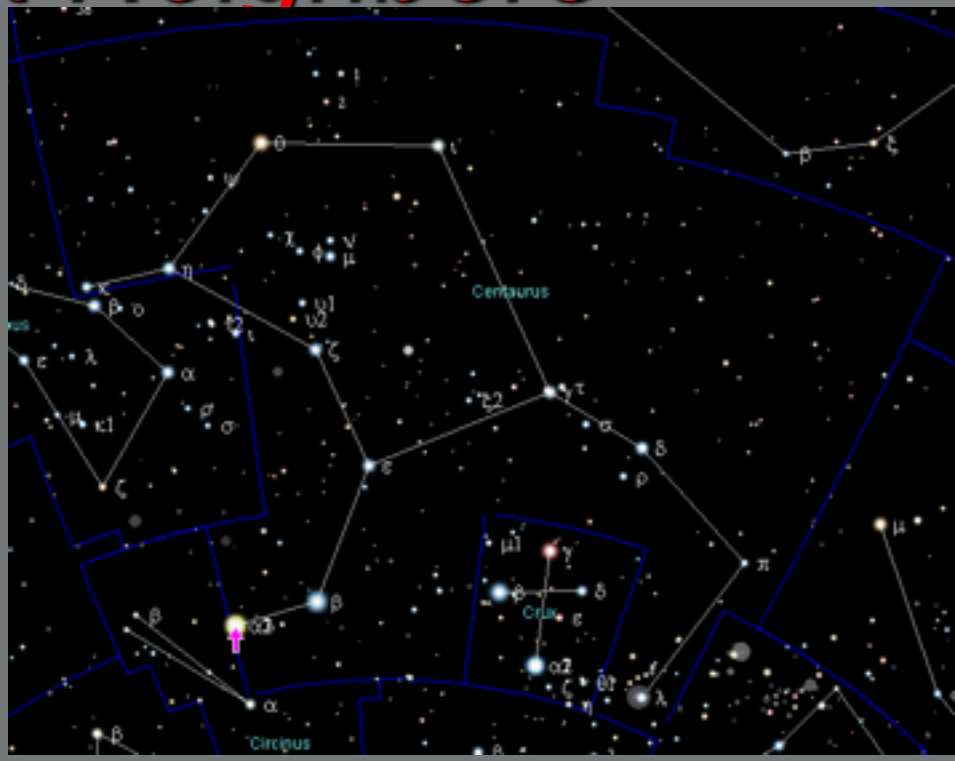
Problem: Pluto now a "dwarf planet"

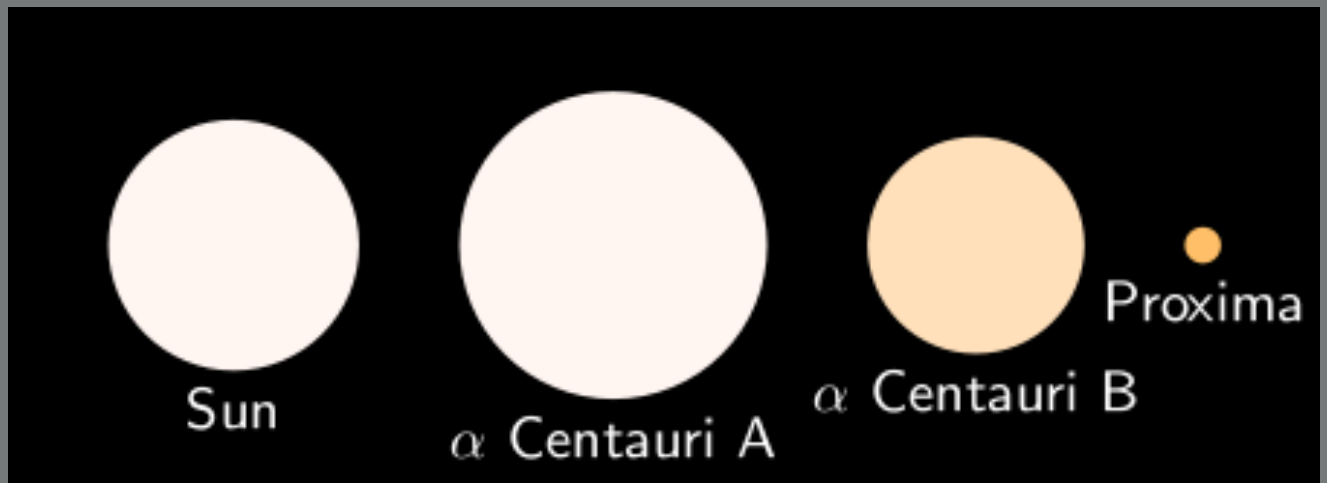
- My Very Excellent Mother Just Served Us Nachos
- "Many Very Extinct Maps Just Sold," Utters NASA

- Want to include Ceres, Pluto, Eris?
  - National Geographic winner: My Very Exciting Magic Carpet Just Sailed Under Nine Palace Elephants???
  - Since this contest, both Makemake and Haumea were declared dwarf planets.

Our Nearest Neighbors

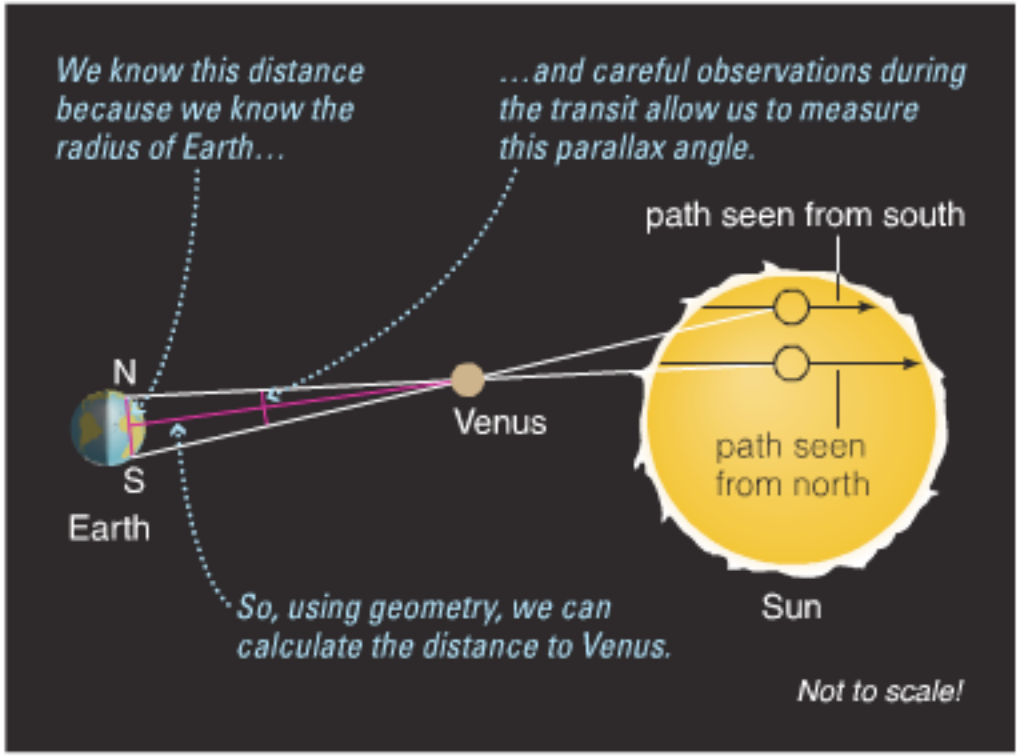
- Proxima Centauri ~4.2 ly
- α Centauri A & B (binary system) ~4.4 ly





Size of the Solar System

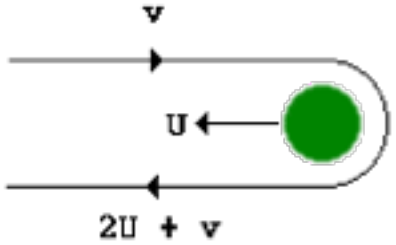
- Distances in space - important, not easy
- Kepler's Laws give distance in AU
- Earlier - transits
- Today, bounce radar waves off of Venus - Radar Ranging

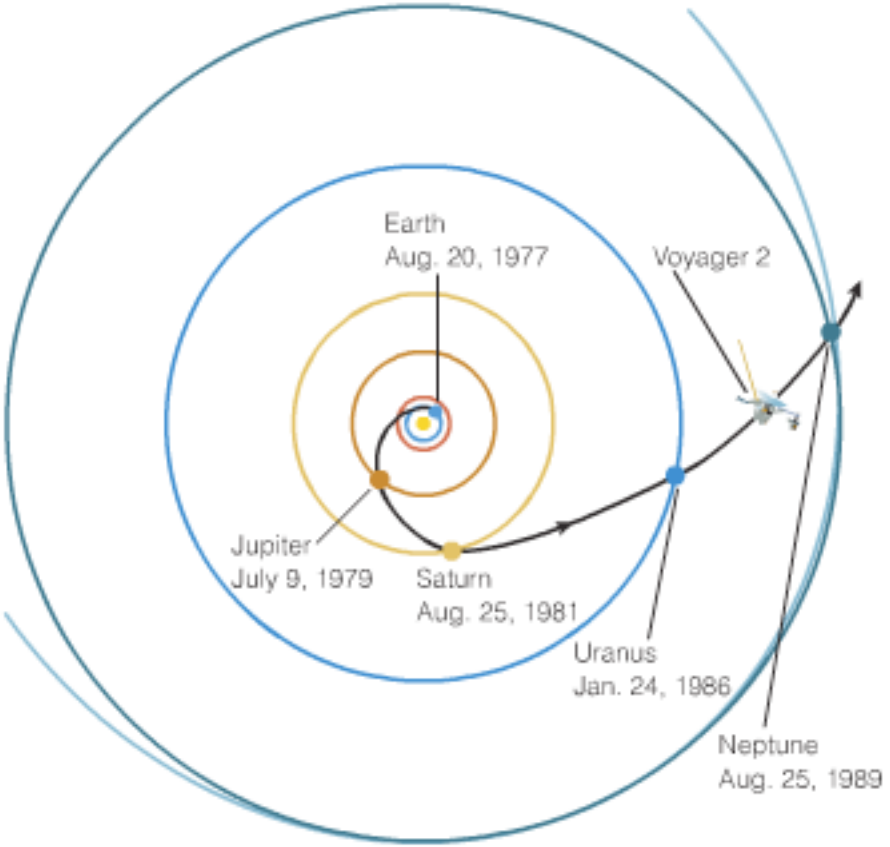


Exploring Space

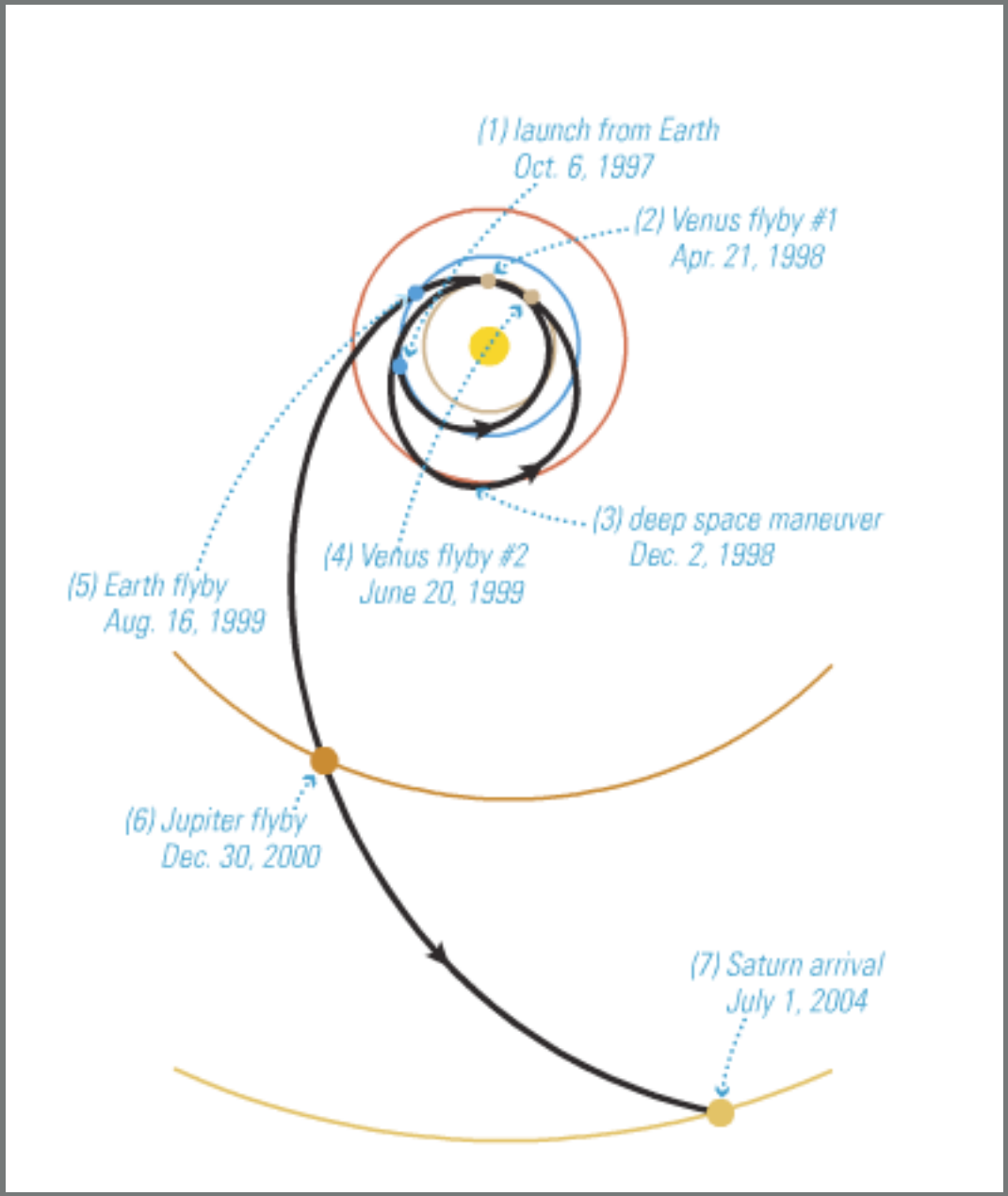
- Flybys
  - Looks at something on its way somewhere else
    - Voyager 1 & 2, 1 has left the building
- Orbiters
  - Stays in orbit for a while
    - Magellan mapped Venus
    - MESSENGER - 2011, Mercury
    - Gaileo - Jupiter
- Landers
  - Lands on the planet
    - Cassini's Huygens Probe dropped onto Titan
    - Spirit on Mars (lasted a bit longer than expected)
    - Deep Impact "landed" on Comet Tempel 1 at 10 km/s (22000 mph)

Flybys


v
U
2U + v


Earth
Aug. 20, 1977
Voyager 2
Jupiter
July 9, 1979
Saturn
Aug. 25, 1981
Uranus
Jan. 24, 1986
Neptune
Aug. 25, 1989

Cassini


(1) launch from Earth
Oct. 6, 1997
(2) Venus flyby #1
Apr. 21, 1998
(3) deep space maneuver
Dec. 2, 1998
(4) Venus flyby #2
June 20, 1999
(5) Earth flyby
Aug. 16, 1999
(6) Jupiter flyby
Dec. 30, 2000
(7) Saturn arrival
July 1, 2004

Why go there?

Real simple - do you learn more by looking at something with binoculars or walking over to it

WE HAVE LEARNED A LOT

MY OPINION - MANNED SPACE TRAVEL, AT LEST RIGHT NOW IS ALMOST POINTLESS

What do you think? Why?

A Brief History of Space Travel

- WW2 - Cold War - display of power
- 1957 - Sputnik (USSR), first orbiter
- 1958 - Luna 3 (USSR) first image of "dark side" of the moon
- 1960 - Pioneer 3 Sun observer (US)
- July 16th1969 - Apollo 11, first moon landing (US)
  - 12 people have walked on the moon
  - Apollo 17, December 17, 1972

History

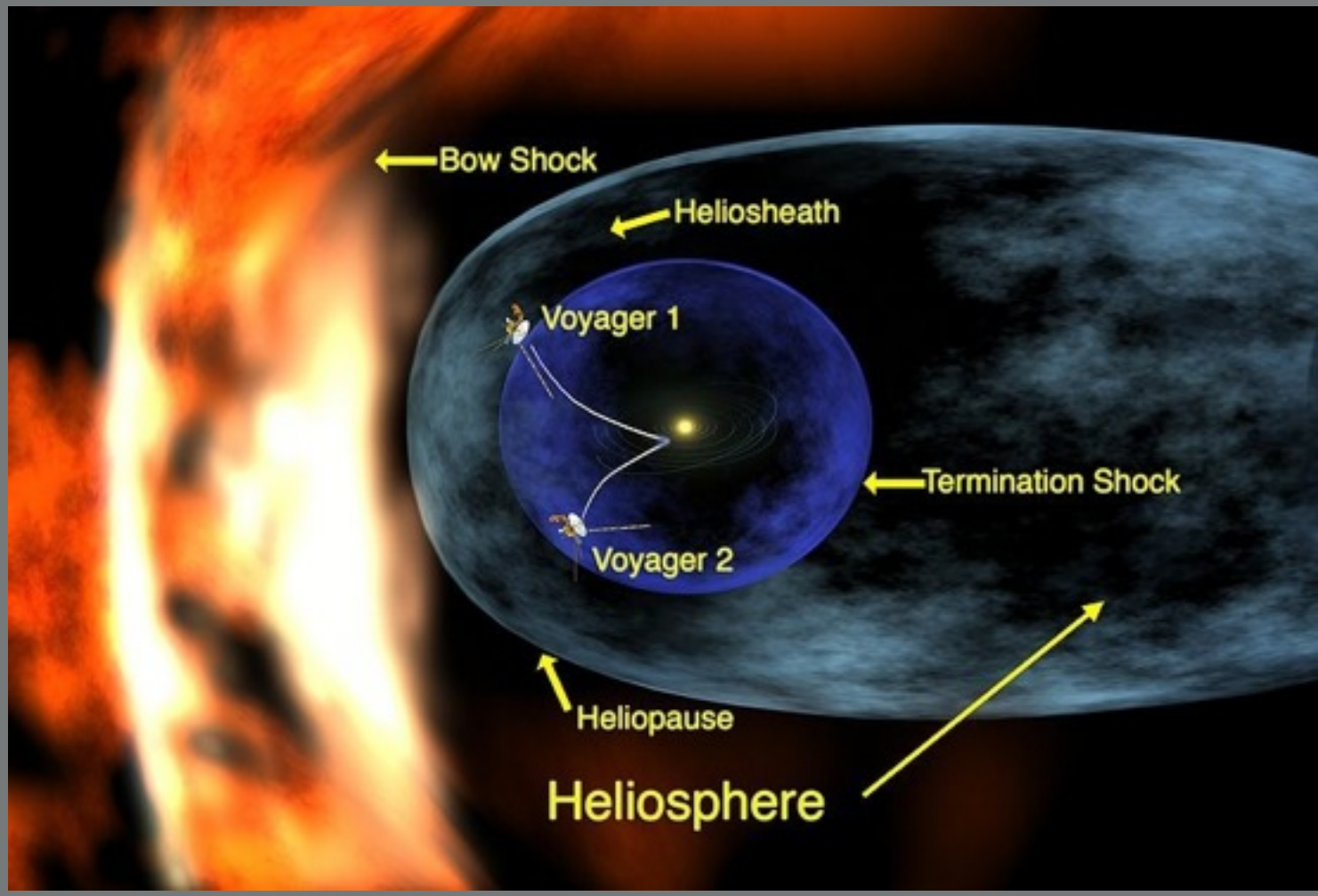
- Saturn 5
  - 7 million pounds
  - 383 feet tall
  - POWER

History

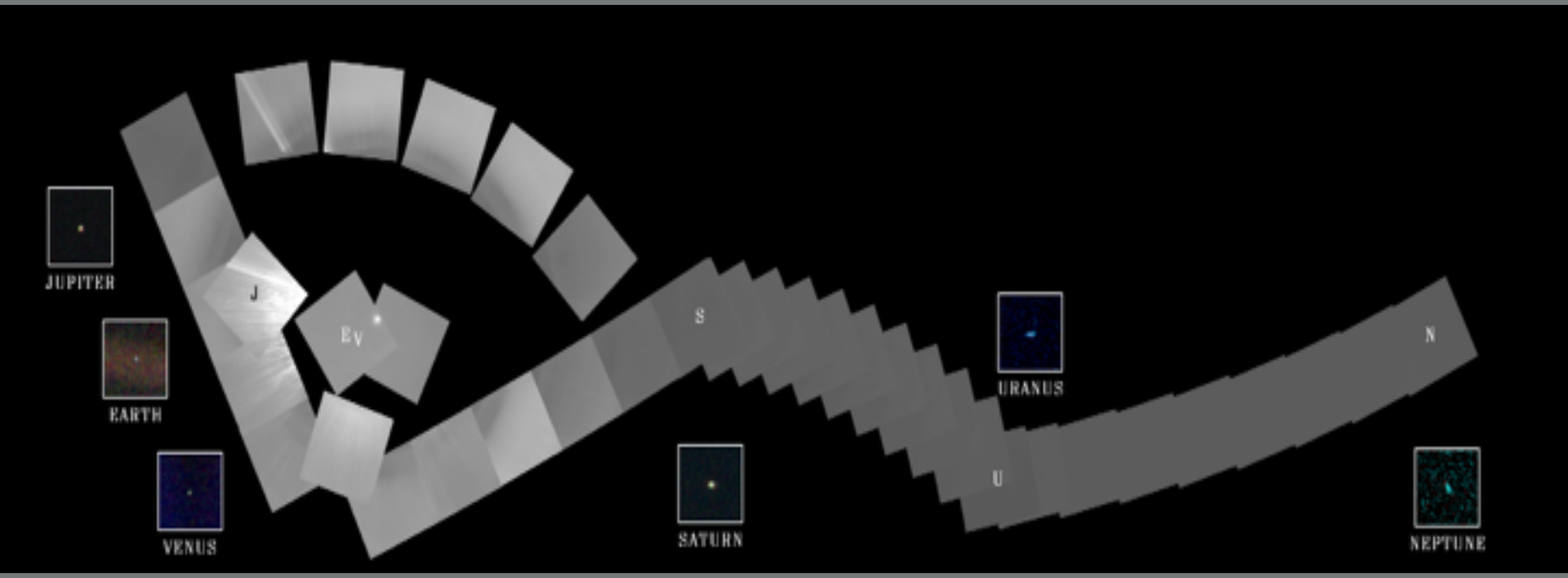
- 1979 Voyager 1 and 2

Voyager has left the building

- Hit the terminatio n shock on 2003
- Heliopause around 2015
- Going around 15 km/s



Voyager



Voyager's Golden Record

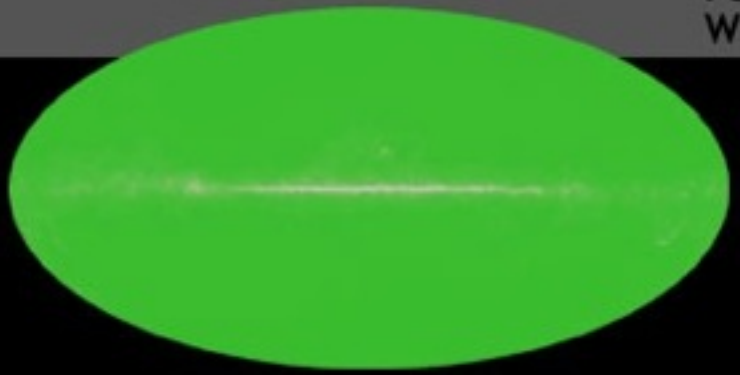
- Voyager will be near another star in 40,000 years
- Greetings in 55 languages
- Songs
- Sounds of Earth
- Picture
  - How to play
  - The hydrogen atom
  - How to find the sun using pulsars

More History

- 1990 - Hubble (optical/UV)
- 1991 - Compton (Gamma Rays)
- 1995 SOHO (Sun)
- 1996 Mars Pathfinder - first roving explorer on another planet
- 1997 Cassini launched, 2004 arrives, 2005 Huygens lands on Titan - Boulder
- 1999 Chandra (X-Ray)
- 2001 WMAP (CMB)
- 2003 Spitzer (IR)
- 2003 Mars Exploration Rover - Spirit lasted ~22 times longer than planned, cool
- 2004 SWIFT (GRBs)
- 2005 Deep Impact (smash)
- 2006 New Horizons (Pluto) - Boulder
- 2009 Kepler (planets) - Boulder

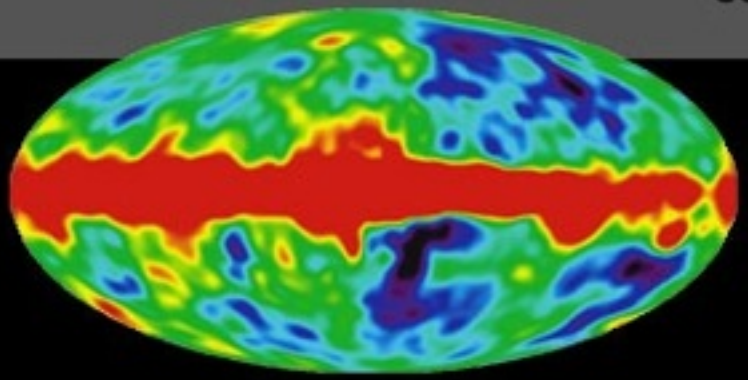
1965

Penzias and Wilson



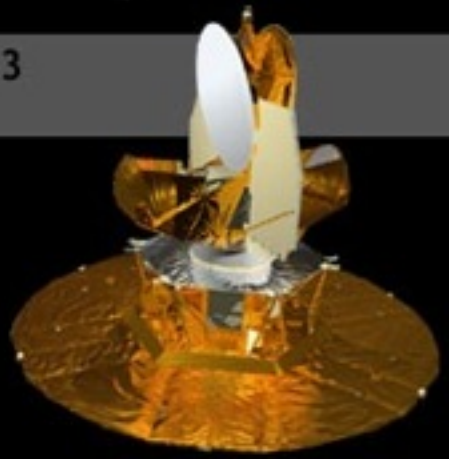
1992

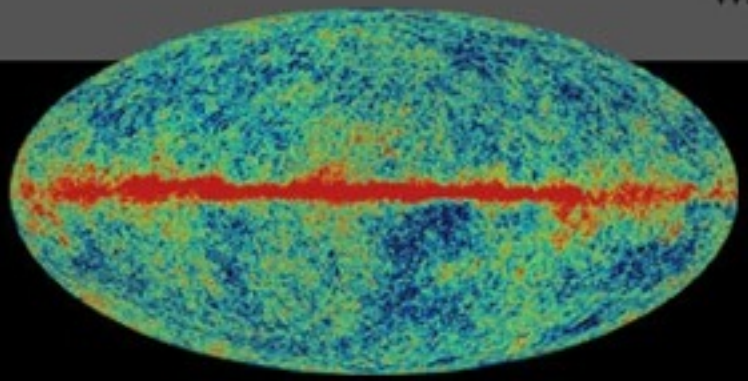
COBE

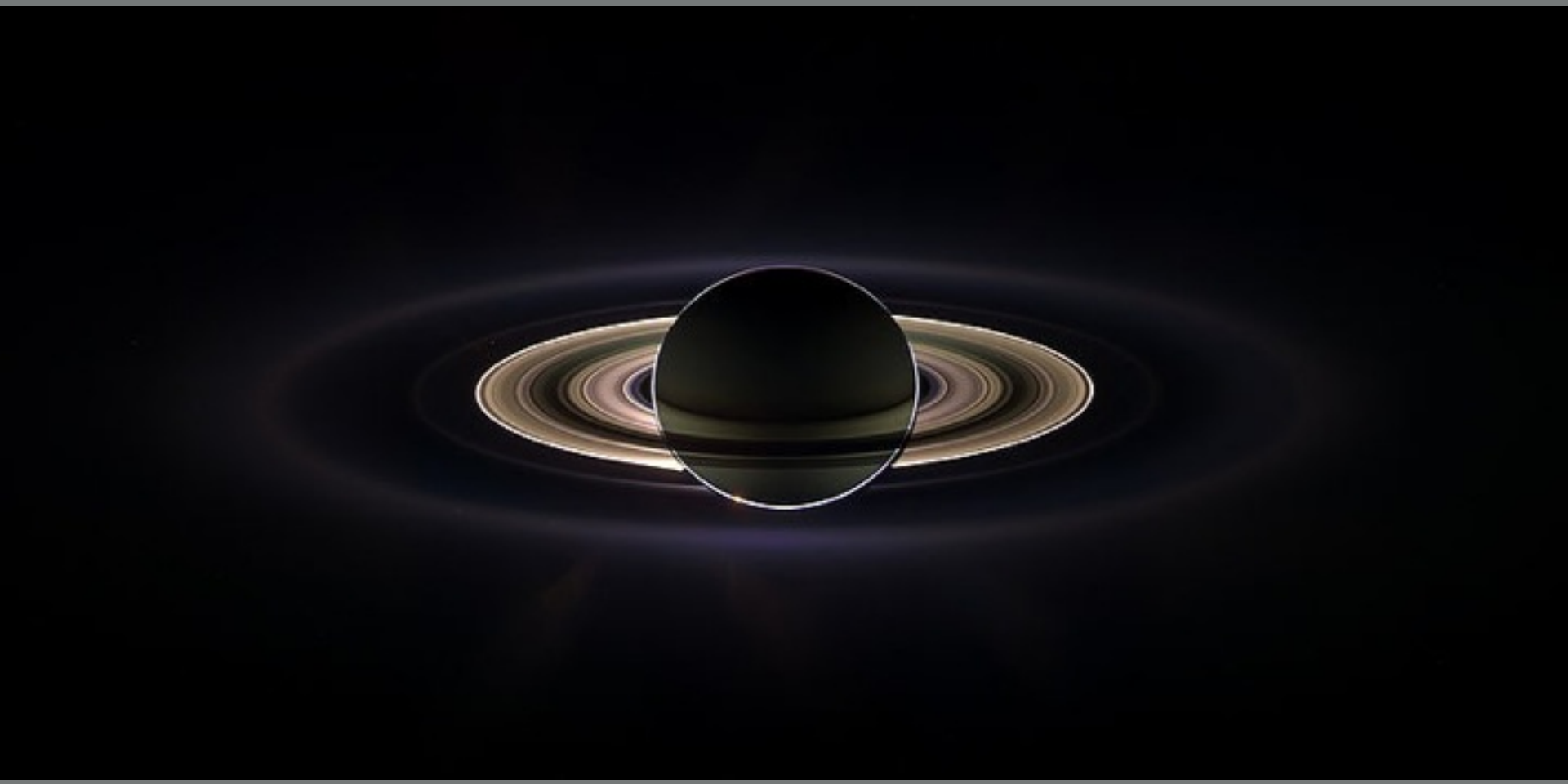


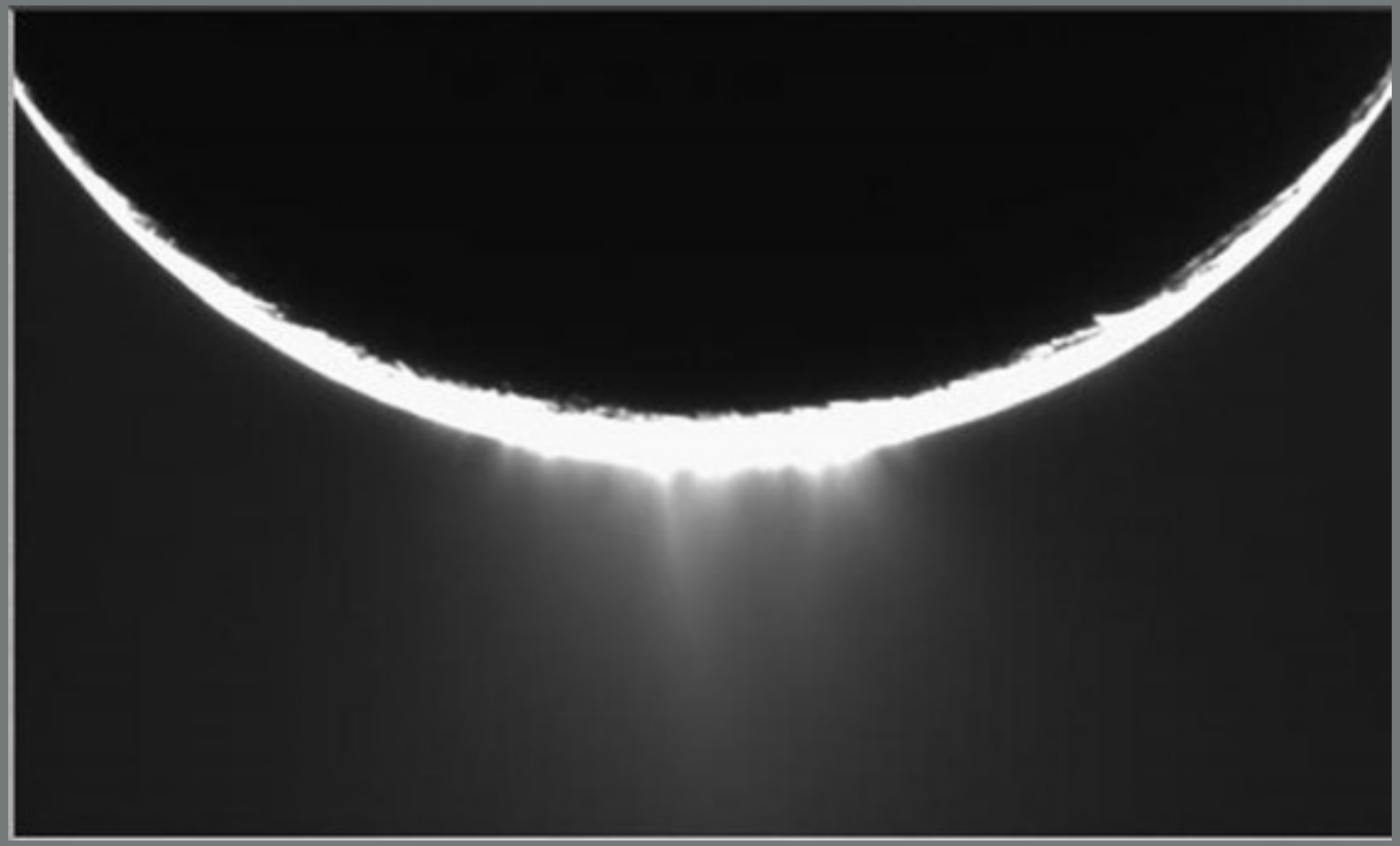
2003

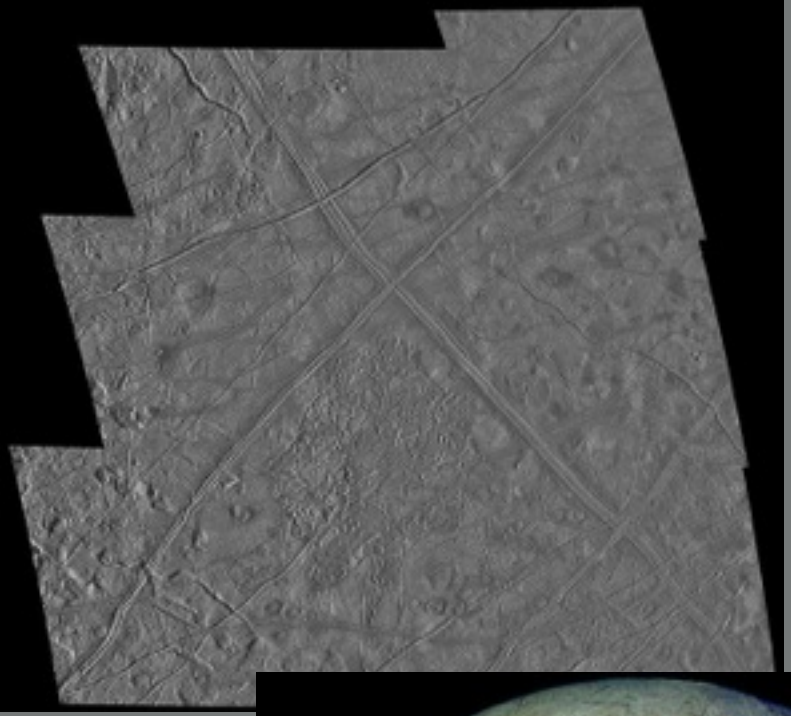
WMAP

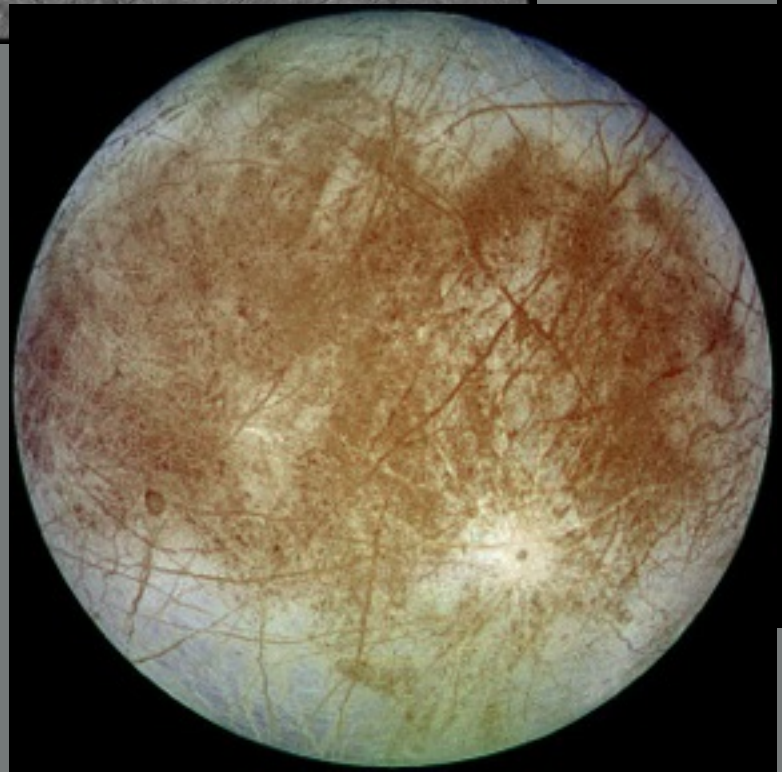


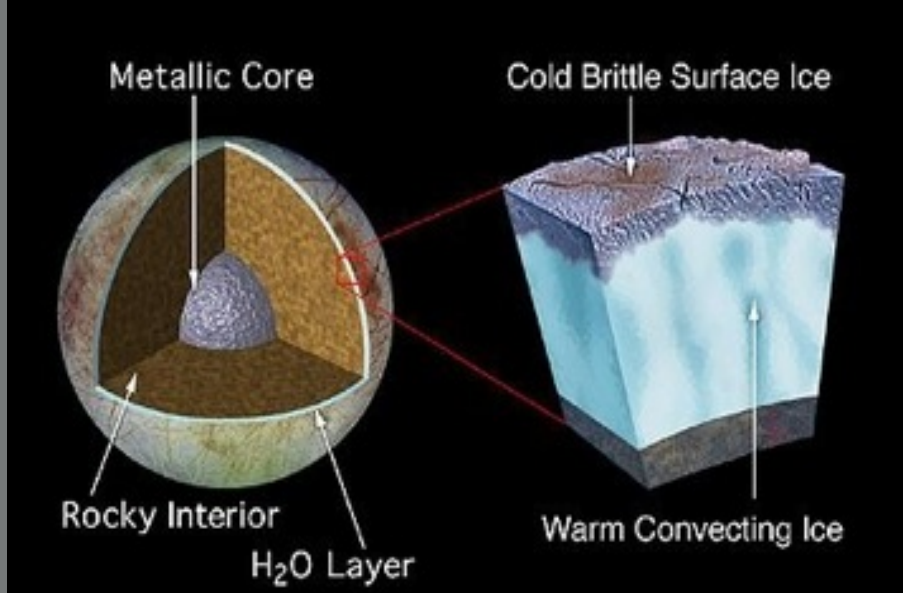


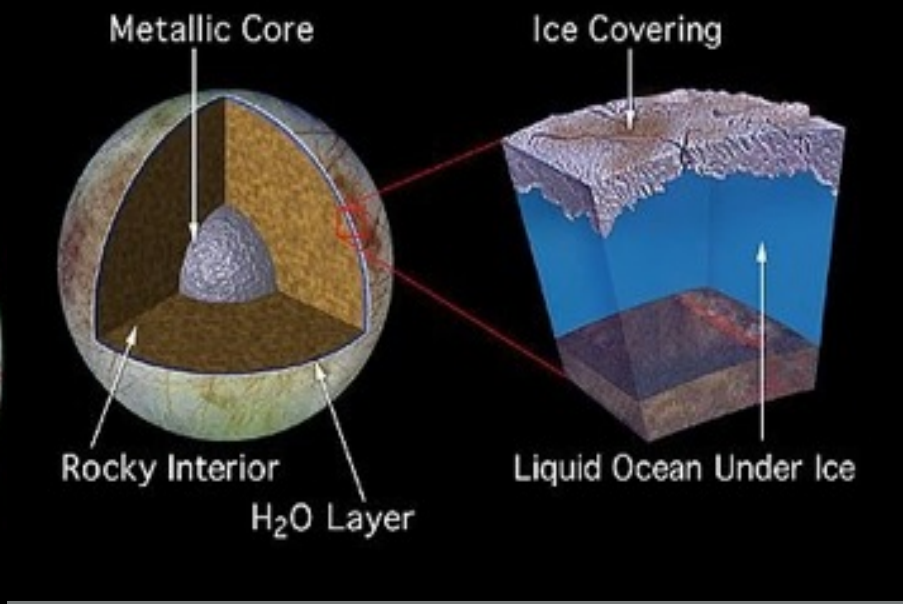


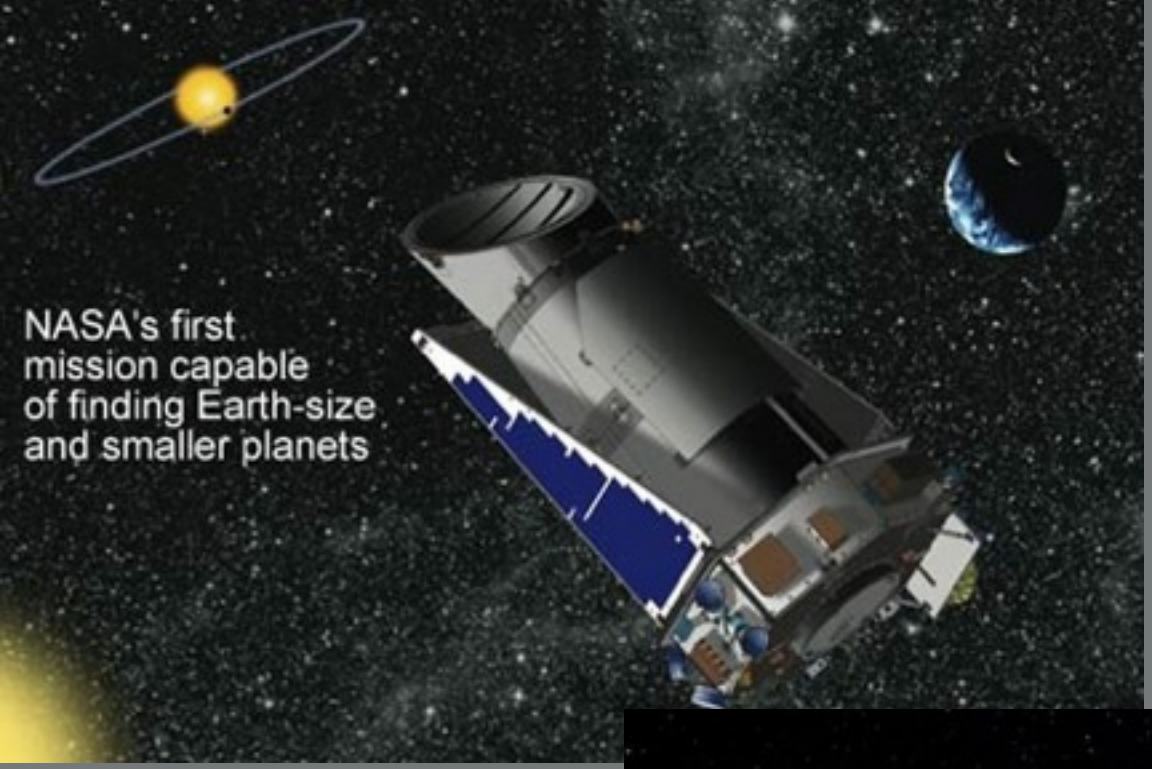


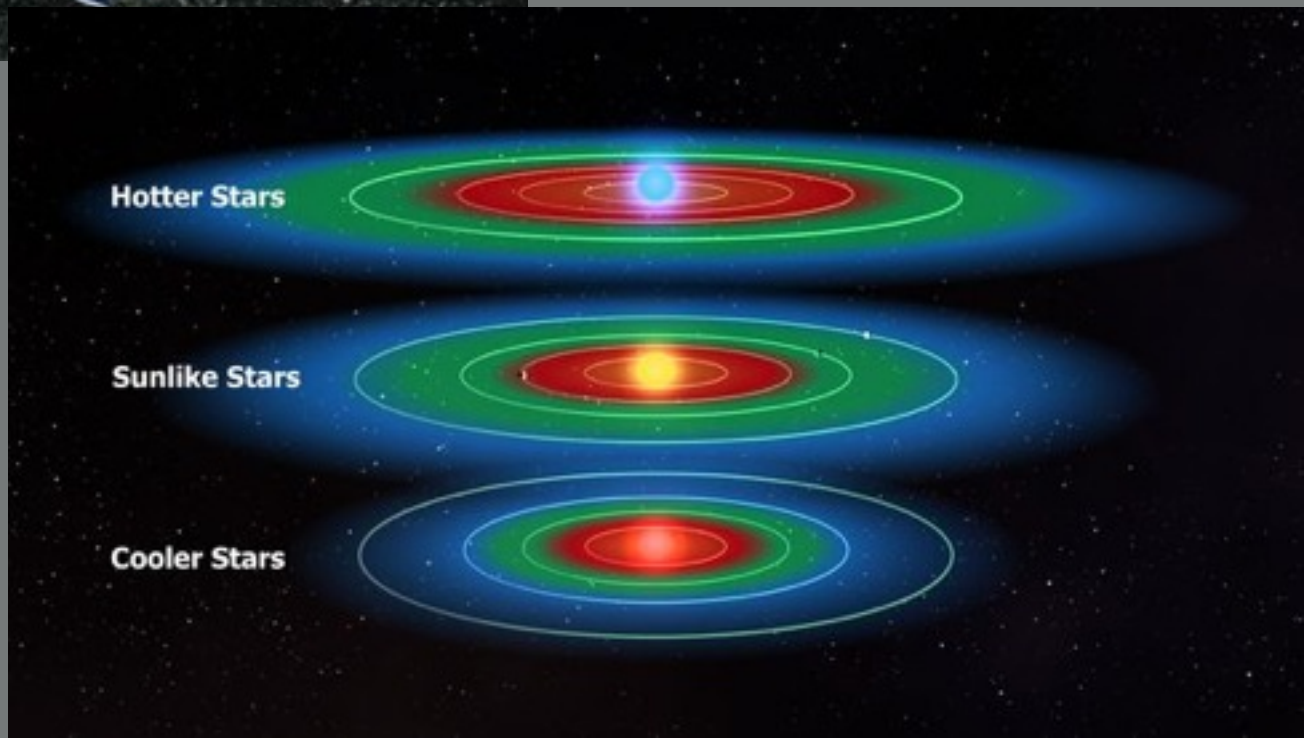


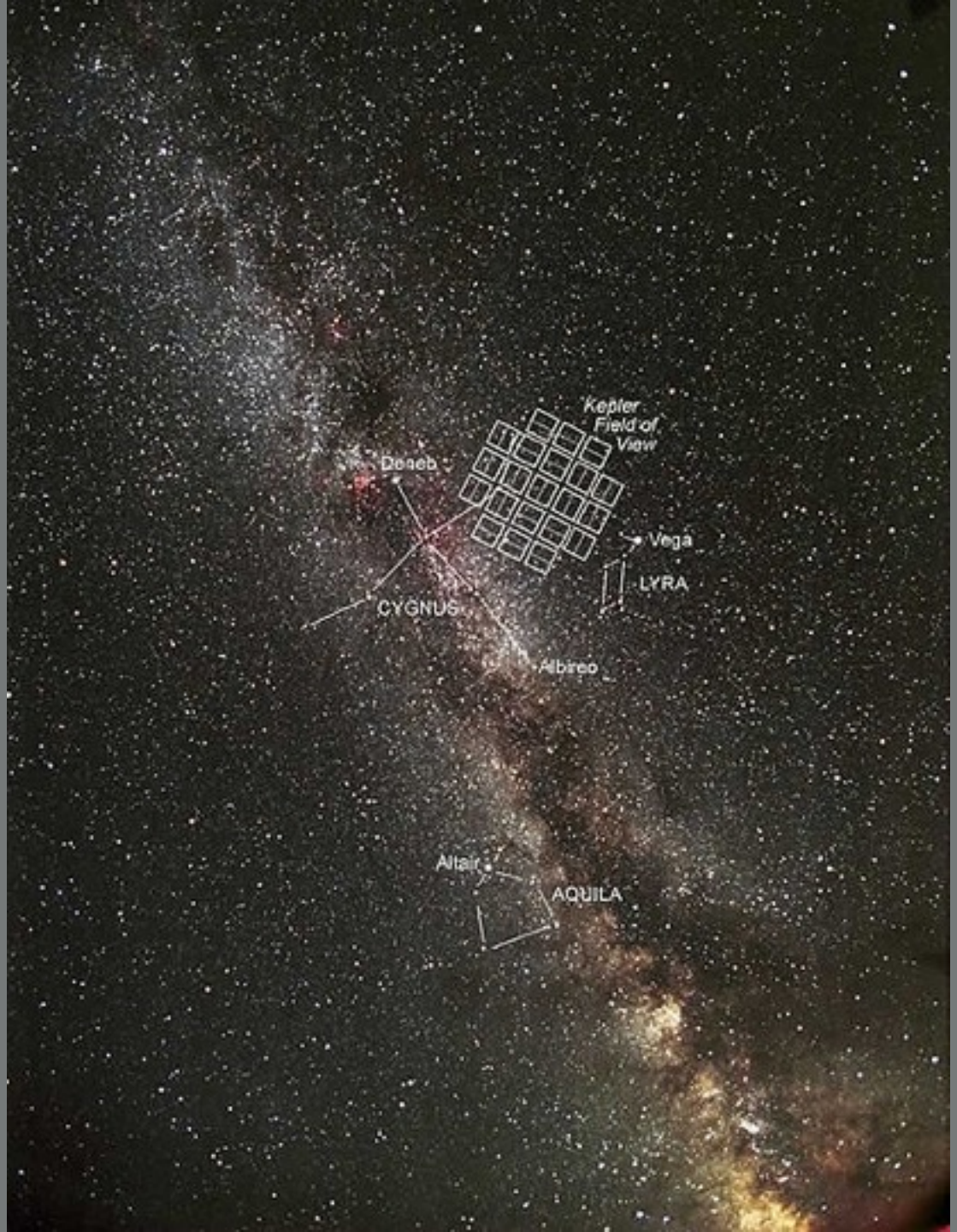


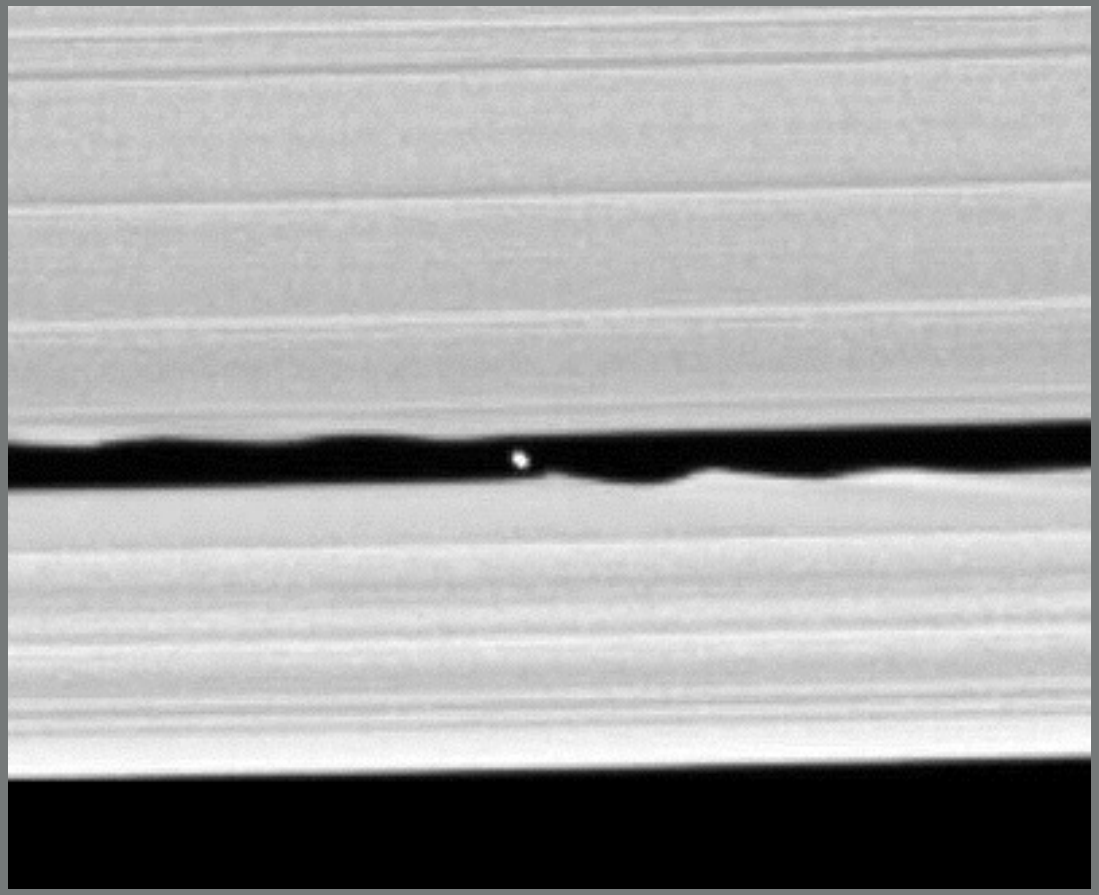

Metallic Core
Cold Brittle Surface Ice
Rocky Interior
H_2O Layer
Warm Convecting Ice

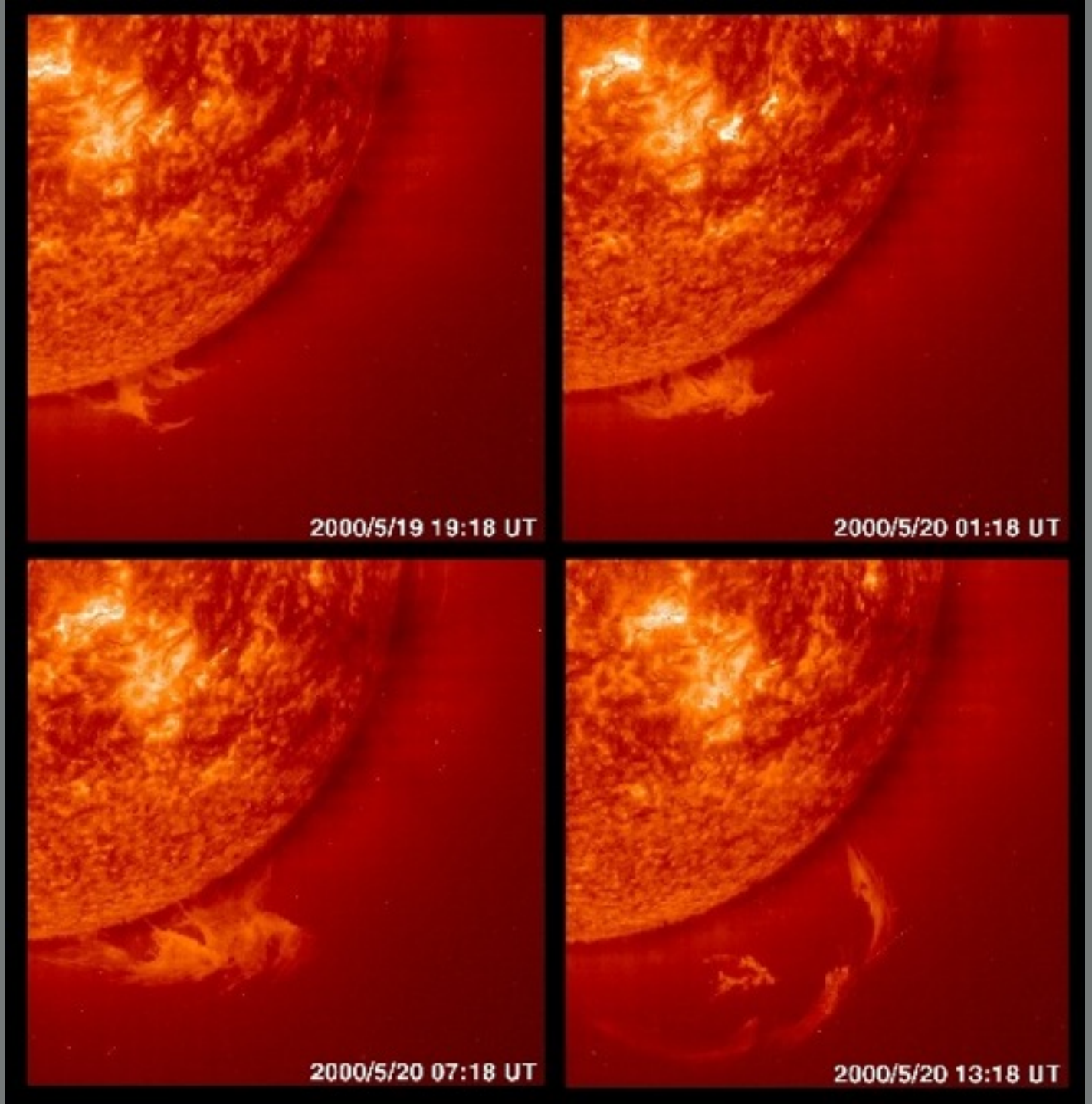

Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice

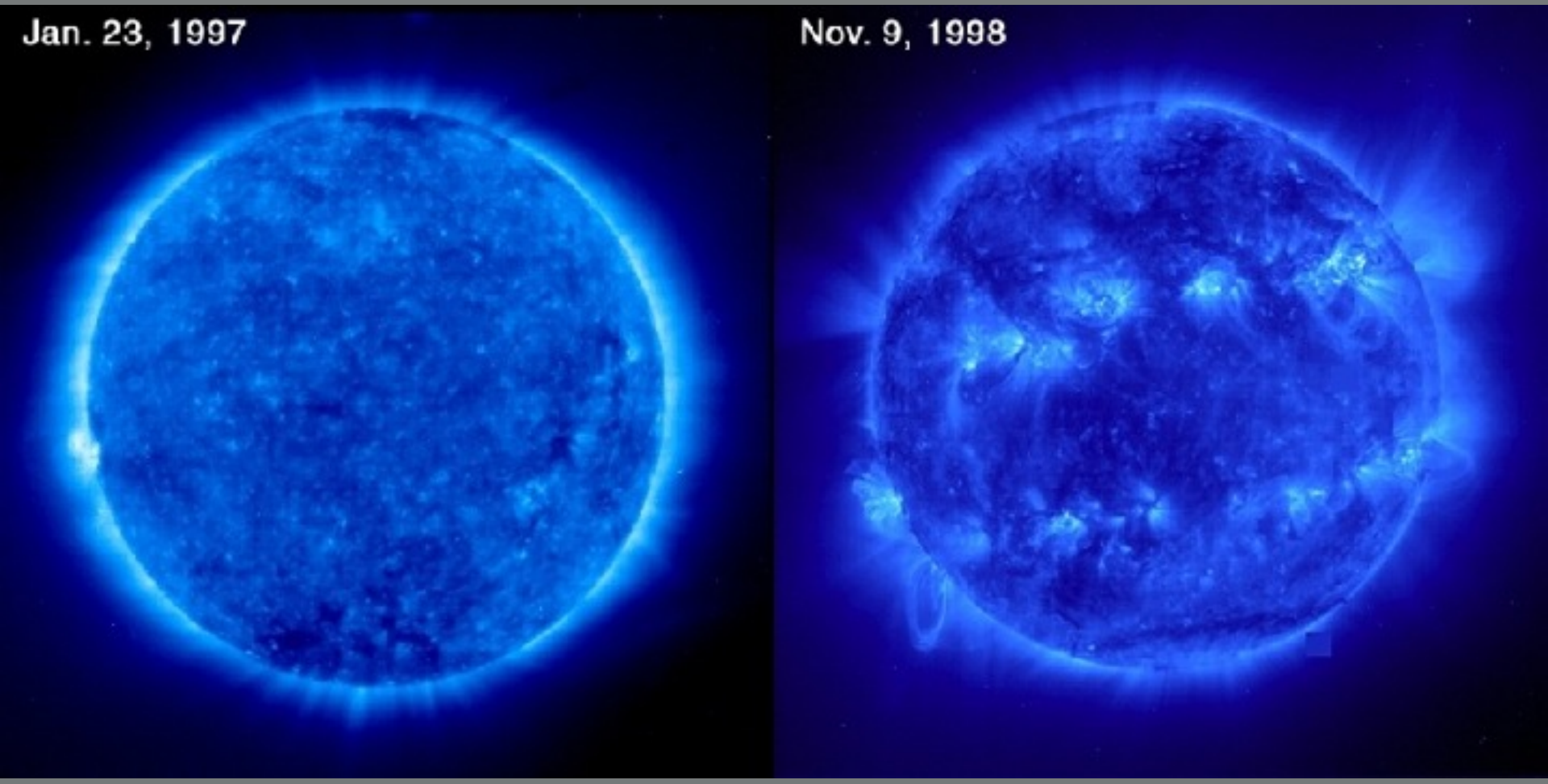

NASA's first
mission capable
of finding Earth-size
and smaller planets


Hotter Stars
Sunlike Stars
Cooler Stars


Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA




2000/5/19 19:18 UT
2000/5/20 01:18 UT
2000/5/20 07:18 UT
2000/5/20 13:18 UT


Jan. 23, 1997
Nov. 9, 1998

ORIGINS

- The Search For Origins
- Birth Of The Solar System
- Planet Formation
- Aftermath
- Age Of Solar System

Reading Question

The elements in the solar nebula …

A. Have been around literally forever
B. Were all created in the Big Bang
C. Were all created in stars
D. Were created in stars and the Big Bang
E. Are continuously created whenever planets form

Four Patterns in the Solar System

1. Orderly motions
2. Two kinds of planets
3. Two kinds of small bodies
4. Exceptions to the rules

Patterns in the Solar System

Orderly Motions

REVIEW

- Almost every body orbits & spins in the same direction.
  - Counterclockwise from above
- Planetary orbits nearly circular, lie in nearly the same plane.
  - Large moons tend to exhibit the same properties.

Patterns in the Solar System

Two Types of Planets

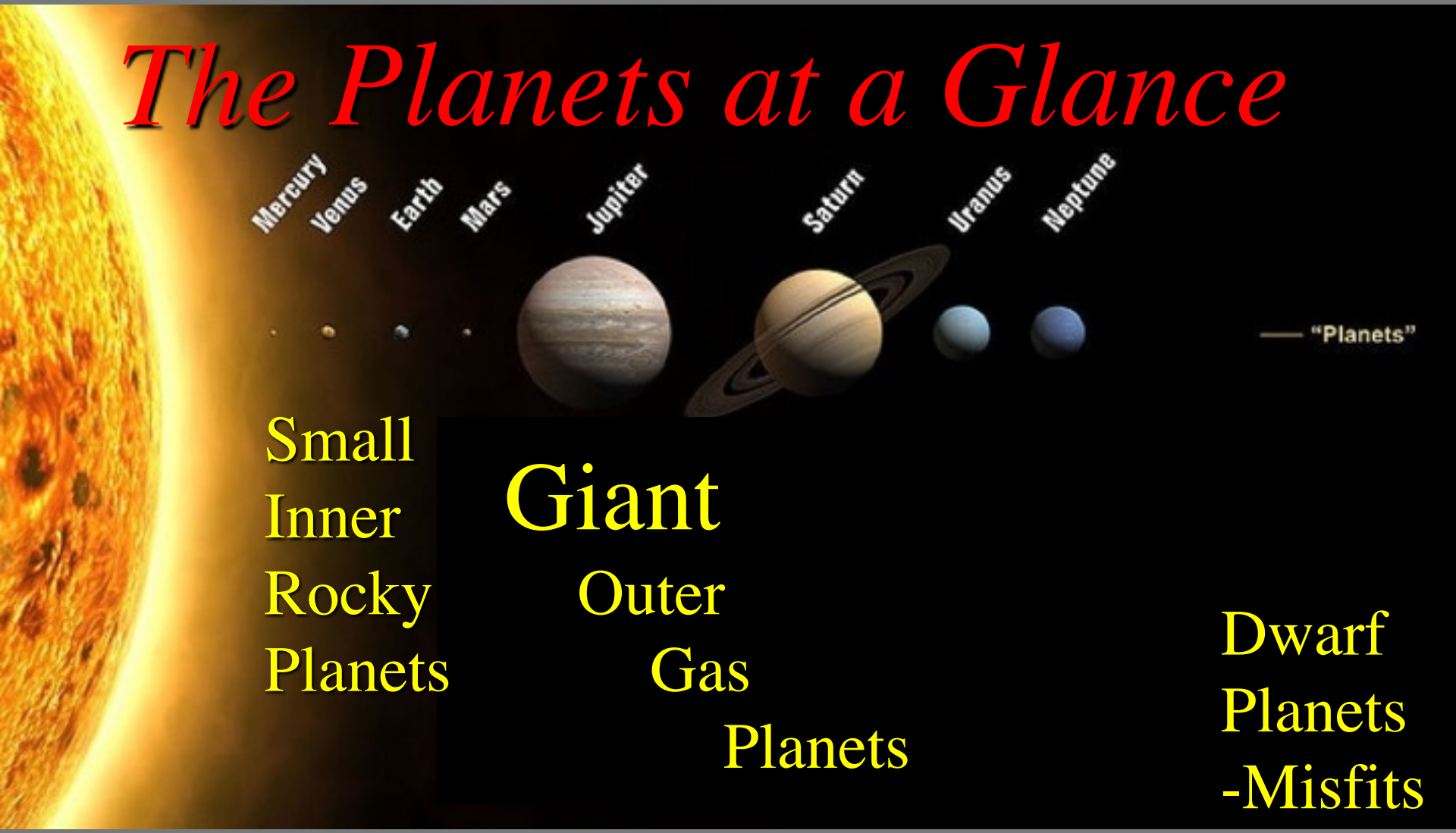
Terrestrial Planets

- Smaller size and mass
- Mostly rock and metal
- High density
- Solid surface
- Few or no moons, no rings
- Closer to the Sun, closer together

Jovian Planets

- Larger size and mass
- Mostly H, He, and H-compounds
- Low density
- No solid surface
- Rings and many moons
- Farther from the Sun, farther apart

The Planets at a Glance



Small
Inner
Rocky
Planets

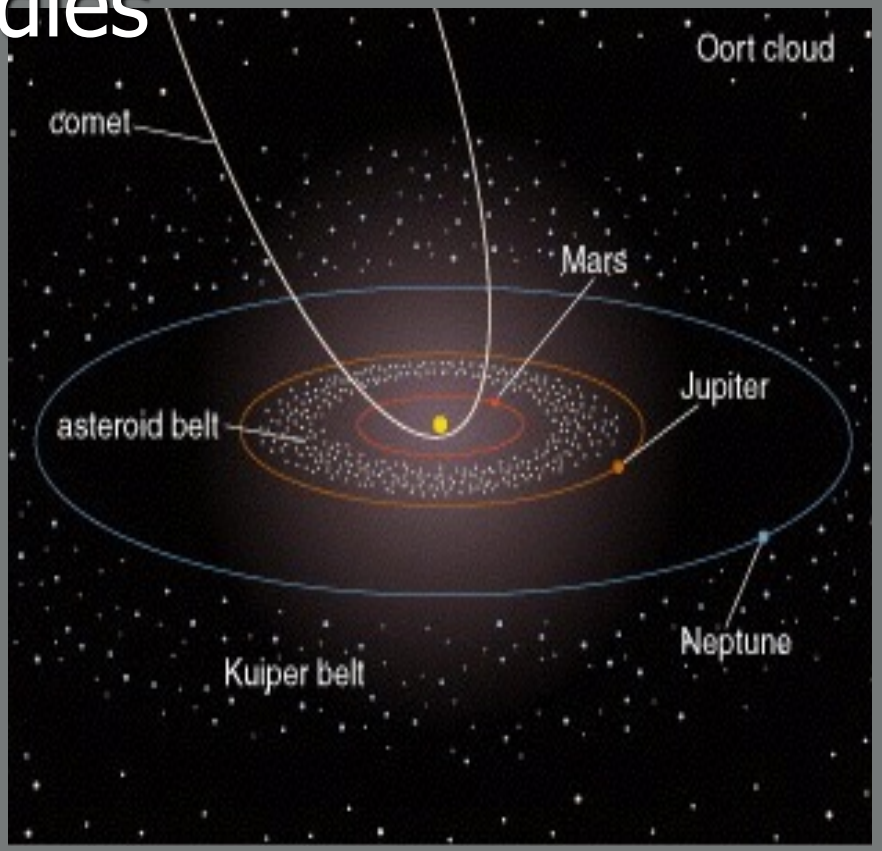
Giant
Outer
Gas
Planets

Dwarf
Planets
-Misfits

Patterns in the Solar System

Two Types of Small Bodies

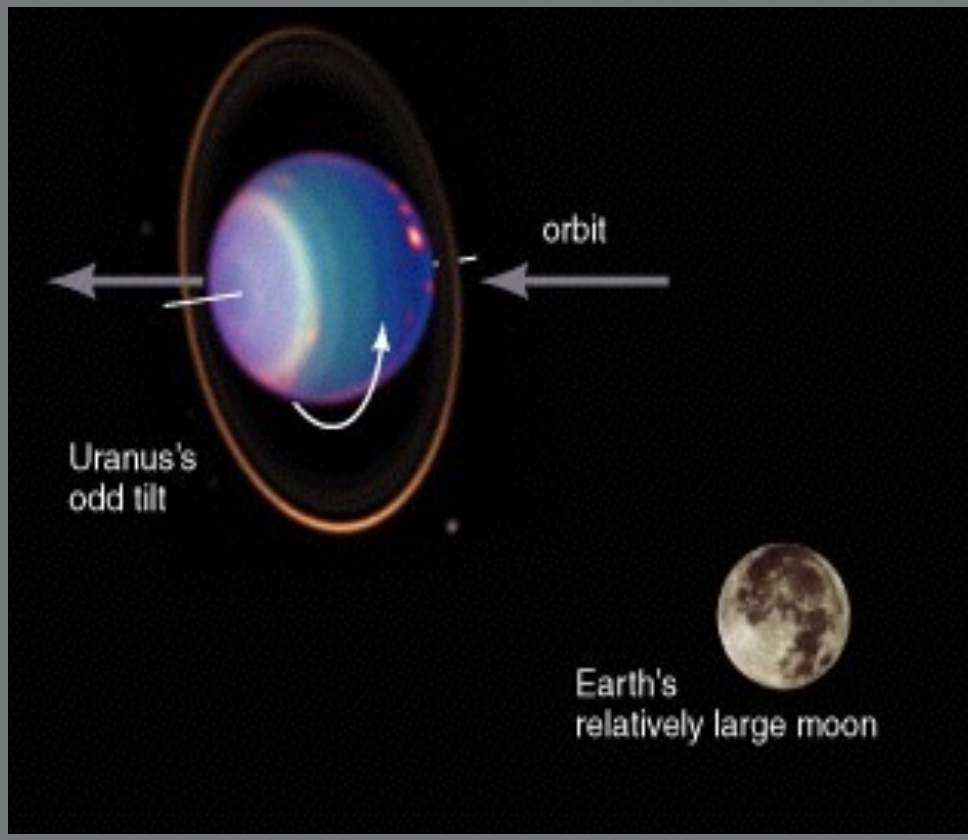
- Rocky
  - Asteroids
- Ice and rock
  - Comets
  - Kuiper belt objects
  - Oort cloud



Patterns in the Solar System

Exceptions to the rules

- Rotations
  - Venus
    - Backwards
  - Uranus
    - On its side
- Orbits
  - Triton
    - Backwards
- Moons
  - Earth's Moon
    - Big (compared to Earth)
  - Most small moons
    - Screwy shapes & orbits



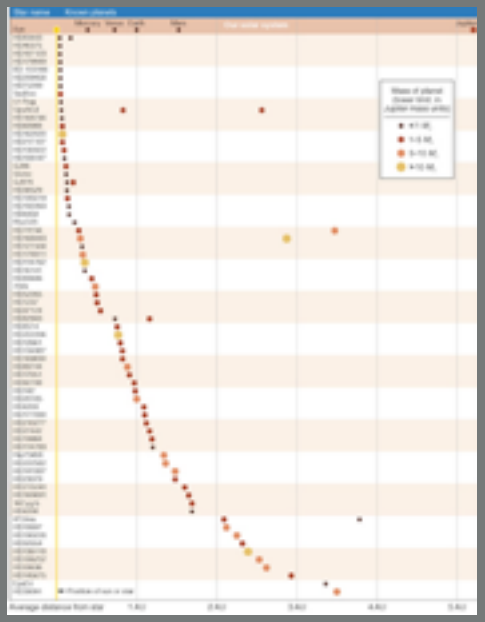
Chapter 8
Formation of the Solar System

Formation: Sources of Evidence

Star-forming regions

Chemistry of space stuff

Our solar system



Other solar systems

Similarities and differences

Formation of the Solar System

- Formation of the Sun seems a good place to start.
- Unfortunately, stars live for millions to billions of years
  - In reality, theories of star formation are based on observing many of stars of different ages.
- Start with a **nebula** of gas and dust.
  - **Nebula = noun = "cloud" (plural = nebulae)**
  - **Nebular = adjective = "cloud-like"**

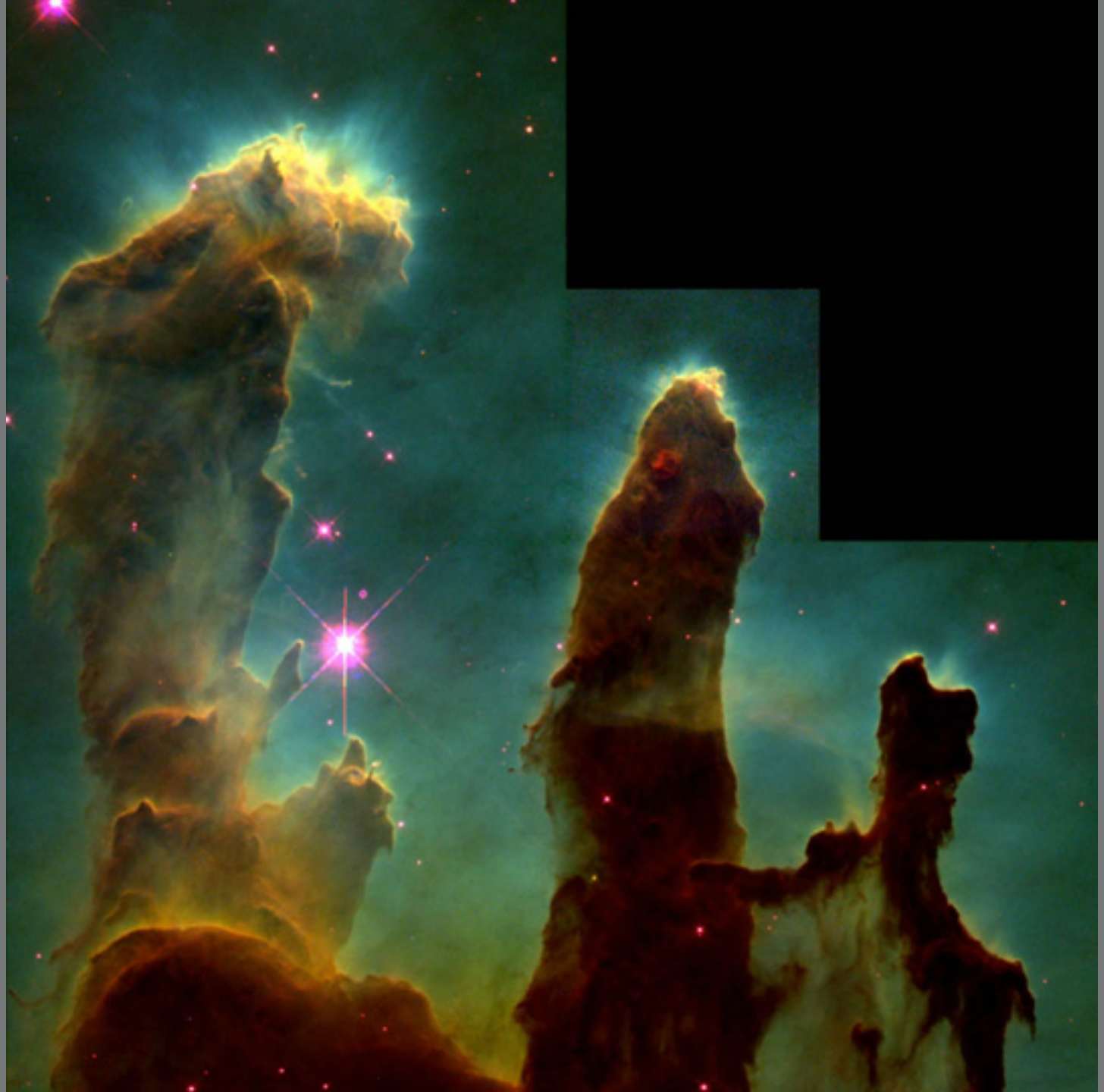
Visible • WFPC2

Infrared • NICMOS

Trapezium Cluster • Orion Nebula

WFPC2 • **Hubble Space Telescope** • NICMOS

NASA and K. Luhman (Harvard-Smithsonian Center for Astrophysics) • STScI-PRC00-19



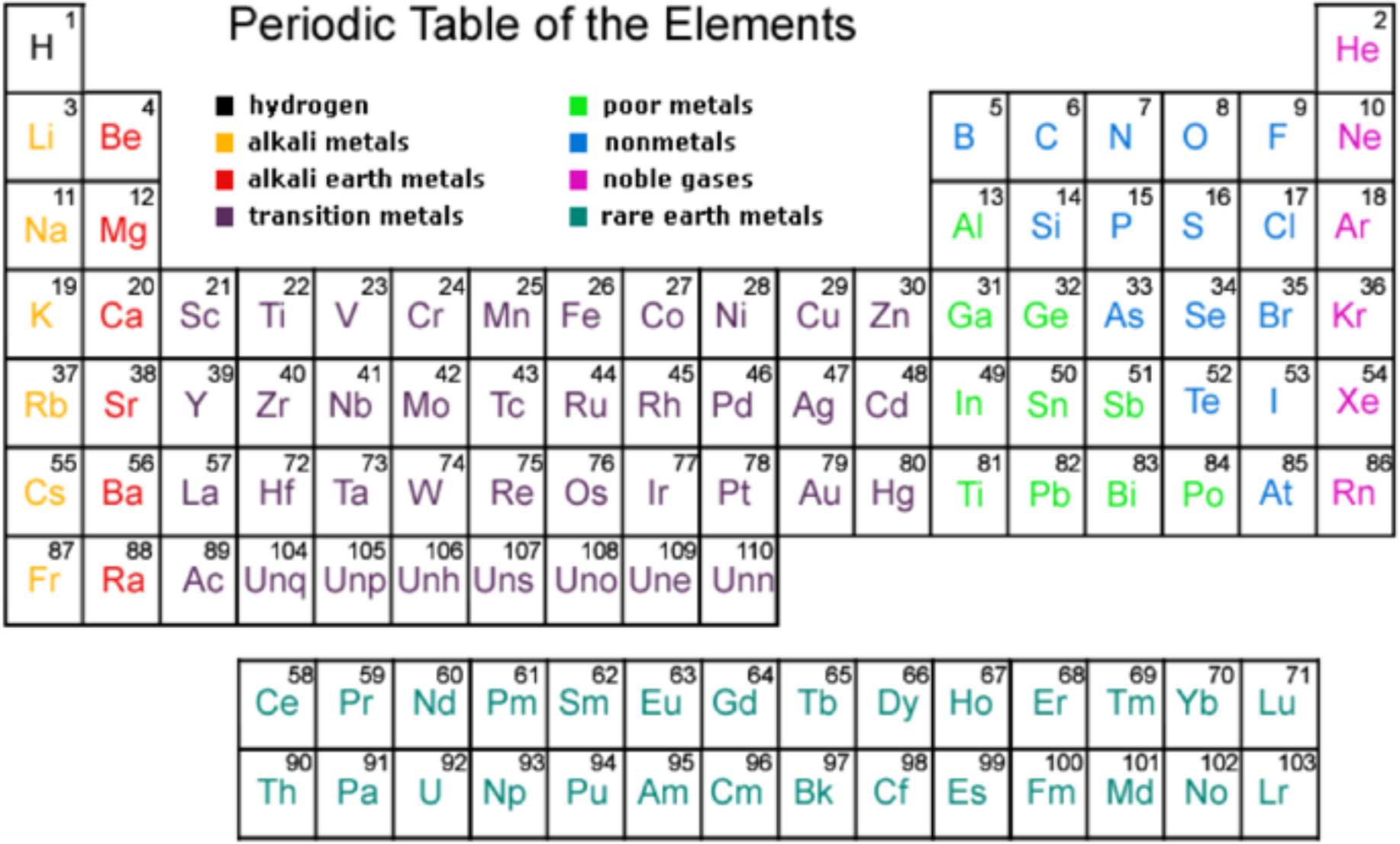
Keyhole Nebula

Hubble Heritage

NASA and The Hubble Heritage Team (STScI) • Hubble Space Telescope WFPC2 • STScI-PRC00-06

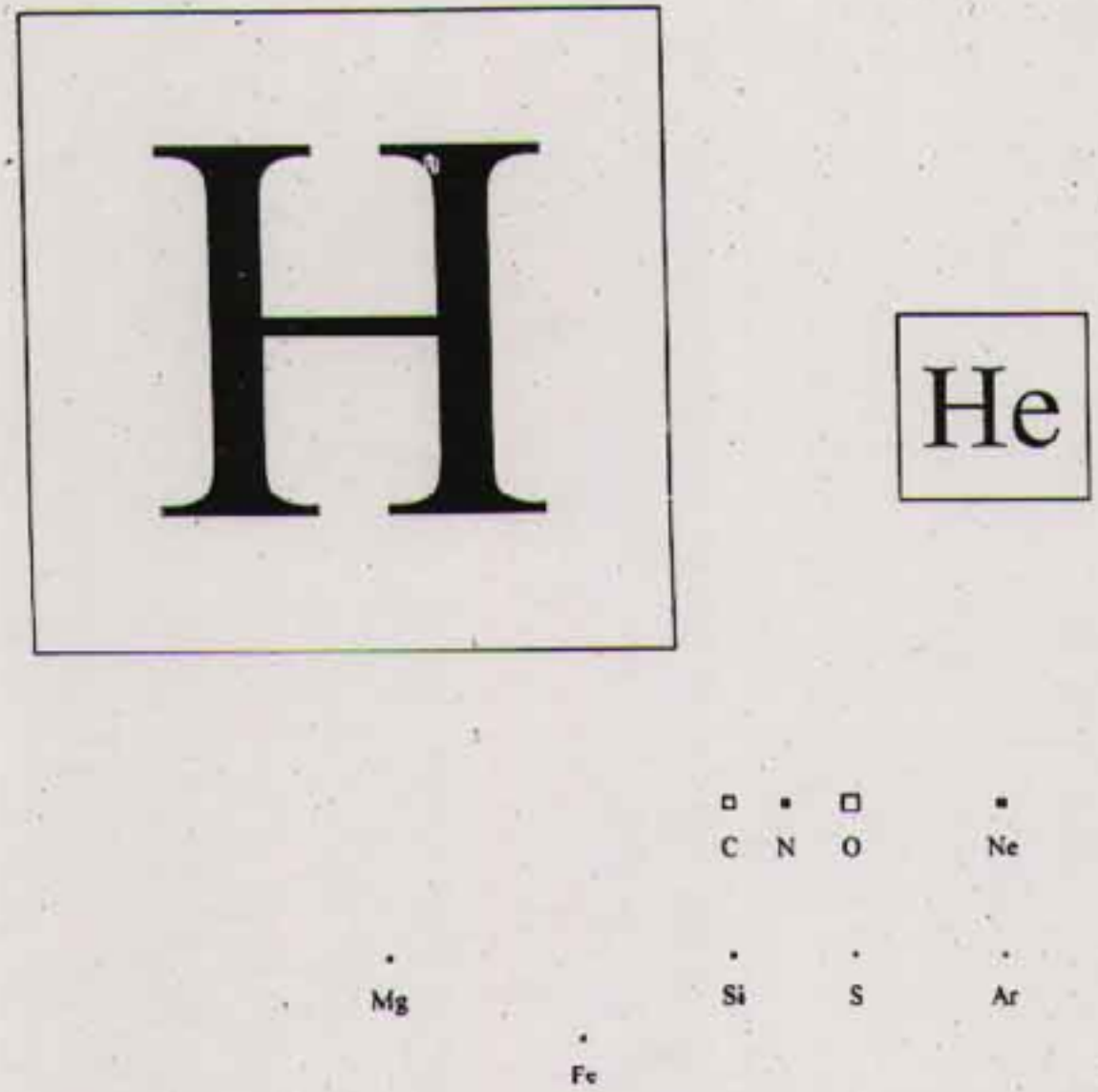
Where did the elements in the solar nebula come from?

Periodic Table of the Elements



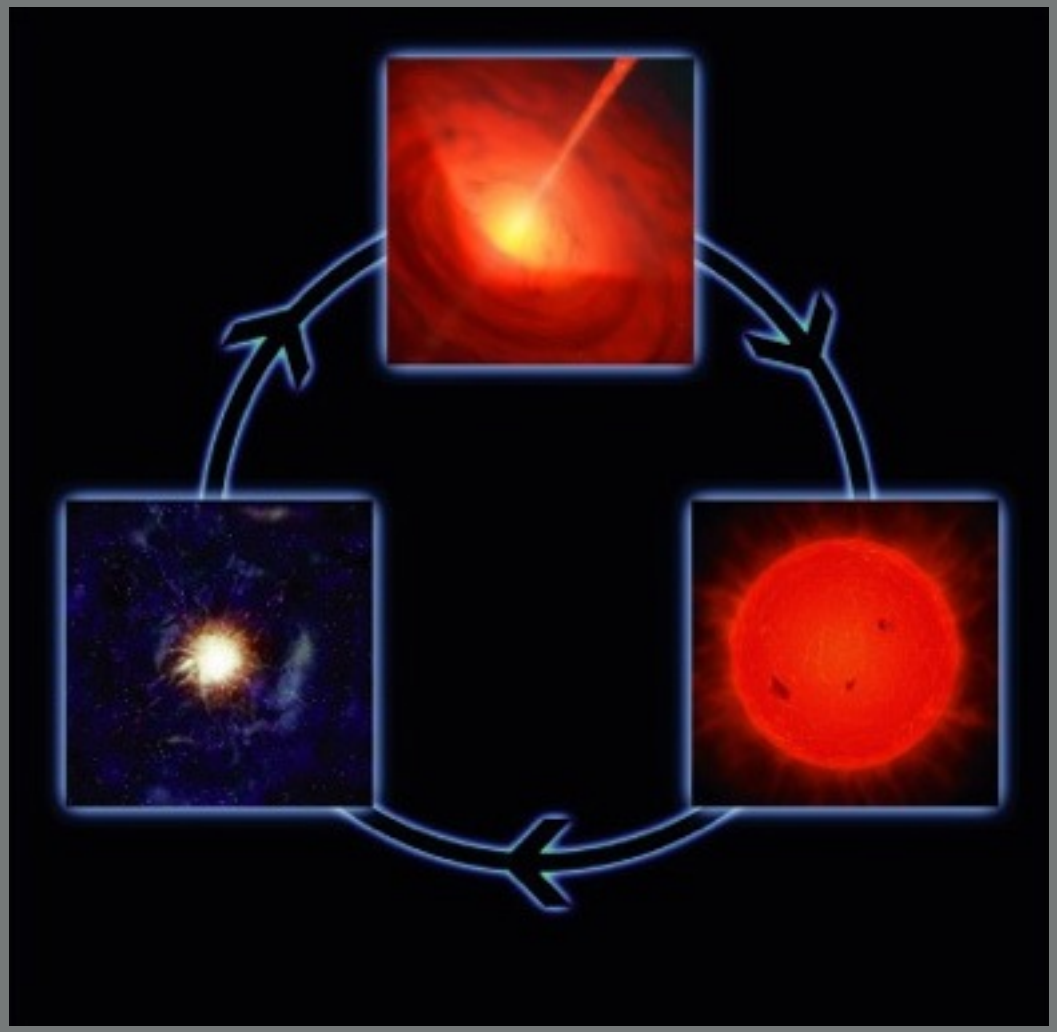
The Astronomer's Periodic Table

(Ben McCall)



- Almost entirely Hydrogen
- Some Helium
- Tiny amount of everything else (we call this stuff metal)

Galactic Recycling

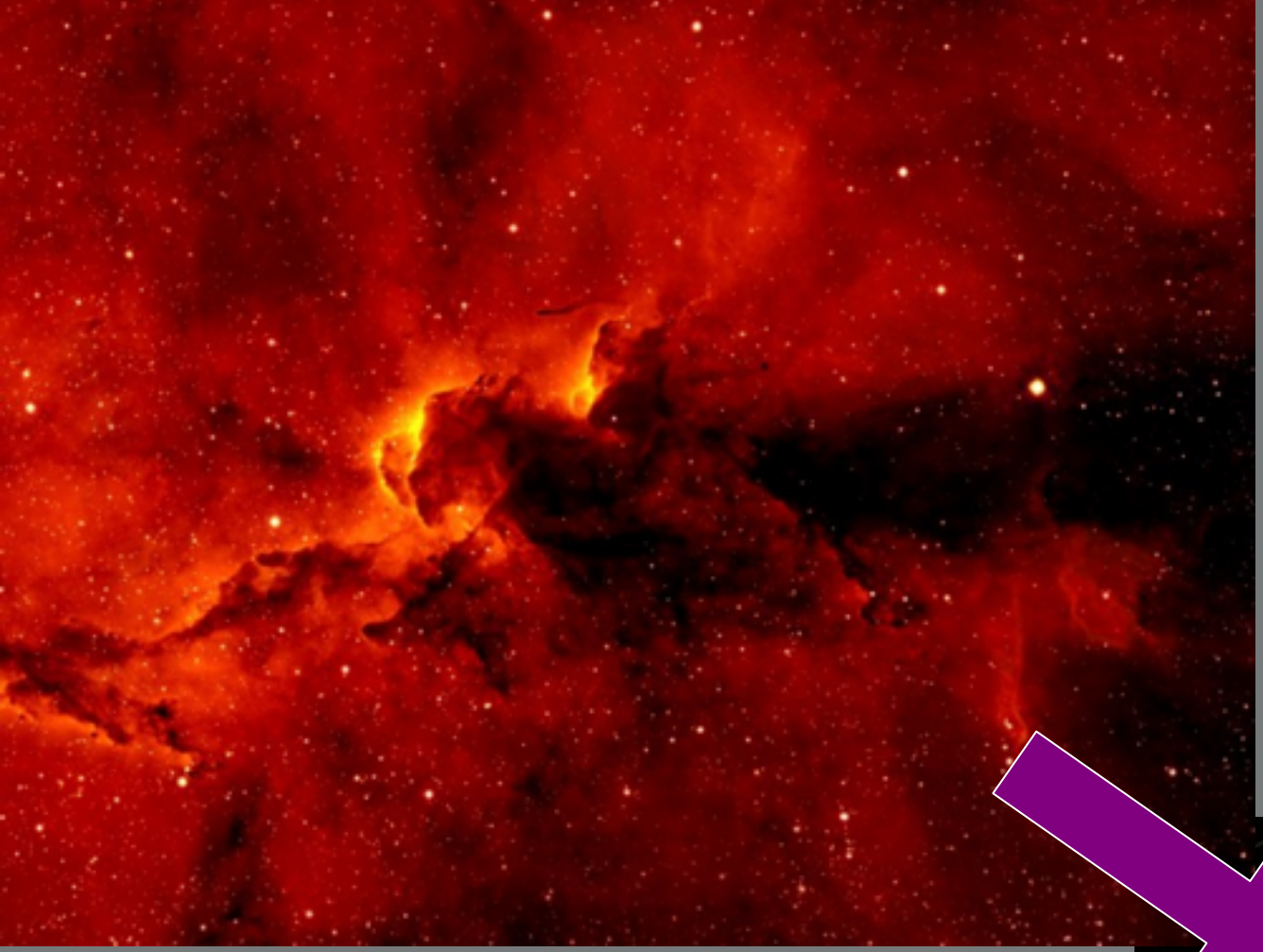


- H & He created in the Big Bang
- Heavier elements (everything else) were made in stars and then recycled through interstellar space

Thought Question

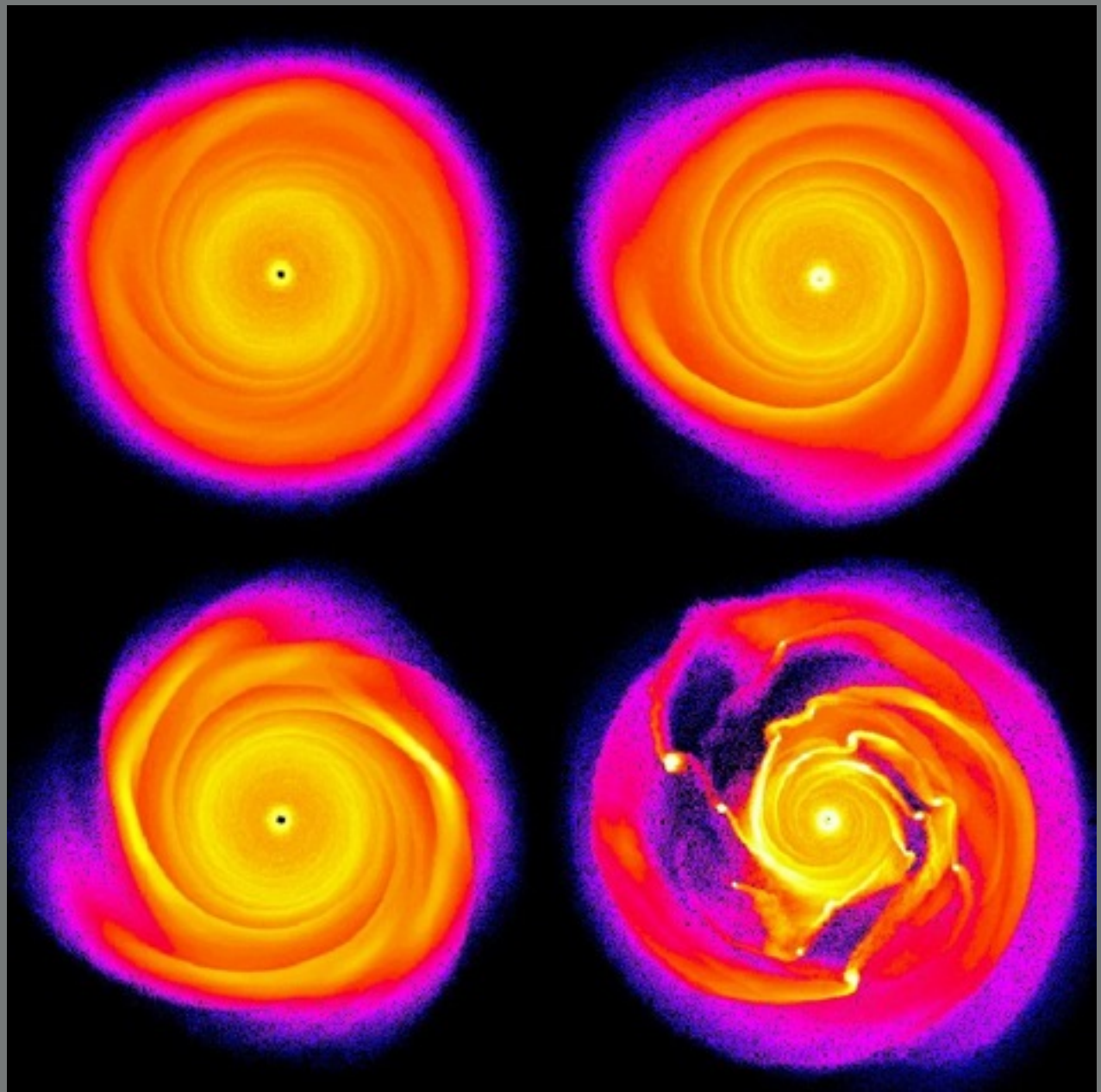
What would the "Astronomer's Periodic Table" look like if we looked at the universe in 10 billion years?

A. It would look exactly the same
B. The H and He would be a little smaller but not much, other elements a little bigger
C. The H and He would be pretty much gone, all converted to heavier elements
D. All the elements would be the same size (I.e. the same amount of everything)
E. We'd be back to the regular periodic table



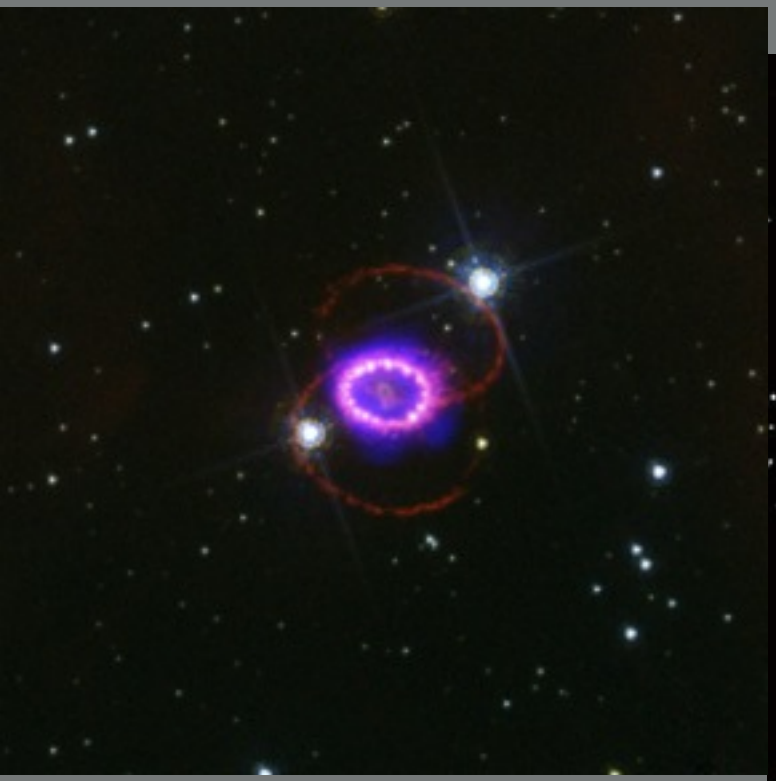
How does a solar system form from a collapsing cloud of gas?

Gravitational Instability



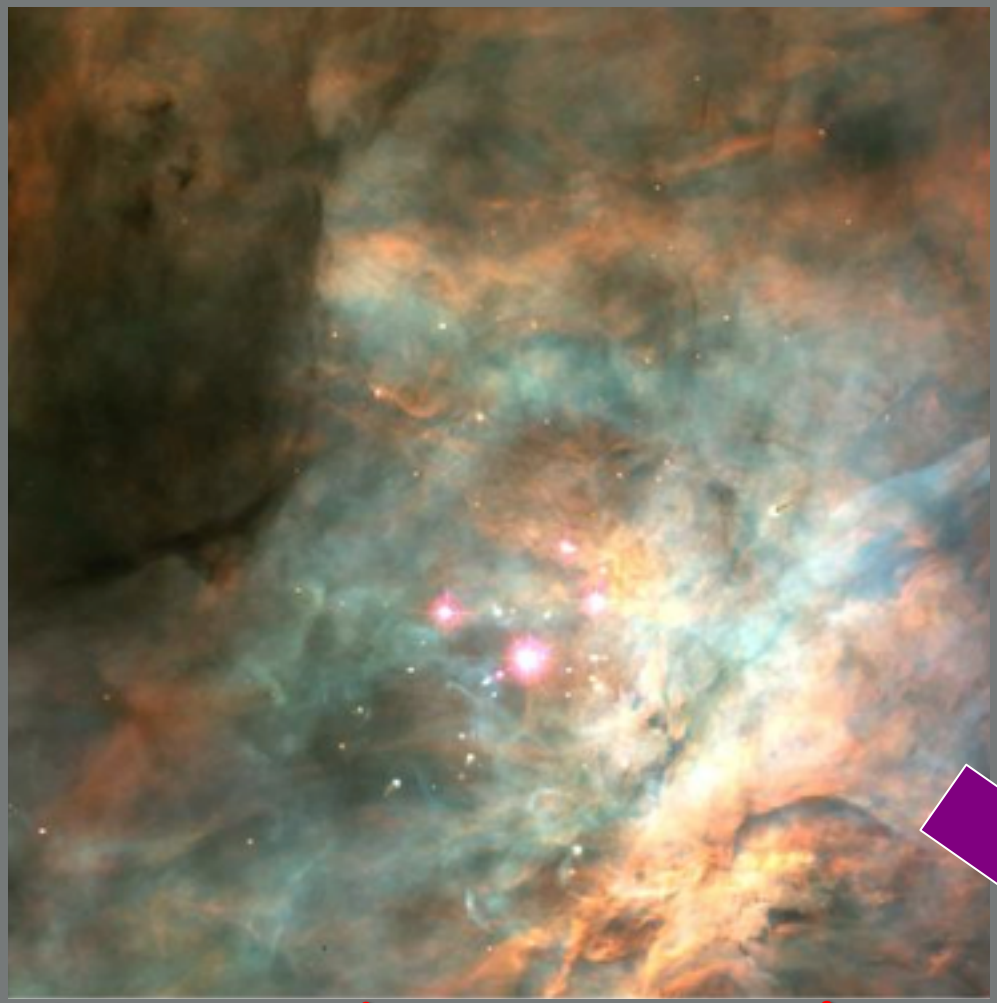
Merging Galaxies

Supernovae



Starburst Galaxies

Spiral Arms

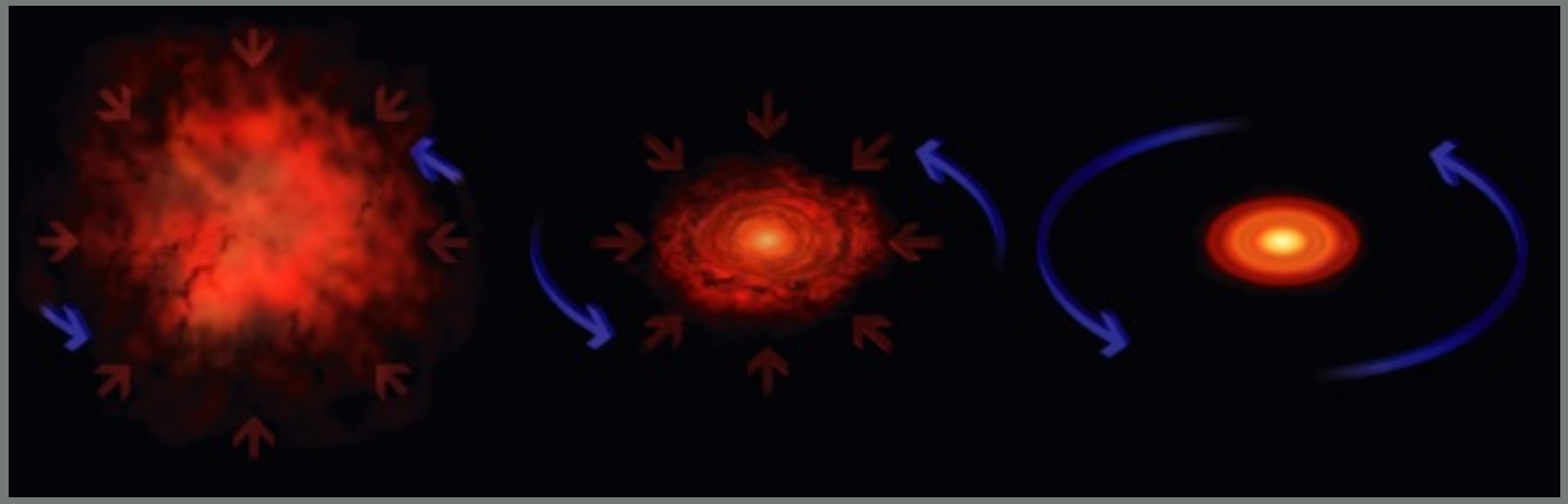


How does a solar system form from a cloud of gas?

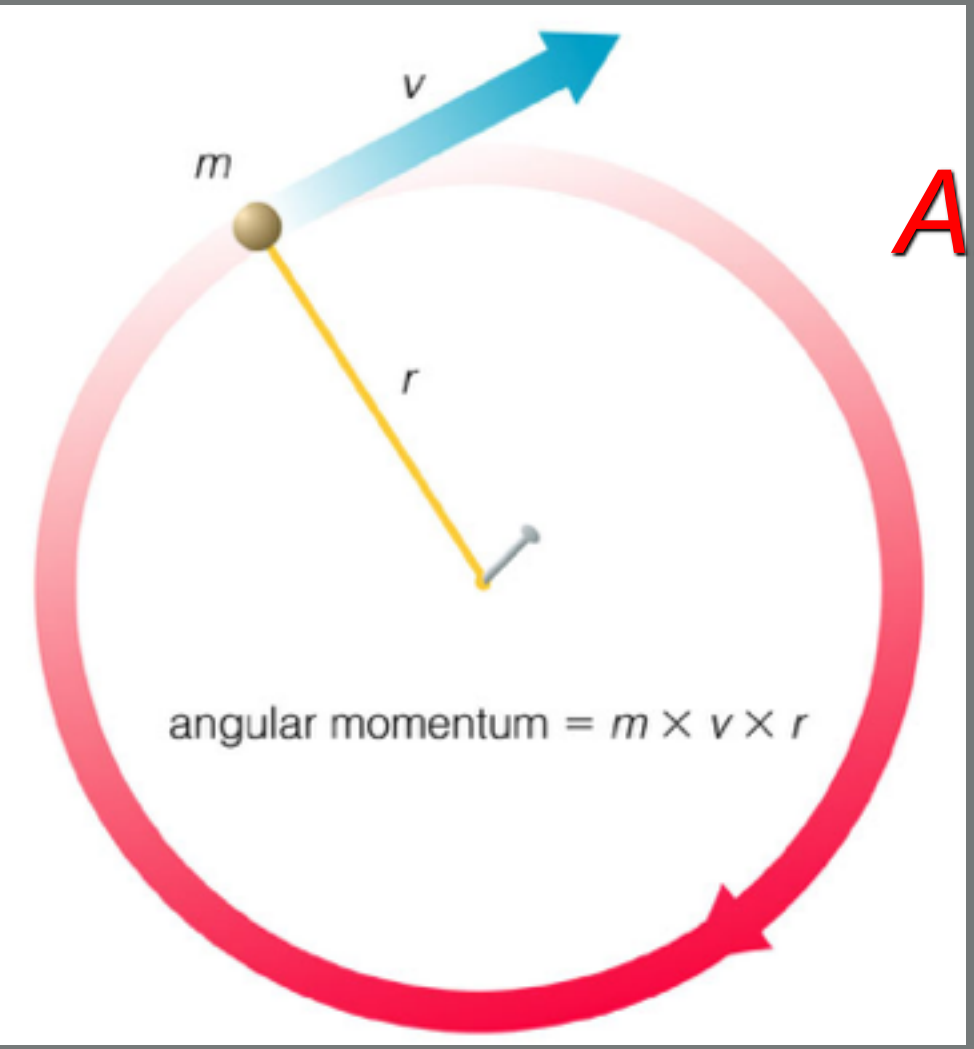
Four Challenges for a Solar System Formation Theory

1. Orderly motions
2. Two kinds of planets
3. Two kinds of small bodies
4. Exceptions to the rules

Collapse of the Solar Nebula



- As the solar nebula collapsed it:
  - Spun faster
  - Heated up
  - Flattened out into a disk



Conservation of Angular Momentum

M x V x R = Constant

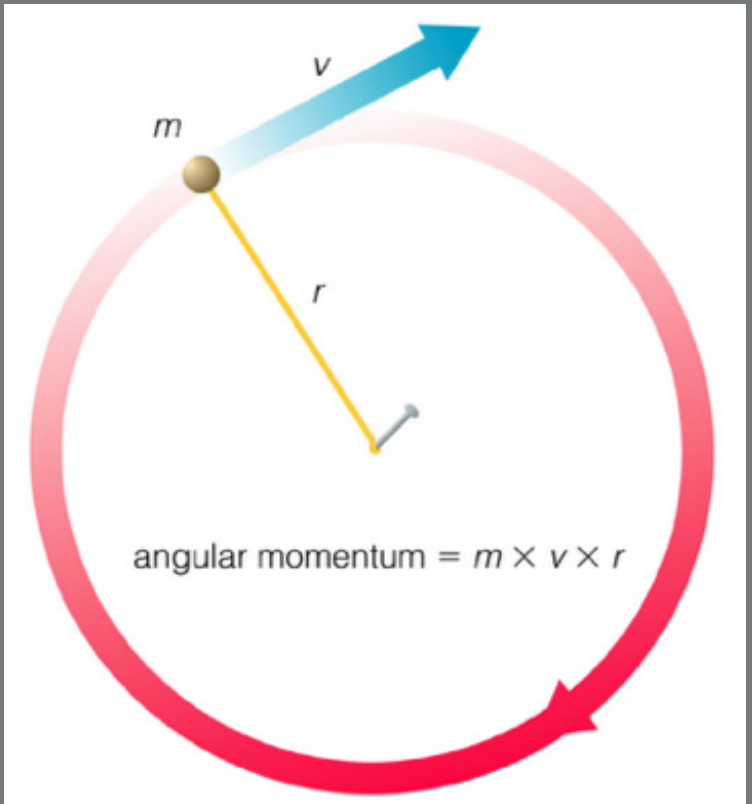
Thought Question

If angular momentum (m×v×r) is conserved (stays constant) what happens if r goes down (no change in m)?

A. v stays the same

B. v goes down

C. v goes up



Reading Question

What is the frost line?

A. The layer in a planet's atmosphere where temperatures are cold enough for ice to form.

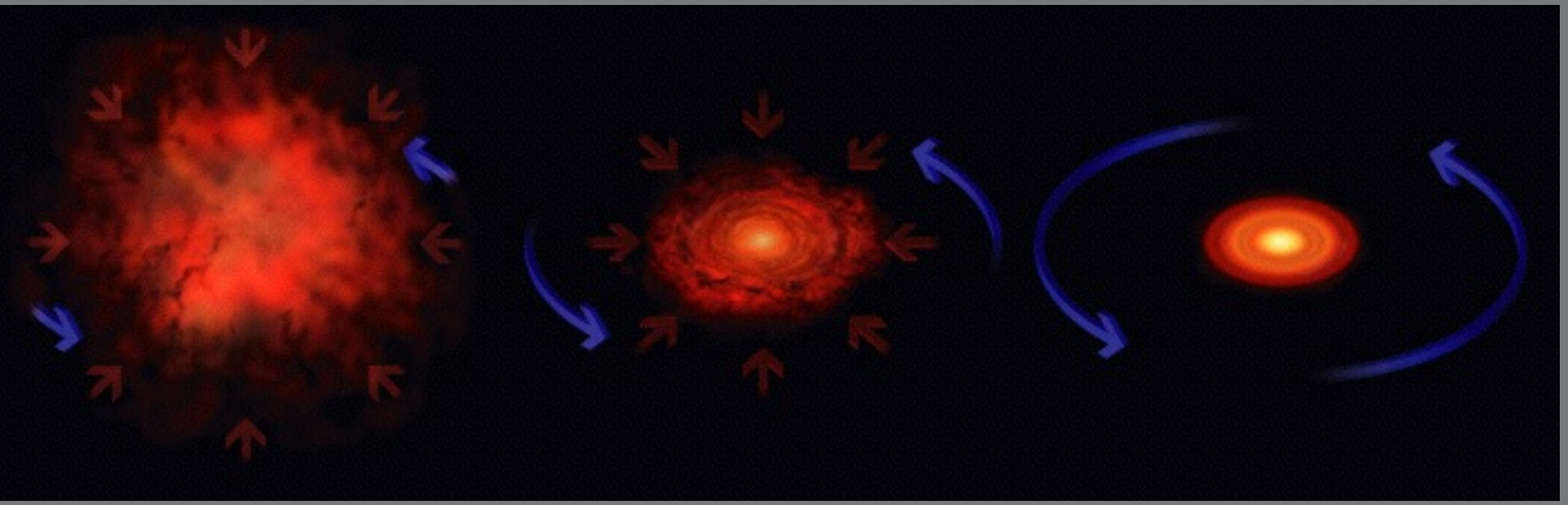
B. The time during the solar system formation that ices formed

C. The distance from the Sun in the solar system where the Dwarf Planets reside

D. The distance in the solar system where ice can begin to form

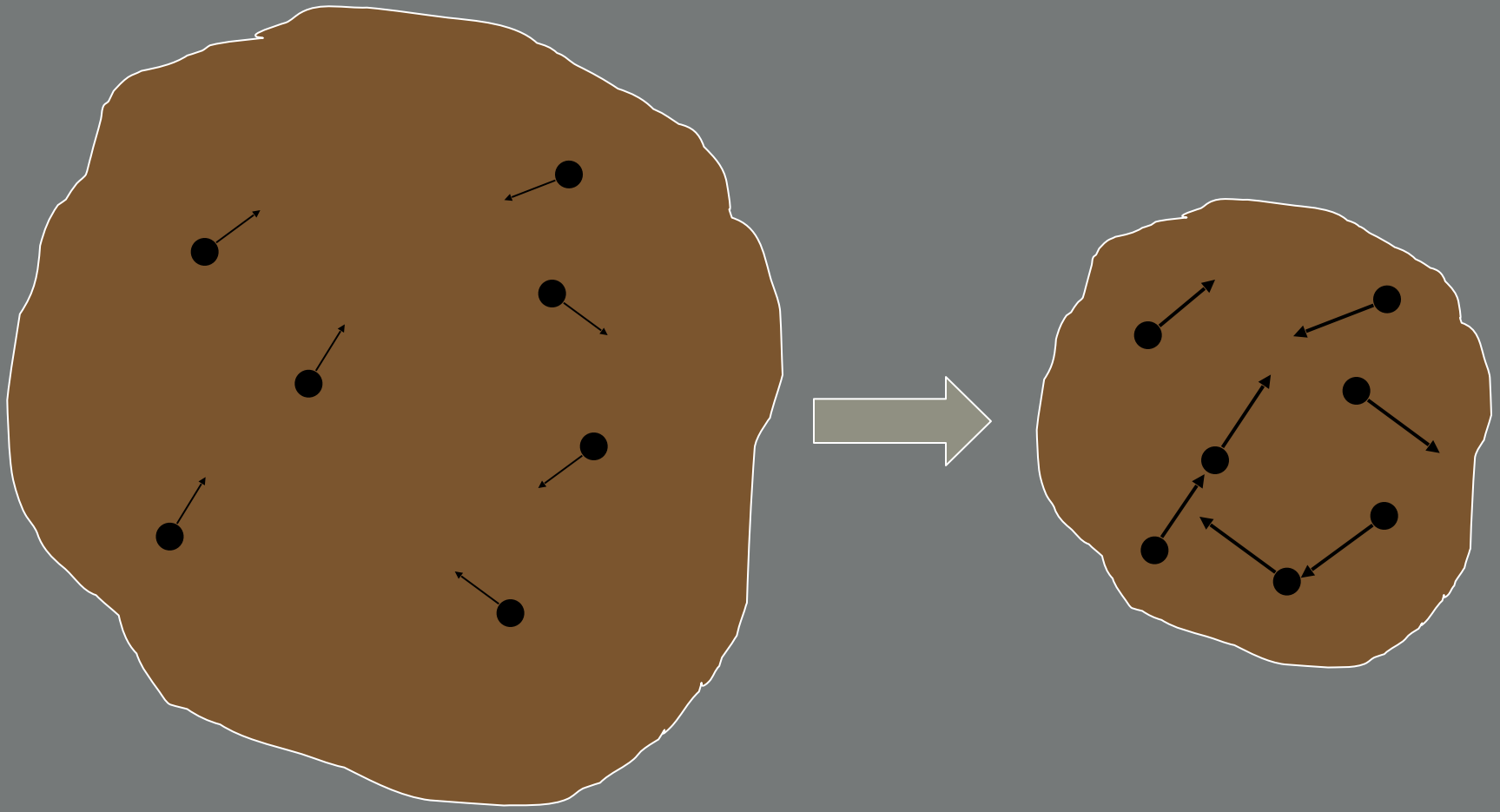
E. The distance from the Earth where water is no longer able to be liquid

Collapse of the Solar Nebula



Why did it heat up?

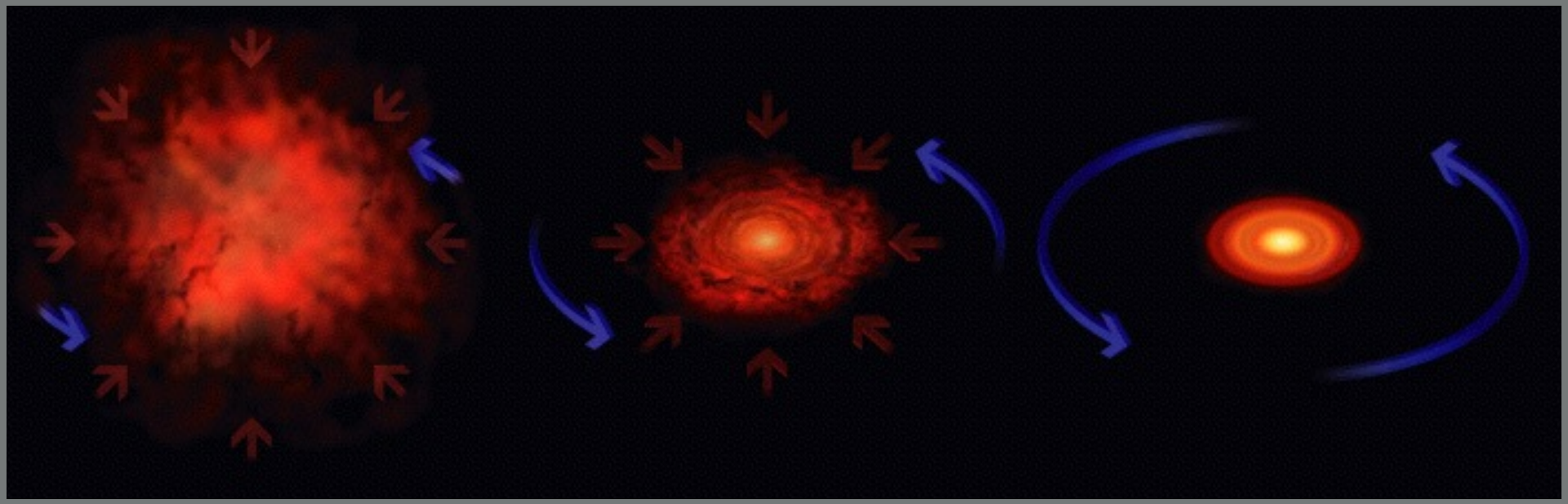
Collapse



Gravitational Energy ⇒ Kinetic Energy

Kinetic Energy ⇒ Thermal Energy

Collapse of the Solar Nebula



Why did it flatten into a disk?

Incorrect Reasons

Gravity is "pulling the material into a disk"

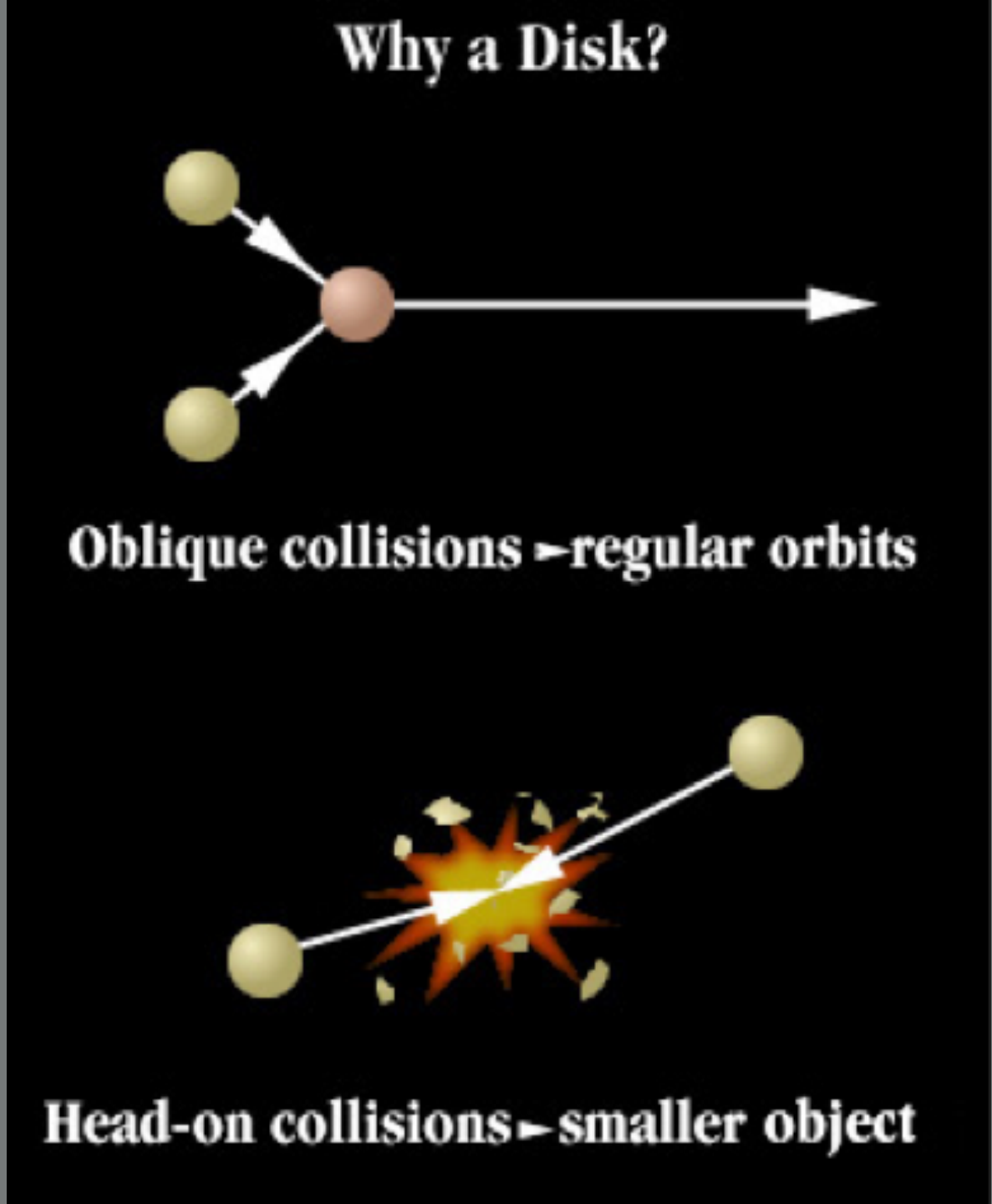
- Gravity is pulling everything in (spherically, not into a flat disk)

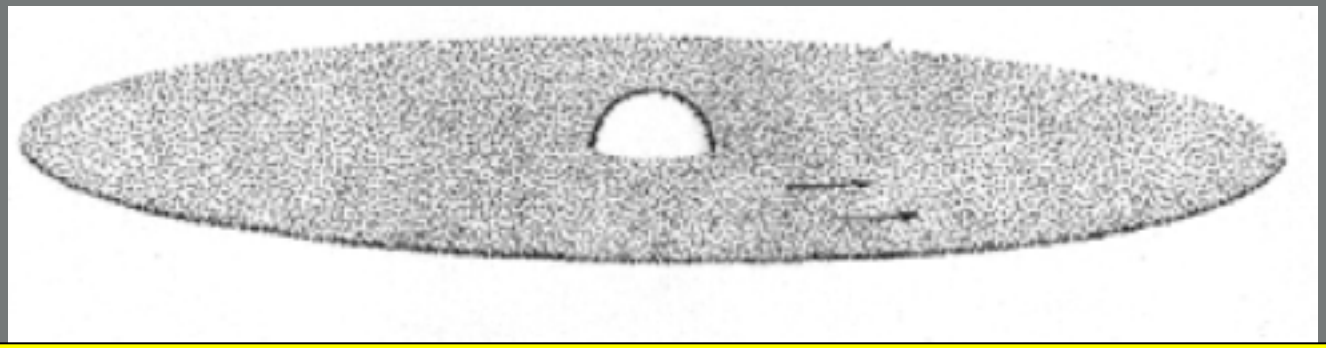
OR

The disk is being "flung out into a disk"

- Individual gas particles are in simple orbits (orbits don't get flung out)

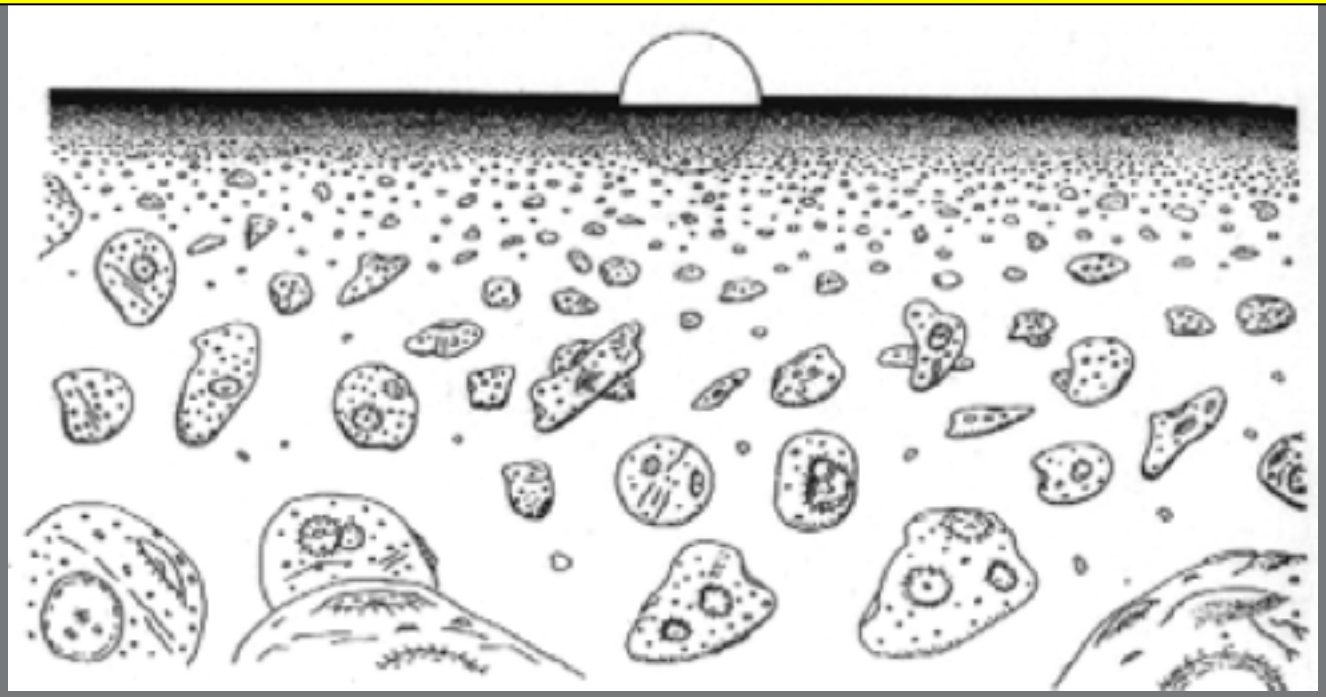
- Small random motions average out to a tiny bulk motion
  - this bulk motion is then "amplified" (due to increased spin rate) as the cloud collapses



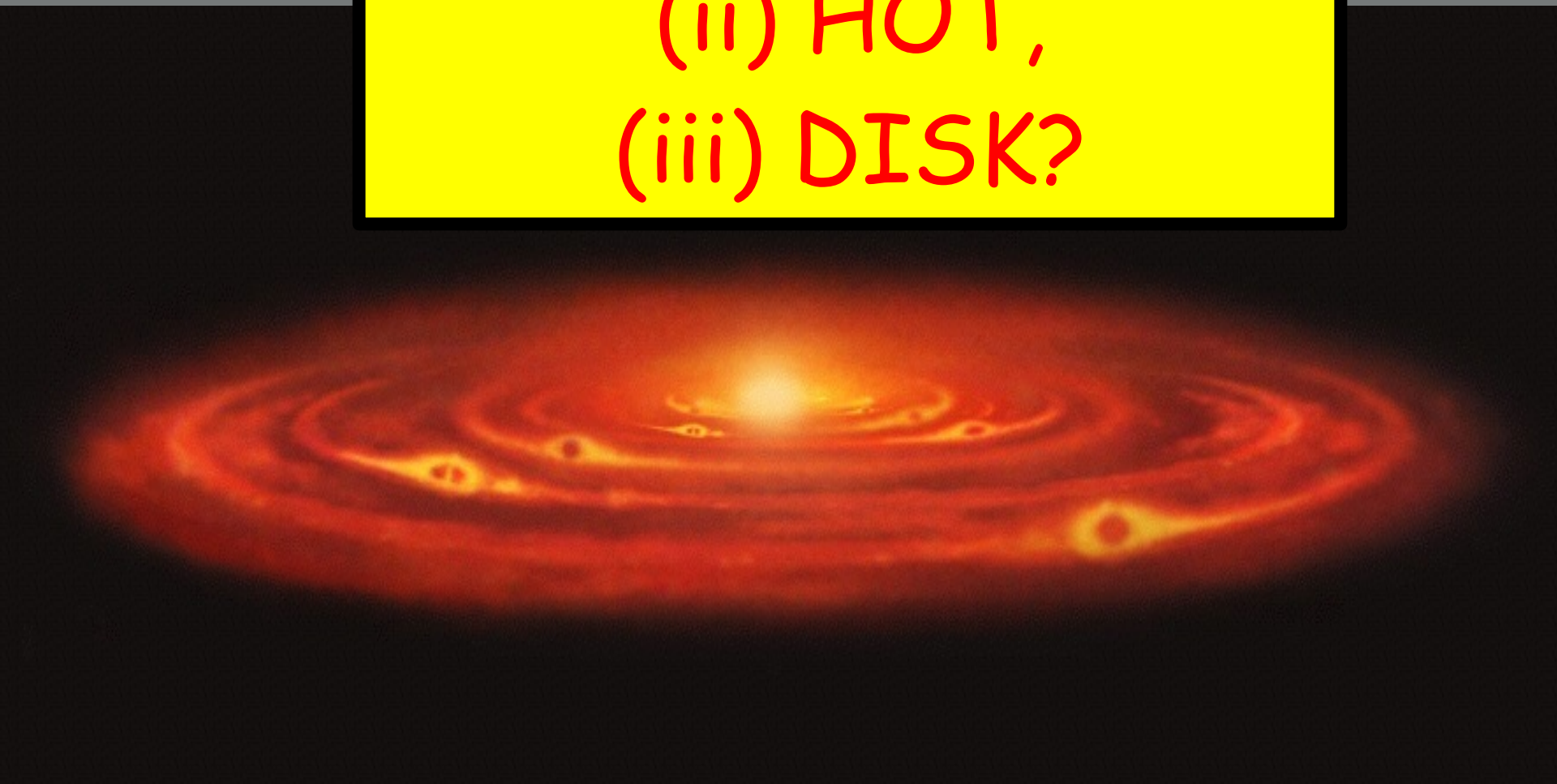


Extreme Conformism!

Go with the flow or crash to oblivion



Solar Nebula:
Why (i) SPINNING,
(ii) HOT,
(iii) DISK?



Solar Nebula: Why …

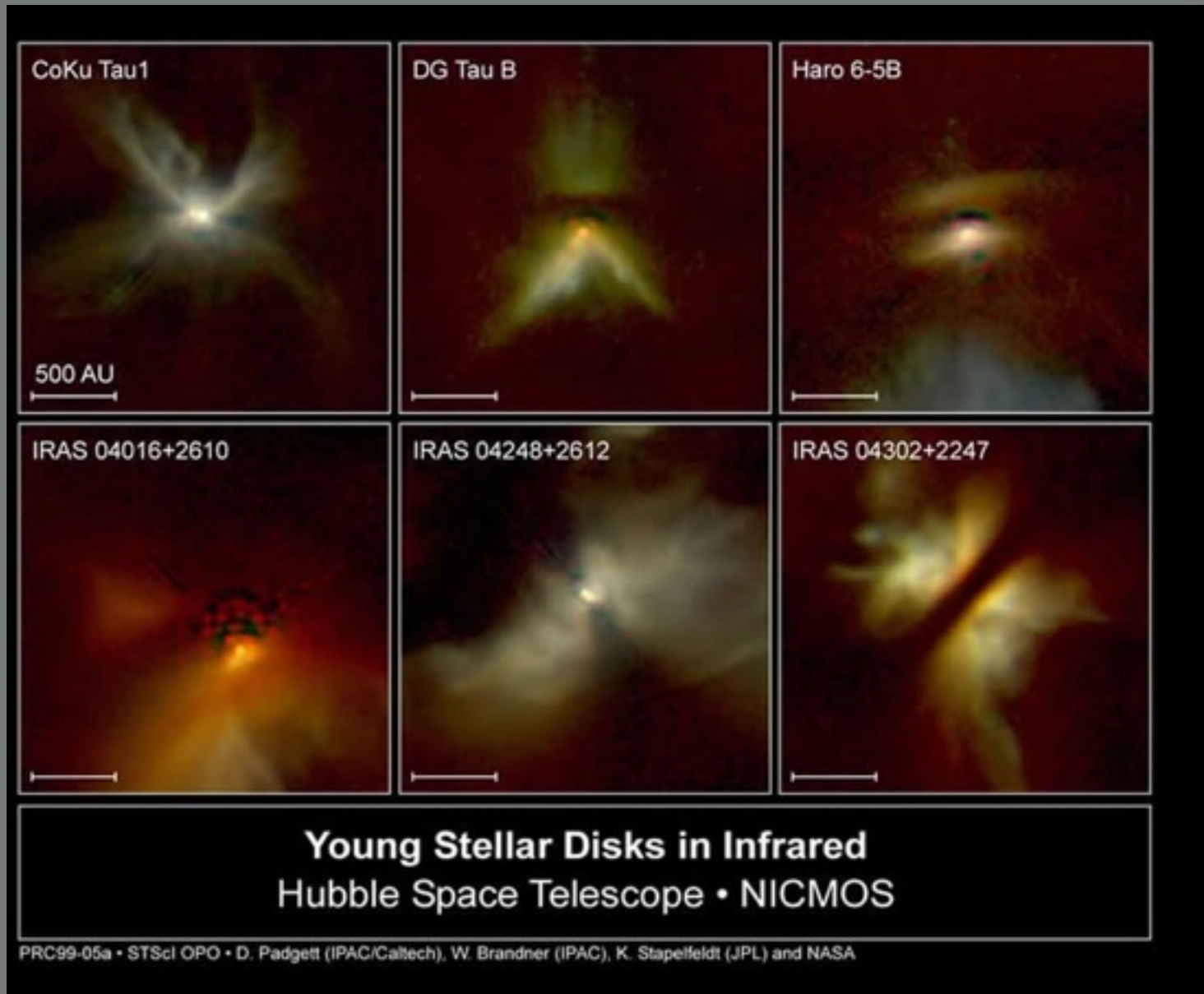
- SPINNING
  - Conservation of angular momentum
- HOT
  - Collapse ⇒ compression
- DISK
  - Collisions force common motions

Collapse

At this point, we are going to skip the details about forming the star

More Support for the Nebular Theory

- Plenty of disks around other stars
- New planetary systems forming?



Four Challenges for a Solar System Formation Theory

1. Orderly motions
2. Two kinds of planets
3. Two kinds of small bodies
4. Exceptions to the rules

Collapse

Building the Planets

- Let's look at the four main ingredients

Materials in the Solar Nebula

	Metals	Rocks	Hydrogen Compounds	Light Gases
				
Examples	iron, nickel, aluminum	various minerals	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)				

Collapse

Thought Question

Materials in the Solar Nebula

	Metals	Rocks	Hydrogen Compounds	Light Gases
				
Examples	iron, nickel, aluminum	various minerals	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)	▪ (0.2%)	▪ (0.4%)	■ (1.4%)	 (98%)

At 400K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds

Collapse

Thought Question

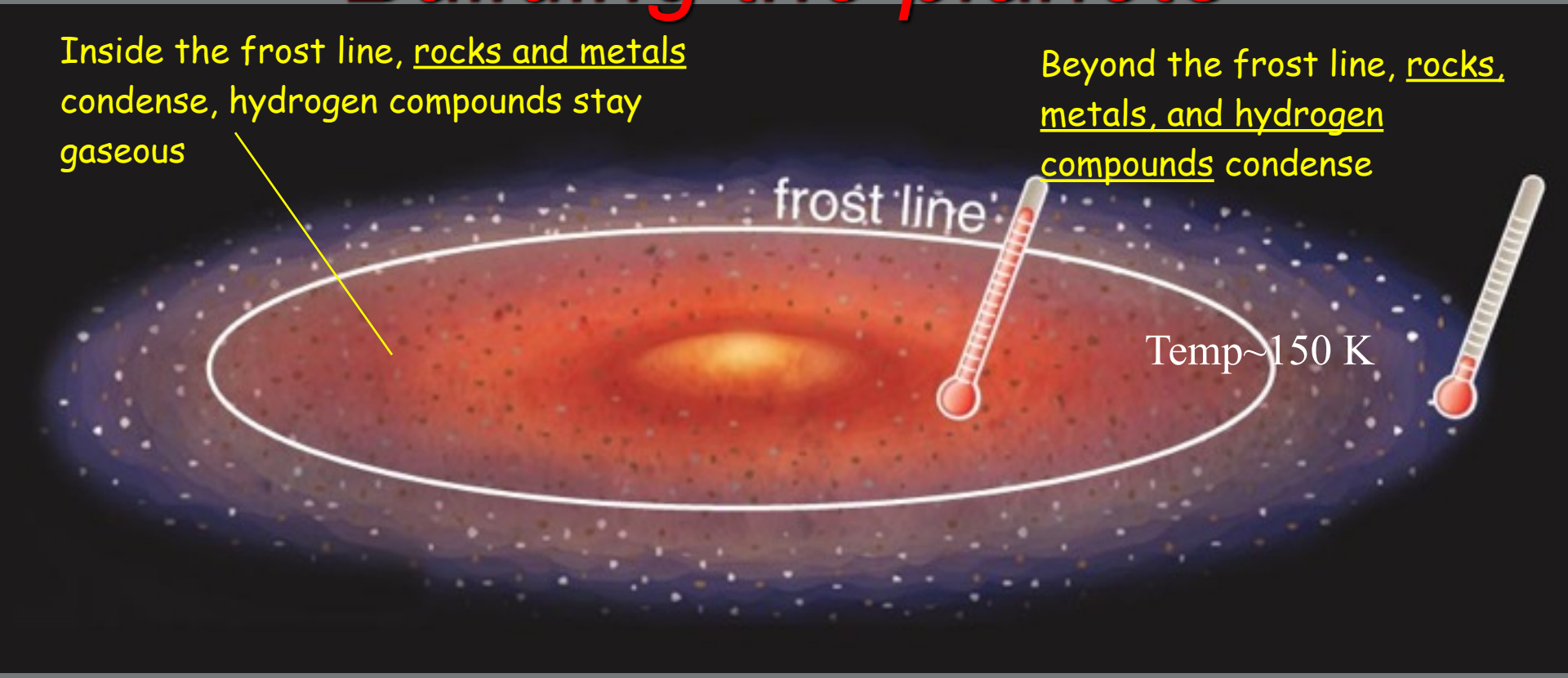
Materials in the Solar Nebula

	Metals	Rocks	Hydrogen Compounds	Light Gases
				
Examples	iron, nickel, aluminum	various minerals	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)	▪ (0.2%)	▪ (0.4%)	■ (1.4%)	 (98%)

At 100K, what exists in solid form?

A. Metals
B. Rocks
C. Hydrogen Compounds
D. Metals & Rocks
E. Metals, Rocks, and Hydrogen compounds

Building the planets



- Condensation
  - The formation of solid/liquid particles from a gas
- This is first step to forming planets

Next step: Turning planet seeds into planetesimals

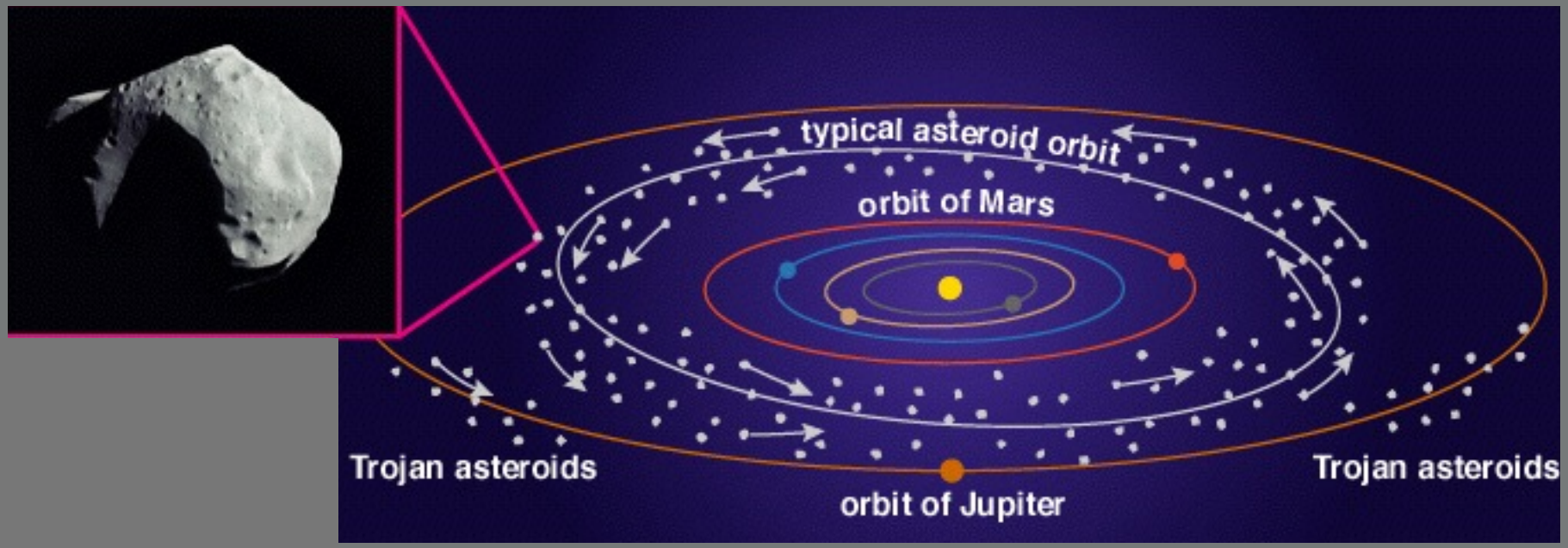
- Accretion
  - Small objects gather together to make larger objects
- The big get bigger - like a snowball
- REALLY big planetesimals (>10-20 M_{Earth}) gravitationally capture hydrogen (the most abundant gas) and become GIANTS
  - Objects outside the frost line had more material available

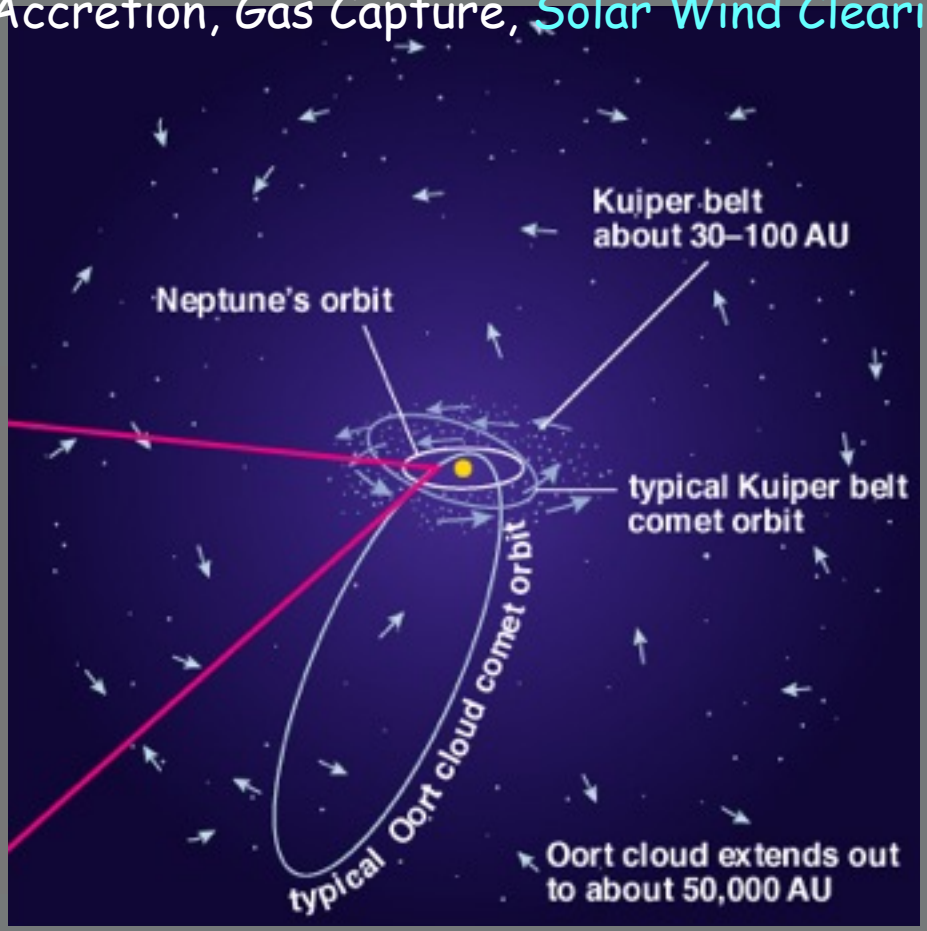
Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. **Two kinds of small bodies**
4. Exceptions to the rules

Origin of the Asteroids

- Leftover rocky planetesimals which did not accrete onto a planet are **asteroids**.
- Most were shepherded into the **asteroid belt** between Mars & Jupiter.
  - Jupiter's gravity prevented a planet from forming there.





Origin of the Comets

- Leftover icy planetesimals are **comets**.
  - Planetesimals beyond Neptune's orbit stayed in the ecliptic plane in the Kuiper belt.
  - Planetesimals among jovian planets 'flung out' in all directions into the Oort cloud.

Thought Question

What would have happened if the solar wind had 'turned on' much earlier (but after condensation/accretion)?

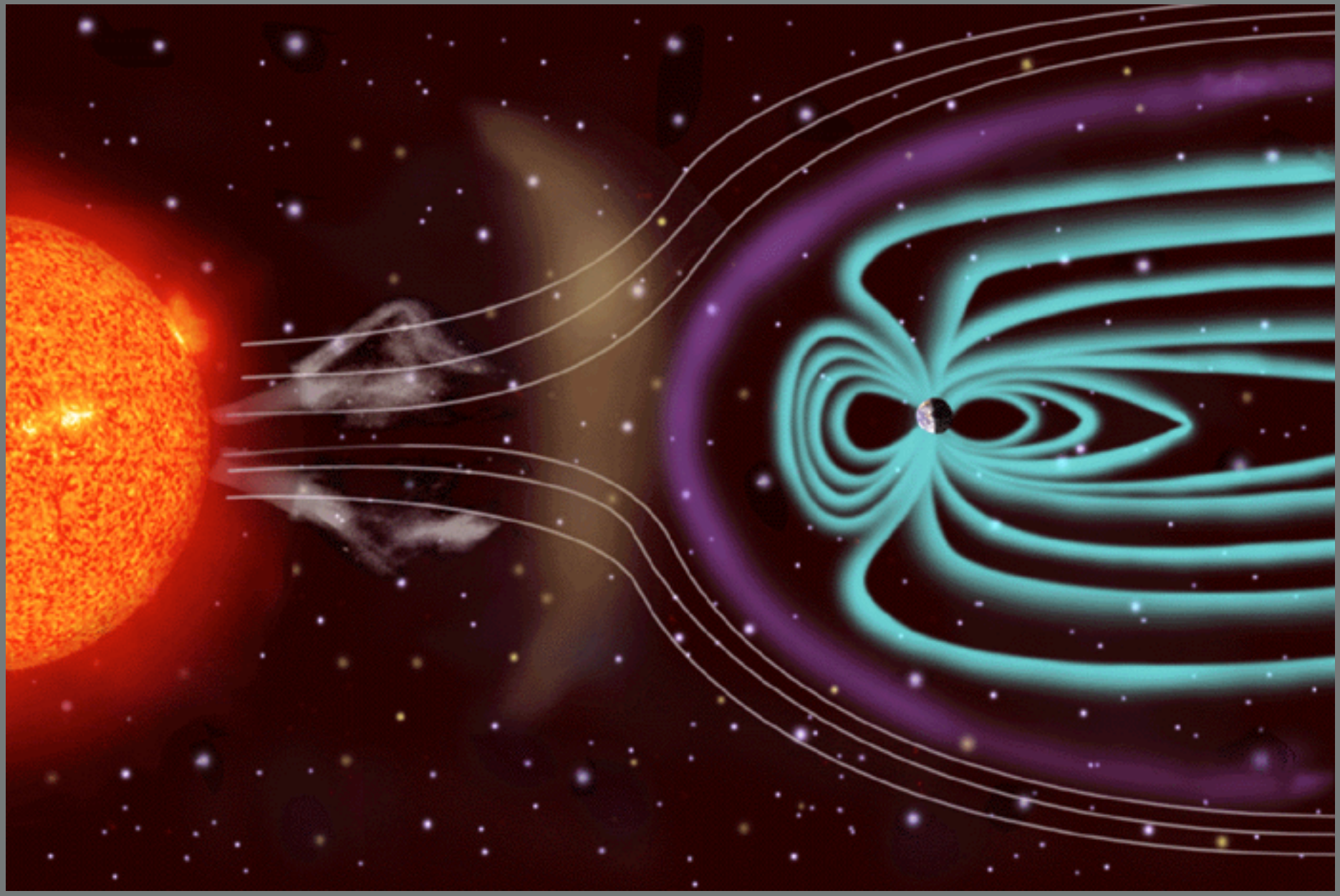
A. The planets would all have much thicker atmospheres
B. Jovian planets would not be as large
C. Terrestrial planets would not be as large
D. Earth's moon would look much different
E. There would be a lot more asteroids and comets

Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules

Original Disk of Gas & Dust, what cleared it?

- Solar Wind
- External Stars
- Instabilities
- Planetary Migration
- Mass Capture into planets



SEGUE TIME

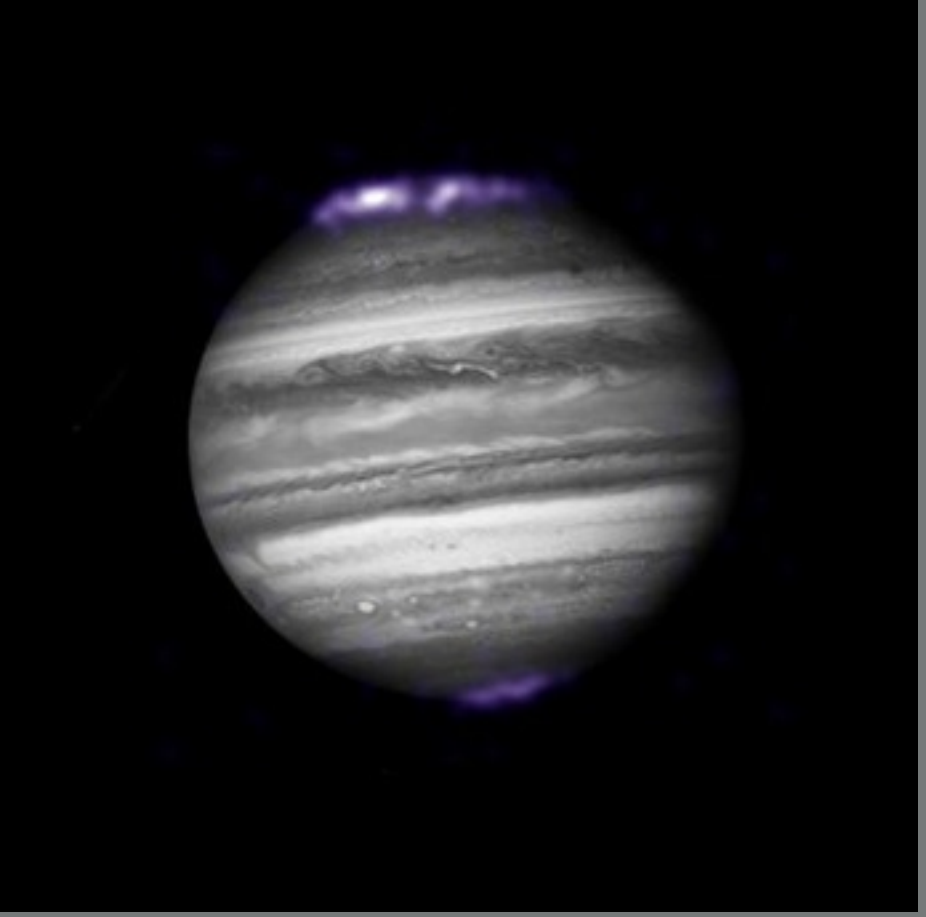
From Wikipedia (cut&paste)

- Auroras are associated with the solar wind, a flow of ions continuously flowing outward from the sun. The Earth's magnetic field traps these particles, many of which travel toward the poles where they are accelerated toward earth. Collisions between these ions and atmospheric atoms and molecules causes energy releases in the form of auroras appearing in large circles around the poles. Auroras are more frequent and brighter during the intense phase of the solar cycle when coronal mass ejections increase the intensity of the solar wind.

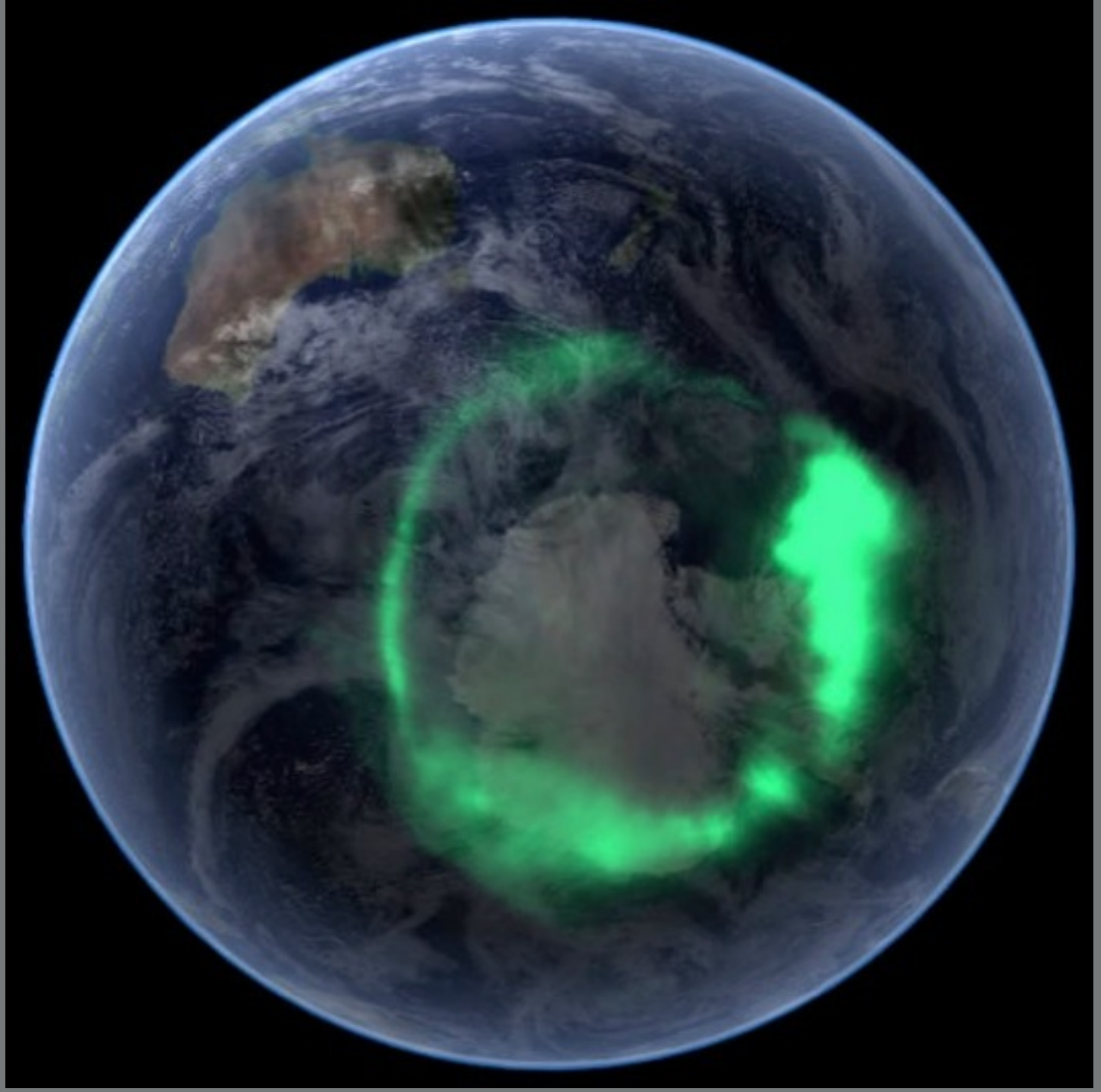
From Wikipedia/ru&nasta\

- Auroras are the result of the emissions of photons in the Earth's upper atmosphere, above 80 km (50 miles), from ionized nitrogen atoms regaining an electron, and oxygen and nitrogen atoms returning from an excited state to ground state. They are ionized or excited by the collision of solar wind particles being funneled down and accelerated along the Earth's magnetic field lines; excitation energy is lost by the emission of a photon of light, or by collision with another atom or molecule:
- oxygen emissions -Green or brownish-red, depending on the amount of energy absorbed.
- nitrogen emissions - Blue or red. Blue if the atom regains an electron after it has been ionized. Red if returning to ground state from an excited state.
- Oxygen is unusual in terms of its return to ground state: it can take 3/4 of a second to emit green light and up to 2 minutes to emit red. Collisions with other atoms or molecules will absorb the excitation energy and prevent emission. The very top of the atmosphere is both a higher percentage of oxygen, and so thin that such collisions are rare enough to allow time for oxygen to emit red. Collisions become more frequent progressing down into the atmosphere, so that red emissions do not have time to happen, and eventually even green light emissions are prevented.
- This is why there is a colour differential with altitude; at high altitude oxygen red dominates, then oxygen green and nitrogen blue/red, then finally nitrogen blue/red when collisions prevent oxygen from emitting anything.

- Solar Wind (electrons and protons at 400-750 km/s ~ 1 million mph)
- Tangent - 6.7 billion tons/hour lost from the sun
- Channeled by Earth's Magnetosphere
- Smacks Nitrogen and Oxygen in atmosphere
- Emits light (red, green, blue)



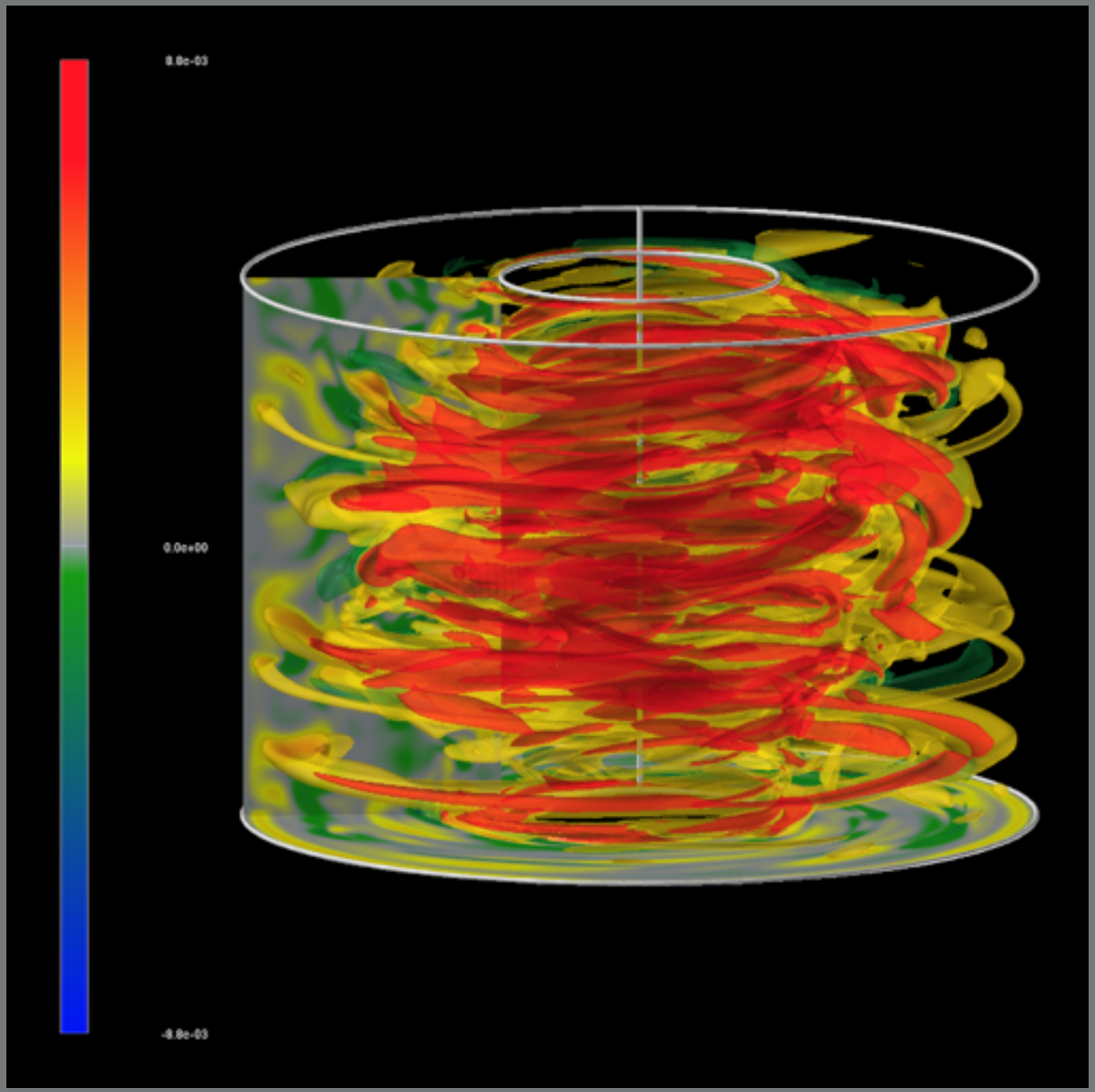

Jupiter's electric-blue aurora
one half billion miles away
centered on magnetic north pole

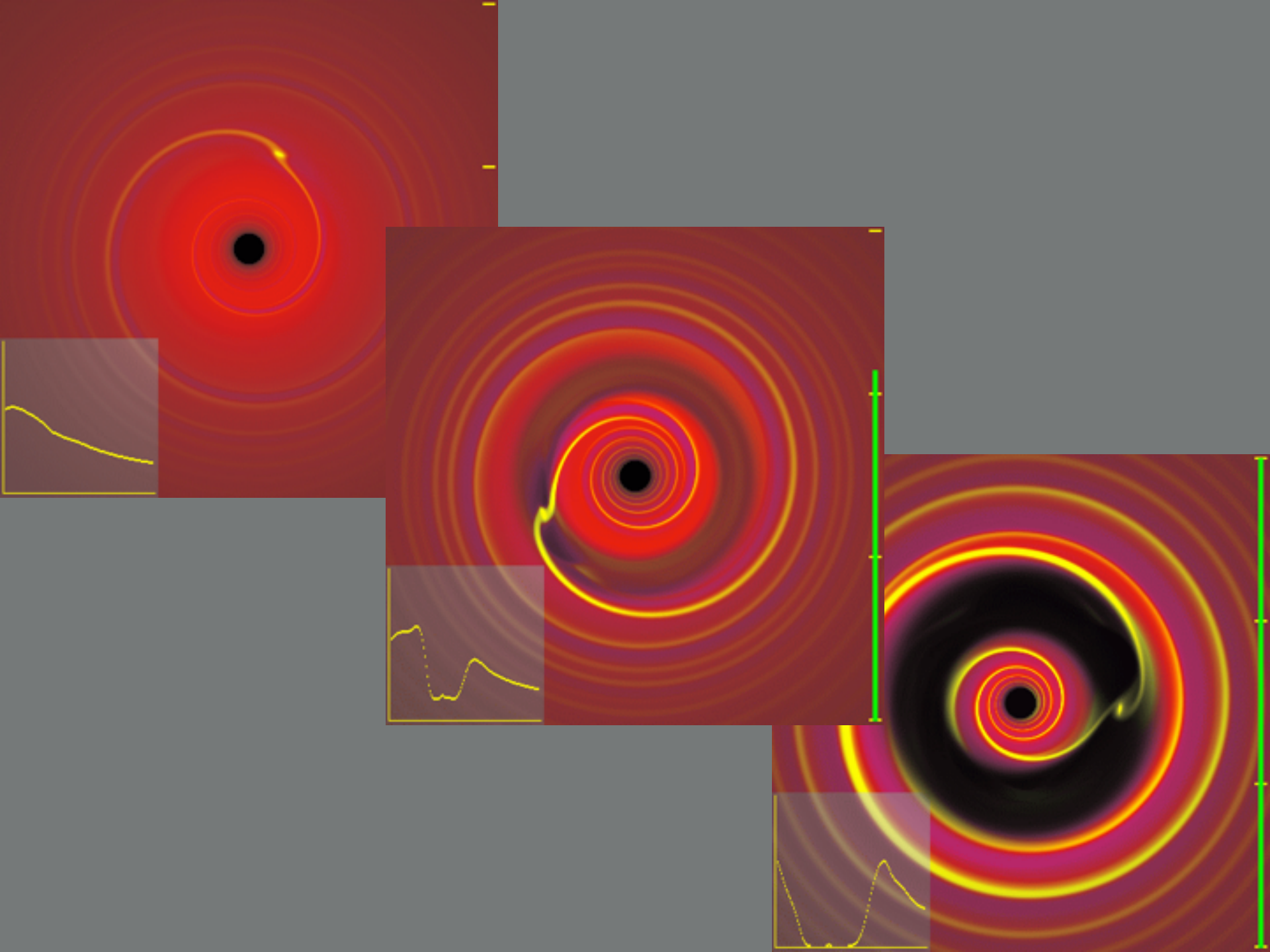


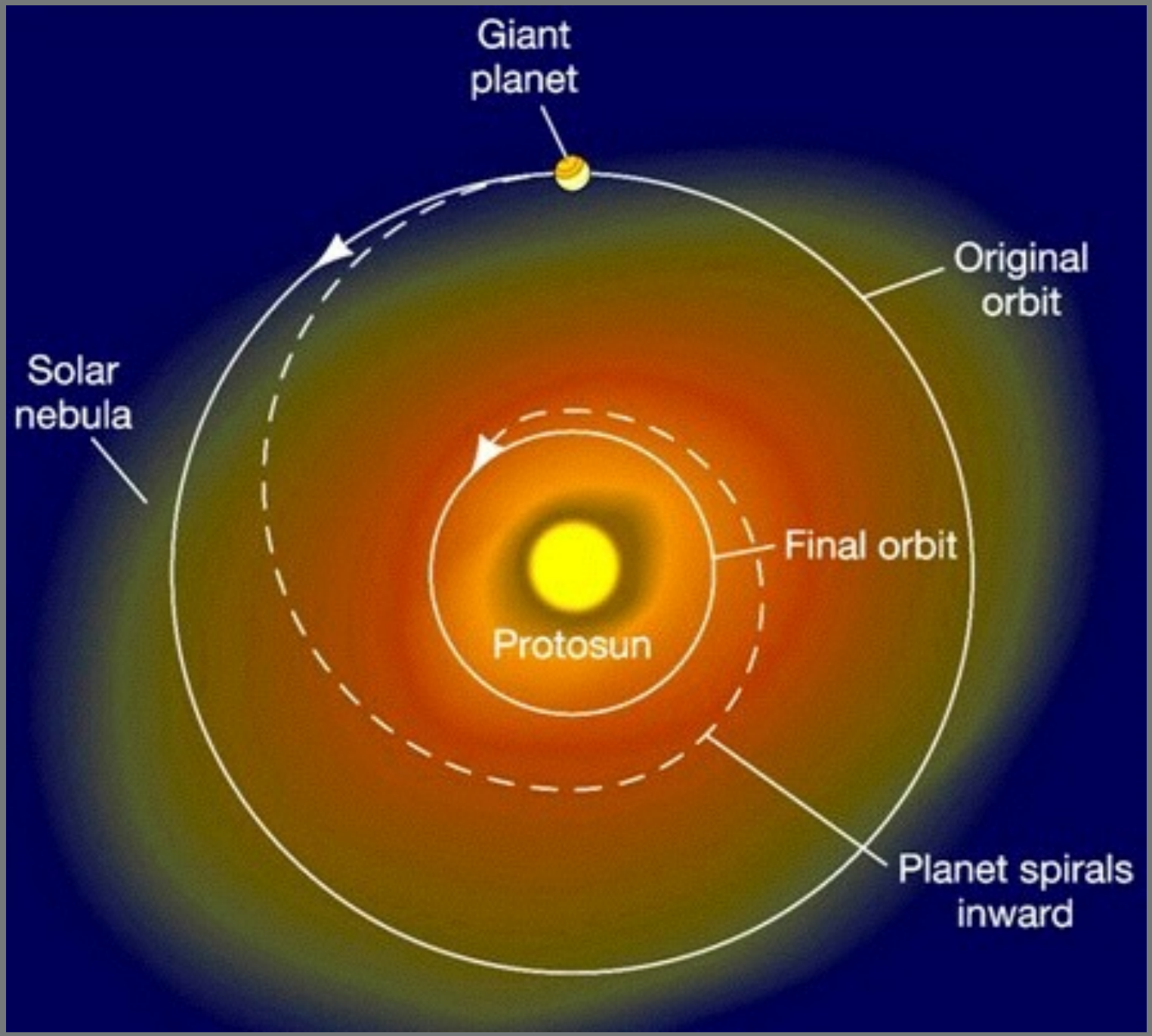
Back on topic

Protoplanetary Disks in the Orion Nebula **HST • WFPC2**

NASA, J. Bally (University of Colorado), H. Throop (SWRI), and C.R. O'Dell (Vanderbilt University) • STScI-PRC01-13


8.0e-03
0.0e+00
-8.0e-03




Giant planet
Original orbit
Solar nebula
Final orbit
Protosun
Planet spirals inward

Thought Question

Which characteristic of Earth is not *explained by our theory so far (nebula collapse, condensation, accretion, gas capture, solar wind clearing)?*

A. Earth is composed of rocks and metals
B. Earth has oceans and a moderate atmosphere
C. Earth orbits the Sun on a fairly circular orbit
D. Earth has very little hydrogen & helium gas
E. Earth is located in the inner solar system

Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules

After all the gas cleared out, there was still lots of planetesimals roaming around

- Collisions were frequent
  - This was known as the period of **heavy bombardment**

Origin of Earth's Water & Atmosphere

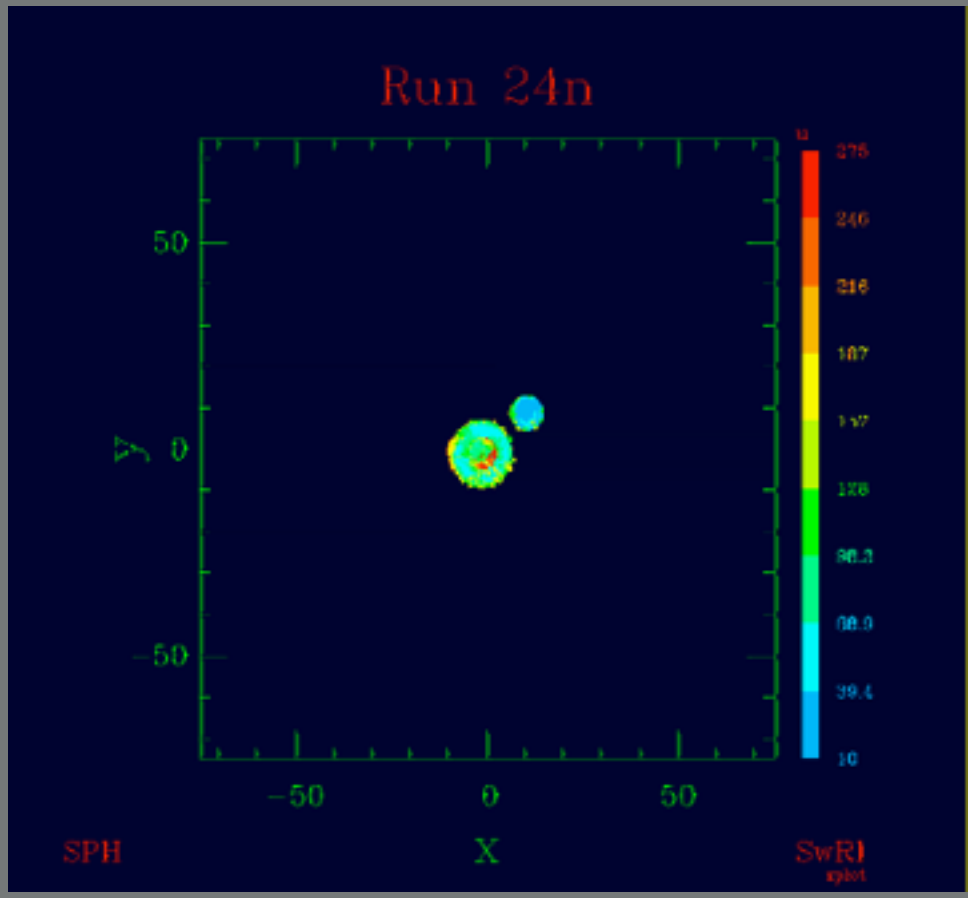
- Bombardment by asteroids brings us 'the good stuff' from beyond the frost line!
  - Water may have come to Earth by way of icy planetesimals from outer solar system

Formation of the Moon (Giant Impact Theory)

- Earth was struck by a Mars-sized planetesimal
- Part of Earth's outer layers was ejected
- This re-accreted into the Moon.

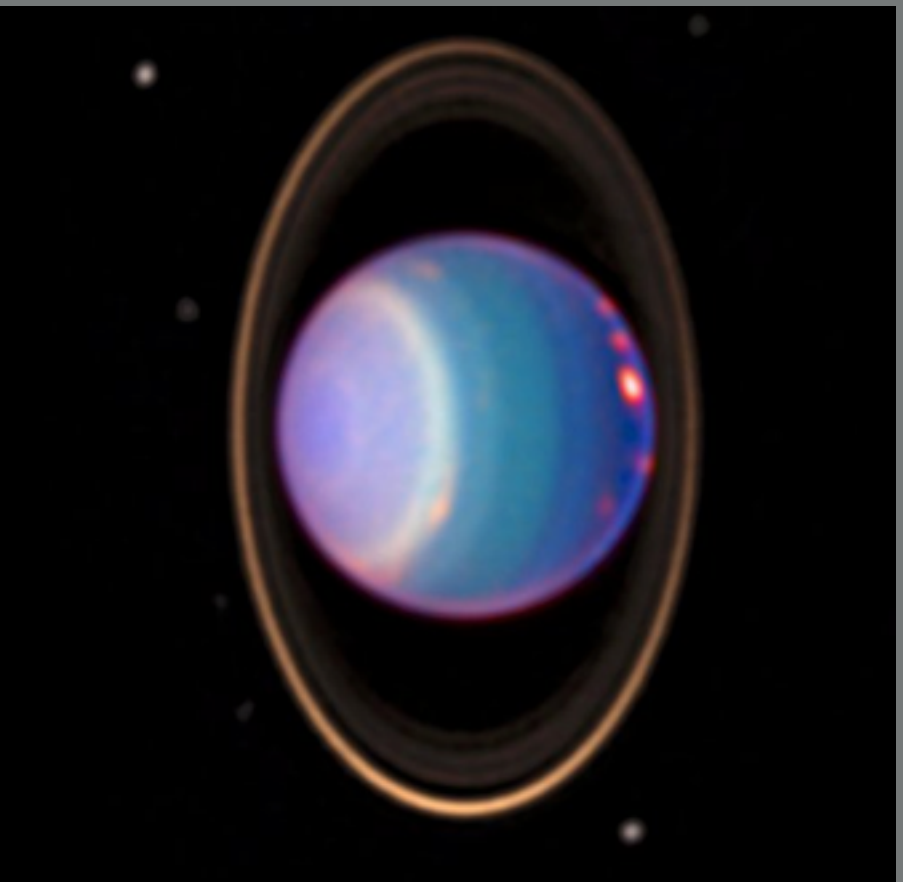
A Bad Day for Earth?

- Earth was struck by a Mars-sized planetesimal
- Part of Earth's outer layers was ejected
- This re-accreted into the Moon.
- This explains why the Moon:
  - orbits in same direction as Earth rotates
  - Has a lower density than Earth
  - Has no easily-vaporized ingredients



Heavy bombardment *could* have caused Venus to spin backwards

Uranus likely to be from something else (look at other systems)



Captured Moons

- Unusual moons of some planets probably are captured planetesimals
  - Also explains screwy orbits

Four Challenges for a Solar System Formation Theory

1. Orderly motions ✓
2. Two kinds of planets ✓
3. Two kinds of small bodies ✓
4. Exceptions to the rules ✓

Thought Question

How would the solar system be different if the solar nebula had been cooler, with a temperature half its actual value?

A. Jovian planets would have formed closer to Sun
B. There would be no asteroids
C. There would be no comets
D. Terrestrial planets would be larger
E. Jovian and Terrestrial planets would switch places

If you really understand the theory, you can think about different situations!

- How would the solar system look if the ices condensed at 50K instead of 150K?

OR

- How would planets in our solar system be different if the nebula had been cleared away before the capture of any nebular gas?

OR

- How would planets in our solar system be different if the whole solar nebula had cooled below the condensation temperature of hydrogen compounds before solar wind clearing?

WHEN did this all happen?

What could we look at to date the age of the solar system?

- Earth?
  - Ø Most of Earth's surface has been recycled over the years
- Moon?
  - Ø Formed AFTER the initial formation of the Earth
- Small Solar System Bodies?
  - These are the remnants from the original formation processes

Oldest Solar System Rocks

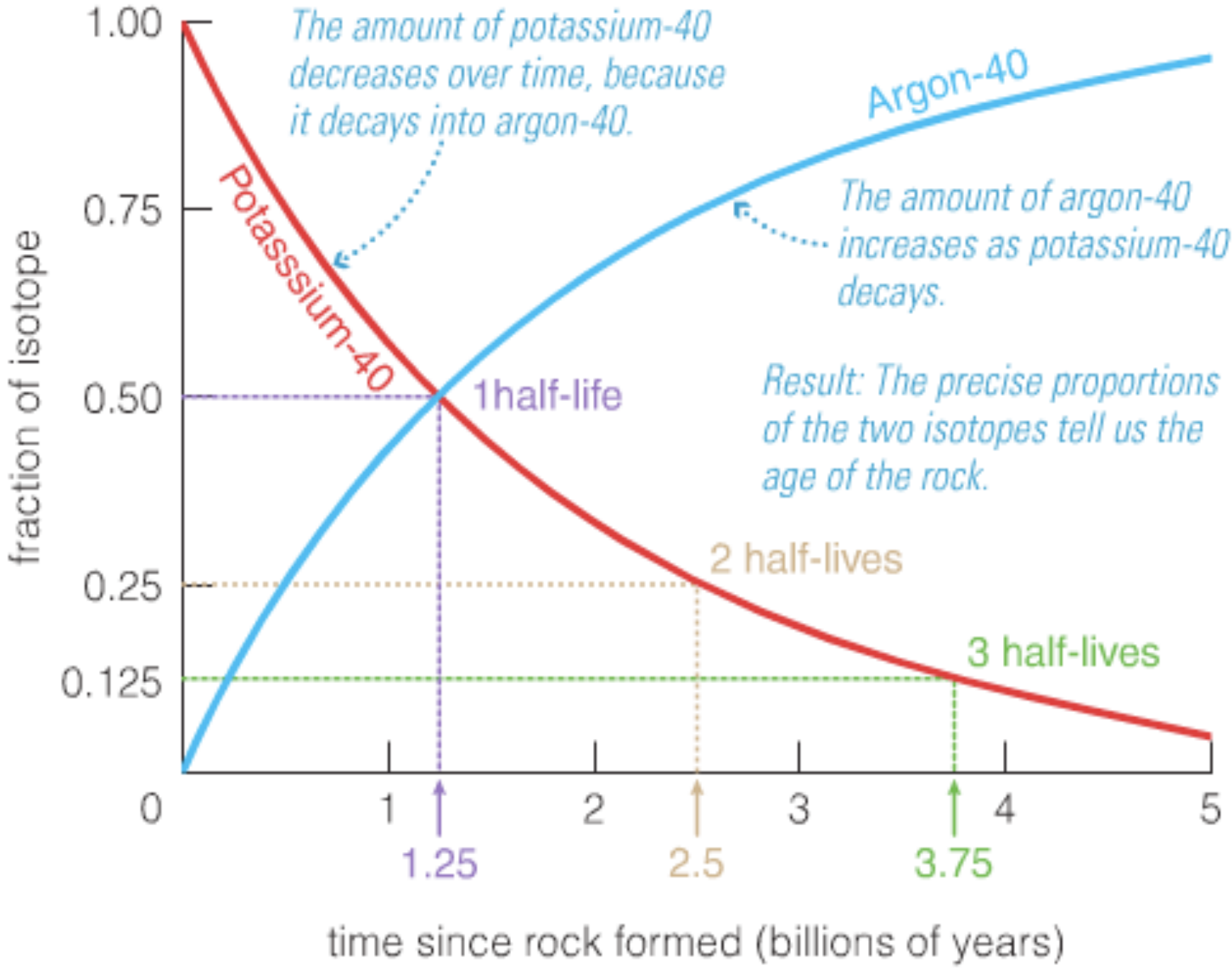
- The oldest dated **moon rocks**, have ages between 4.4 - 4.5 billion years

- **Meteorites** dated to be between 4.53 and 4.58 billion years old

4.55 BY to <1% accuracy

Radiometric Dating

- Radioactive substance decay to 1/2 there amount in a time known as their "half-life"
- They decay by emitting either an electron (beta decay)or a helium nucleus (alpha particle)
- They turn into something else
- We measure the ratios of the parent and daughter products
- That's the essentials


1.00
0.75
0.50
0.25
0.125
0
fraction of isotope
The amount of potassium-40 decreases over time, because it decays into argon-40.
Potasssium-40
Argon-40
The amount of argon-40 increases as potassium-40 decays.
1half-life
Result: The precise proportions of the two isotopes tell us the age of the rock.
2 half-lives
3 half-lives
1
2
3
4
5
1.25
2.5
3.75
time since rock formed (billions of years)

Stages of Solar System Formation

Collapse

Condensation

Accretion

-Gas Capture

Gas Clearing

Heavy Bombardment