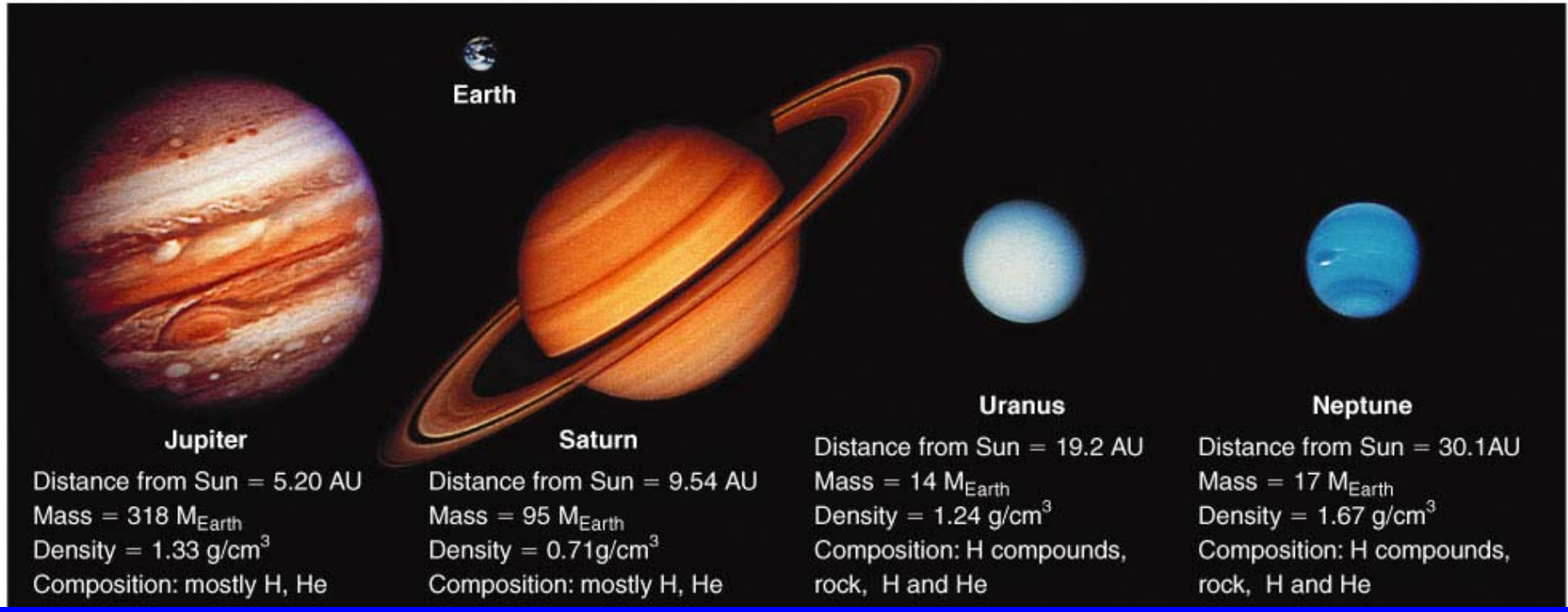
Jovian Planet Systems (Chapter 11)

Based on Chapter 11

- This material will be useful for understanding Chapters 12 and 13 on "Remnants of ice and rock" and "Extrasolar planets"
- Chapters 3, 4, 5, 6, 7, 8, 9, and 10 on "Why does the Earth go around the Sun?", "Momentum, energy, and matter", "Light", "Telescopes", "Our planetary system", "Planetary geology", and "Planetary atmospheres" will be useful for understanding this chapter.

Goals for Learning

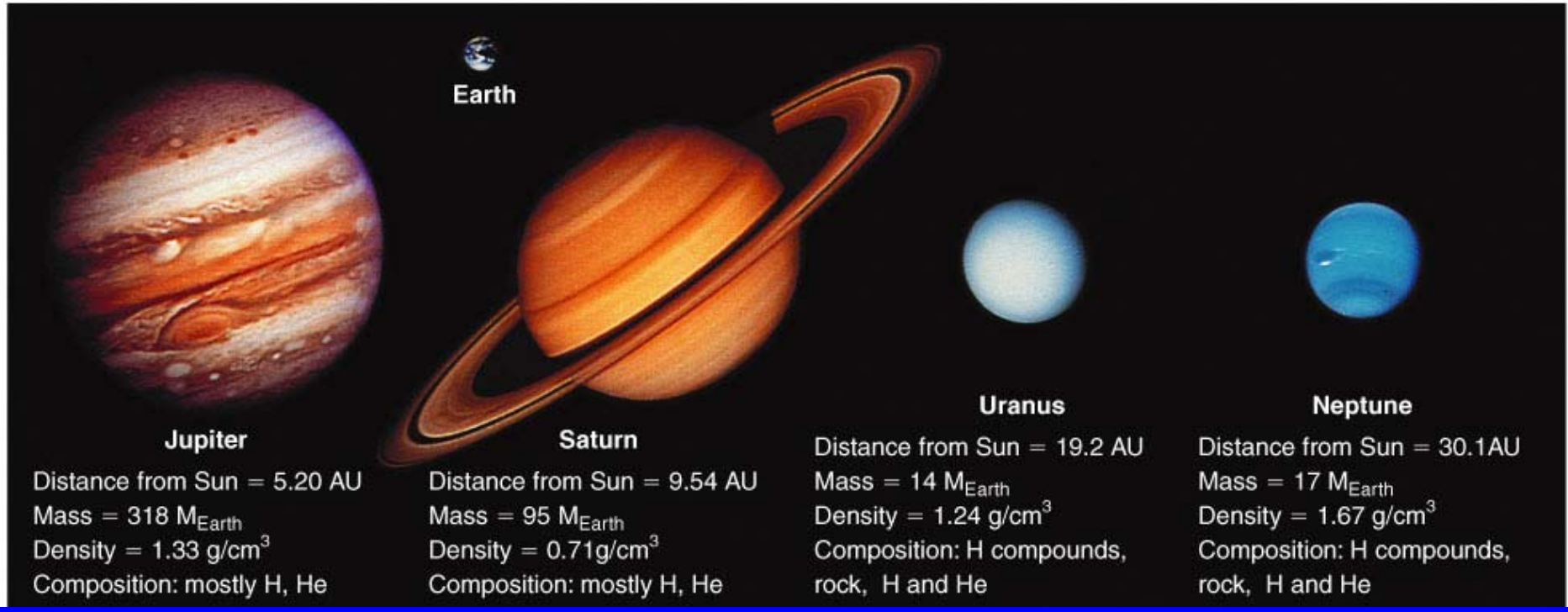
- What are the interiors of jovian planets like?
- What is the weather like on jovian planets?
- What are the moons of jovian planets like?
- How where those moons formed?
- Why do jovian planets have rings?



Jupiter and Saturn are mostly H, He with few percent of ices/rock/metal

Uranus and Neptune are mostly H_2O, CH_4, NH_3 (compounds of hydrogen, ices) with some hydrogen/helium and few percent of rock/metals

<u>Why are J/S different from U/N?</u>

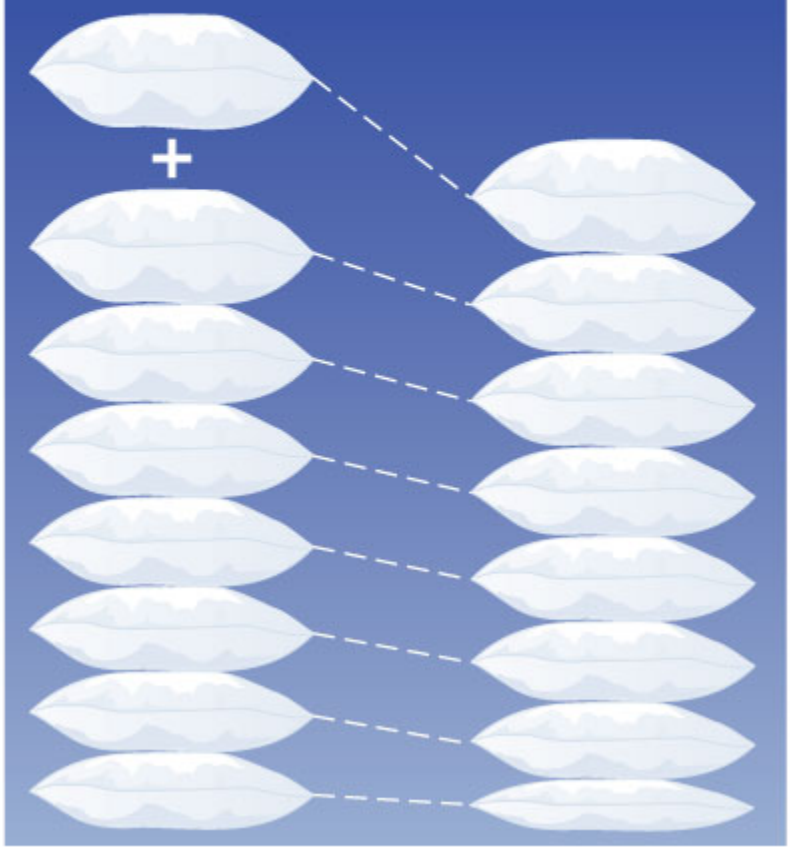


Jupiter: 318 M_{Earth}, 1.33 g/cm^3 Saturn: 95 M_{Earth}, 0.71 g/cm^3

Jupiter is 3x heavier than Saturn. Why isn't it 3x larger?
Same chemical compositions, why are the densities so different?

Adding a pillow increases the height, but not by the full width of one pillow

Pillows are compressible (squishy)



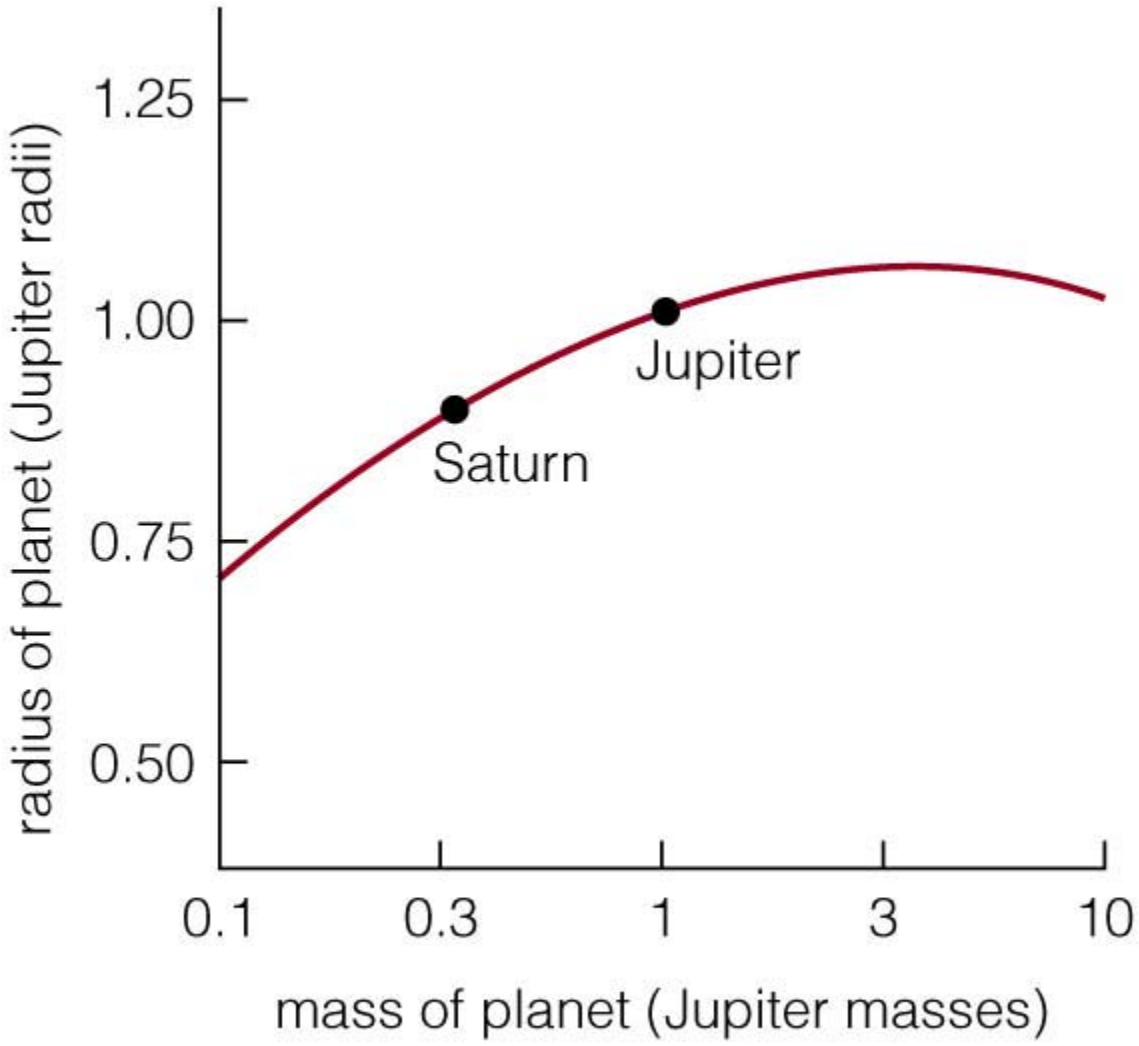
Jupiter: 318 MEarth, 1.33 g/cm^3
Saturn: 95 MEarth, 0.71 g/cm^3

Jupiter is heavier than Saturn
Jupiter is more dense than Saturn

Hydrogen and helium are compressible

If you add more and more hydrogen to Jupiter, it will keep getting heavier

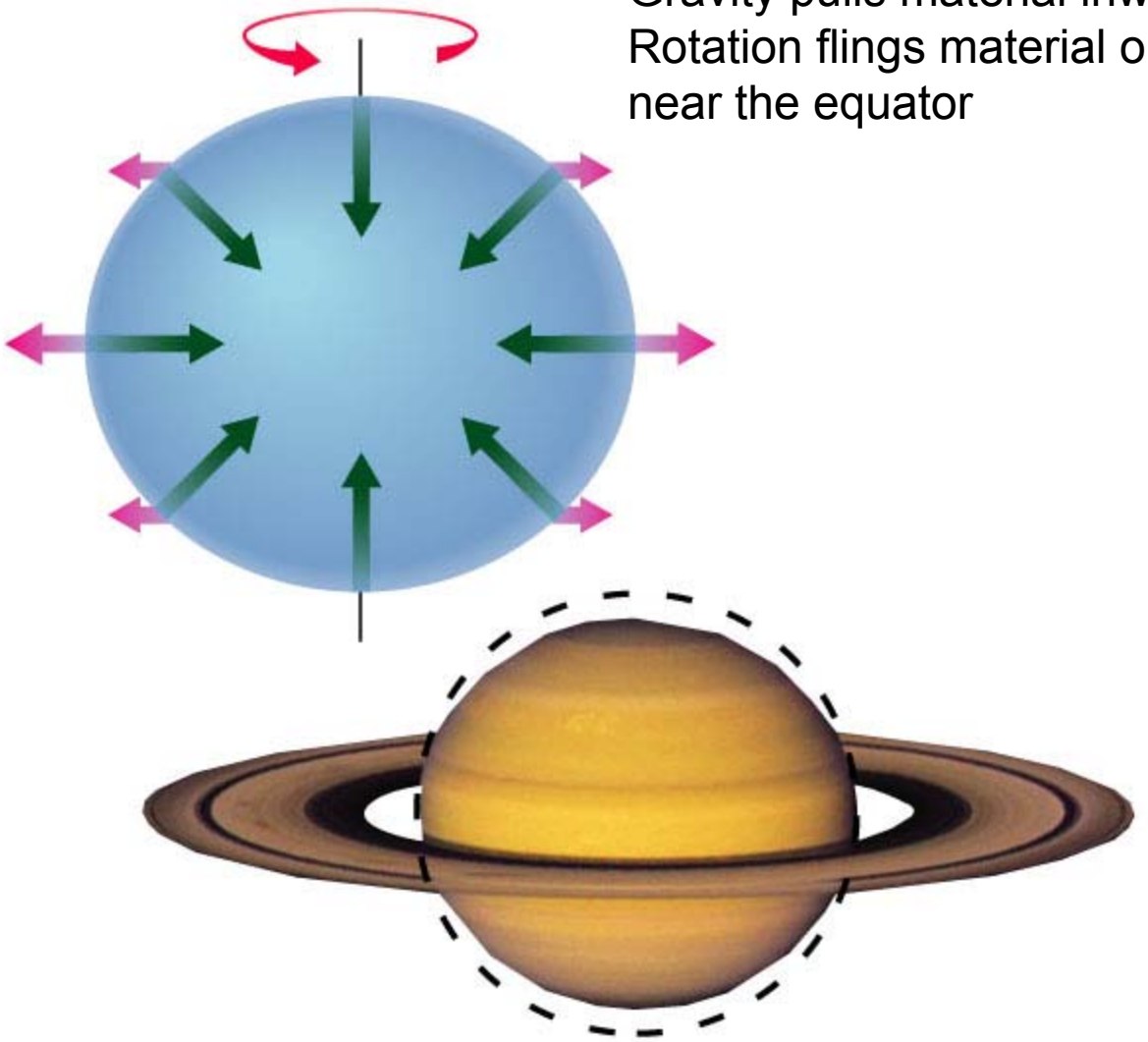
Will its density keep increasing?
Will its radius keep increasing?



If you add a little more mass to Jupiter, then its radius will still increase

If you add a lot more mass to Jupiter, its radius will actually get smaller

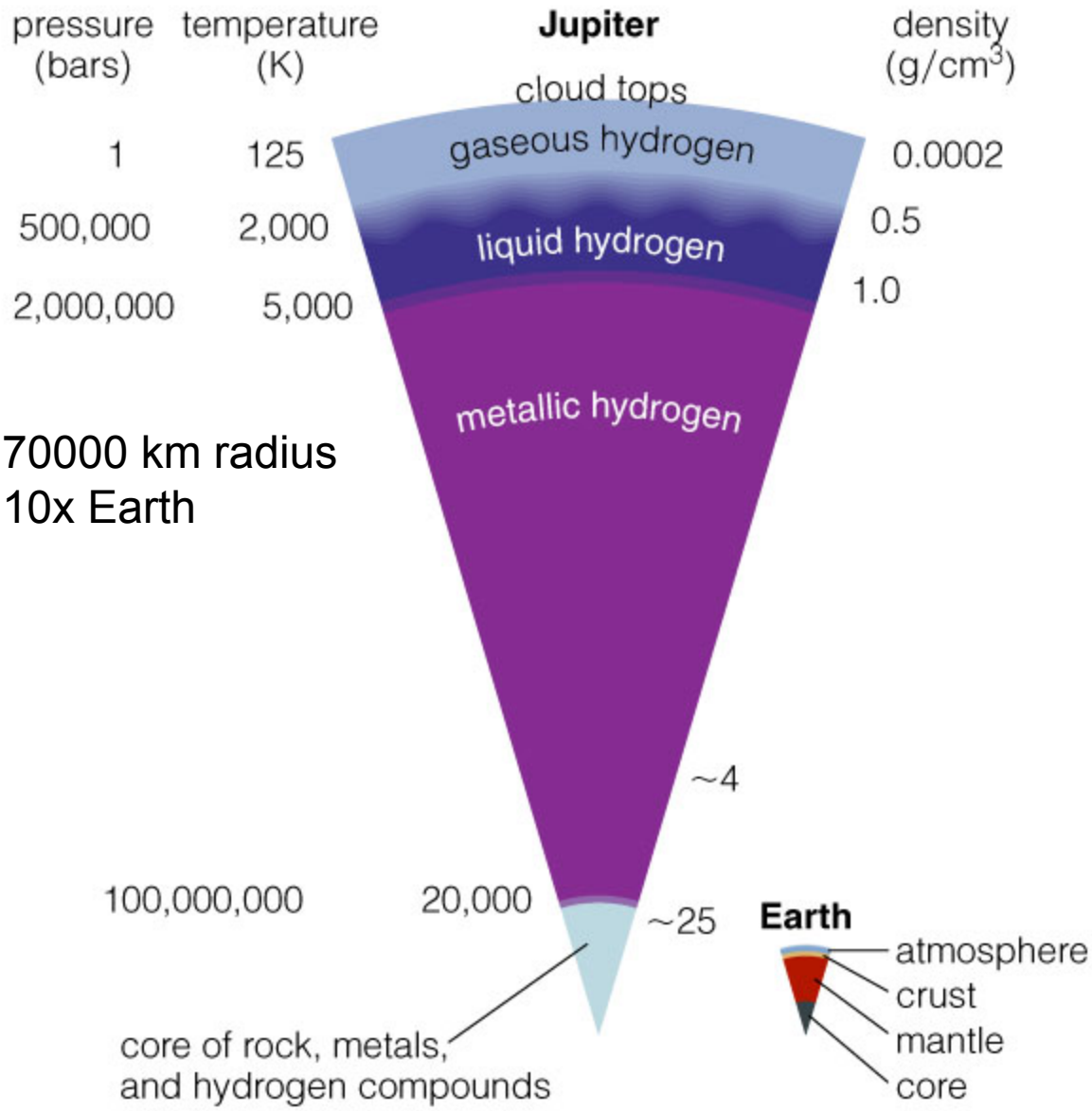
Reason:
How materials, such as hydrogen, respond to changes in pressure at VERY high pressures



Rapid rotation and relatively weak gravity make Saturn 10% wider at equator than poles

This equatorial bulge keeps moons and rings in the equatorial plane

The shapes of rocky terrestrial planets like Earth and Mars are also affected by this process – despite having surfaces of solid rock



70000 km radius
10x Earth

All mixed together, not separated into rocks and metals and ices

Layered structure, like terrestrial planets

Chemical composition doesn't change much with depth until the core

Layers are changes of phase
Gas -> Liquid -> "Metallic"

Metallic hydrogen is a fluid, not really a solid. Liquid is at such high pressure that electrons can move freely.
It conducts electricity easily.
Magnetic field generated here.

Core = 10 Earth masses, but same size as Earth
Very high density

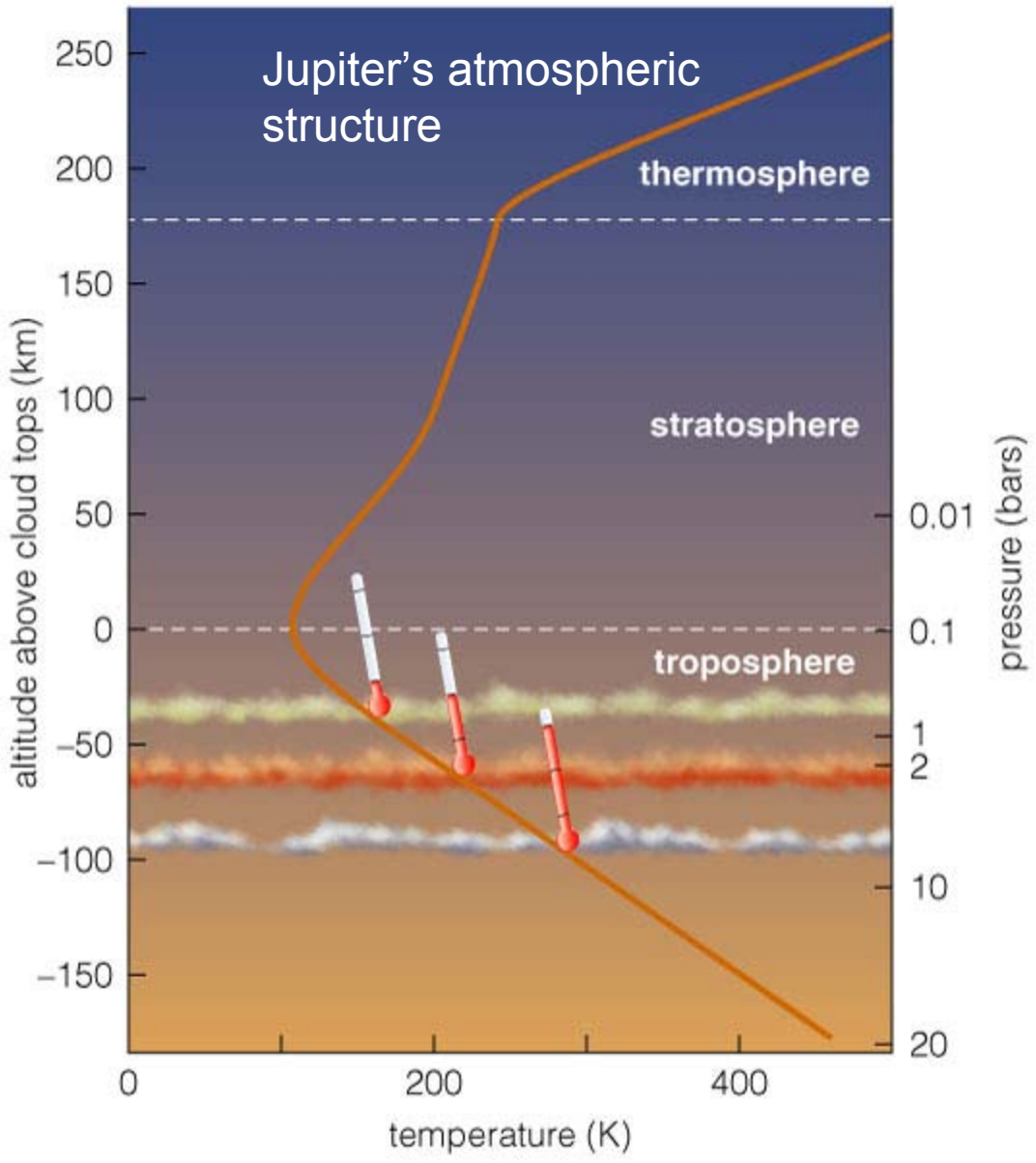
Jupiter is not a giant gasbag

Other Interiors

- Saturn = same as Jupiter
- Uranus = same as Neptune

- U/N: Hydrogen gas
  Water/methane/ammonia mantle
  Rock/metal core

- Is mantle liquid or solid?



Jupiter has three cloud layers

Highest altitude/lowest temperature cloud is ammonia (NH_3)

Intermediate cloud is a compound of ammonia and water

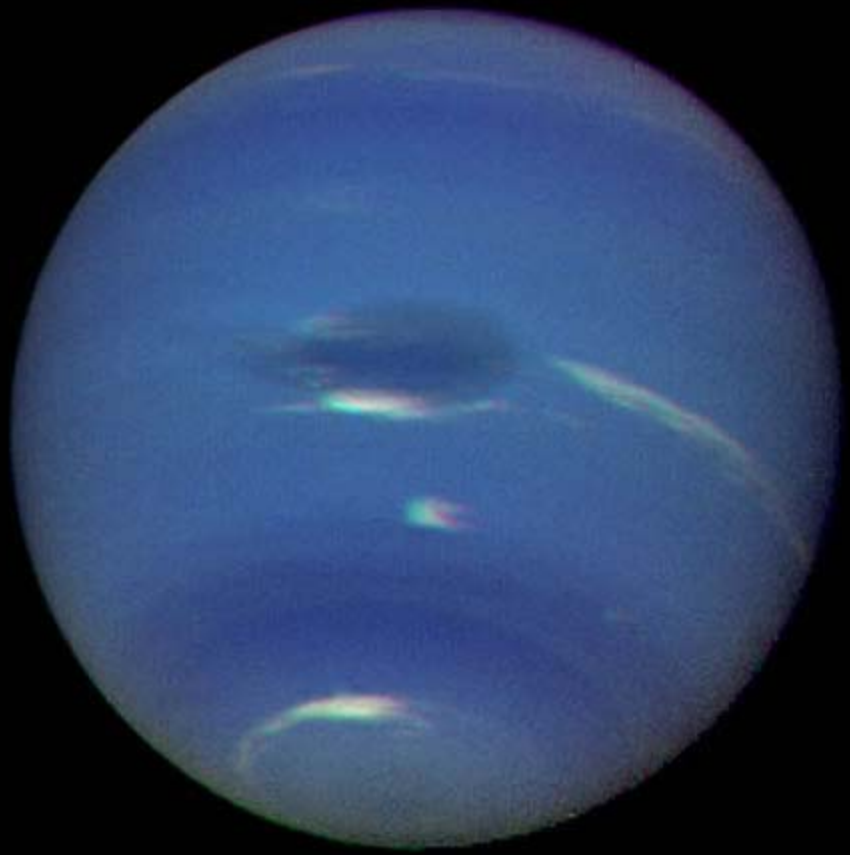
Lowest altitude/highest temperature cloud is water (H_2O)

Other, less common, chemicals are responsible for the colours

Similar clouds on Saturn, Uranus, and Neptune

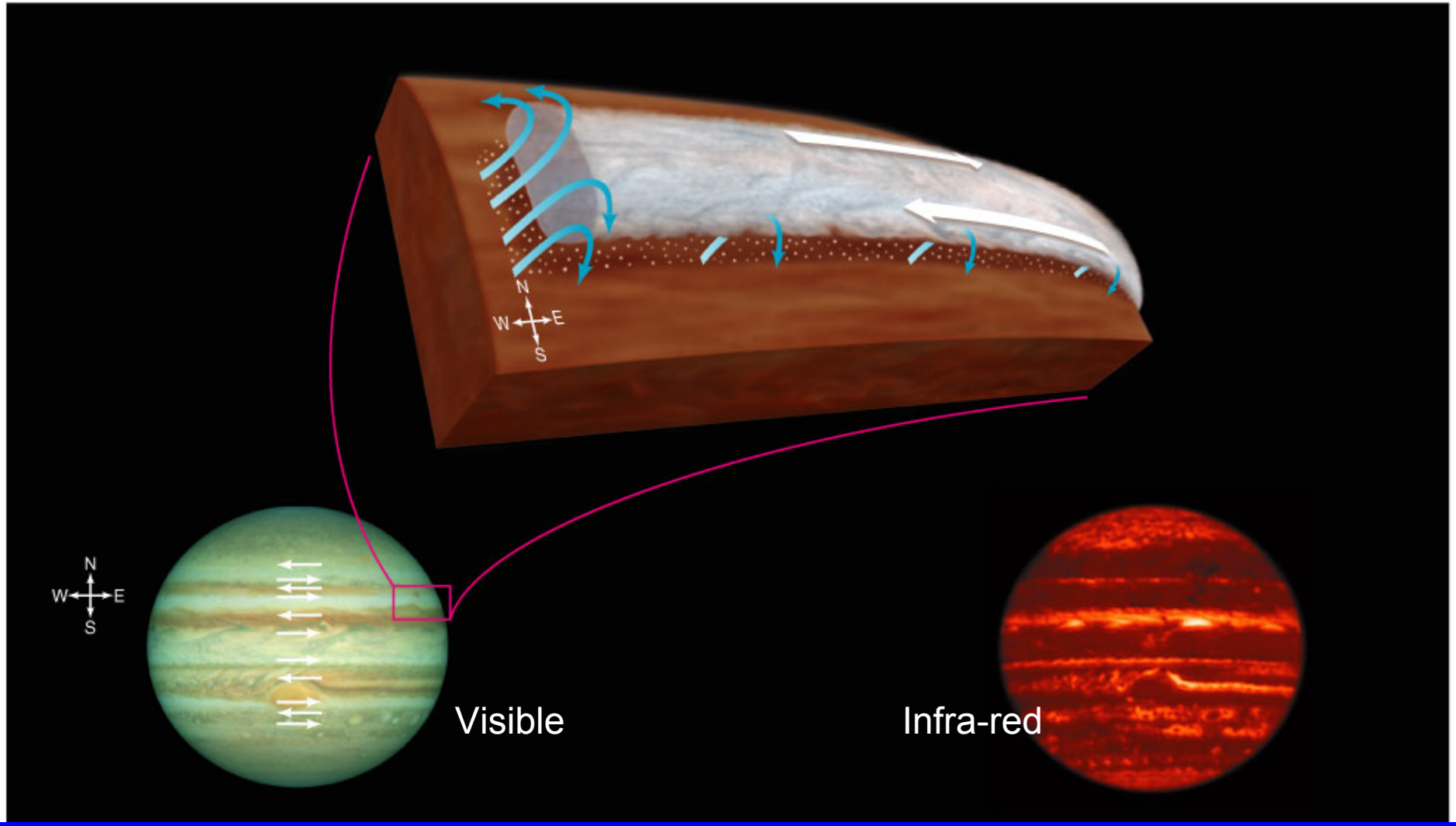
Plus methane (CH_4) on Uranus and Neptune only – why?

Neptune

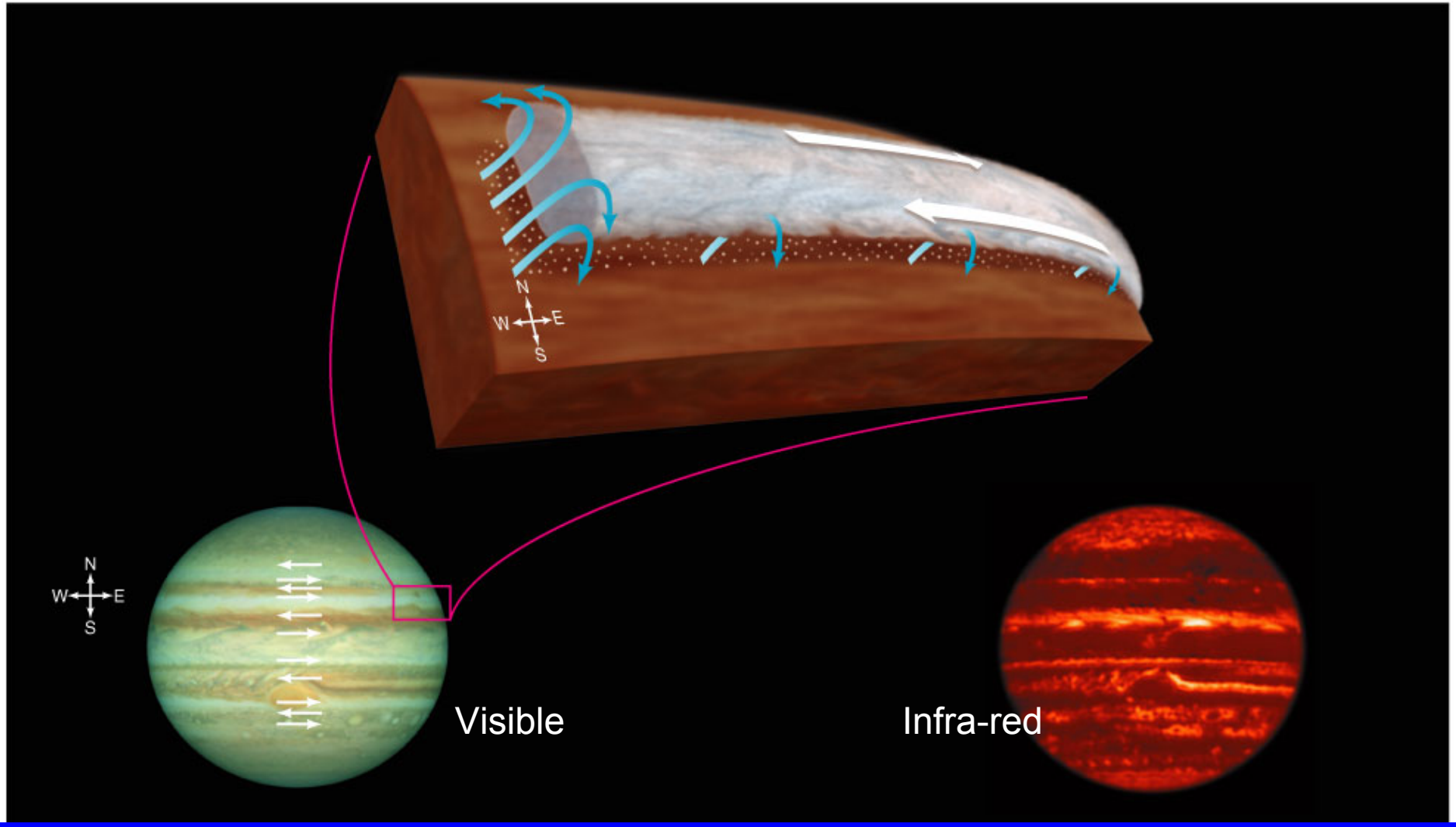


Global Winds on Jupiter

- One convection cell per hemisphere on a non-rotating planet, three per hemisphere on Earth, many on Jupiter – why?
- This leads to alternating bands of rising and falling air
- On Earth, rising air at equator makes lots of clouds and rain forests, falling air at 30N makes few clouds and deserts
- What do you expect to happen on Jupiter?



Brown middle cloud layer covers the whole planet
White top layer of ammonia clouds only form in rising air
Ammonia snow falls out of clouds, as air moves north or south, then descends
Descending ammonia-poor air doesn't have enough ammonia to form clouds

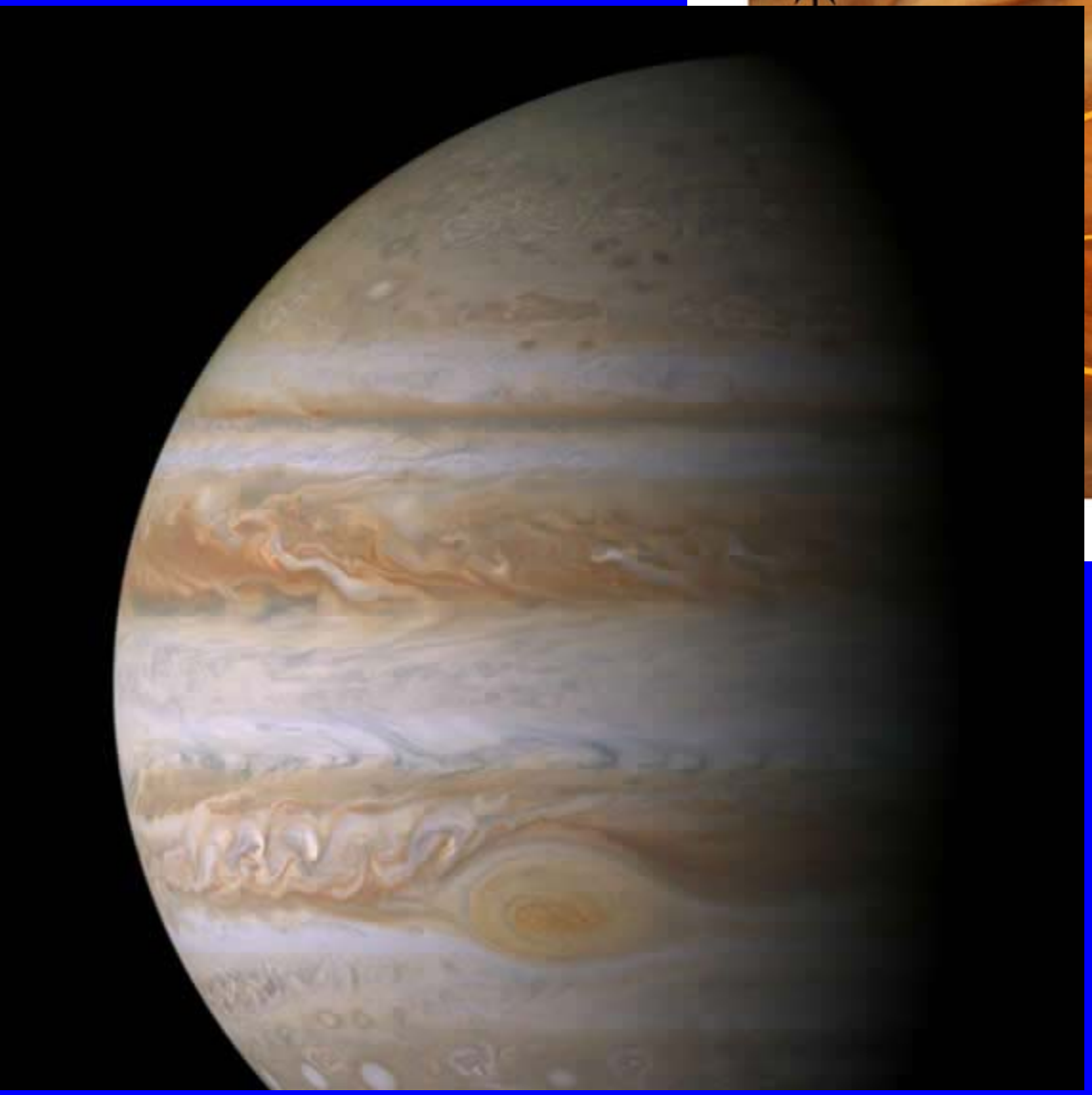


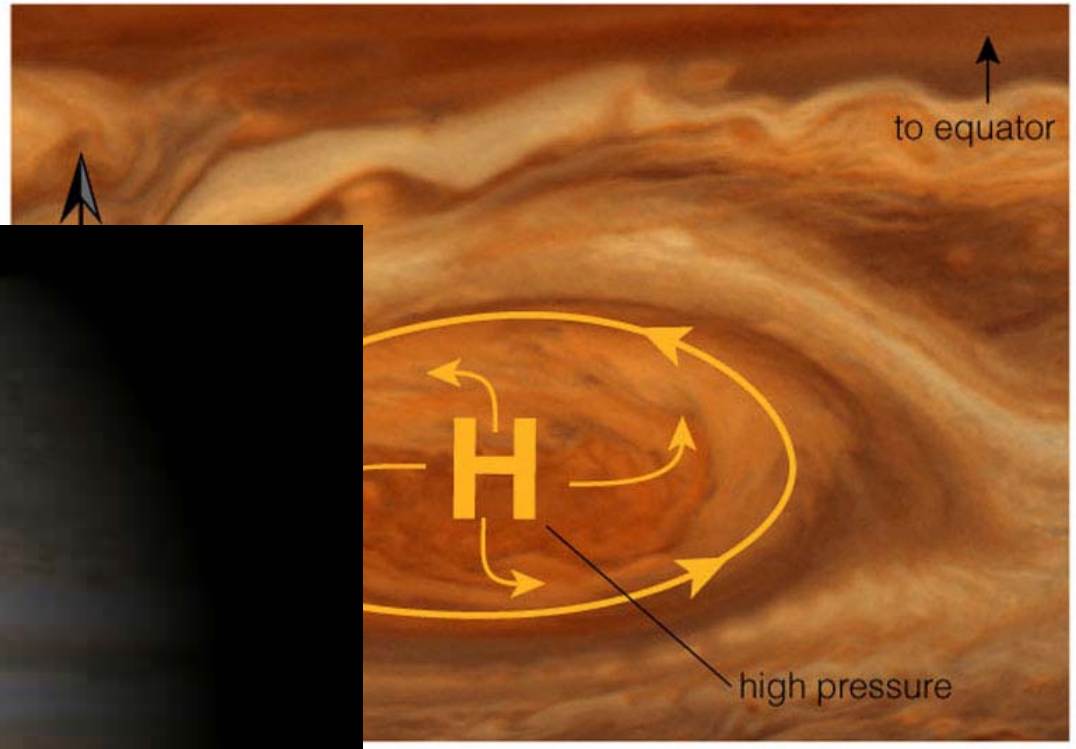
Brown middle cloud layer is warmer than white, high altitude ammonia cloud layer
Compare visible and infra-red images

Very fast winds, hundreds of miles per hour all the time

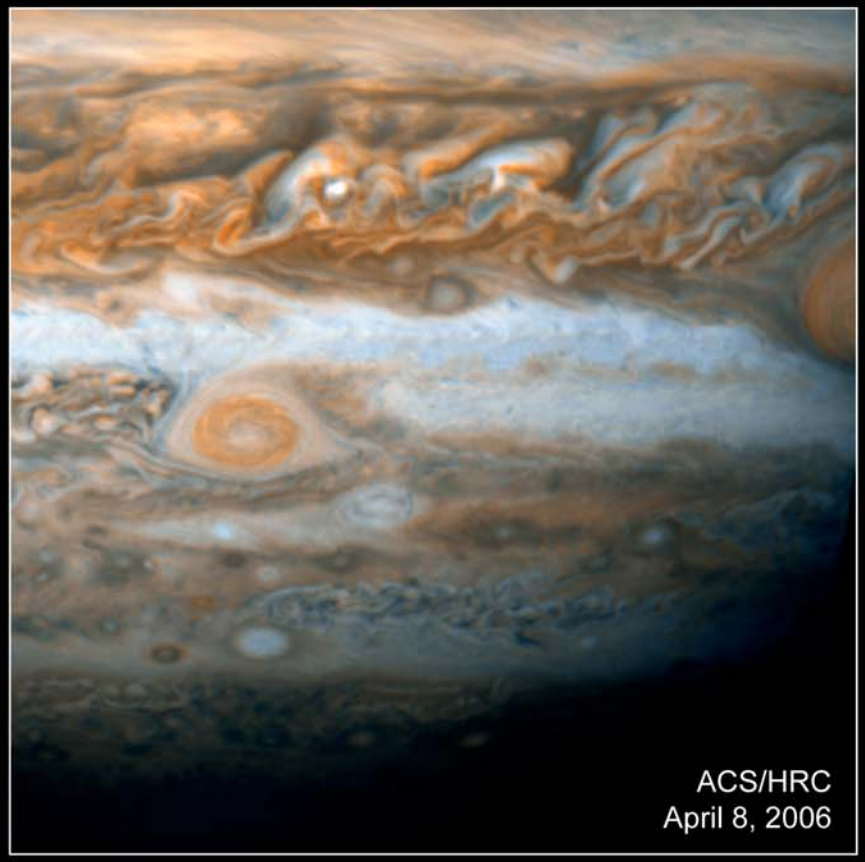
Great Red Spot

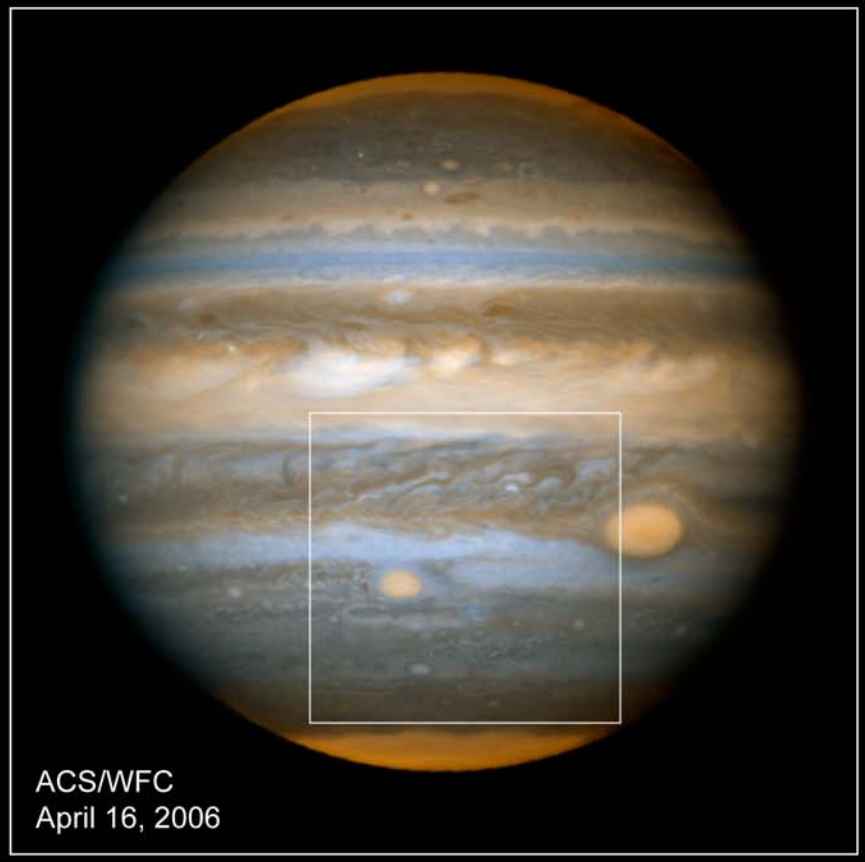
An old, big storm





Textbooks say “Jupiter has only one Great Red Spot”





Jupiter's Red Spots

Hubble Space Telescope • Advanced Camera for Surveys

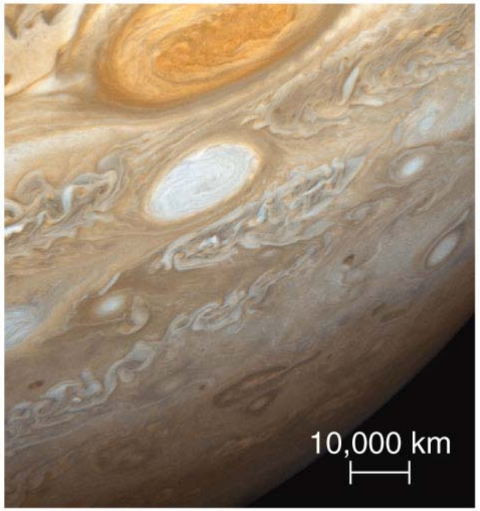
NASA, ESA, A. Simon-Miller (NASA/GSFC), I. de Pater and M. Wong (University of California, Berkeley)

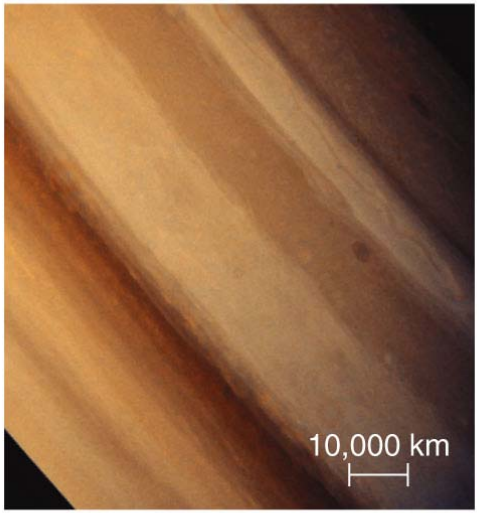
STScI-PRC06-19

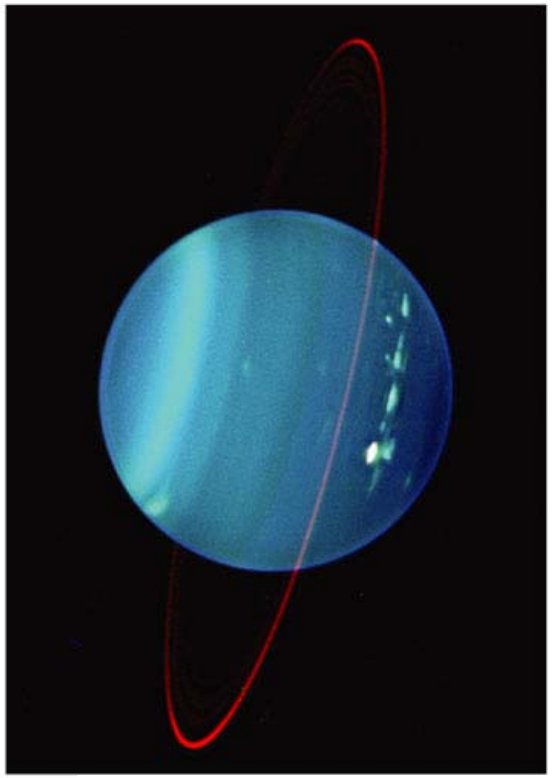
Weather on other jovian planets

- What causes bands on Jupiter? Should we see them on the other jovian planets?

- Which of the jovian planets have seasons? What information do you need to answer?



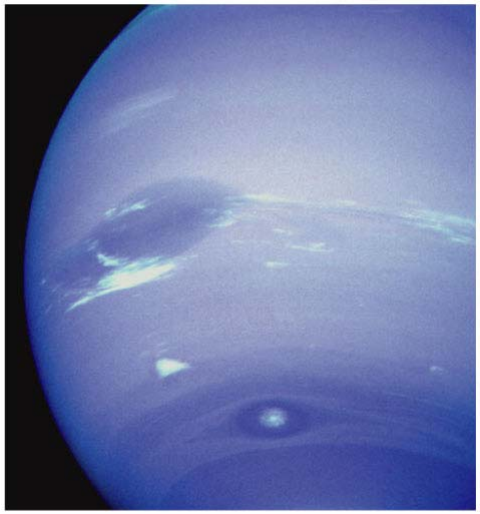


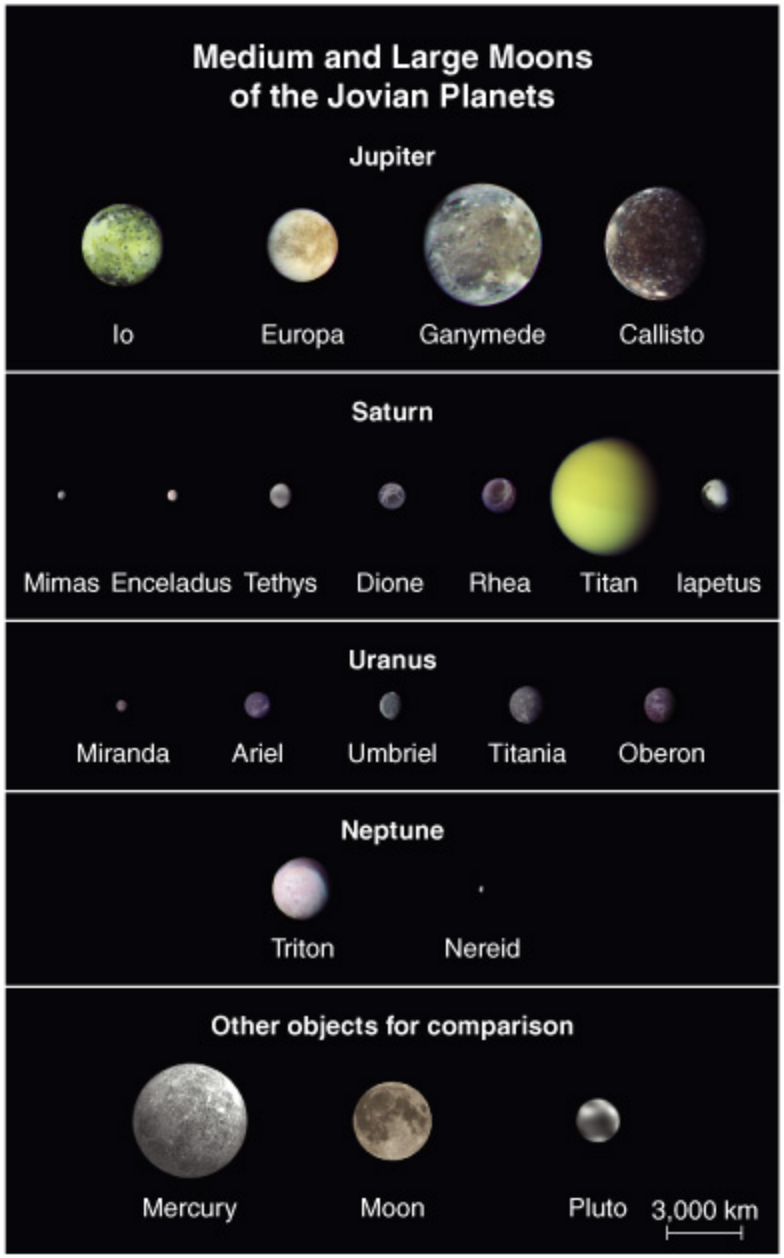


Jupiter, Saturn, Uranus, and Neptune all have dramatic weather patterns

Jupiter, Saturn, and Neptune all have banding
Saturn and Neptune don't show seasonal changes, despite 20^{o} axial tilt – internal heat?
Large storm, Great Dark Spot, seen on Neptune, but vanished 6 years later

Uranus had no storms/banding 20 years ago, but does now. Strong seasons likely due to large axial tilt and lack of any internal heat.





MOONS

Lots of moons, lots of diversity

Small: <300 km diameter, no geological activity

Medium: 300-1500 km diameter, past geological activity

Large: >1500 km diameter, present geological activity

Made of 50% ice, 50% rock, unlike objects in the inner solar system

Orbits and Rotation

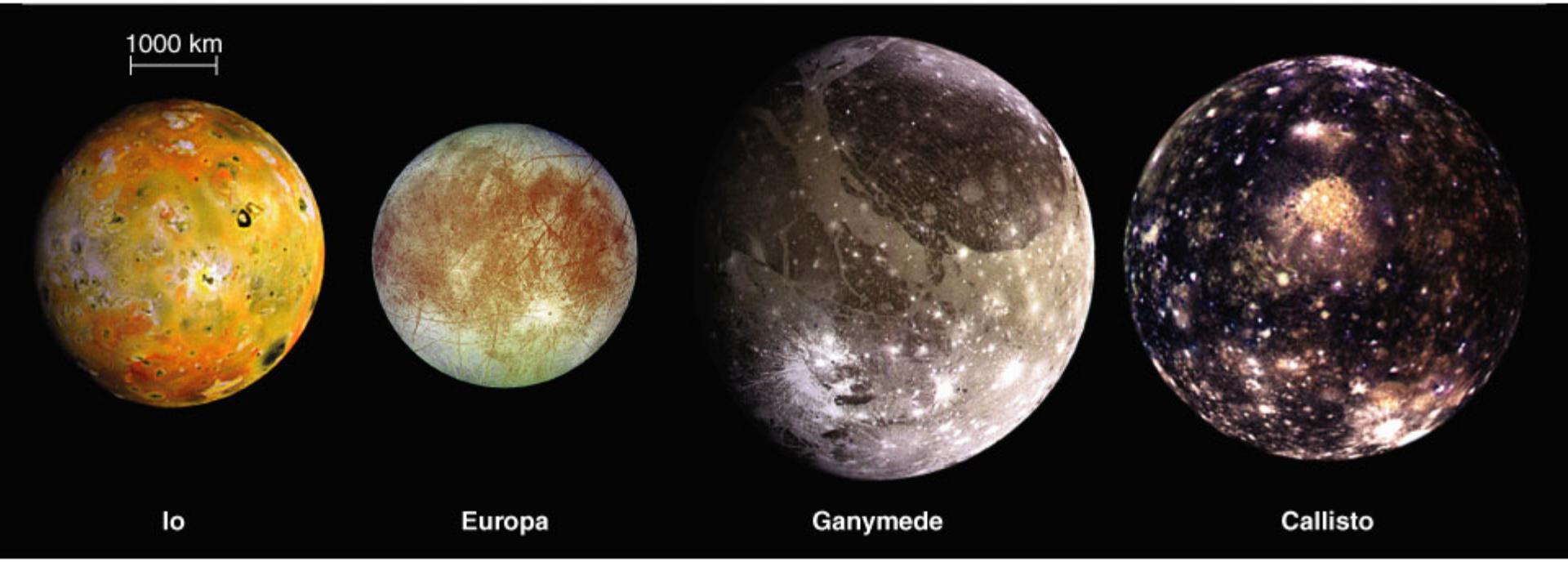
- Most medium and large moons
  - Circular orbits in planet's equatorial plane
  - Orbit in same direction as planet's rotation
  - So formed by accretion in mini-nebula around planet, not captured later
  - Rotate once per orbit, like Earth's moon, due to tidal forces from planet
- Small moons
  - Irregular orbits, not always circular, not always in equatorial plane, not always in expected direction
  - Mostly captured objects

Five smaller moons of Saturn

Moons with diameters less than ~300-400 km are not spherical

Their gravitational forces are not strong enough to deform their rigid ice and make it flow “downhill”

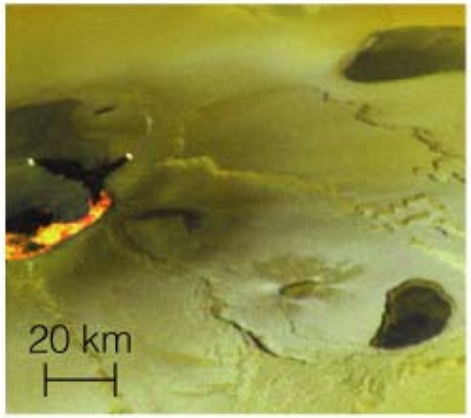
Where do the names come from?
Each planet has a theme for the names of its moons.
Jupiter: Lovers of Jupiter and related Greek/Roman mythological names
Saturn: Titans, giants conquered by Jupiter in Roman mythology
Uranus: Characters from Shakespeare
Neptune: Greek/Roman mythological characters related to the sea



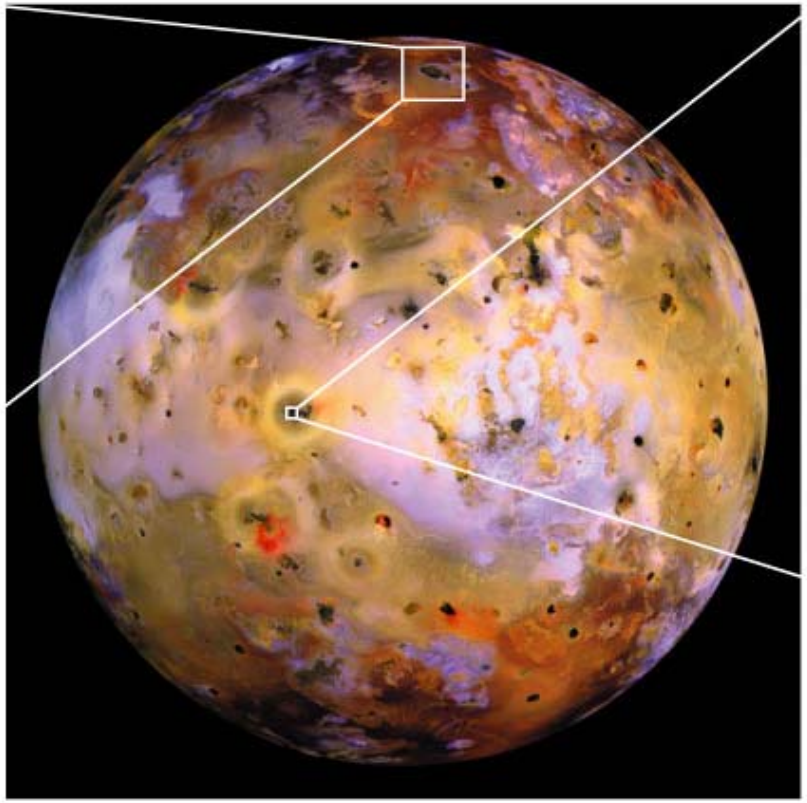
The four Galilean satellites of Jupiter. Unresolved points of light until 1980.

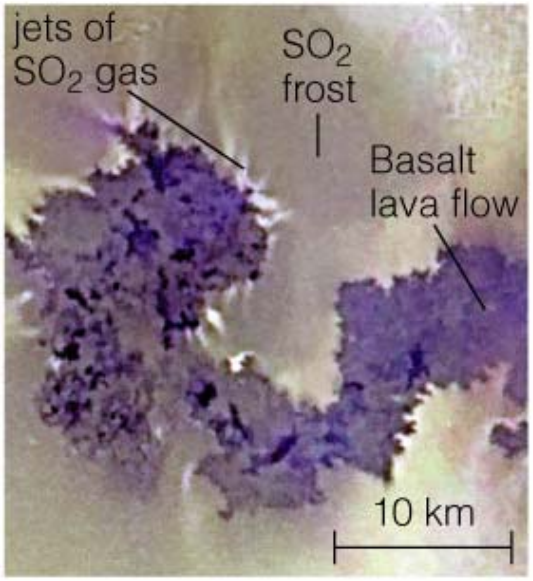
Io: Volcanoes, very active
Europa: Ice crust above a liquid water ocean, active surface
Ganymede: Some old regions, some young regions, also an internal ocean
Callisto: Heavily cratered iceball

Composition trend
Io: Mostly rock, some ice
Callisto: Mostly ice, some rock



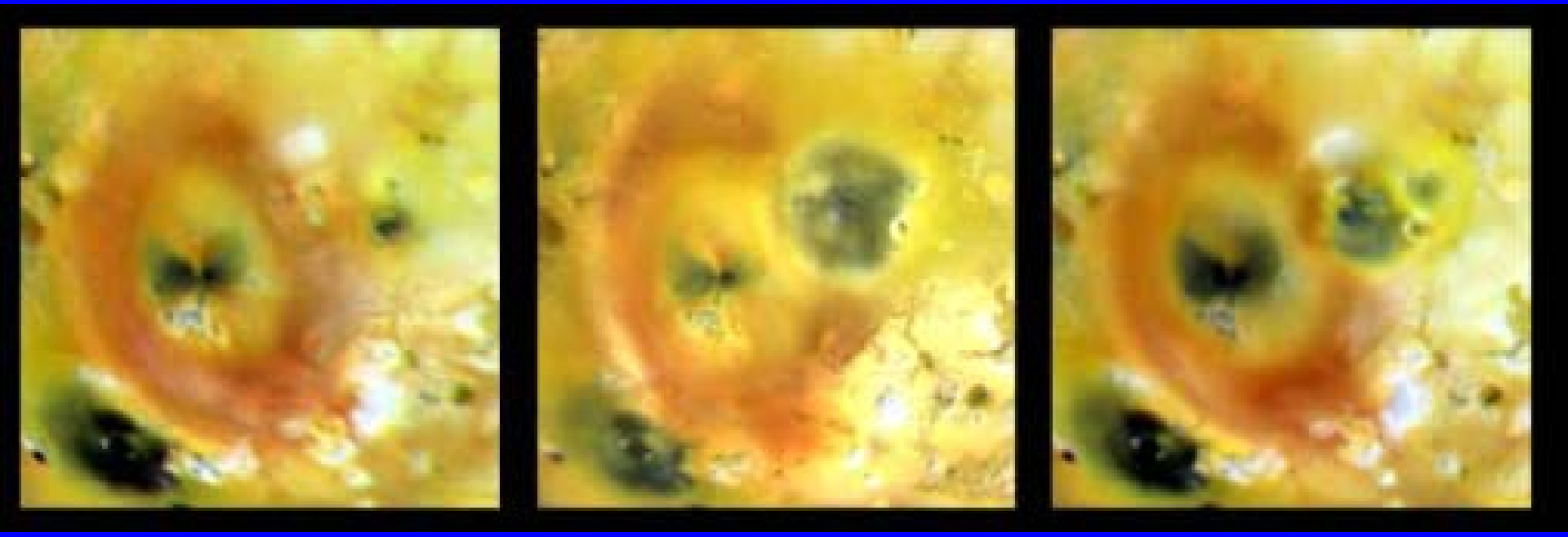
Io: Only other volcanically active world in the solar system





Lava is accompanied by sulphur and sulphur dioxide gas
Condensed sulphur = red, orange.
Condensed sulphur dioxide = white

All this gas gives Io a thin atmosphere



April 1997

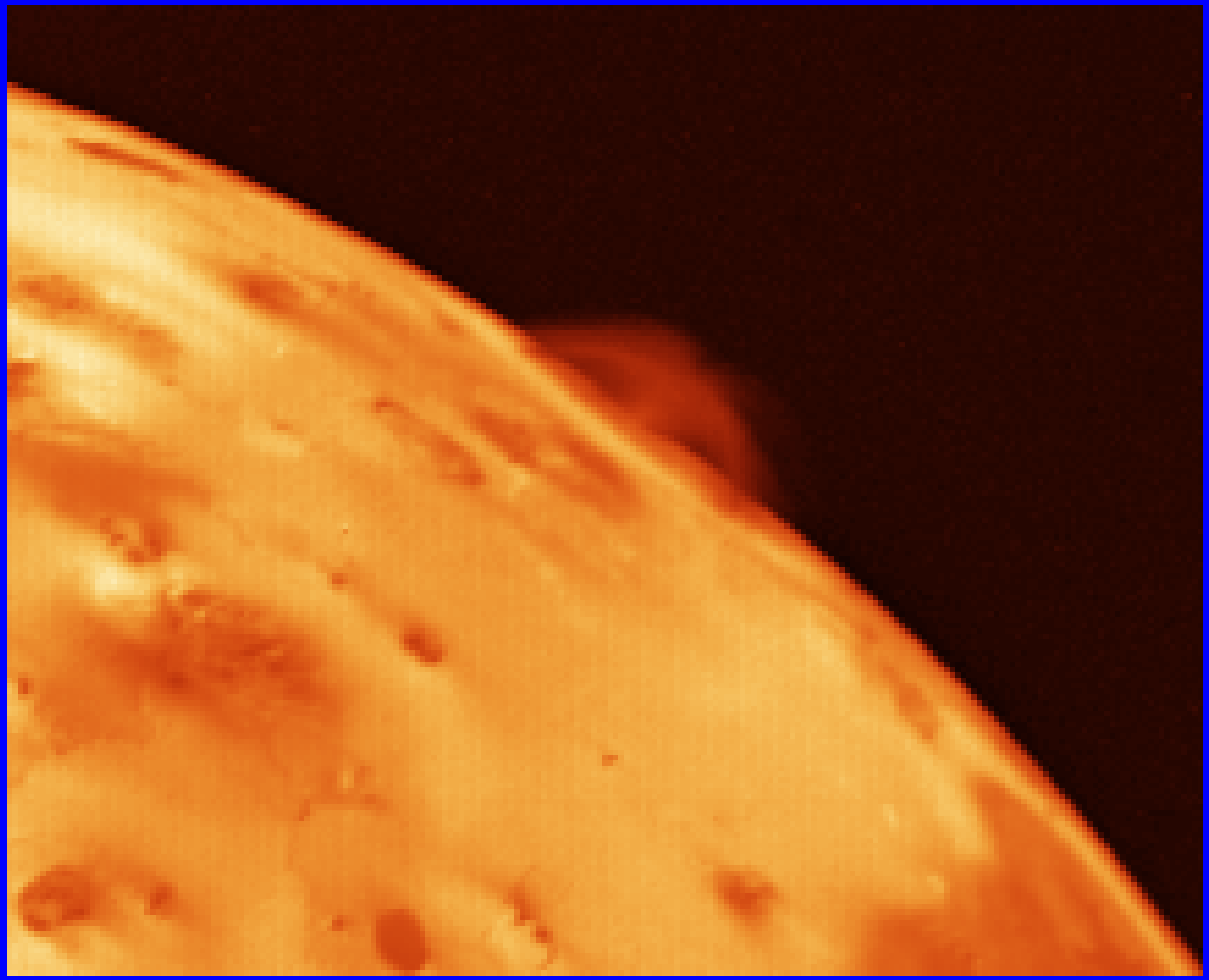
Complete red ring

September 1997

Large black patch appeared

July 1999

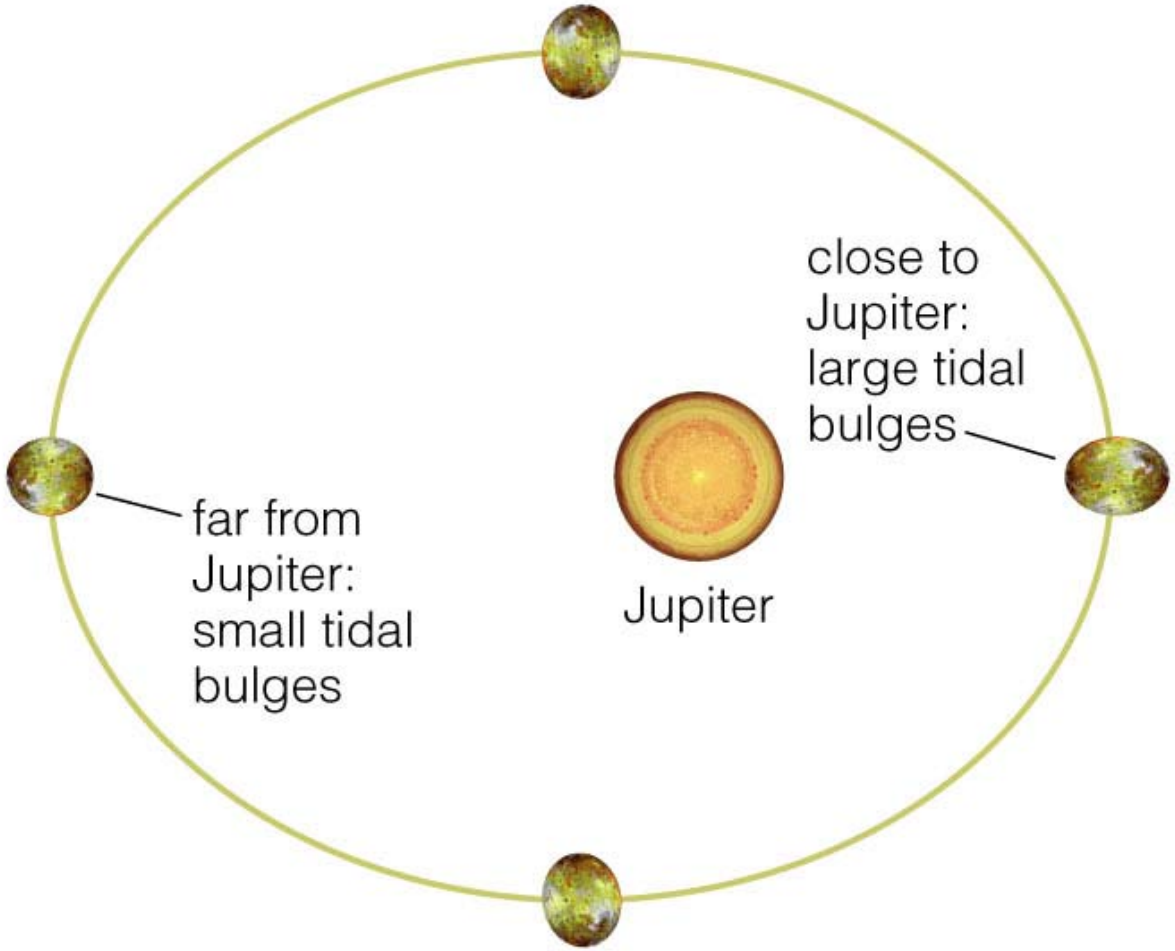
Red material starts to cover up black patch



Unusual Io

- Active volcanism needs interior heat
- What sources of interior heat have we discussed so far?
- Which of them might be heating Io?

Answer – None of them work



Tides

Moon causes tides on Earth oceans and rocks

Earth causes tides in the Moon as well

Jupiter causes tides on Io

Io's orbit is elliptical

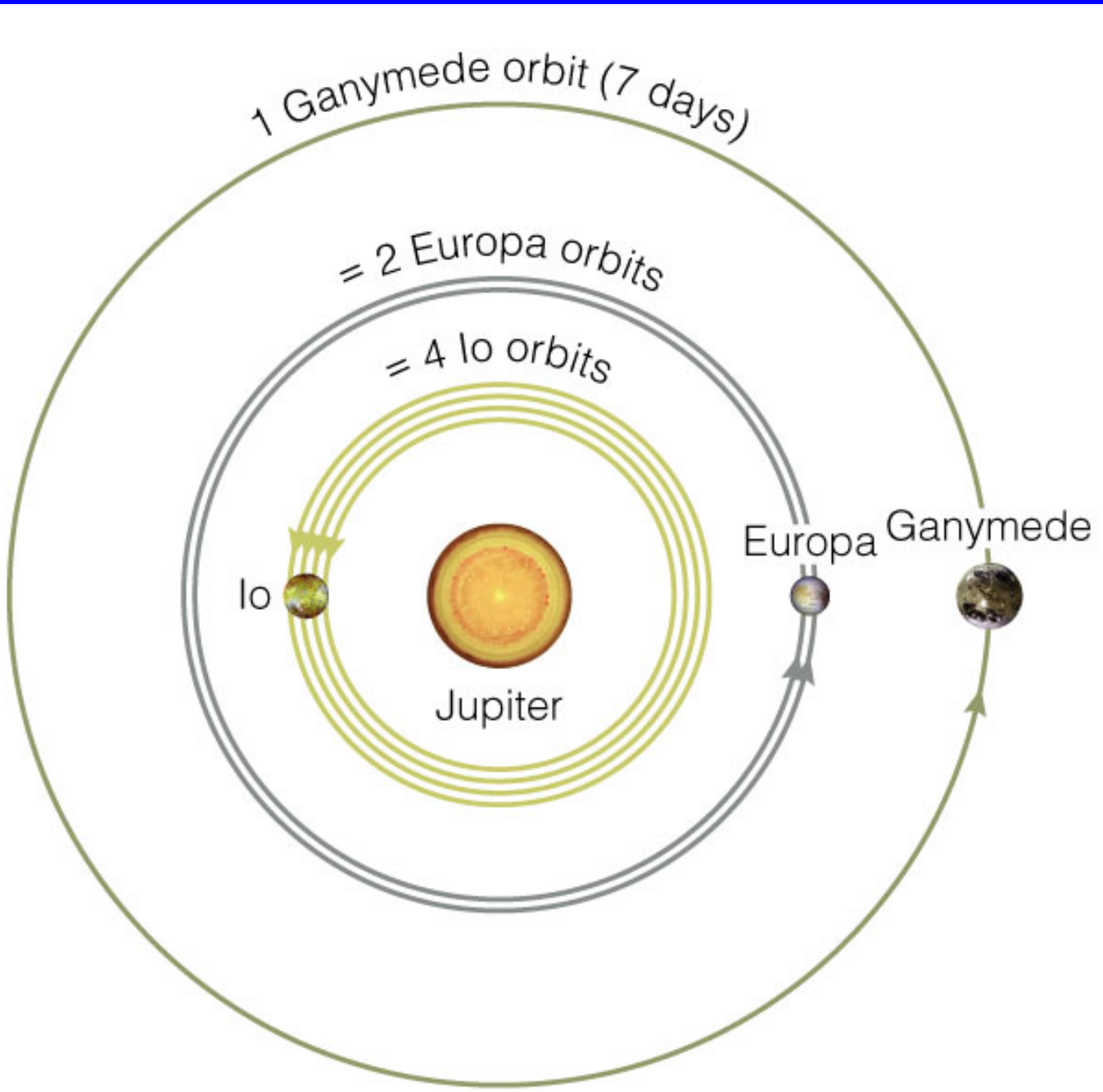
Why doesn't Io's orbit become circular?

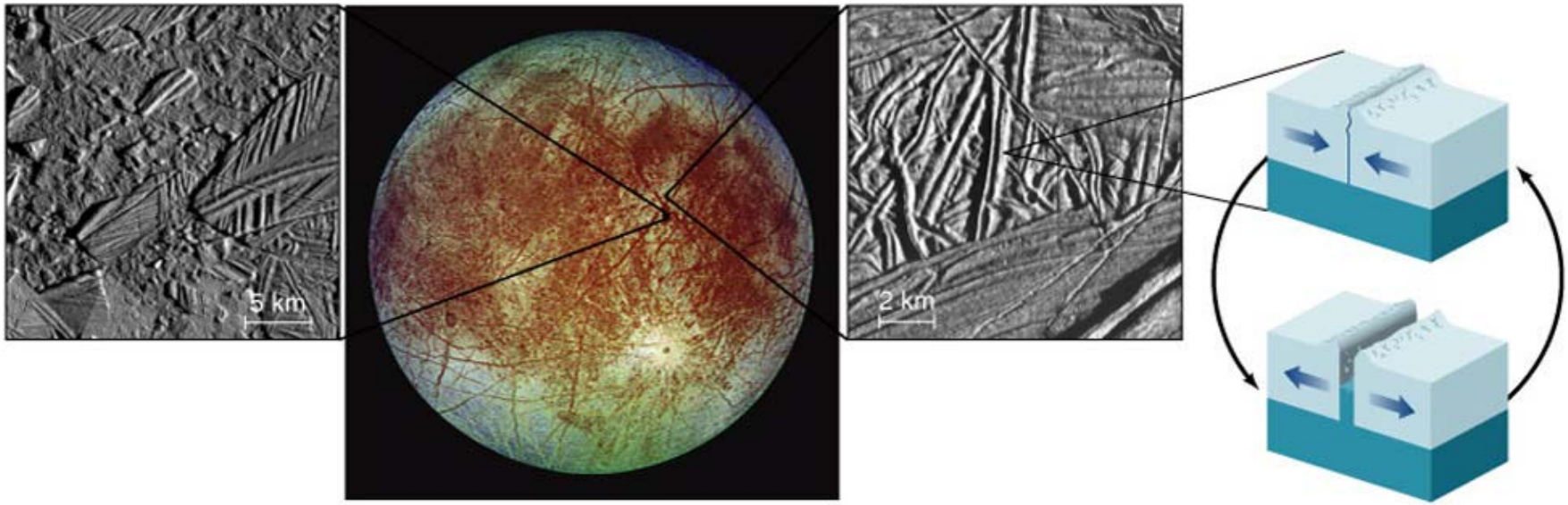
Europa and Ganymede stop it

Io gets pulled outwards each time it comes close to Europa

This always happens when Io is furthest from Jupiter ("Aphelion" …)

Keeps Io's orbit elliptical





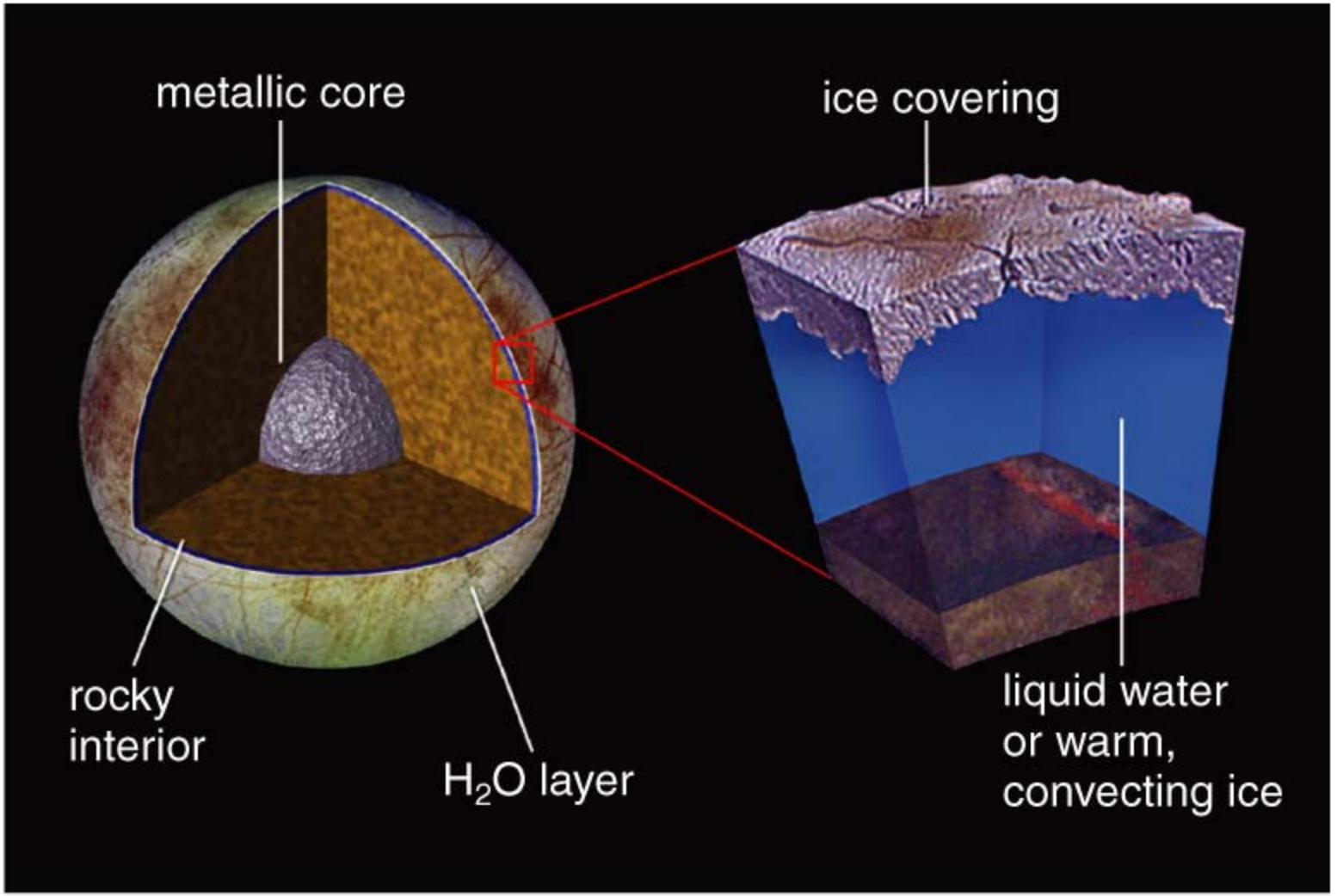
Europa

Surface is only tens of millions of years old (very few large craters)

Some regions look like blocks of ice trapped when liquid water froze solid

Double-ridges may have formed as tidal flexing opens and closes crack in ice crust

Lots of geological evidence for sub-surface water beneath 10 km (approx) of ice
Geology alone doesn't exclude possibility of warm, deformable ice at depth



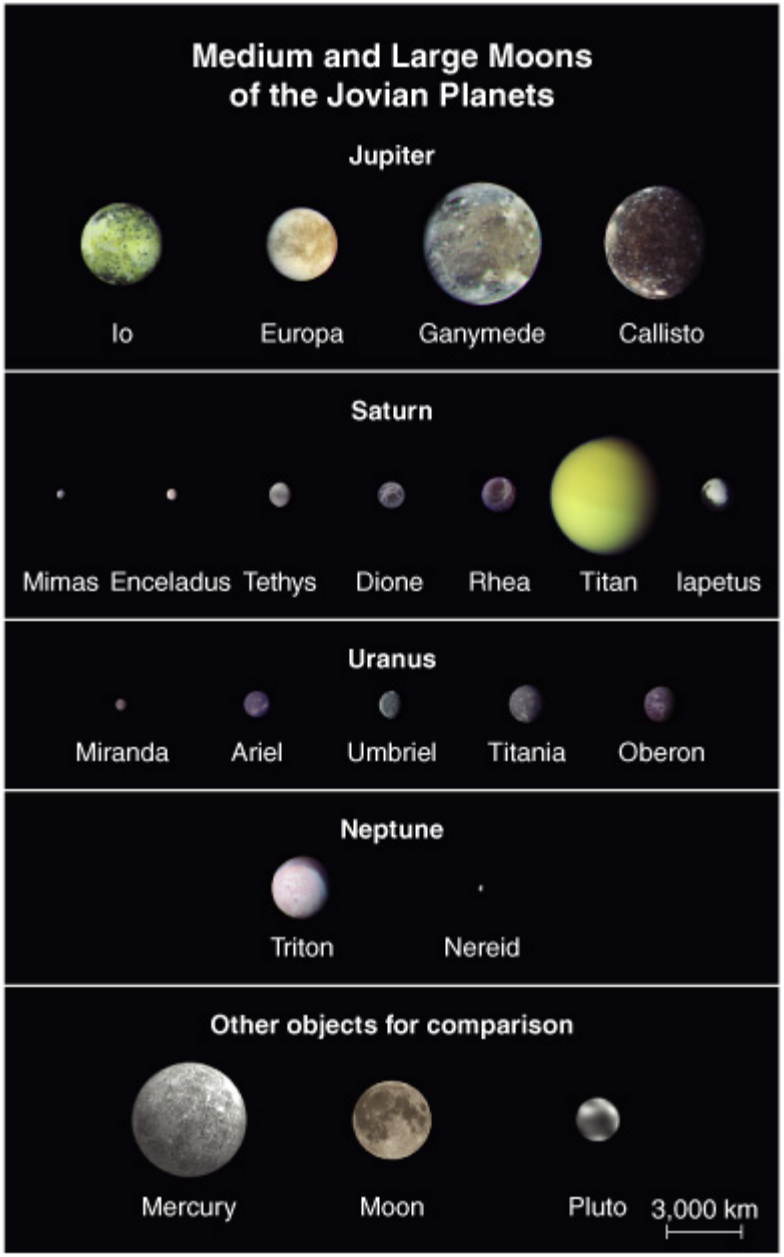
Europa has a weak magnetic field that is “induced” by Jupiter’s magnetic field

Salty subsurface ocean can conduct electricity, convecting ice cannot

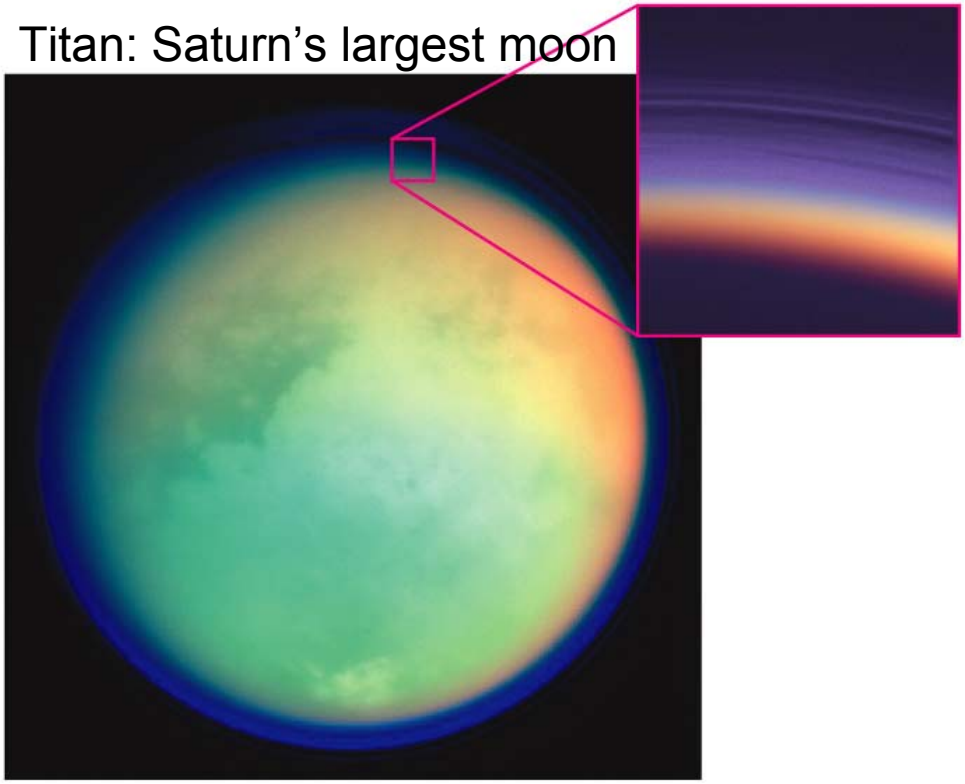
This discovery is about 10 years old

Ganymede and Callisto

- Not as interesting as Io or Europa



Titan: Saturn's largest moon

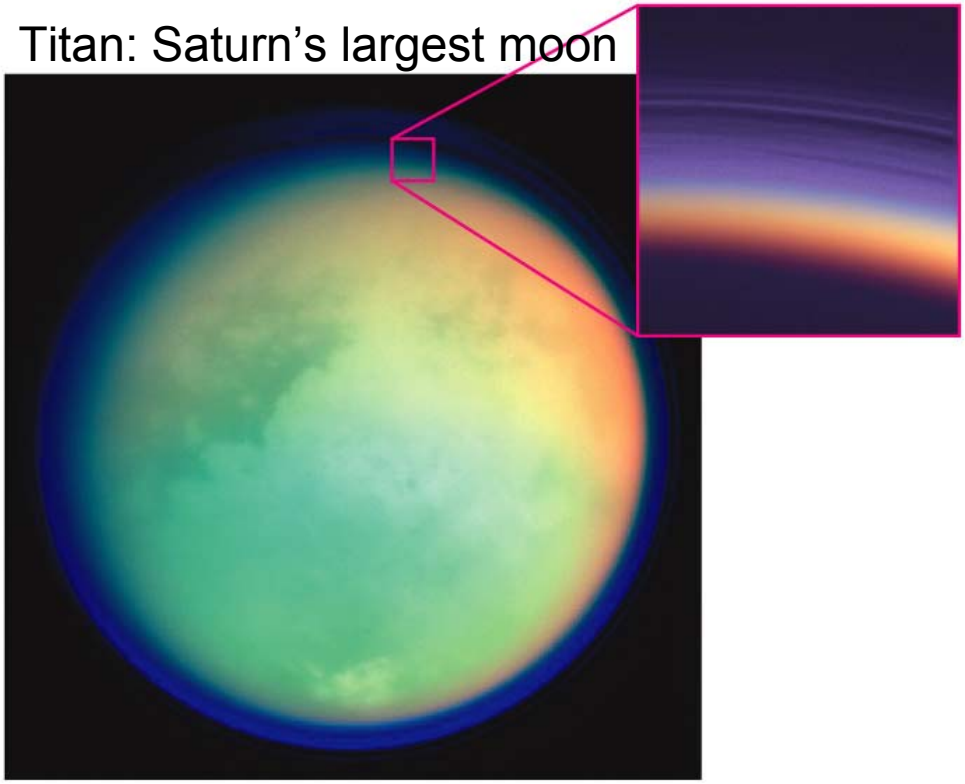


Thick atmosphere

What gases do you think could be in Titan's atmosphere?

Remember Venus, Earth, and Mars

Titan: Saturn's largest moon



Thick atmosphere

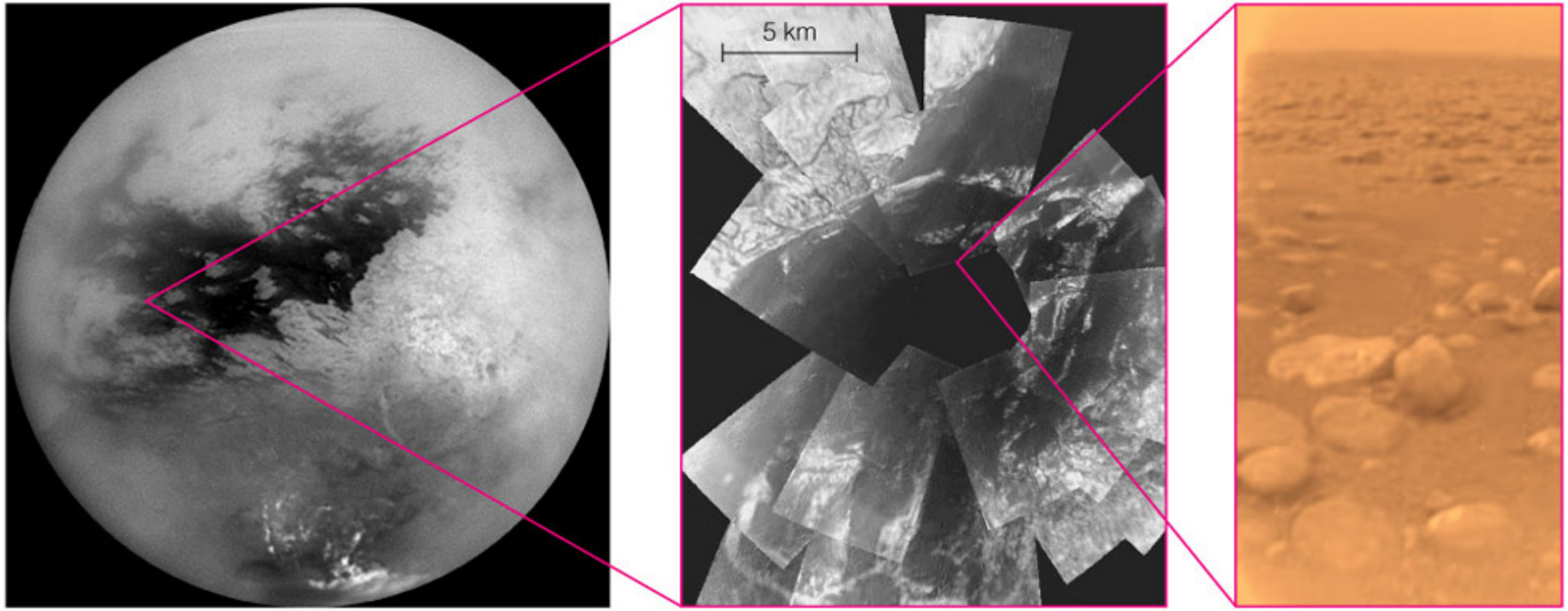
Mostly N_2, like Earth
Some CH_4, methane

UV light from Sun breaks CH_4 molecules apart.

Fragments react with N_2 and CH_4 to make new molecules

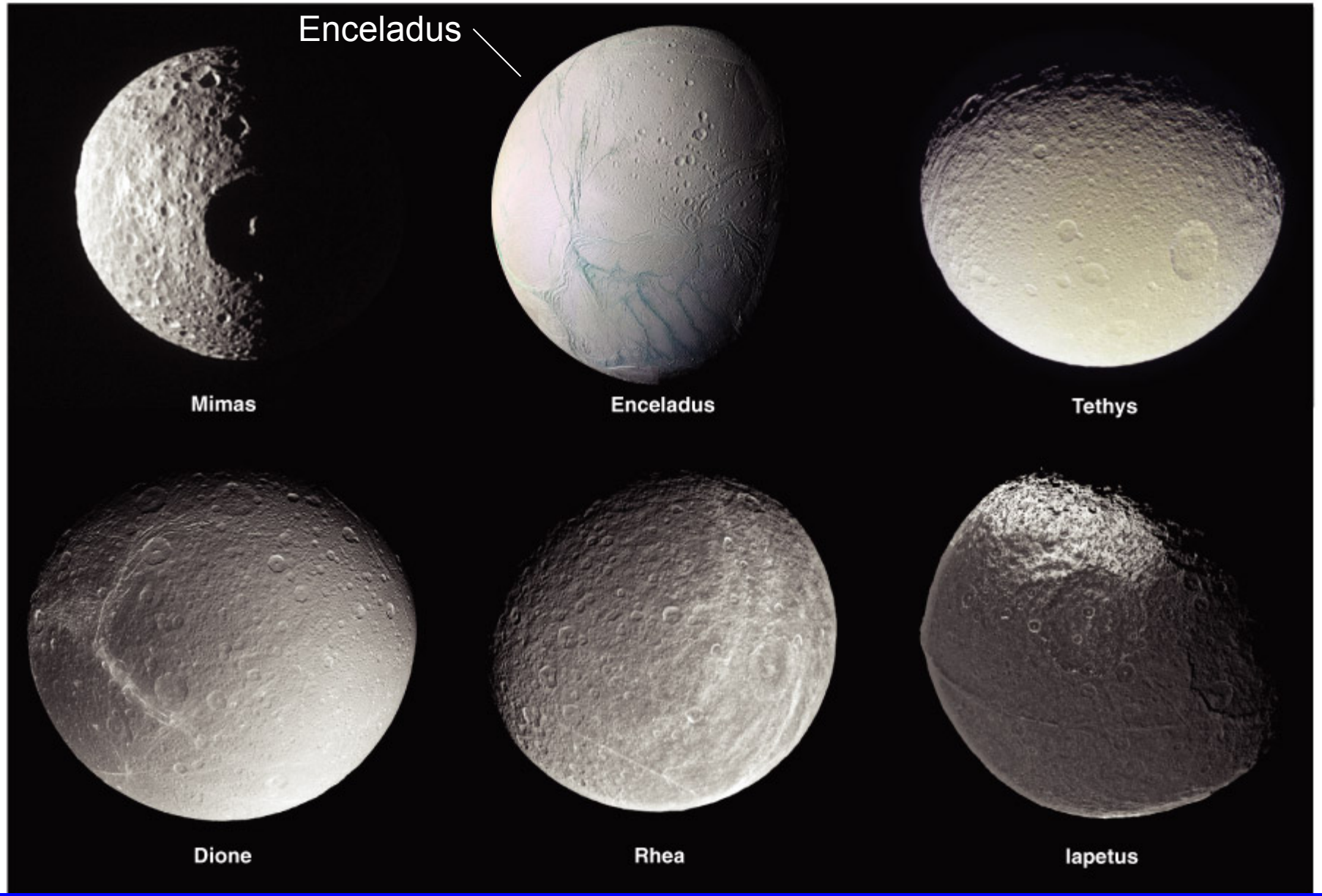
Imagine a gasoline refinery

What does life need?
Is Titan a potential home for life?

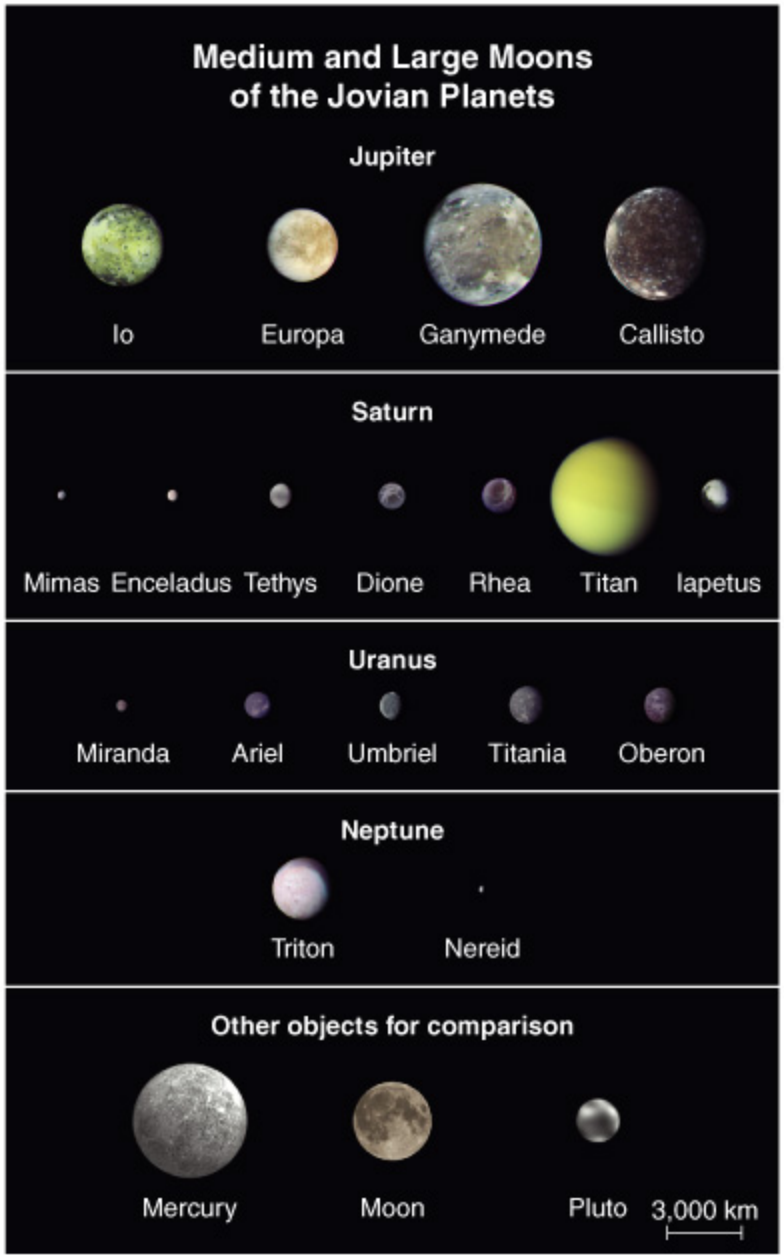


Dark, smooth terrain looks like playas from the southwestern USA
Infrequent heavy rainfall causes flash-floods, lots of erosion, carries material into low-lying areas. Liquid then evaporates or seeps into the ground, leaving dirt behind

Liquid hydrocarbons, not water. Methane rain, not water.
Erupting slushy ice, not lava. Earth-like?



All heavily cratered, old surfaces. Only Mimas has no evidence of past volcanism or tectonism. Enceladus south pole is young surface, hot, outgassing – why?



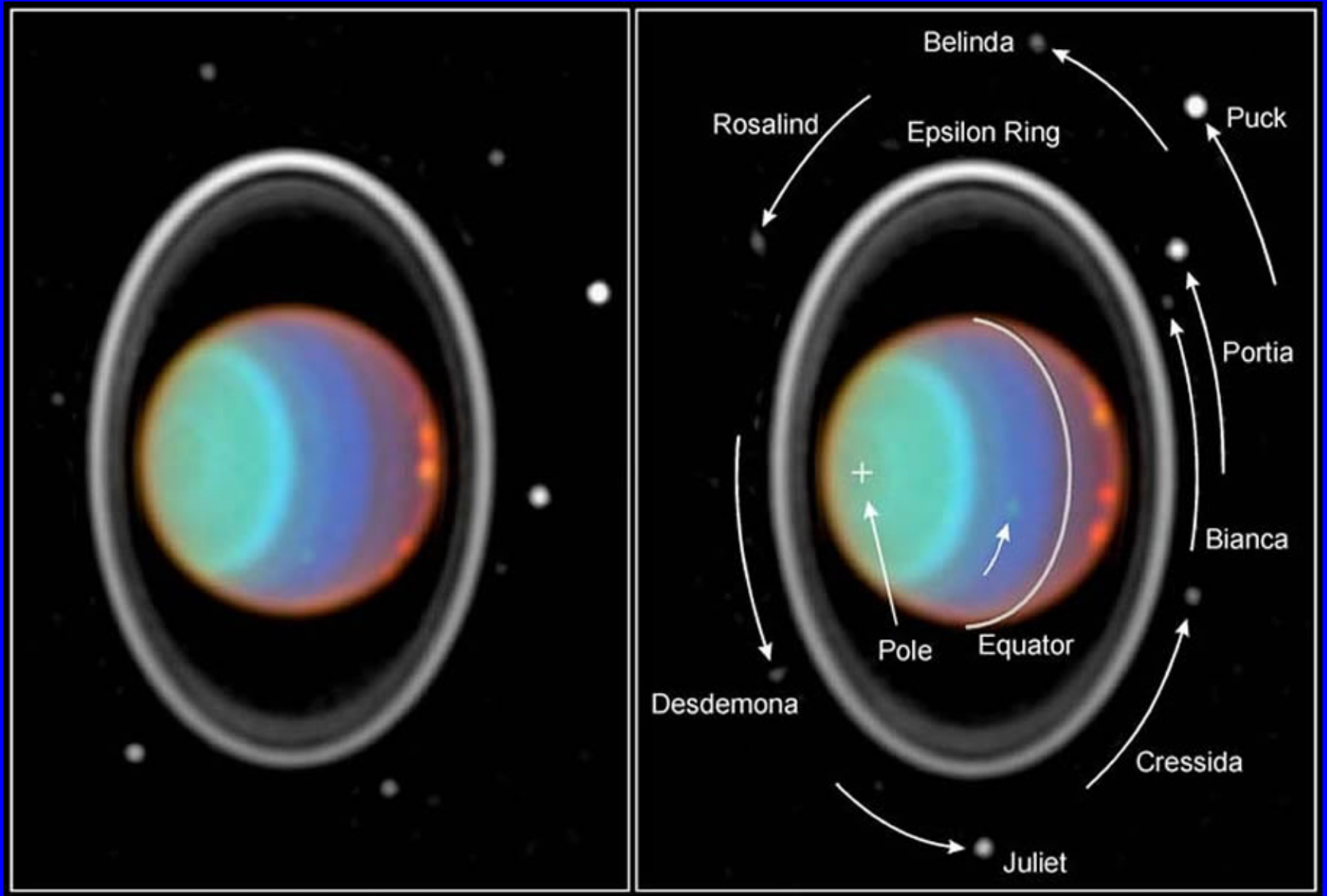
Uranus has no large moons

Neptune has one large moon, Triton

Triton orbits Neptune "backwards" and with a high inclination. Triton was probably captured.

Triton is very large for a captured moon.

What do you think Triton was before it was captured?

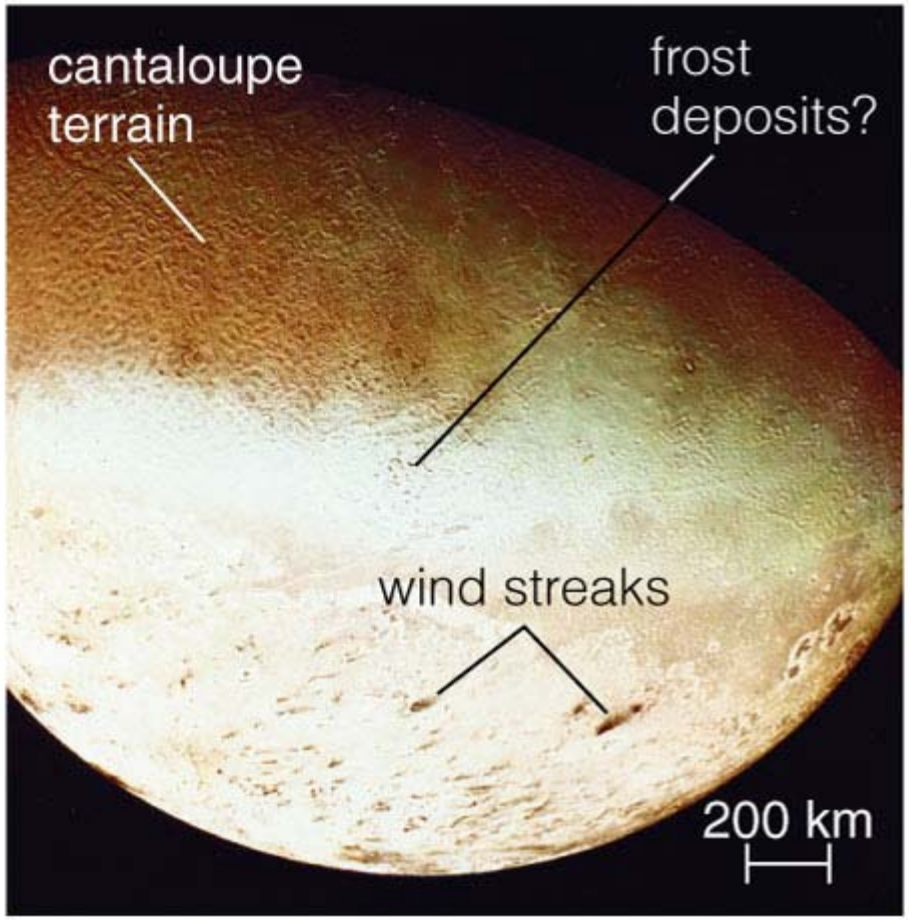


Uranus • July 28, 1997

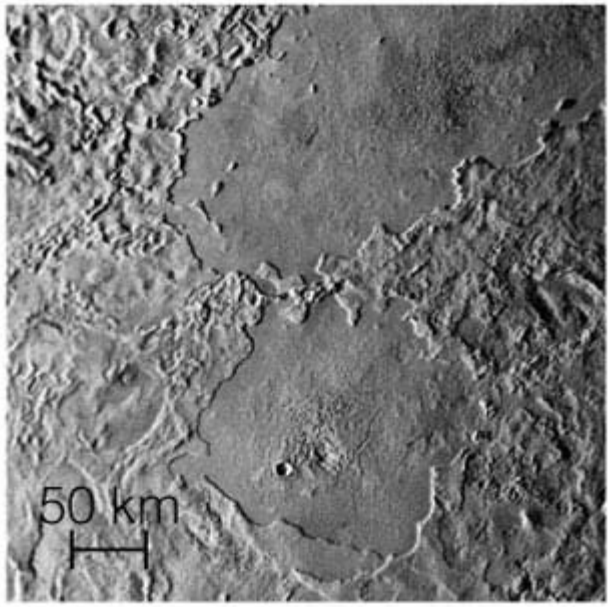
HST • NICMOS

PRC97-36a • November 20, 1997 • ST ScI OPO

E. Karkoschka (University of Arizona Lunar & Planetary Lab) and NASA



Triton's southern hemisphere as seen by *Voyager 2.*



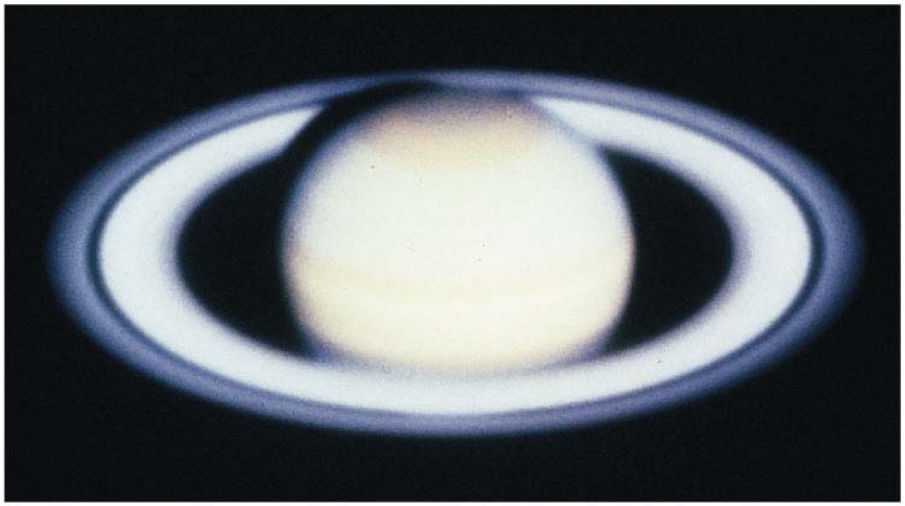
This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

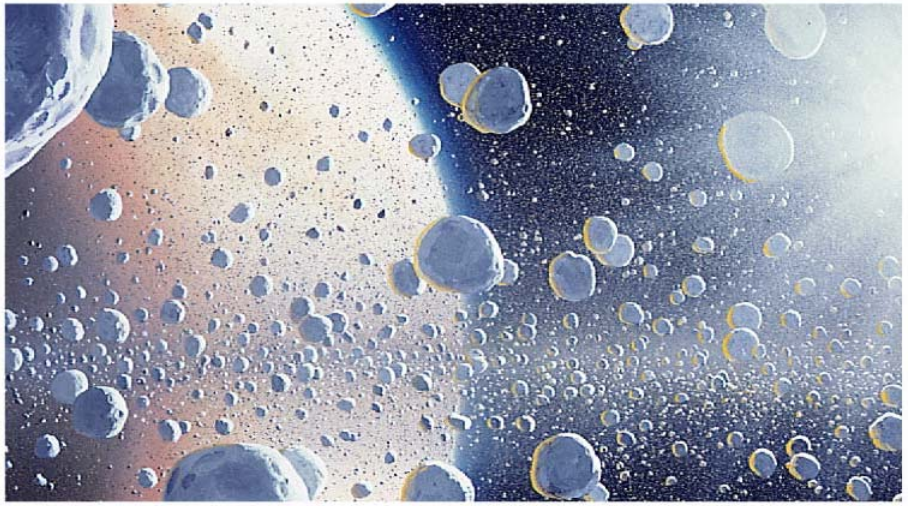
Lots of past geological activity, volcanism, tectonism
Currently outgassing (geysers?) and has a thin atmosphere
Very unexpected discoveries at the end of the Voyager 2 "Grand Tour"

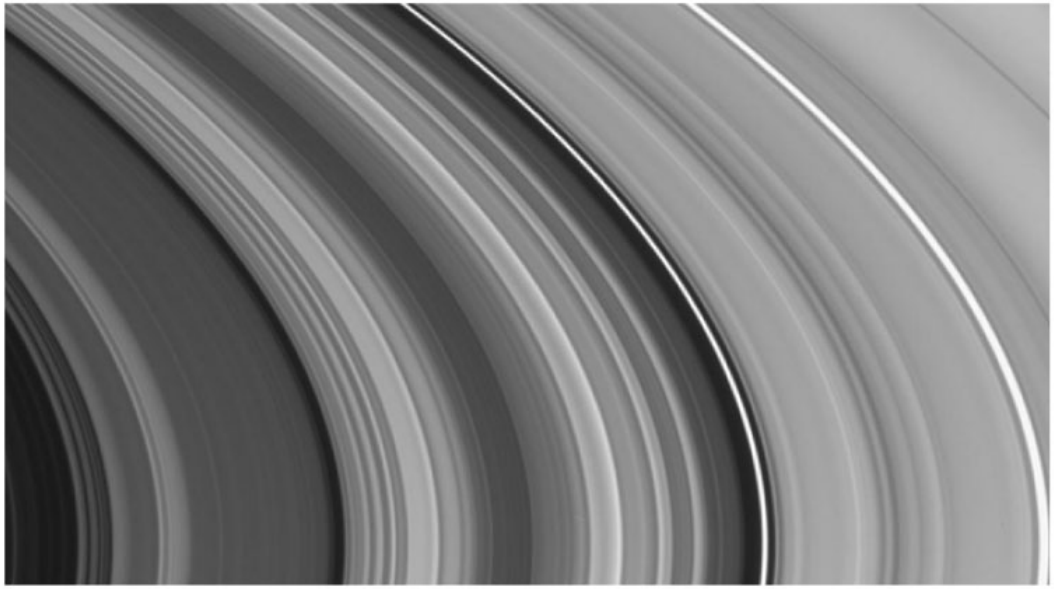
Differences

- Which are most geologically active?
- Moon, Mercury, Io, Europa, Titan

- What reasons can you think of for this difference?







Saturn's Rings

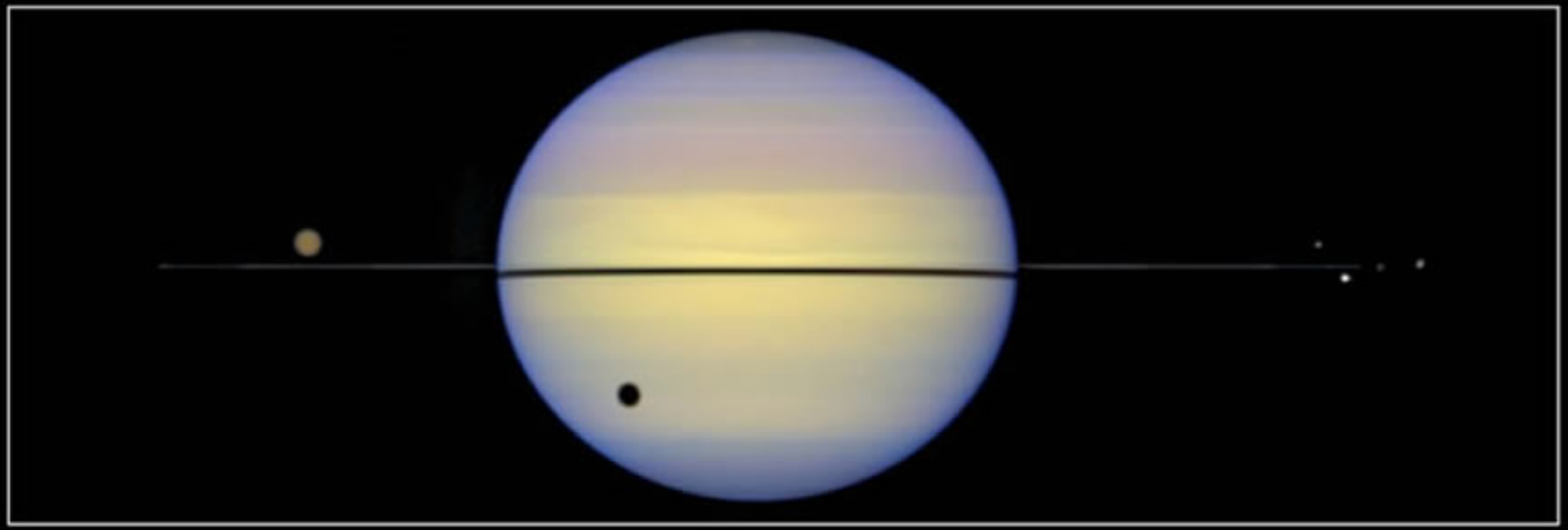
Everything is controlled by gravity – GM_1M_2/R^2

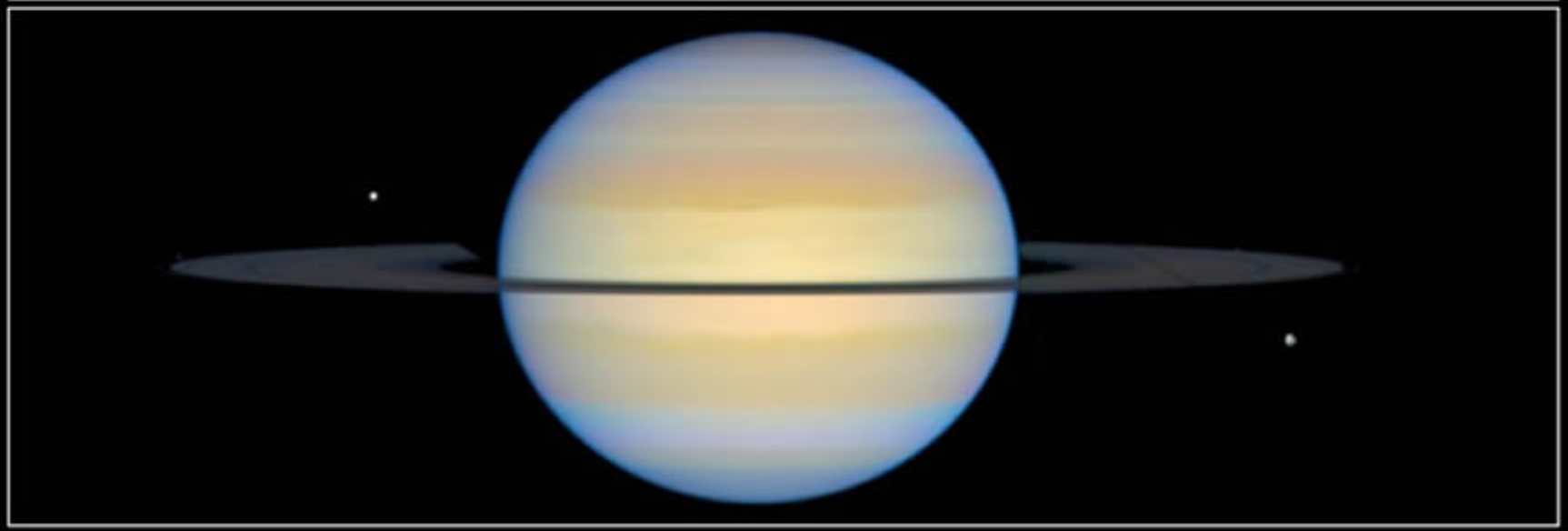
Lots and lots of structure

Rings are <100 m thick, made of many icy particles from specks to boulders in size

Jovian Planet Rings

- All of them have rings, Saturn's are most dramatic
- Ring particles are orbiting just like tiny moons
- Ring particles orbit in equatorial plane, with circular orbits, going in same direction as planet's rotation
- Why is ring plane so thin? Why are orbits all circular, not elliptical? Does this remind you of anything else from this class?

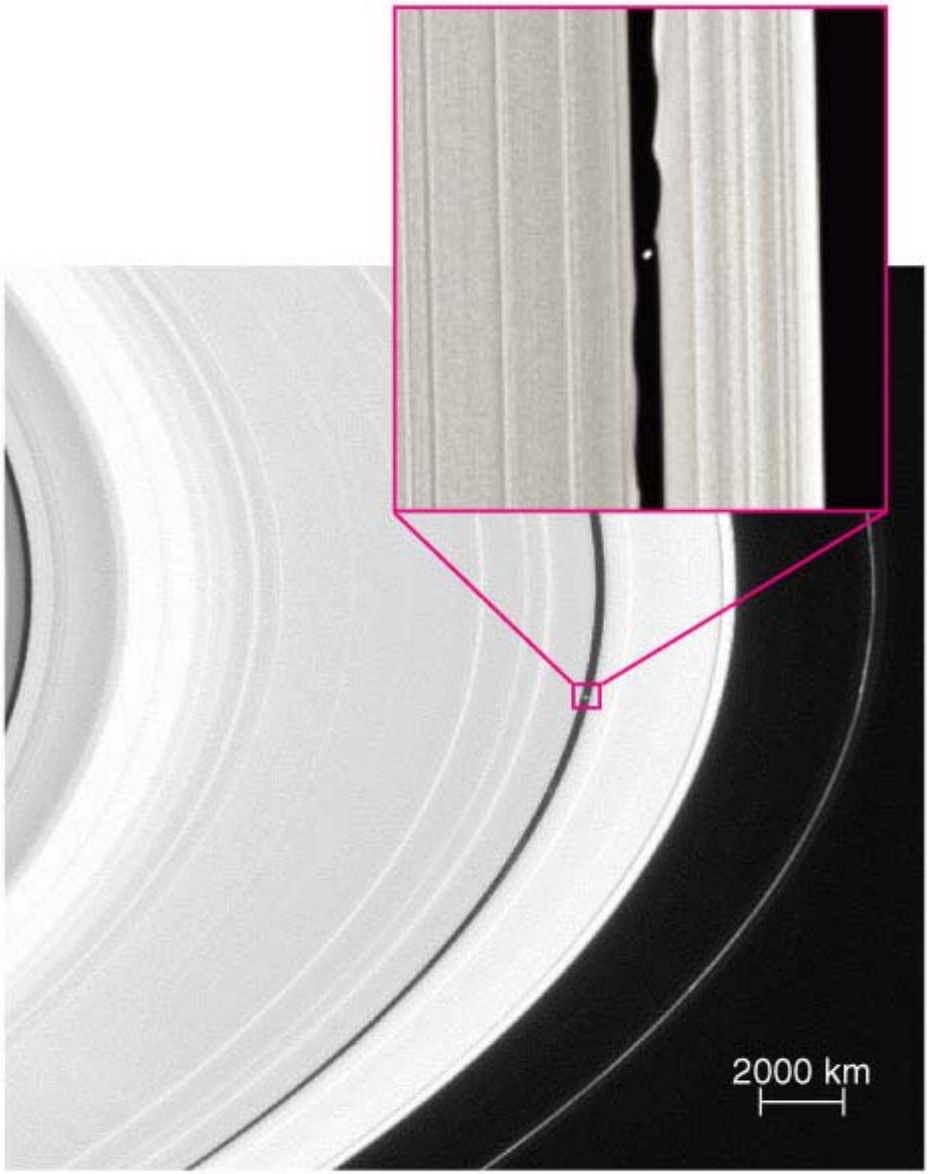




Saturn Ring-Plane Crossing

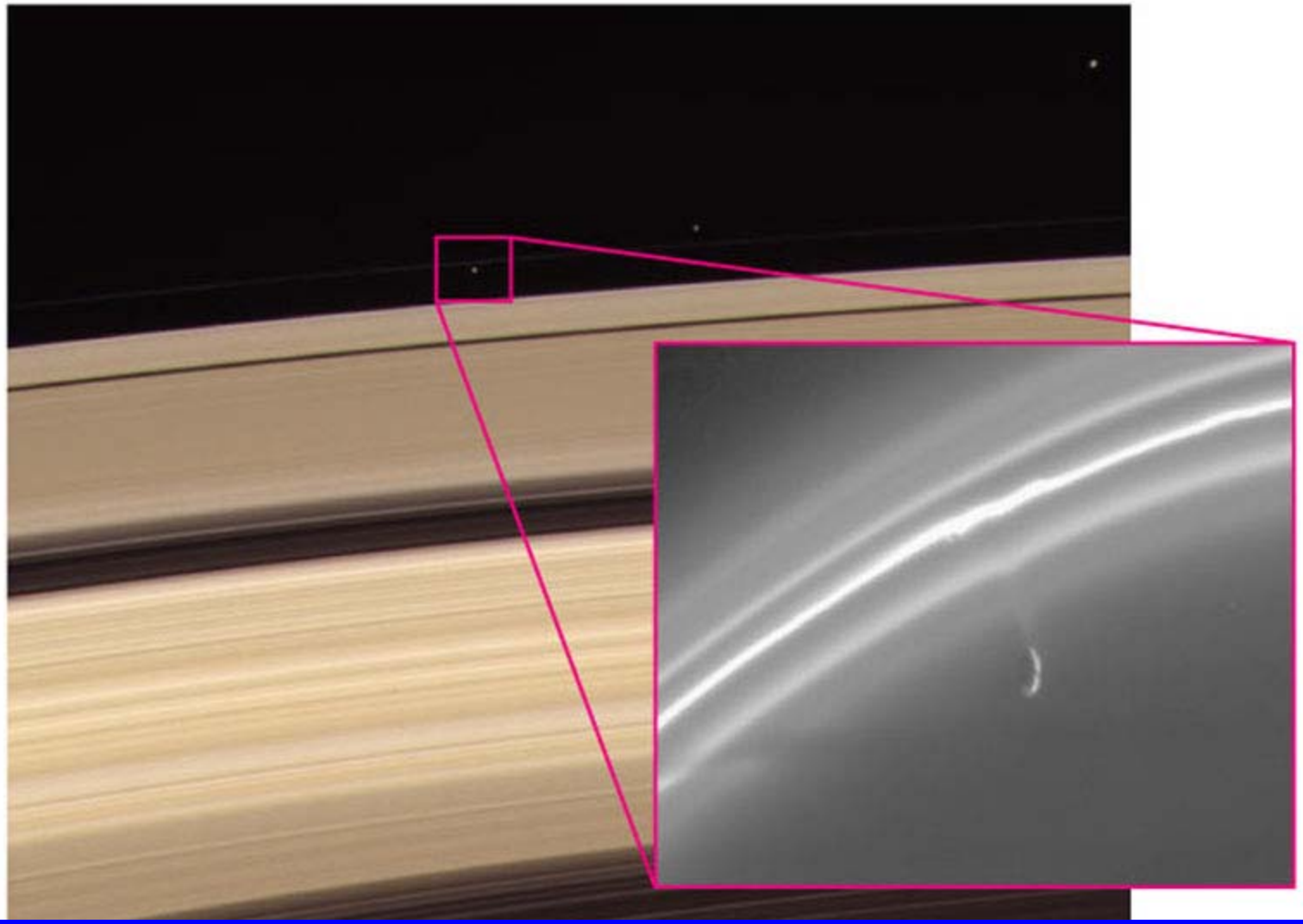
Hubble Space Telescope • Wide Field Planetary Camera 2

PRC96-16 • ST ScI OPO • April 24, 1996 • E. Karkoschka (LPL) and NASA



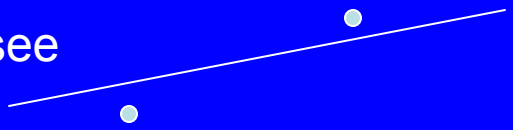
Some small moons
create gaps within the rings

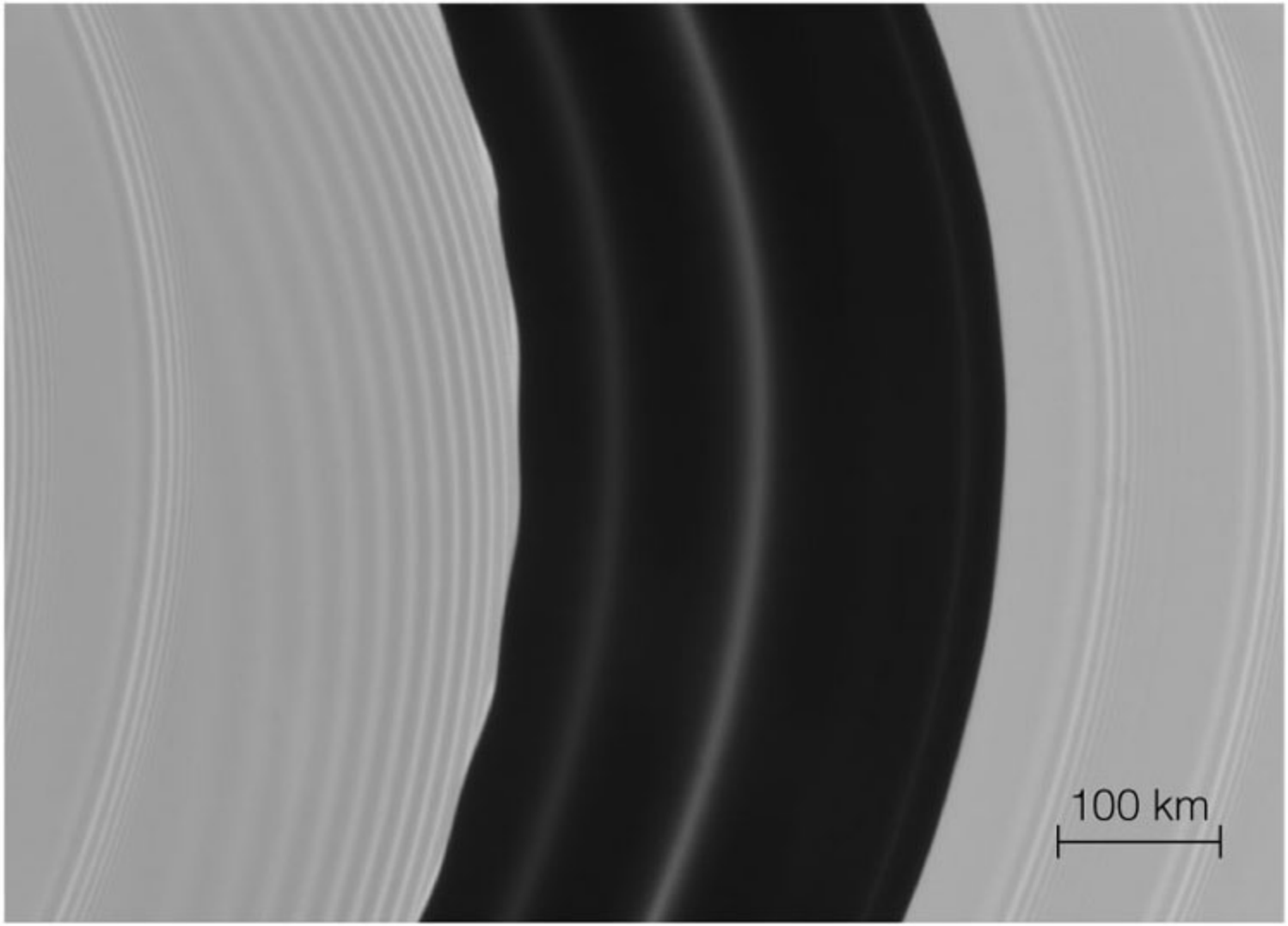
Observe ripples in edges
of rings caused by small moon



Some small moons act in pairs to trap a narrow ring between them

Picture is hard to see

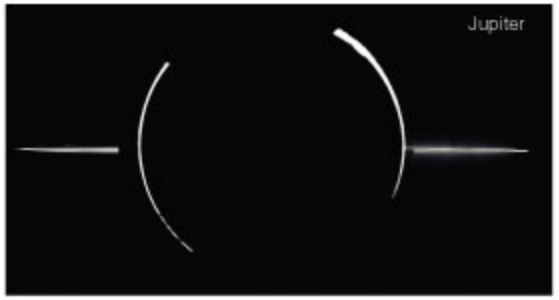




An orbital resonance with the moon Mimas created this gap in the rings
Observe spiral bright/dark waves

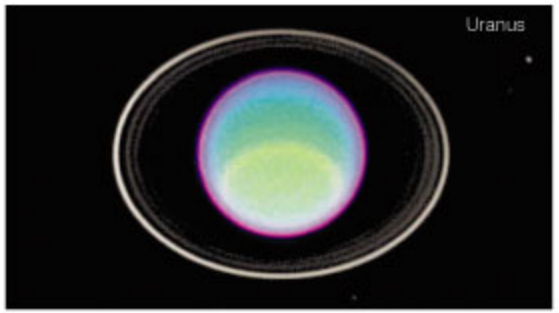
Ring Complexities

- Gravity GM_1M_2/R^2
- Interactions between ring particles and other ring particles
- Interactions between ring particles and small, nearby moons
- Interactions between ring particles and large, distant moons through orbital resonances

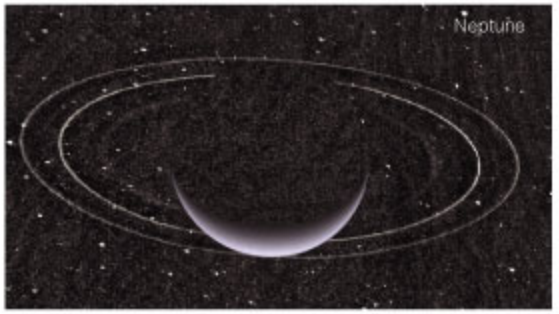


Jupiter

Saturn



Uranus



Neptune

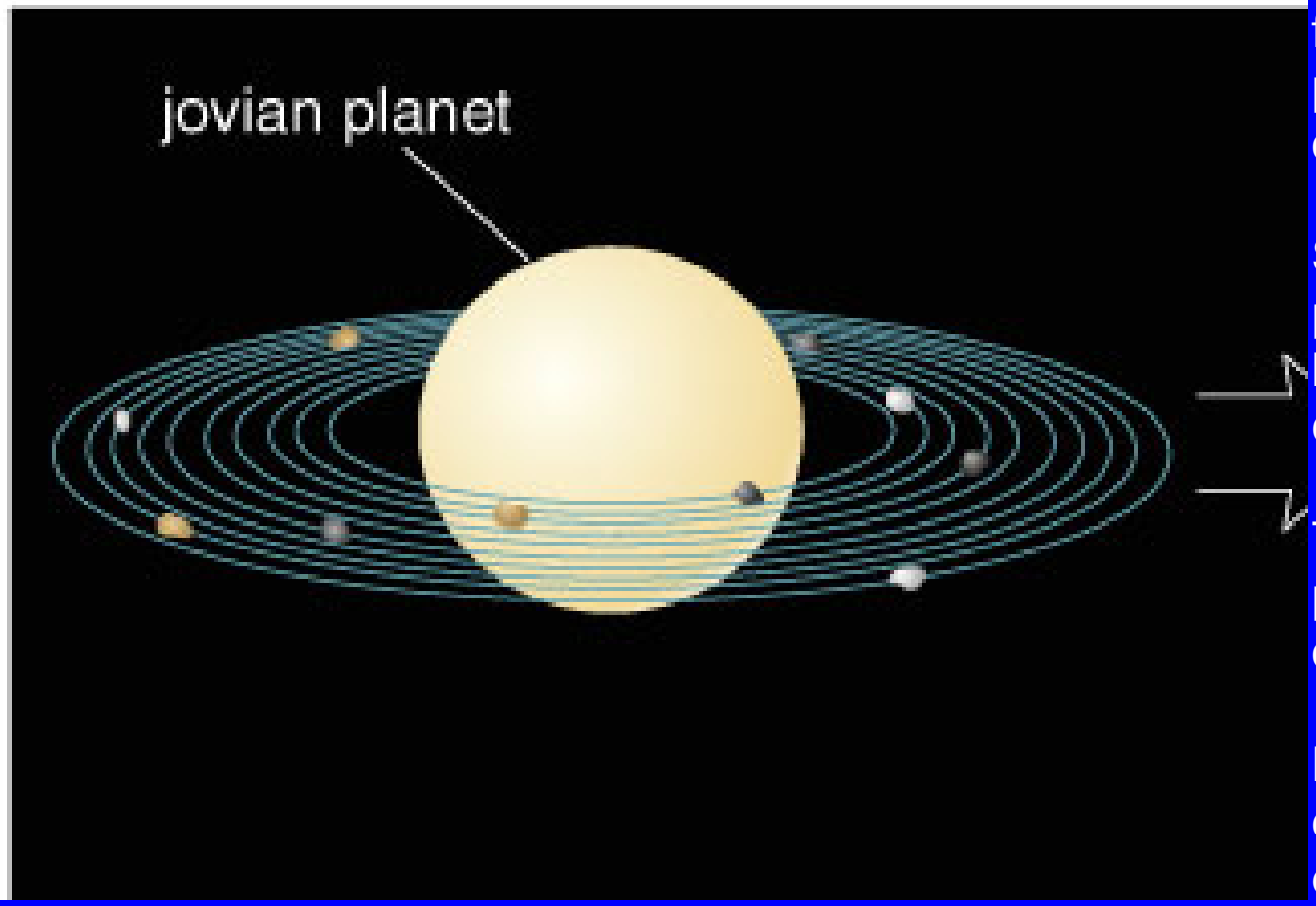
Are rings the result of some special, rare, and unusual event?
Or do they appear to be a standard part of planet formation?
Can they be left over from each planet's mini-nebula?

Particles in Saturn's rings are:

More numerous
Larger
Brighter

than those in rings of Jupiter, Uranus, and Neptune

Why are they so different?

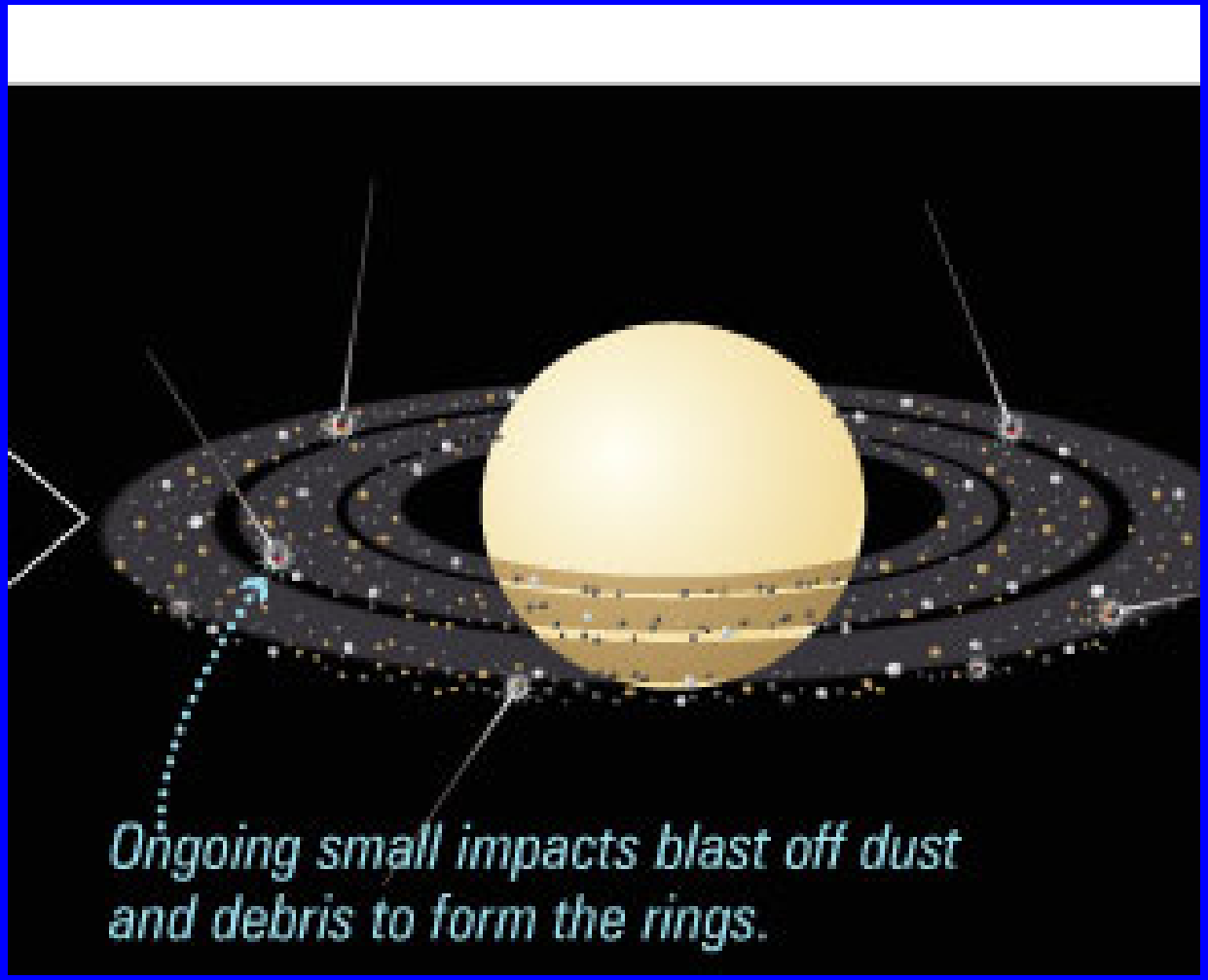


Lots of small moons formed in equatorial plane during the birth of the solar system

Strong tidal forces prevent small moons becoming large moons close to the planet

Tiny impacts will blast particles off surfaces of these moons

Moons are large enough and numerous enough that there are still some left today, 4.5 billion years after solar system birth



Small impacts on small moons release small, dust-sized particles

Larger impacts on small moons release larger, boulder-sized particles

Sometimes an impact will shatter a small moon apart completely

Impactors can be ring particles themselves or objects from outside the Saturn system

Are Saturn's rings brighter than those of other planets because of some special property of Saturn or just by chance?

Goals for Learning

- What are the interiors of jovian planets like?
- What is the weather like on jovian planets?
- What are the moons of jovian planets like?
- How where those moons formed?
- Why do jovian planets have rings?

Goals for Learning

- What are the interiors of jovian planets like?
  - Jupiter and Saturn are mostly hydrogen, with layers of gas, liquid, and metallic hydrogen above a rock/ice core
  - Uranus and Neptune have a thinner outer layer of hydrogen, a thick ice mantle, and a rock core
  - The nebular theory explains these differences

Goals for Learning

- What is the weather like on jovian planets?
  - Clouds of water and ammonia on Jupiter and Saturn, clouds of methane on Uranus and Neptune
  - Circulation cells are broken into narrow bands by rapid rotation
  - Fast winds
  - Great Red Spot

Goals for Learning

- What are the moons of jovian planets like?
  - Large moons are geologically active, medium-sized moons show evidence of past activity, small moons are rugged ice potatoes
  - Io has active volcanoes due to Jupiter's tides
  - Europa has a liquid water ocean beneath a frozen ice crust
  - Titan has a dense and chemically interesting atmosphere

Goals for Learning

- How where those moons formed?
  - Most large moons formed in mini-nebulas around their planet just like planets around the Sun
  - Many small moons were captured by the gassy mini-nebula around each planet
  - Triton, a large moon of Neptune, was probably captured as well

Goals for Learning

- Why do jovian planets have rings?
  - Ring particles cannot survive for the age of the solar system, they must be continually produced
  - Impacts onto moons create debris that becomes ring particles
  - The size and brightness of rings change over the course of the solar system

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