

# Lecture 14: The Giant Planets, their Moons, and their Rings



**Jupiter's Great Red Spot**

**Claire Max  
May 22, 2014  
Astro 18: Planets and Planetary Systems  
UC Santa Cruz**

# Class Projects

- **Today: Each group send me your lists of questions**
- **Today: Each person send me a quick email about how things are going in your group**

# Class Projects, continued

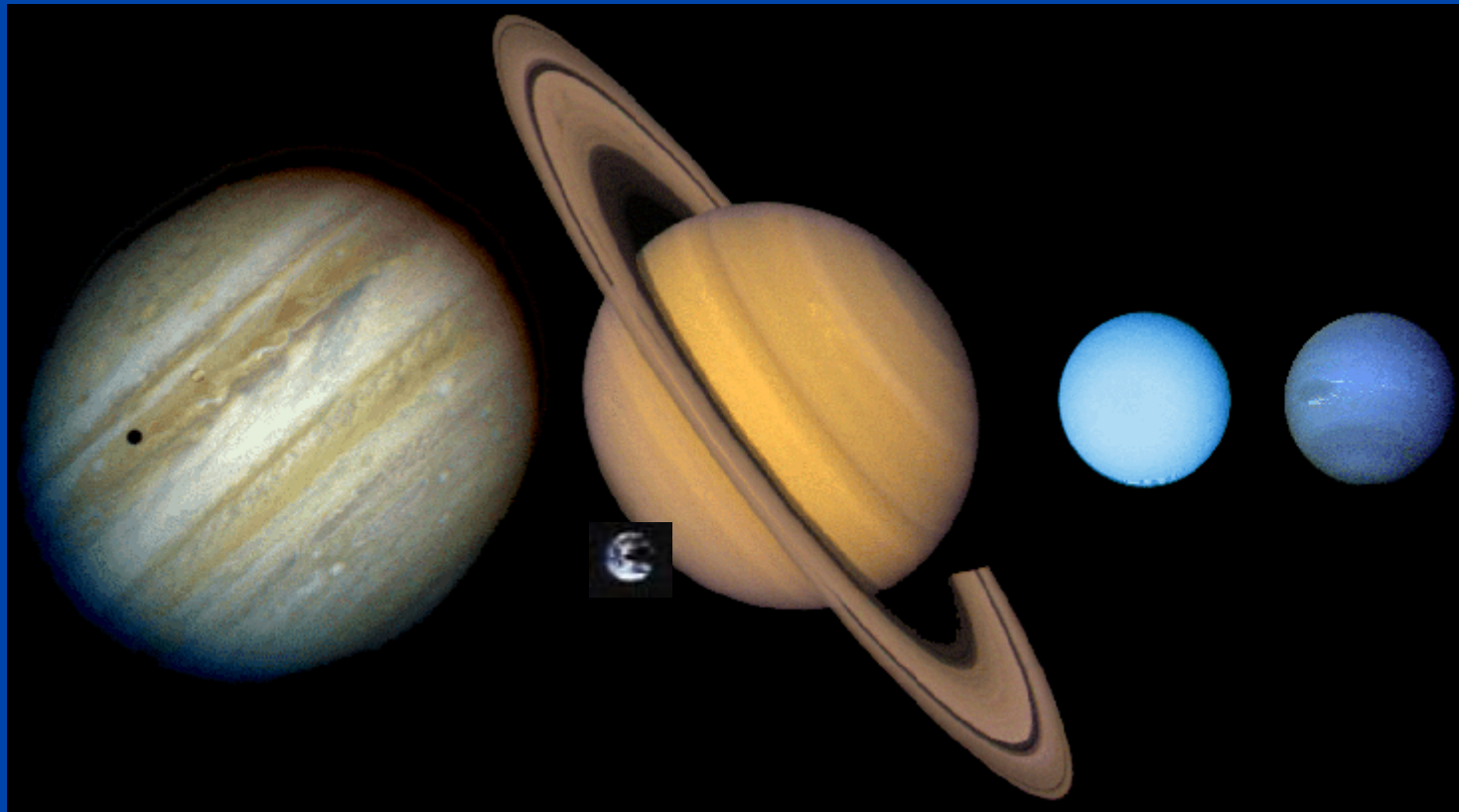
- What should your reference sources be?
- At least the following, for each question:
  1. Two authoritative websites to get started, frame the issues for you to work on, help identify other references. Use to get the “big picture”.
  2. Two journal articles on your topic. Look over four or five (read abstracts, skim contents, take notes) before choosing the two you are going to use. Search at [http://adsabs.harvard.edu/default\\_service.html](http://adsabs.harvard.edu/default_service.html)
  3. One book or monograph (need not be the whole thing, but use the relevant sections). Use Science Library or UCSC Library website to search.

# The Giant Planets in our own Solar System

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- **Jupiter, Saturn, Uranus, Neptune**  
(and Earth for comparison)



# Outline of lecture

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- **Jovian Planets:**
  - **Properties**
  - **Formation**
  - **Interior structure**
  - **Atmospheres**
- **Moons of the Giant Planets**

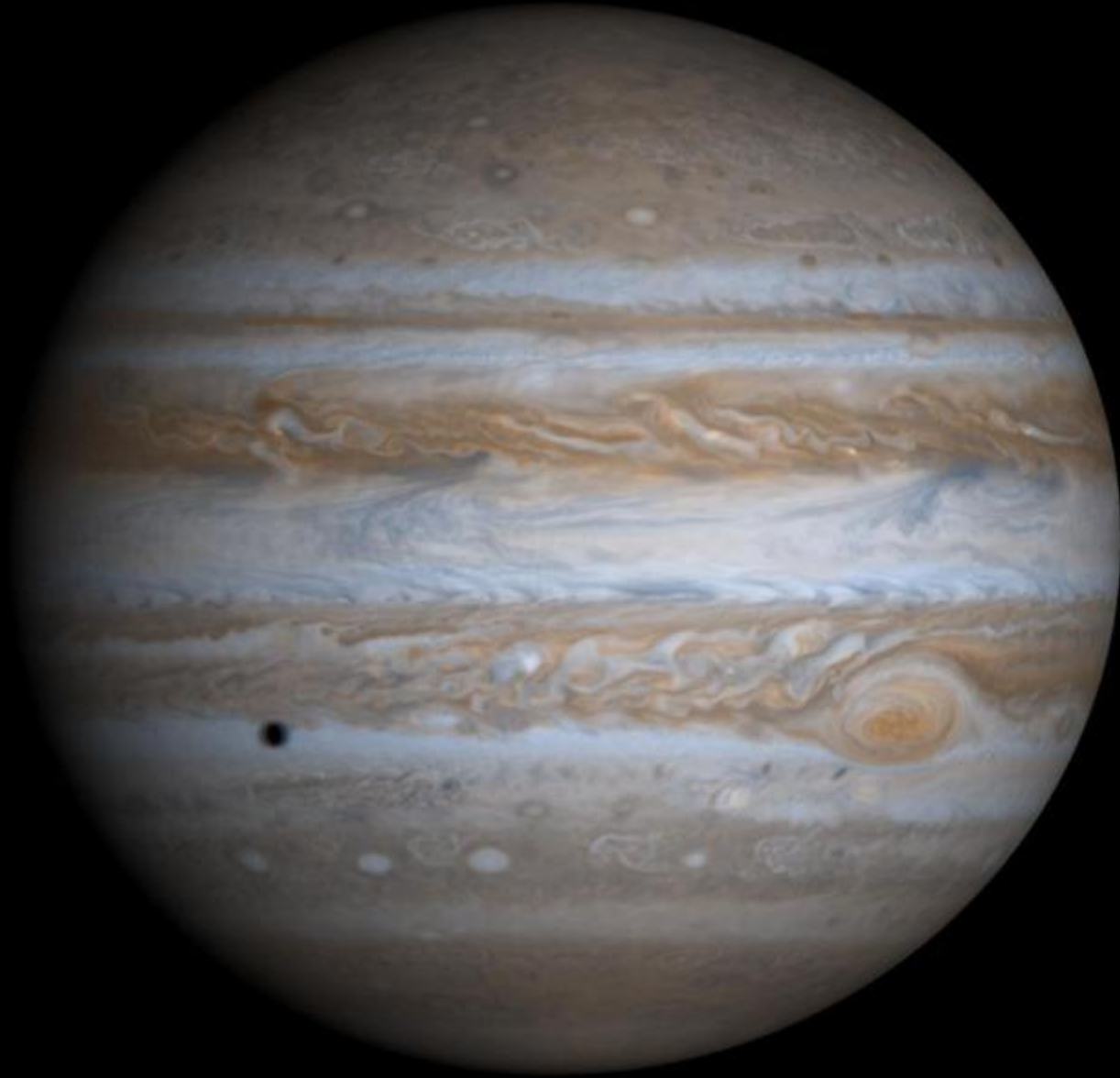
# Jovian (or Giant) Planet Properties

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- **Compared to the terrestrial planets, the Jovians:**
  - are much larger & more massive
  - are composed mostly of Hydrogen, Helium, & Hydrogen compounds
  - have no solid surfaces
  - rotate more quickly
  - have slightly “squashed” shapes
  - have ring systems
  - have many moons

**Jupiter – 318 x Earth**

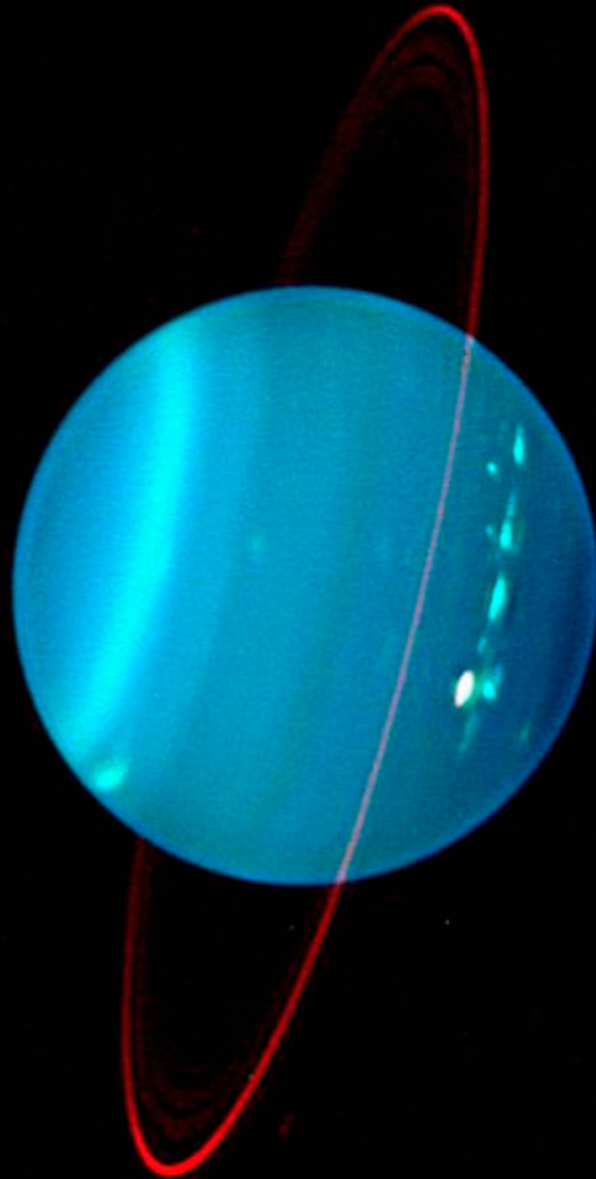




**Saturn**  
95x Earth

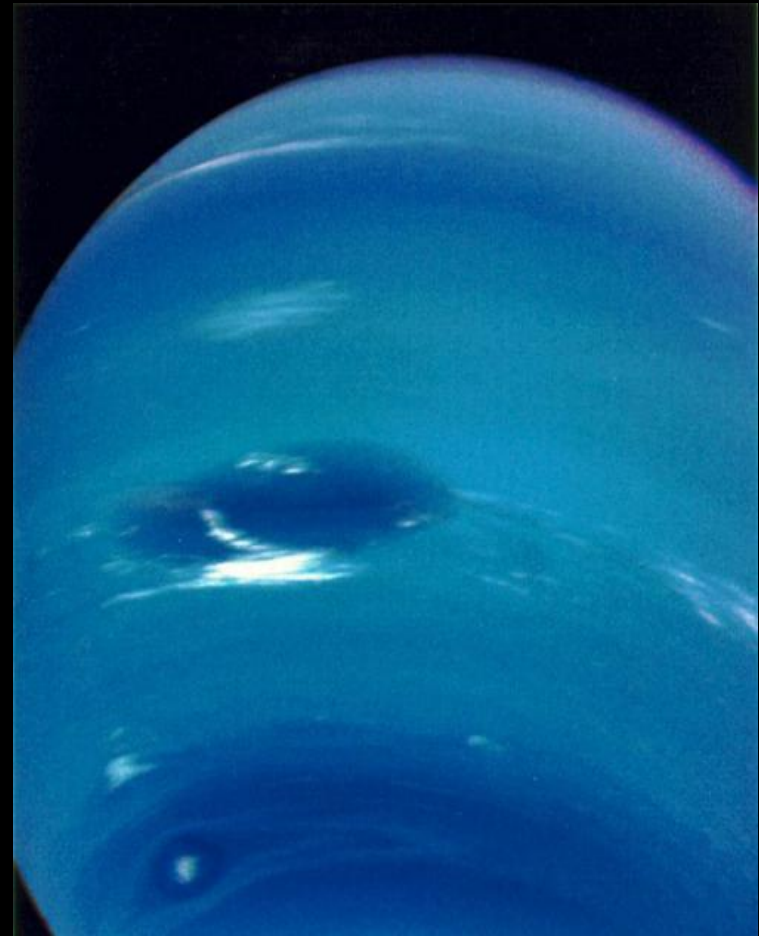


**Uranus**  
14x Earth



# Neptune

17x Earth

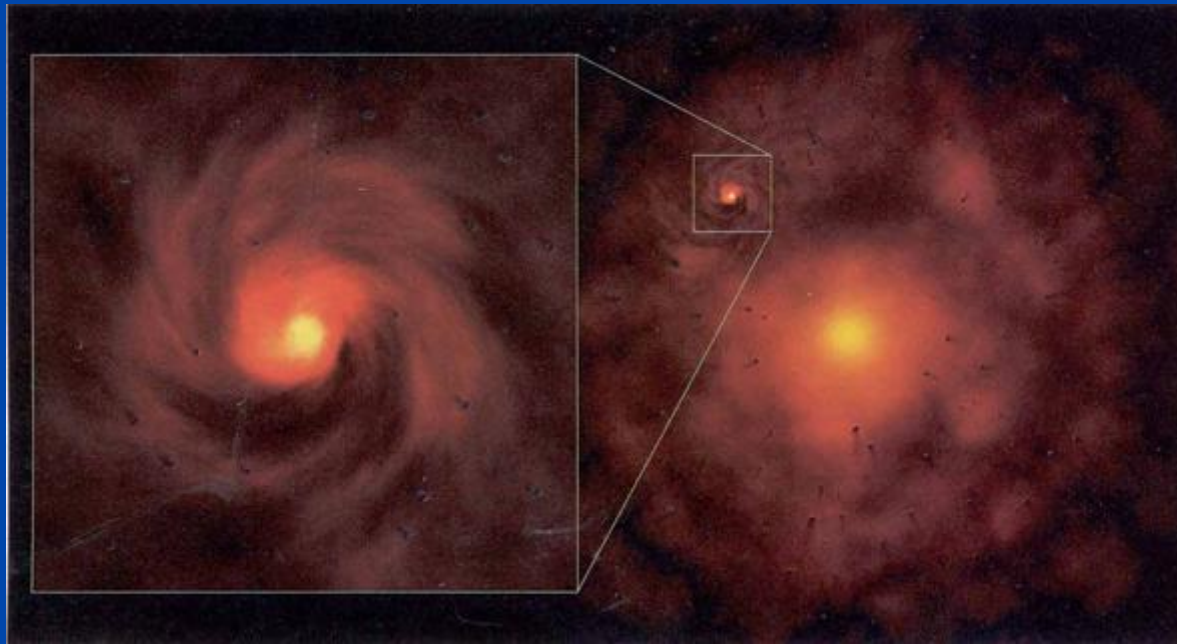




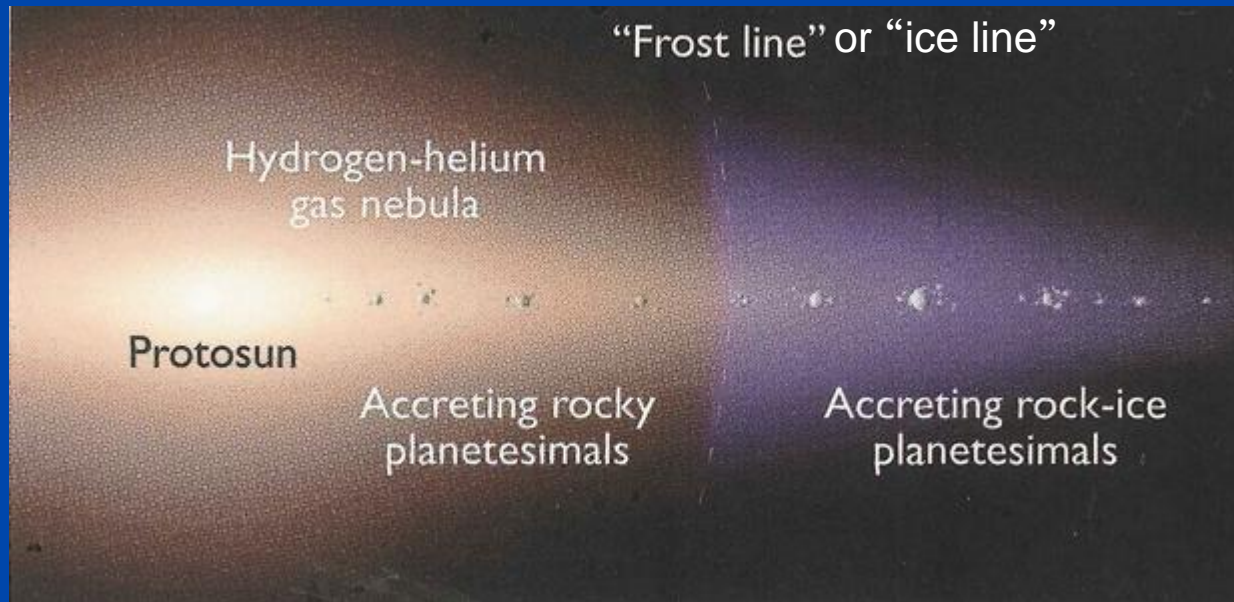
## Why are the Jovian Planets so Different?

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- They formed beyond the frost line to form large, icy planetesimals which were massive enough to...
  - Capture H/He far from Sun to form gaseous planets.
  - Each Jovian planet formed its own “miniature” solar nebula.
  - Moons formed out of these disks.



# Giant planets were farther from early Sun than the “ice line” or “frost line”



- **Best estimate: “frost line” was between current orbits of Mars and Jupiter**
- **Outside “frost line”: rocky cores could attract icy solid material fast enough that planets were already quite massive before early solar wind blew gas nebula away**

# What are the distinguishing features of the Giant Planets?

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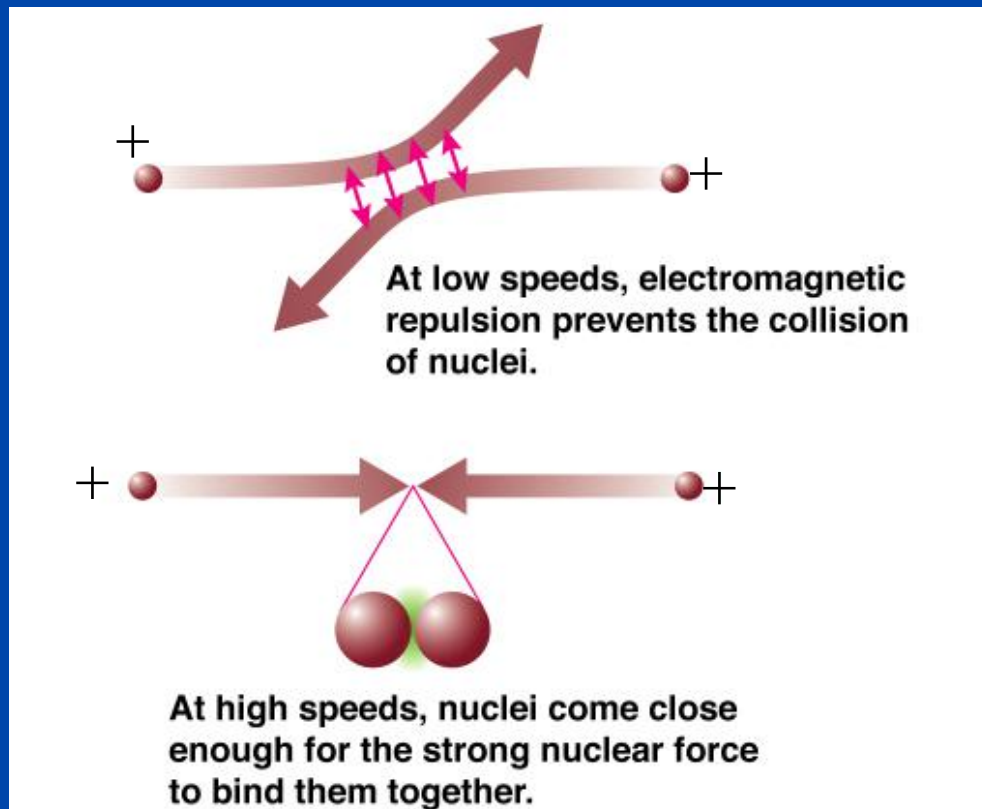


- **Big puffy gas balls!**
  - No solid surface, in contrast with terrestrial planets
- **Jupiter and Saturn: mostly hydrogen & helium**
  - Terrestrial planets are made of rocks - little H and He
  - Because of small mass, low gravity, of terrestrial planets, light elements like H, He escaped to space
- **Giant Planets are farther from Sun**
  - Beyond the “ice line” in the early Solar System
  - Water and other hydrogen compounds were solid
  - Allowed higher-mass objects to form by accretion

# Difference between a Giant Planet and a star?



- **Stars get their heat from nuclear fusion**
  - Four hydrogen atoms fuse to form a helium atom



- To make hydrogen atoms move fast, need high temperatures in core of star
- The more massive a ball of gas is, the hotter its core
- Don't get any fusion for masses  $< 13 - 14 M_{\text{Jupiter}}$

# Distances of Giant Planets from Sun

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• Earth                      1 AU

• Jupiter                    5.2 AU

**Five times farther from Sun**

• Saturn                    9.5 AU

• Uranus                    19 AU

• Neptune                 30 AU

**30 times farther from Sun!**

# Jovian Planet Composition

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- **Jupiter and Saturn**
  - Mostly H and He gas
  
- **Uranus and Neptune**
  - Mostly hydrogen compounds: water (H<sub>2</sub>O), methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>)
  - Some H, He, and rock



# Interiors: qualitative description

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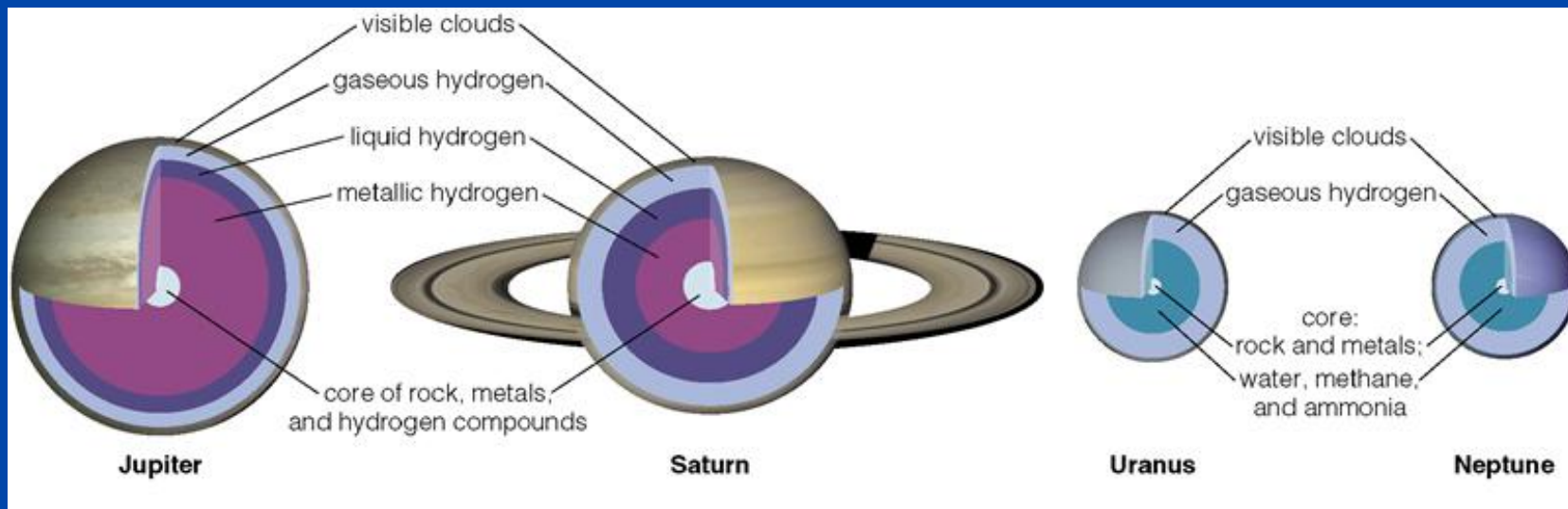


- **Mostly gases plus the odd forms of matter that are made when gases are put under high pressure**
  - Liquid hydrogen, metallic hydrogen
- **It is probable (but not completely proven yet) that all the Giant Planets have rocky cores at their centers**
  - Accretion of matter to make planets started with these rocky cores, then added ices

# Inside the Jovian Planets



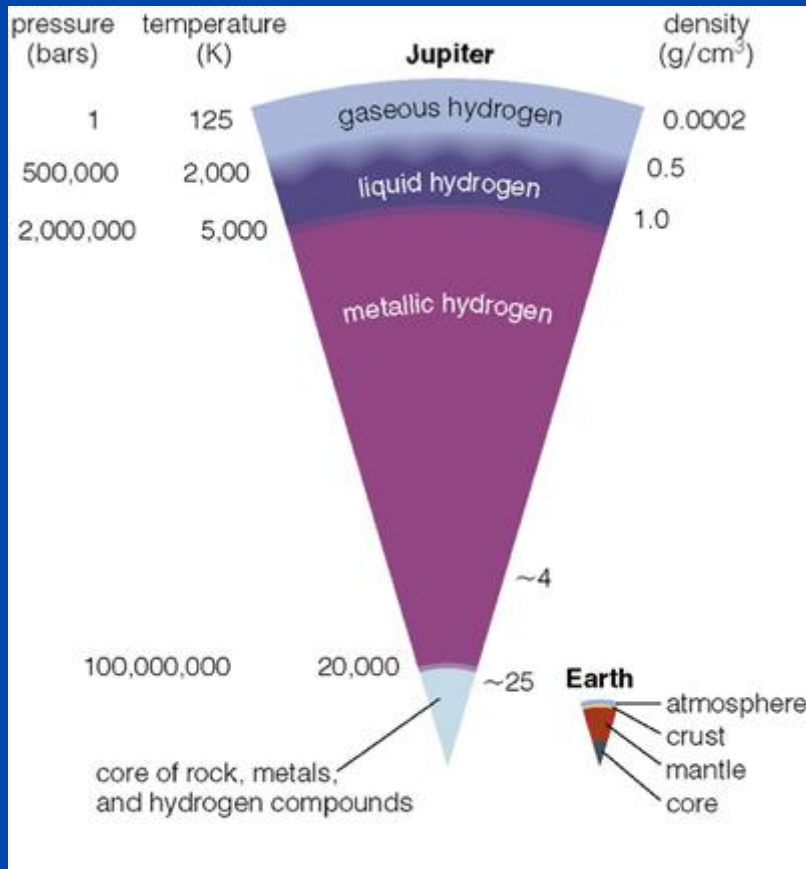
- **All Jovian cores appear to be similar.**
  - made of rock, metal, and Hydrogen compounds
  - about 10 x the mass of Earth
- **Uranus & Neptune captured less gas from the Solar nebula.**
  - accretion of planetesimals took longer
  - not much time for gas capture before nebula was cleared out by Solar wind
- **Only Jupiter and Saturn have high enough pressure for H & He to exist in liquid and metallic states.**



# Inside Jupiter



Although Jupiter has no solid surface and consists mostly of H & He, it does have distinct interior layers, defined by *phase*.



- Moving from the surface to the core:
  - temperature increases
  - pressure & density increases
- The core of Jupiter is slightly larger than Earth in size.
- But it is 5 times as dense!
  - thank to tremendous weight from above
- So Jupiter's core has 10 times the mass of Earth.

# More about Jupiter's core

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- **“Liquid metallic hydrogen”**: a very unusual state of matter (“degenerate”).
- **Predicted many years ago**
  - Jupiter’s core has temperature of 25,000 K and pressure of 12 million bars -- 12 million times as large as sea level pressure on the Earth
- **Such a state for hydrogen has now been reproduced in labs on Earth.**

# Liquid metallic hydrogen?

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- **Liquid hydrogen: if you poured it into a cup, it would assume the shape of the cup, but would not spread out throughout the entire volume (as would a gas).**
- **Metallic hydrogen: will conduct electricity.**
- **Fact that this layer can flow and can conduct electricity means that Jupiter and Saturn can support large internal electrical currents and should thus show large magnetic fields.**

# All the Giant Planets except Uranus are generating some of their own heat

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- **Jupiter, Saturn, Neptune radiate more energy into space in infrared light than they receive from Sun in visible light**
- **Reason: they are still contracting under their own gravity!**
  - Planet contracts or gets more centrally condensed
  - Material in core is squeezed, feels more pressure
  - Temperature of core increases
  - Additional heat conduction to outer parts of planet, stronger infrared radiation to space

# Internal heat, continued

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- **Another way to think about gravitational contraction making heat**
  - Planet contracts
  - Decreases its gravitational potential energy –  $GmM/r$
  - Total energy = kinetic energy –  $GmM / r = \text{constant}$
  - So kinetic energy must increase
  - Particles in core move faster (random motions)
  - Means their temperature is higher

# Very important spacecraft

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- **Voyager 1 and 2 (1980's)**
  - Flew by Jupiter, Saturn, Uranus, Neptune
  - First close-up views of all these planets
- **Galileo (recently ended mission)**
  - In orbit around Jupiter for several years
  - Also sent a probe into Jupiter's atmosphere
- **Cassini (in orbit around Saturn now, but passed by Jupiter)**
- **Galileo and Cassini have great websites**



# Jovian Planet Atmospheres

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## Goals for learning:

- How is Jupiter's atmospheric structure similar to Earth's?
- Why does Jupiter have three distinct cloud layers?
- What is the Great Red Spot?
- How do other Jovian atmospheres compare to Jupiter's?

# Atmospheres of the Giant Planets

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- **Dominated by hydrogen and helium gases**
  - Thus very different from terrestrial planets
  - Earth's atmosphere mostly nitrogen
- **Clouds form out of this gaseous soup in a variety of striking colors**
- **Cloud patterns are organized by winds, which get their energy from the planets' internal heat**
  - By contrast, terrestrial planets' weather is determined by heat from the Sun

# Cloud bands

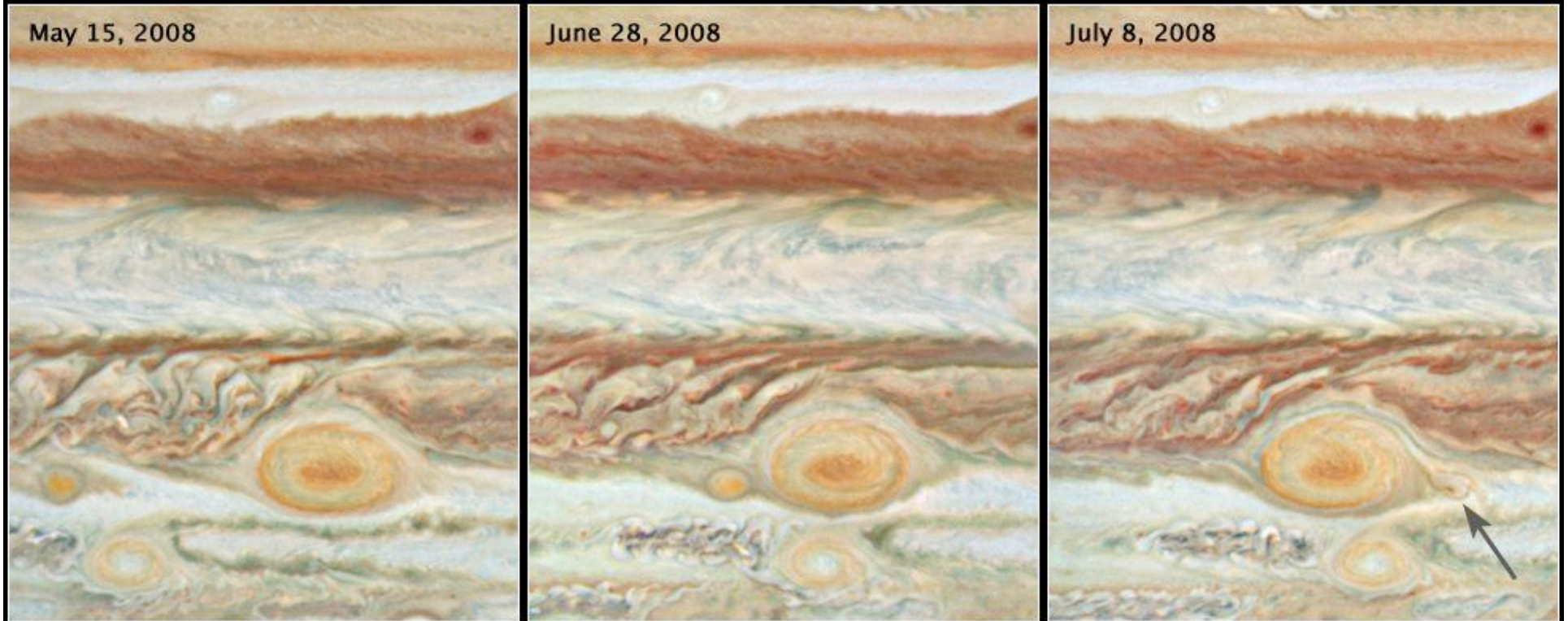


- **Jupiter, Saturn clouds in fast-moving bands**
- **On Earth, transient storms break up such bands, but not on Jupiter or Saturn**
- **Storms on Jupiter can last tens to hundreds of years!**
- **Why the cloud bands are particular colors is not clear; color depends on chemistry which we don't understand.**





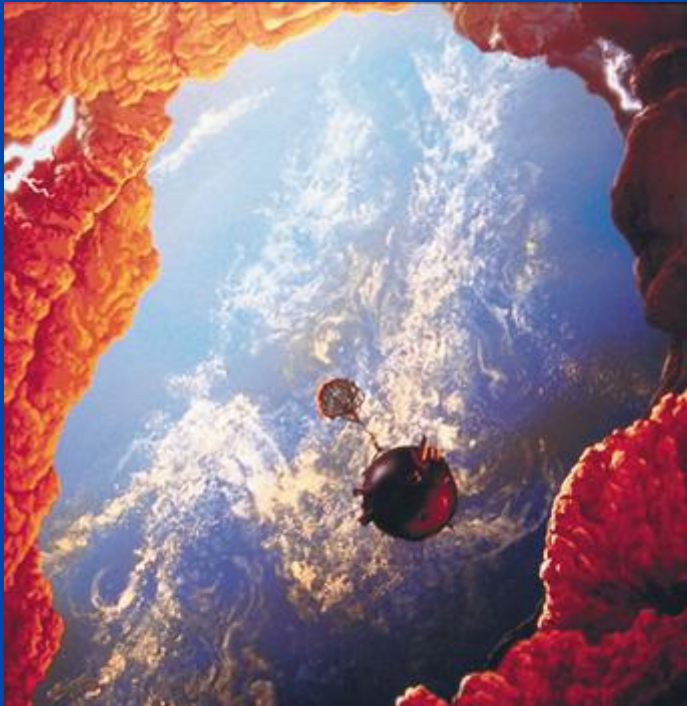
## Jupiter's Red Spots ■ *Hubble Space Telescope* WFPC2



NASA, ESA, and A. Simon-Miller (NASA Goddard Space Flight Center) ■ STScI-PRC08-27

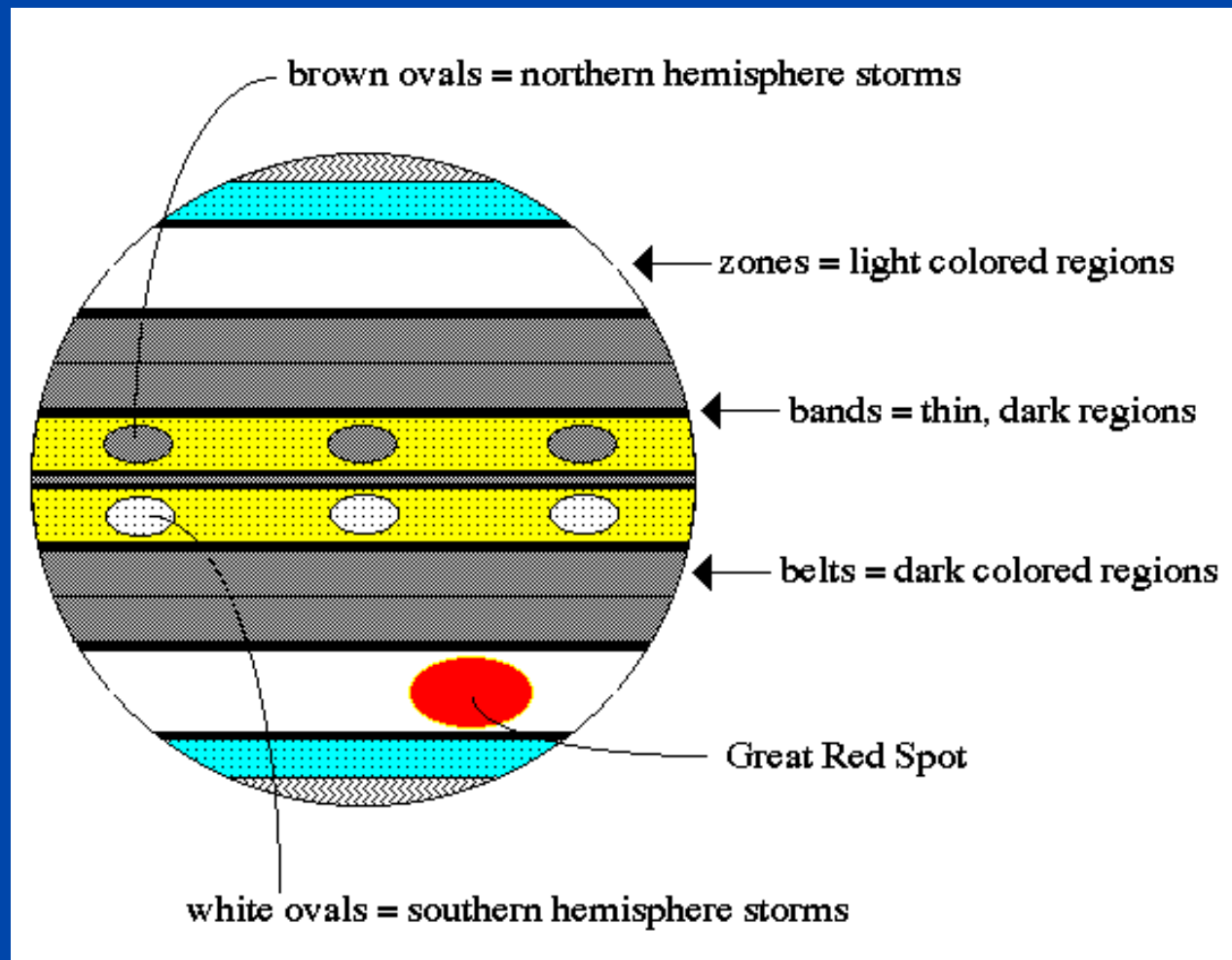
# Jupiter's Atmosphere

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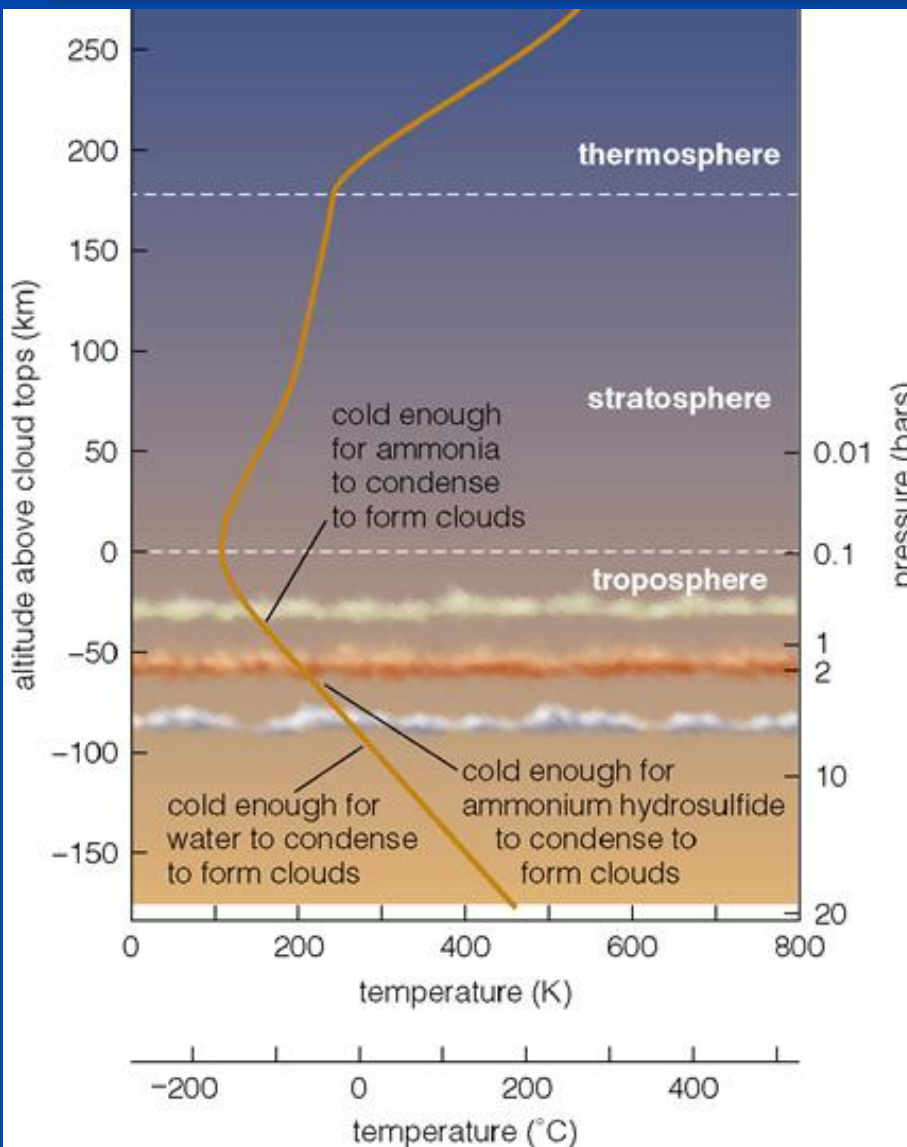
- In 1995, the Galileo space probe plunged into the planet Jupiter!
- It measured the atmospheric structure of Jupiter
  - thermosphere **absorbs Solar X-rays**
  - stratosphere **absorbs Solar UV**
  - troposphere **greenhouse gases trap heat from both Jupiter and the Sun**
- These are the same structures found in Earth's atmosphere.
- Atmospheres are governed by interactions between sunlight and gases.

# Features on Jupiter



- Credit: Imamura, U. Oregon

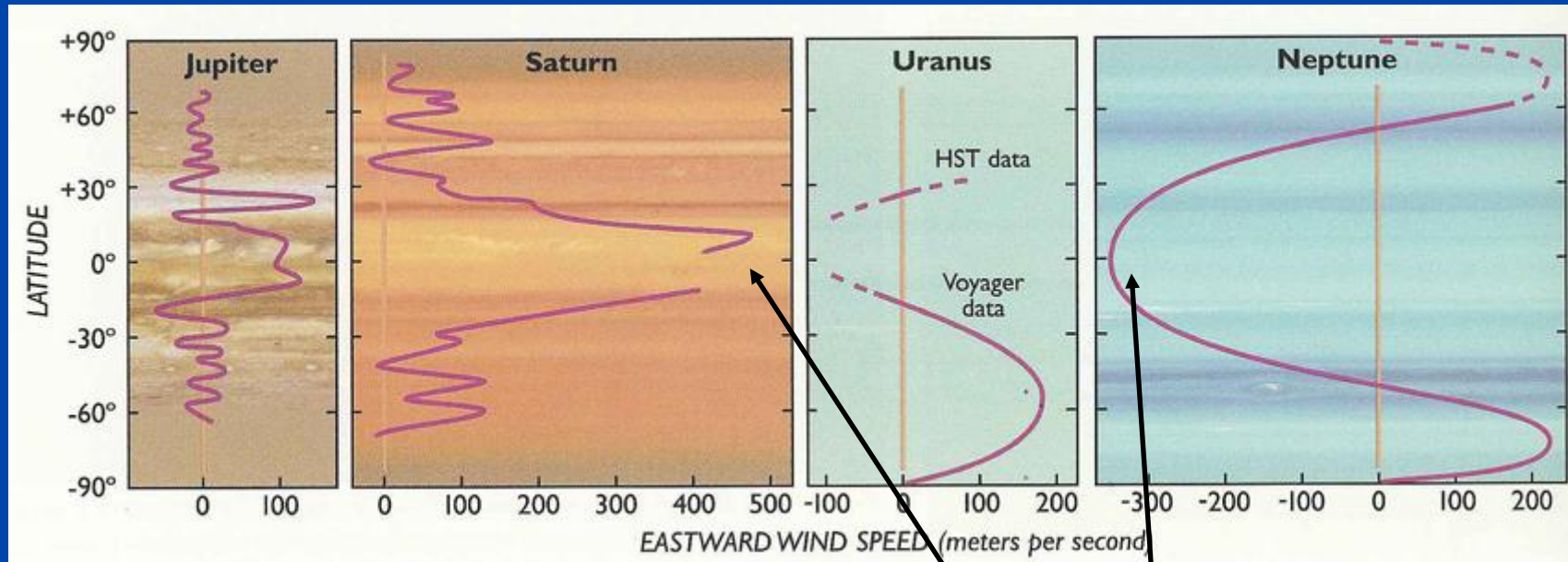
# Jupiter's Cloud Layers



- **Convection in the troposphere causes Jovian weather.**
- **Warm gas rises to cooler altitudes, where it condenses to form clouds.**
- **Three gases condense in the Jovian atmosphere:**
  - ammonia (NH<sub>3</sub>)
  - ammonium hydrosulfide (NH<sub>4</sub>SH)
  - water (H<sub>2</sub>O)
- **They condense at different temperatures, so their clouds form at different altitudes.**

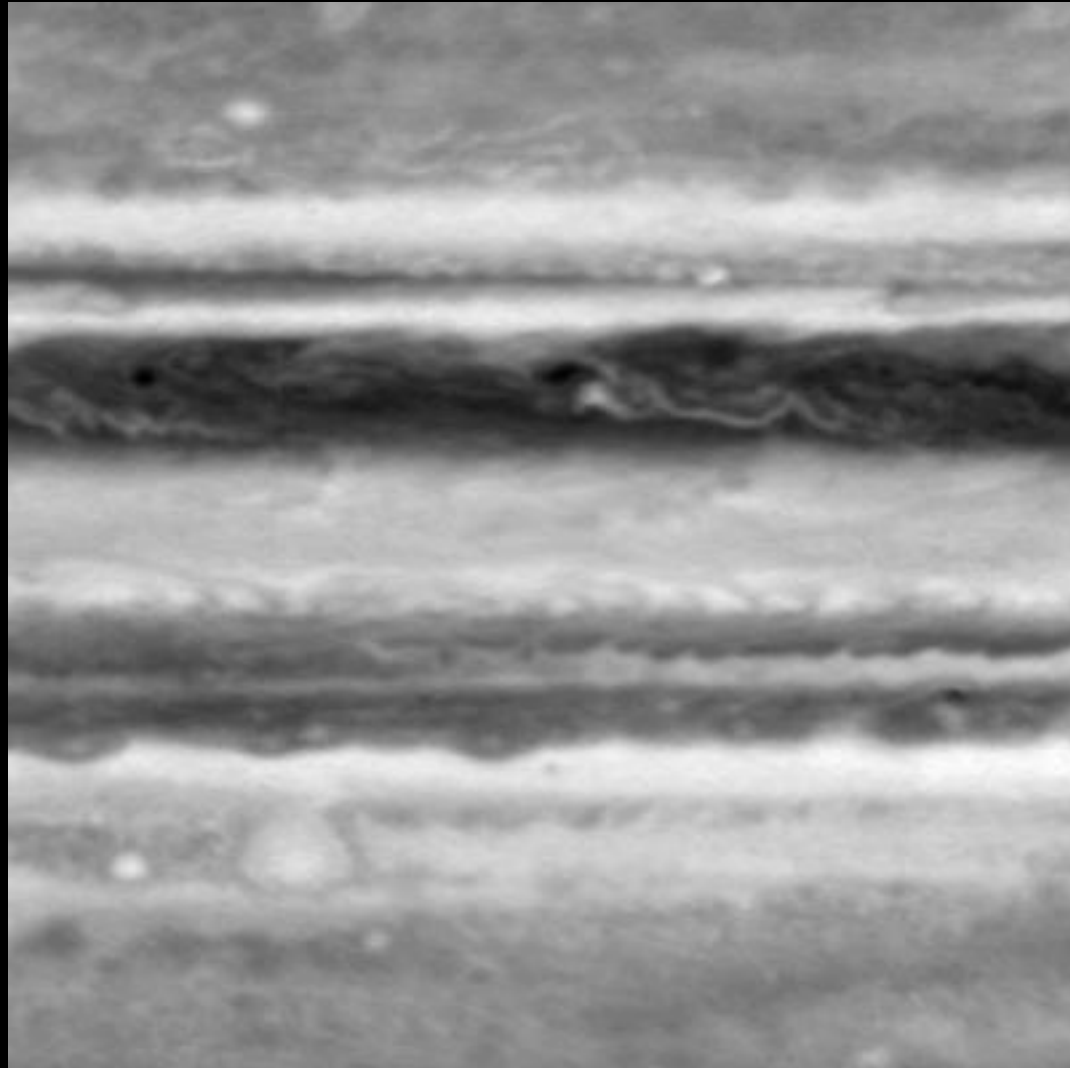


# Winds are strongly latitudinal



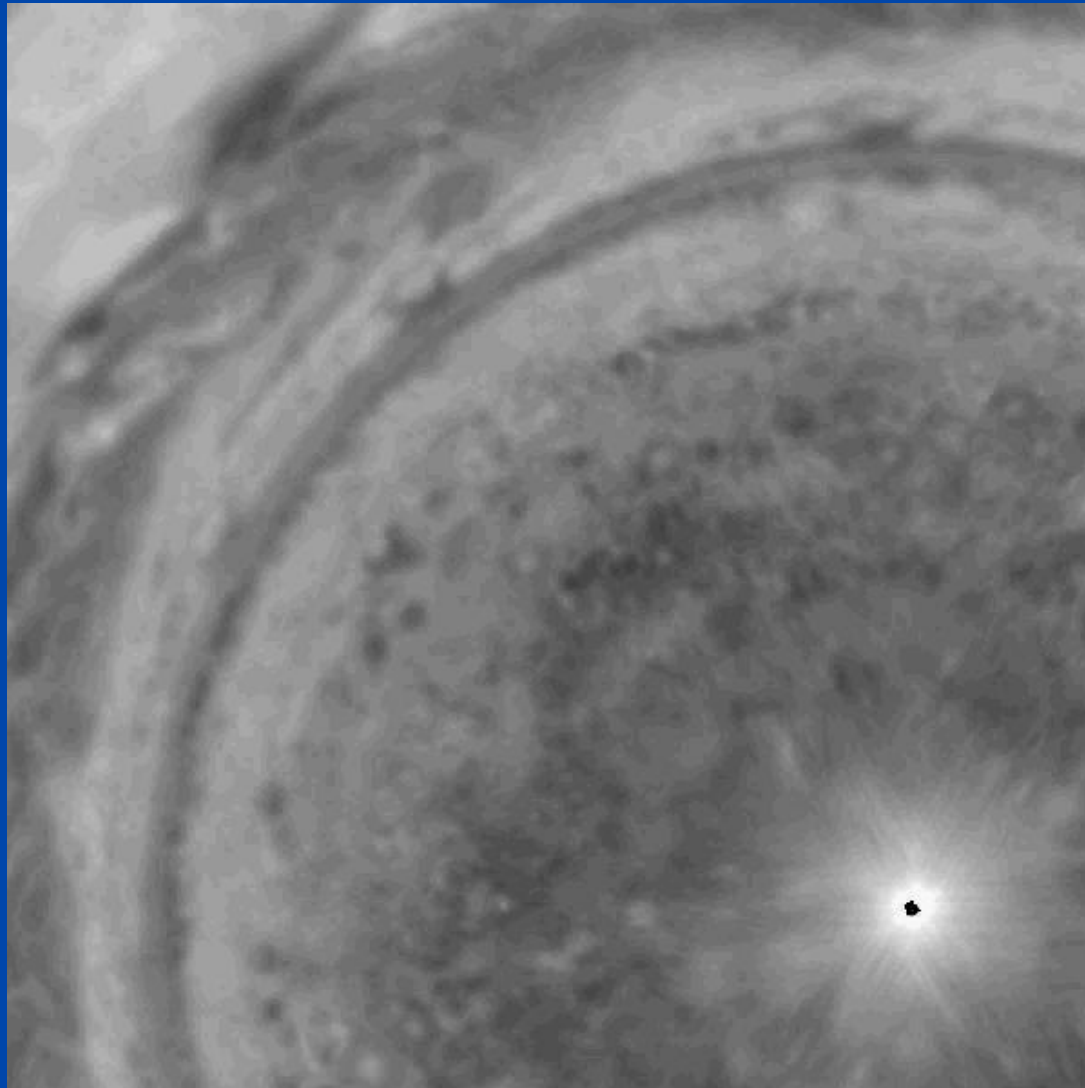
“Zonal winds” of alternating direction

Huge wind speeds on Saturn, Neptune



**There are even opposing zonal winds at poles!**

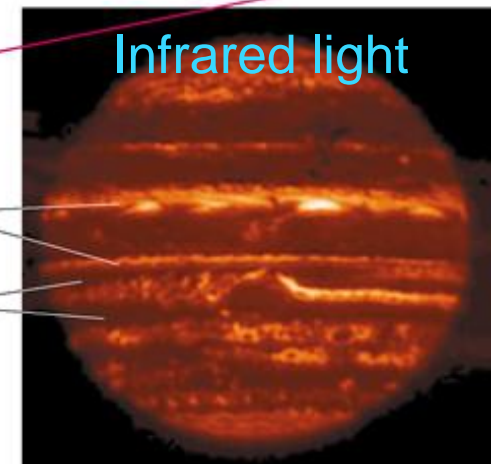
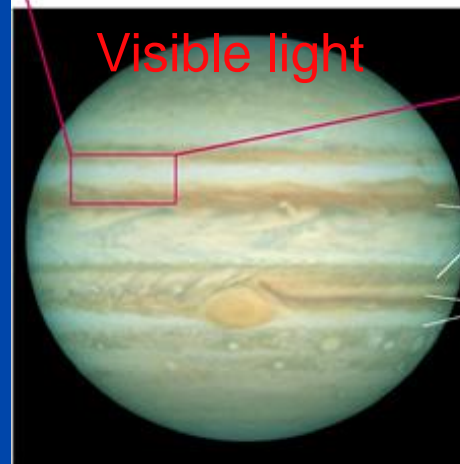
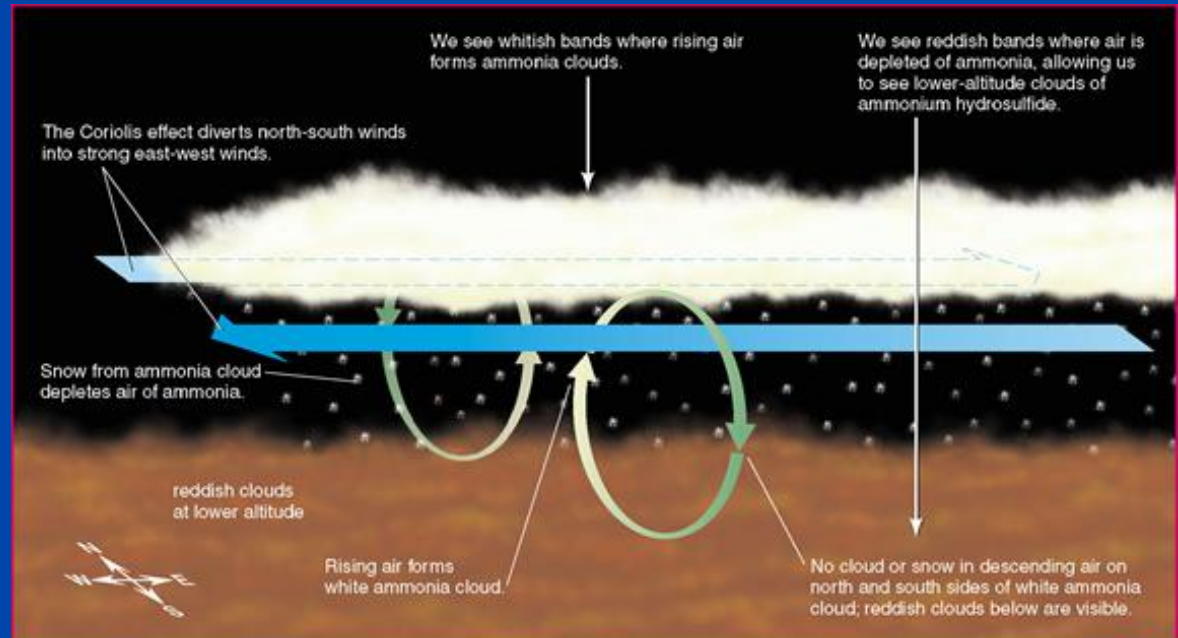
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# What makes Jupiter's cloud bands so colorful?



- Like Earth, Jupiter has circulation cells in its atmosphere.
- Jupiter is much larger & rotates much faster.
  - Coriolis effect is much stronger
  - circulation cells are split into many bands of rising and falling air
  - these are the colored “stripes” we see
- Belts: warm, red, low altitude
- Zones: cool, white, high altitude



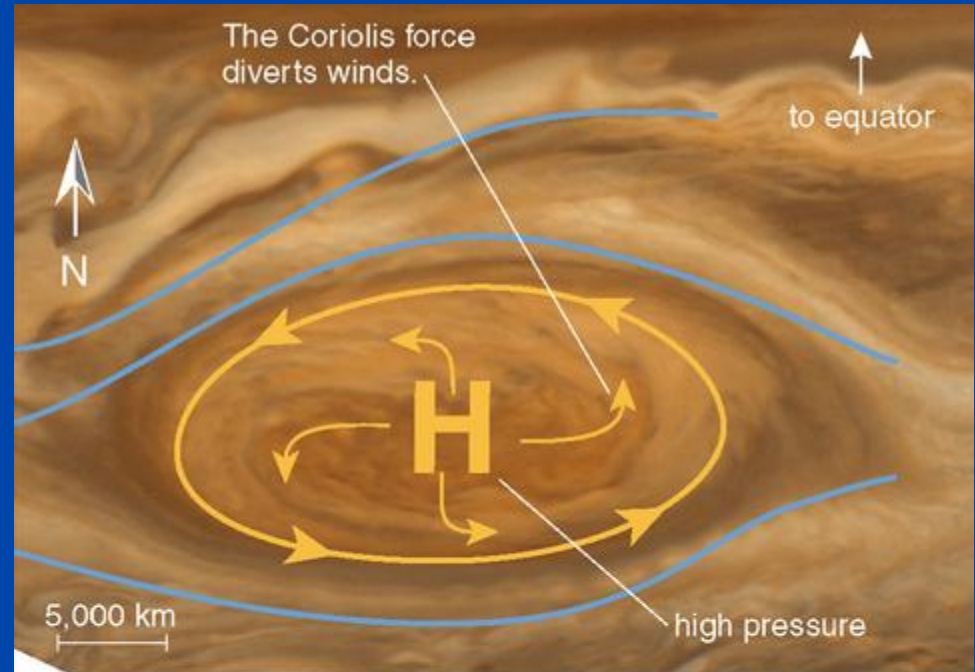
These bands are warm, red, low-altitude clouds.

These bands are cool, white, high-altitude clouds.

# We also see high pressure storms



- **Jupiter**
  - the Great Red Spot
  - we are not sure why it is red
- **Neptune**
  - the Great Dark Spot



# Jupiter Storms: best example is the Great Red Spot

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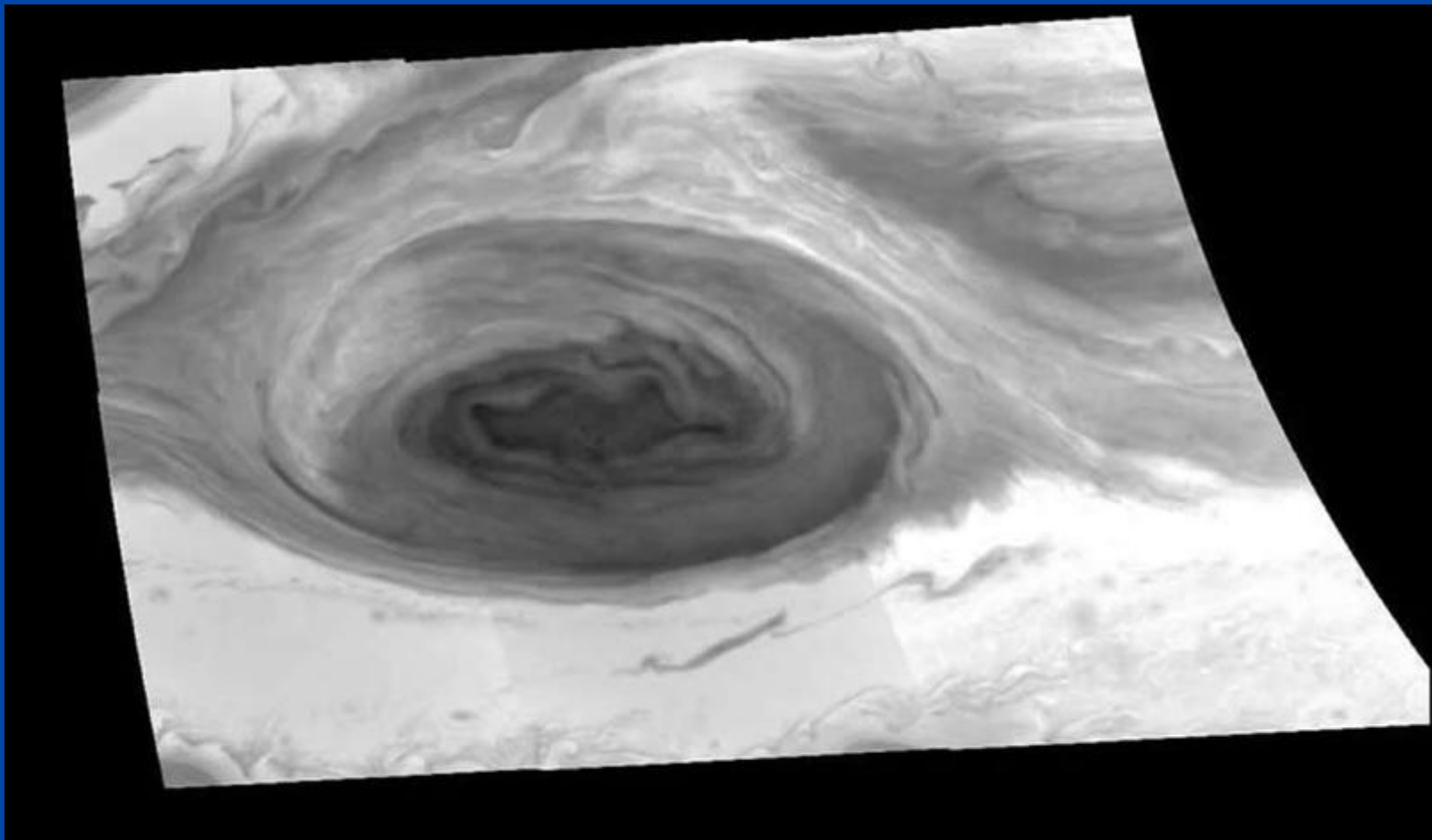
- **Great Red Spot has been around for at least 300 yrs**
  - Seen in 17th century!
- **A stable vortex**
- **Wind speeds >400 km/hr**

# Another view of Jupiter's Great Red Spot

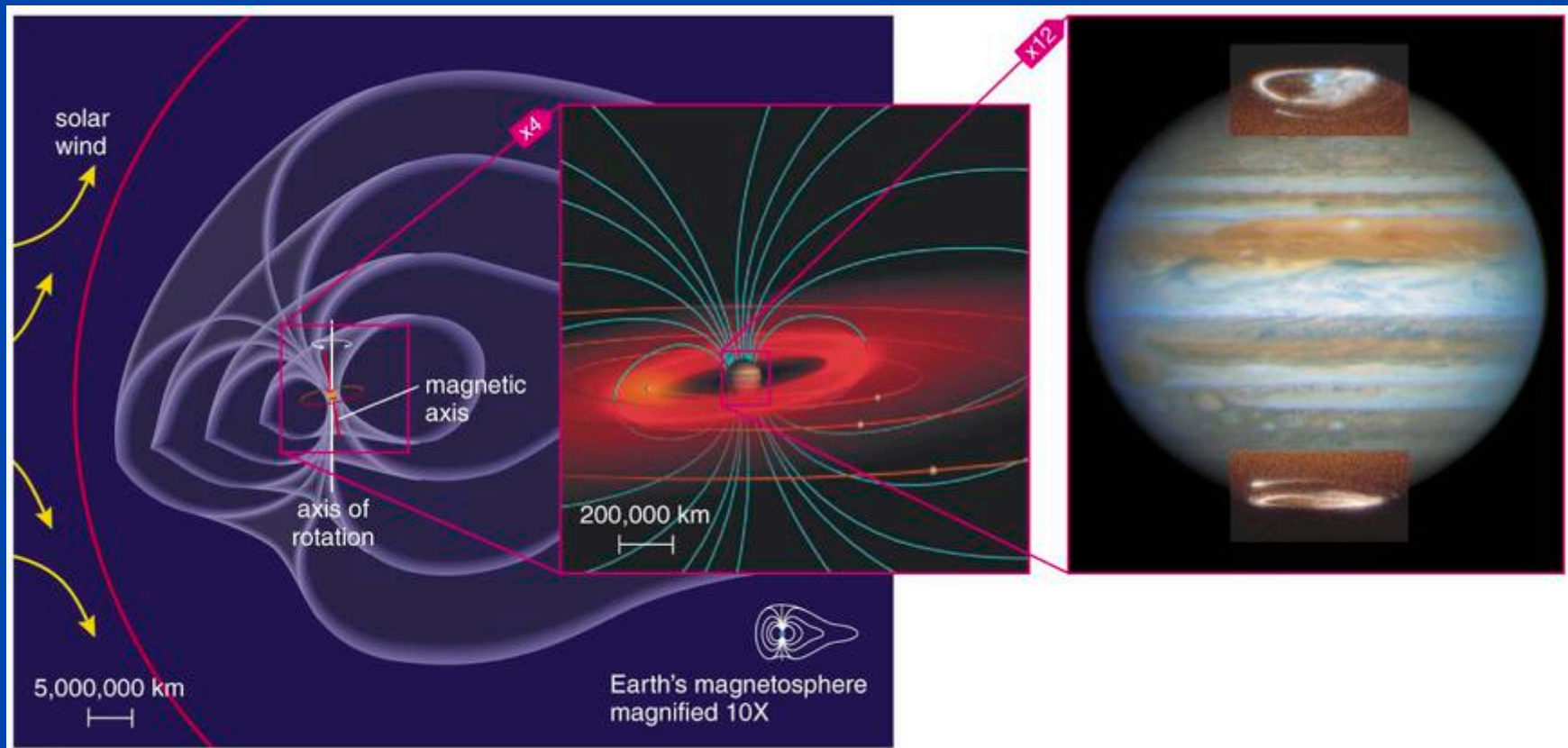
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- From Galileo spacecraft



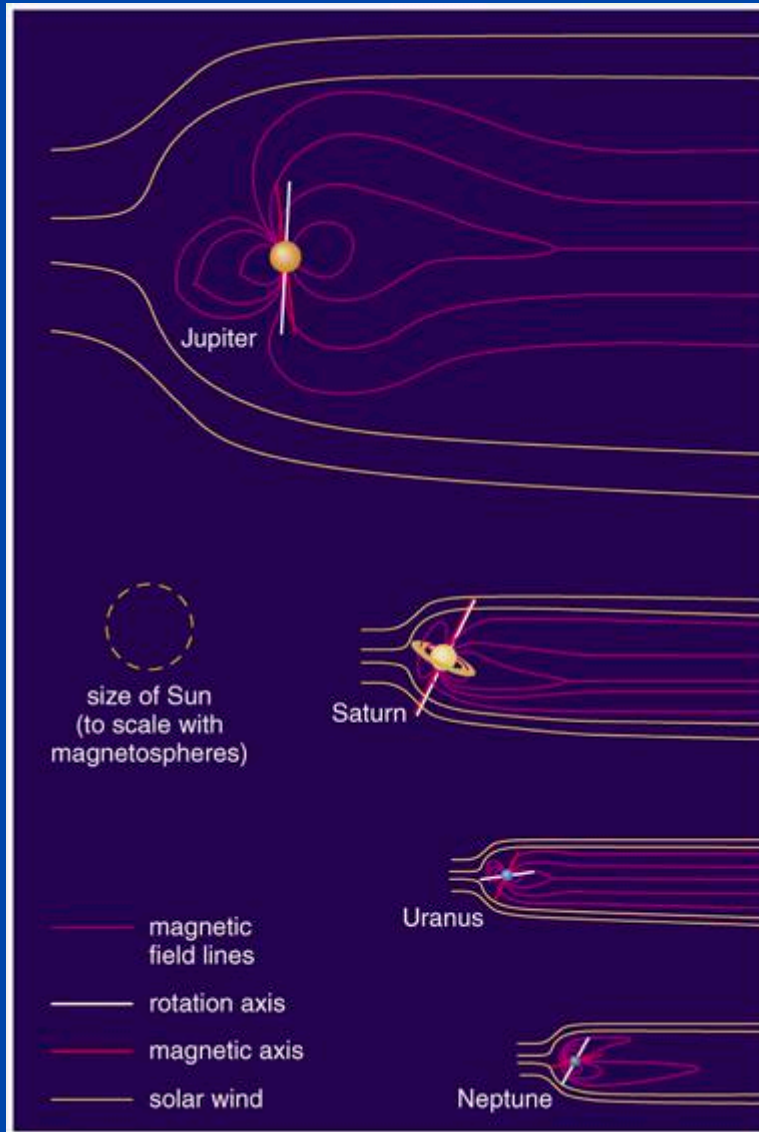
# Jupiter's Magnetosphere



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



# Magnetospheres of other giant planets



- All jovian planets have substantial magnetospheres, but Jupiter's is the largest by far.

# 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.**

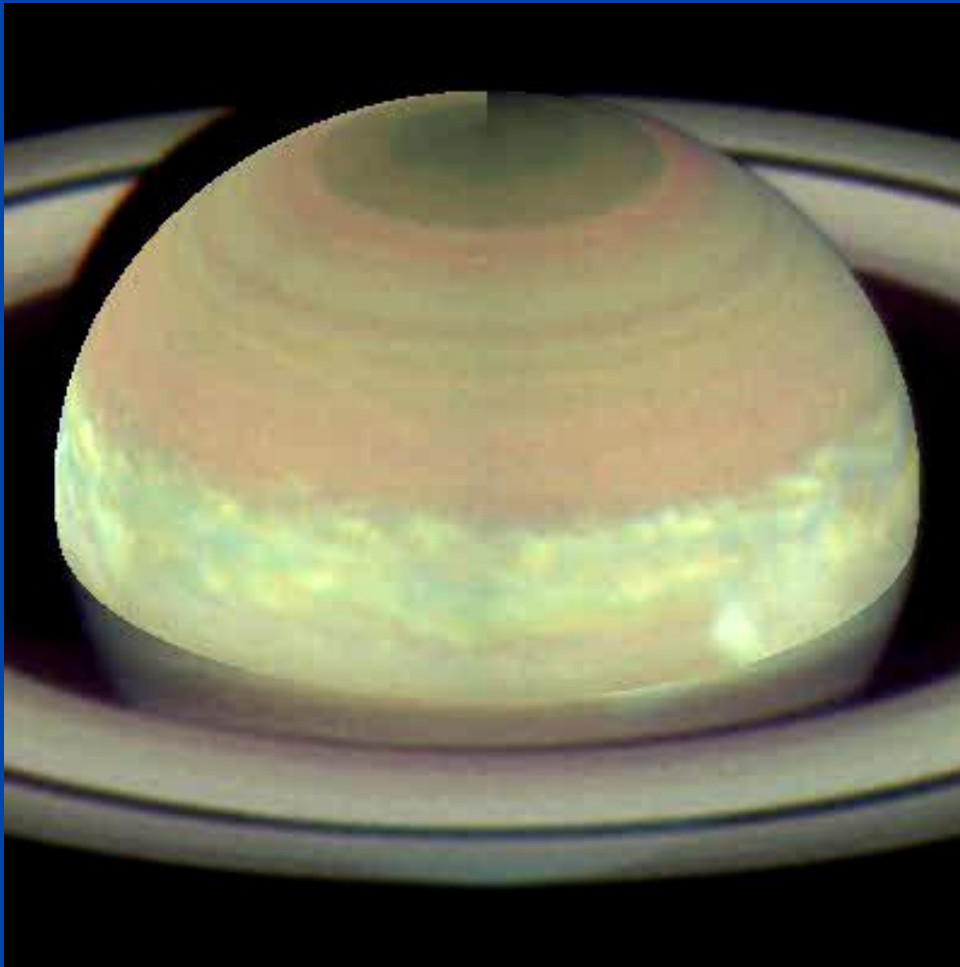
# Thought Question

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# Saturn has giant storms

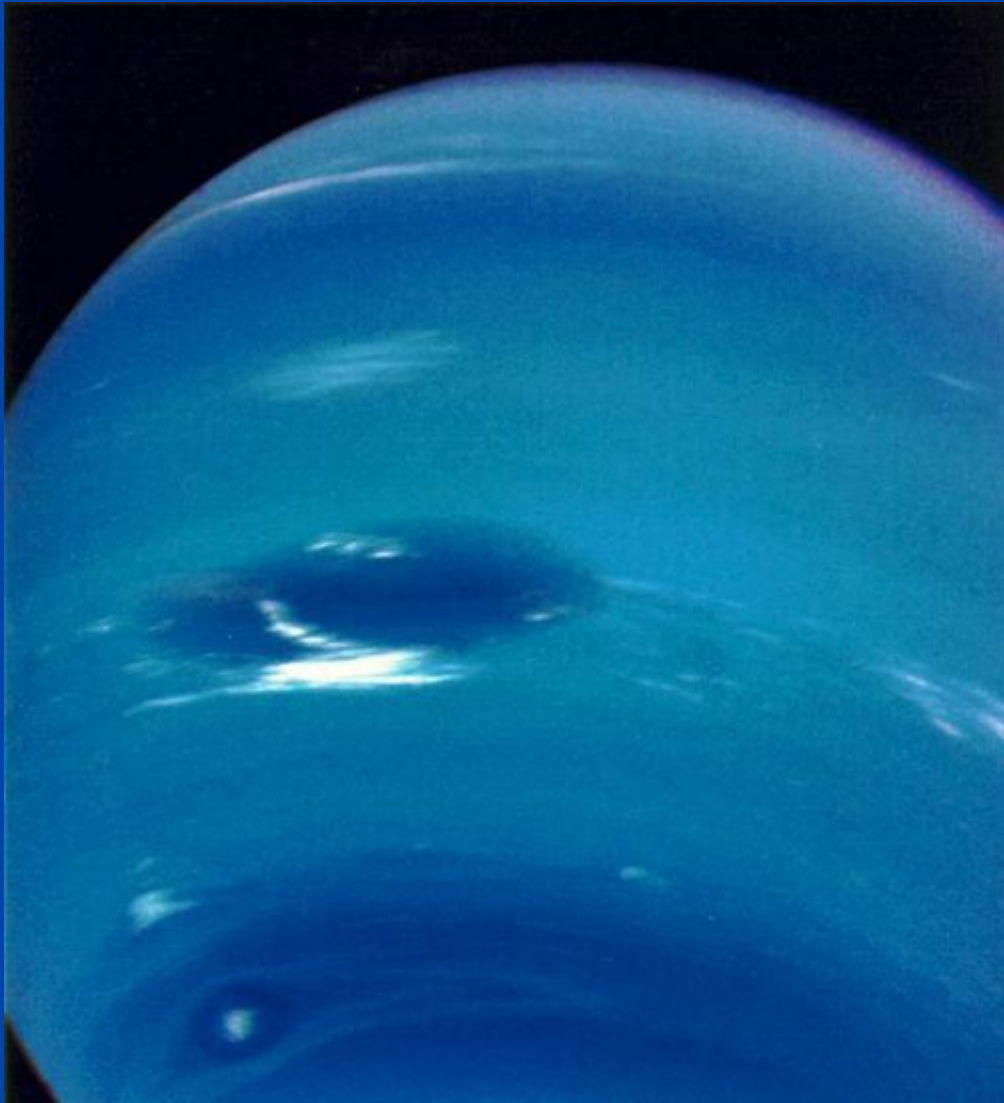
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- **Outbreaks of Saturn storms every ~30 yrs**
- **Corresponds to summertime in Northern Hemisphere**
  - **Not seen in S.**
- **Origin of storms not yet understood**

# Neptune: Great Dark Spot

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- Lasted for several months as Voyager 2 spacecraft flew by
- Wasn't there a decade later when Hubble Space Telescope looked

# Concept Question

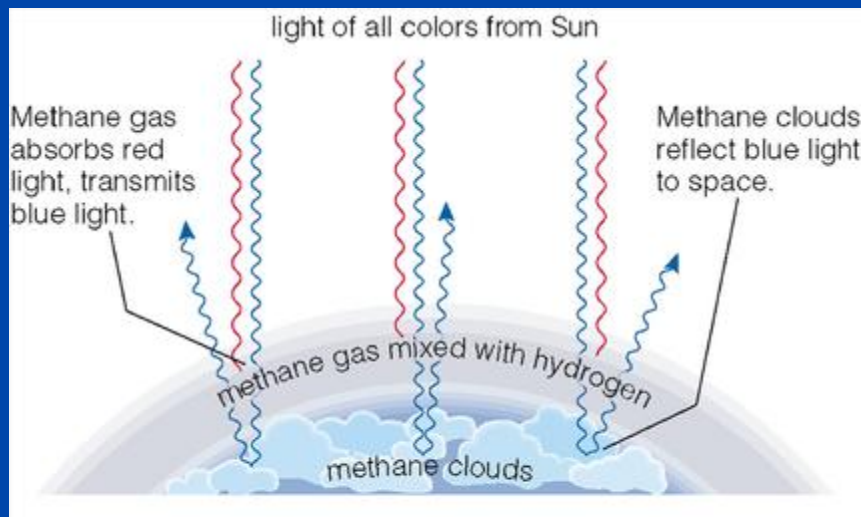
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- On Earth, convection cells are formed when air is heated at the Earth's surface
- What sources of heating might power convective cells on Jupiter?



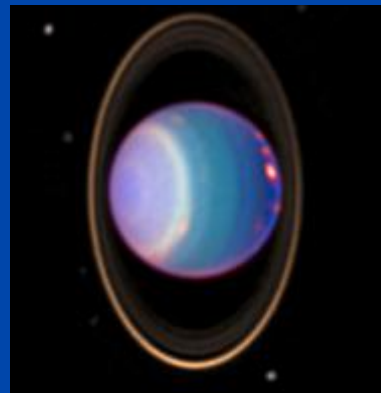
## Why Uranus & Neptune are Blue



- **They both have a higher fraction of methane gas.**
  - Methane absorbs red sunlight.
  - Only blue light is reflected back into space by the clouds.
- **Uranus is “tipped” on its side.**
- **It should experience the most extreme seasonal changes.**
  - no clouds or banded structure seen in 1986 when N pole facing Sun
  - no weather, no internal heat?
  - HST saw storms in 1998, perhaps because the S hemisphere is warming now



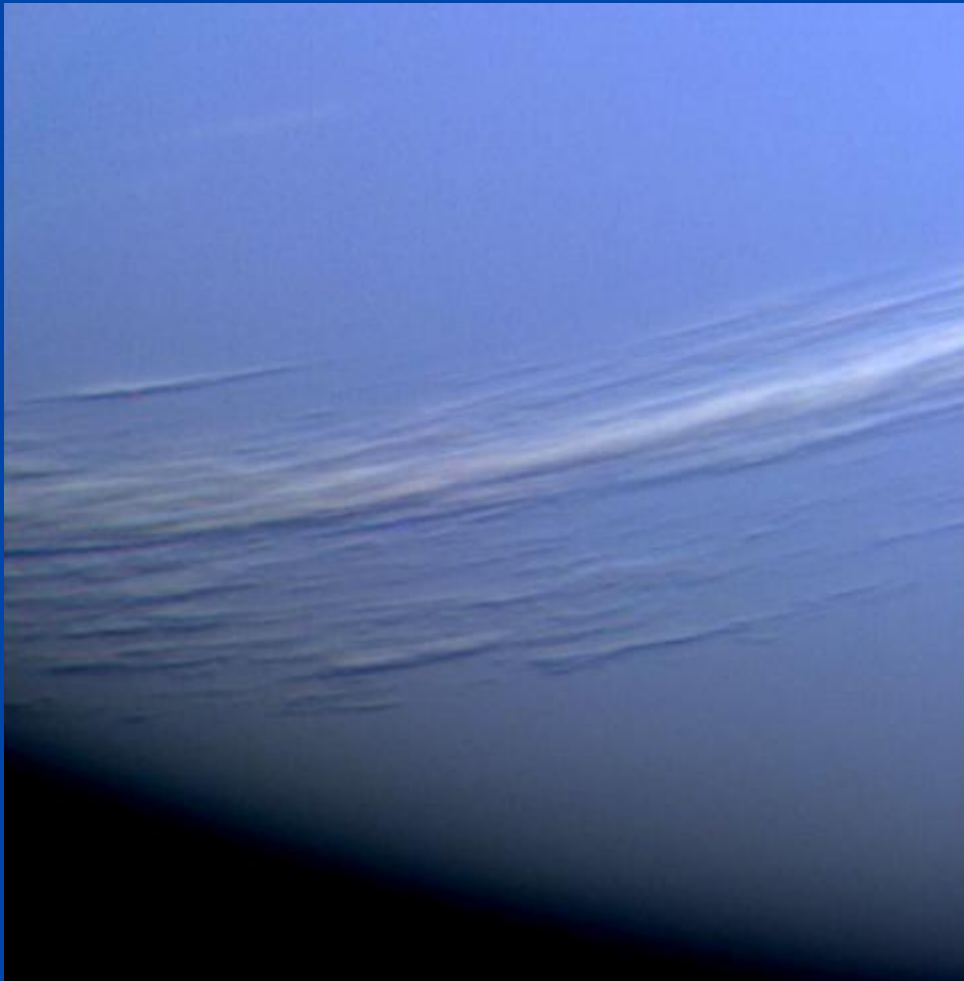
1986 - Visual



1998 - IR

# Circumferential cloud bands seen by Voyager spacecraft as it flew by Neptune

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- Linear features seen by Voyager in visible light were very thin
- Circumferential (followed lines of constant latitude)
- Similar in location and shape to the bands we see in infrared light
- Probably “pulled out” into circumferential shape by Neptune’s huge winds



# Adaptive optics has been big help in studying Neptune from the ground

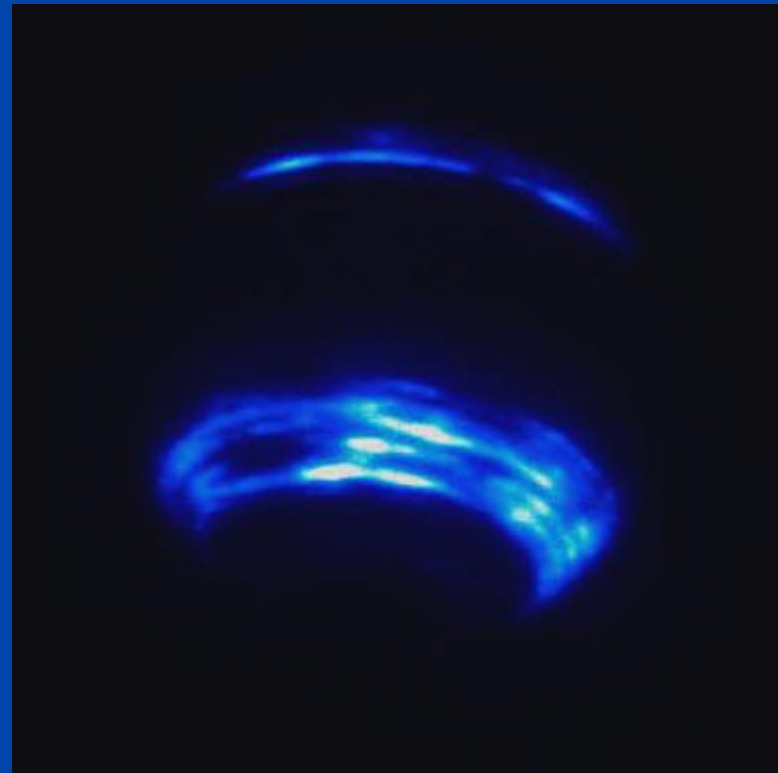
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Neptune in infrared light  
without adaptive optics



Neptune in infrared light  
with Keck adaptive optics



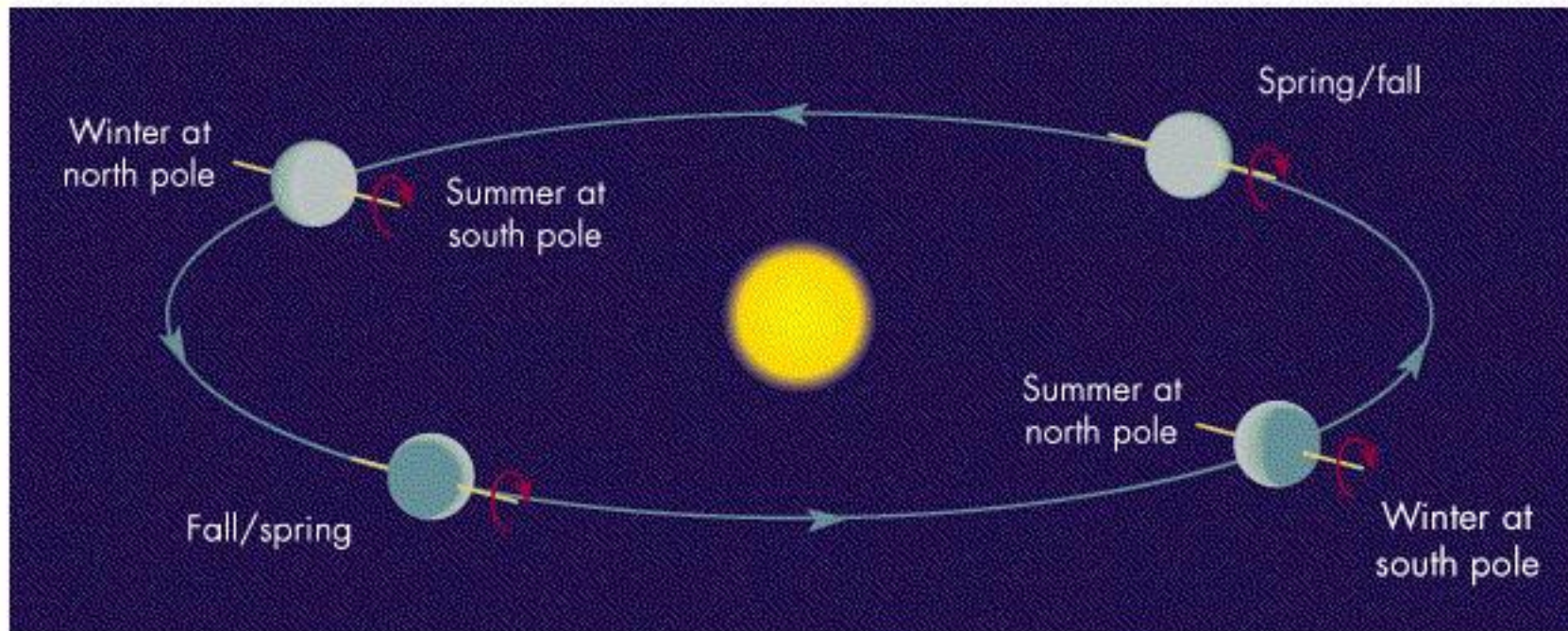
# Concept Question

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- **Uranus' year is 80 Earth-years long**
- **The axis of rotation of Uranus lies almost in the plane of Uranus' orbit, so that the planet "rolls its way around the Sun."**
- **As a consequence, seasons on Uranus are**
  - a) **As long as one Uranus year**
  - b) **Non-existent**
  - c) **One fourth of Uranus' year, or about 20 Earth years long**
  - d) **Four times Uranus' year, or about 320 Earth years long**

# Concept Question



# The Main Points

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- **Briefly describe major features of the Jovian planets.**
  - Largely composed of hydrogen, helium, & hydrogen compounds. No solid surfaces. Fast rotation. Slightly “squashed” shapes. Many moons. Ring systems.
- **Why are Jovian planets so different from terrestrial planets?**
  - Formed in cold, outer Solar System at the centers of “miniature protoplanetary disks.”
- **Briefly describe the interior structure of Jupiter.**
  - Central core of H compounds, rocks, & metals.
  - Next layer up contains metallic H, followed by a layer of liquid H, followed by the gaseous atmosphere.
  - Pressure, density, & temperature all increase with depth.

# The main points, continued

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- **How do the Jovian planet interiors differ, and why?**
  - All have cores of about the same mass, but differ in the amount of surrounding H and He.
  - Accretion took longer in the more spread out regions of the outer Solar System, so the more distant planets captured less gas from the Solar nebula before it was blown away by the Solar wind.

# Moons of the Giant Planets

# **Main points: Giant Planet Moons**

- **Why can active geology occur on much smaller worlds when they are made of ice rather than rock?**
  - Ices soften and melt at lower temperatures than rock, allowing icy volcanism and tectonics at surprisingly low temperatures in the outer Solar System.
- **What makes Io so volcanically active?**
  - Interior heating due to tidal forces of Jupiter and other Galilean moons, as Io moves through its elliptical orbit.
- **Why do we suspect a subsurface ocean on Europa?**
  - Photos show evidence of water flows and fountains on the surface, magnetic field measurements support the presence of a salty ocean, and there is enough tidal heating to melt a thick layer of ice beneath the surface.

# 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

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



# You might think these moons are too small for active geology to occur

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- **You would be wrong!**
- **Terrestrial planets are made mostly of rock.**
- **Jovian moons are made mostly of ice.**
- **Ices melt at lower temperatures than rock.**
  - Less heating is required to have molten cores
  - Volcanism and tectonics can occur
- **There is another heat source besides Sun.**
  - Tidal heating of the interior plays a more important role; radioactivity contributes too

# The Large Jovian Moons are very active

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- **Jupiter**
  - Io sulfur volcanoes
  - Europa world of water ice, subsurface liquid
  - Ganymede active ice world
  - Callisto dead & dirty ice world
  - (Jupiter has > 60 known moons!)
- **Saturn**
  - Titan thick atmosphere (N<sub>2</sub> & CH<sub>4</sub>)
  - Enceladus warm-water volcanoes
- **Neptune**
  - Triton nitrogen volcanoes, retrograde orbit

# Large Moons of Jupiter

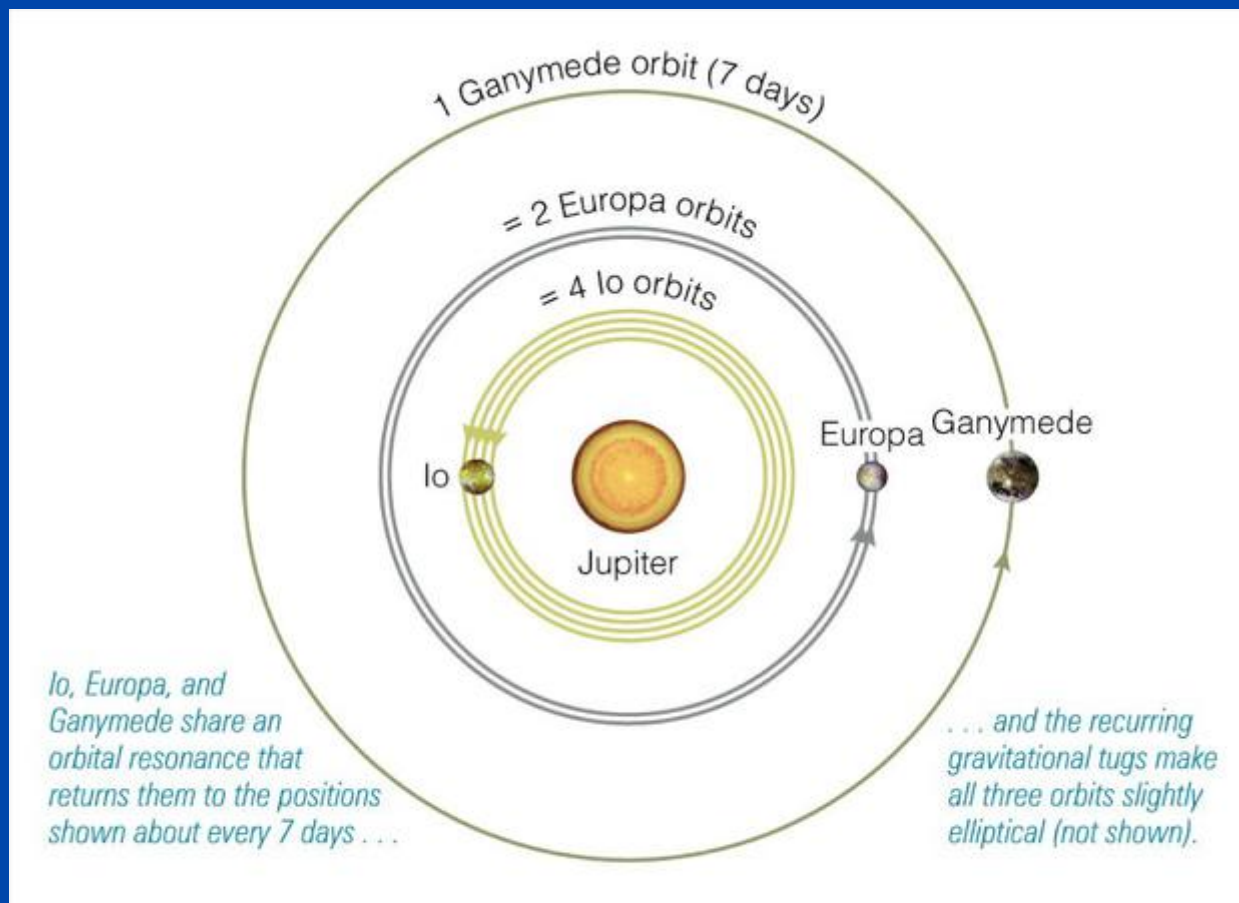
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- “Galilean” moons: the four biggest ones
- Discovered by Galileo
- Closest to Jupiter



# Orbital Resonances play important role

- Every 7 days, these 3 moons line up.
- The tugs add up over time, making all 3 orbits elliptical.



[Animation of Io's tidal heating](#)

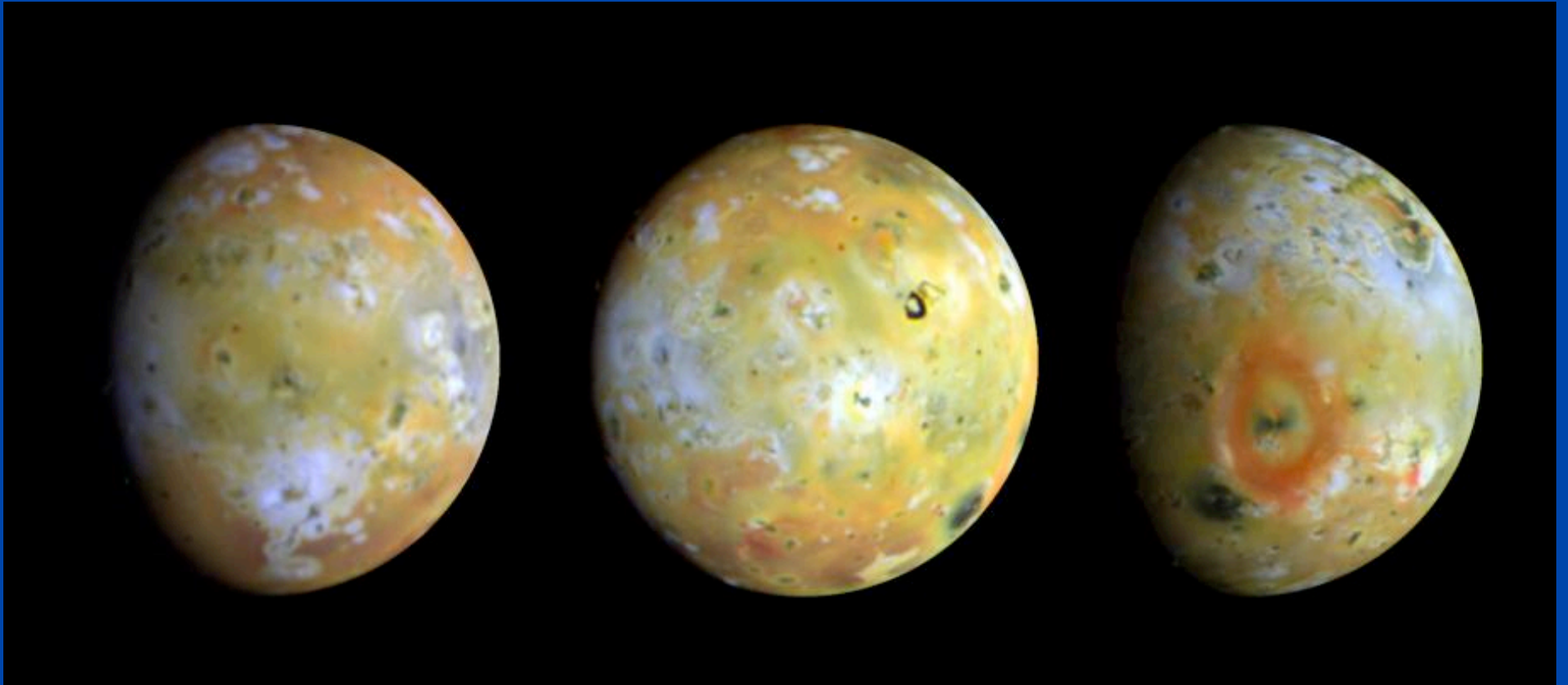
# Io: Jupiter's closest moon

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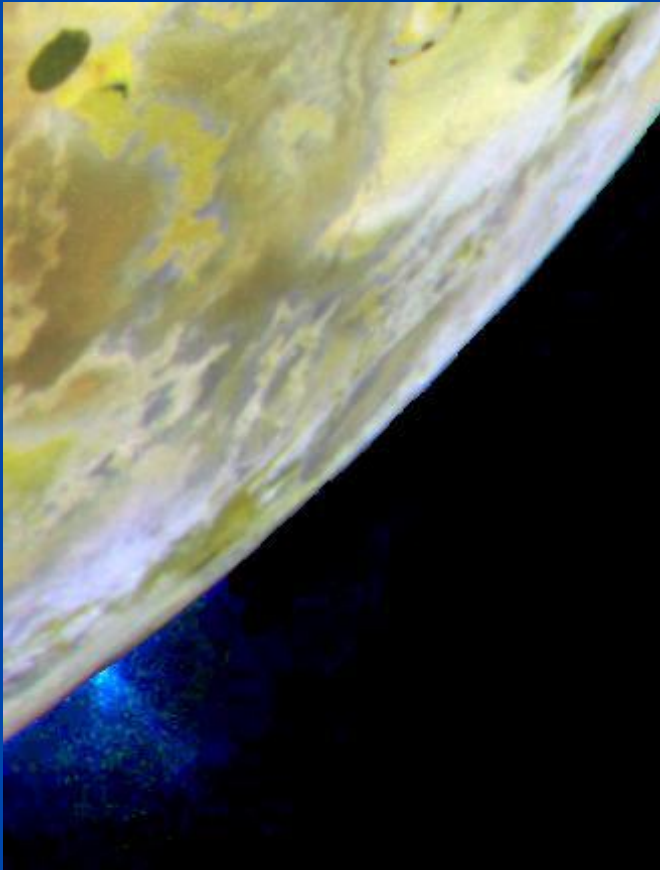


- **Jupiter's tidal forces flex Io like a ball of silly putty.**
  - Friction generates heat
  - Interior of Io is molten
- **Volcanoes erupt frequently.**
  - Sulfur in the lava accounts for yellow color
  - Surface ice vaporizes and jets away
  - Lava is hotter than on Earth
- **Evidence of tectonics & impact cratering is covered over by the lava flows.**

# Three views of Io, from Galileo spacecraft at Jupiter



# Io Volcanoes: Two Kinds



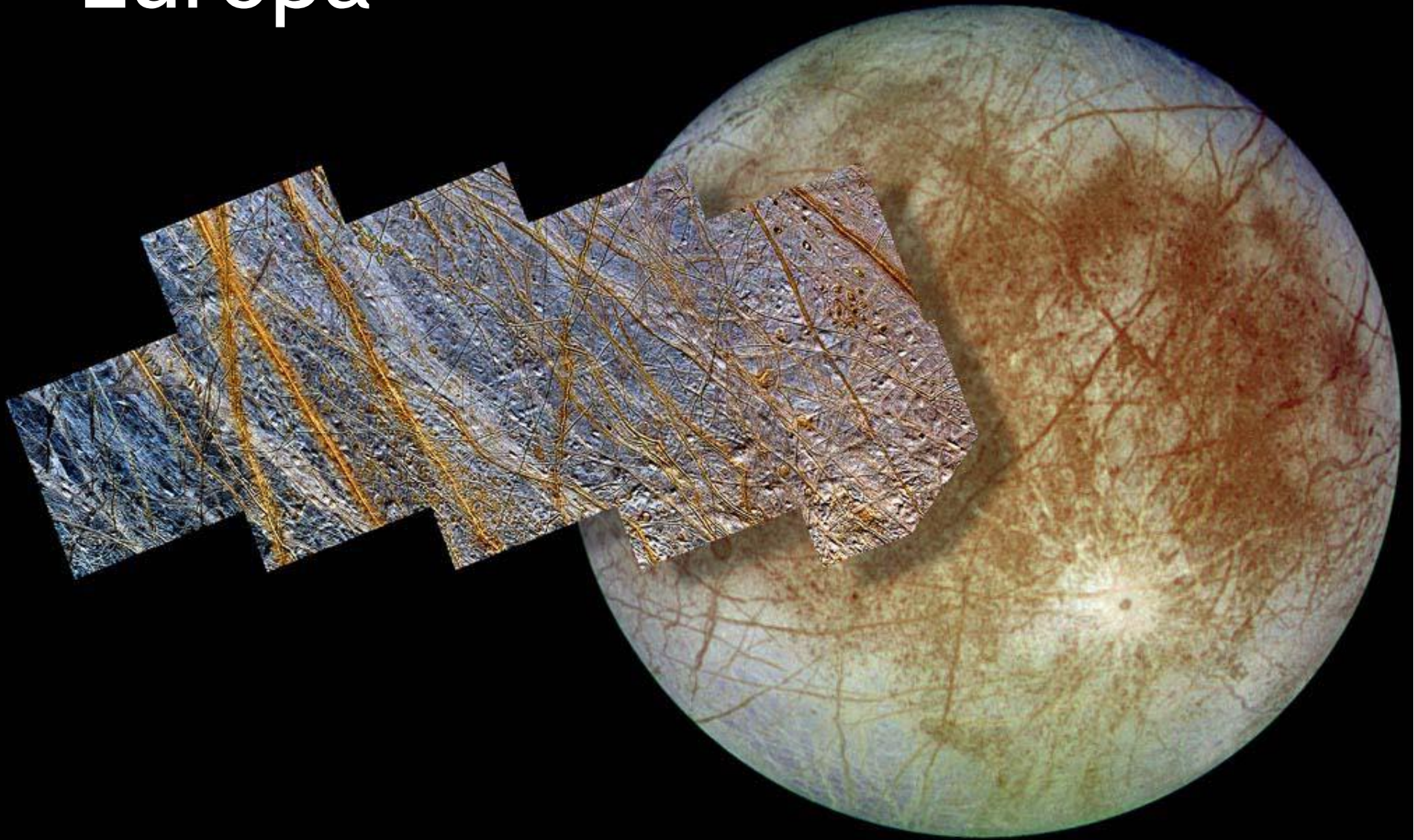
**Eruptive**



**Effusive (lava flows)**

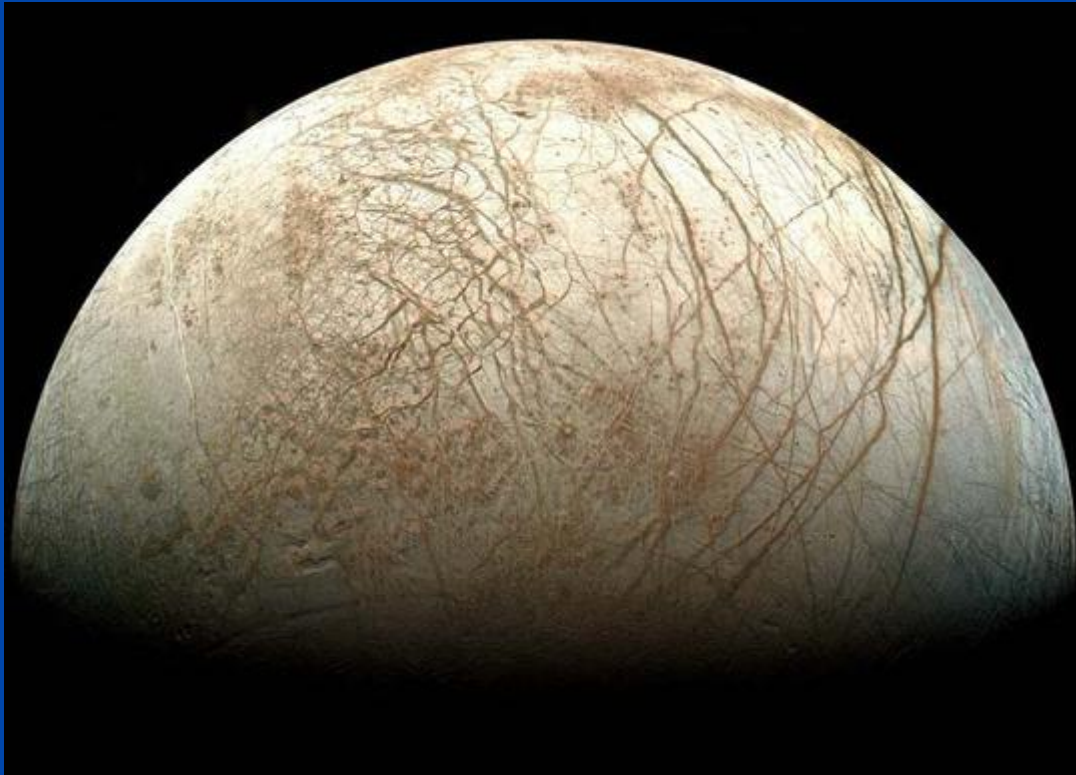


# Europa



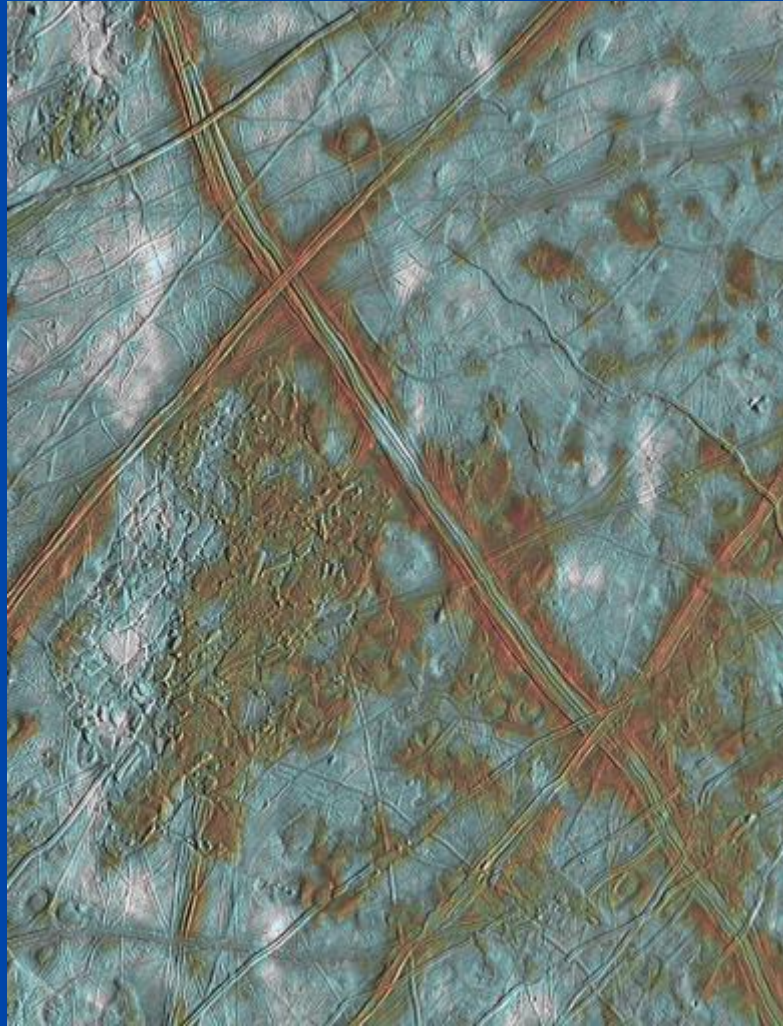
# Europa

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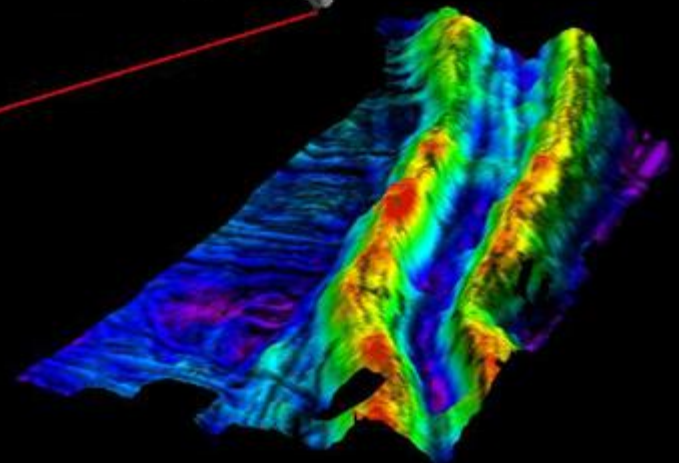
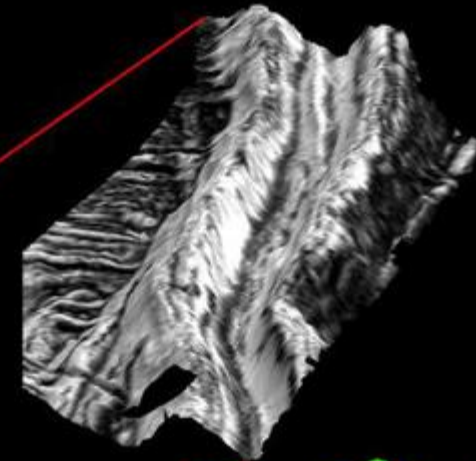
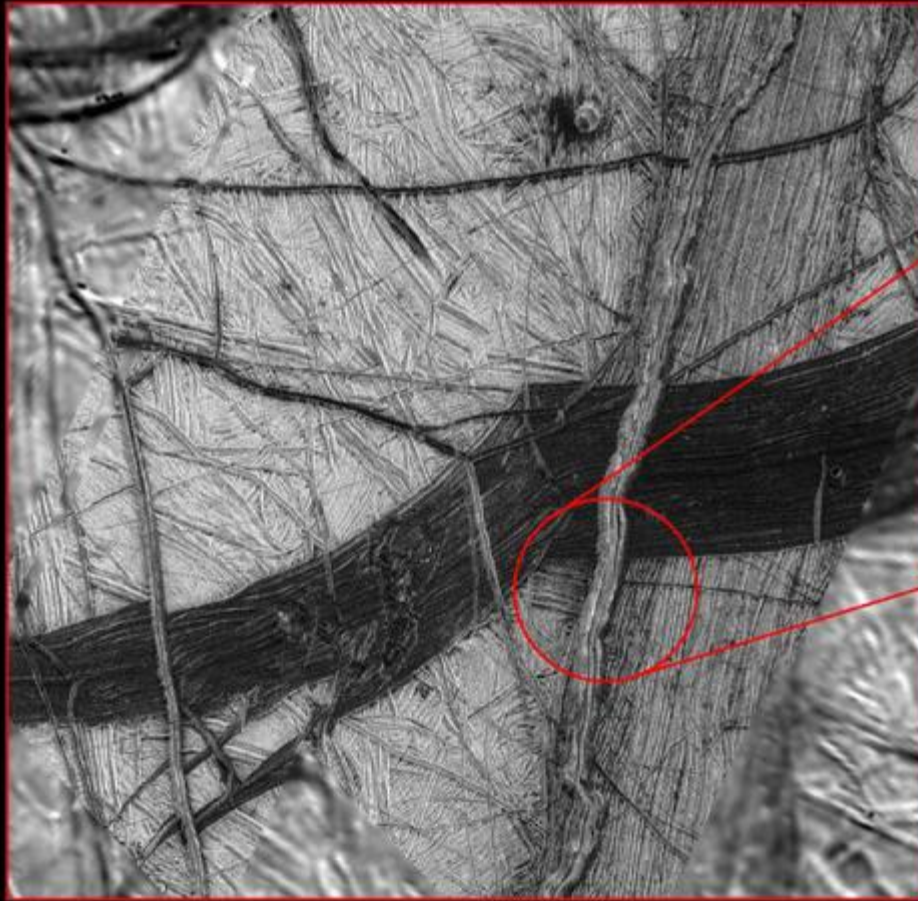


- **Metallic core, rocky mantle, and a crust made of H<sub>2</sub>O ice**
  - **Its fractured surface tells us that Europa has active tectonics**
    - few impact craters
    - double-ridged cracks
    - jumbled icebergs
  - **Photographic evidence of a subsurface ocean.**
- 
- **Europa has a magnetic field. Implies liquid salt water beneath icy crust.**
  - **Where liquid water exists, there could be life!**

# Ice Rafts on Europa (ice floating on liquid water?)



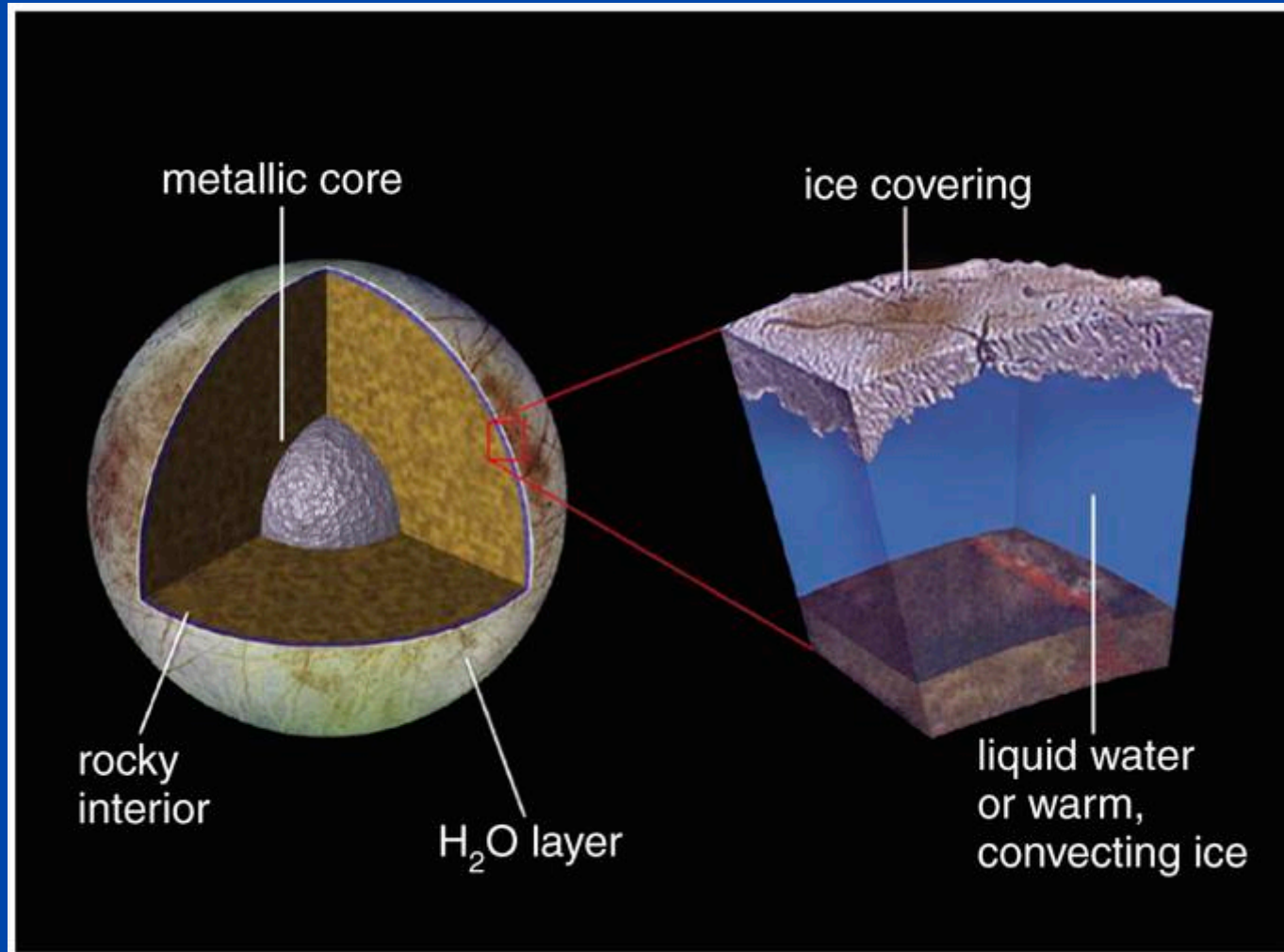
# Double ridges on Europa



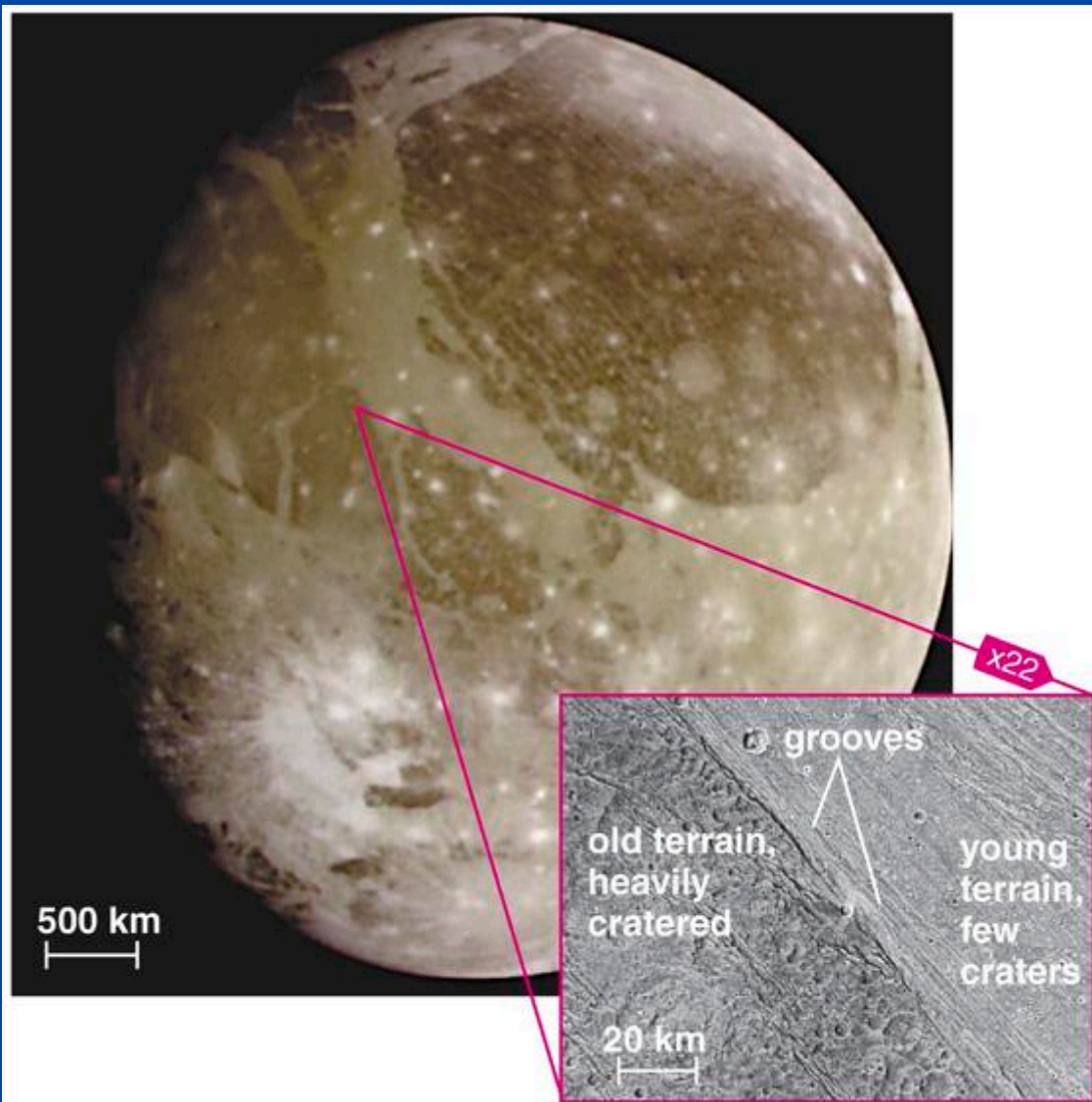
## Why double ridges?

- “Rafts” develop high edges by banging into each other repeatedly
- “Rafts” drift apart
- Fresh water flows up into the crack

# Europa's interior warmed by tidal heating.

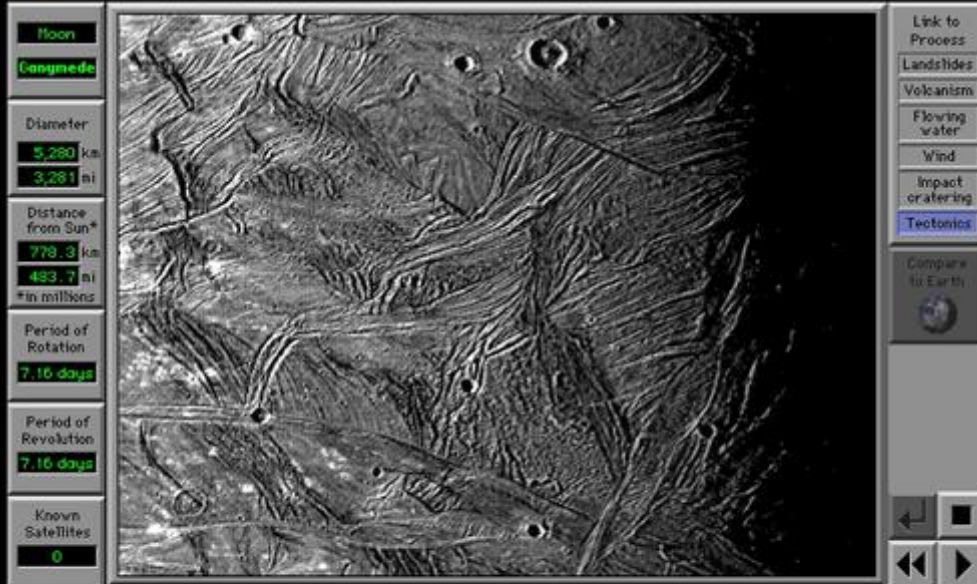


# Ganymede



- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?

# Ganymede geological features: grooved terrain



moon  
Ganymede

Diameter  
5,280 km  
3,281 mi

Distance from Sun\*  
779.3 km  
483.7 mi  
\*in millions

Period of Rotation  
7.16 days

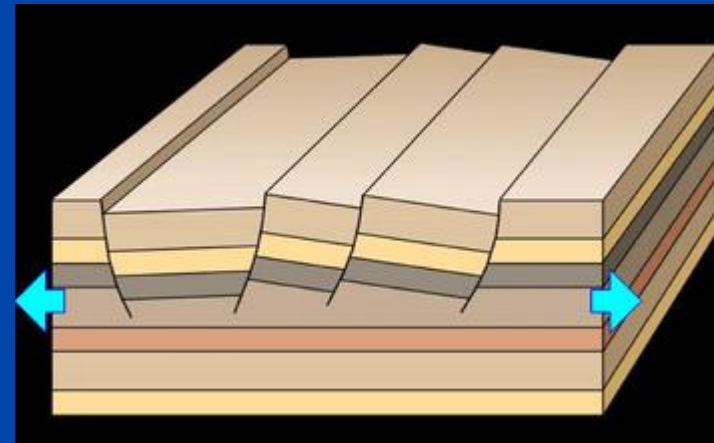
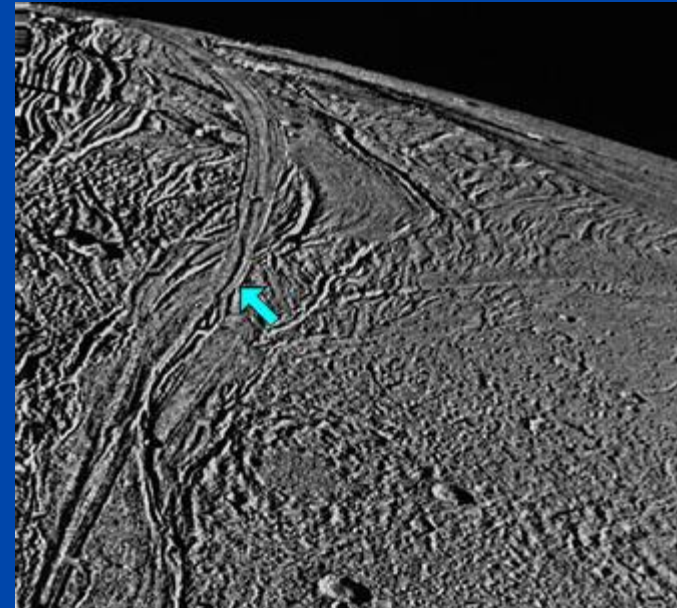
Period of Revolution  
7.16 days

Known Satellites  
0

Link to Process  
Landslides  
Volcanism  
Flowing water  
Wind  
Impact cratering  
Tectonics

Compare to Earth

Individual bundles of grooves can be over 100 kilometers long. The pattern seems to be formed by some type of faulting, probably normal faults, accompanied by eruption of liquid water.





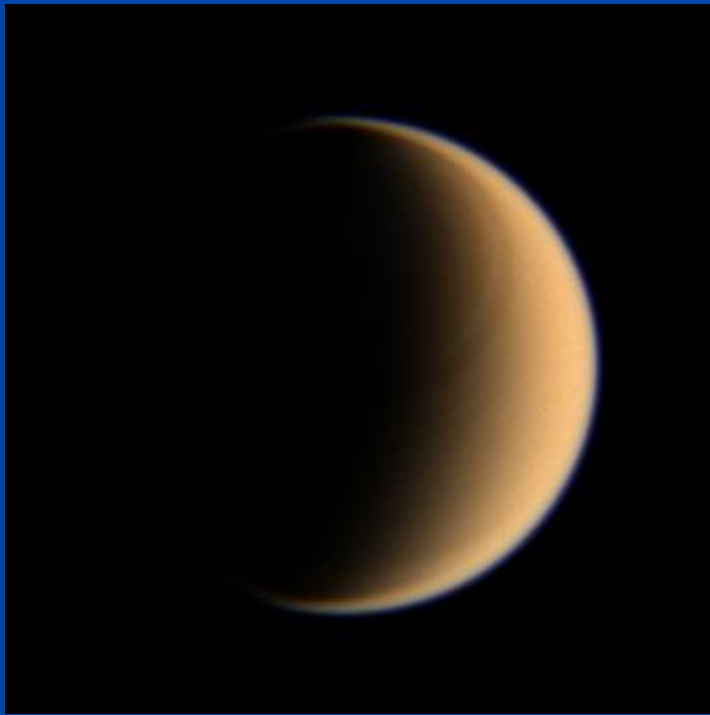
# Callisto



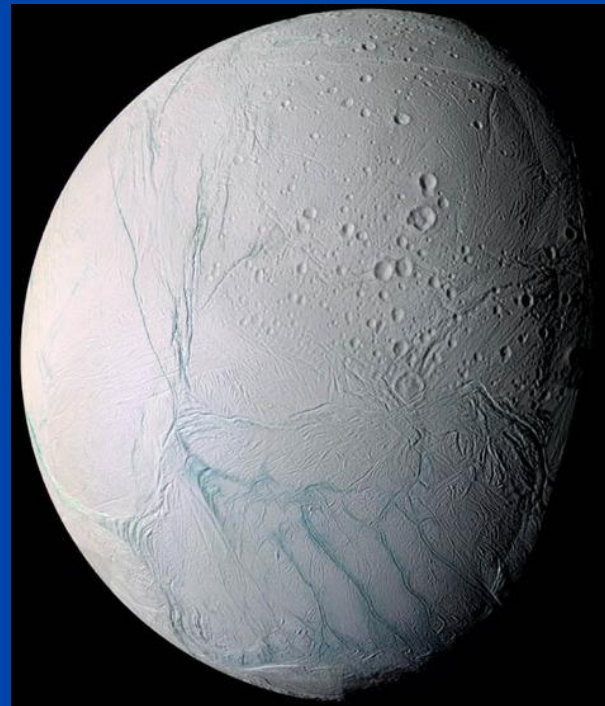
- **It has an old surface.**
  - heavily cratered, dirty ice
  - cratering reveals clean, white ice underneath
  - no evidence of tectonics
- **Its interior did not differentiate.**
  - rock mixed with ice
- **It does not experience tidal heating.**
- **Yet it has a magnetic field.**
- **Could it have a subsurface ocean anyway?**

# Moons of Saturn

I'll discuss only two of them....

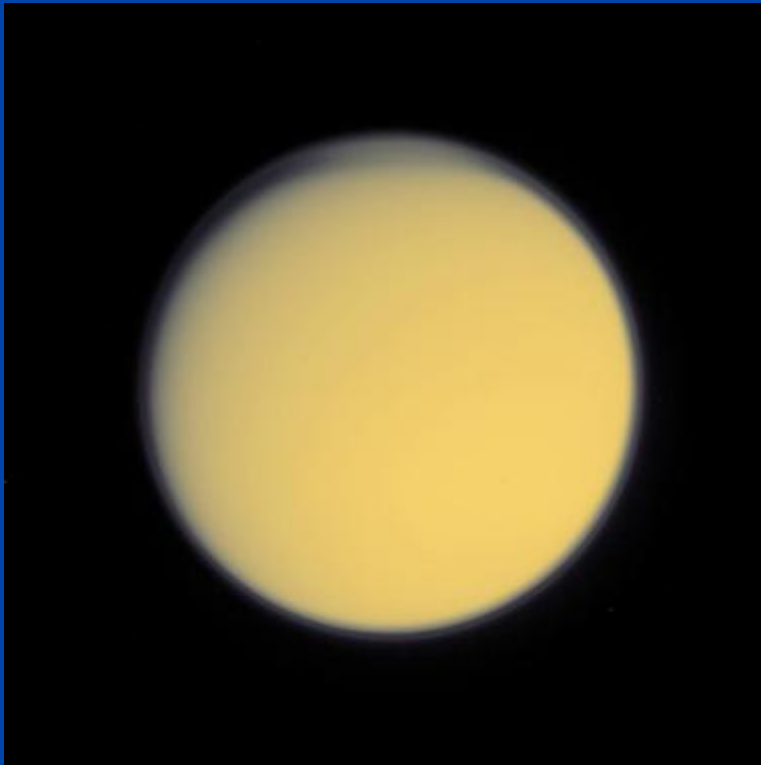


**Titan**



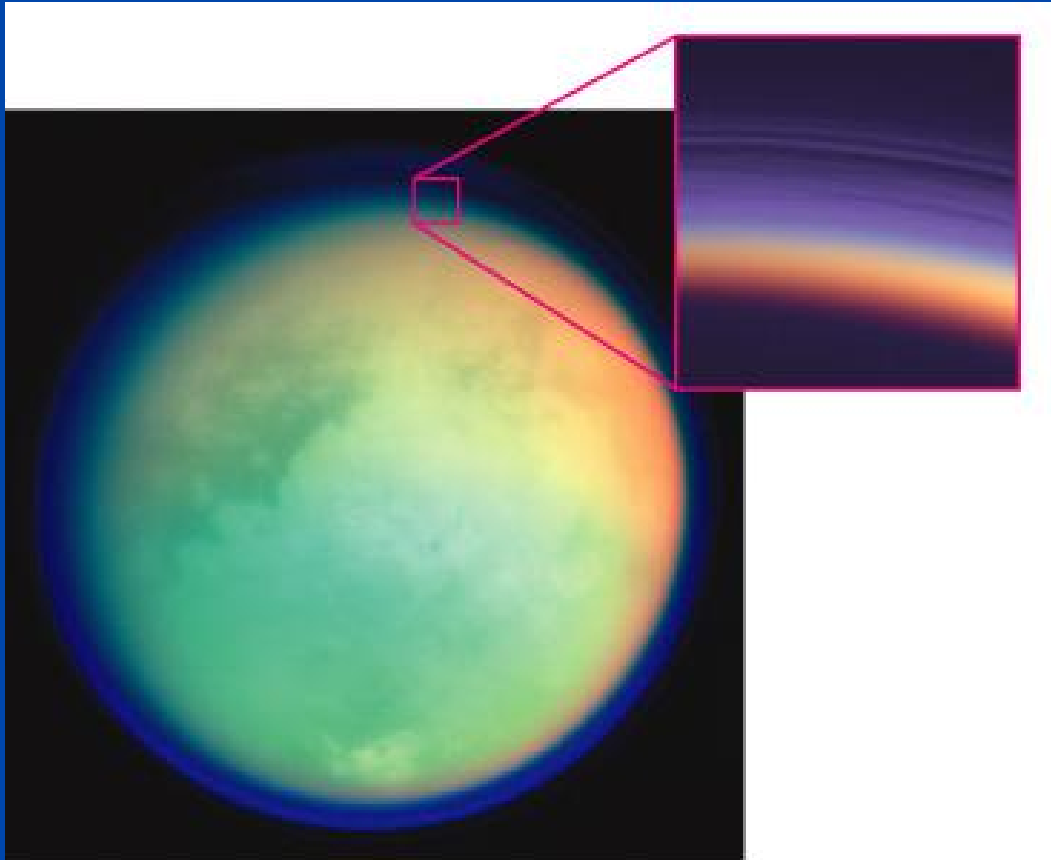
**Enceladus**

# Titan, Saturn's largest moon

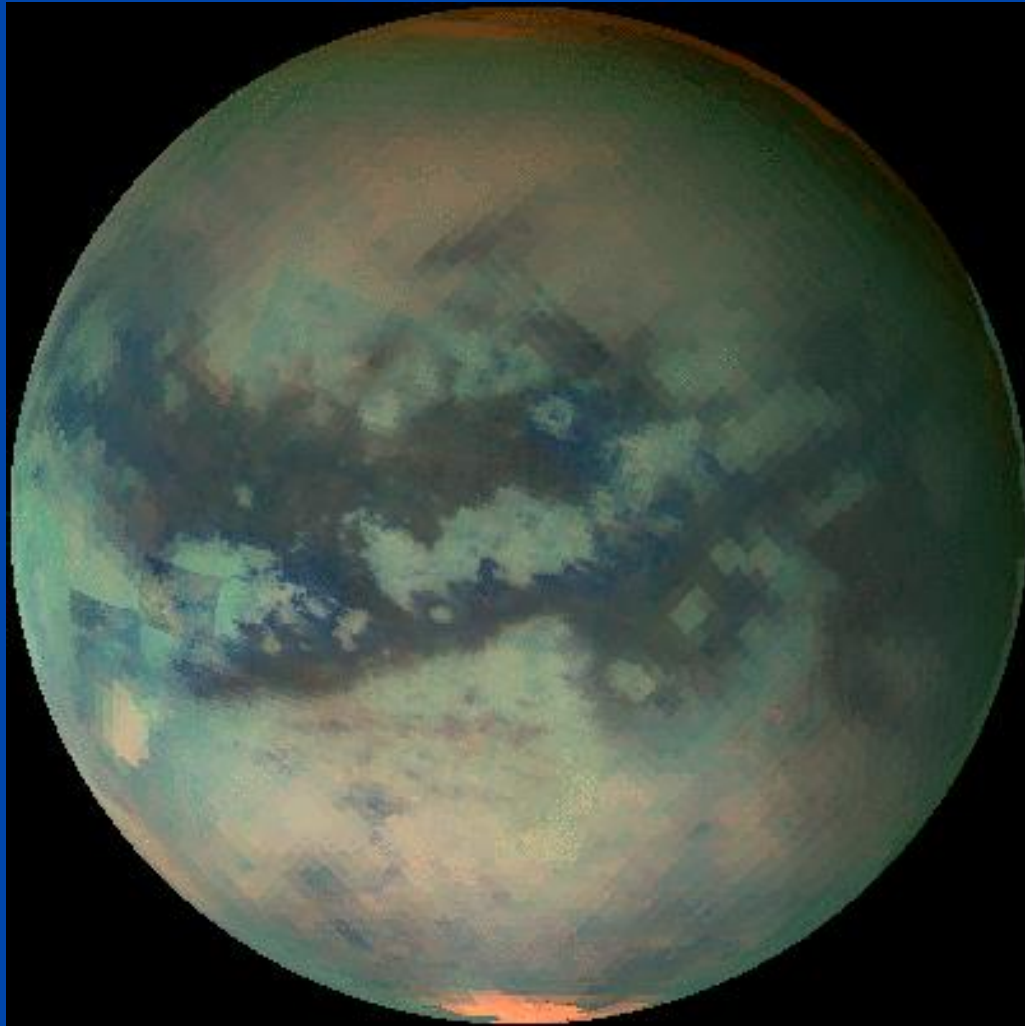


- **Has a thick atmosphere.**
  - Nitrogen (90%), Argon, methane, ethane
  - methane, ethane are greenhouse gases: surface is warmer than it should be
  - ethane may condense to form clouds and rain
- **The atmosphere blocks our view of Titan's surface.**
  - Hazy!
- **It has large lakes of liquid hydrocarbons!**
- **Erosion may be important**

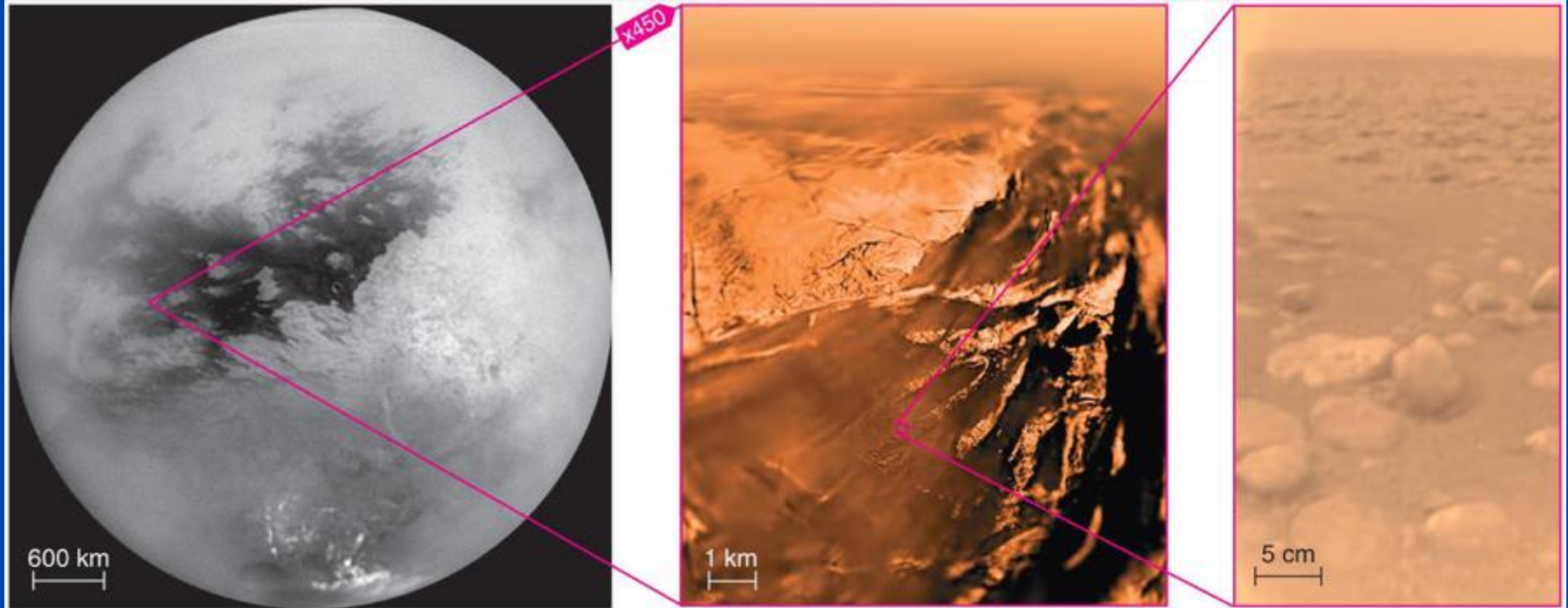
# Titan's Atmosphere



- Titan is the only moon in the solar system to have a thick atmosphere
- It consists mostly of nitrogen with some argon, methane, and ethane
- Surface atmospheric pressure similar to ours on Earth



# Titan's Surface

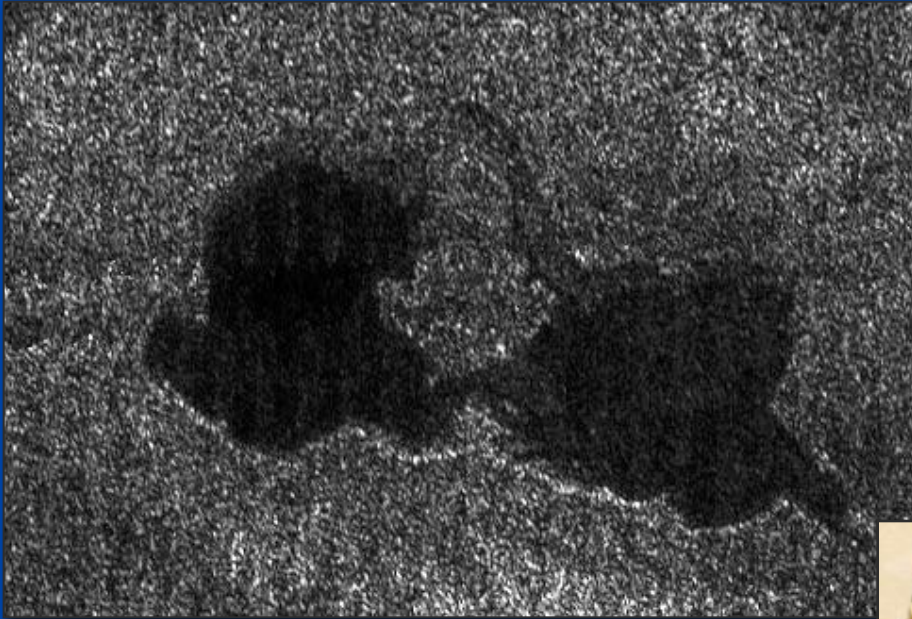


- *Huygens* probe provided first look at Titan's surface in early 2005
- Liquid methane, "rocks" made of ice

# Huygens probe landing on Titan

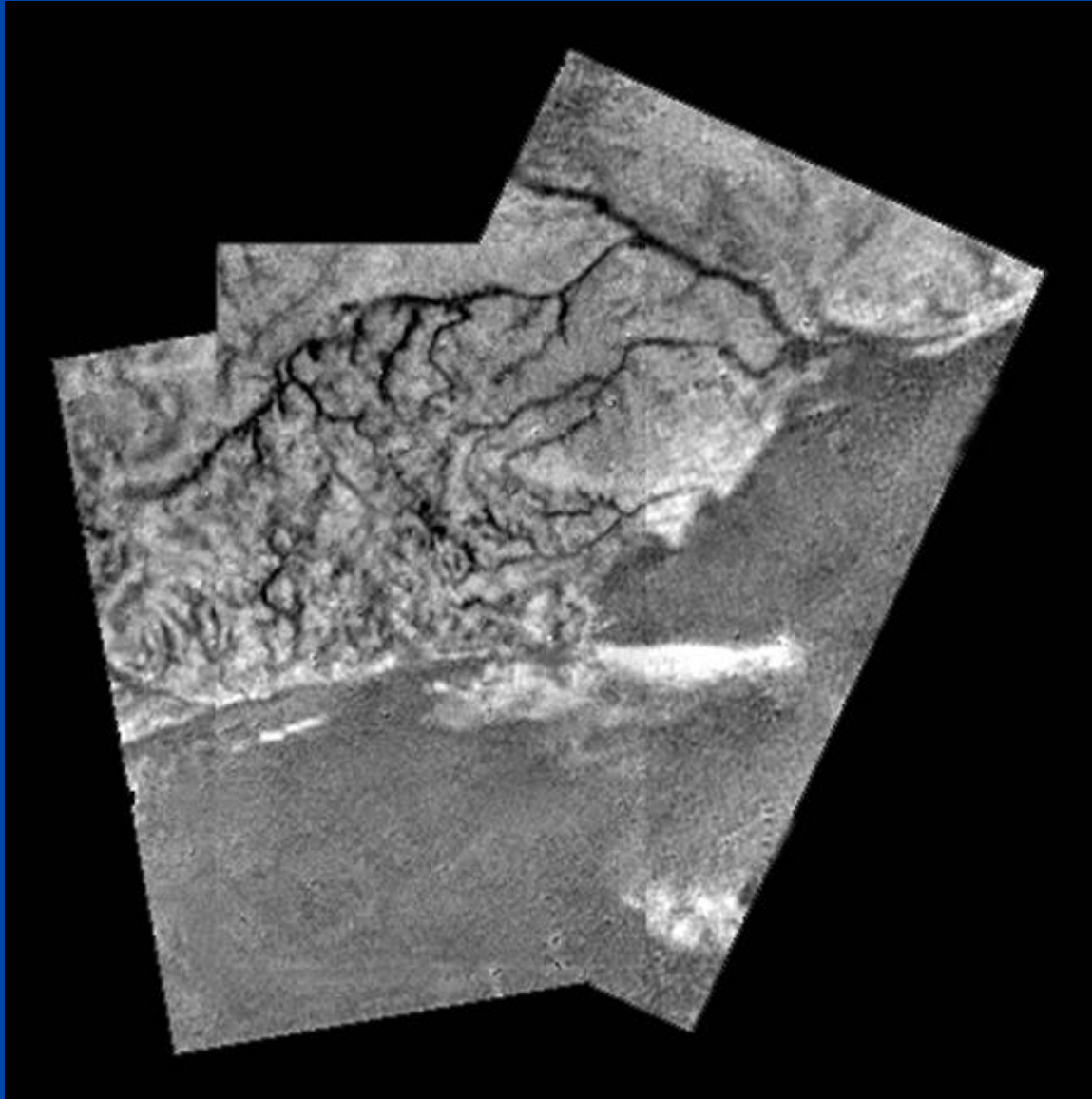
- [Titan Landing Movie](#)

# Radar images of Titan lakes (!)





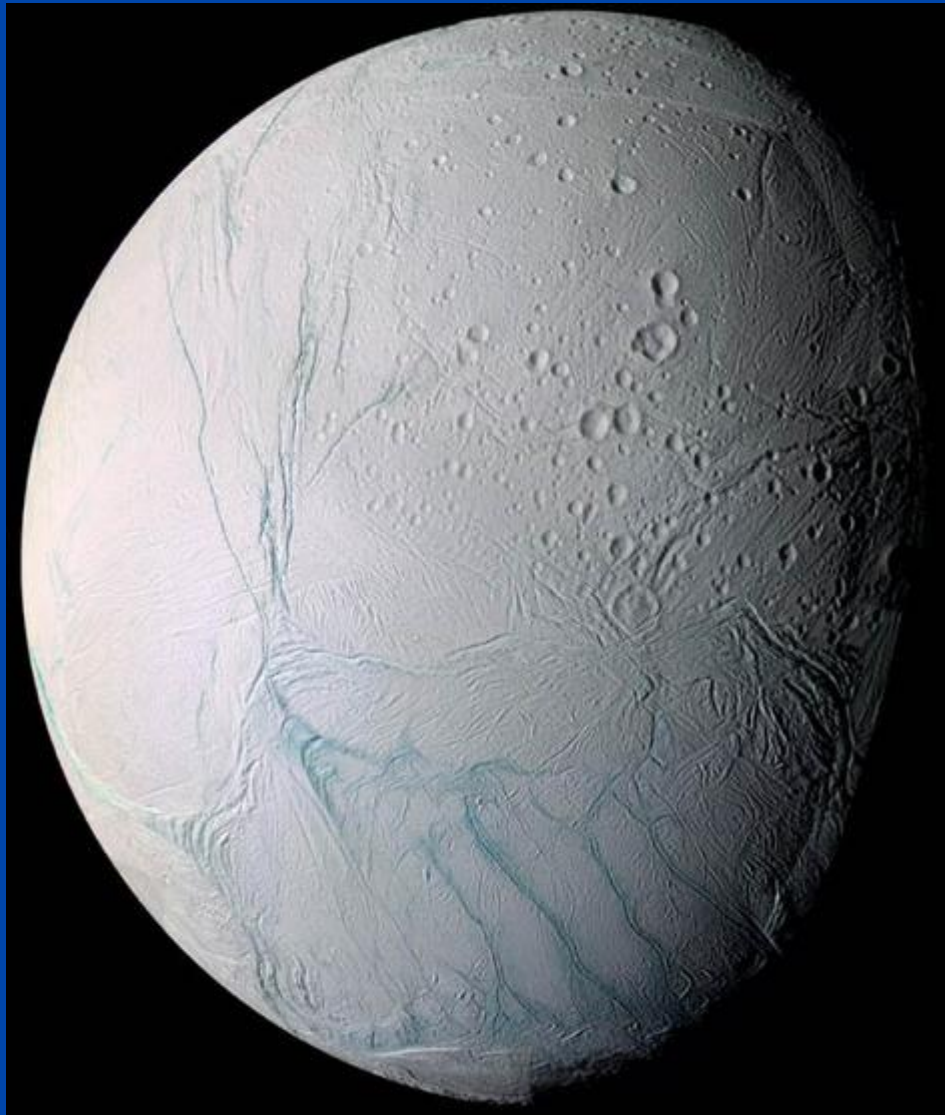
# Dry riverbeds on Titan



# Titan's "hydrological" cycle

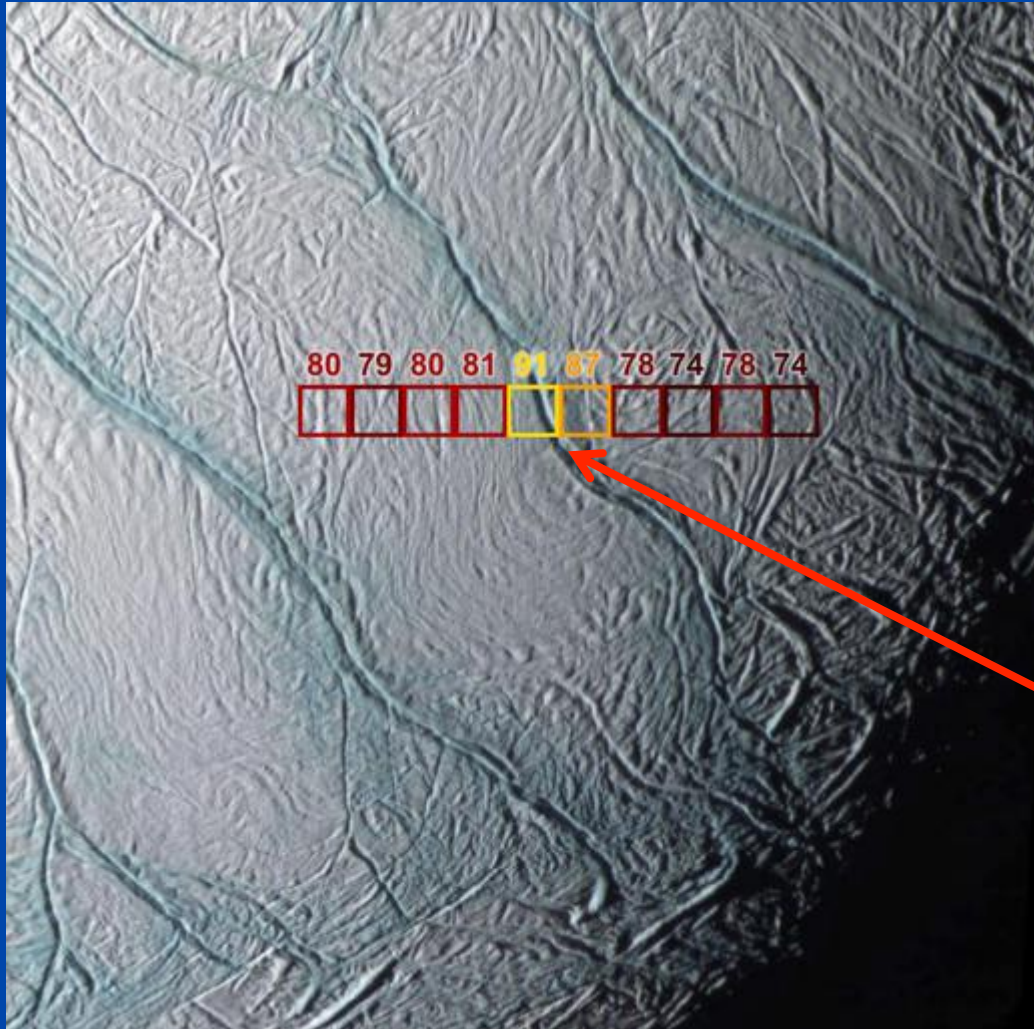
- Unmistakable river channels cut into Titan's terrain. So there must be some kind of rainfall, almost certainly drops of liquid methane.
- Raindrops would condense around the aerosol particles that Huygens lander detected.
- "Methane rain" and lakes of liquid hydrocarbons play the role of water on Earth.

# Enceladus: one of Saturn's “medium moons”



- What are the blue linear features?

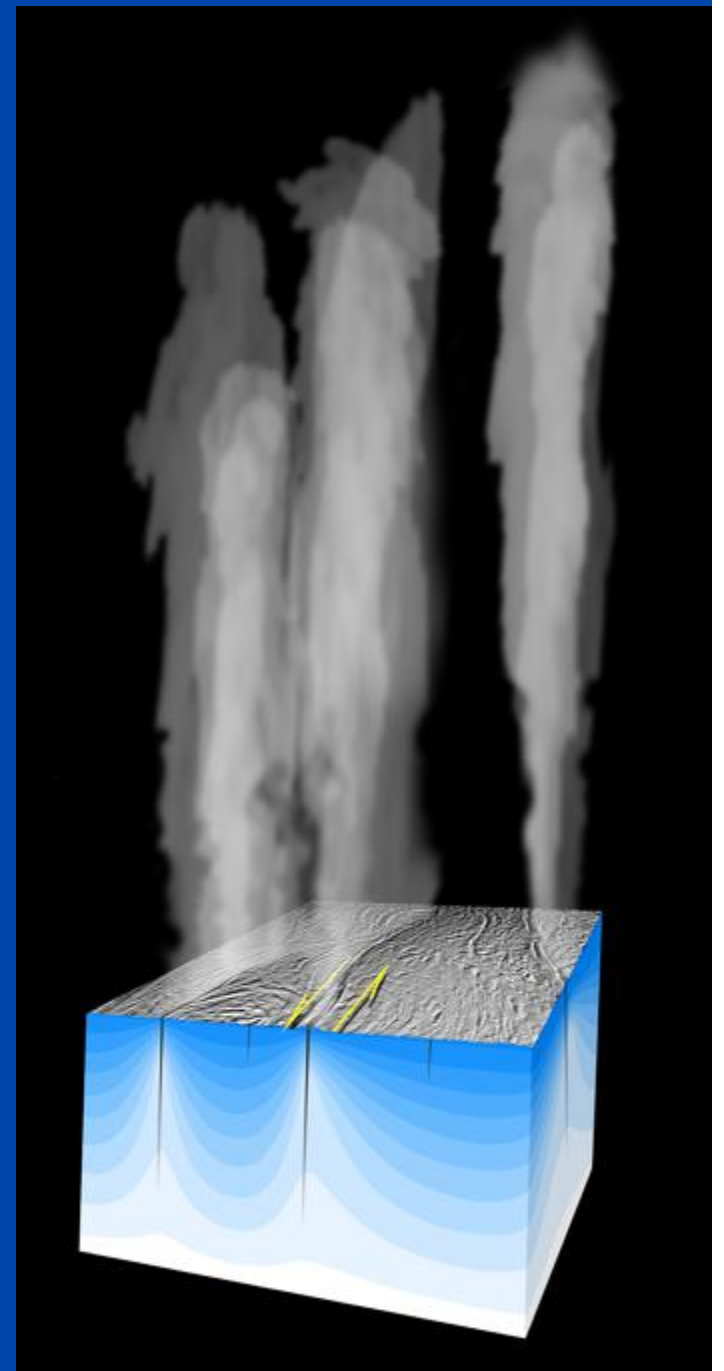
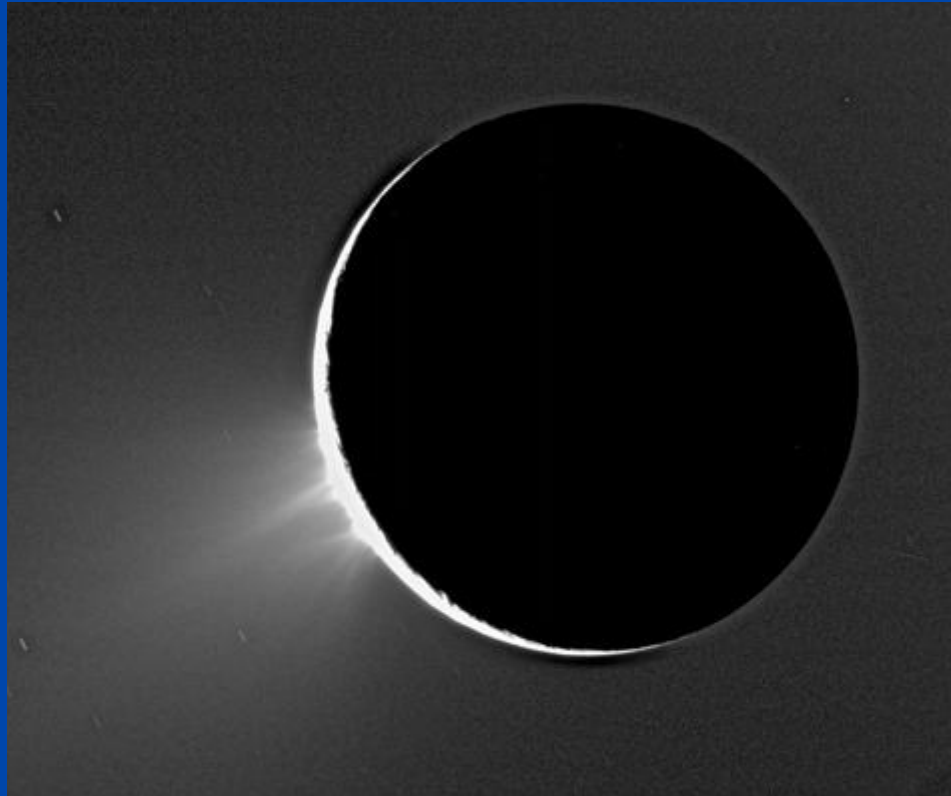
# Enceladus: one of Saturn's “medium moons”



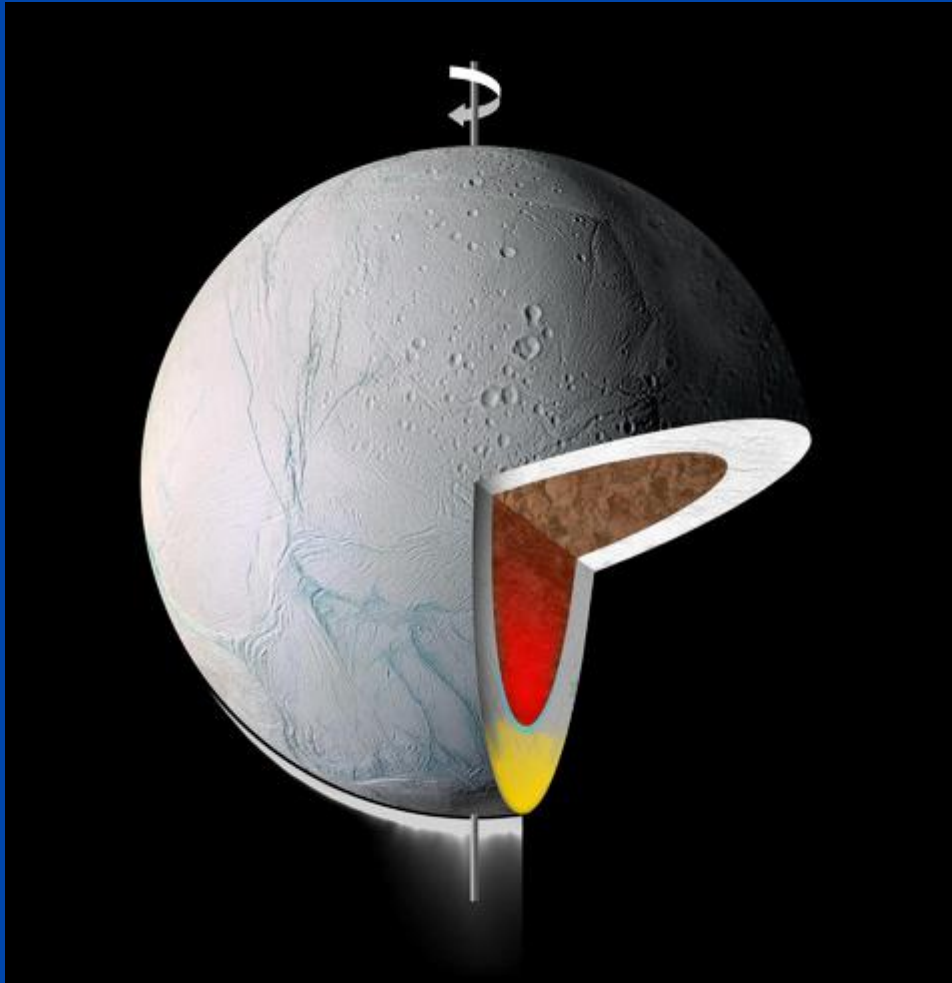
- What are the blue linear features?
- Warm cracks!

**Temperature scale**

# Plumes from the blue cracks



# Models for Enceladus plumes



- Southern “hot spot” ?

Enceladus "Cold geyser" Model

H<sub>2</sub>O vapor plus ice particles

H<sub>2</sub>O Ice T = ~77 K

Vent to surface

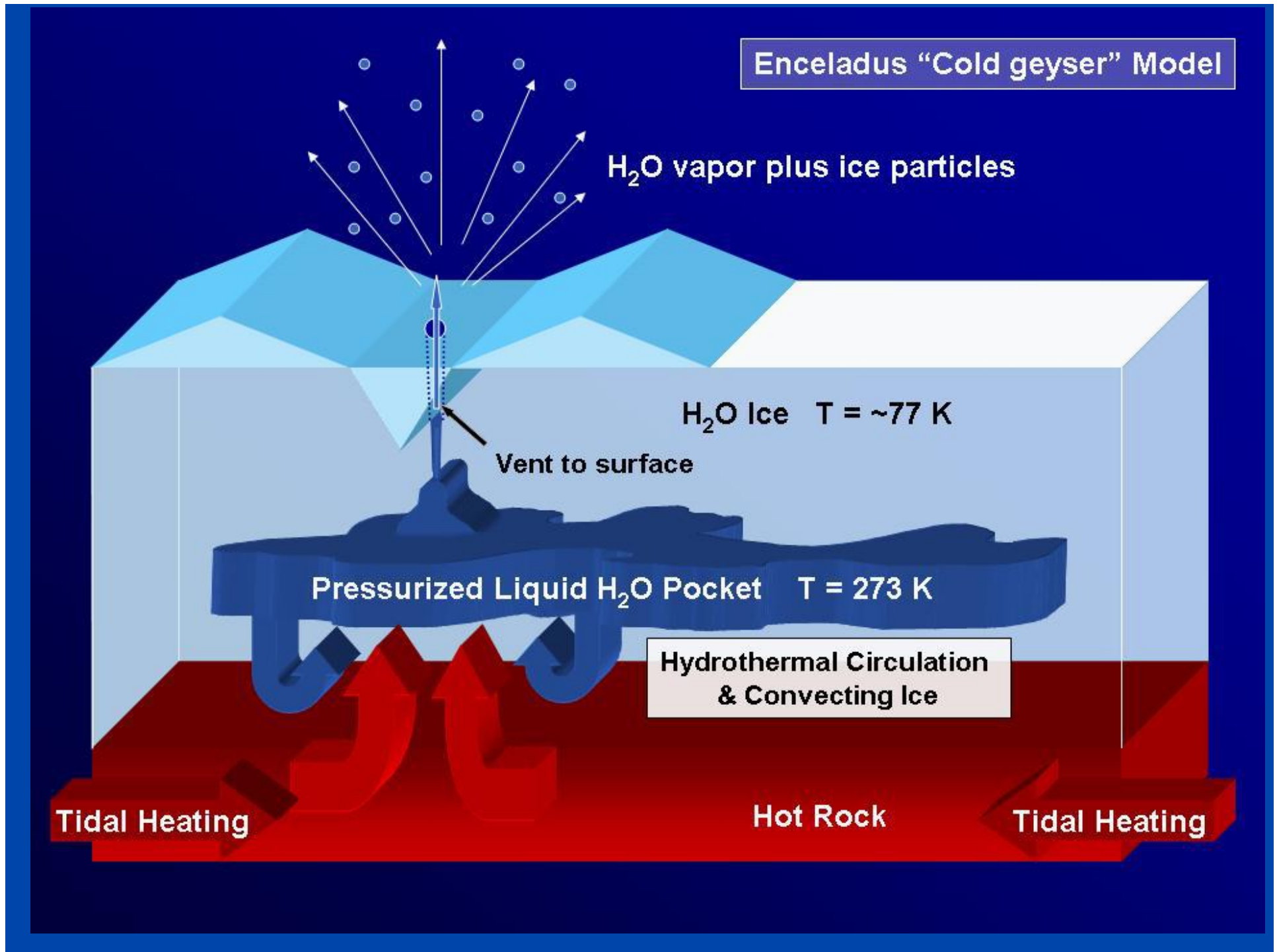
Pressurized Liquid H<sub>2</sub>O Pocket T = 273 K

Hydrothermal Circulation  
& Convecting Ice

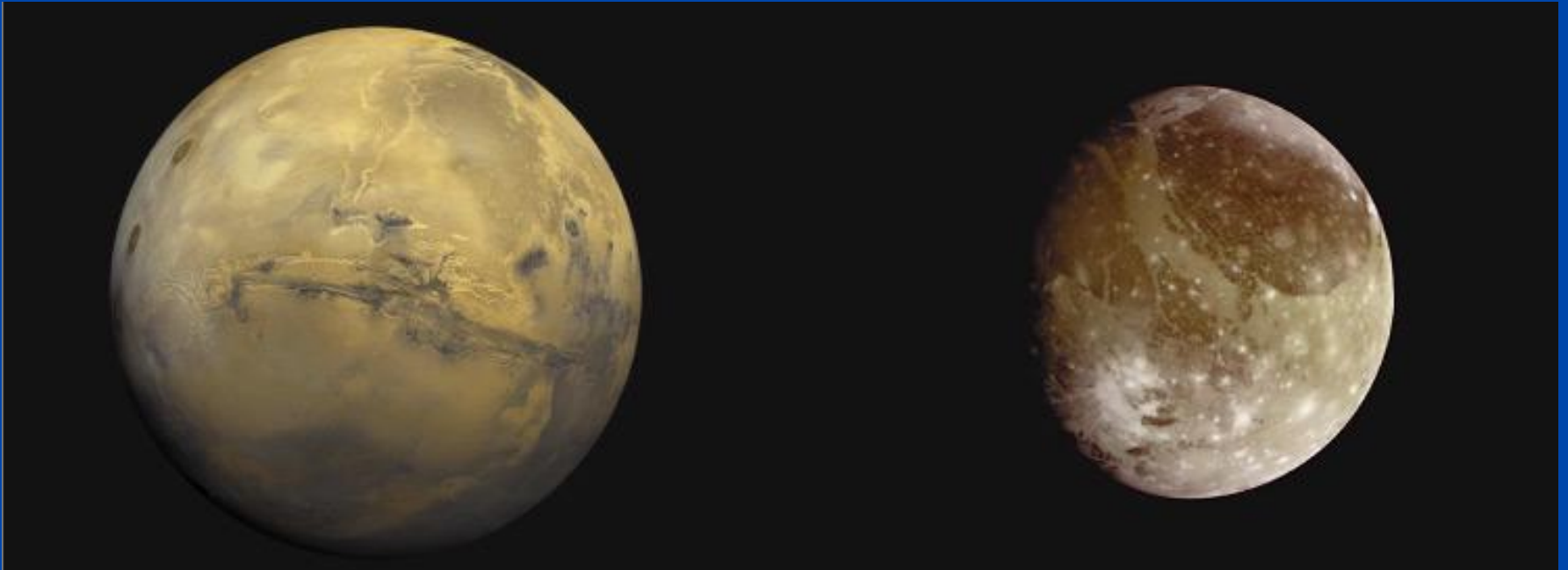
Tidal Heating

Hot Rock

Tidal Heating



# Rocky Planets vs. Icy Moons



- **Rock melts at higher temperatures**
- **Only large rocky planets have enough heat for activity**
- **Ice melts at lower temperatures**
- **Tidal heating can melt internal ice, driving activity**



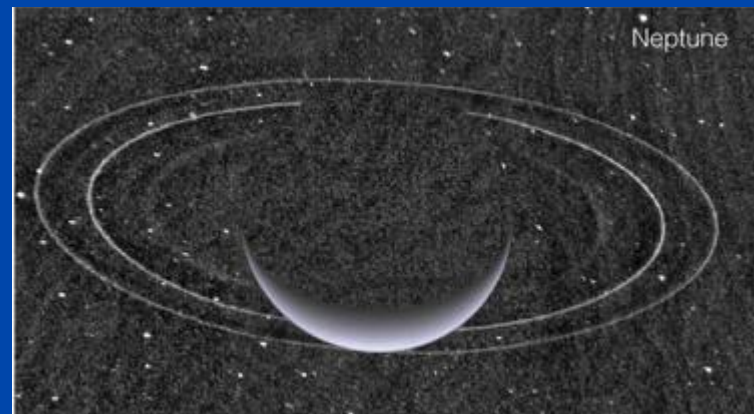
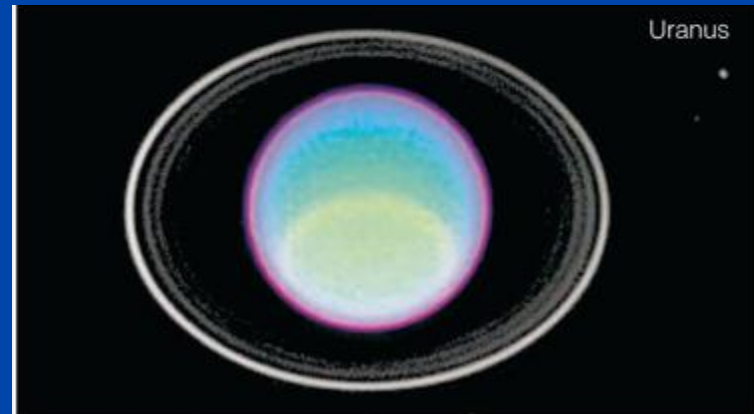
# What have we learned?

- *What kinds of moons orbit jovian planets?*
  - Moons of many sizes
  - Level of geological activity depends on size
- *Why are Jupiter's Galilean moons so geologically active?*
  - Tidal heating drives activity, leading to Io's volcanoes and ice geology on other moons

# What have we learned?

- ***What is special about Titan and other major moons of the solar system?***
  - Titan is only moon with thick atmosphere
  - Many other major moons show signs of geological activity
- ***Why are small icy moons more geologically active than small rocky planets?***
  - Ice melts and deforms at lower temperatures enabling tidal heating to drive activity

# Jovian Planets: Ring Systems



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

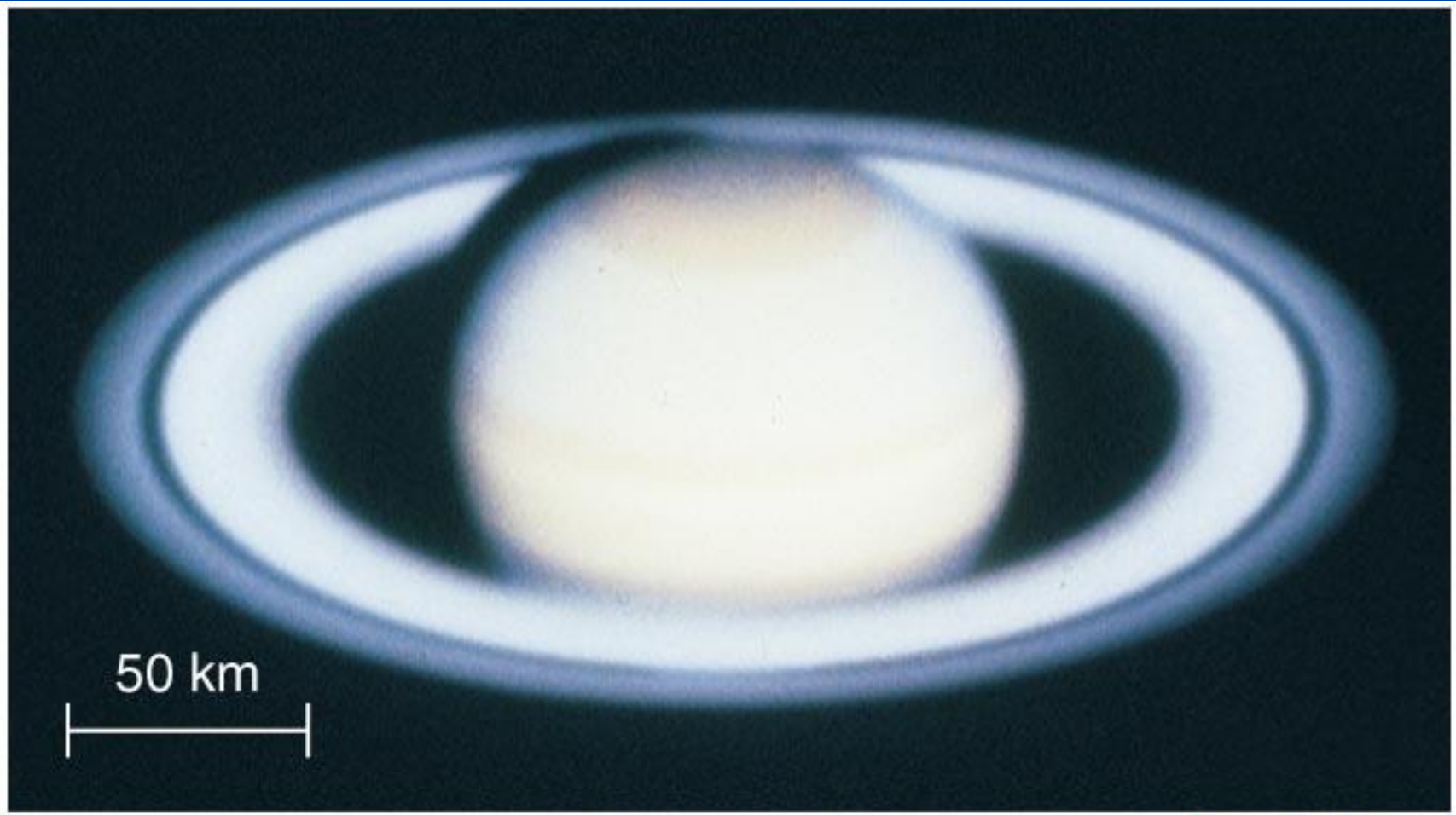
# Rings of the Jovian Planets

- **All four Giant Planets have rings**
  - Chunks of rock, ice, dust in orbit around planet
- **Saturn's rings are the most massive and spectacular**
- **Formation: a moon can't survive intact within the "Roche tidal zone"**
- **Ring systems may be short-lived, always changing**
  - Each chunk in Saturn's rings has a collision with another chunk every few hours!
  - Implies that rings are always being replenished

# What are Saturn's rings like?

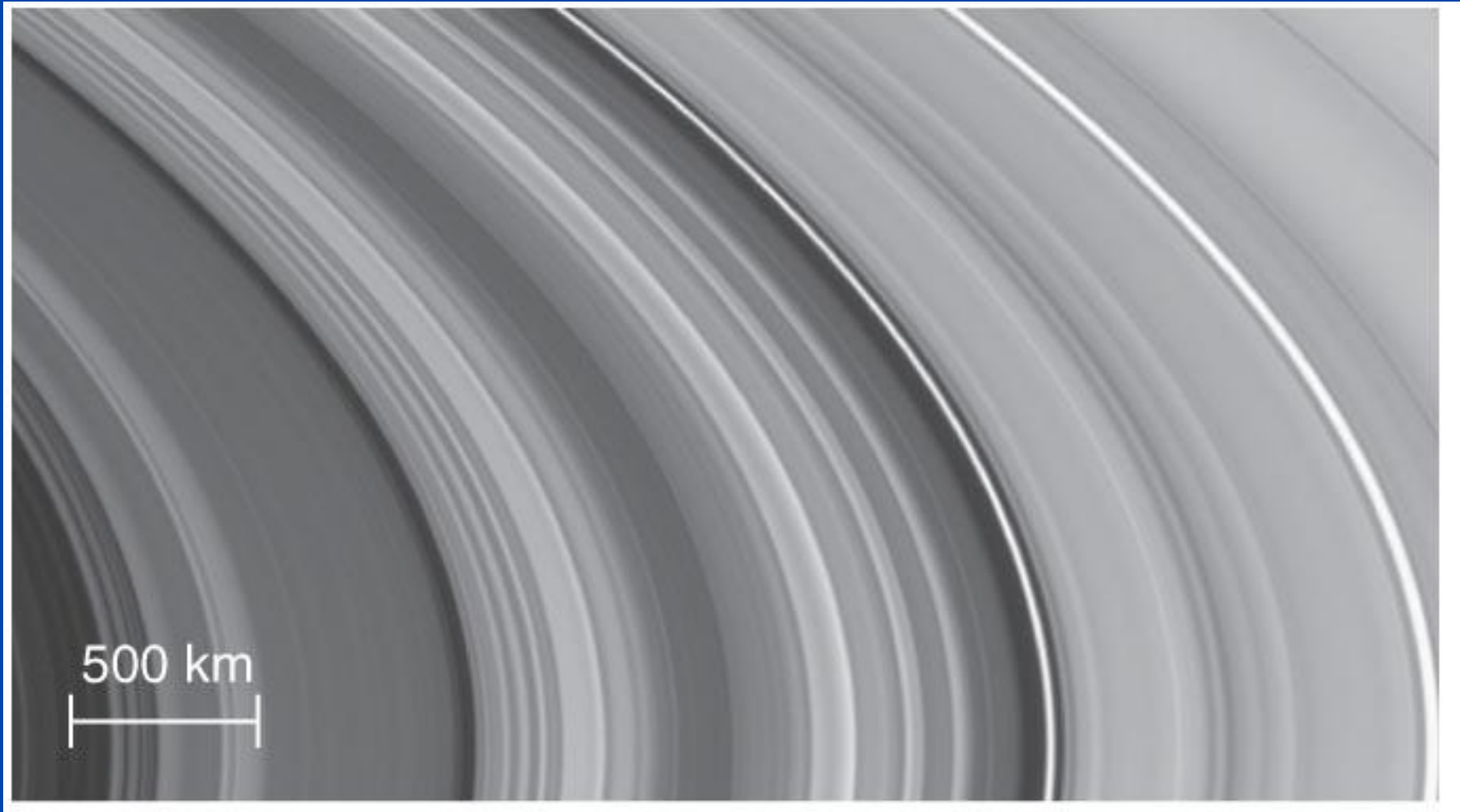
- They are made up of numerous, tiny individual particles and rocks
- They orbit over Saturn's equator
- They are very thin

# Earth-based view



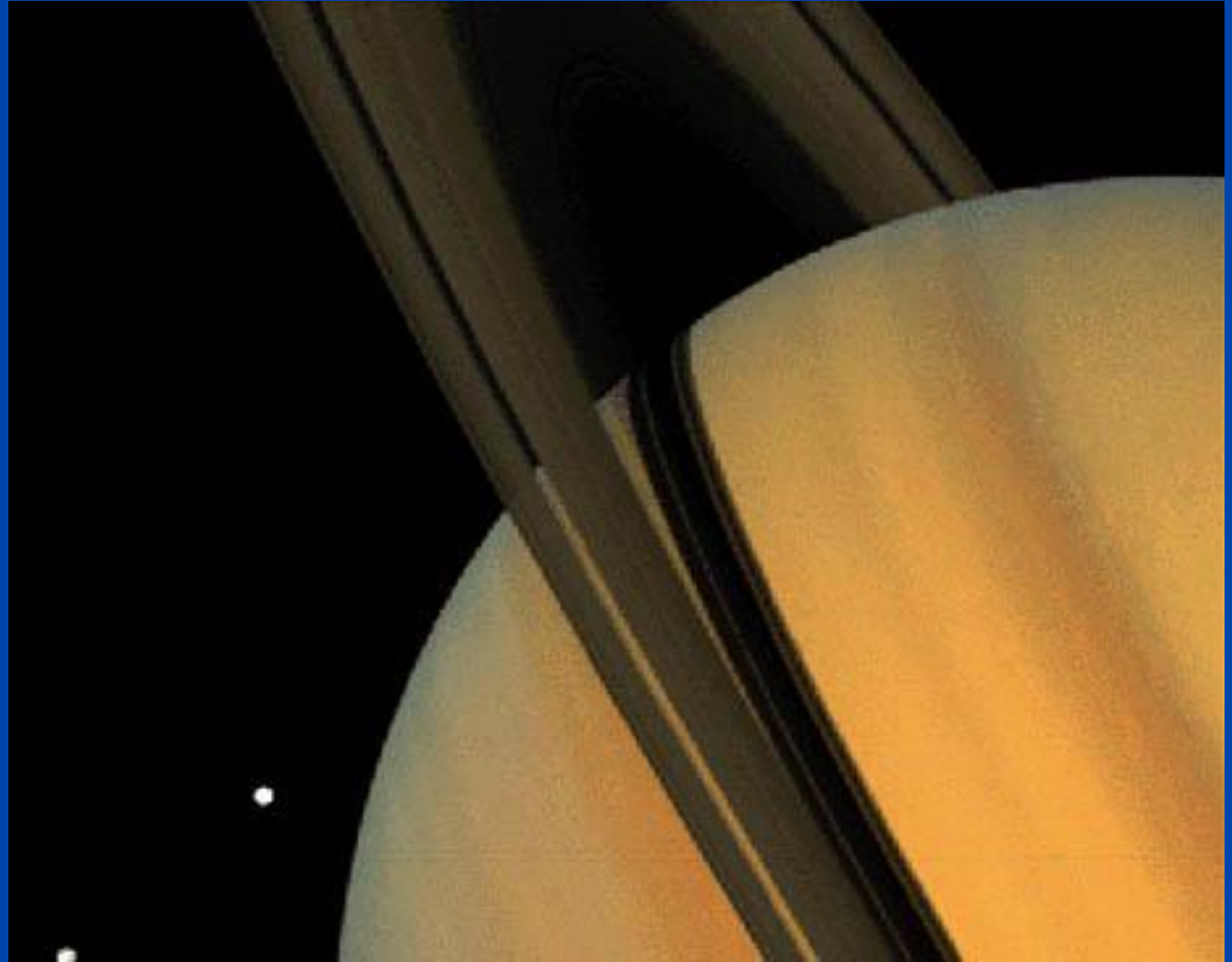
Interactive Figure 

# Spacecraft view of ring gaps



# Not much mass in Saturn's rings

- If gathered together, material in rings would make a sphere 500 km across
- Smaller than our Moon!





# Saturn's rings are very thin



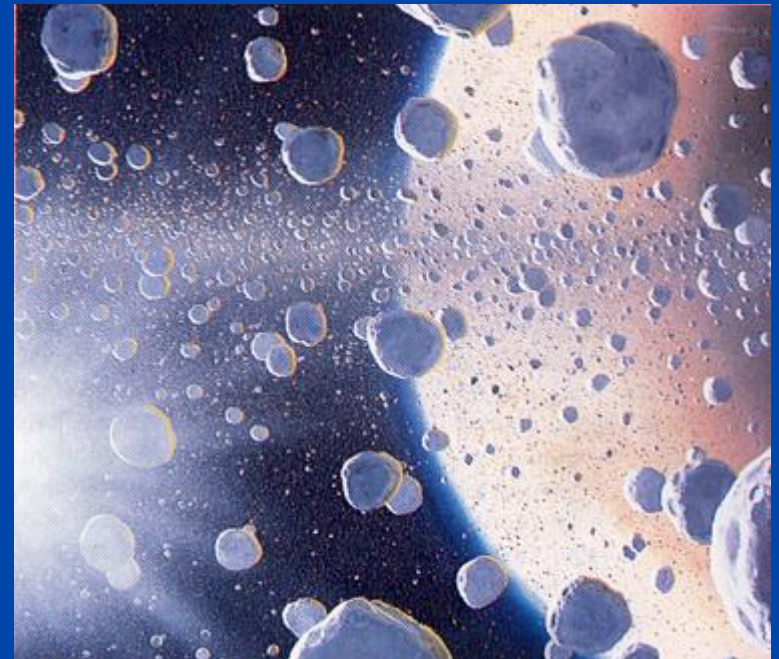
- **Movies from the Cassini spacecraft**

- <http://photojournal.jpl.nasa.gov/archive/PIA12795.mov>

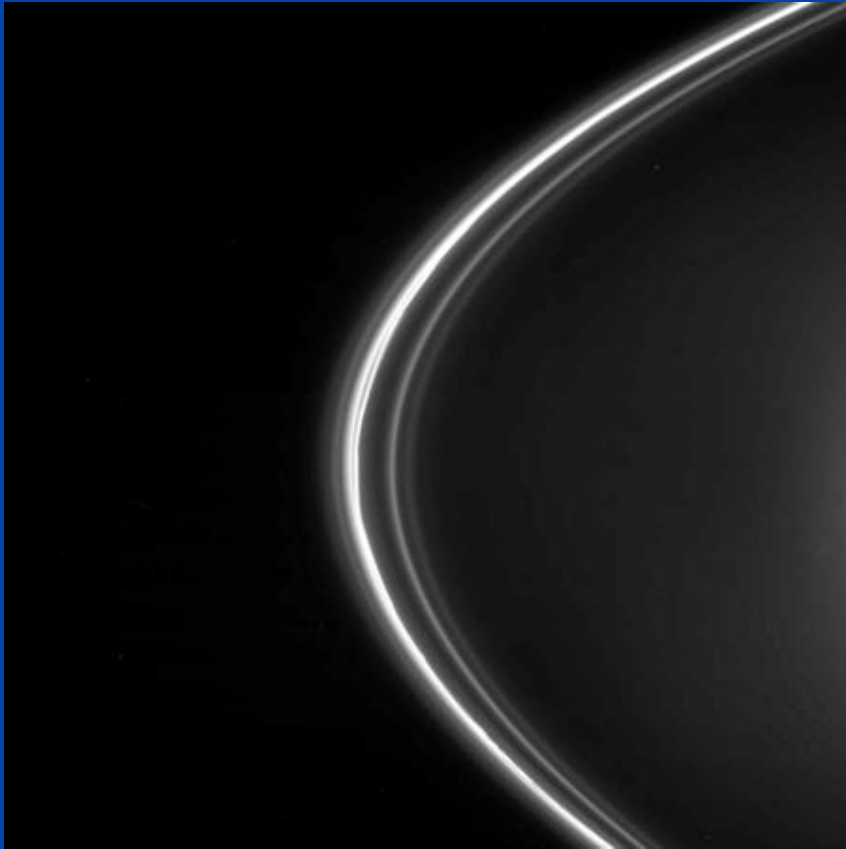
**Saturn's rings are 270,000 km in diameter, but only about 30 meters thick!**

# Saturn's rings are probably a transient phenomenon

- Each chunk of rock and ice in Saturn's rings collides with another one every few hours
- Must grind up smaller chunks into tiny pieces
- Needs mechanism for regeneration: collisions of some of Saturn's small moons?
  - Not well understood yet.



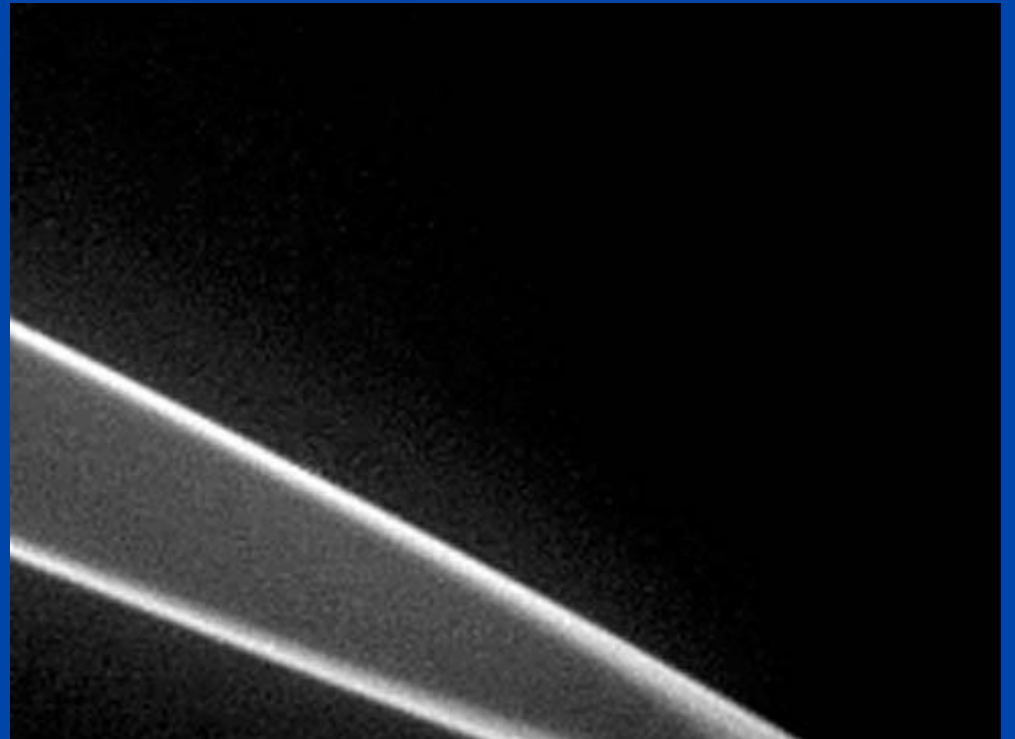
# Shepherd Moons maintain ring patterns



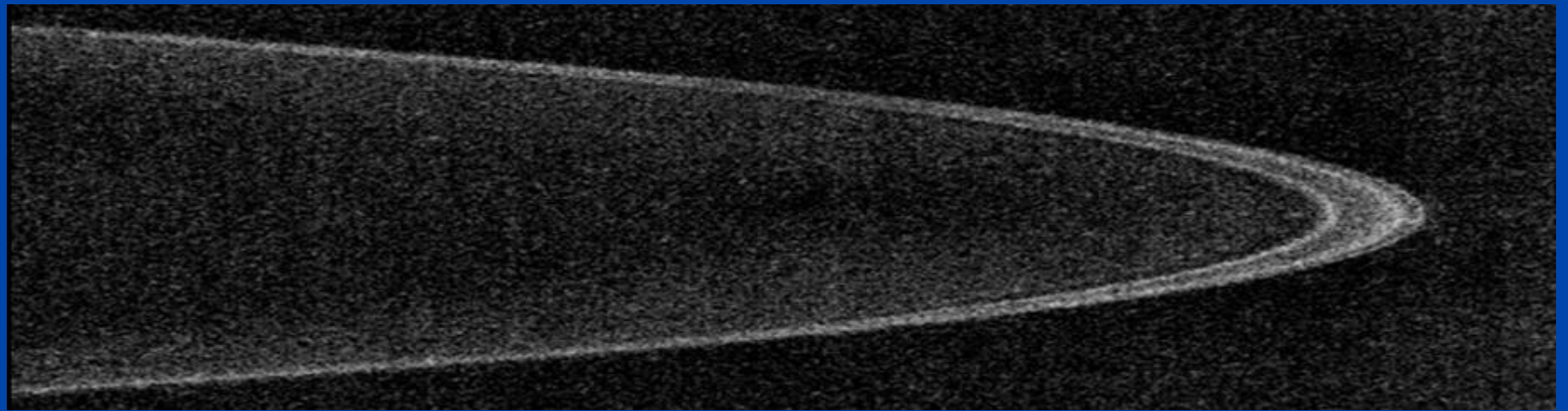
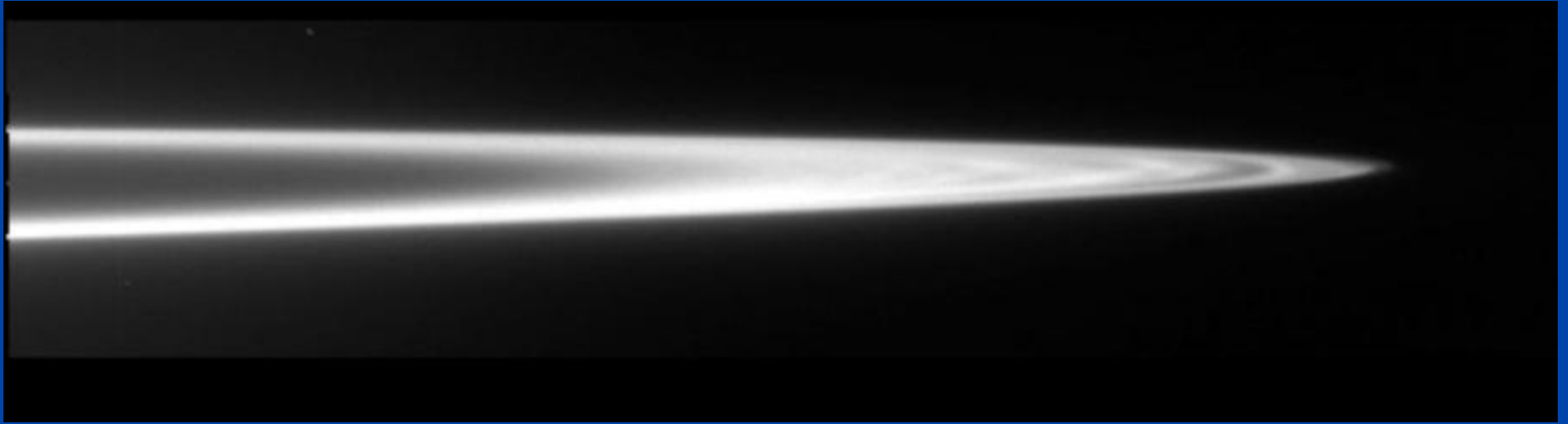
- **Prometheus and Pandora shepherd Saturn's F Ring**
  - From Cassini spacecraft

# Jupiter's ring

- **Not much stuff**
- **If you gathered all the material in Jupiter's ring together into a ball, it would be only 30 meters in diameter!**

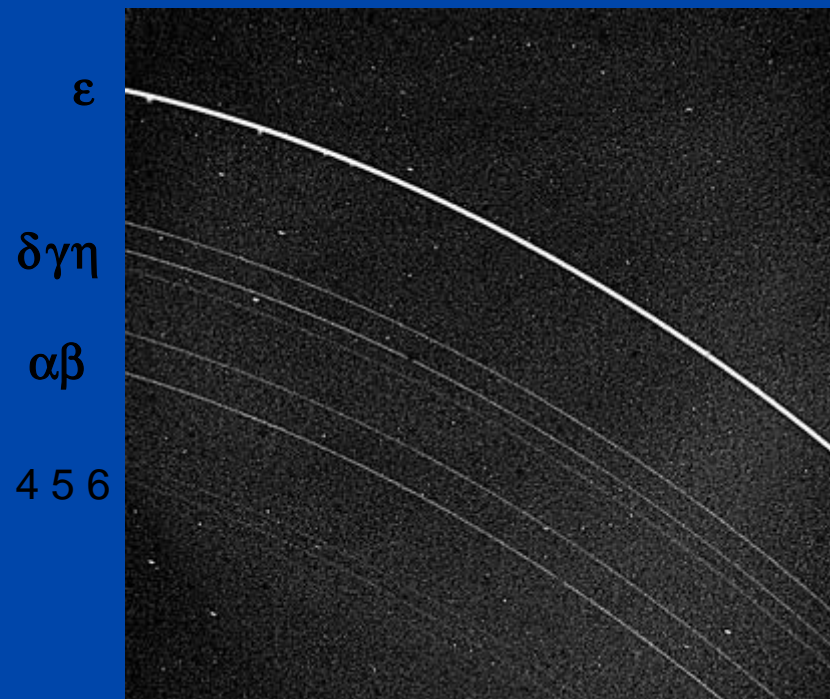


## Jupiter's ring: other views

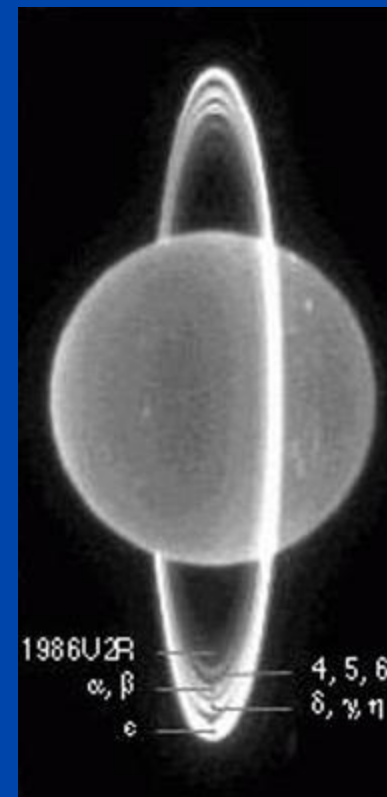


# Rings of Uranus

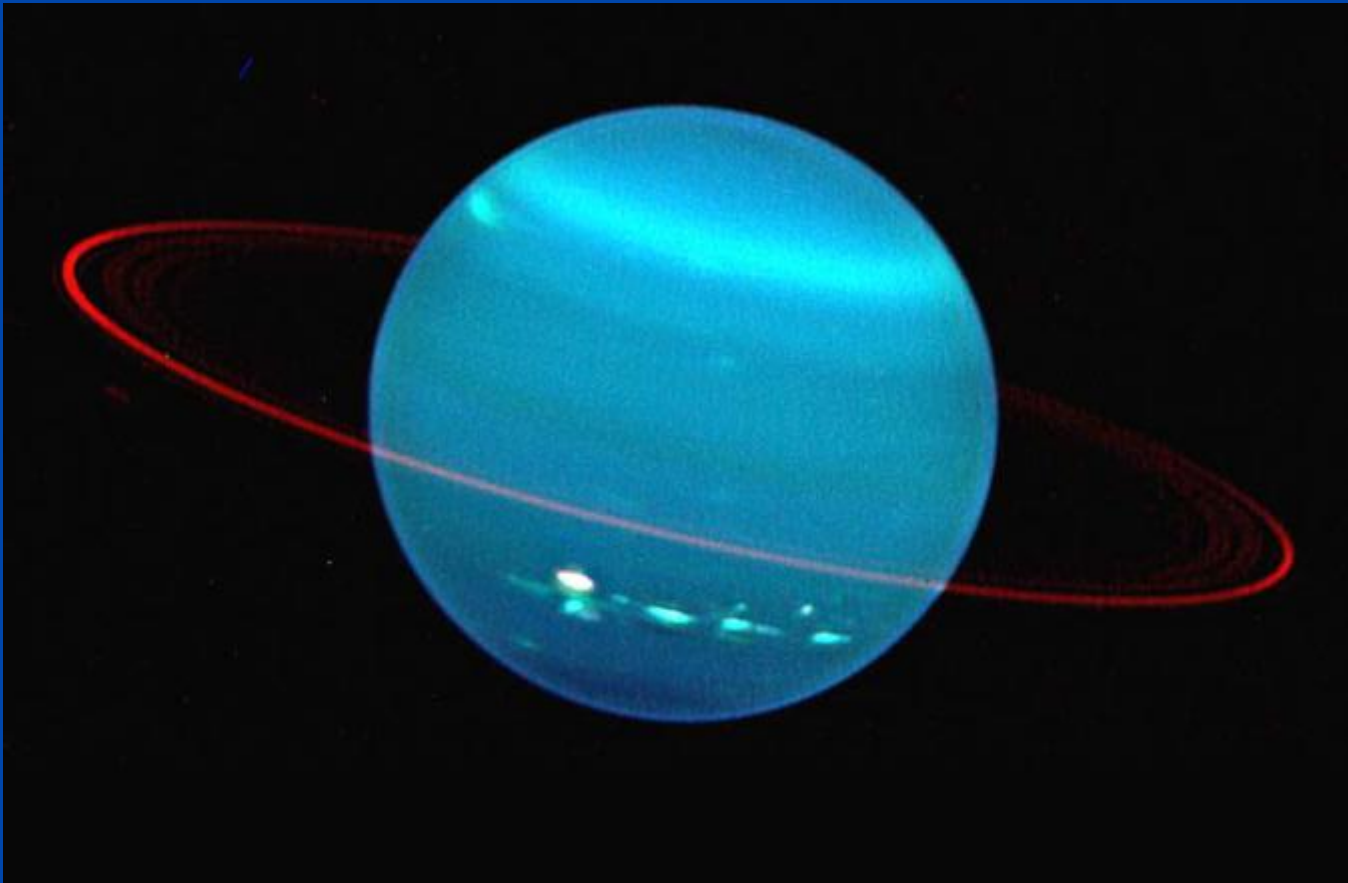
Voyager: 4 groups of rings



Keck Adaptive Optics, 2004  
(de Pater)



## Uranus rings, another view

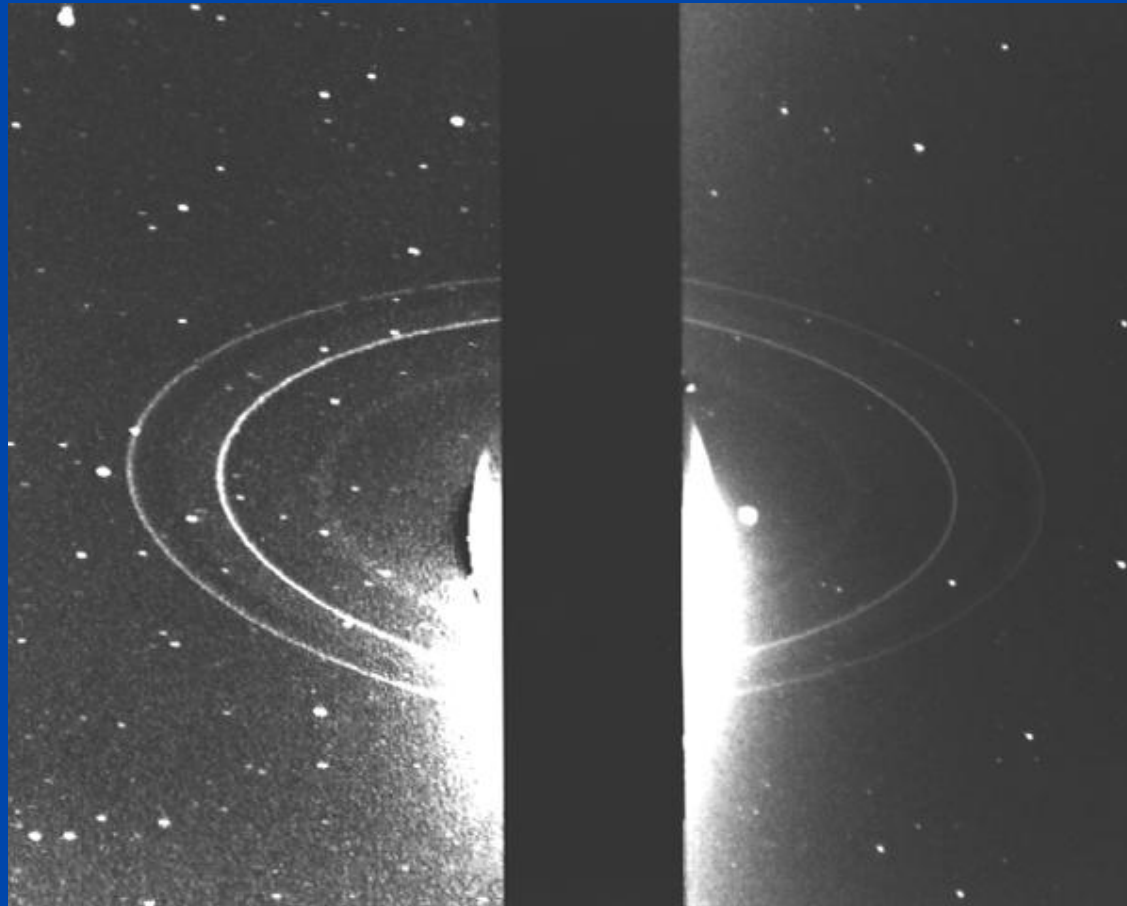


• Credit: L. Sromovsky

Keck adaptive optics

# Rings of Neptune

- Neptune's rings from Voyager





# Theories for how rings formed

- **Theory 1:**
- **A satellite got disrupted when it got too close to Saturn and was ripped apart by strong tidal forces**



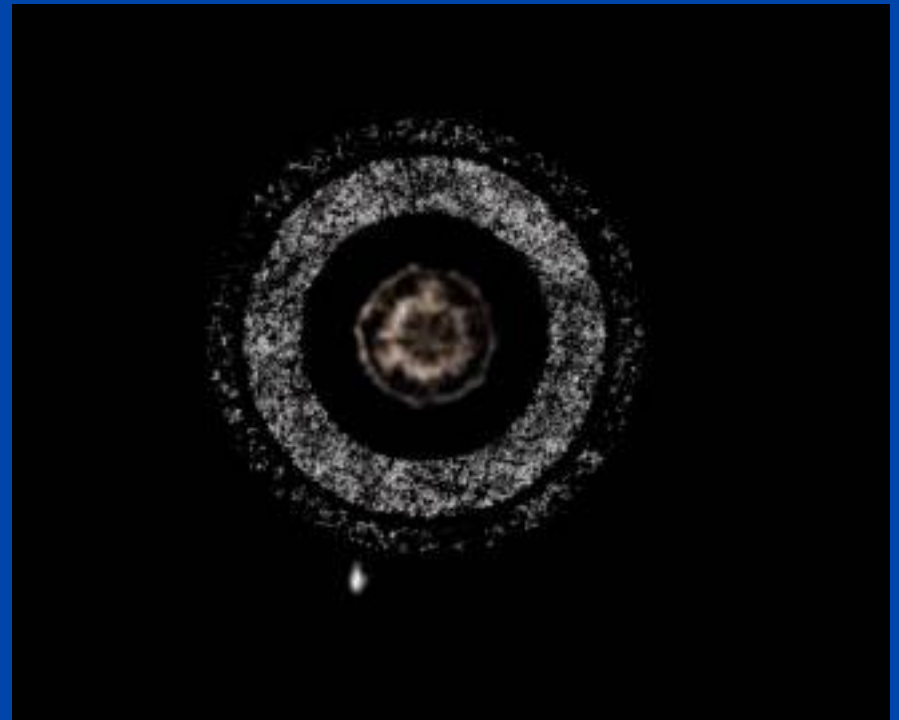
## Ring theory 2

- A moon of Saturn was broken apart in a collision, and the remnants stayed in orbit as rings



## Ring theory 3

- Ring developed during initial formation of Saturnian system
- Gravitational tugs from Saturn and other moons prevented material from gathering together to form a moon



## **But rings aren't left over from planet formation**

- **Rings aren't leftover from planet formation because the particles are too small to have survived this long.**
- **There must be a continuous replacement of tiny particles.**
- **The most likely source is impacts with moons.**

# The Main Points: Rings

- **All four Giant Planets have rings**
  - Chunks of rock and ice, dust in orbit around planet
- **Saturn's rings are the most massive and spectacular**
- **Formation: a moon can't survive intact within the "Roche tidal zone"**
- **Ring systems may be short-lived, always changing**
  - Each chunk in Saturn's rings has a collision with another chunk every few hours!

# Main points: Giant Planet Moons

- *What makes Io so volcanically active?*
  - Tidal heating, caused by the tidal force of Jupiter as Io moves through its elliptical orbit, which in turn is caused by orbital resonances with Europa & Ganymede.
- *Why can active geology occur on much smaller worlds when they are made of ice rather than rock?*
  - Ices soften and melt at much lower temperatures than rock, allowing icy volcanism and tectonics at surprisingly low temperatures.
- *Why do we suspect a subsurface ocean on Europa?*
  - Photos show evidence of water flows on the surface, magnetic field measurements support the presence of a salty ocean, and there is enough tidal heating to melt a thick layer of ice beneath the surface.