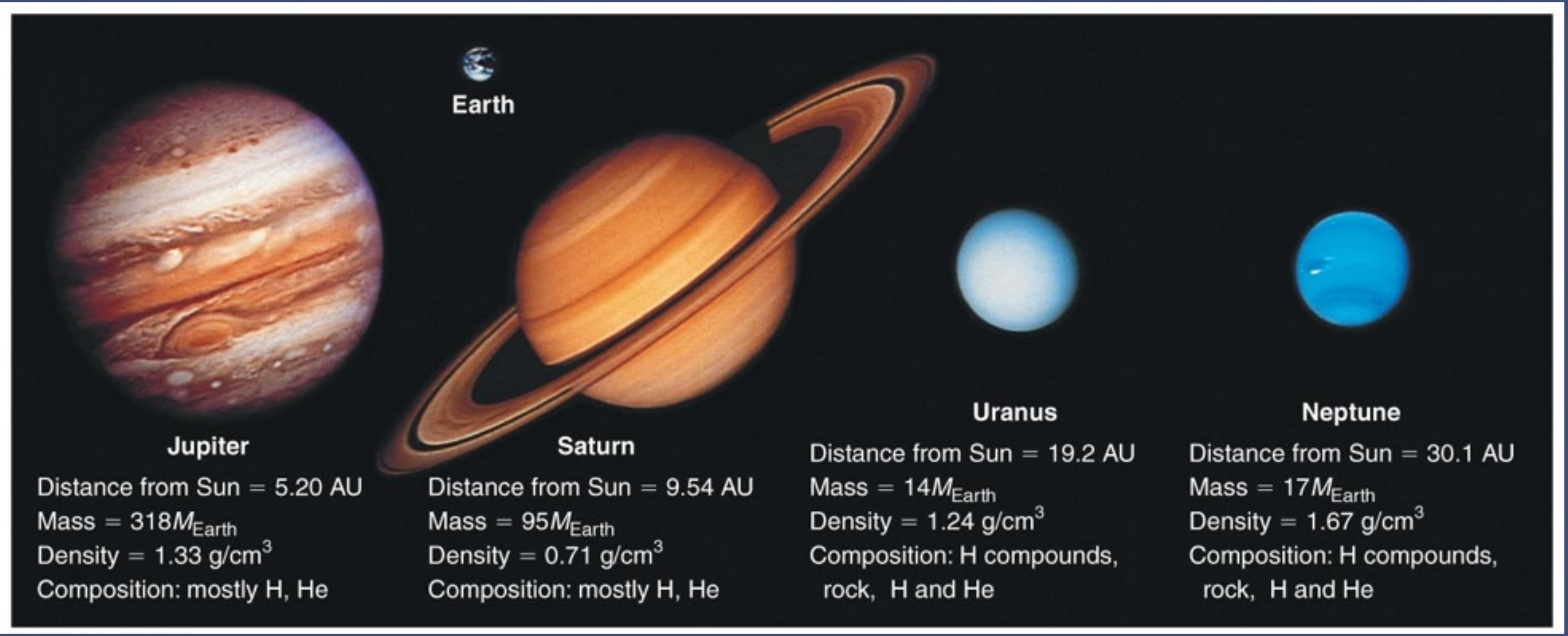
Jovian Planets



Jupiter

- First of the Jovian planets
  - Defining characteristics of Jovian planets:
    - large diameter

$$\text{Diameter} = D = 143{,}000\ \text{km} = 11 D_{Earth}$$

    - large mass
      - Jupiter is twice as massive as all the other planets combined

$$\text{Mass} = M = 1.9 \times 10^{27}\ \text{kg} = 318 M_{Earth}$$

    - low average density

$$\text{Average density of Jupiter} = 1300\ \text{kg/m}^3$$

$$\text{Average density of Earth} = 5500\ \text{kg/m}^3$$

Saturn

- Jovian planet
  - Defining characteristics of Jovian planets:
    - large diameter

$$\text{Diameter} = D = 121{,}000\ \text{km} = 9.4 D_{Earth}$$

    - large mass
      - more massive than 6 smallest planets combined

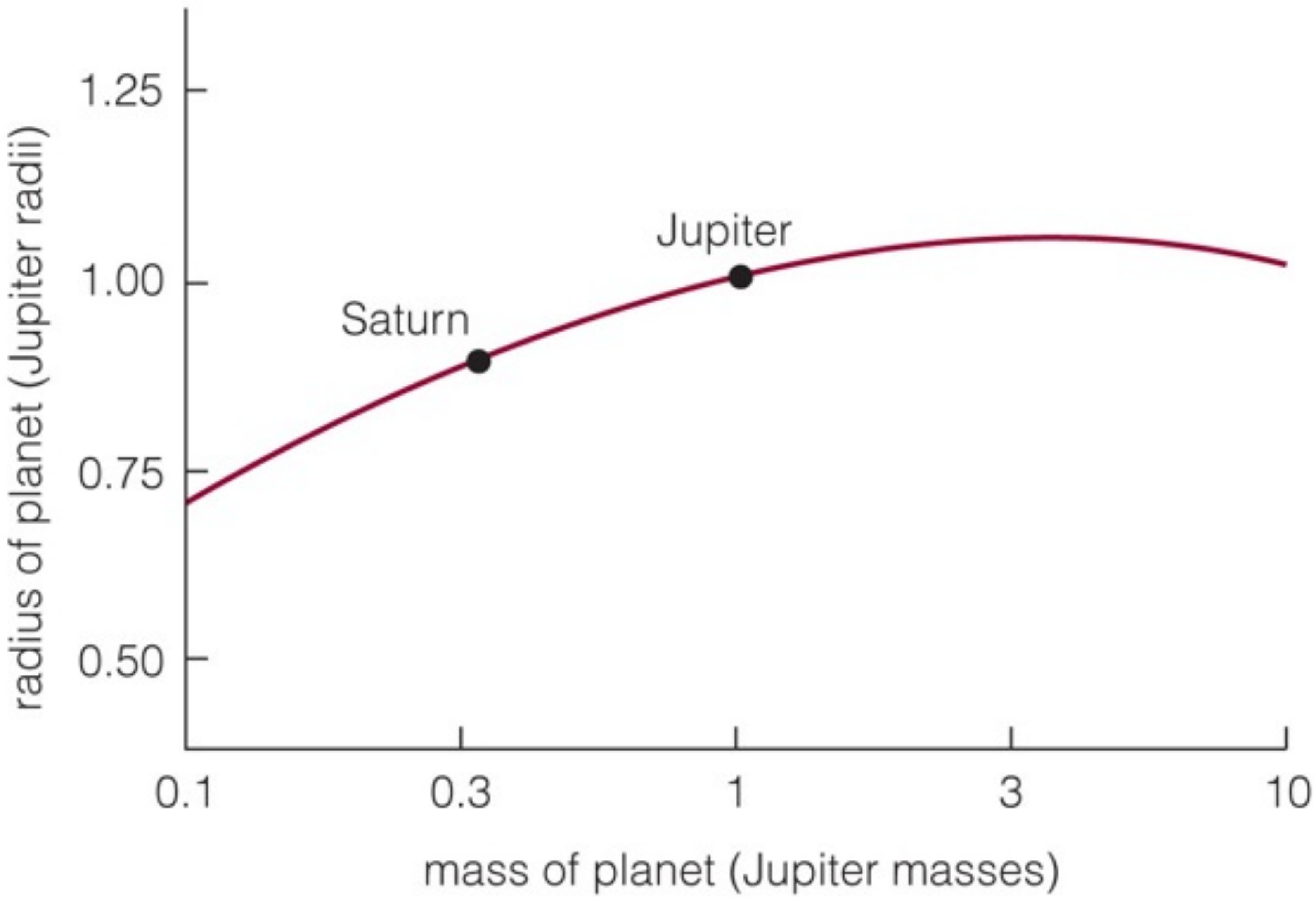
$$\text{Mass} = M = 5.7 \times 10^{26}\ \text{kg} = 95 M_{Earth}$$

    - low average density

$$\text{Average density} = 687\ \text{kg/m}^3$$

Lowest density of any planet

Sizes of Jovian Planets



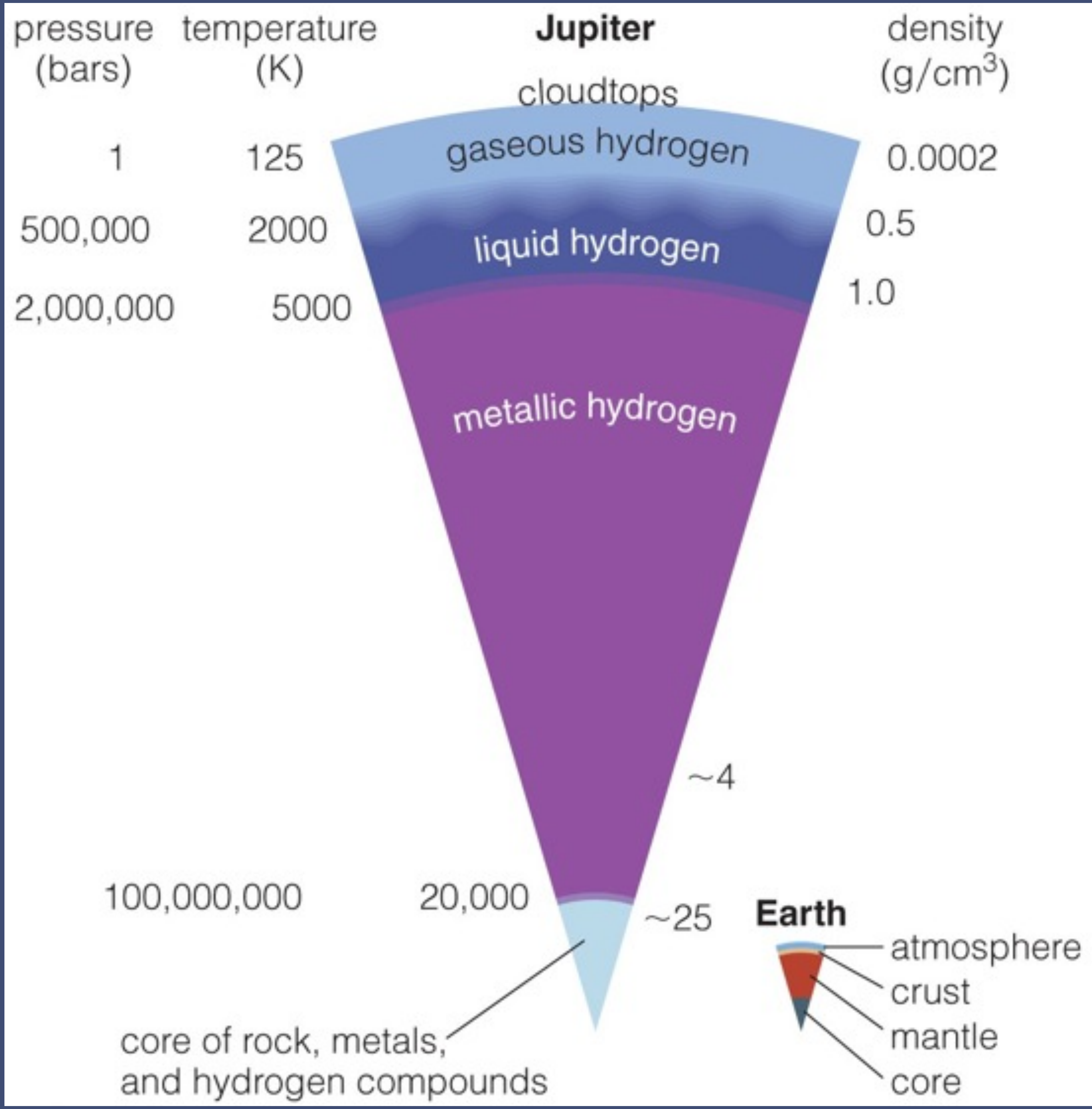
- Greater compression is why Jupiter is not much larger than Saturn even though it is three times more massive.
- Jovian planets with even more mass can be smaller than Jupiter.

Jovian planets

- Composed mostly of low mass elements
  - primarily hydrogen & helium
- Gravity of Jovian planets is strong enough to retain these light elements
  - H & He escape from terrestrial atmospheres
- Gravity of Jovian planets is strong enough to compress H & He into liquid phase
  - Incorrect to call them “gas” giants
- Jovian planets do not have hard, rocky surfaces

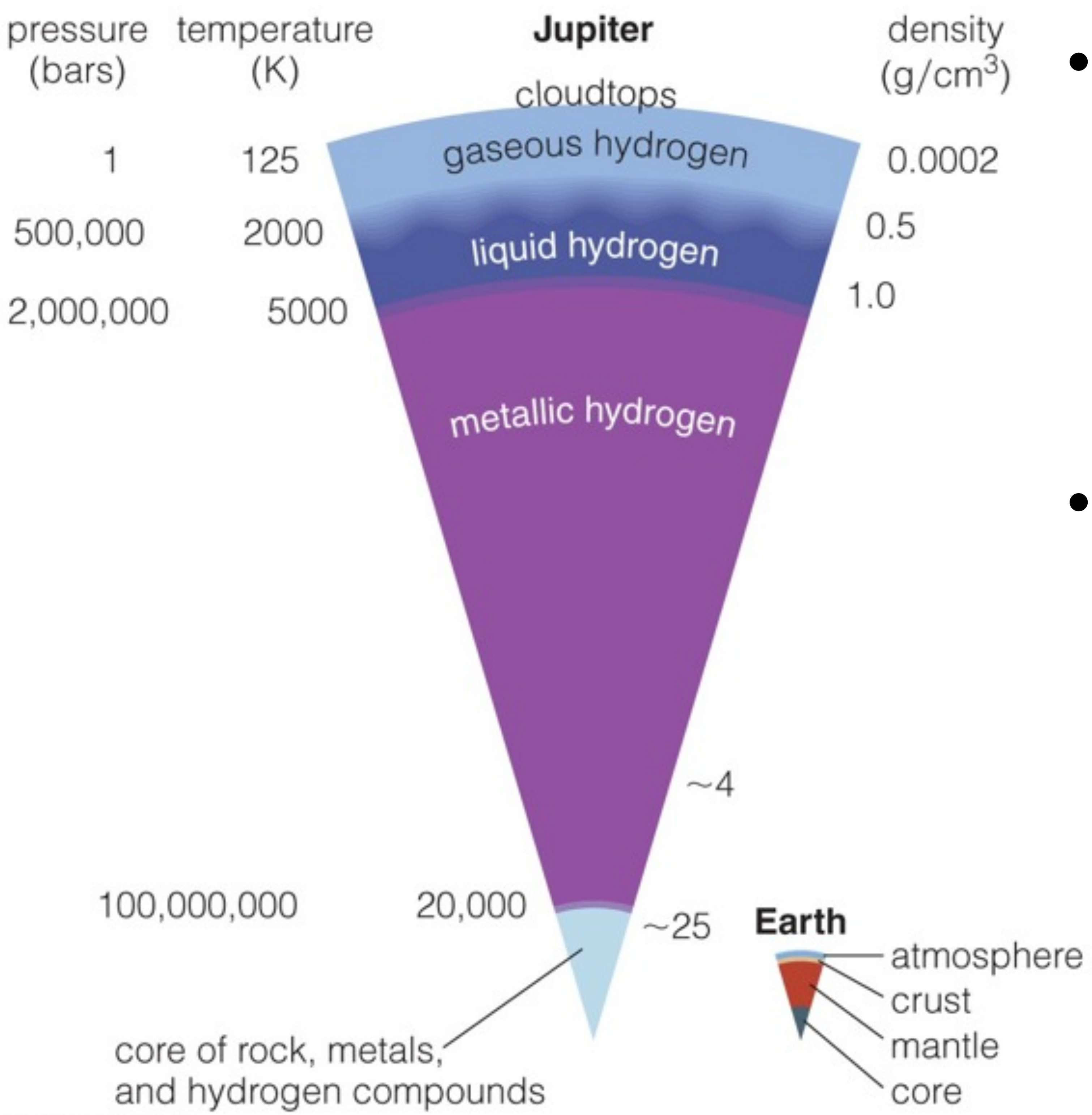
Internal Structure of Jupiter

- 0-5500 km
  - rocky core
    - about the size of Earth
- 5500-8500 km
  - liquid water, methane, & ammonia
    - probably from comets
- 8500-64000 km
  - liquid He & liquid metallic H
    - metallic because it conducts electricity like a metal
- 64000-71000 km
  - ordinary H & He gas
- 71000+ km
  - 100 km thick cloud layer
    - Ammonia, water, …



The “surface” we see is just the top layer of clouds

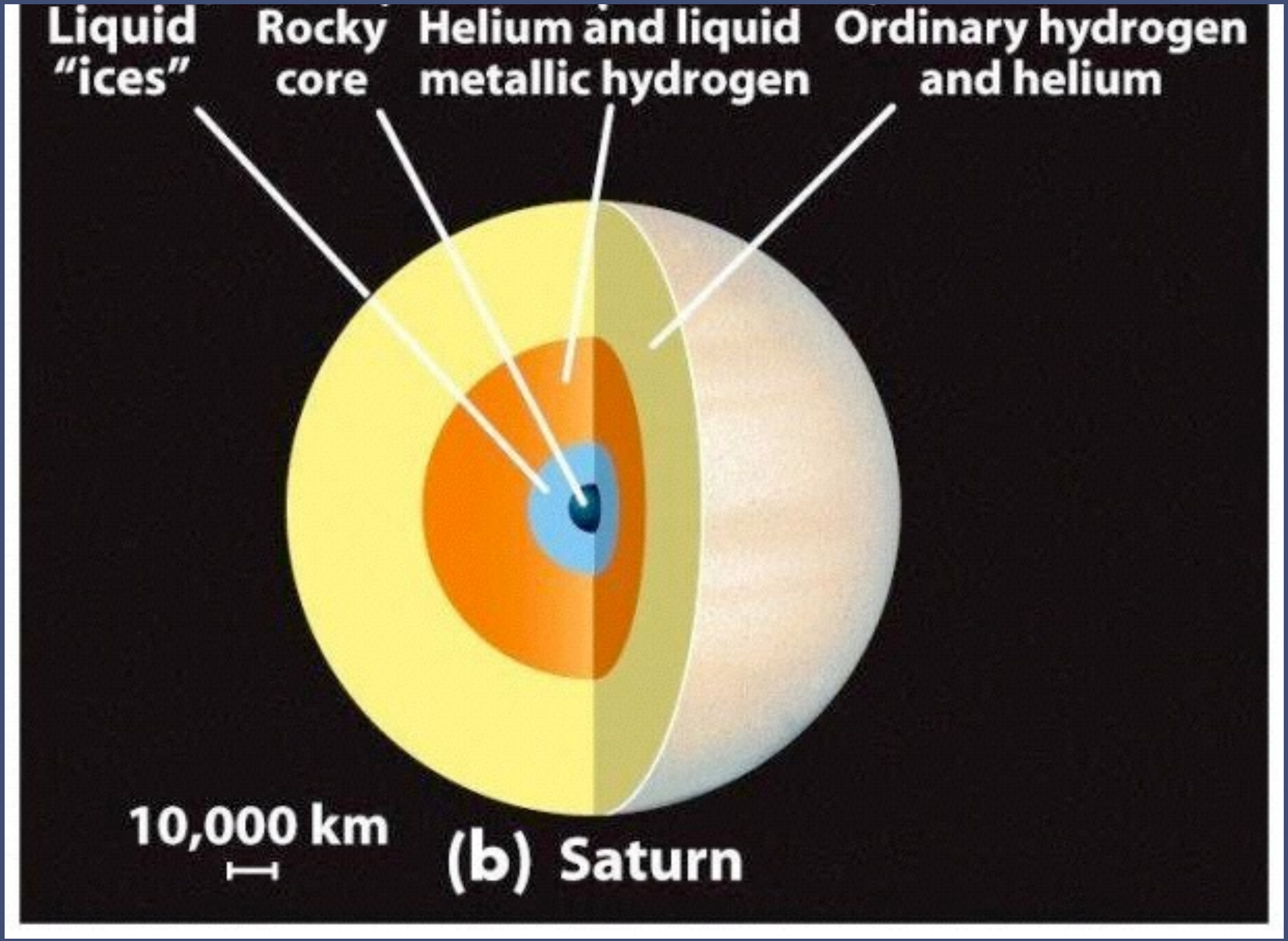
Jupiter's Internal Heat



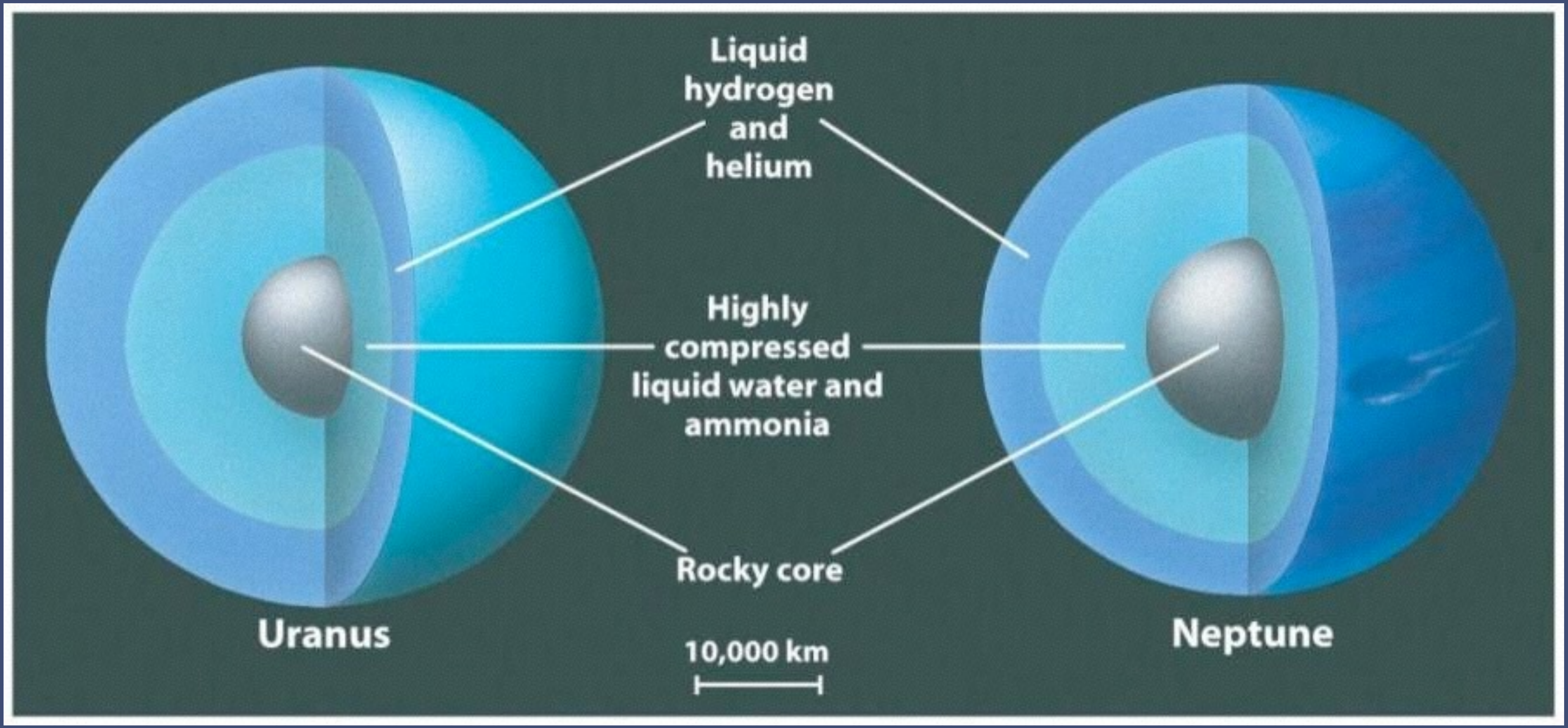
- Jupiter radiates twice as much energy as it receives from the Sun.
- Energy probably comes from slow contraction of interior (releasing potential energy).

Internal Structure of Saturn

- 0-4000 km
  - rocky core
- 4000-13000 km
  - liquid water, methane, & ammonia
    - probably from comets
- 13000-40000 km
  - liquid He & liquid metallic H
    - metallic because it conducts electricity like a metal
- 40000-60500 km
  - ordinary H & He gas
- 60500+ km
  - 100 km thick cloud layer
    - Ammonia, water, …

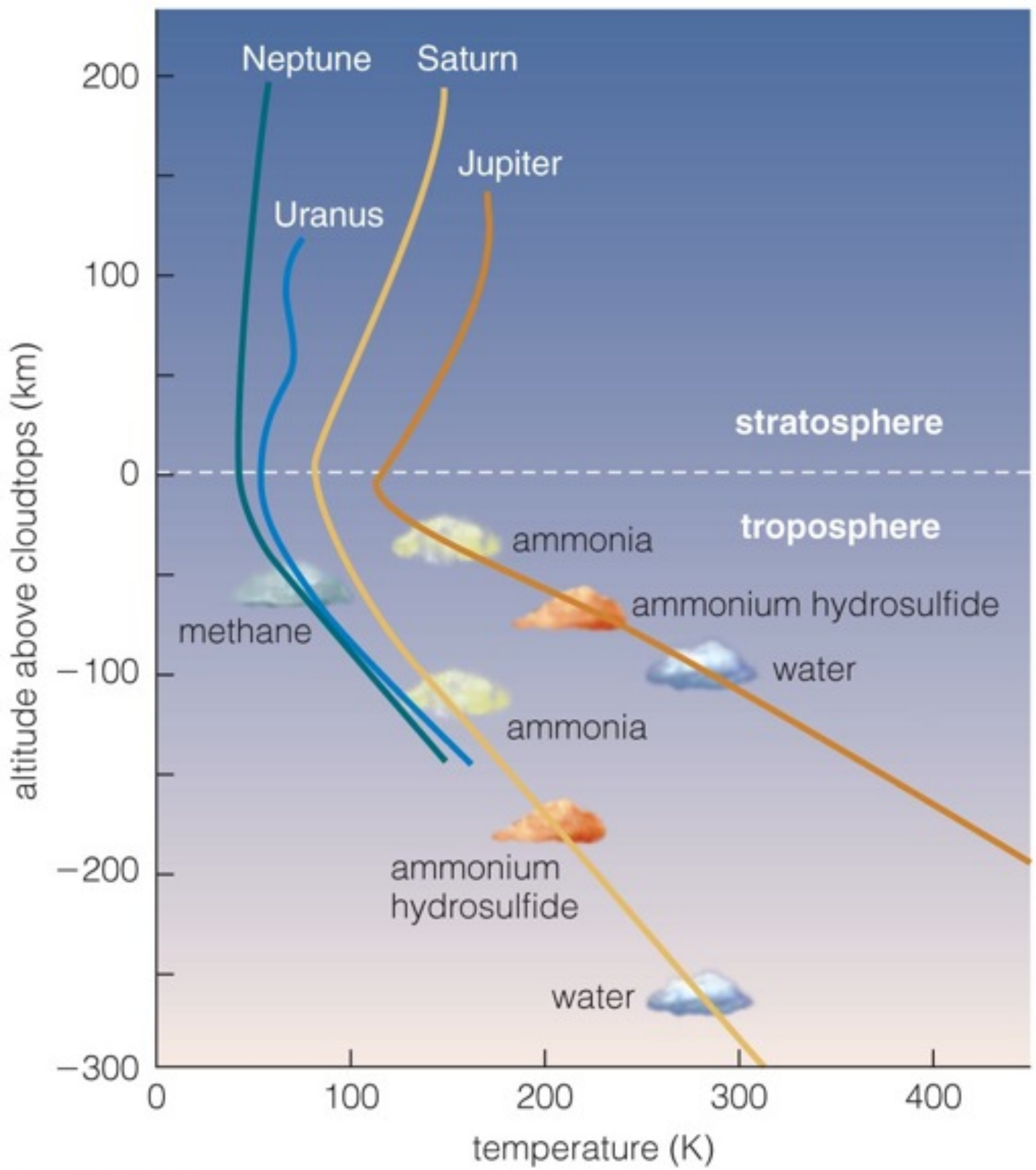


Structure of Uranus & Neptune



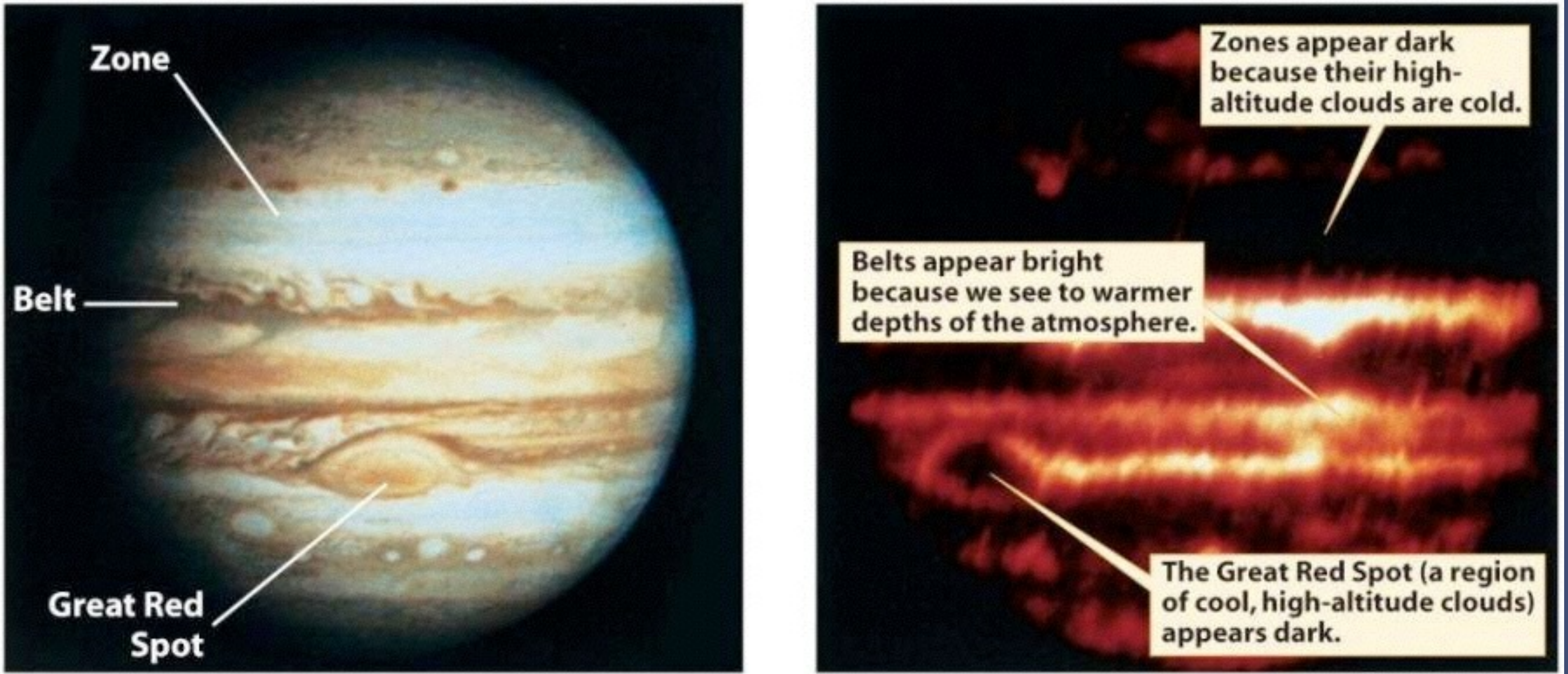
- What is missing as compared to Jupiter & Saturn?
  - Liquid metallic hydrogen layer

Jovian Planet Atmospheres



- Different compounds make clouds of different colors.

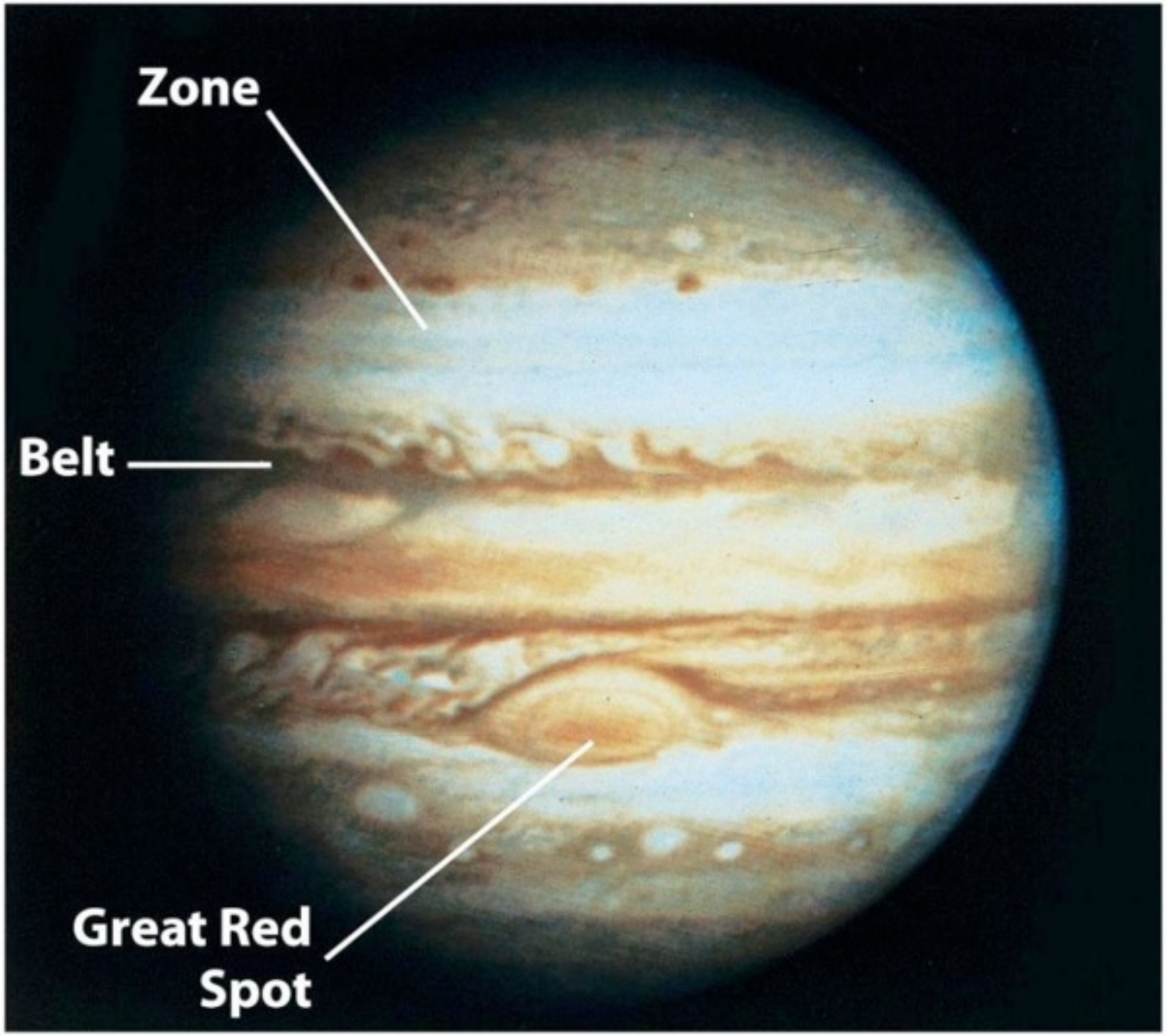
Cloud Layers of Jupiter



(a) Visible-light image (b) Infrared image

Cloud Layers of Jupiter

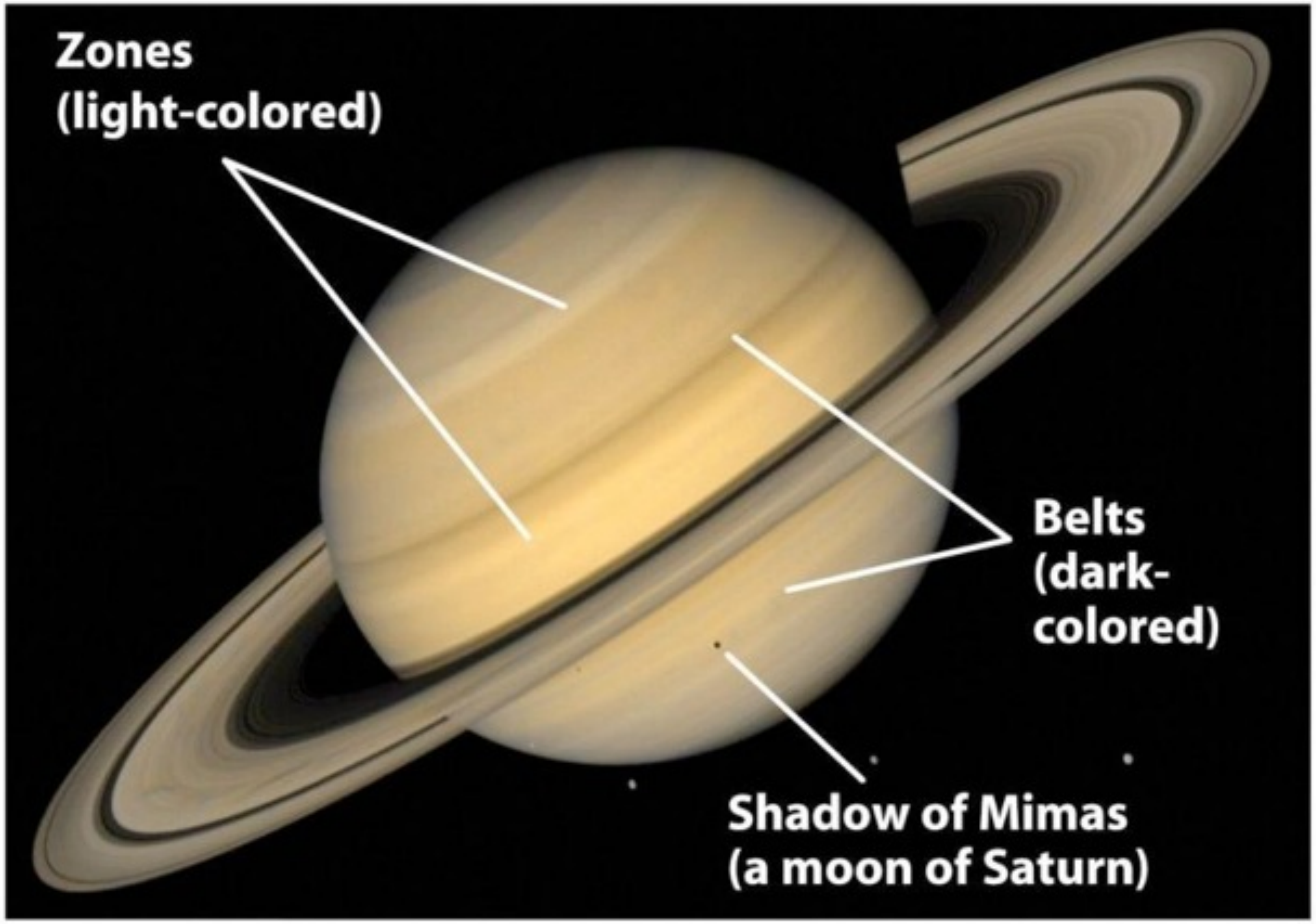
- Zones
  - high altitude
  - cold
  - appear white
- Belts
  - low altitude
  - warm
  - appear brown
- Great Red Spot
  - highest altitude
  - very cold
  - appears red



(a) Visible-light image

Cloud Layers of Saturn

- Zones
  - high altitude
  - cold
  - appear light
- Belts
  - low altitude
  - warm
  - appear dark
- Saturn's layers are similar, but deeper in and farther from the Sun (more subdued).



Saturn

Rotation of Jupiter & Saturn

- Jupiter is the fastest rotating planet in the Solar System

Rotation period = 9 h 50 min

- Saturn, like Jupiter, rotates very rapidly

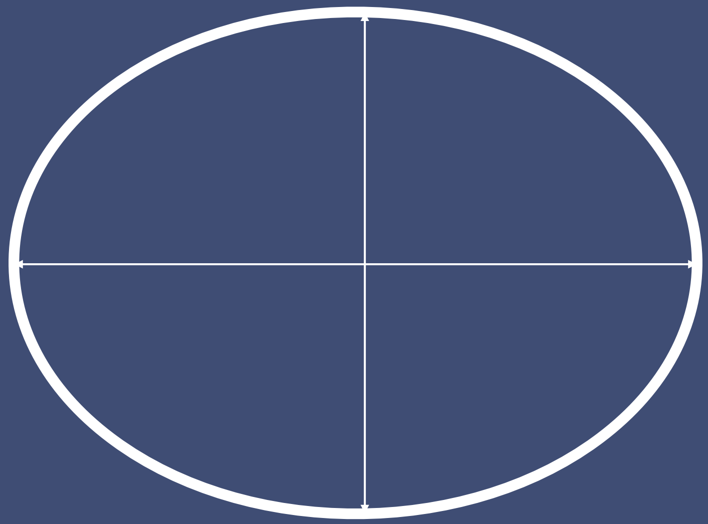
Rotation period = 10 h 14 min

- Jovian planets undergo ***differential rotation***
  - –different parts of planet rotate at different speeds
  - –differential rotation is possible because there is no solid crust

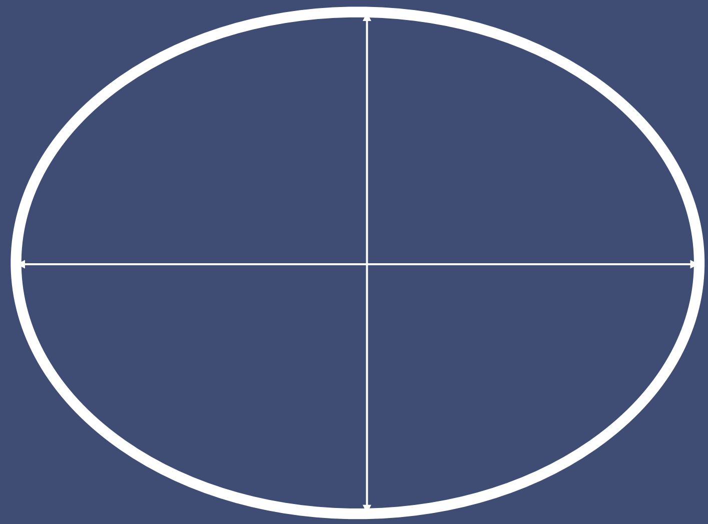
Effect of rapid spin on Jupiter & Saturn

- Spinning object experiences an outward apparent force
  - called centrifugal force
    - this is the force that keeps you stuck to the wall on the carnival ride where the wall falls out from under you
- Centrifugal force causes Jupiter's equator to bulge out

Jupiter

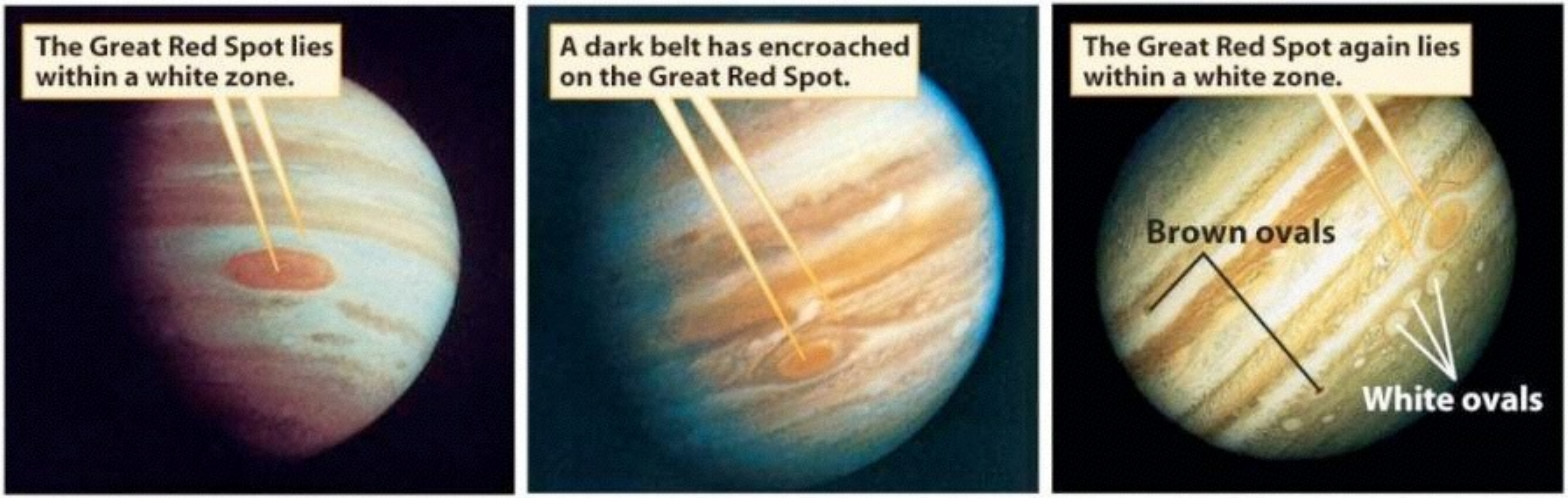


Saturn



Storm of the Centuries

- The Great Red Spot



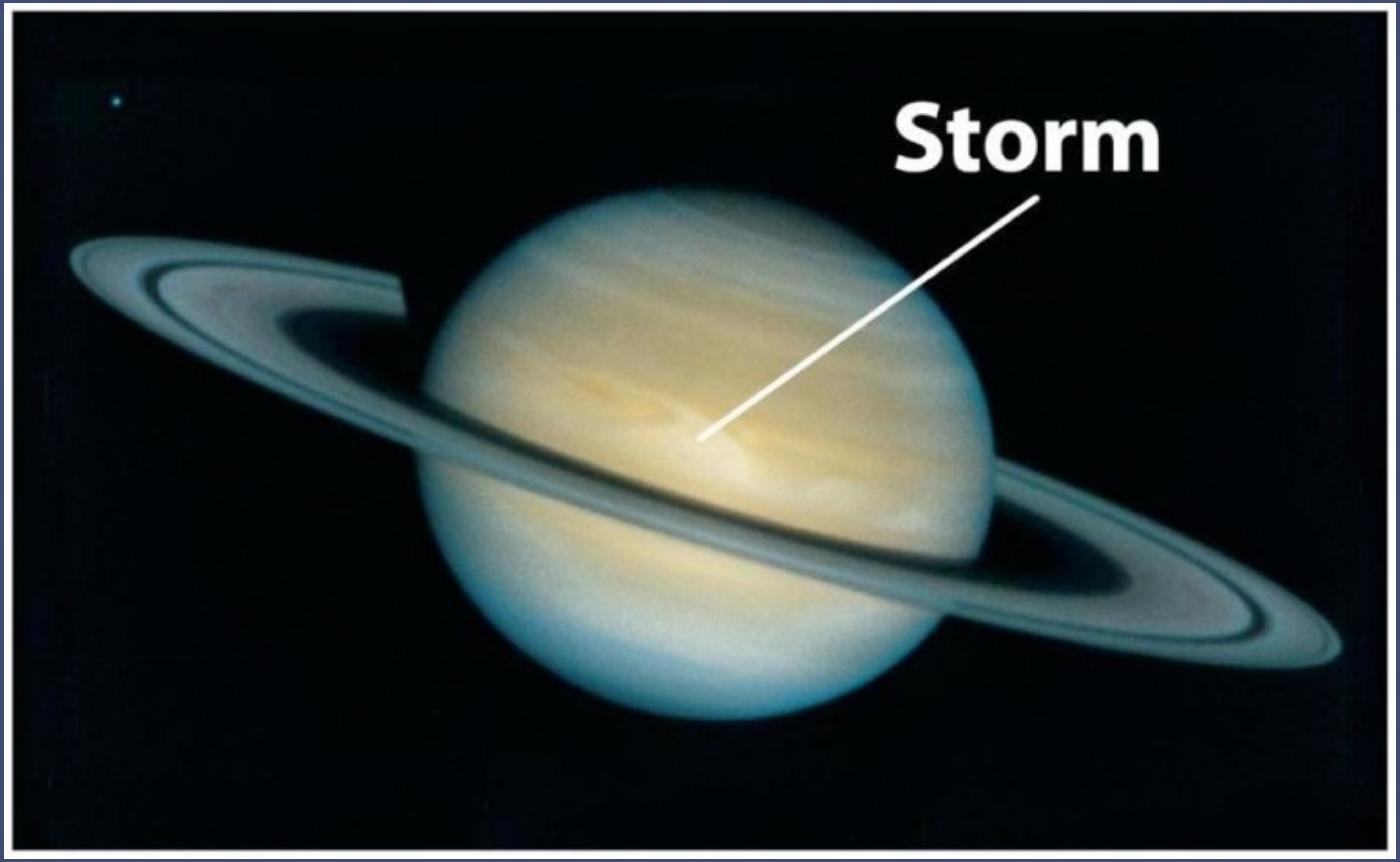
(a) *Pioneer 11*, December 1974 (b) *Voyager 2*, July 1979 (c) HST, February 1995

Storm of the Centuries

- The Great Red Spot
  - the longest lived, most powerful storm known in the Solar System
    - First observed over 300 years ago
    - documented in 1664
    - Has changed but never disappeared
  - Similar to a hurricane on Earth, except
    - it’s a high-pressure storm (hurricanes on Earth are low-pressure storms)
    - it’s large enough that our entire planet would fit inside it!!!

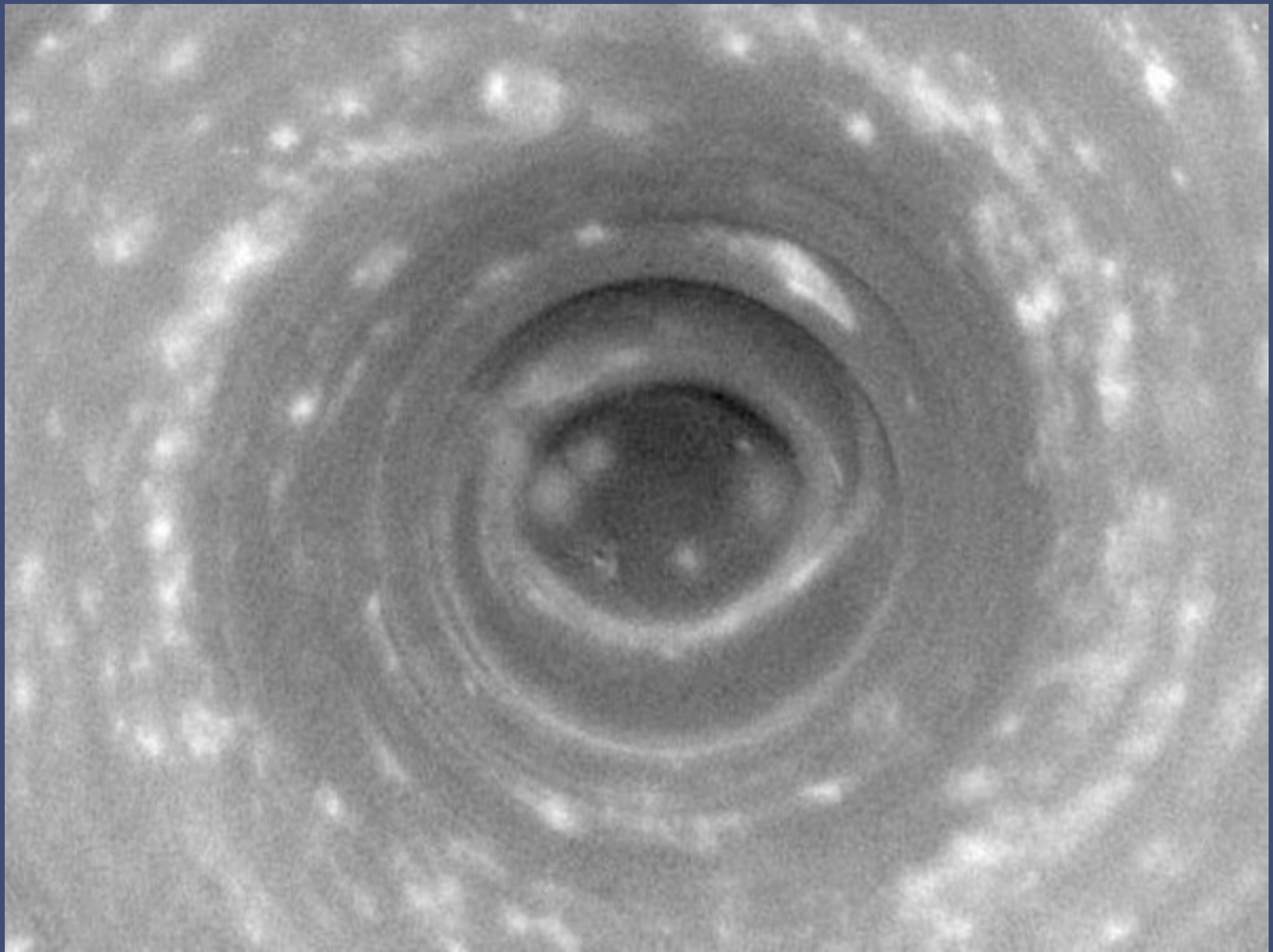
Saturn's Storms

- Many short-lived storms observed near the equator
- Recording of lightning on Saturn



Saturn’s Storms

- Cassini discovered major storm near Saturn’s South Pole
  - possible this storm has been raging for billions of years



Discoveries of Uranus & Neptune

- Ancient astronomers only knew of 5 planets besides Earth
  - Mercury, Venus, Mars, Jupiter, & Saturn
  - These planets can be easily seen with the unaided eye
- Uranus, at its brightest, is just barely visible to the unaided eye
  - Ancient astronomers probably saw Uranus, but did not identify it as a planet
  - When is Uranus brightest as seen from Earth?
  - Near opposition

Uranus

- Accidentally discovered in 1781 by William Herschel, a German astronomer
- Definition of a planet
  - (1) A 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, and (c) has cleared the neighborhood around its orbit.
- Herschel had to observe Uranus long enough to be sure it orbited the Sun
  - no easy task since Uranus's orbit is 84 years!
  - obviously he didn't watch it for its entire orbit, but he watched it long enough (a year or so) to prove that it was orbiting the Sun

Anomaly of Uranus's Orbit

- After its discovery, astronomer noticed that Uranus did not appear to follow Newton's laws of motion
  - At certain points in its orbit Uranus appeared to speed up for no apparent reason
  - At other points it appeared to slow down, also without any apparent reason
- Some scientists speculated that Newton's laws may not hold over very large distances
- Others explored the idea that maybe Uranus's orbit was being affected by an undetected planet

Neptune

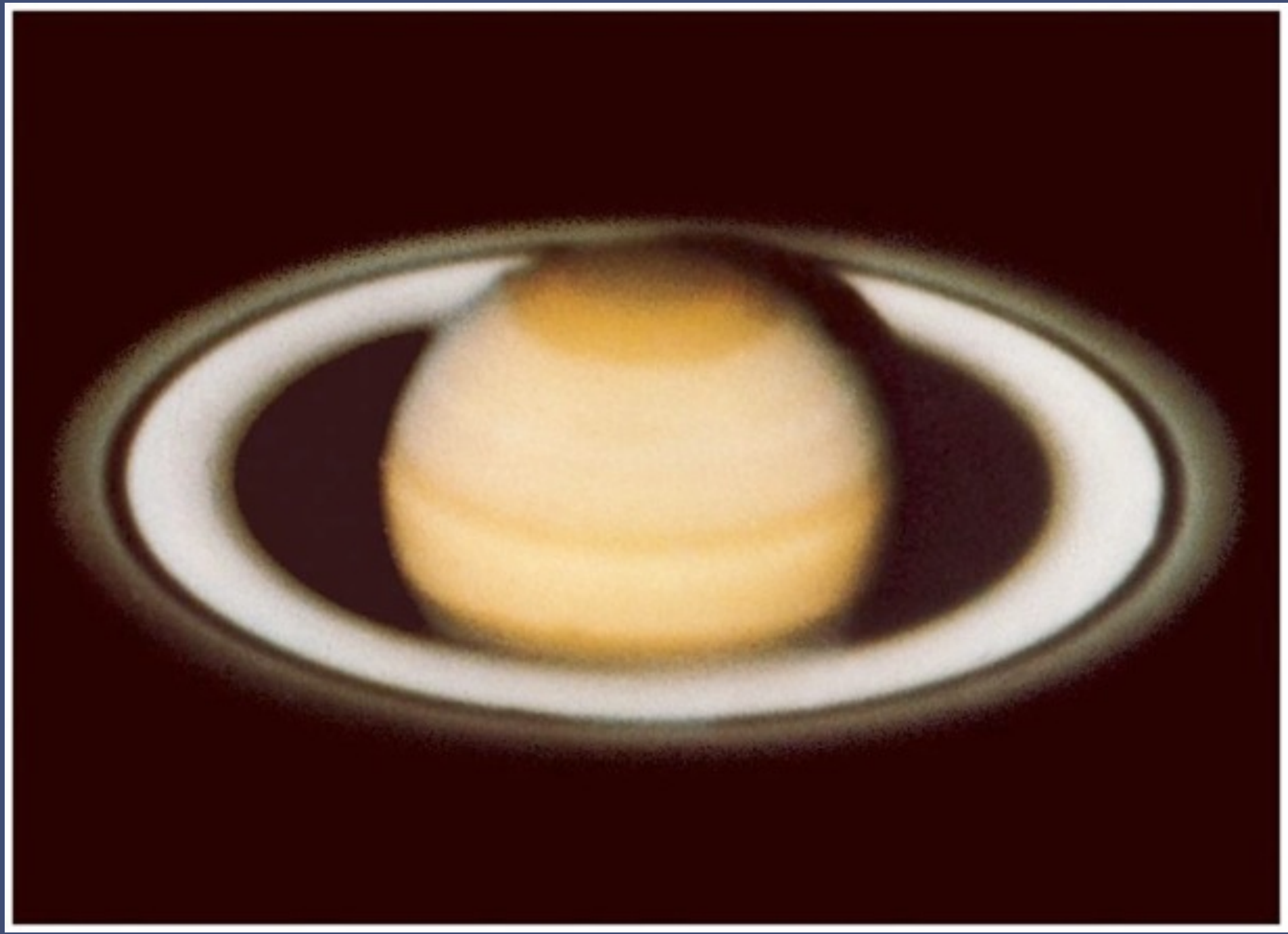
- The discovery of Neptune was ***predicted***
- Two scientists, independently, worked out predictions for where the new planet would be found
  - John Adams of England worked this out first, but was unable to convince the observers of the Royal Astronomical Society to actually look for the new planet
  - The German astronomer Johann Galle used the calculations of Urbain Jean LeVerrier of France to finally find Neptune in 1846
- Actually there are records that Galileo was the first person to observe Neptune during his observations of Jupiter, but he mistook it for a background star

Very Long Orbital Periods

- Uranus
  - 84 years
- Neptune
  - 165 years
- Pluto
  - 249 years
- In 2011, Neptune completed its first orbit since discovery
  - Pluto has not even completed 1 orbit since its discovery!!

Saturn's Rings

- Most obvious feature of Saturn is its rings
  - –Discovered in 1610 by Galileo

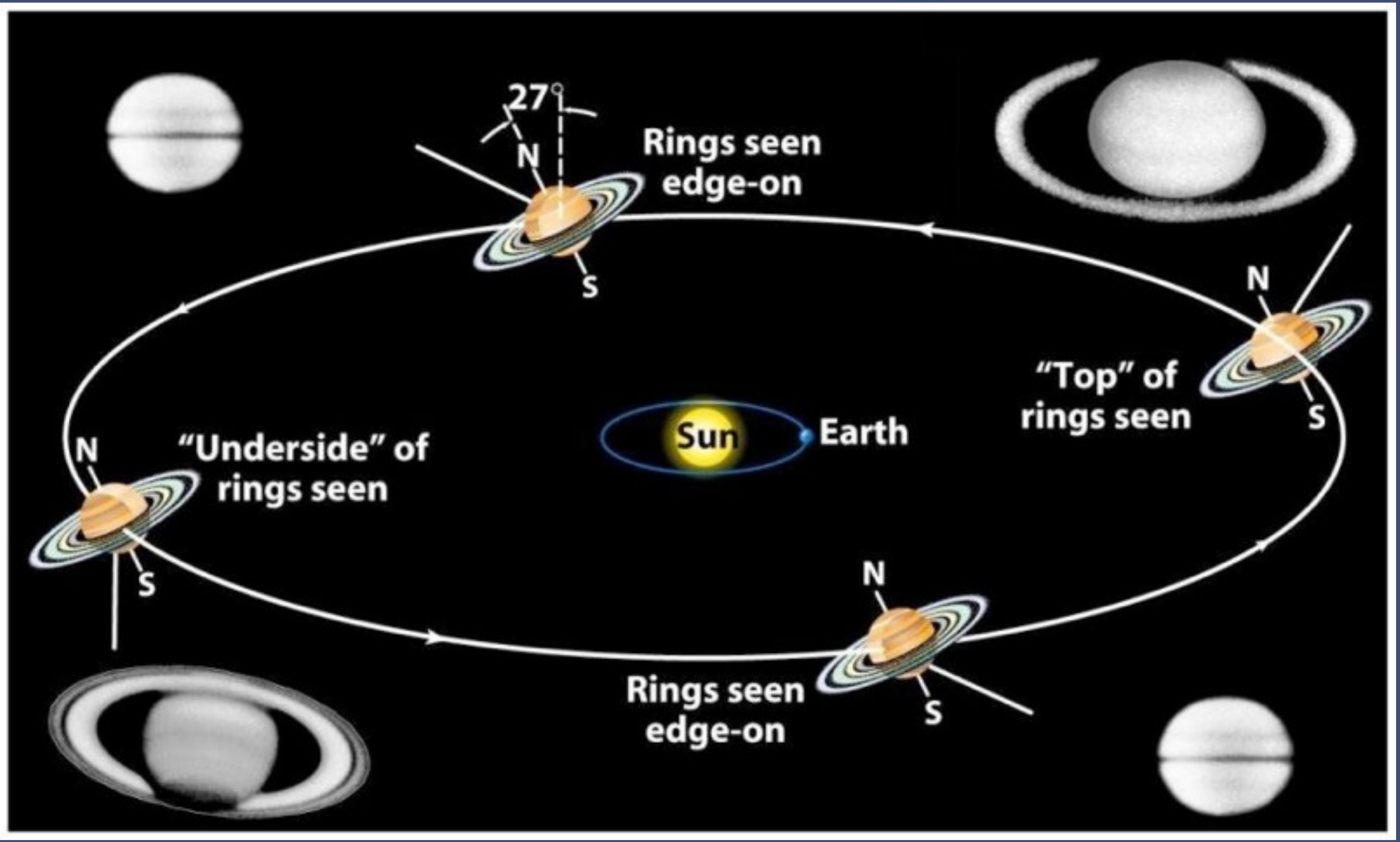


Changing Appearance of Saturn's Rings

- Galileo noted that the appearance of Saturn's rings changed with time
- Explanation?
  - Tilt of Saturn's spin axis to its orbit

Tilt = 27°

Changing Appearance of Saturn's Rings

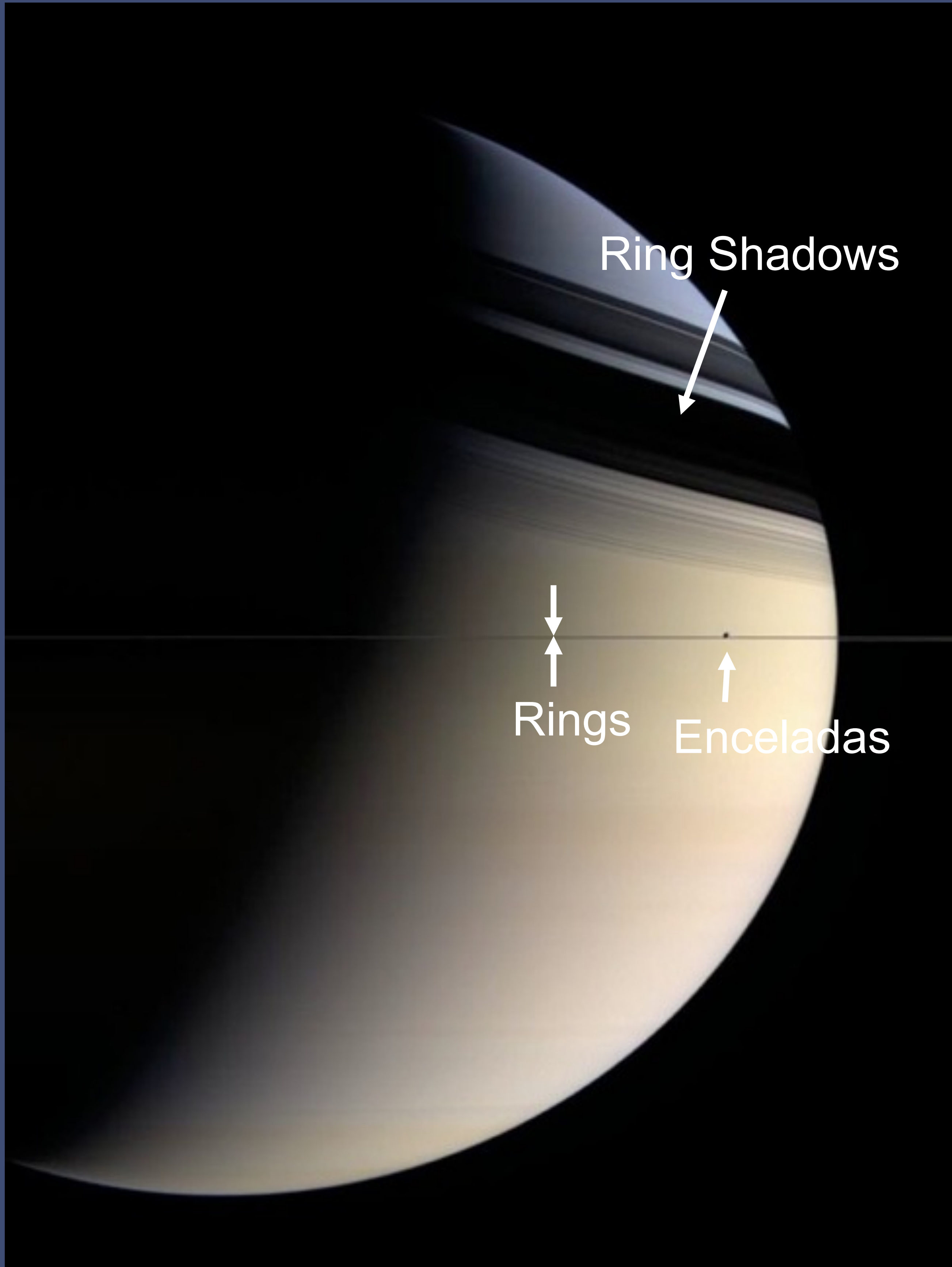


- Appearance changes slowly due to long orbital period of Saturn

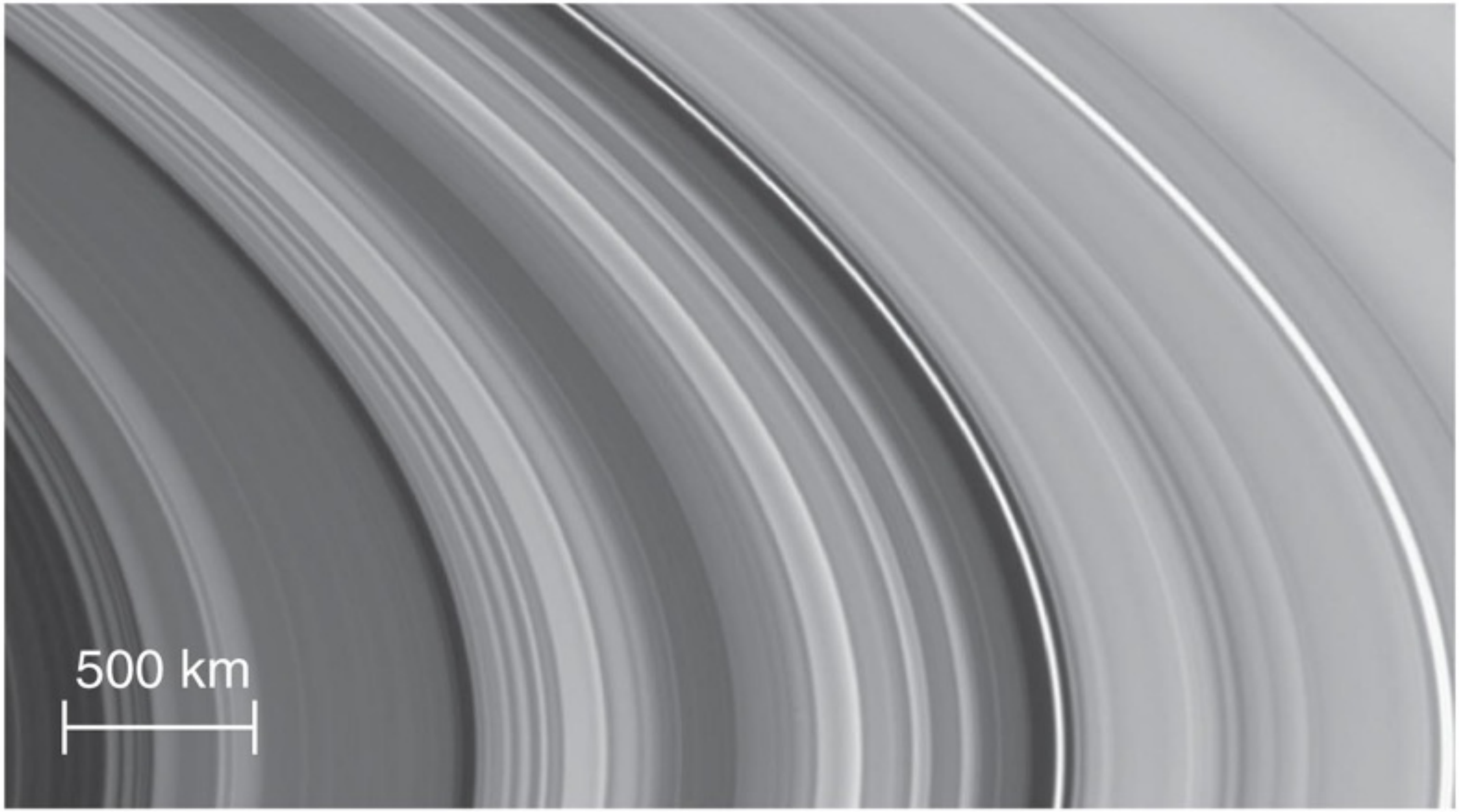
Period = 29.4 yrs

Saturn’s Rings

- Rings are extremely thin
  - –10’s of meters thick vs.
  - –274,000 km in diameter
- Formation of Rings
  - –probably formed from destruction of one or more moons of Saturn
- Composition of Rings
  - –Chunks of mostly water ice
  - –some rock
  - –size of tiny snowflakes up to size of a house
  - –mostly the size of snowballs



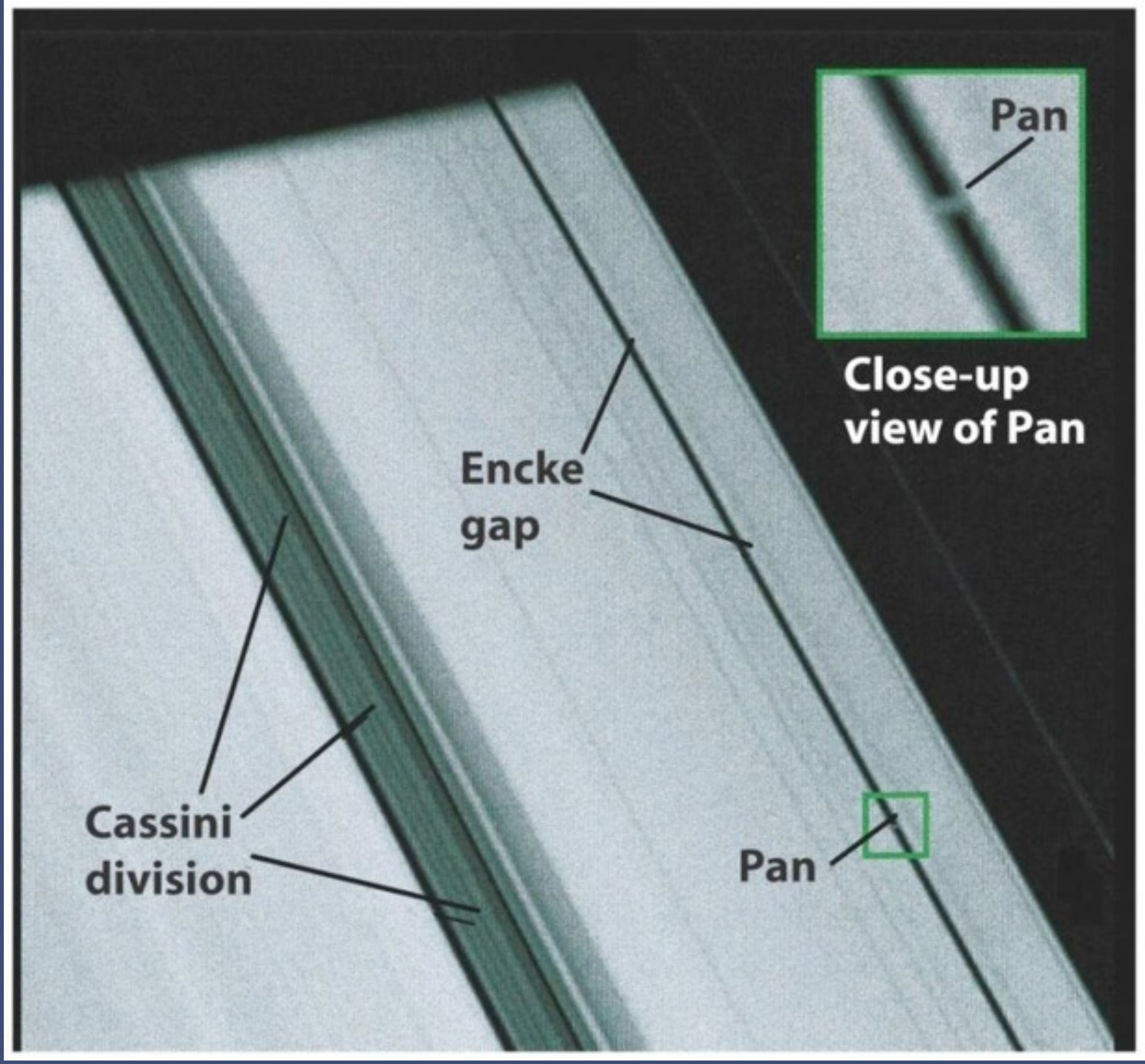
Spacecraft View of Ring Gaps



b This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.

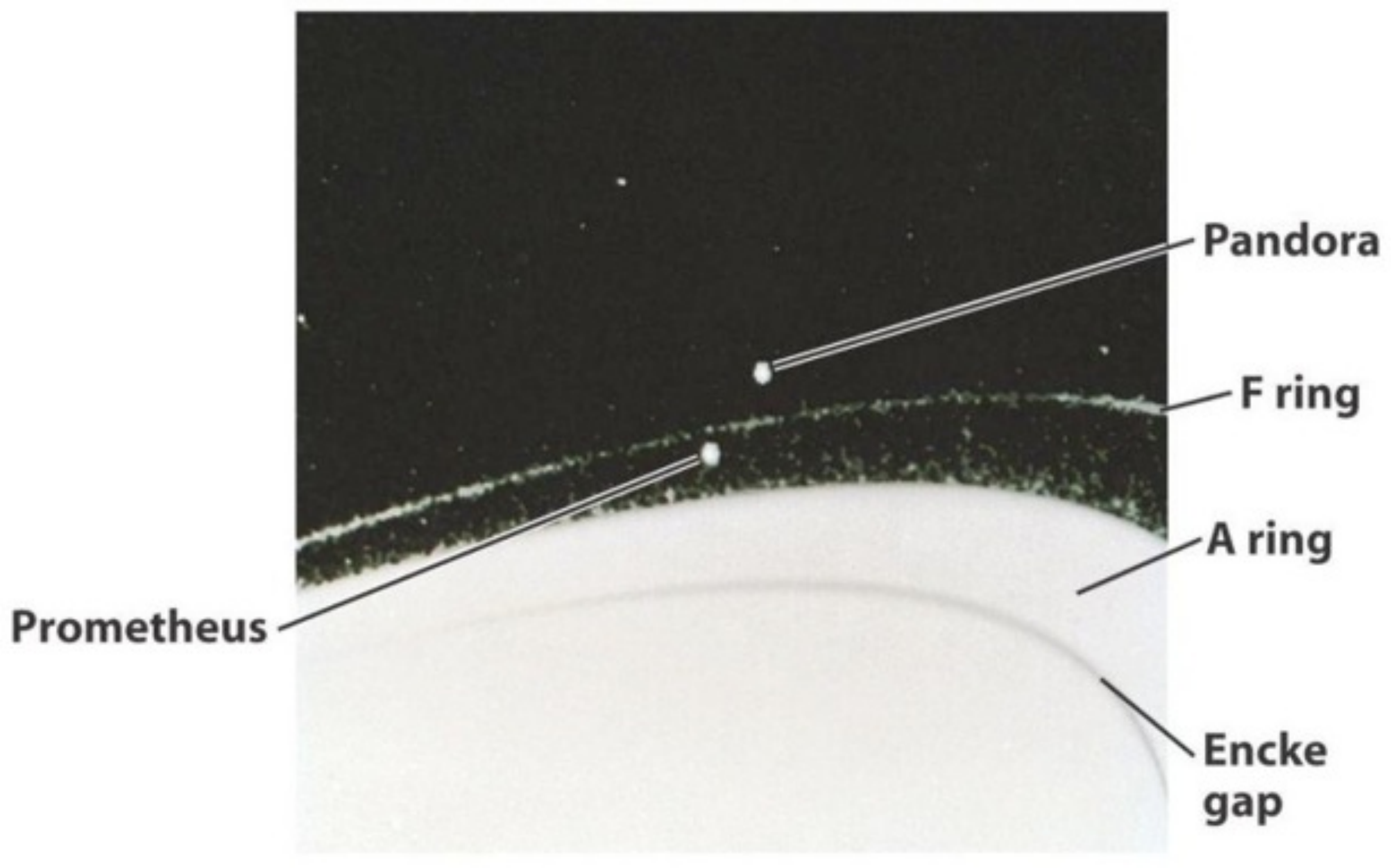
Maintaining the Structure of Saturn's Rings

- Two types of moons in Saturn's rings:
  - –Sweeper moons
    - sweep out gaps in the rings
    - Example: Pan, which sweeps out the Encke gap

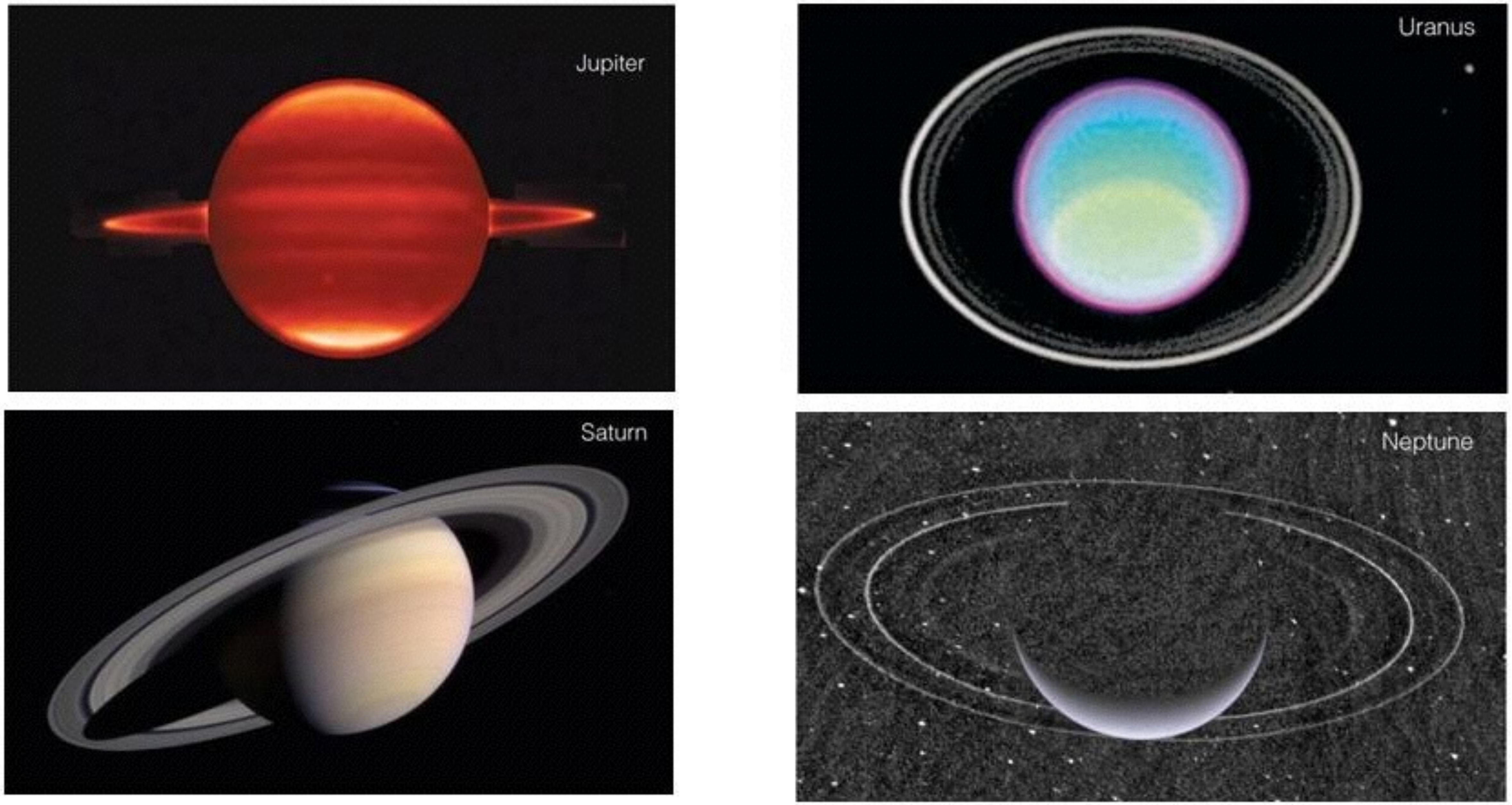


Maintaining the Structure of Saturn's Rings

- Two types of moons in Saturn's rings:
  - –Sweeper moons
    - sweep out gaps in the rings
    - Example: Pan, which sweeps out the Encke gap
  - –Shepherd moons
    - two moons working together to confine a ring
    - Example: Pandora & Prometheus maintaining the F ring

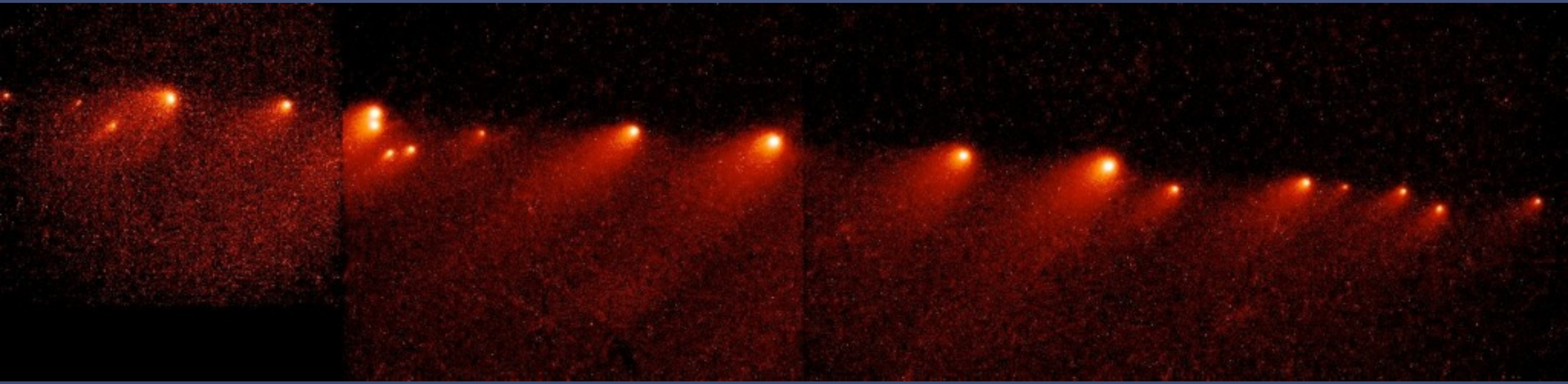


Jovian Ring Systems



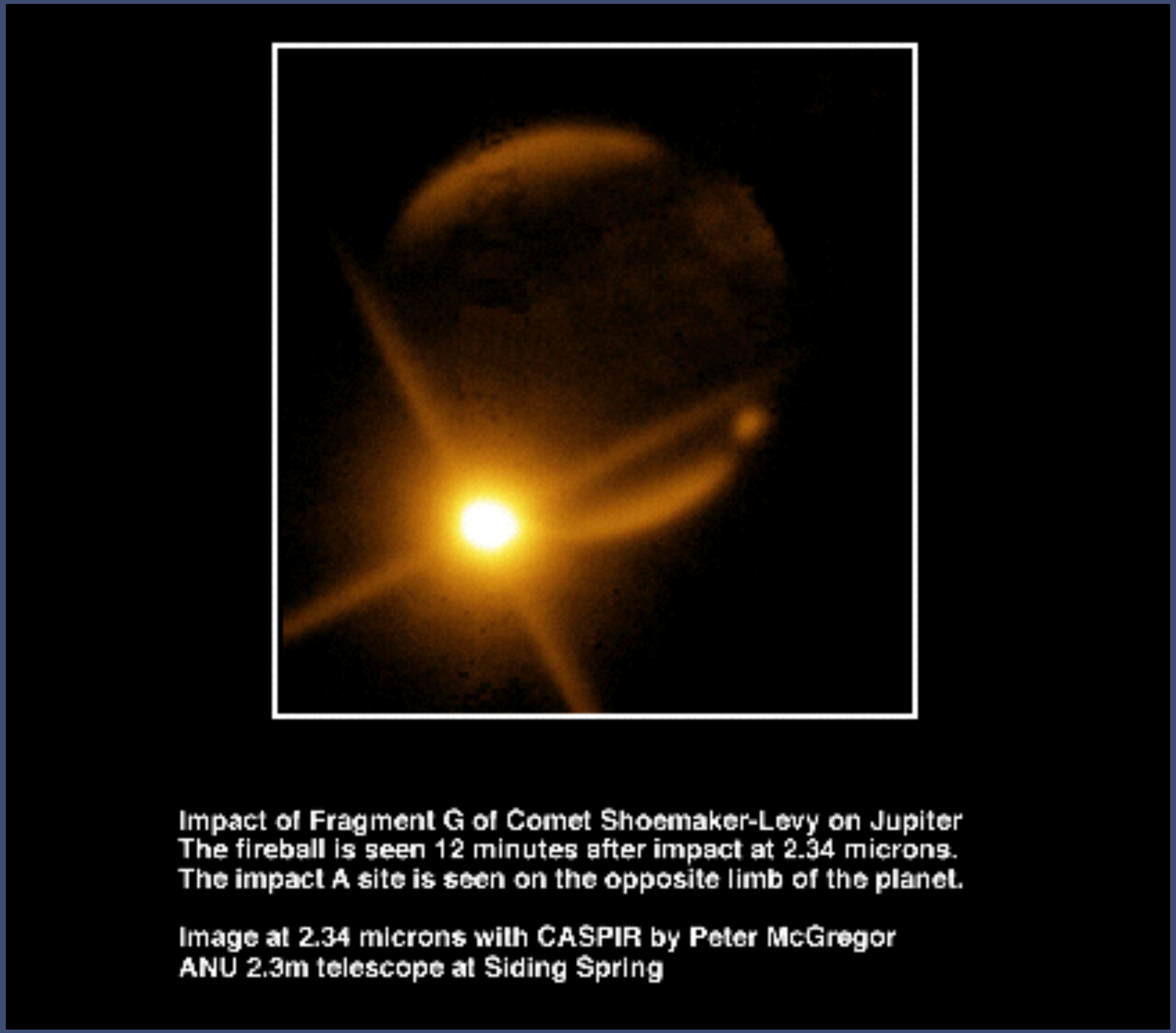
- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than Saturn.

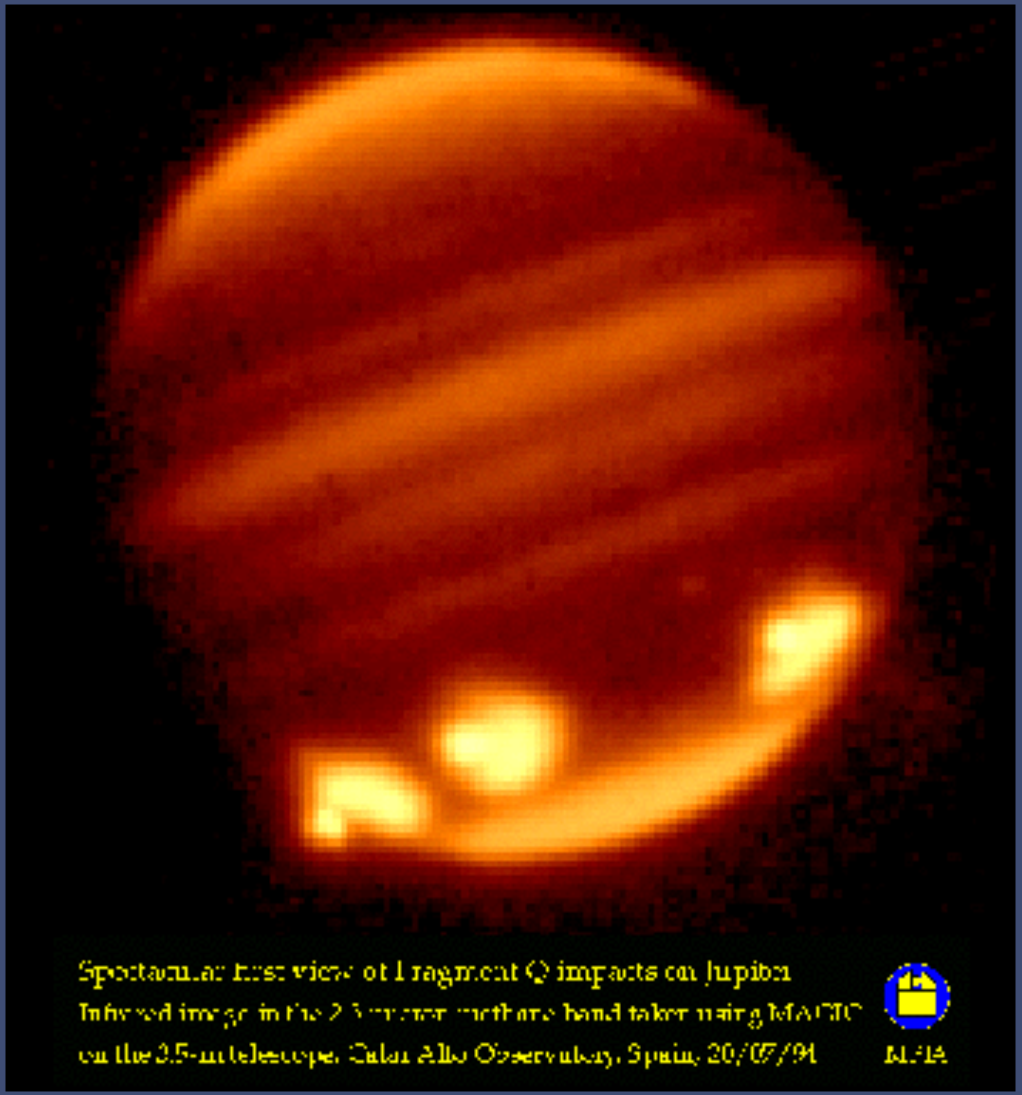
Shoemaker-Levy 9



- Ordinary comet that was broken apart as it passed close to Jupiter in its orbit
  - created the “string of pearls” observed by Hubble Space Telescope
- Each fragment roughly the size of CofC campus
- The string subsequently collided with Jupiter on a later pass through the Solar System

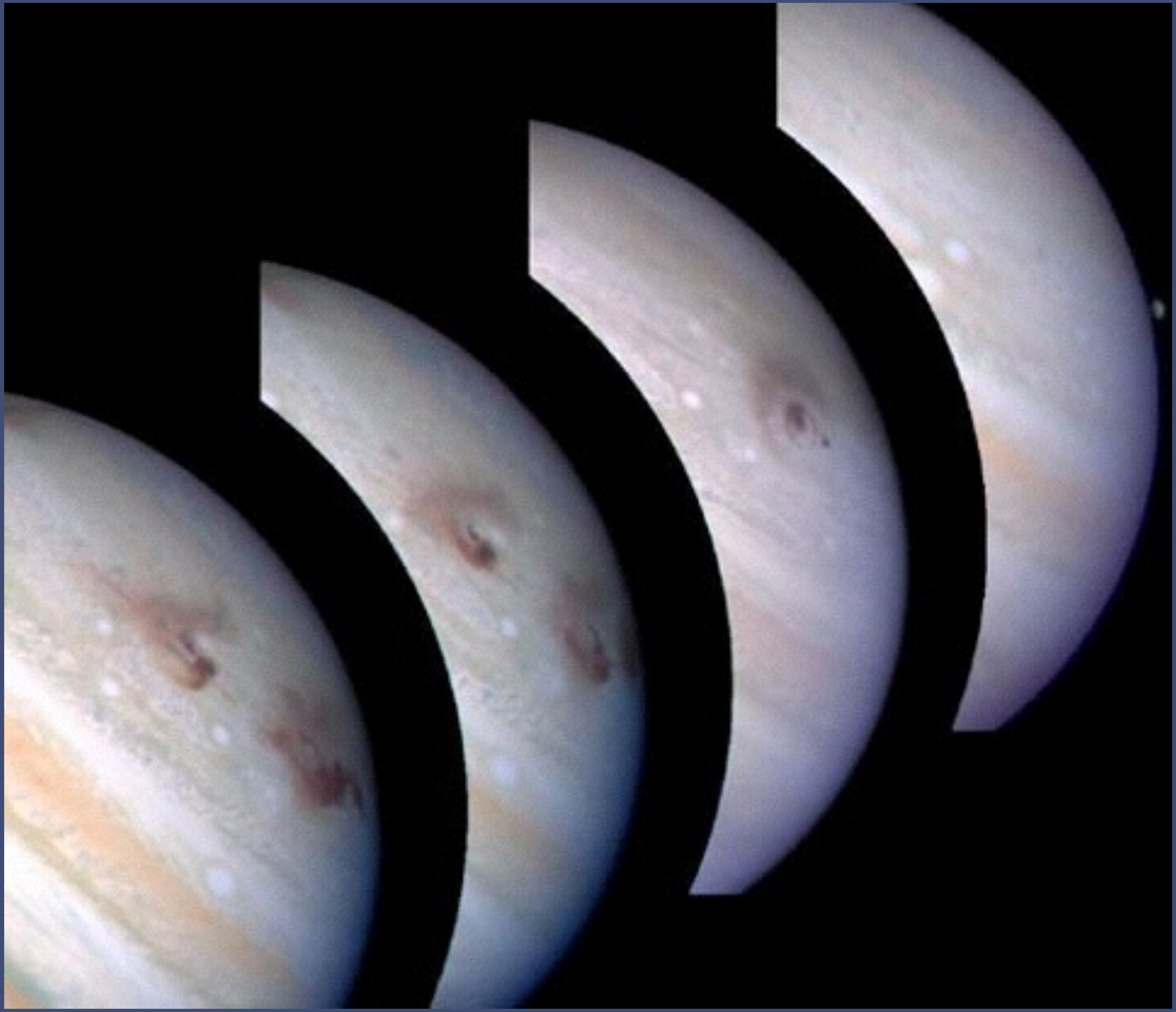
Shoemaker-Levy 9





- Fragments traveling at 60 km/s=130,000 mi/hr when they collided with Jupiter
- Each collision released an energy equivalent to 600 million megatons of TNT
  - –that's more than the total destructive energy of all the nuclear weapons in the world (for each fragment!!!)

Shoemaker-Levy 9

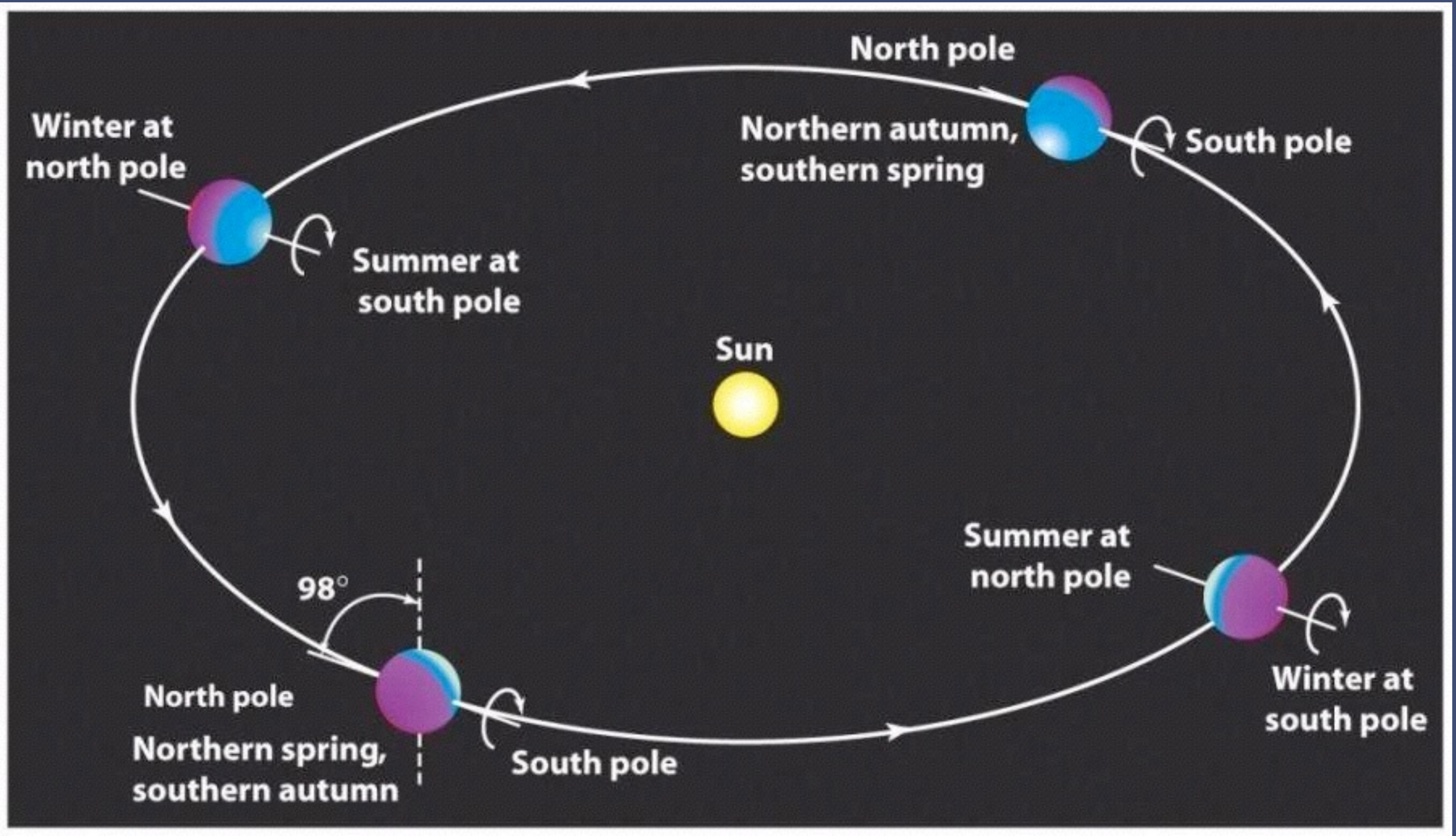


Shoemaker-Levy 9

- What would happen if Shoemaker-Levy 9 had hit Earth or if something like it hits us in the future?
  - Mass extinction
    - mostly due to “nuclear winter”
      - so much dust & debris would be kicked up into the atmosphere that we would be plunged into a period of near darkness lasting months or even years
      - plants would die because of lack of sunlight
      - animals would starve (plant eaters first, then meat eaters)
  - Probably happen about once every 300,000 years

Extreme Seasons on Uranus

- http://bcs.whfreeman.com/universe9e/
  - Animation 14-1



Moons of Solar System

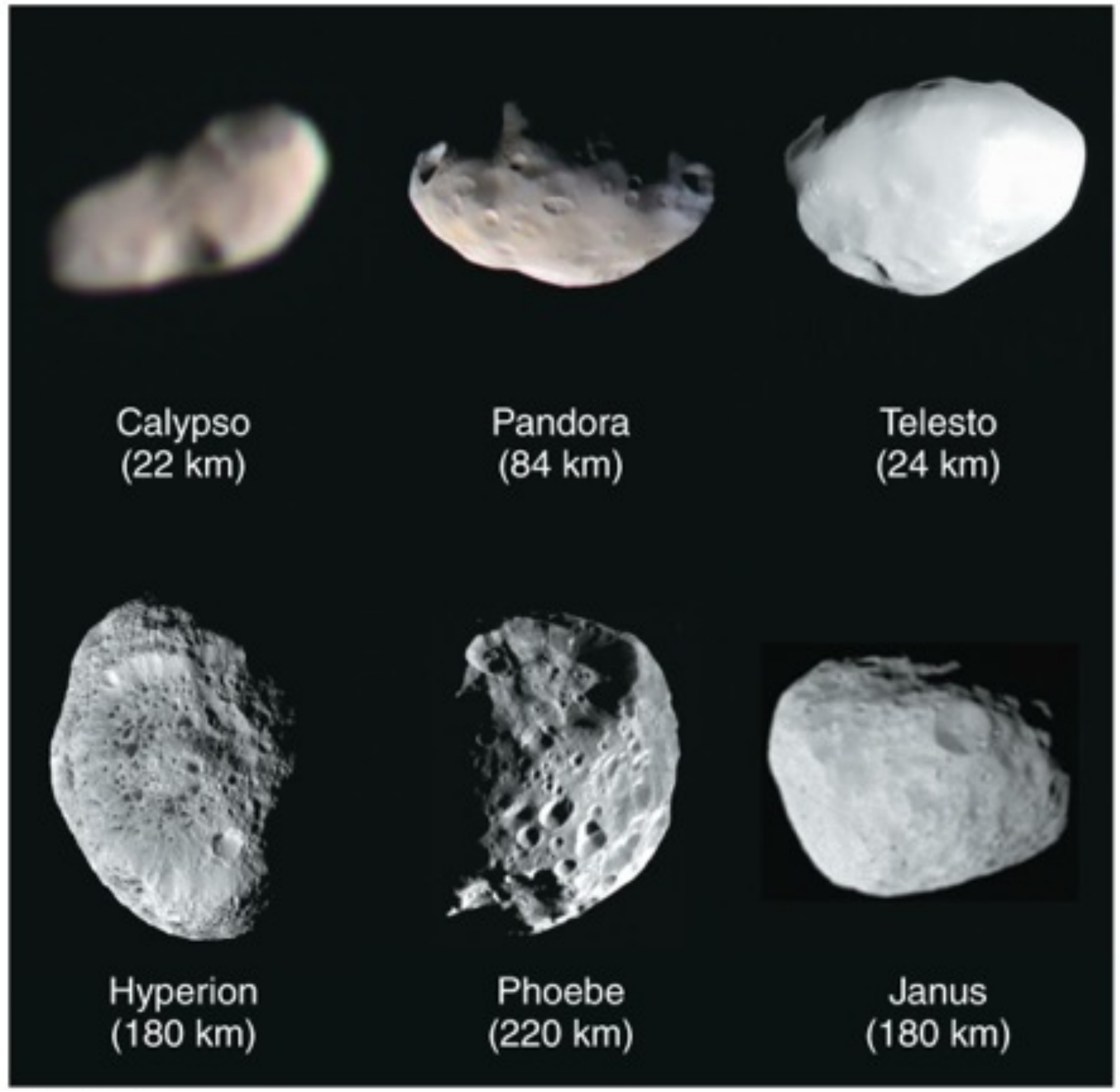
- Moons can sometimes be as large as planets
  - Ganymede & Titan are larger than Mercury
  - All 7 of these moons are larger than Pluto

	Moon	Io	Europa	Ganymede	Callisto	Titan	Triton
Parent planet	Earth	Jupiter	Jupiter	Jupiter	Jupiter	Saturn	Neptune
Diameter (km)	3476	3642	3130	5268	4806	5150	2706
Mass (kg)	7.35×10^{22}	8.93×10^{22}	4.80×10^{22}	1.48×10^{23}	1.08×10^{23}	1.34×10^{23}	2.15×10^{22}
Average density (kg/m^3)	3340	3530	2970	1940	1850	1880	2050
Substantial atmosphere?	No	No	No	No	No	Yes	No

Medium and Large Moons

- Enough self-gravity to be spherical
- Have substantial amounts of ice
- Formed in orbit around jovian planets
- Circular orbits in same direction as planet rotation

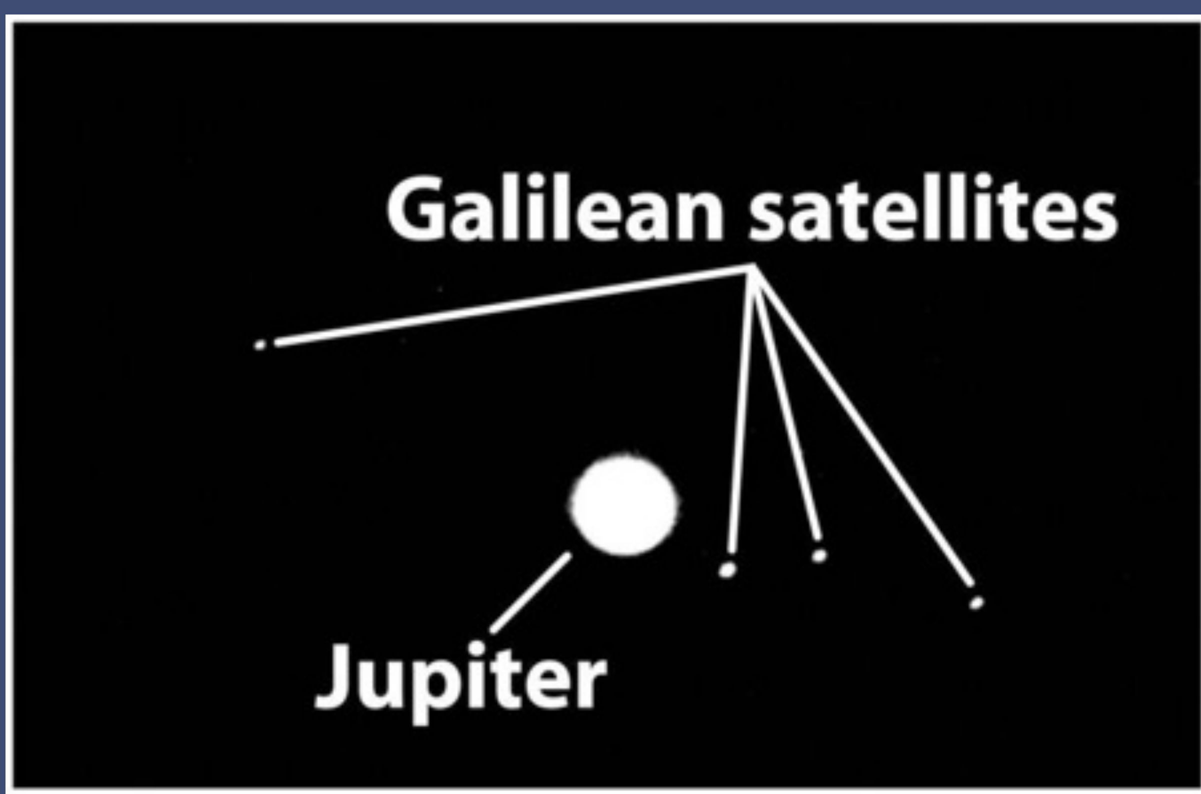
Small Moons

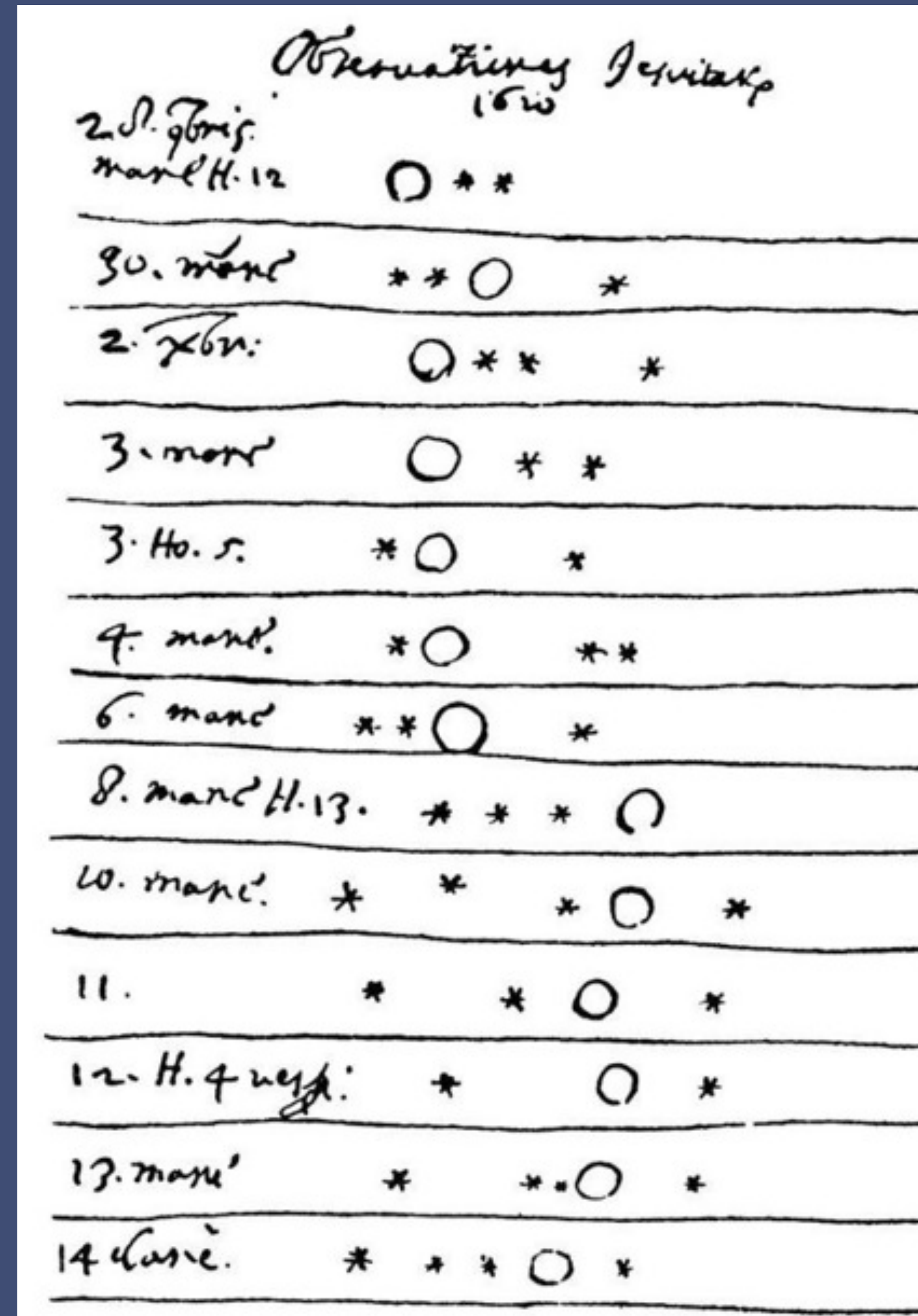


- These are far more numerous than the medium and large moons.
- They do not have enough gravity to be spherical: Most are "potato-shaped."
- They are captured asteroids or comets, so their orbits do not follow usual patterns.

Galilean Moons

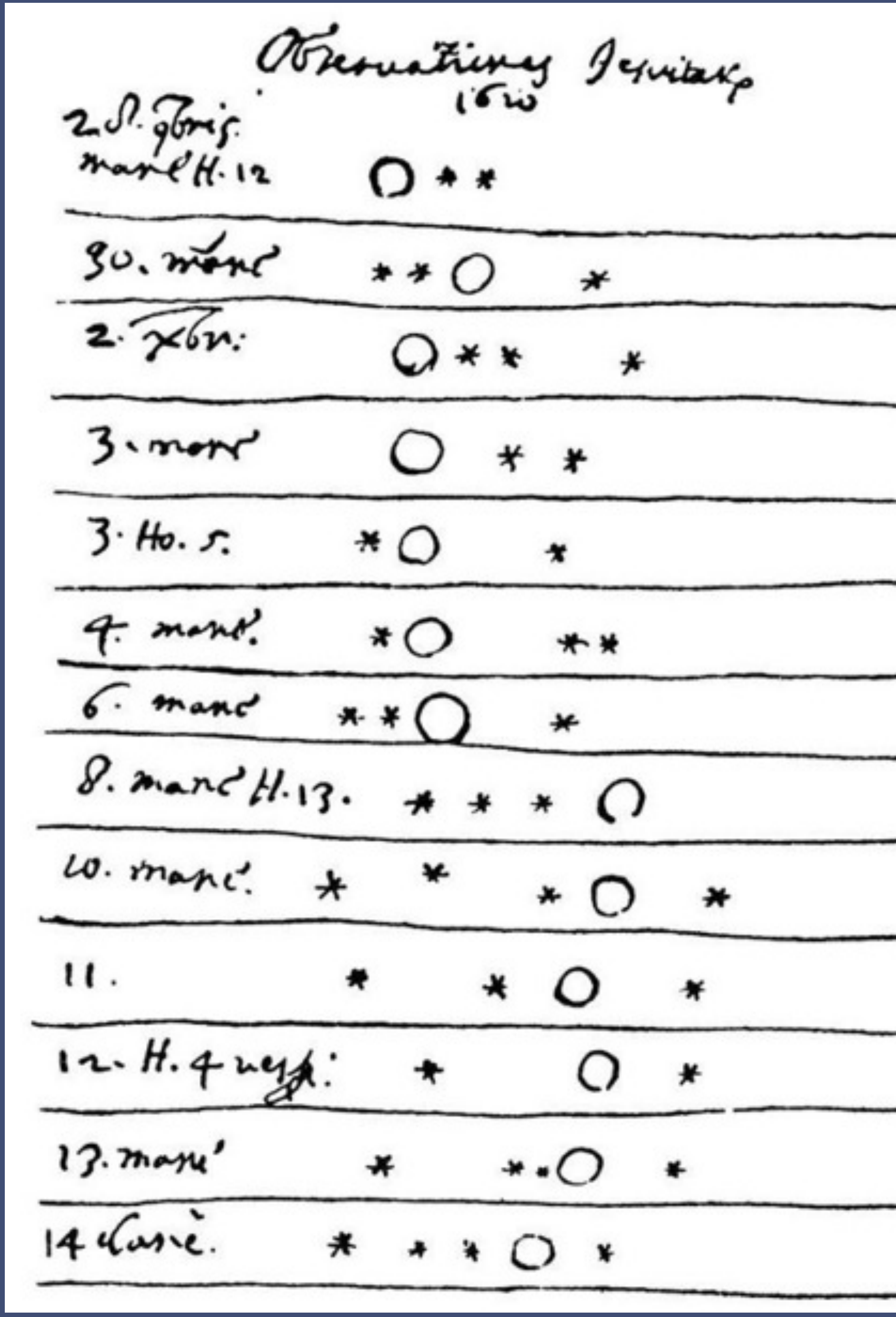
- Io, Europa, Ganymede, & Callisto
- Large & bright enough they should be visible with the naked eye
  - Why did Galileo need a telescope to see them?
    - Overwhelmed by the light of Jupiter
    - Need binoculars or telescope to increase your angular resolution





Galilean Moons

- Galilean moons always appear in a nearly straight line across Jupiter
- Must orbit on nearly the same plane
- This plane must be oriented so that we always see it nearly edge on from Earth



Motions of the Galilean Moons

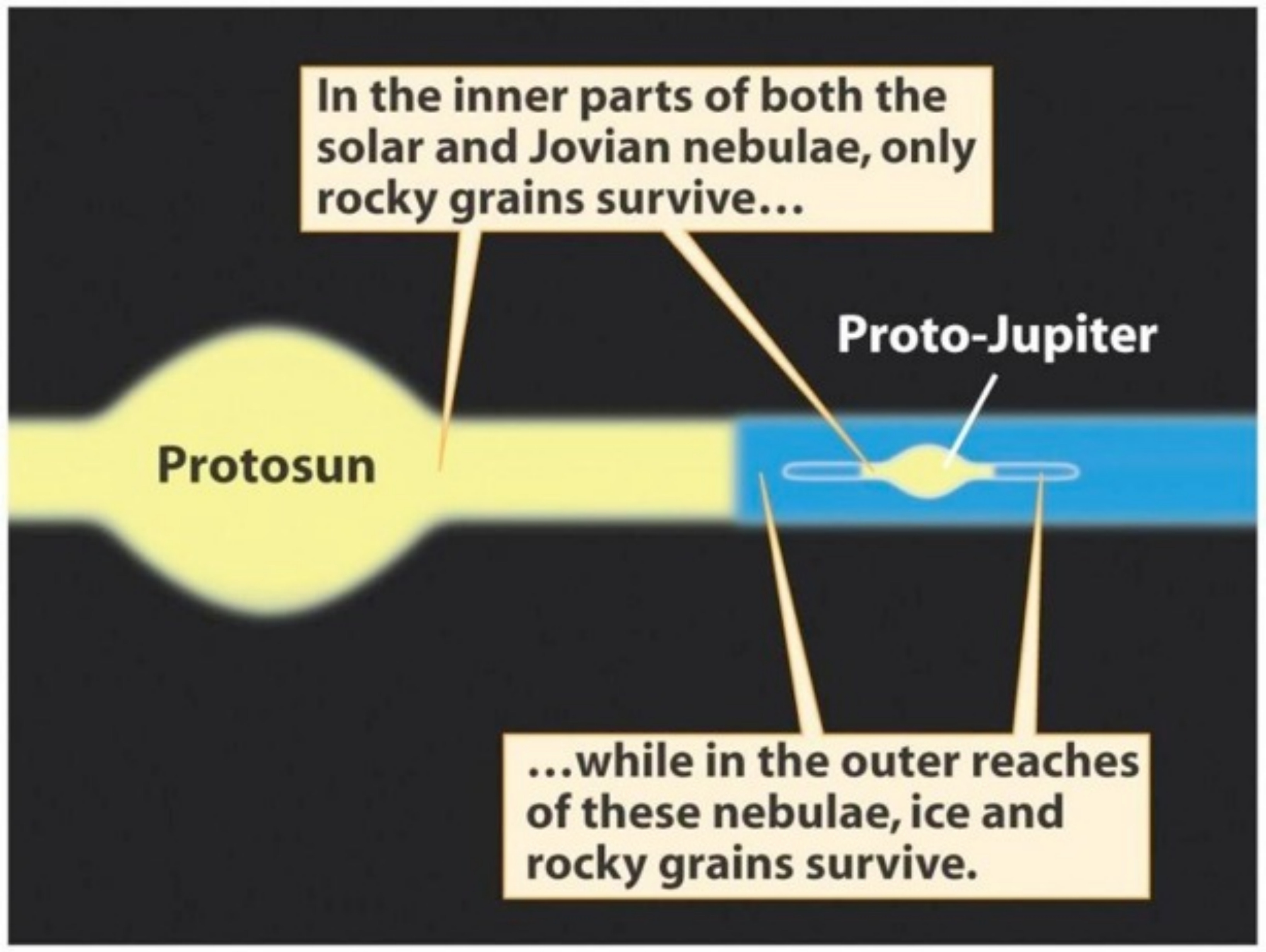
- Orbits of inner 3 Galilean moons (Io, Europa, & Ganymede) are “coupled” (or linked together)
  - 1:2:4 harmonic relation
    - every 1 orbit of Ganymede corresponds to 2 orbits of Europa and 4 orbits of Io

Motions of the Galilean Moons

- All 4 Galilean moons undergo ***synchronous rotation*** (1-to-1 spin-orbit coupling)
  - Same side (or face) of each of these moons faces Jupiter at all times

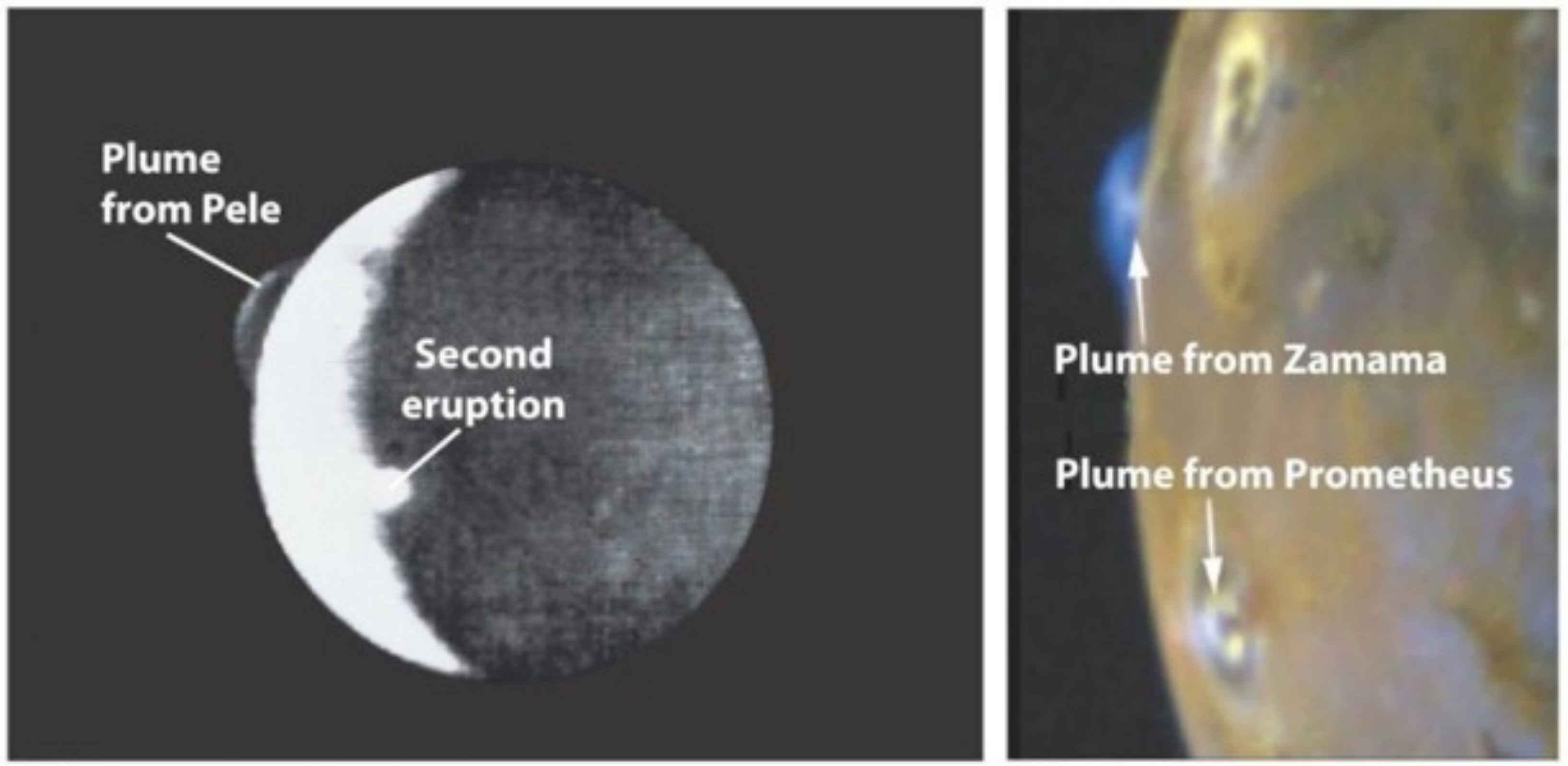
Formation of Galilean Moons

- Co-creation theory
  - Galilean moons likely formed roughly where they are now at the same time that Jupiter was forming
  - “Jovian nebula”
  - Io & Europa are similar to terrestrial planets
    - composed of silicates
    - Io may have an iron core



Io (Jupiter)

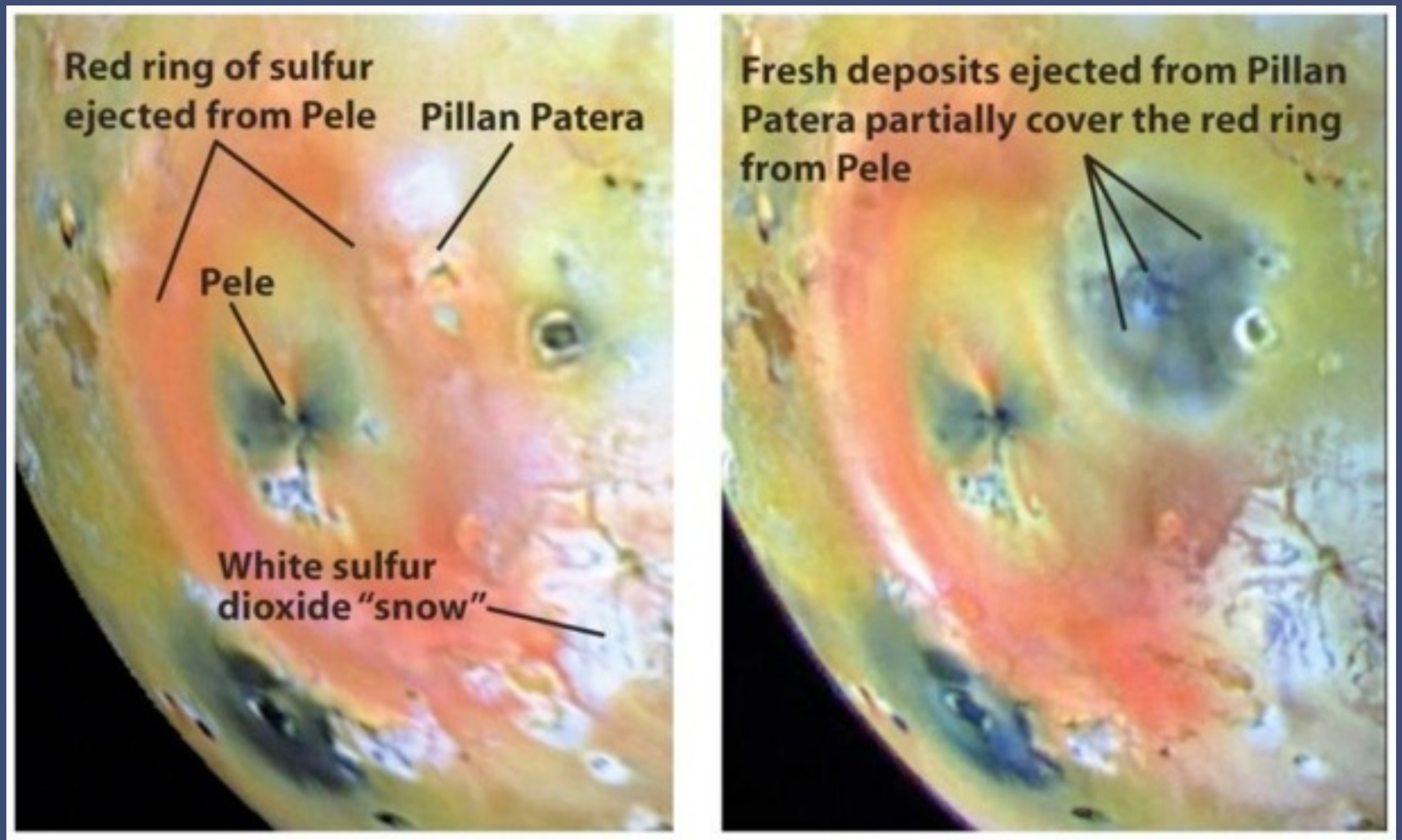
- http://bcs.whfreeman.com/universe9e/
  - Video 13.1
- Small objects, like moons, are expected to cool faster than large objects, like planets
  - Would have expected all moons to have solidified by now
  - Therefore, should not be geologically active, but it is!!



(a) *Voyager 1*, March 1979 (b) *Galileo*, November 1997

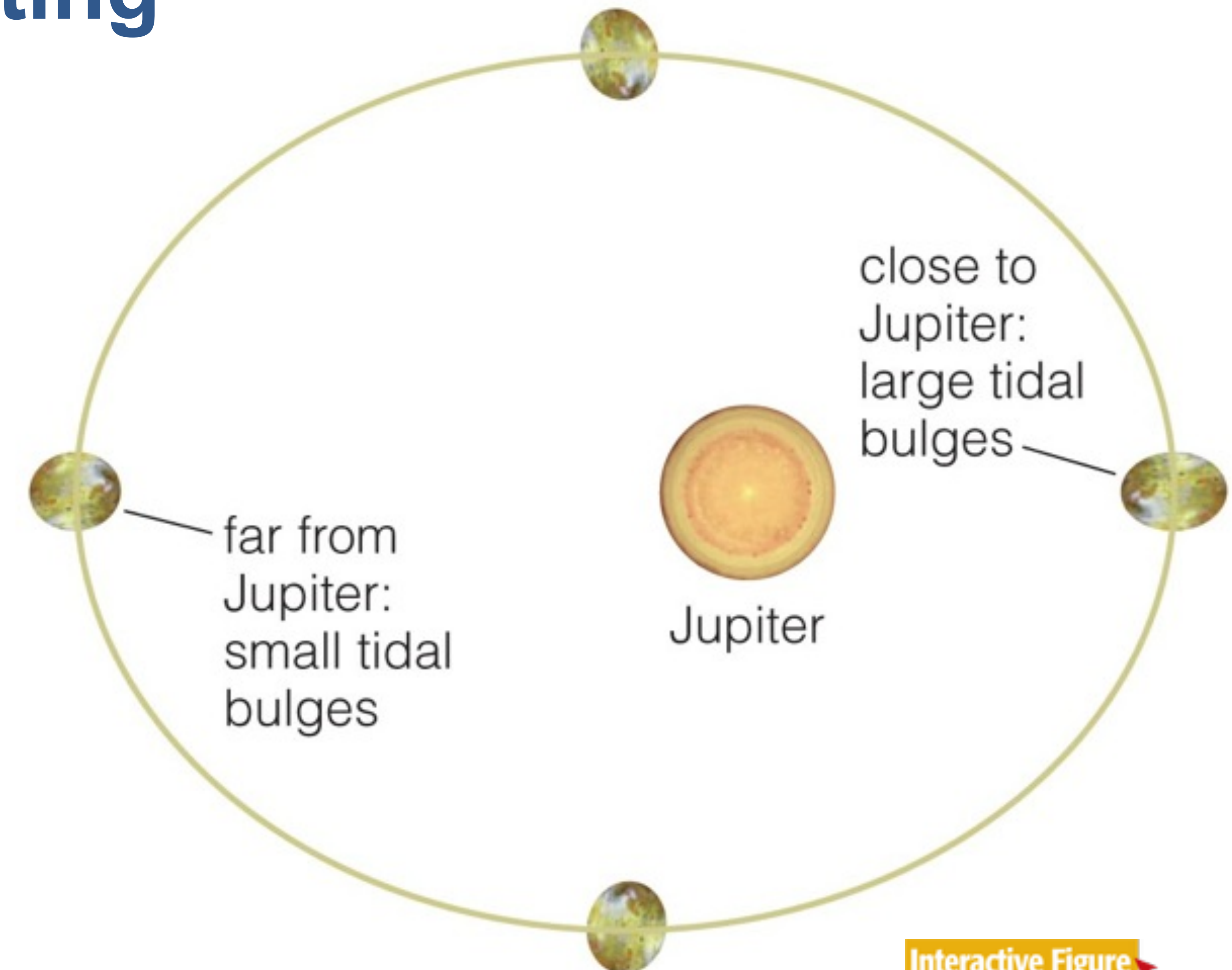
Io (Jupiter)

- Heat for geological activity probably comes from tidal flexing of the crust as Io orbits Jupiter
- One of the most geologically active bodies in the Solar System
- Surface changes appearance in a matter of months



yellow = sulfur
red = sulfur
white = sulfur dioxide ice

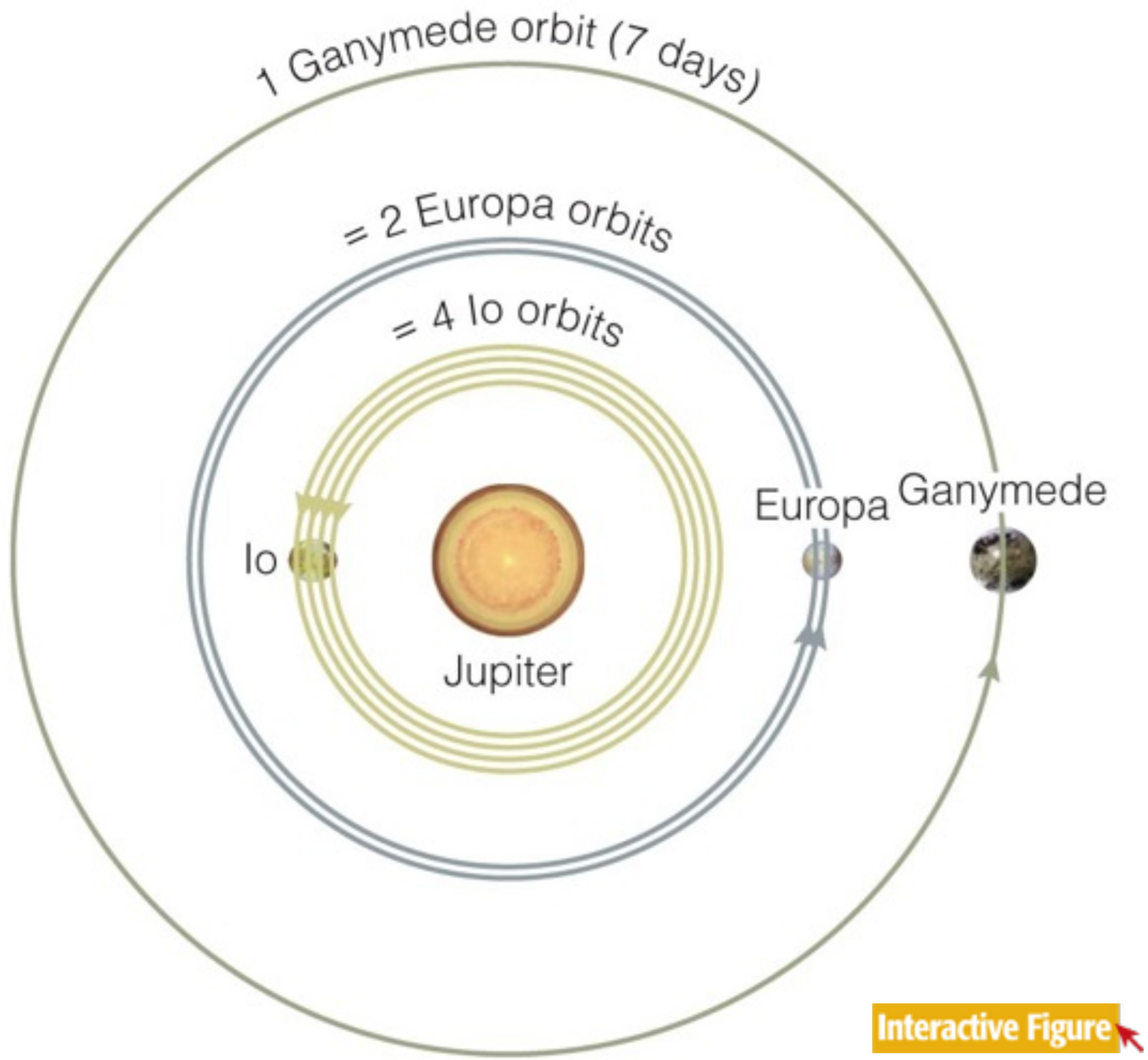
Tidal Heating



Io is squished and stretched as it orbits Jupiter.

But why is its orbit so elliptical?

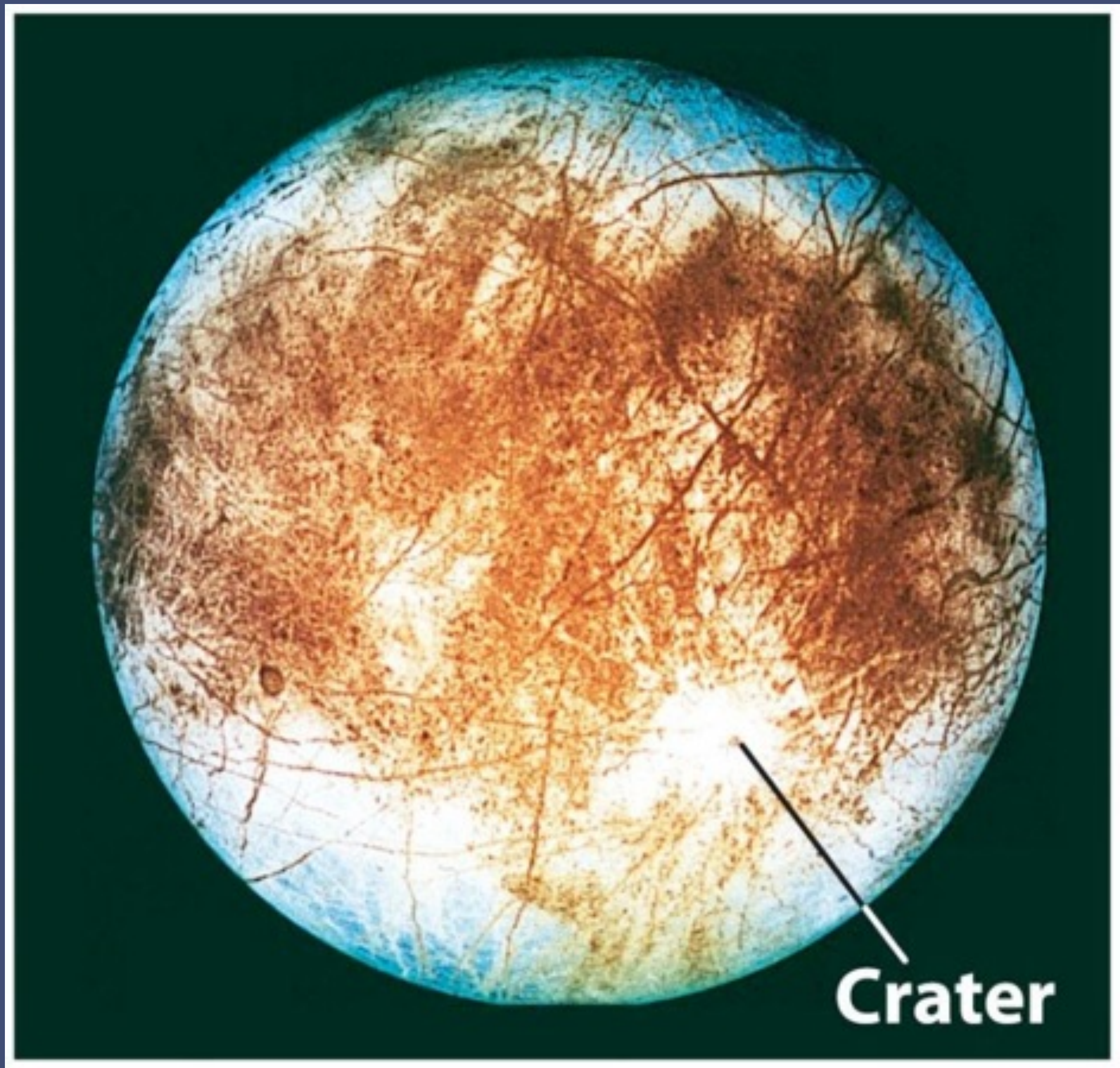
Orbital Resonances



- Every 7 days, these three moons line up.
- The tugs add up over time, making all three orbits elliptical.

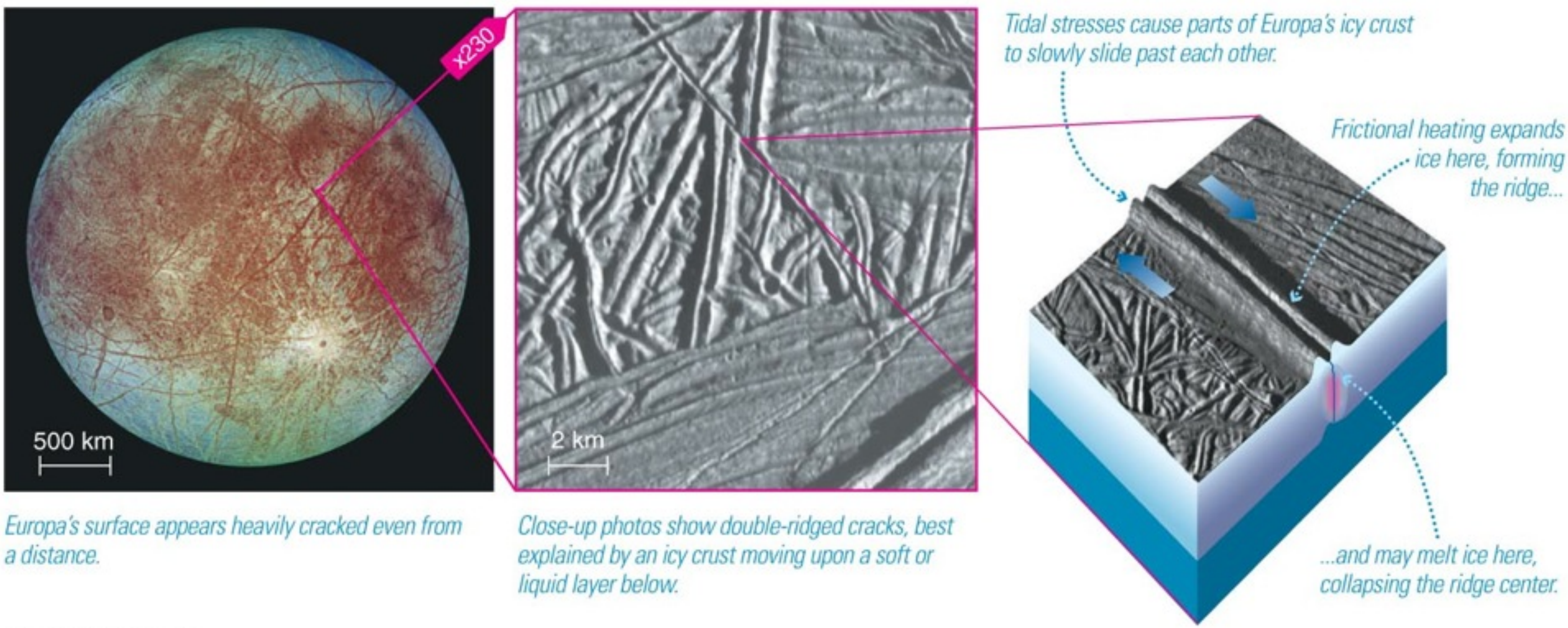
Europa (Jupiter)

- Very smooth surface composed almost entirely of water ice
- Crisscrossed with a network of cracks
- May be a liquid ocean underneath the ice
  - could potentially host certain types of living organisms



Combination optical & infrared image
Red coloring in cracks is due to minerals trapped in the ice

Tidal stresses crack Europa's surface ice.

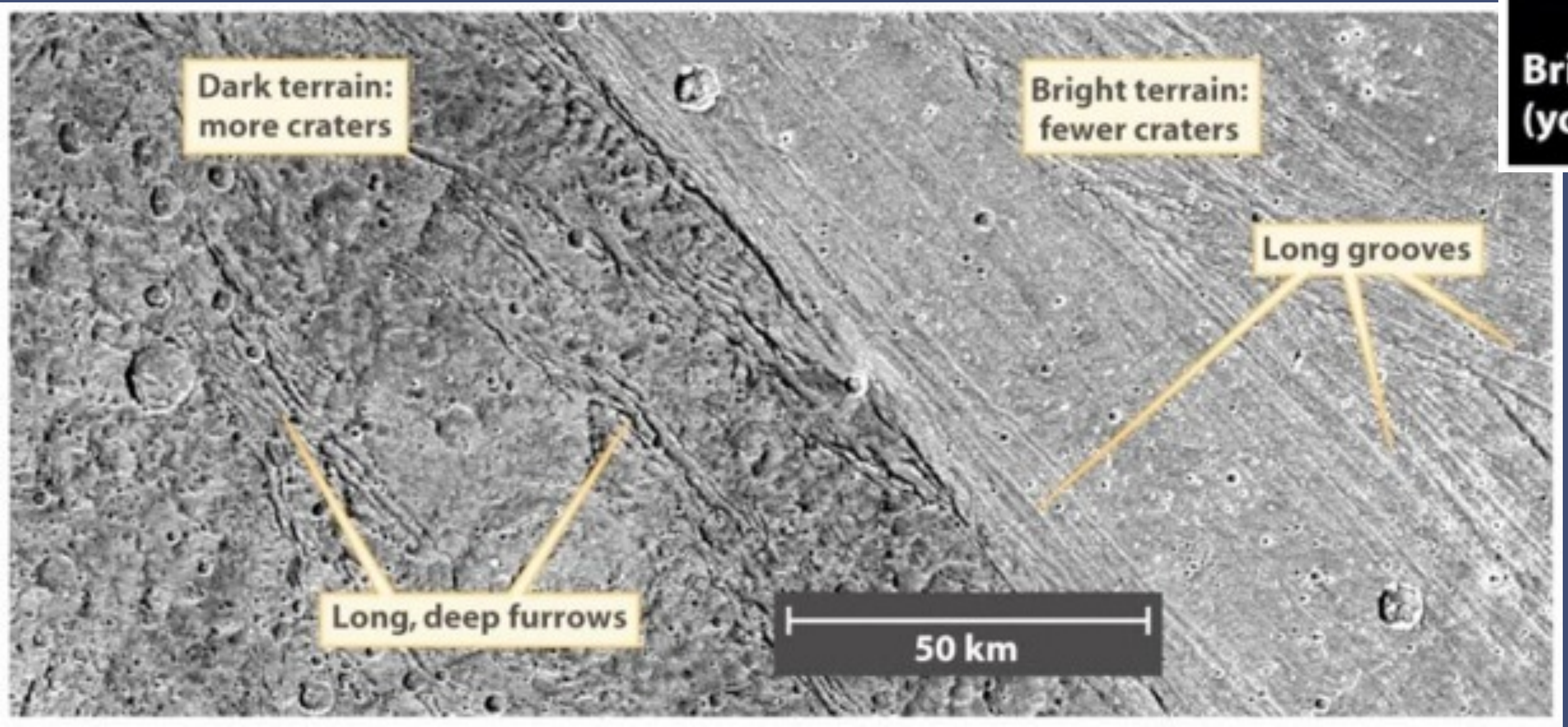


Europa's surface appears heavily cracked even from a distance.

Close-up photos show double-ridged cracks, best explained by an icy crust moving upon a soft or liquid layer below.

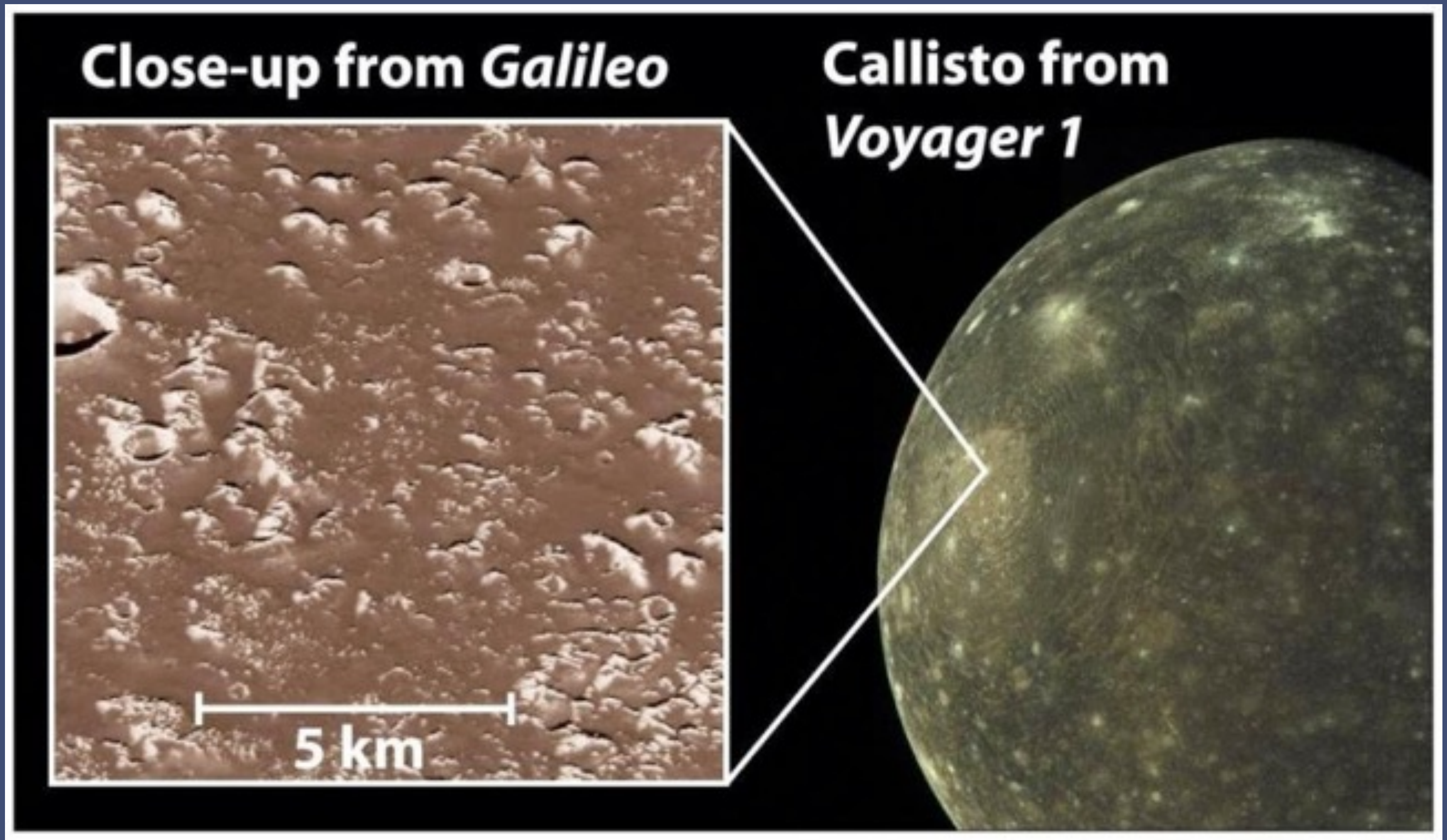
Ganymede (Jupiter)

- Largest moon
- Low density
- Two types of terrain
  - very old, cratered highlands
  - somewhat younger "plains"
- Evidence for tectonic activity

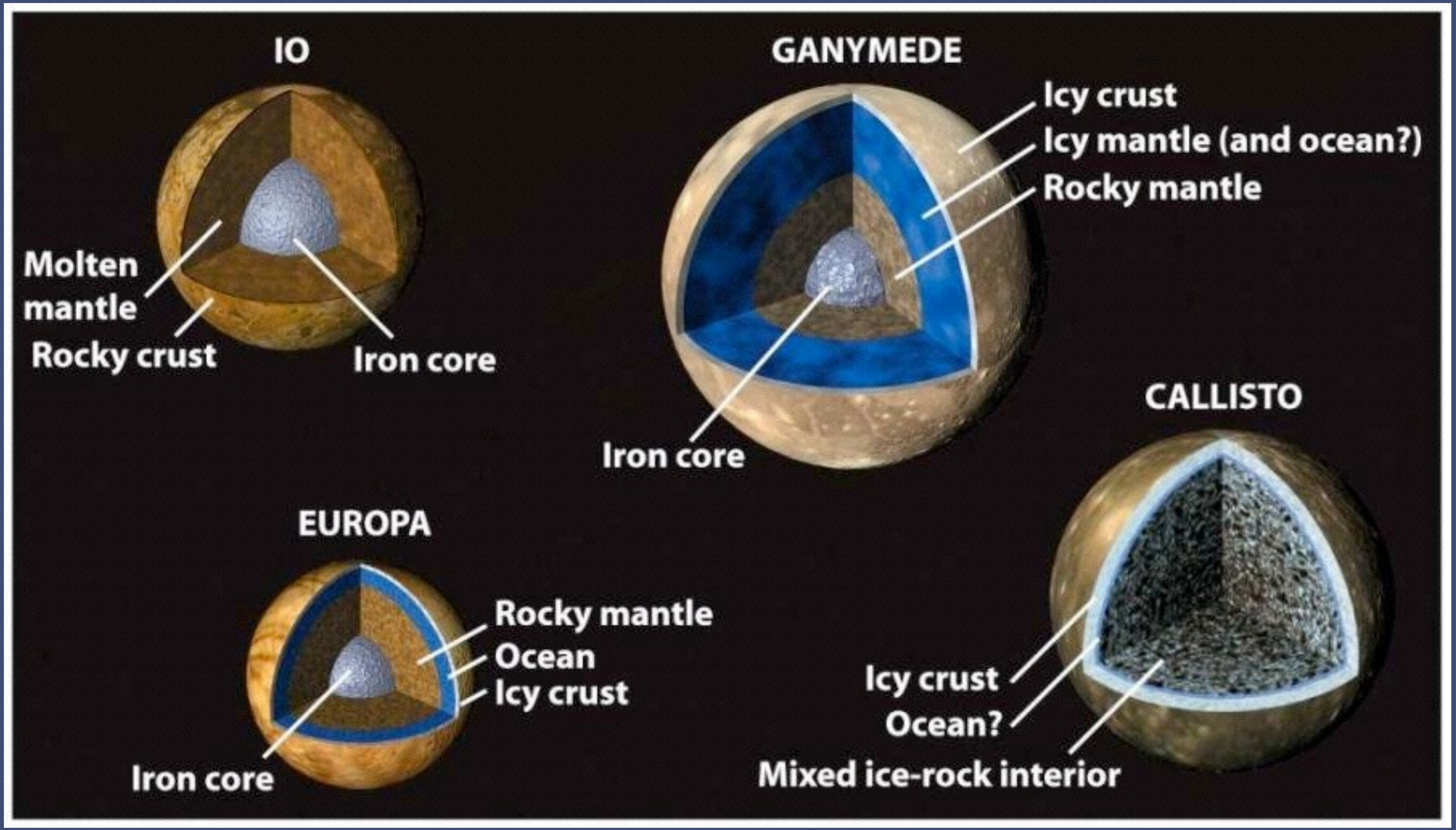


Callisto (Jupiter)

- Oldest surface known in the Solar System
- Mostly rock & ice
- Surface ice can flow slowly
  - small craters have been “erased”

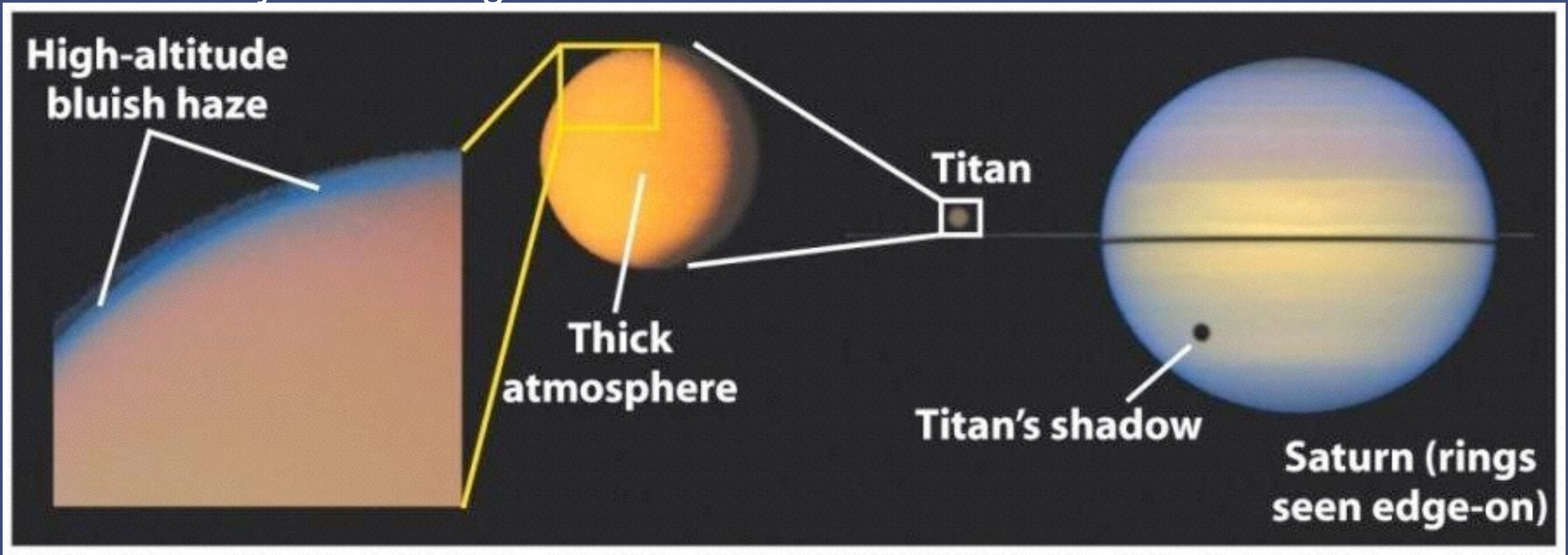


Structure of Galilean Moons

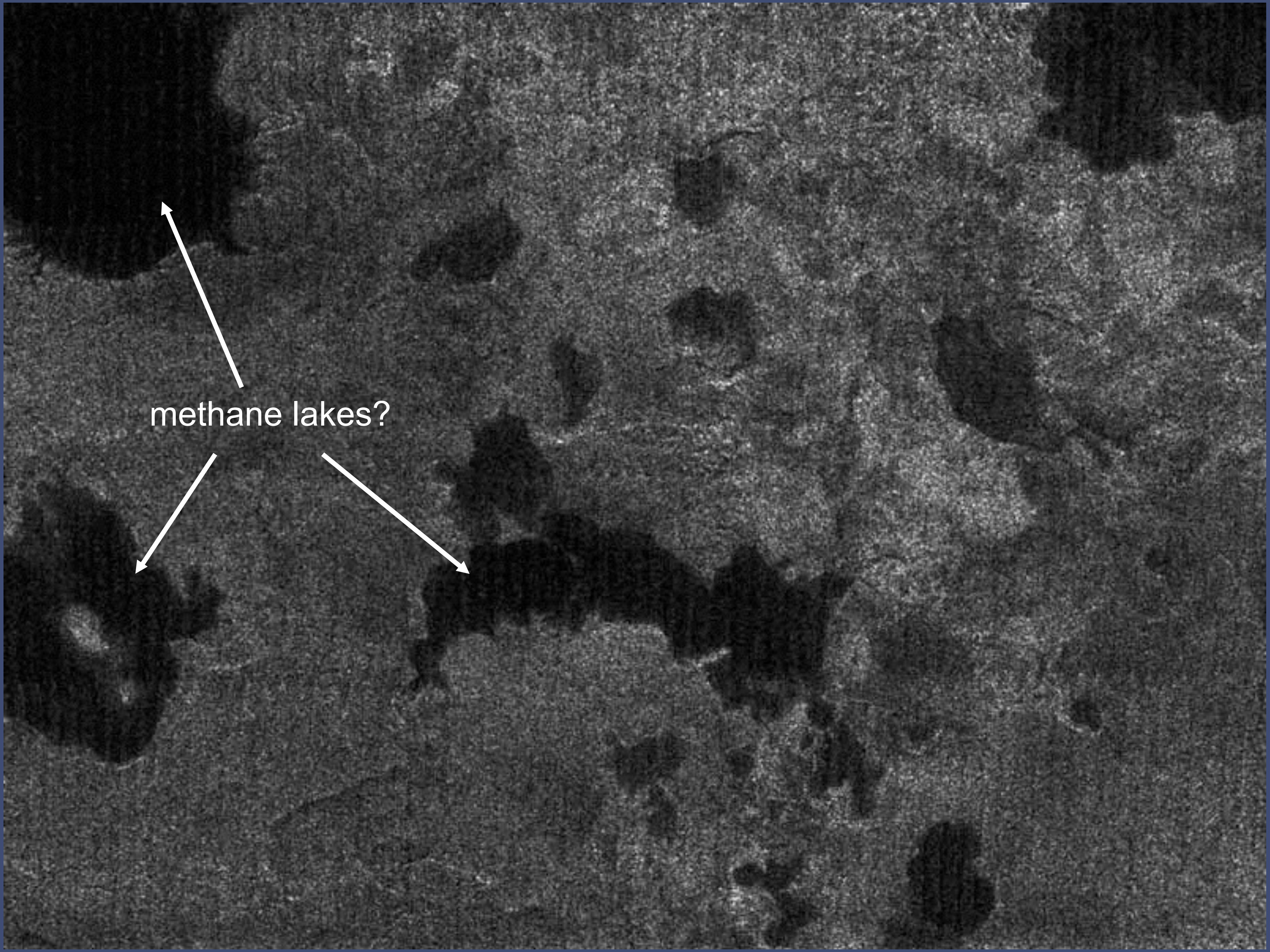


Titan (Saturn)

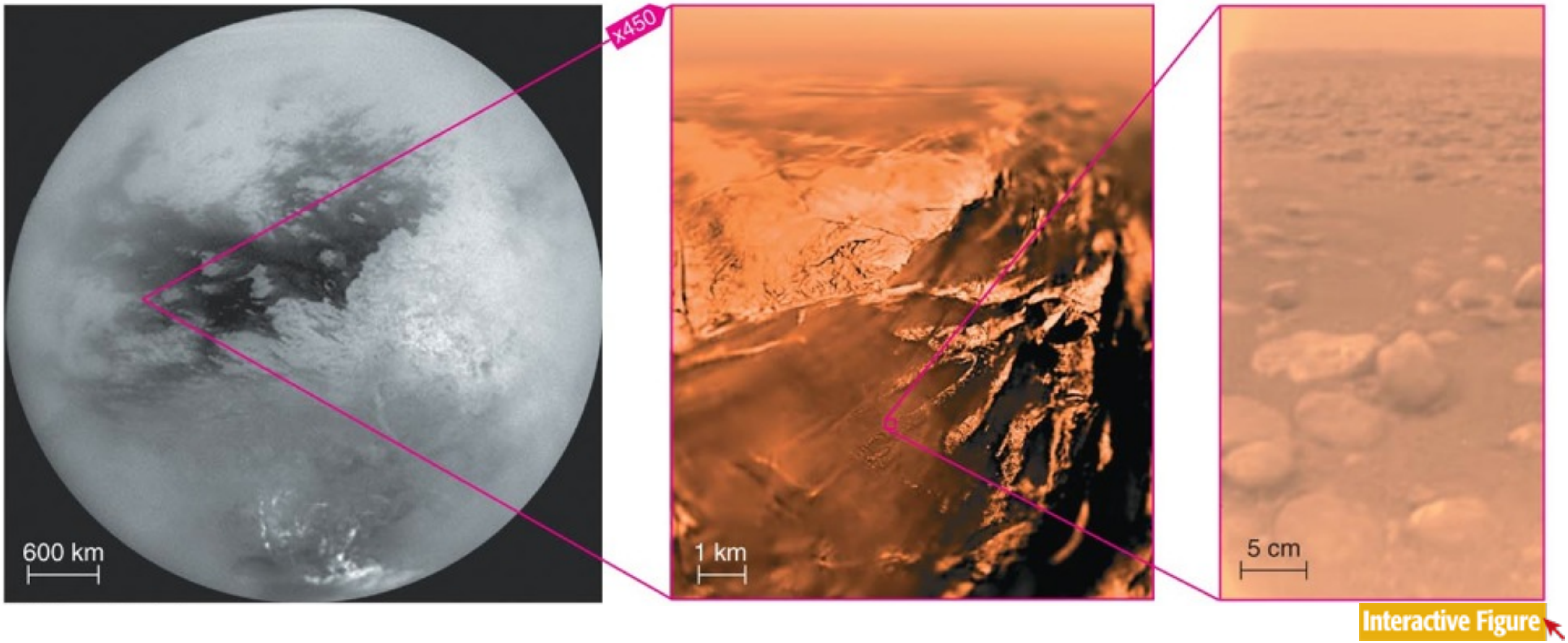
- Only moon in Solar System with a substantial atmosphere
  - Galilean moons all have tenuous atmospheres
- Titan's atmosphere is composed mostly of Nitrogen (similar to Earth)
- Also contains significant amounts of organic chemicals (hydrocarbons)
  - Speculation that these chemicals may rain out of Titans atmosphere to create rivers and lakes on the surface
  - Possibly has the ingredients for new life to form



Titan (Saturn)



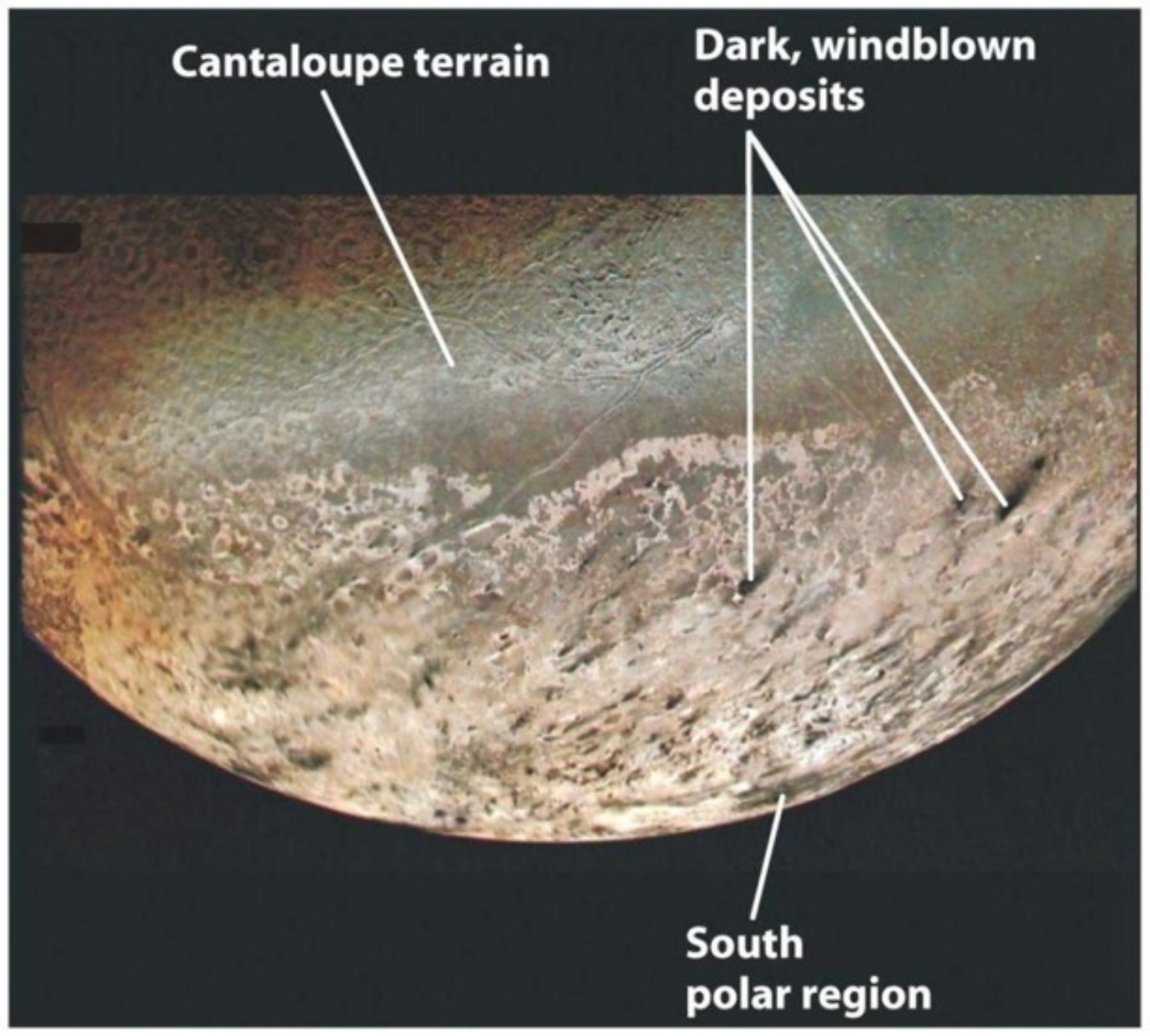
Titan's Surface



- *Huygens* probe provided first look at Titan's surface in early 2005.
- It found liquid methane and "rocks" made of ice.

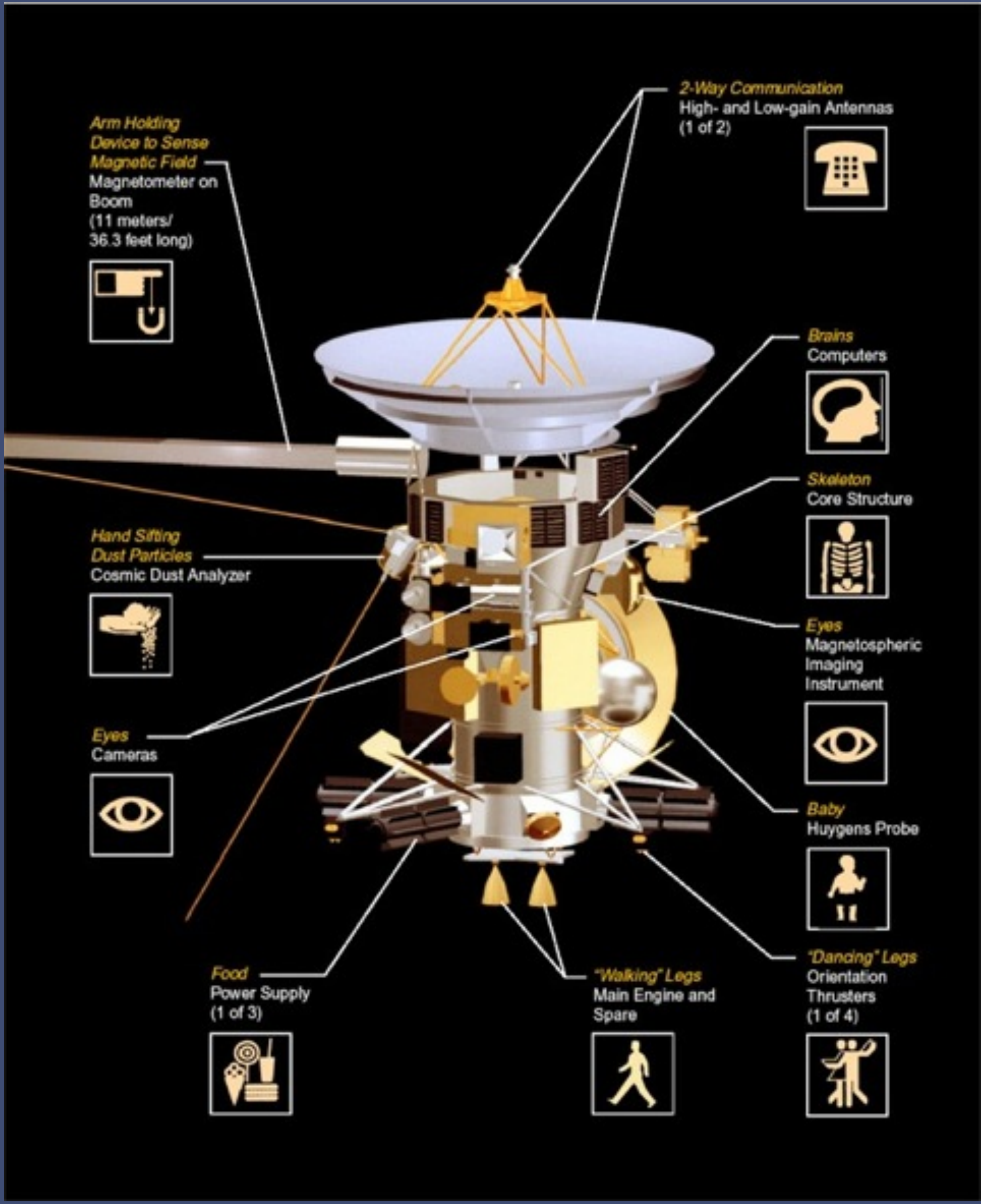
Moons of Neptune

- Triton
  - 7th largest moon in Solar System
  - in retrograde orbit around Neptune
    - probably captured by Neptune
  - tenuous nitrogen atmosphere
  - losing orbital energy due to tidal interaction with Neptune
    - will eventually spiral inside Roche limit and be destroyed

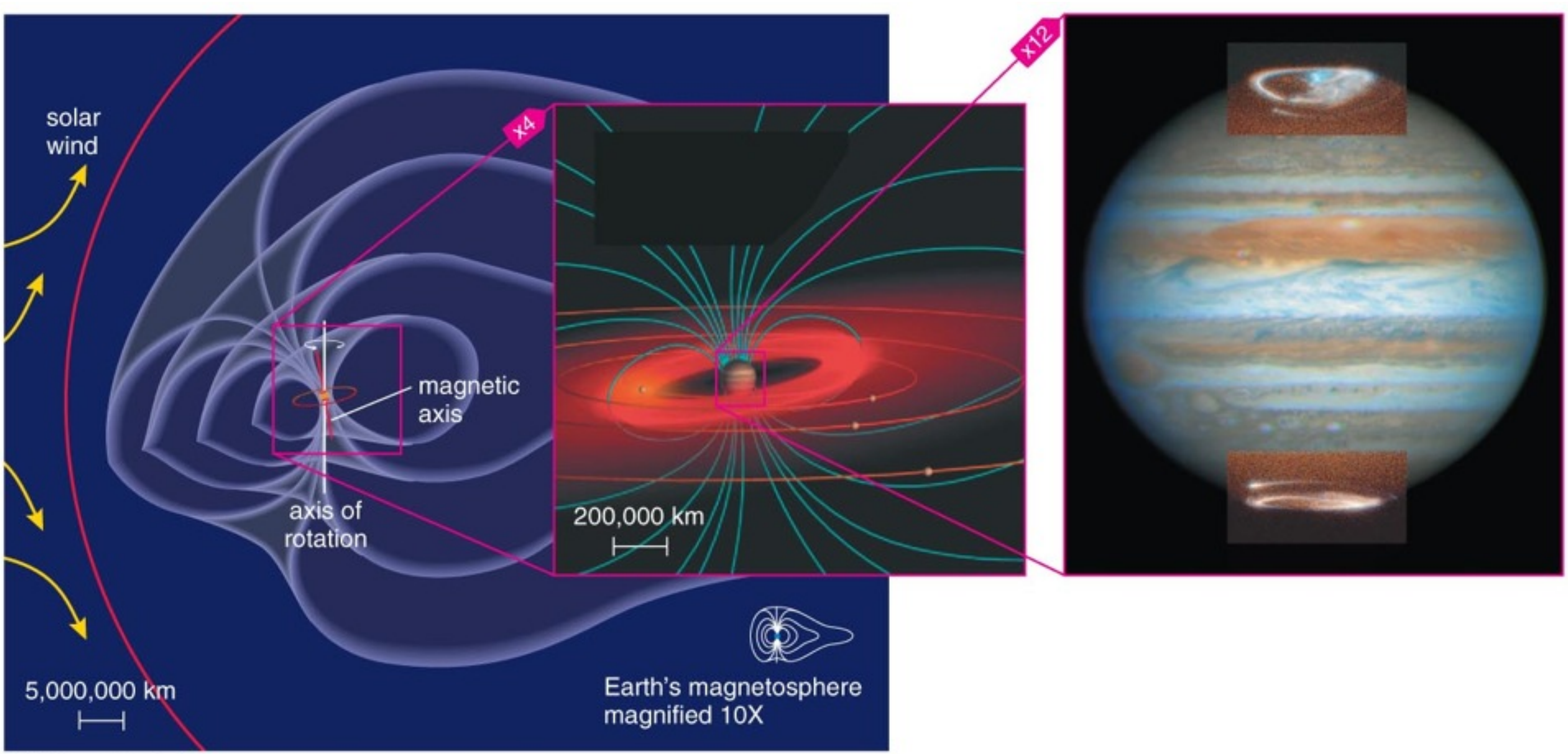


Cassini Spacecraft

- Currently in orbit around Saturn
- Returning a tremendous amount of data
- http://saturn.jpl.nasa.gov/



Jupiter's Magnetosphere



- Jupiter's strong magnetic field gives it an enormous magnetosphere.
- Gases escaping Io feed the donut-shaped Io torus.

Thought Question

Jupiter does *not* have a large metal core like the Earth. How can it have a magnetic field?

a) The magnetic field is left over from when Jupiter accreted.
b) Its magnetic field comes from the Sun.
c) It has metallic hydrogen inside, which circulates and makes a magnetic field.
d) Its core creates a magnetic field, but it is very weak.

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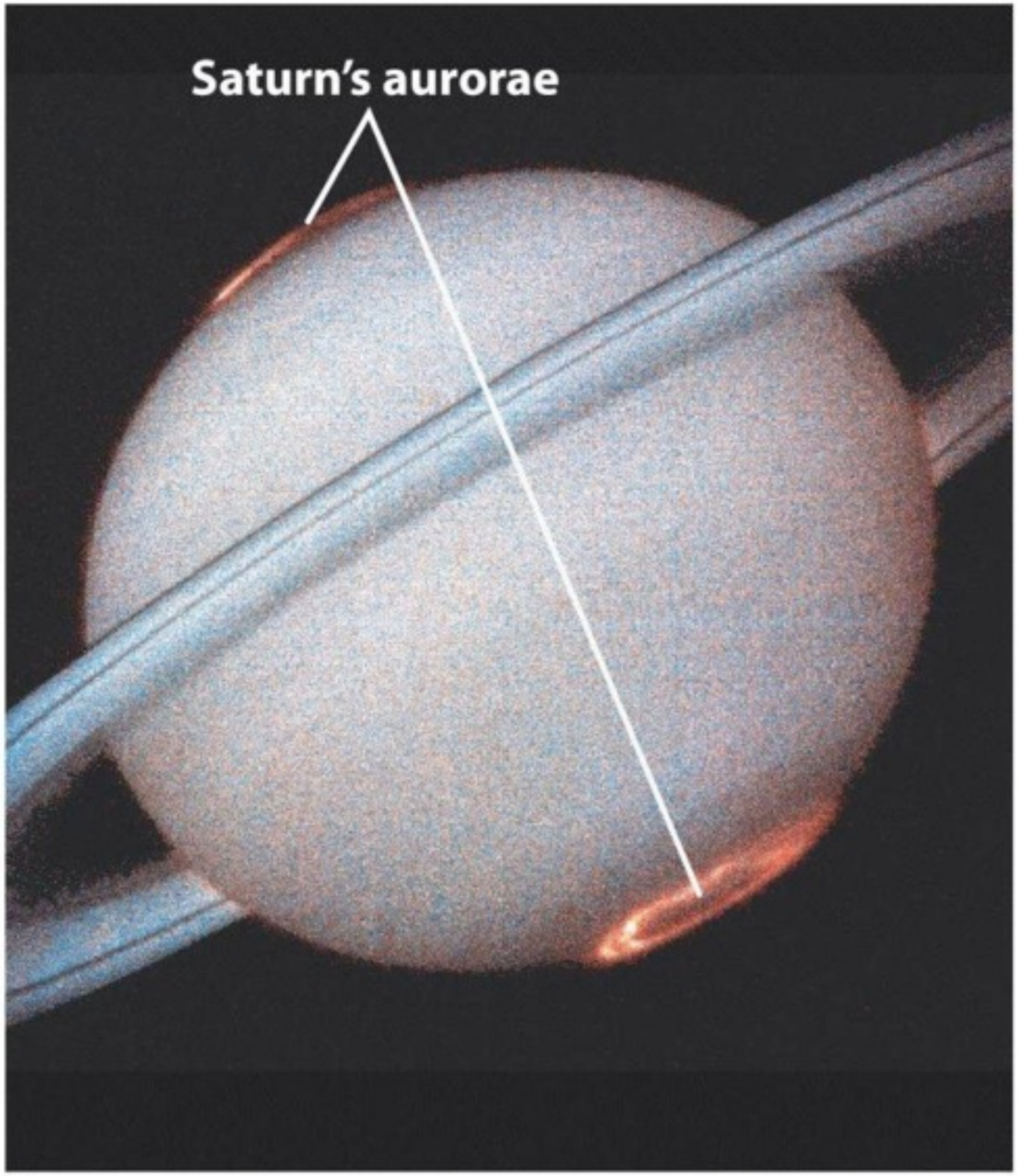
Auroras on Jupiter

- Charged particles spiraling down Jupiter's field lines and colliding with its atmosphere create auroras like those seen on Earth

(a) Jupiter

Auroras on Saturn

- Charged particles spiraling down Saturn's field lines and colliding with its atmosphere create auroras like those seen on Earth



(b) Saturn