



Today

- Moons

Events

- Exam II
 - Tuesday 3/31
 - longer
 - cumulative

Selected Moons of the Solar System, with Earth for Scale

Earth

Mars

Asteroid
Ida

Jupiter

Saturn

Uranus

Neptune

Pluto

Eris

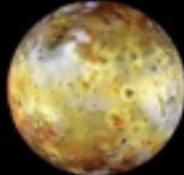


Moon

Phobos

Deimos

Dactyl



Io



Europa



Ganymede



Callisto

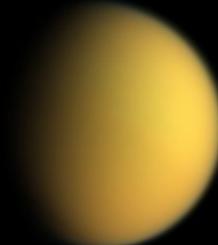
Mimas

Enceladus

Tethys

Dione

Rhea



Titan

Hyperion

Iapetus

Iapetus

Phoebe

Puck

Miranda

Ariel

Umbriel

Titania

Oberon

Oberon

Proteus



Triton

Nereid



Charon

Dysnomia

Scale: 1 pixel = 25 km



Earth

Obvious Definition

- A moon is an object that orbits a planet

Sizes of Moons

- Small moons (< 300 km)
 - No geological activity
- Medium-sized moons (300–1,500 km)
 - Geological activity in past
- Large moons ($> 1,500$ km)
 - Ongoing geological activity

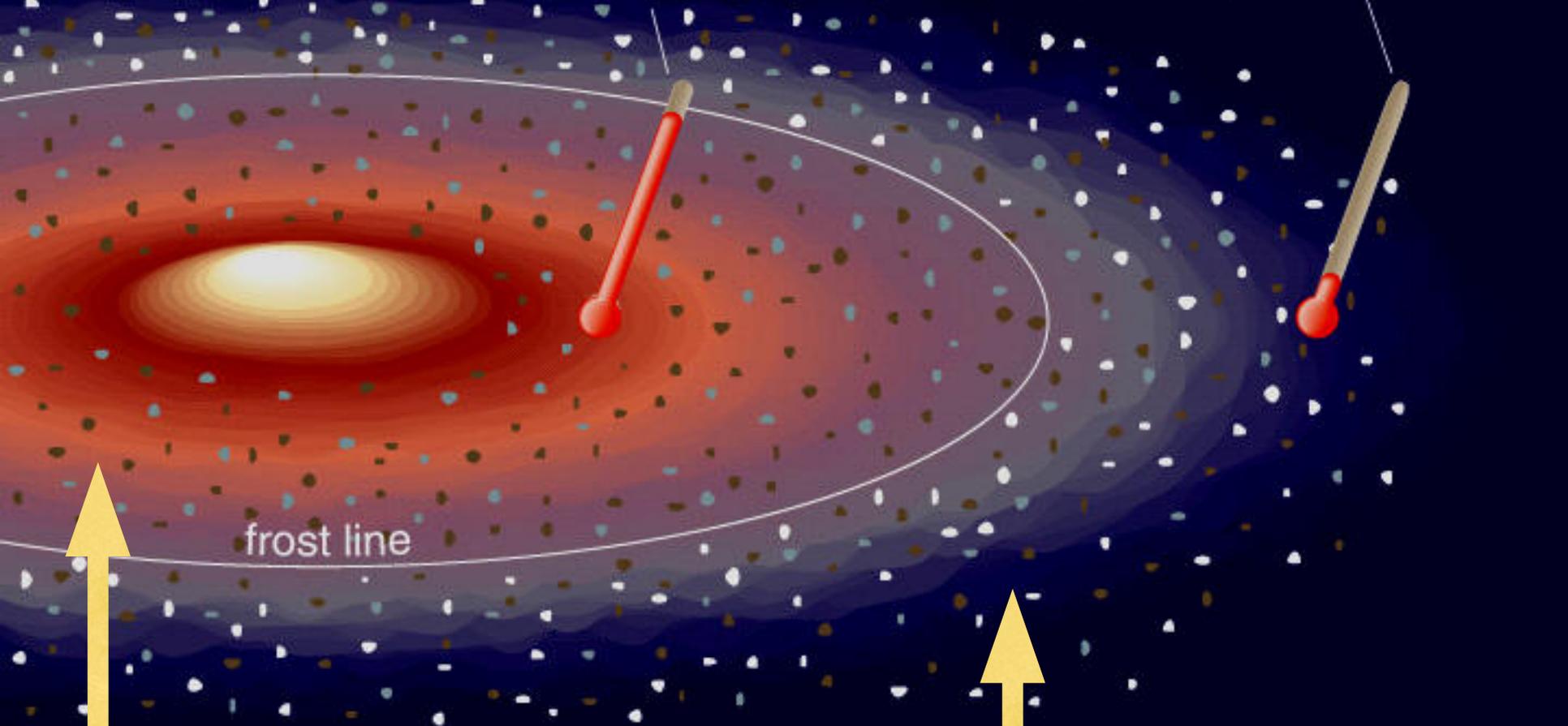


Medium and Large Moons

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

Rocks and metals condense,
hydrogen compounds stay vaporized.

Hydrogen compounds, rocks,
and metals condense.



frost line

Inside frost line: terrestrial planets

Beyond frost line: Gas giants, icy moons, dwarf planets, comets



Medium and Large Moons

- Density
 - low
 - typically ~ 2 g/cc
 - more than Gas giants
 - less than Terrestrials
- Composition
 - rock
 - ice / subsurface water

Ice is just another common “rock” mineral in the outer solar system.

Small Moons



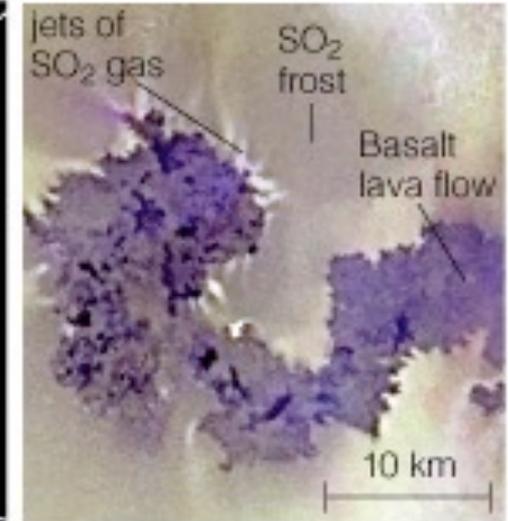
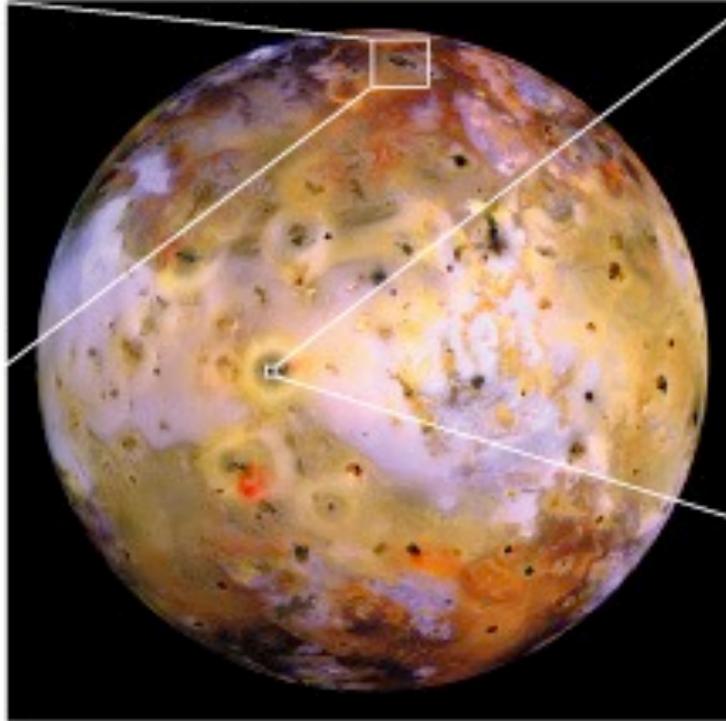
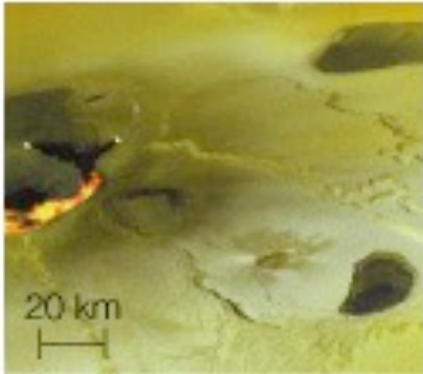
- Far more numerous than the medium and large moons
- Not enough gravity to be spherical: “potato-shaped”
- Often just captured asteroids

The moons of the Jovian planets



Galilean moons of Jupiter
("Medici stars")

Io

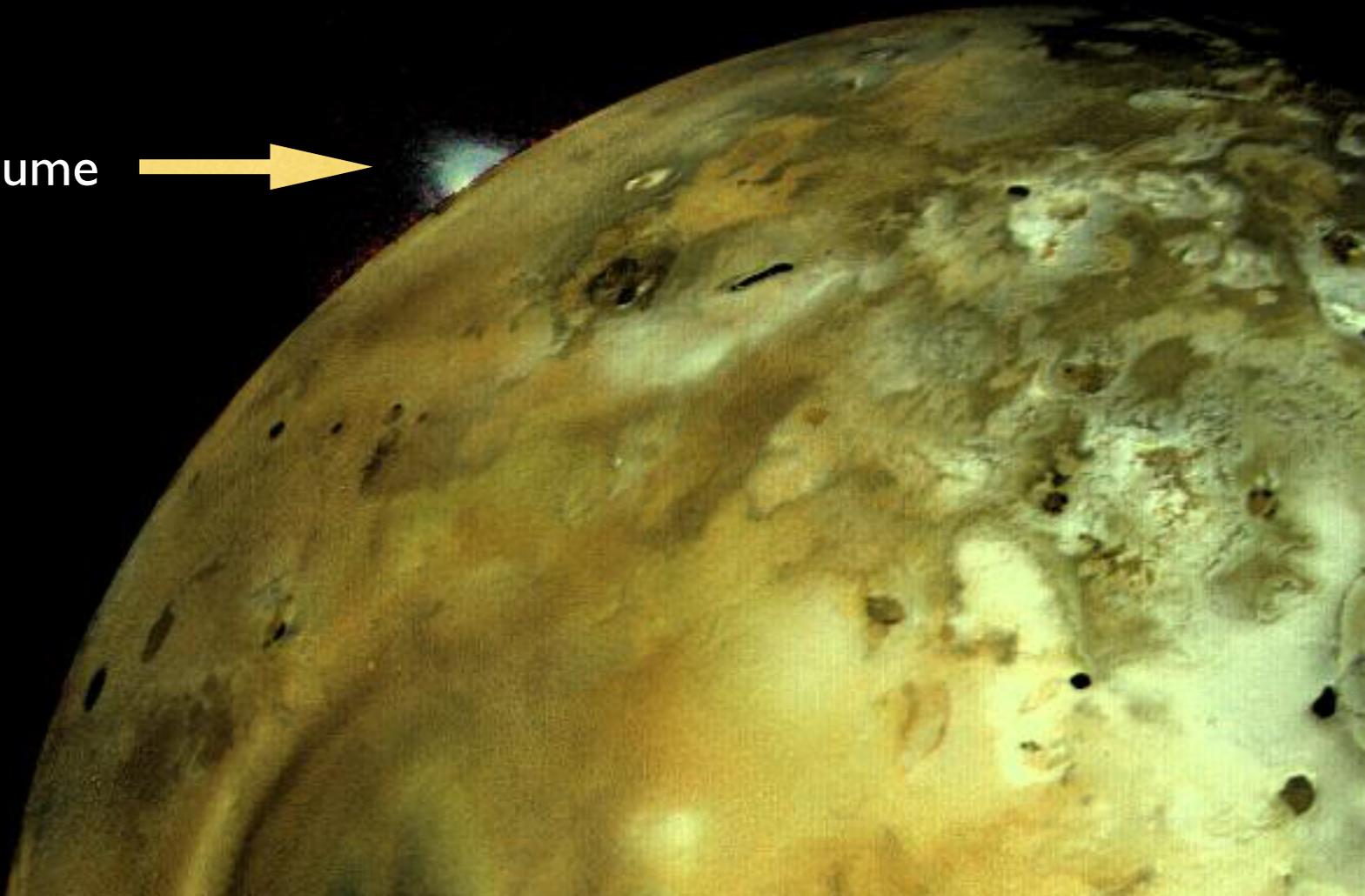


- Io is the most volcanically active body in the solar system.

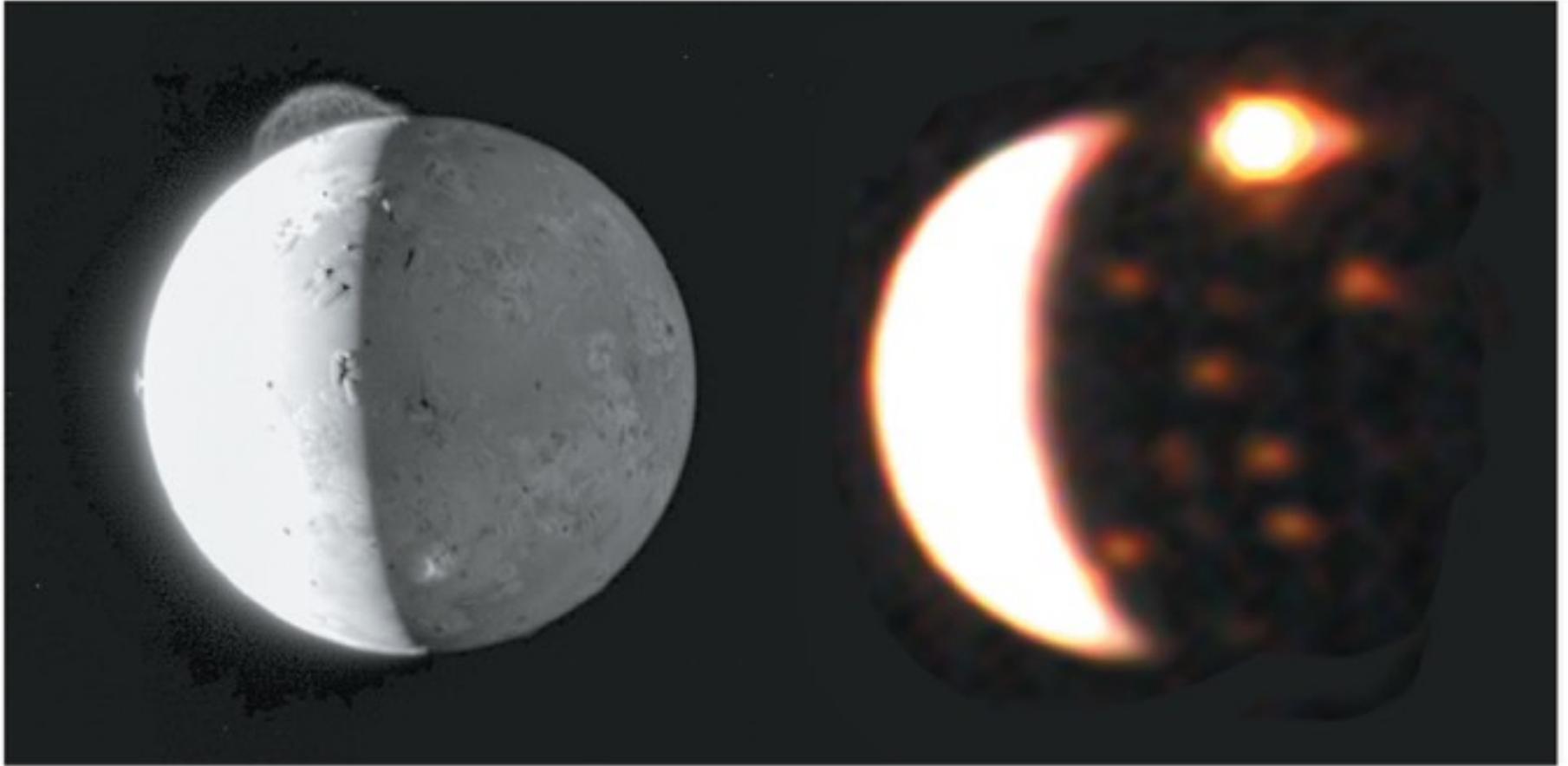
Volcanic activity discovered on Io during the Voyager fly-by

What're the odds?

volcanic plume

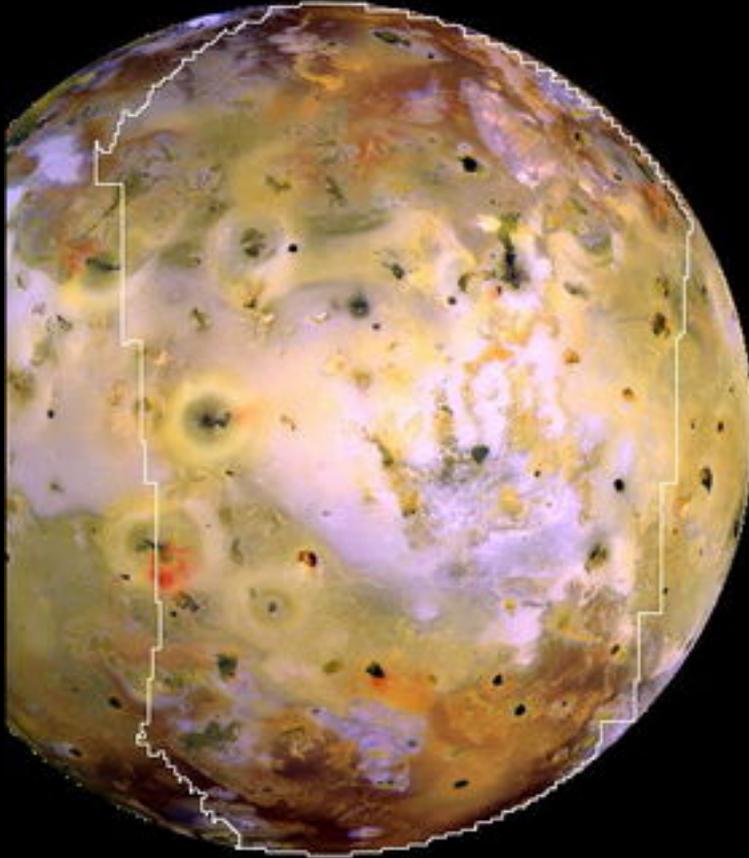


Io's Volcanoes

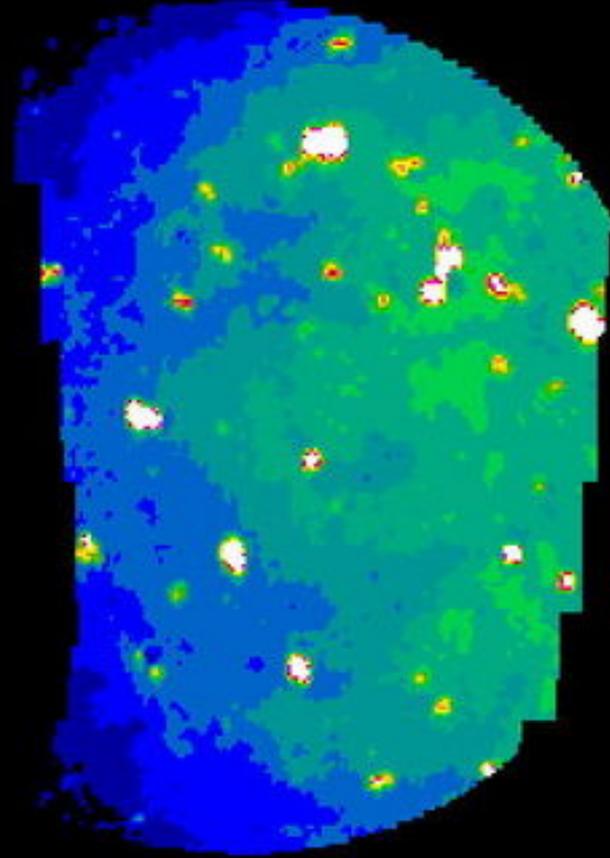


- Volcanic eruptions continue to change Io's surface.

optical



infrared

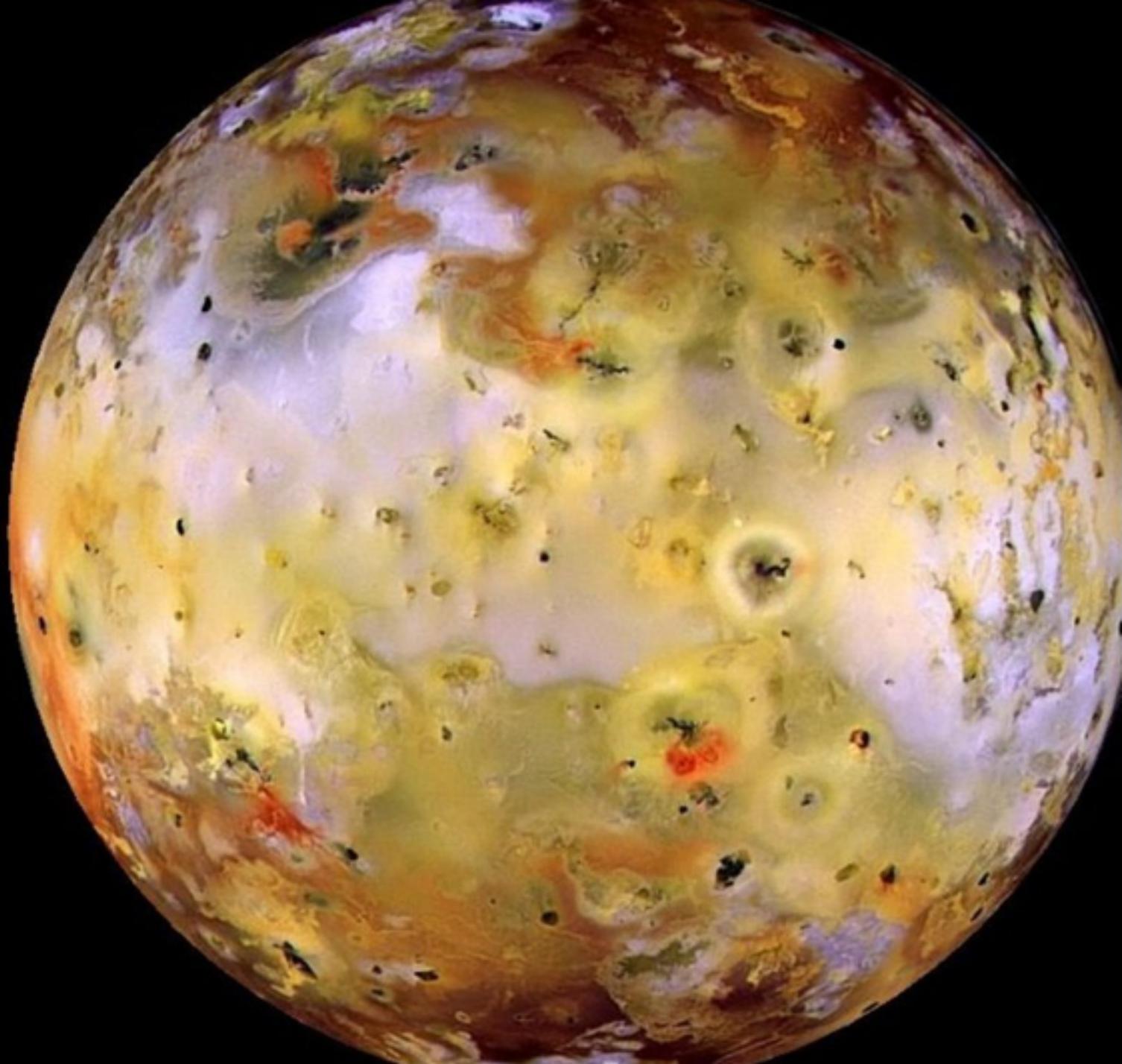


dark volcanic craters in the optical
correspond to hot spots in the infrared

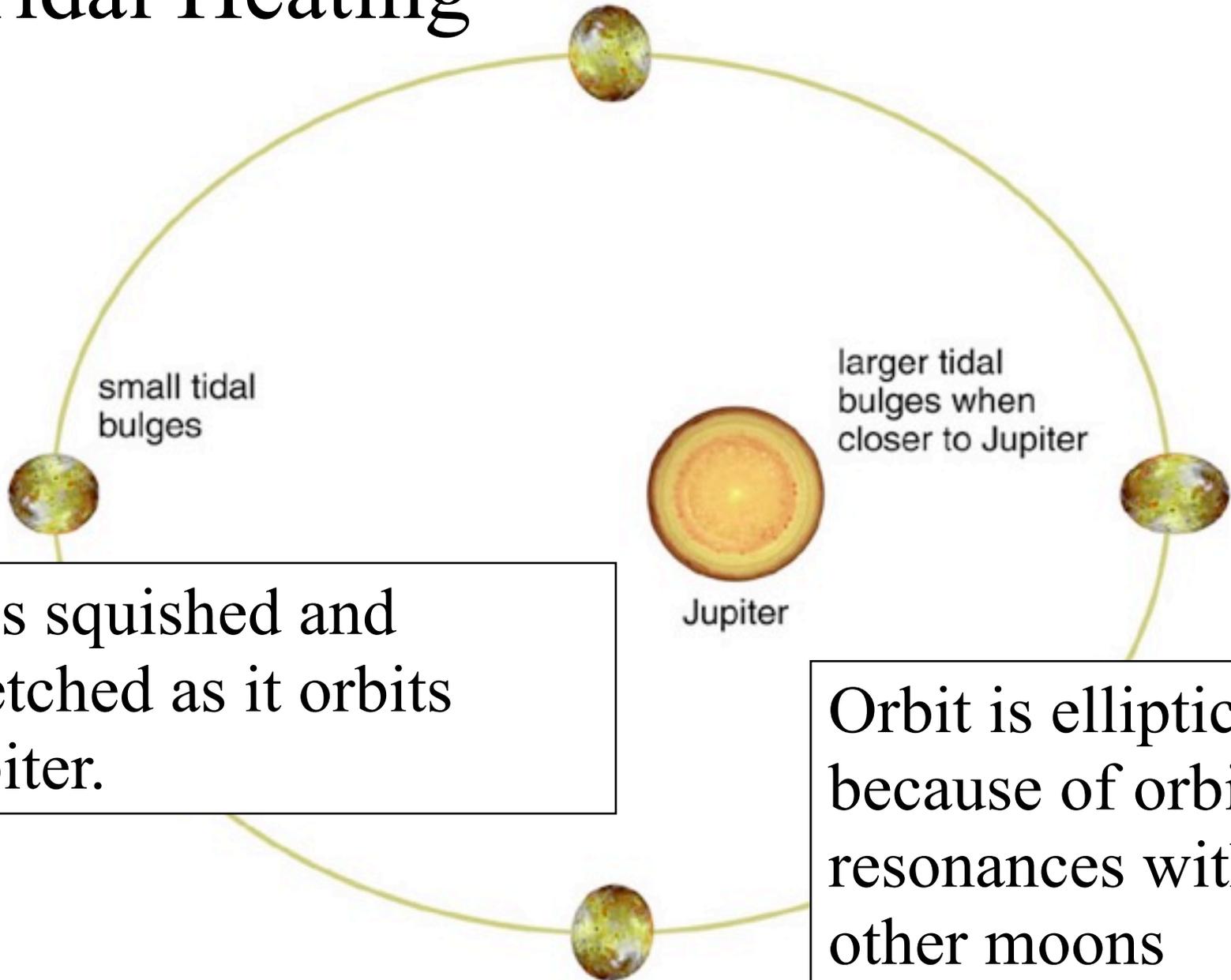
show interactive optical/IR image

Io's surface
very young

Constantly
re-covered in
fresh lava &
sulfur dioxide
snow



Tidal Heating

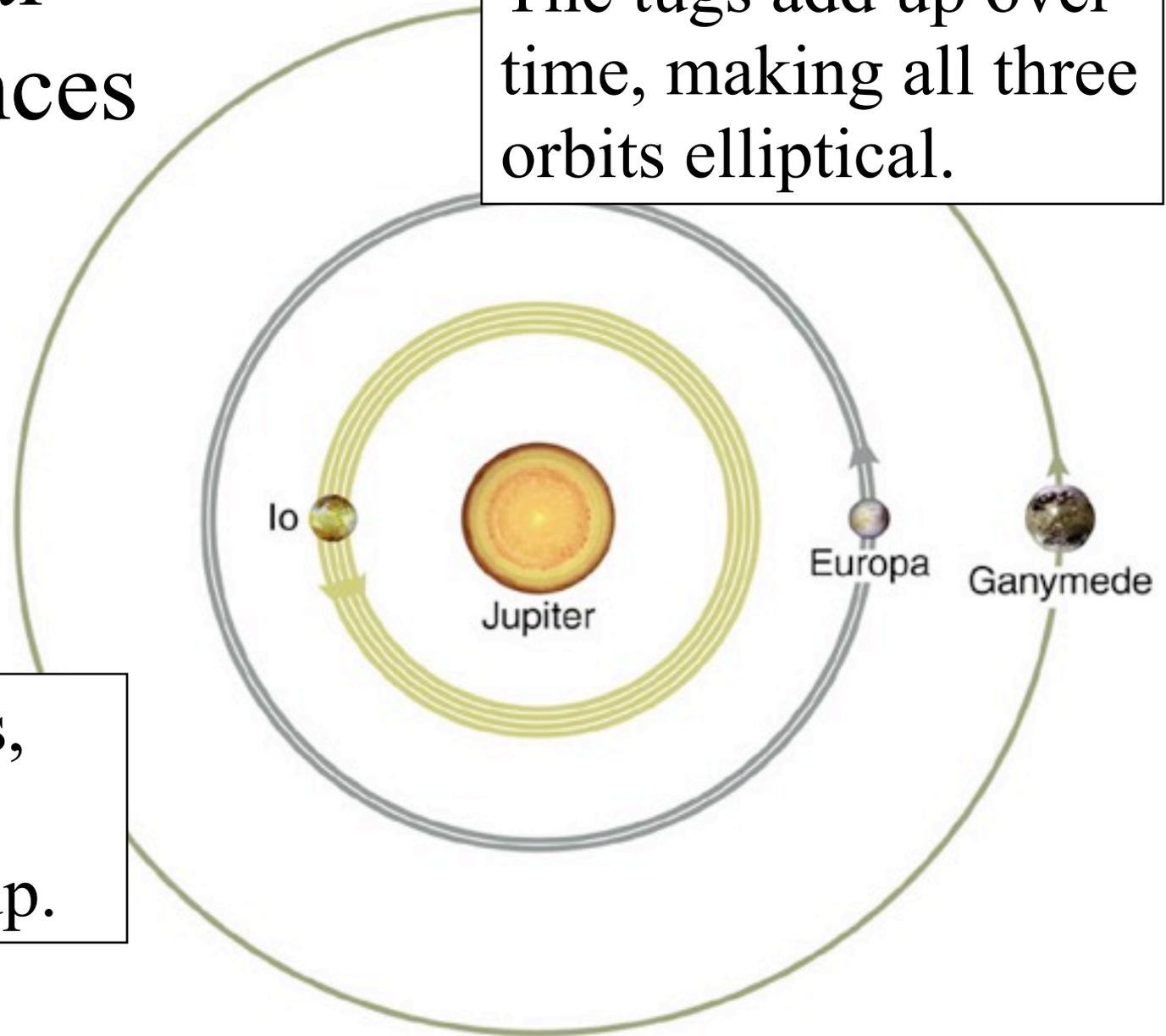


Io is squished and stretched as it orbits Jupiter.

Orbit is elliptical because of orbital resonances with other moons

Orbital Resonances

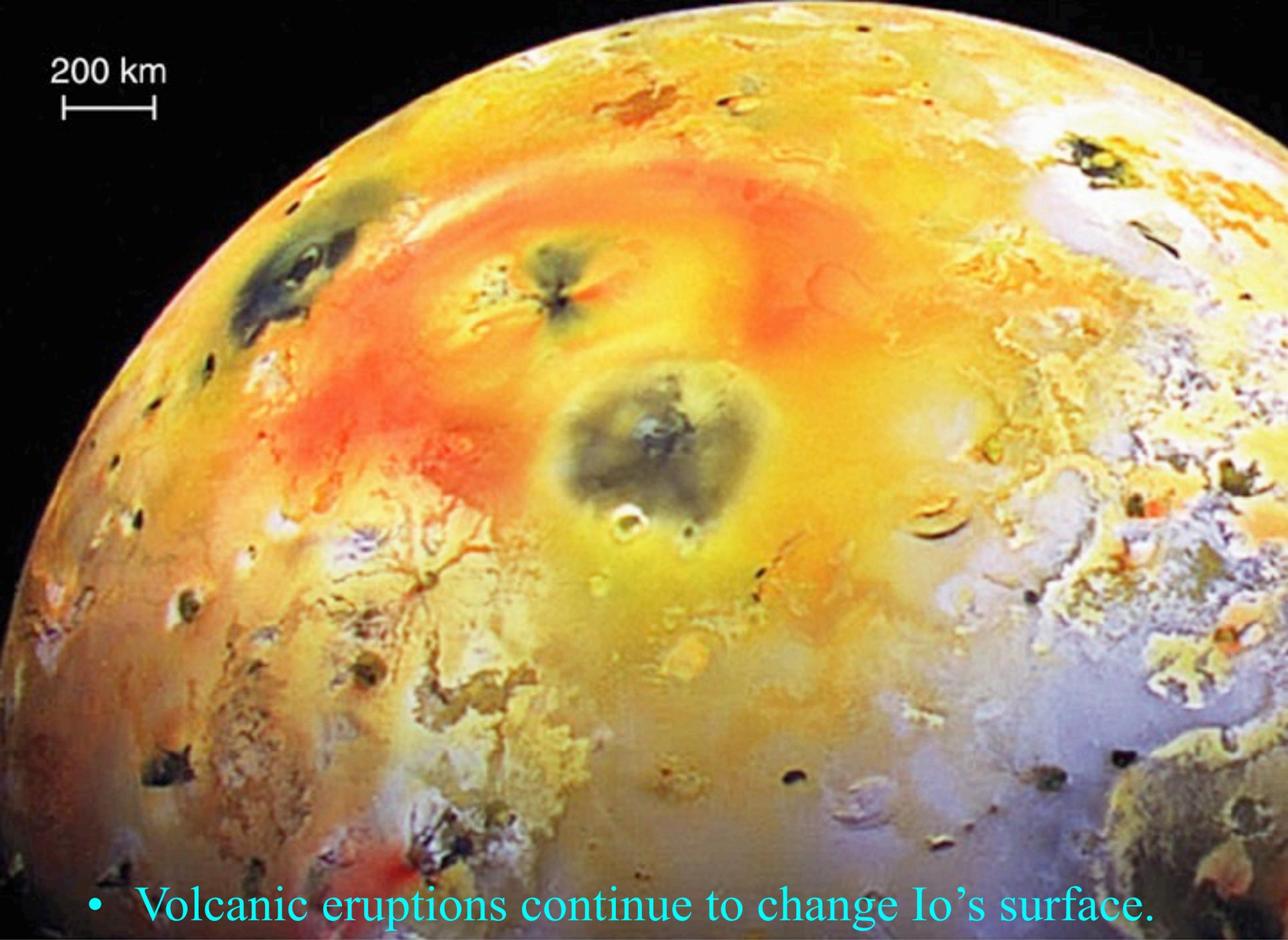
The tugs add up over time, making all three orbits elliptical.



Every 7 days, these three moons line up.

show interactive figure

200 km
┌───┐



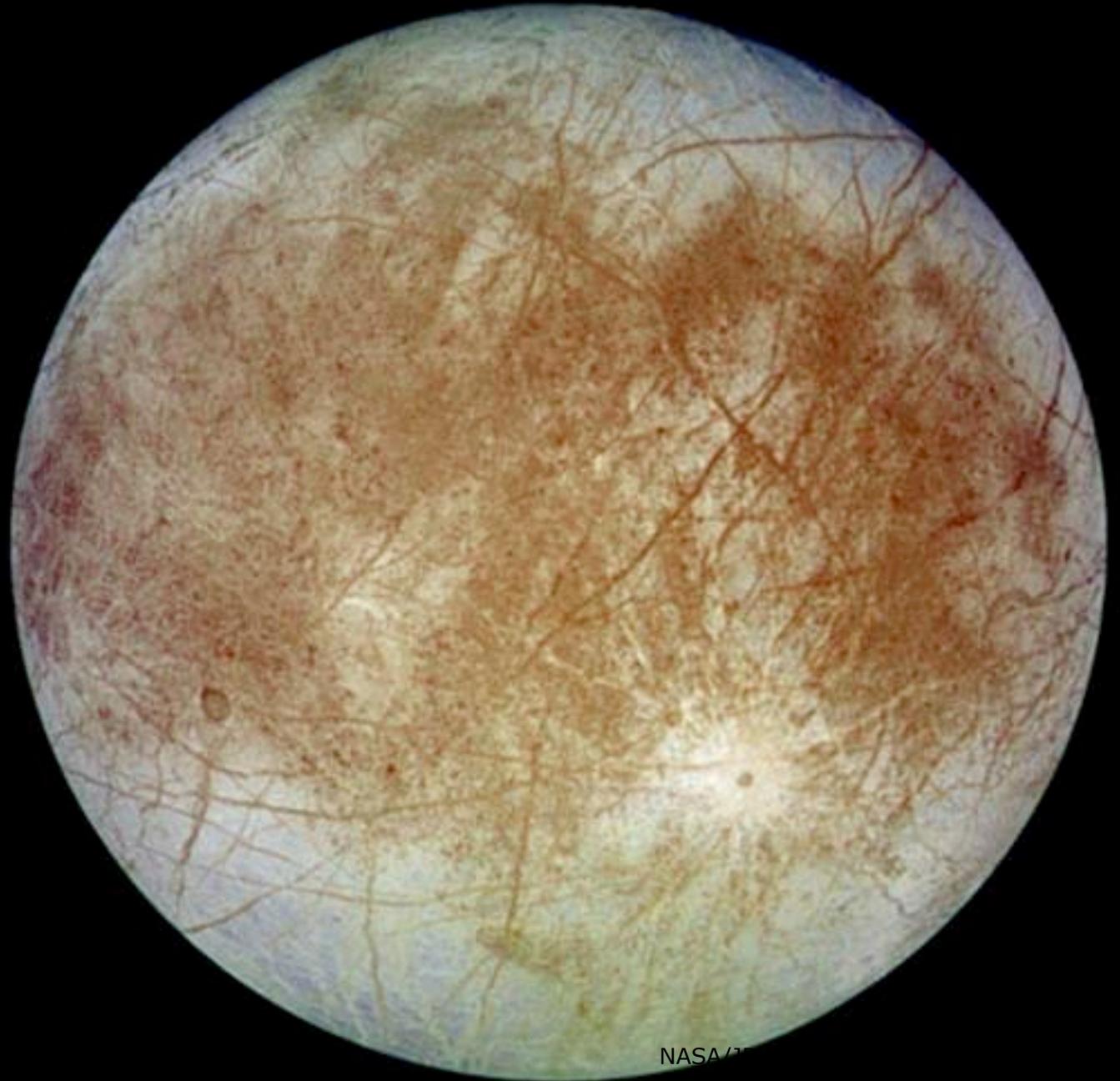
- Volcanic eruptions continue to change Io's surface.

The moons of the Jovian planets

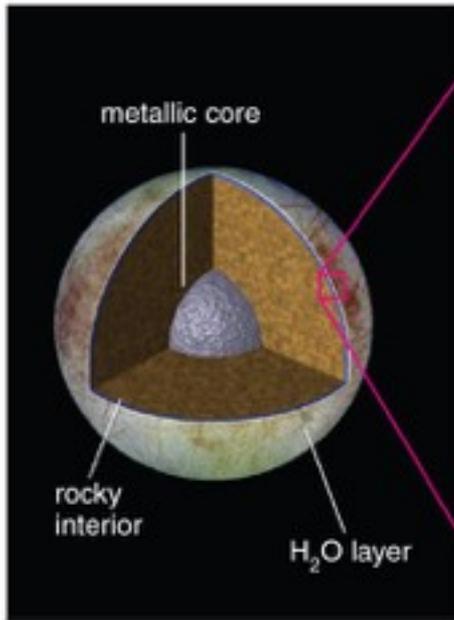


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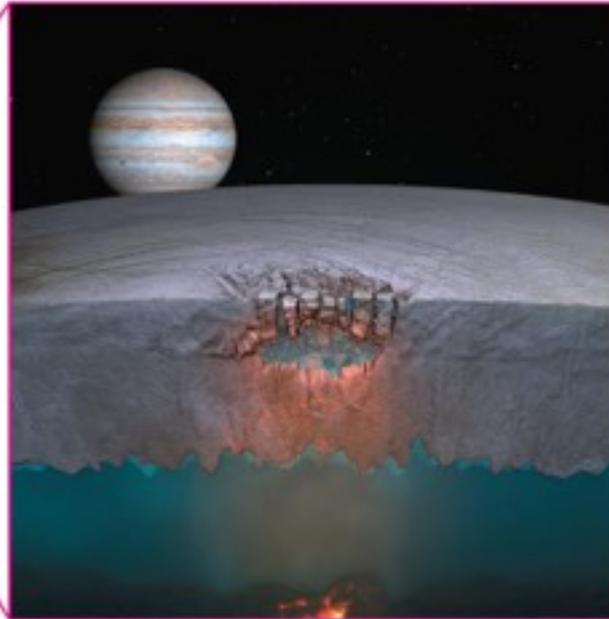
Europa



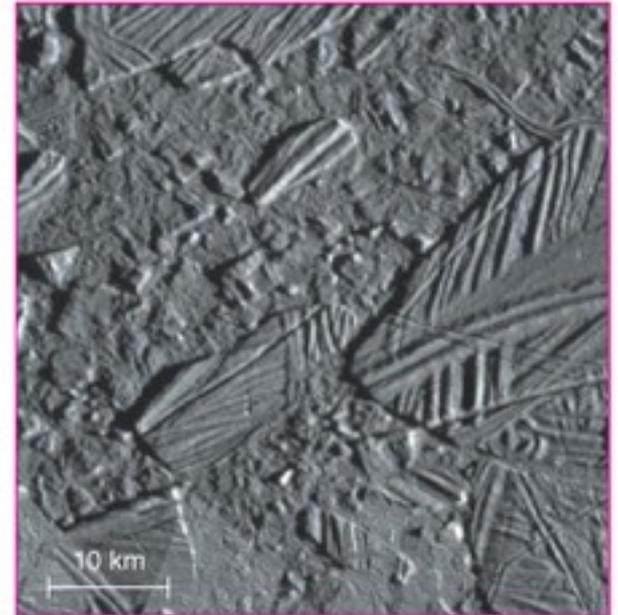
Europa's interior also warmed by tidal heating.



Europa may have a 100-km-thick ocean under an icy crust.

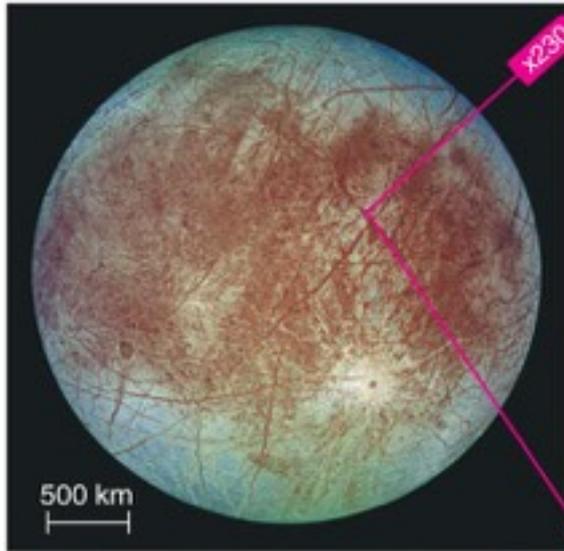


Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .

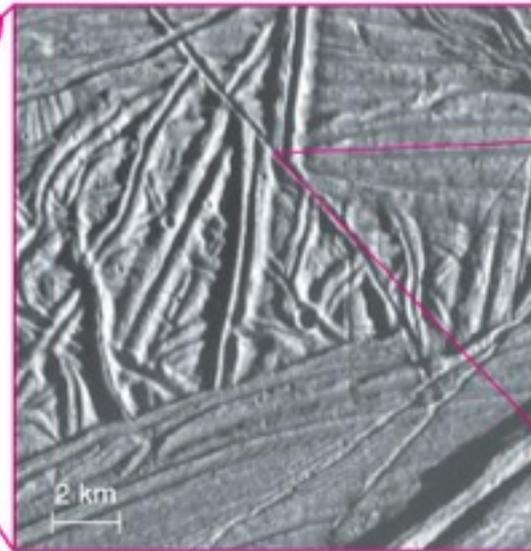


. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

Tidal stresses crack Europa's surface ice.

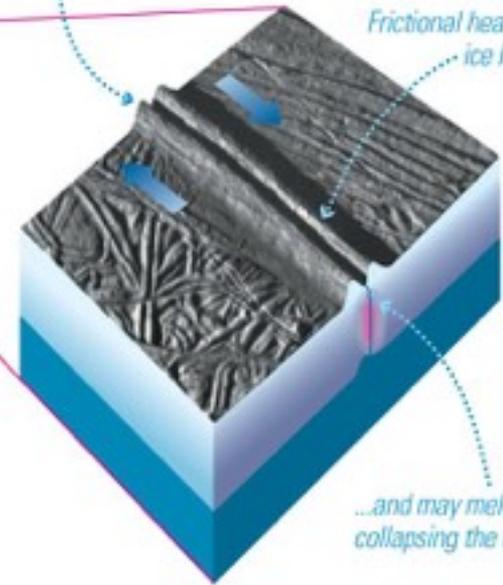


Europa's surface appears heavily cracked even from a distance.



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

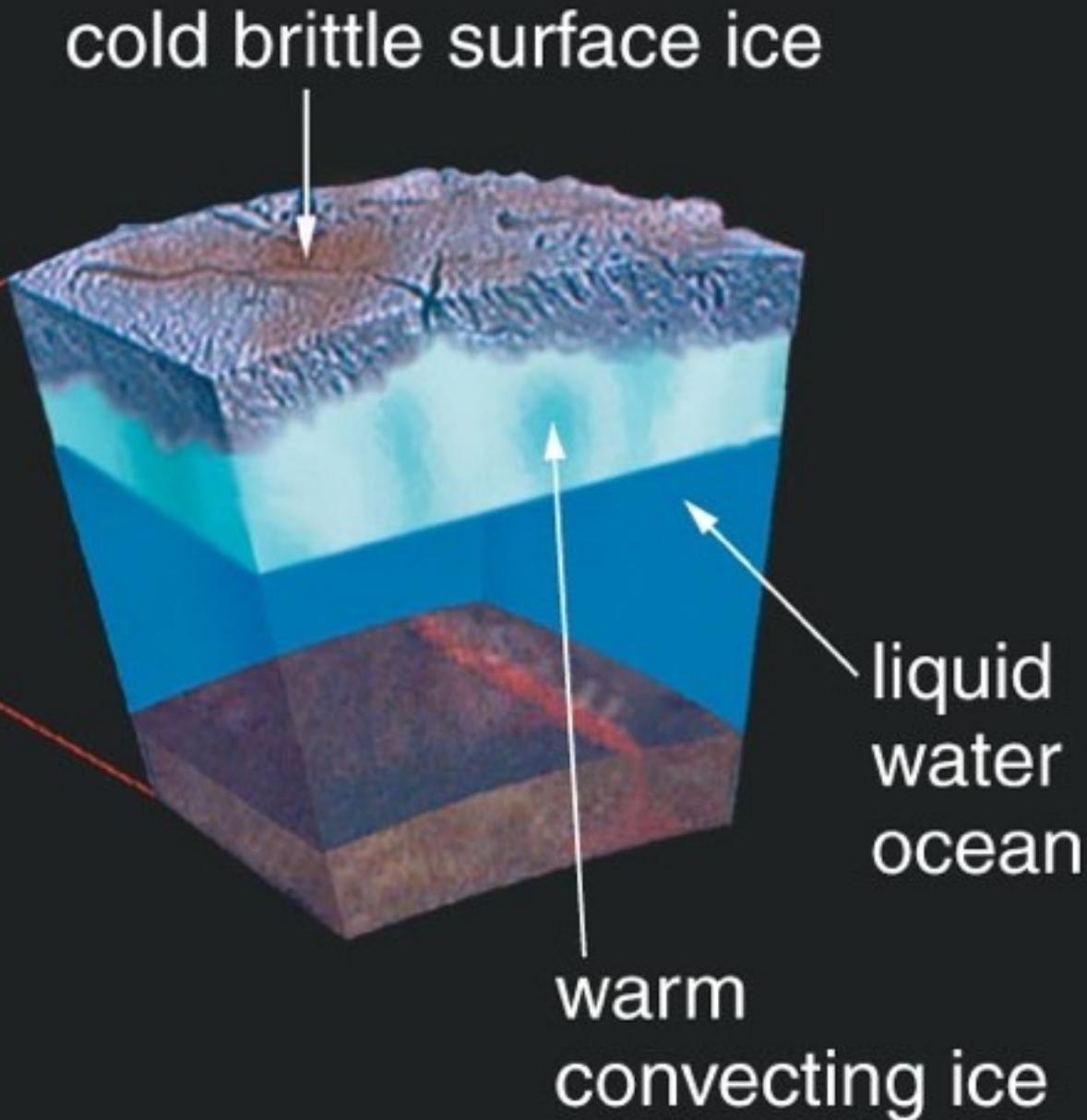
Tidal stresses cause parts of Europa's icy crust to slowly slide past each other.



Frictional heating expands ice here, forming the ridge...

...and may melt ice here, collapsing the ridge center.

Europa



- Icy surface
 - cracks driven by some “geological” activity
- Liquid ocean beneath?
 - popular spot to speculate about the potential for life

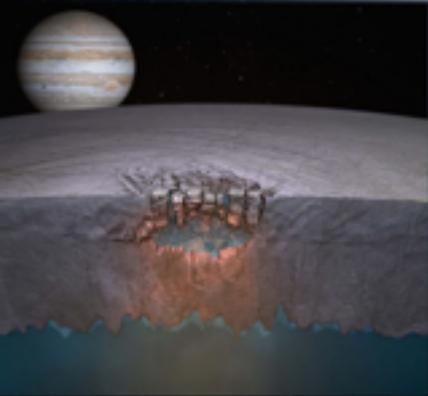
2001 Space Odyssey

written when 2001 was far in the future

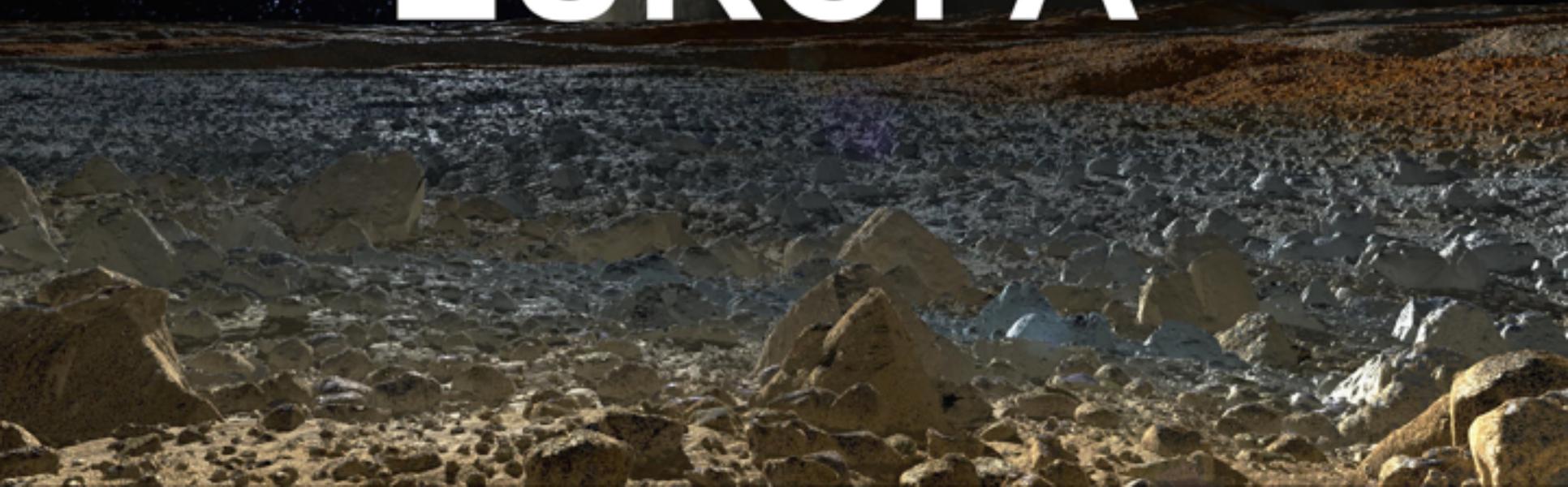


There are serious proposals to send a robotic submersible to Europa.

2001 warned against that because this thing will eat you. ♀



EUROPA

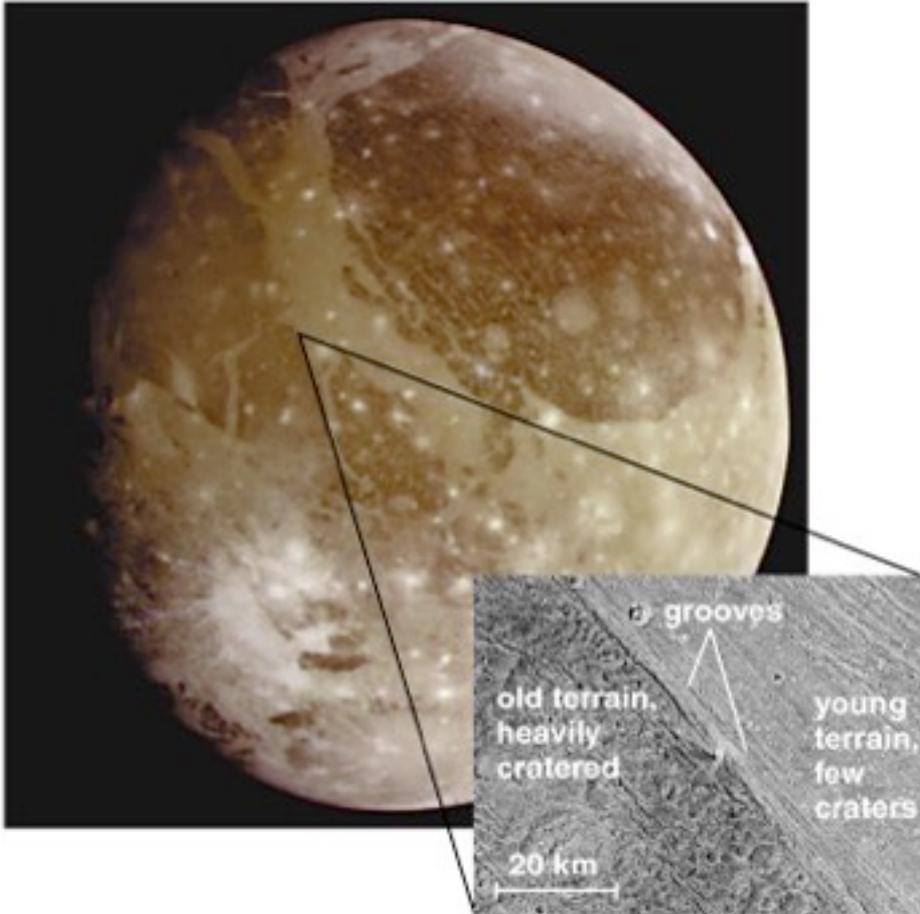


The moons of the Jovian planets



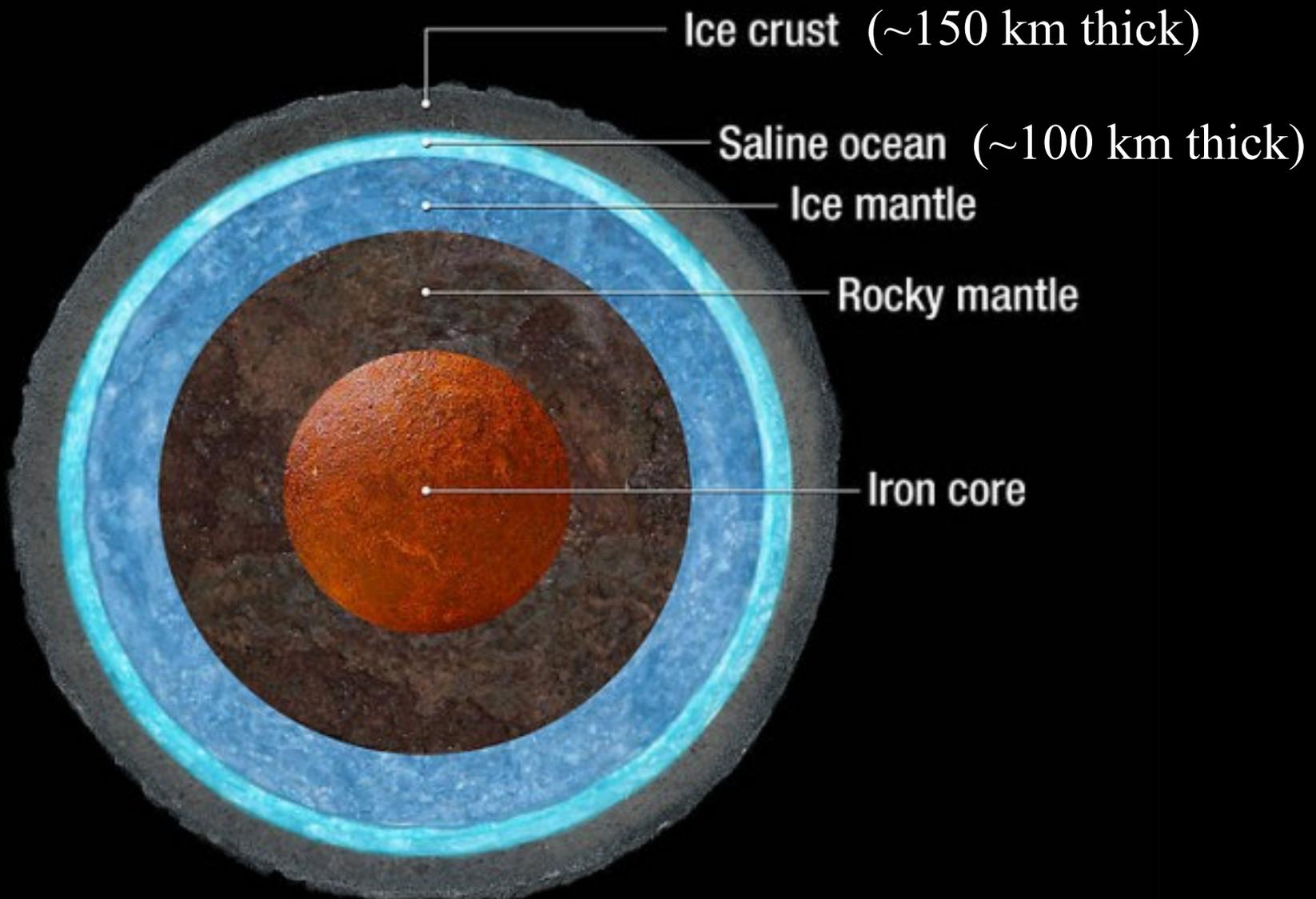
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Ganymede



- Largest moon in the solar system
- Clear evidence of geological activity
- Salty ocean under thick crust of ice
- Tidal heating plus heat from radioactive decay?

Ganymede Interior

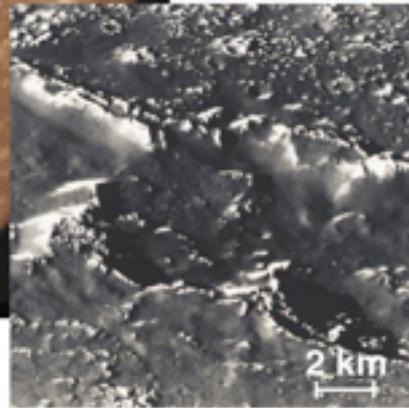
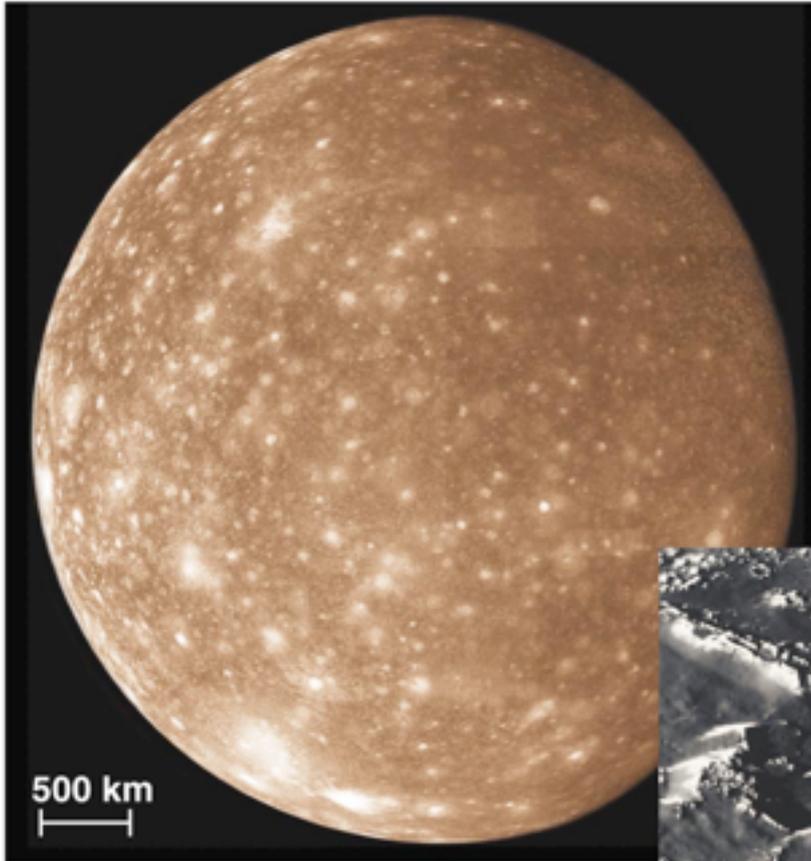


The moons of the Jovian planets



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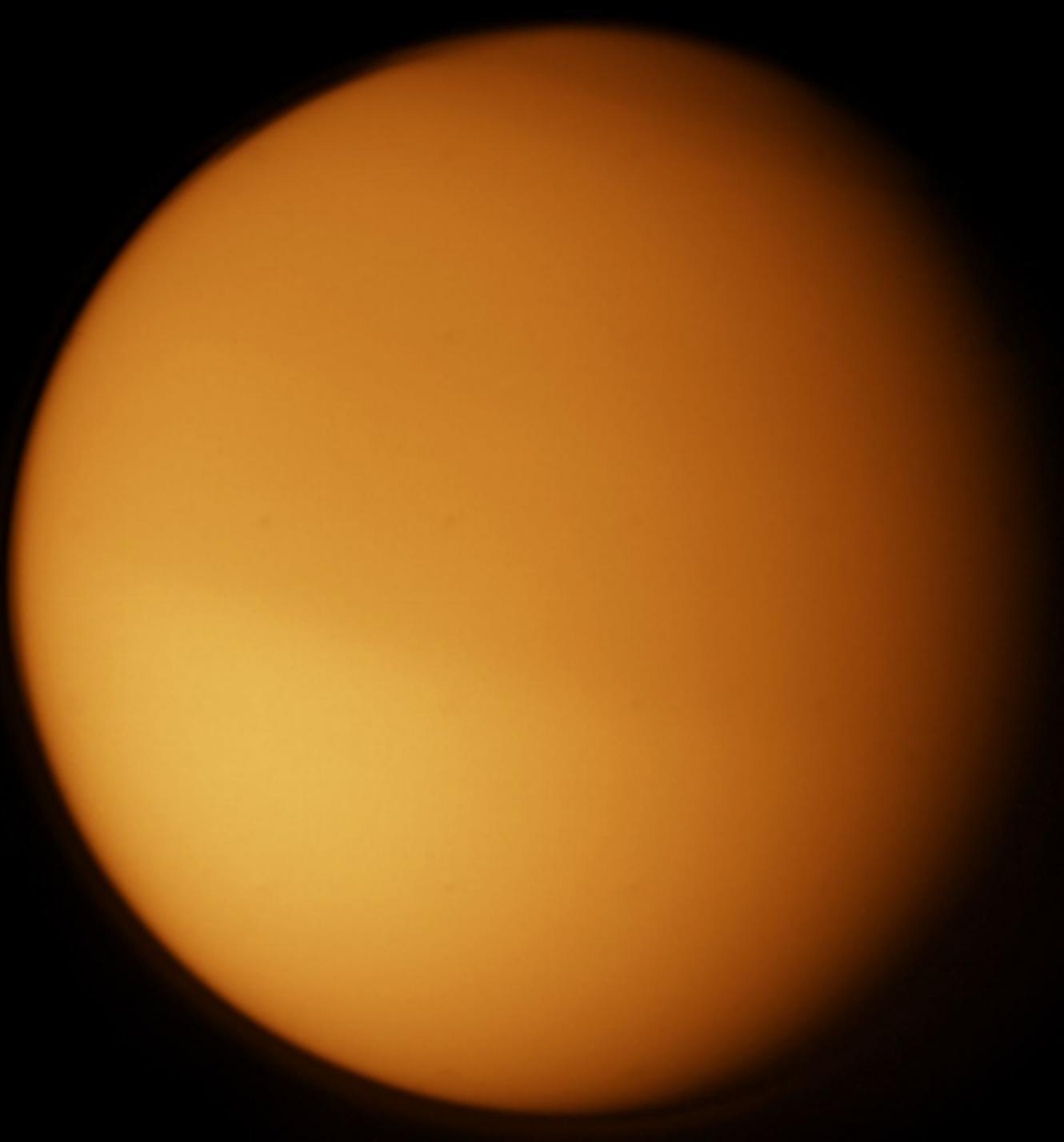
Callisto



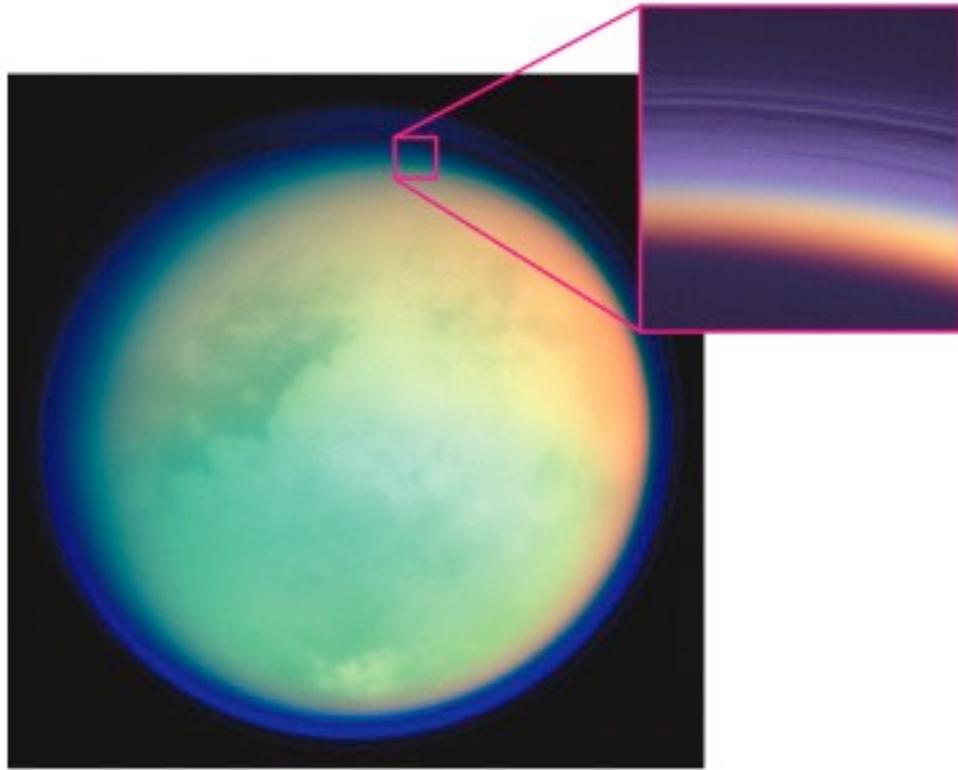
- "Classic" cratered iceball
- No tidal heating, no orbital resonances

Saturn

- Has one large moon - **Titan**
- a large number of medium-sized and small moons
- Rings composed of many tiny icy moonlets

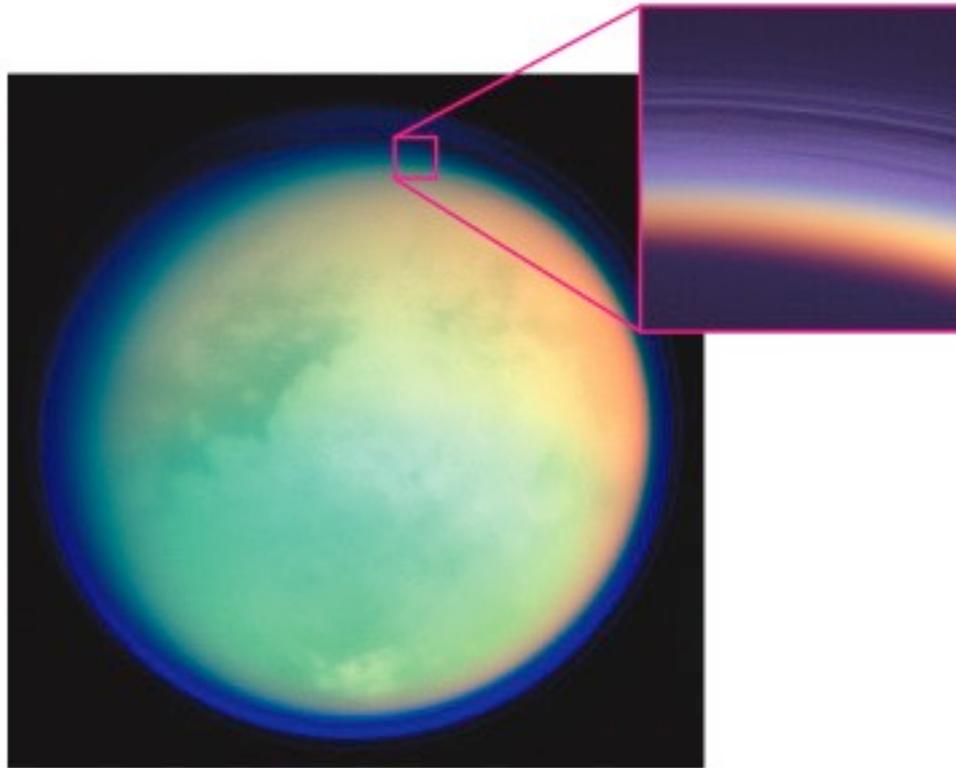


Saturn's large moon Titan



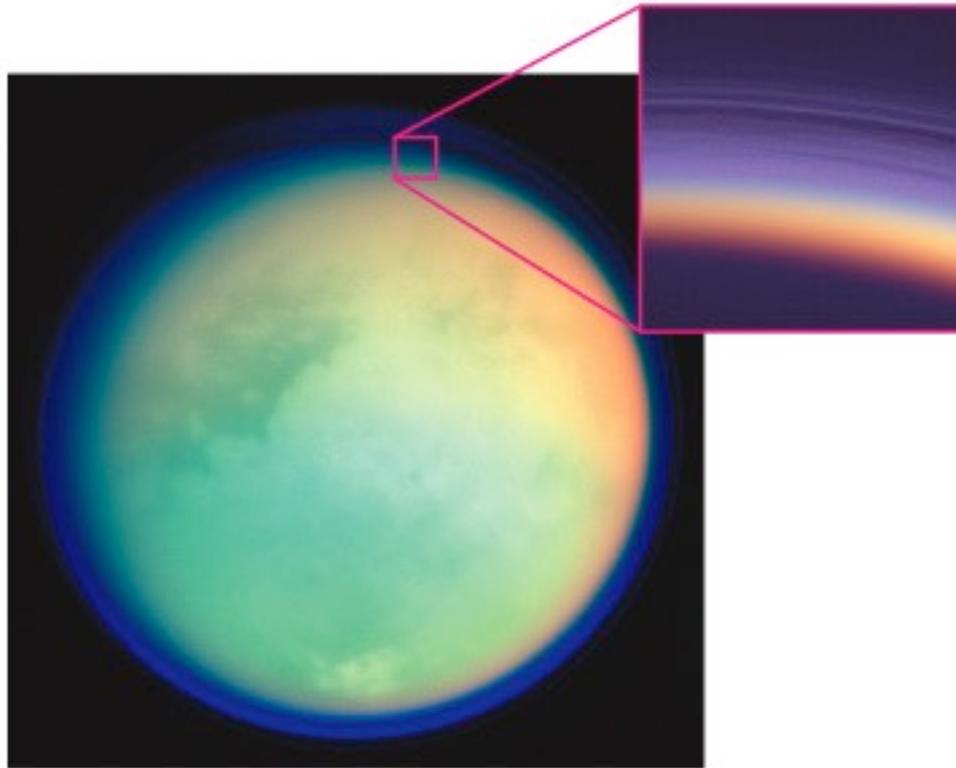
- Titan is the only moon in the solar system which has a thick atmosphere.
- It has a thick haze layer that obscures the surface at optical wavelengths.

Saturn's large moon Titan



- Atmospheric composition:
 - 90% N₂
 - 5% Argon
 - 5% CH₄ (methane)
 - other hydrocarbons
- Hazy

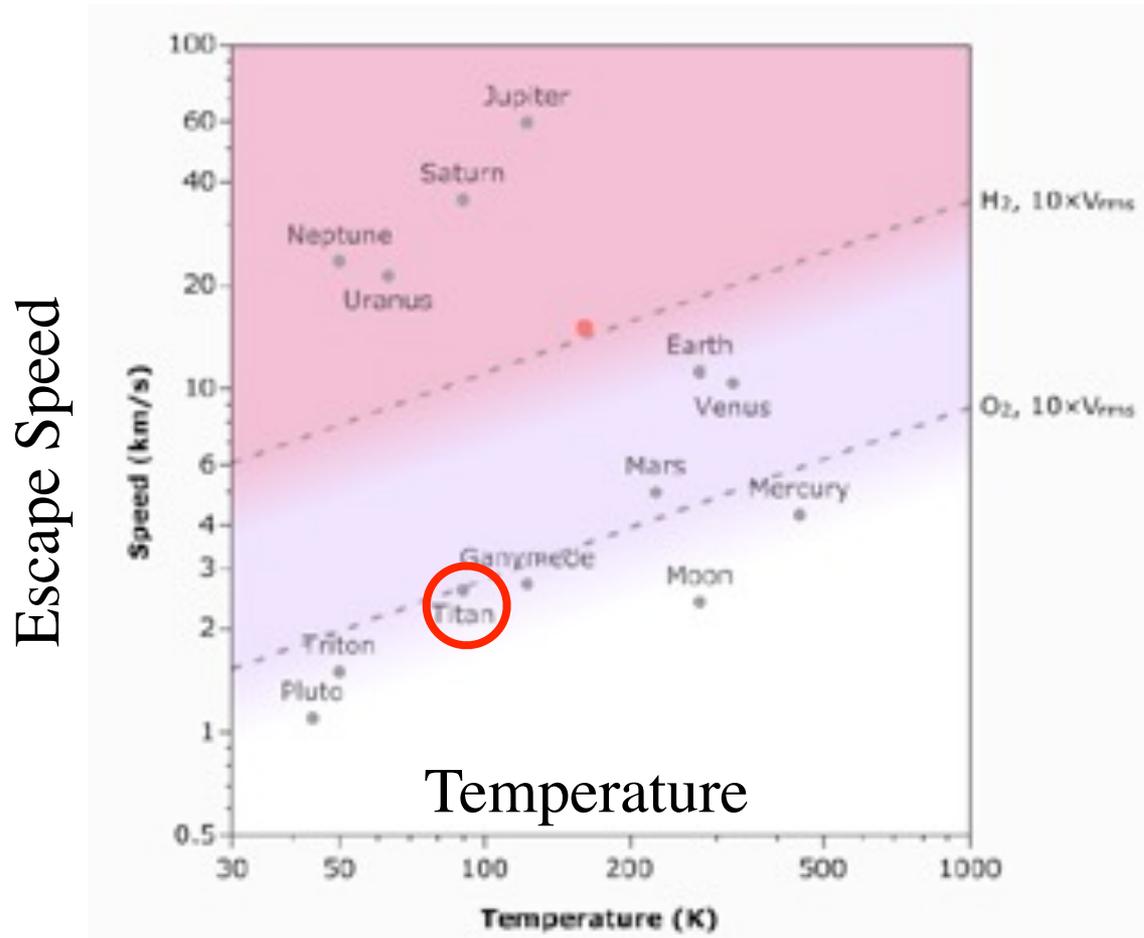
Saturn's large moon Titan



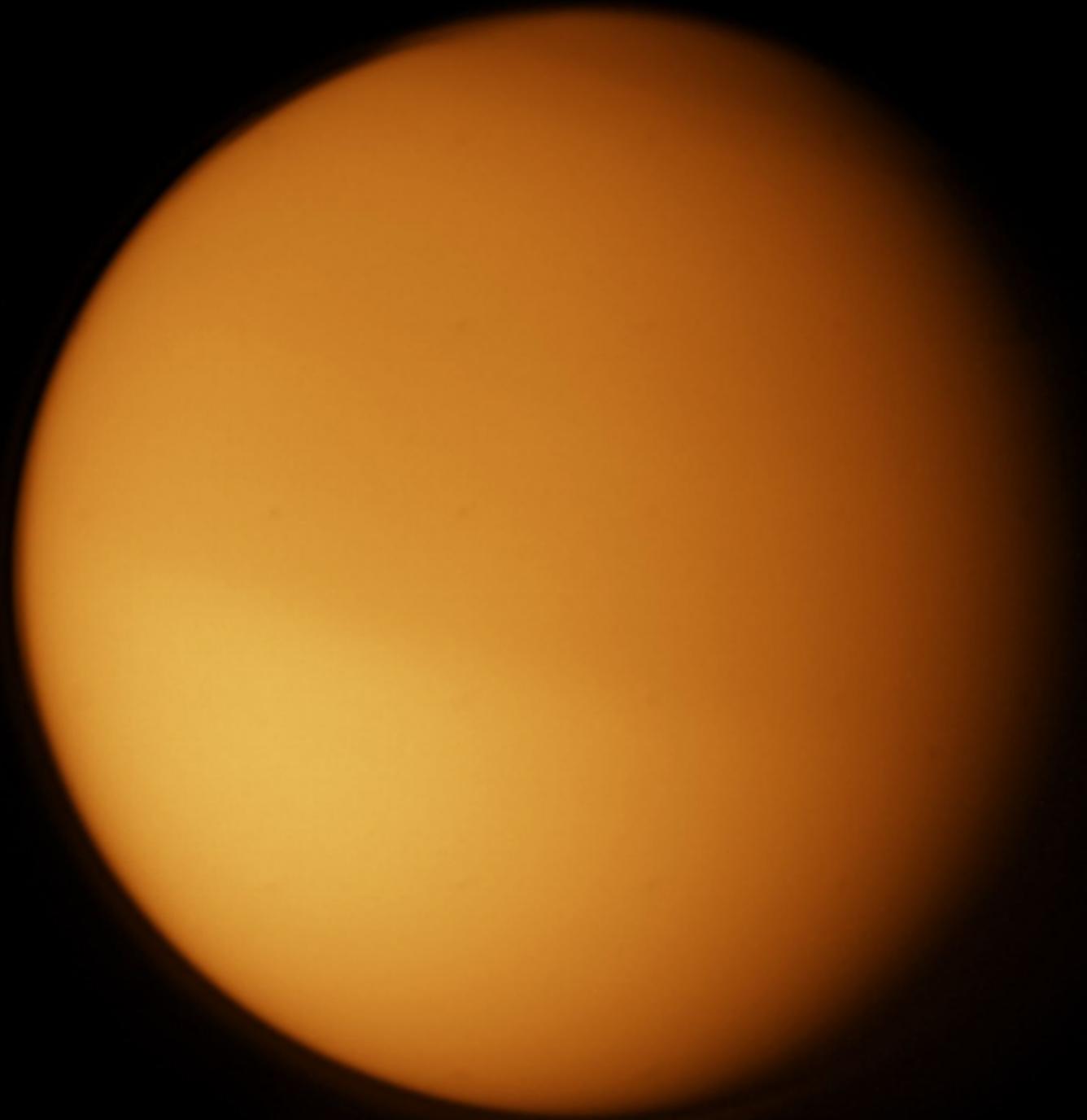
- Relative to Earth:
 - 1.5 Atm pressure
 - 4x denser
 - comparable total mass (1.2x)
 - more extended
 - due to lower gravity
- Cold
 - -180°C

Titan is

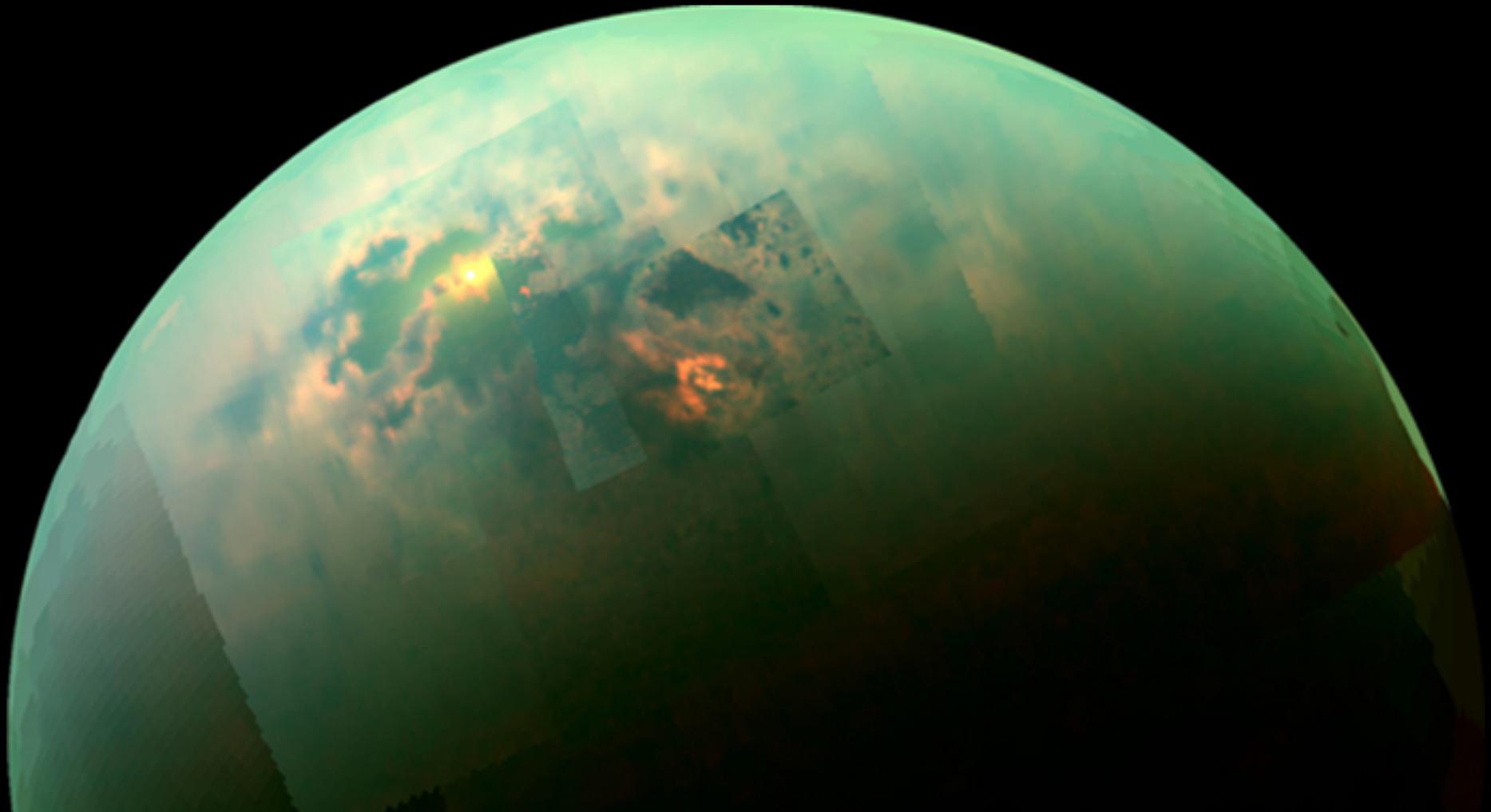
- Big for a moon, and
- cold - can retain an atmosphere



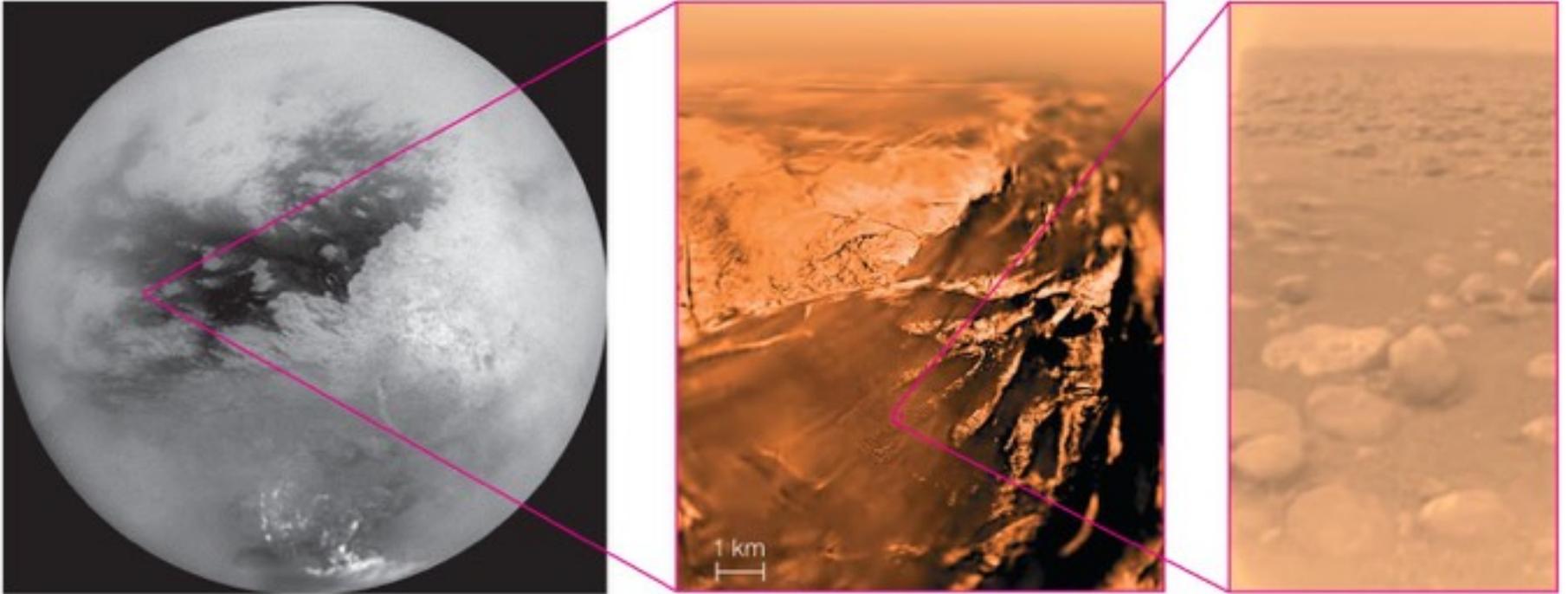
atmospheric haze
in optical light



Some transparent windows in the infrared.
Reveals widespread lakes of liquid methane.
Weather on Titan involves methane clouds and rain.

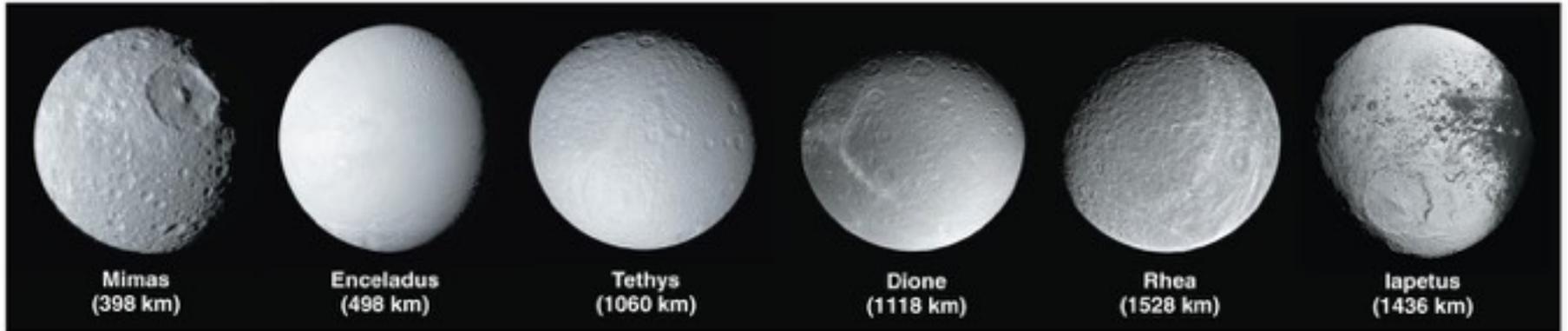


Titan's Surface



- The *Huygens* probe provided a first look at Titan's surface in early 2005.
- It had liquid methane, “rocks” made of ice.

Medium Moons of Saturn



- Almost all of them show evidence of past volcanism and/or tectonics.

Medium Moons of Saturn



Mimas
(398 km)



Enceladus
(498 km)



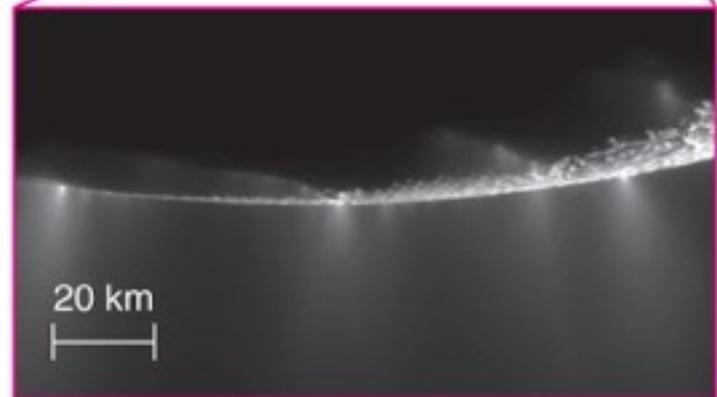
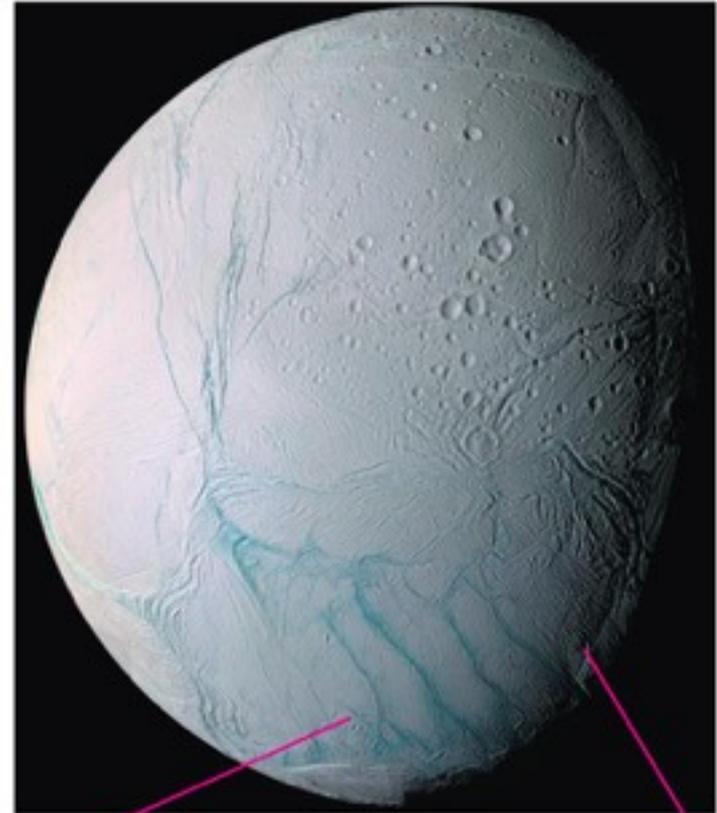
Tethys
(1060 km)

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- Mimas has a big crater that makes it look like the Death Star.

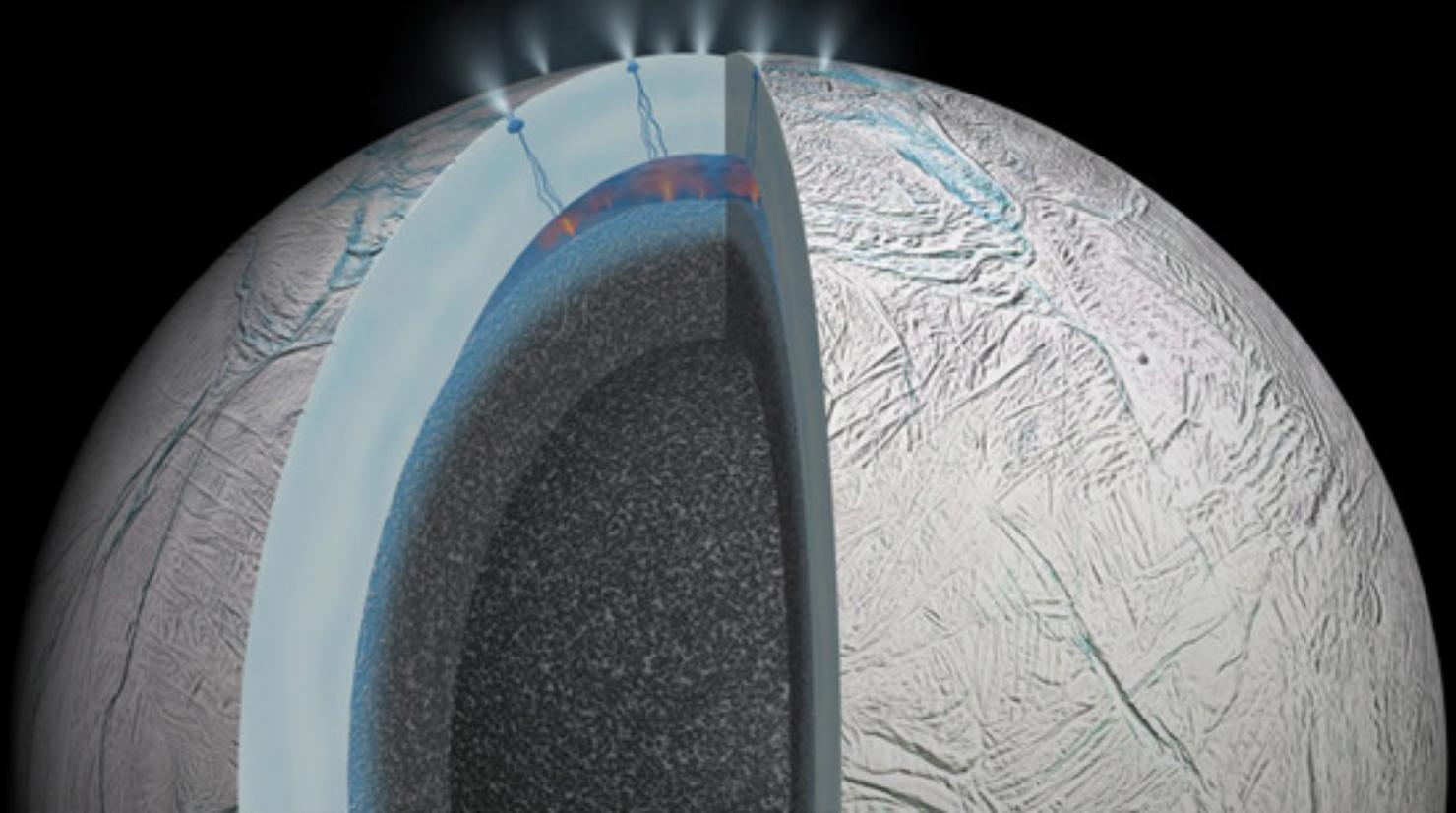
Medium Moons of Saturn

- Ice fountains of Enceladus suggest it may have a subsurface ocean.



Medium Moons of Saturn

- Ice fountains of Enceladus suggest it may have a subsurface ocean.



Medium Moons of Saturn



Dione
(1118 km)



Rhea
(1528 km)

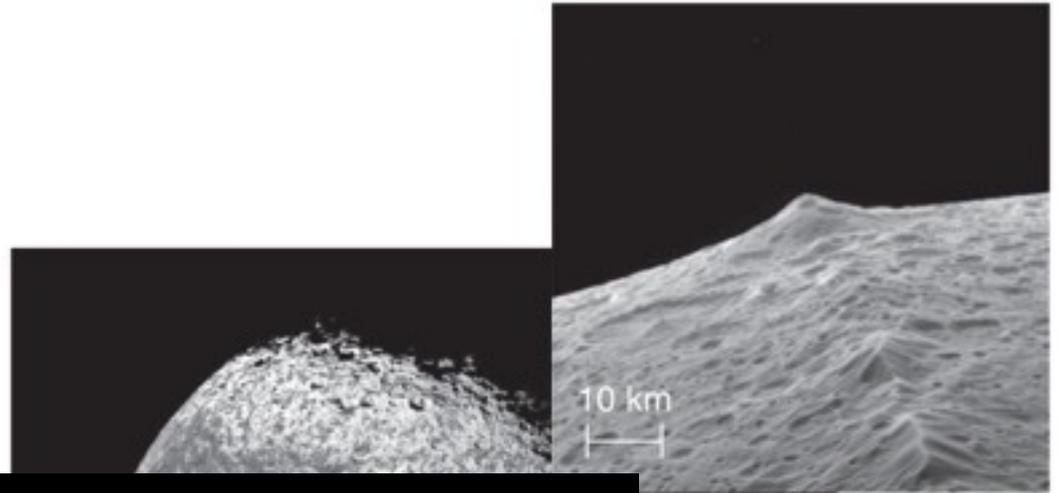


Iapetus
(1436 km)

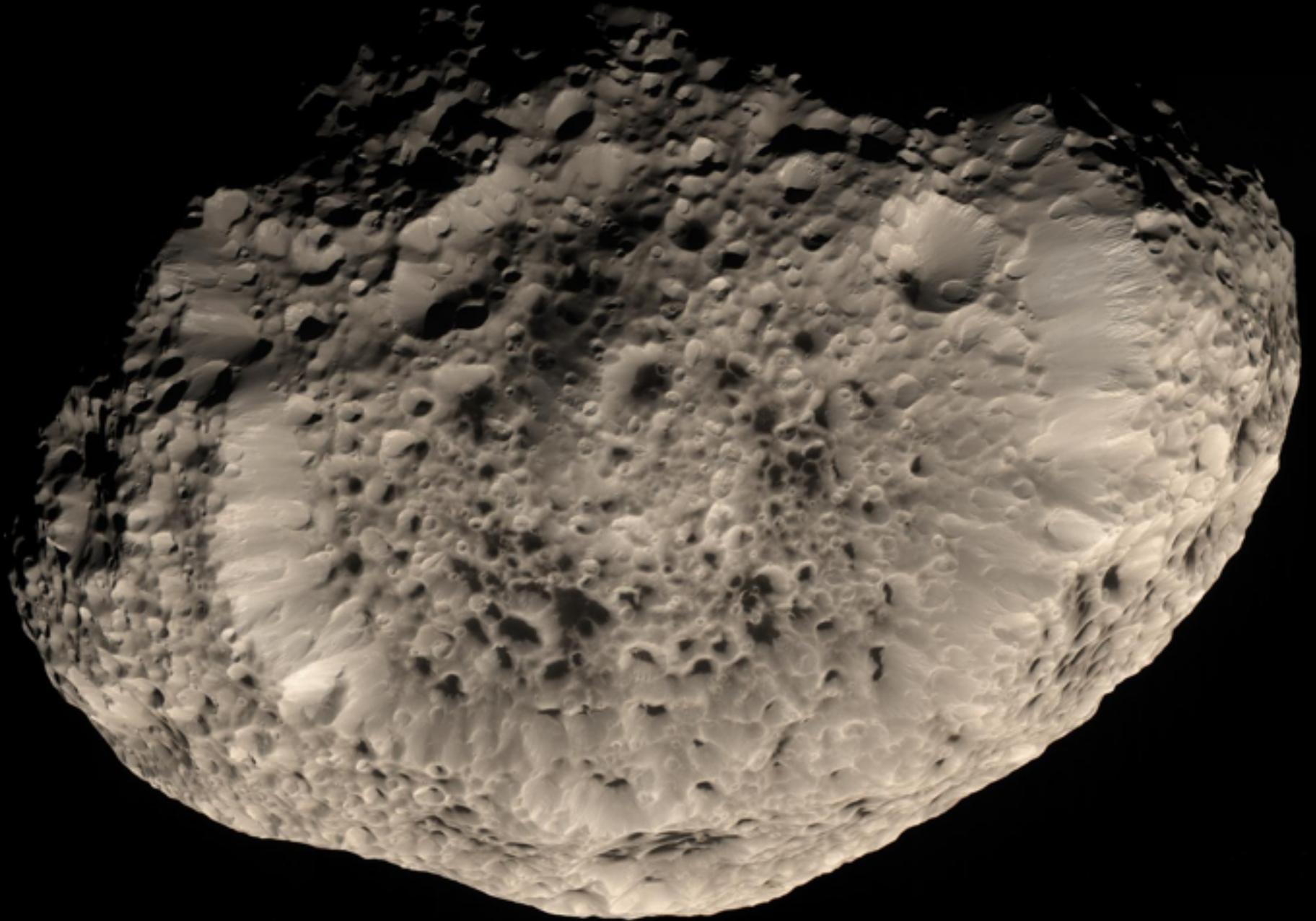
- Iapetus is dark on one side & bright on the other. It seems to have collected a goo of space debris emitted by Phoebe on the leading (dark) side of

Medium Moons of Saturn

- Iapetus has a curious ridge around much of its equator



Small moons can also be weird. Hyperion looks like a sponge.



Uranus

medium sized moons



Miranda

Ariel

Umbriel

Titania

Oberon

Neptune

one big moon



Triton

Nereid

Other objects for comparison



Mercury

Moon

Pluto

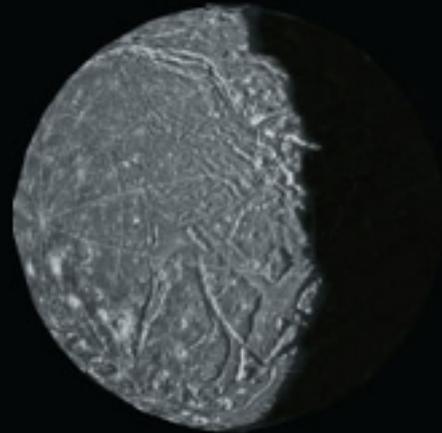
3000 km



Moons of Uranus



Miranda



Ariel



Umbriel

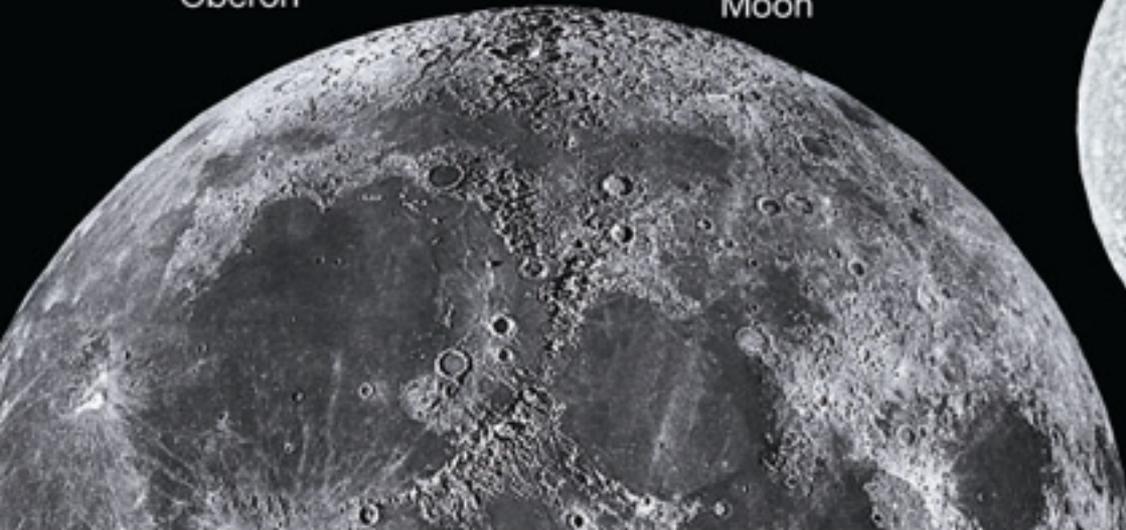


Oberon

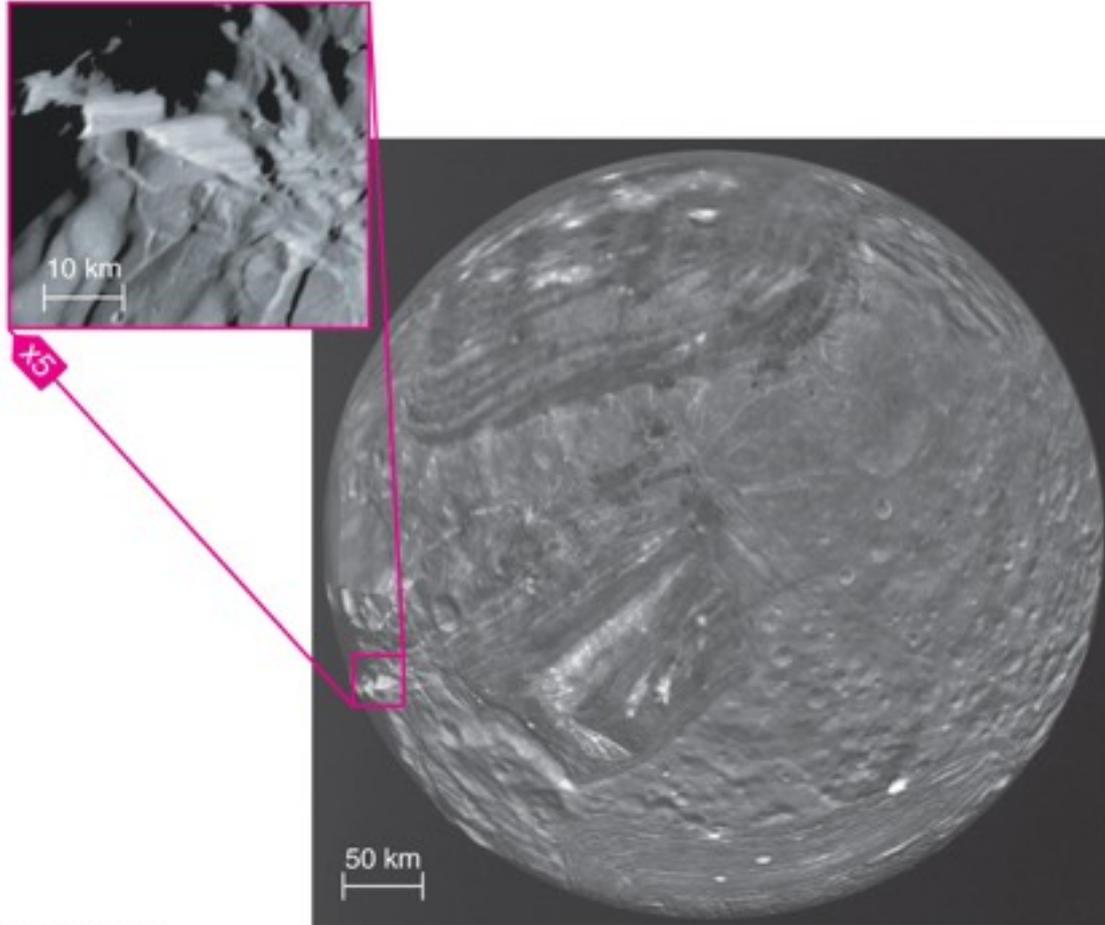
Earth's
Moon



Titania

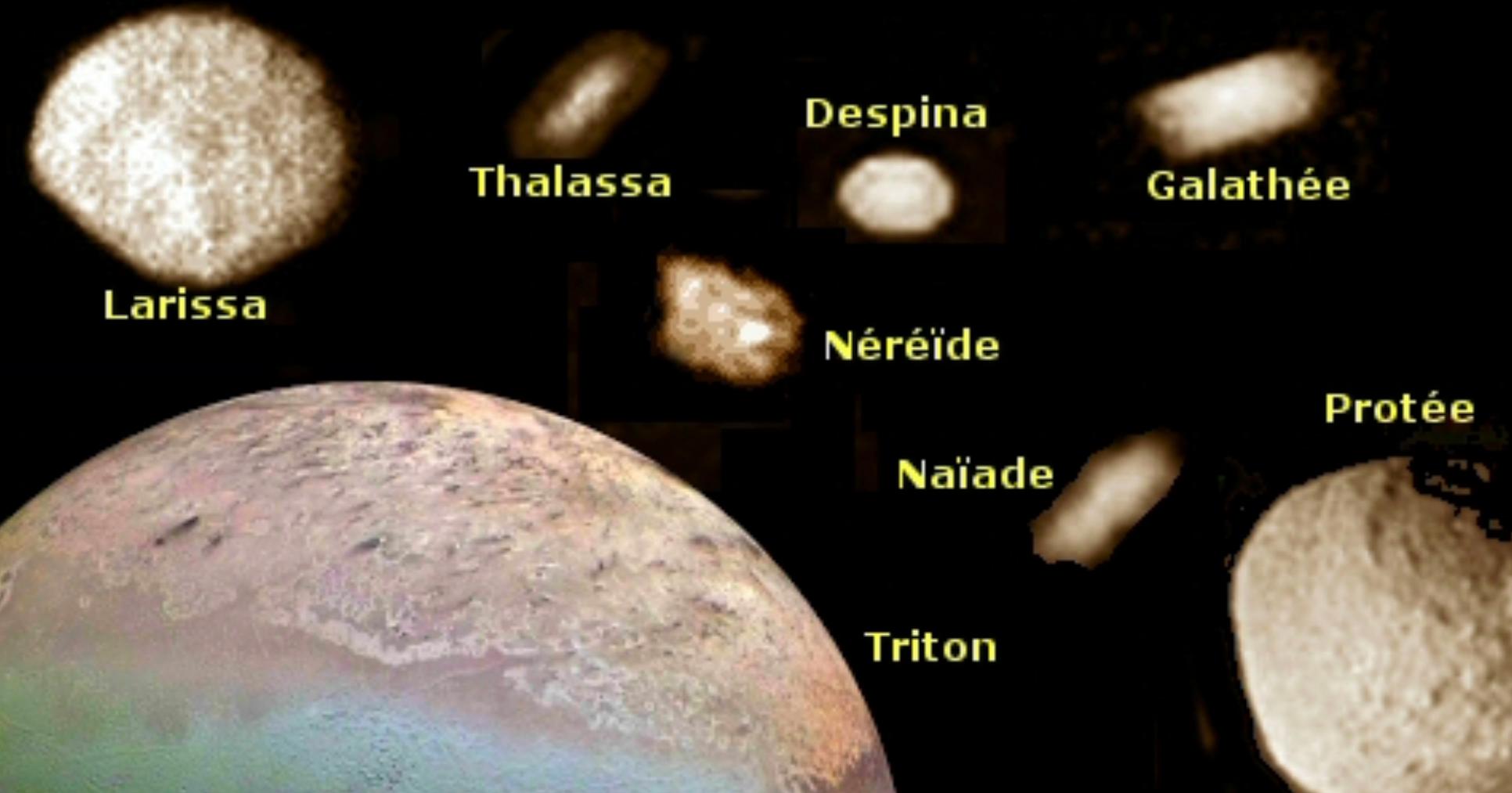


Medium Moons of Uranus



- They have varying amounts of geological activity.
- Miranda has large tectonic features and few craters (possibly indicating an episode of tidal heating in past).

Moons of Neptune



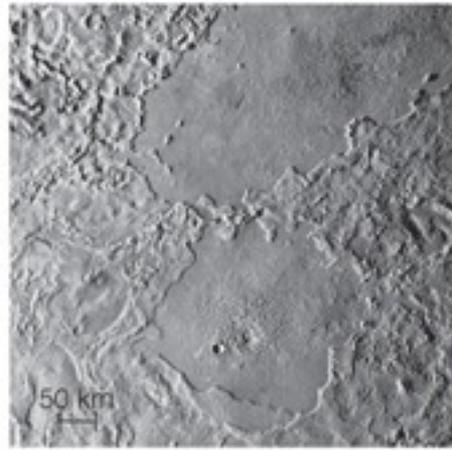
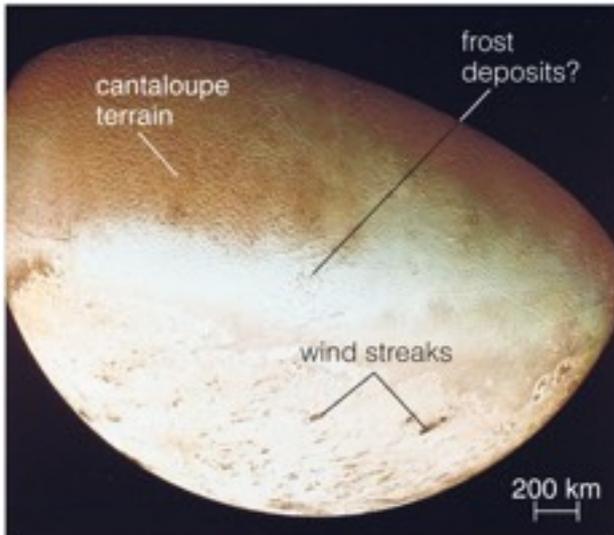
Triton



cantaloupe terrain

Neptune's Moon Triton

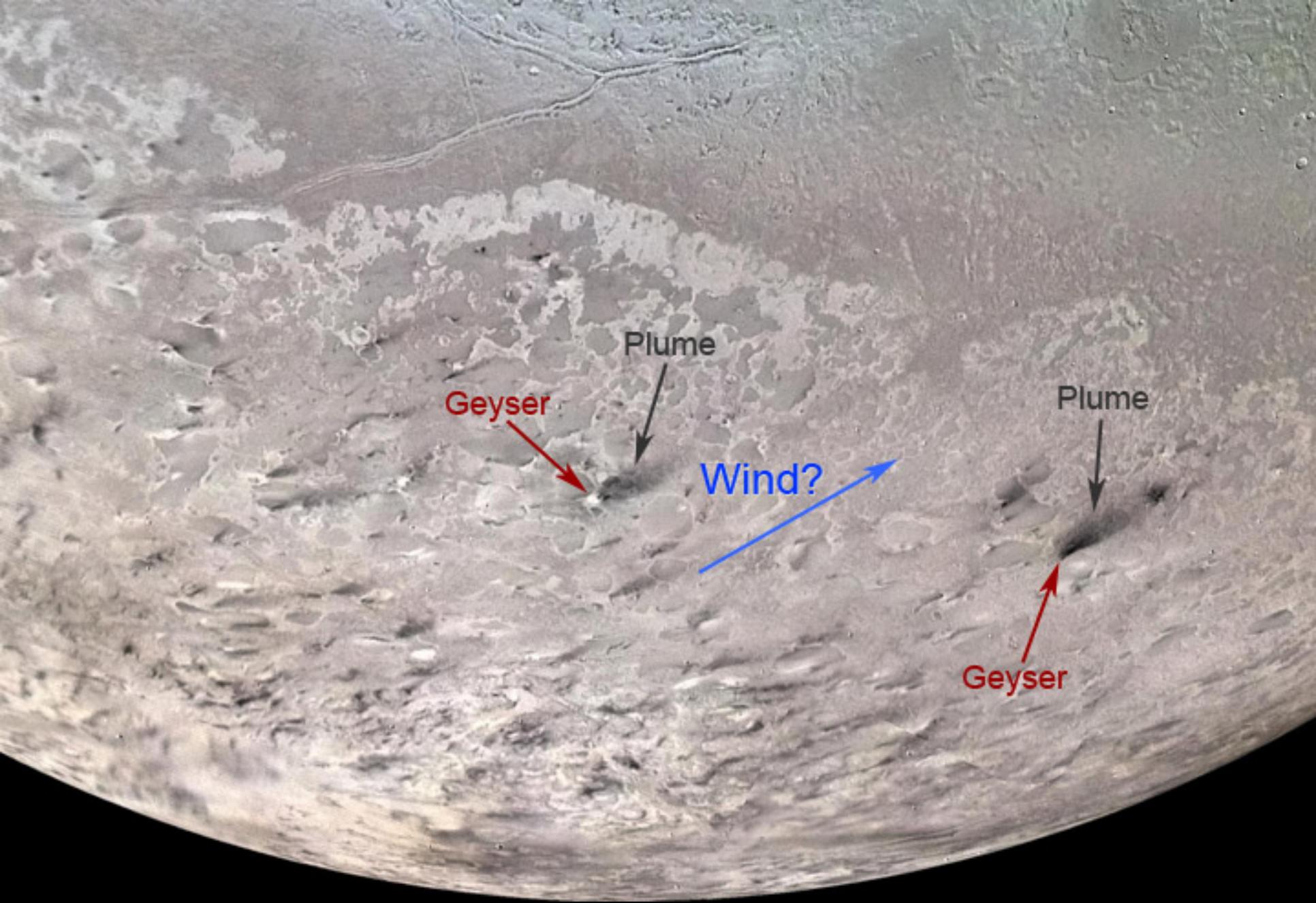
- Similar to Pluto, but larger
- Evidence for past geological activity
- orbits retrograde
 - unique for such a large moon
 - may have been a binary partner of Pluto captured by Neptune



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

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

The occasional geyser streaks the downwind terrain with dark material



Geyser

Plume

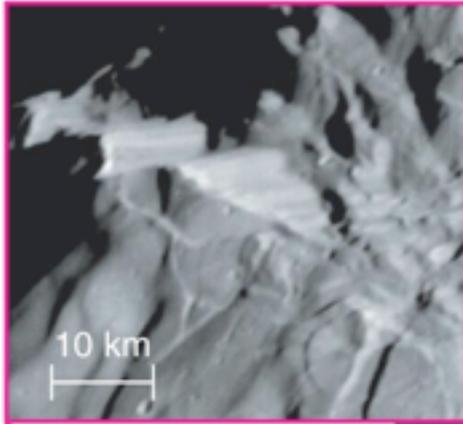
Wind?

Plume

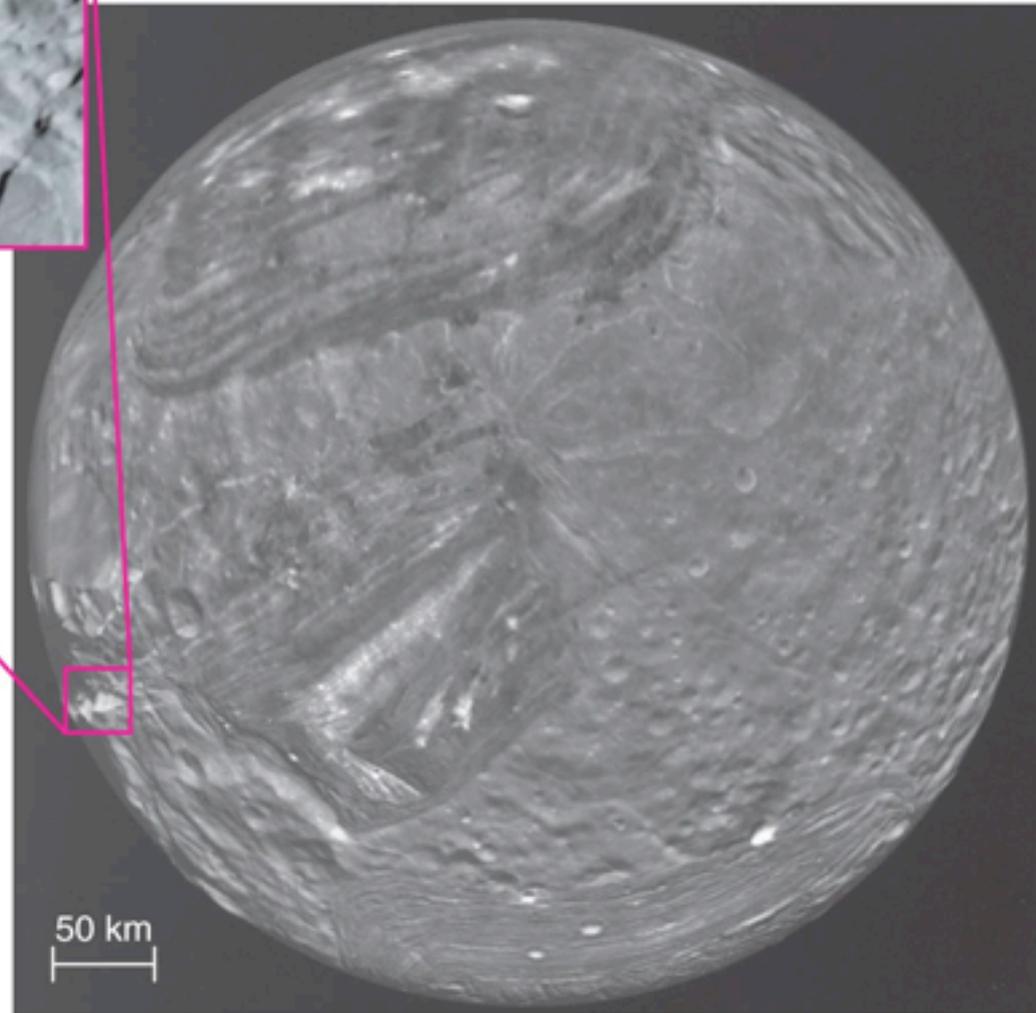
Geyser

geysers

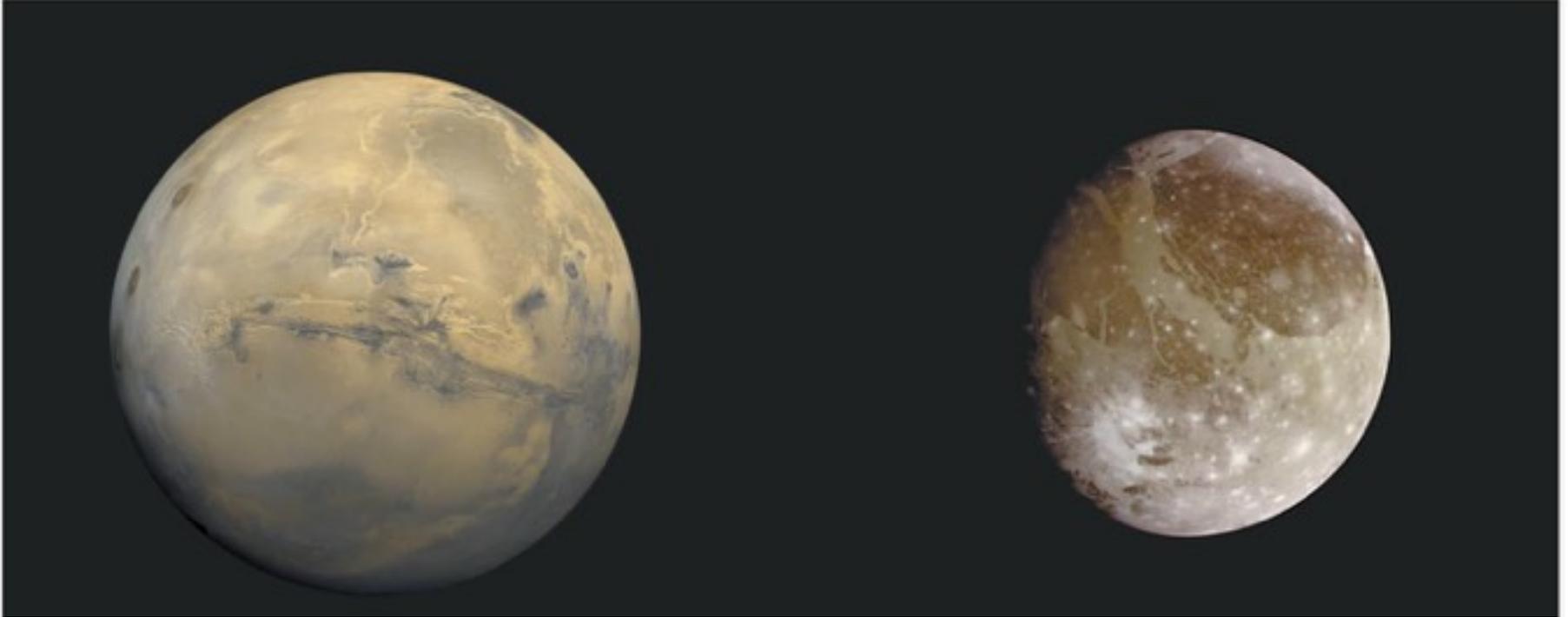
Why are small icy moons more geologically active than small rocky planets?



x5



Rocky Planets versus 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.

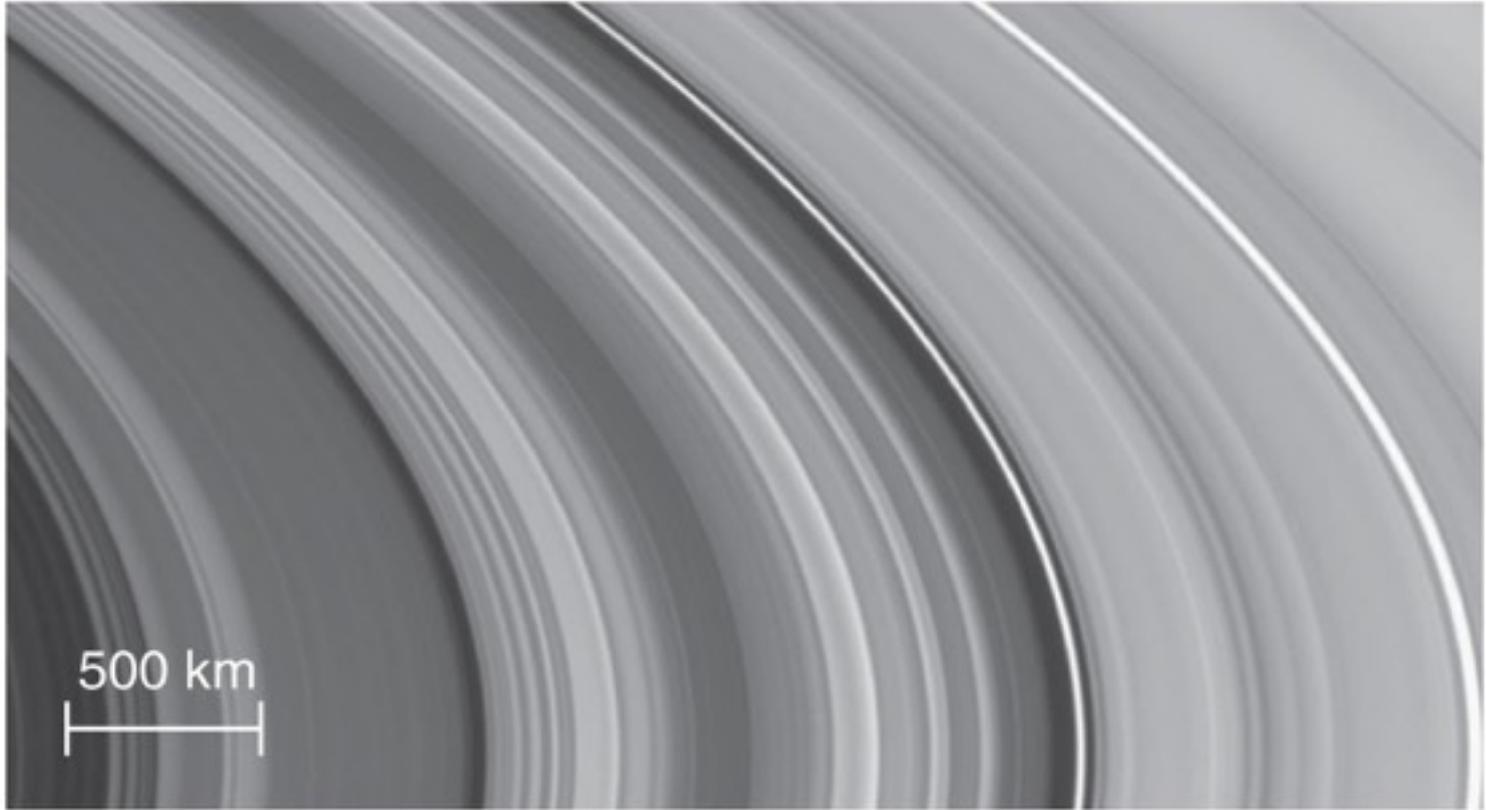
Saturn's rings



What are Saturn's rings like?

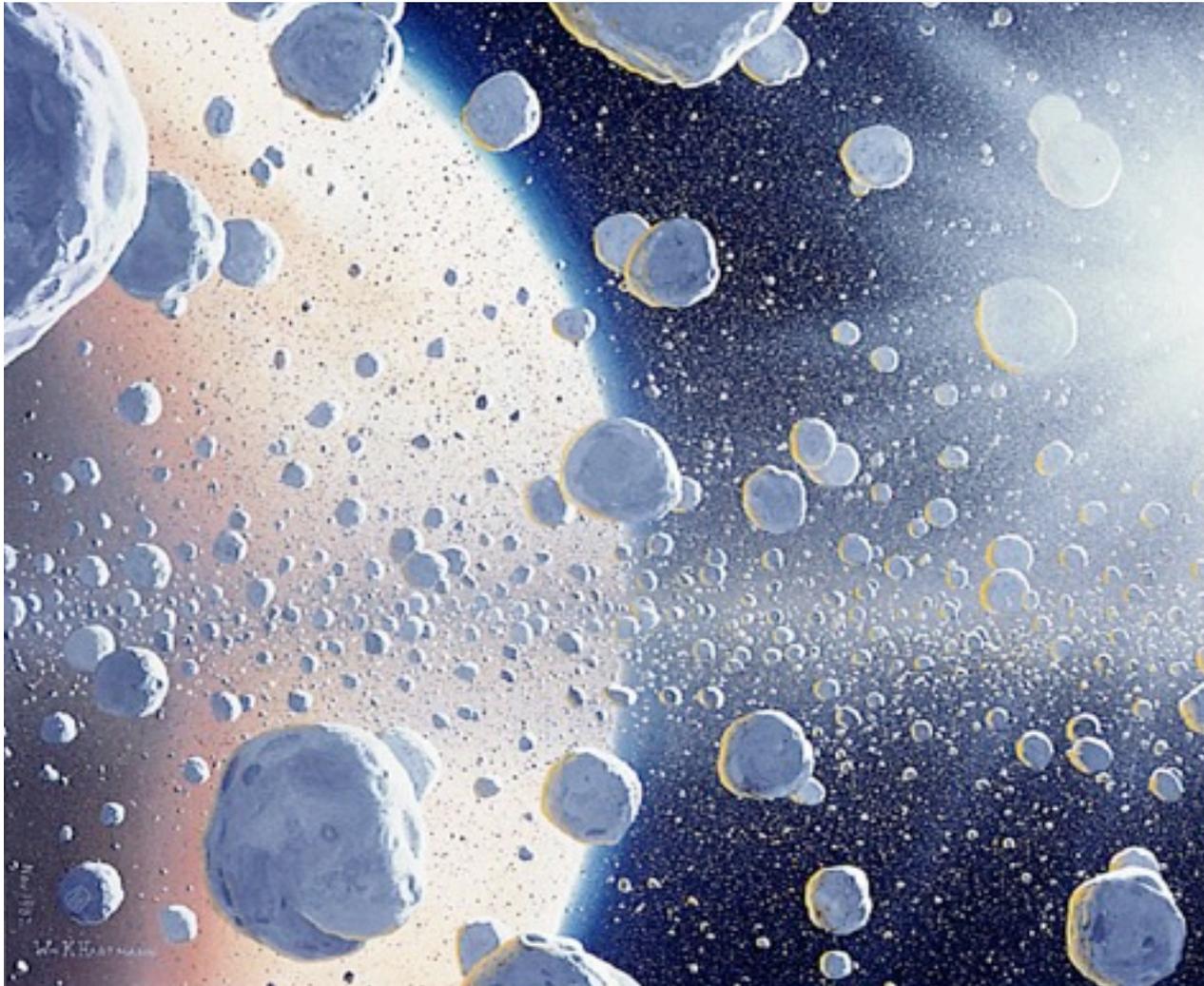
- They are made up of numerous, small, icy particles.
- They orbit over Saturn's equator.
- They are very thin.

Spacecraft View of Ring Gaps



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

Artist's Conception in Ring

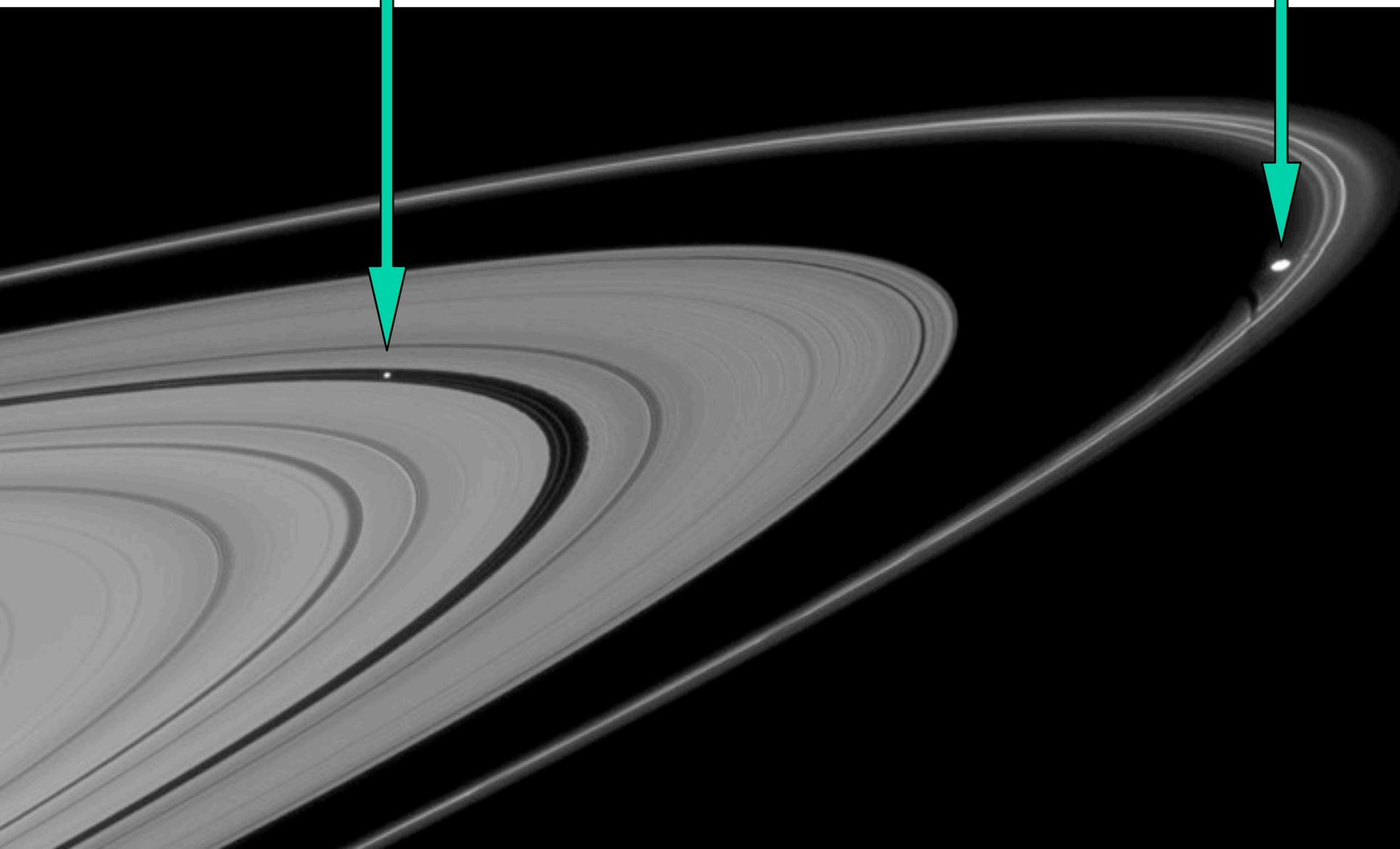


Elaborate structure in rings controlled by the gravity of “shepherd” moons

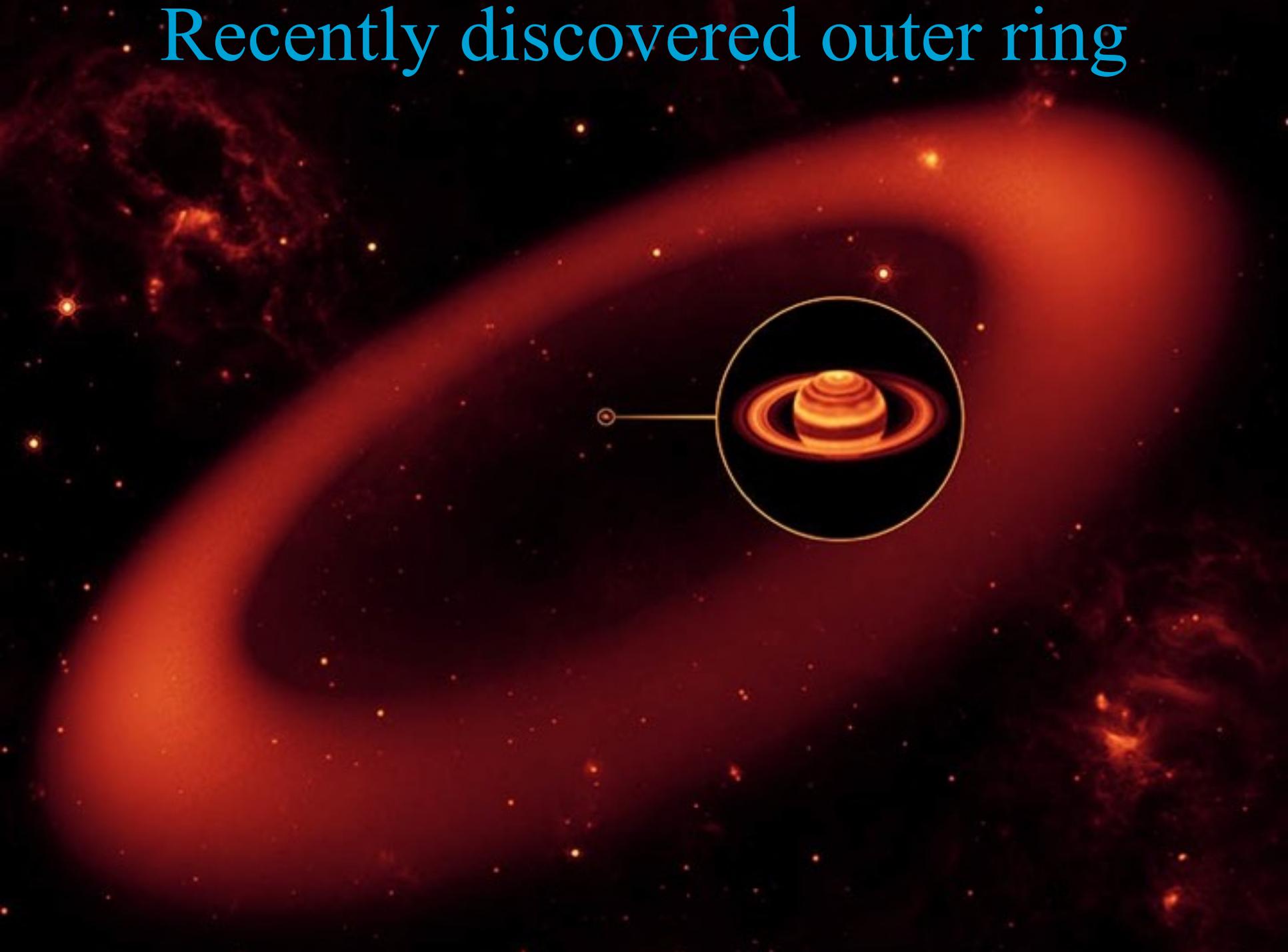
Pan



Prometheus



Recently discovered outer ring



Saturn

Phoebe

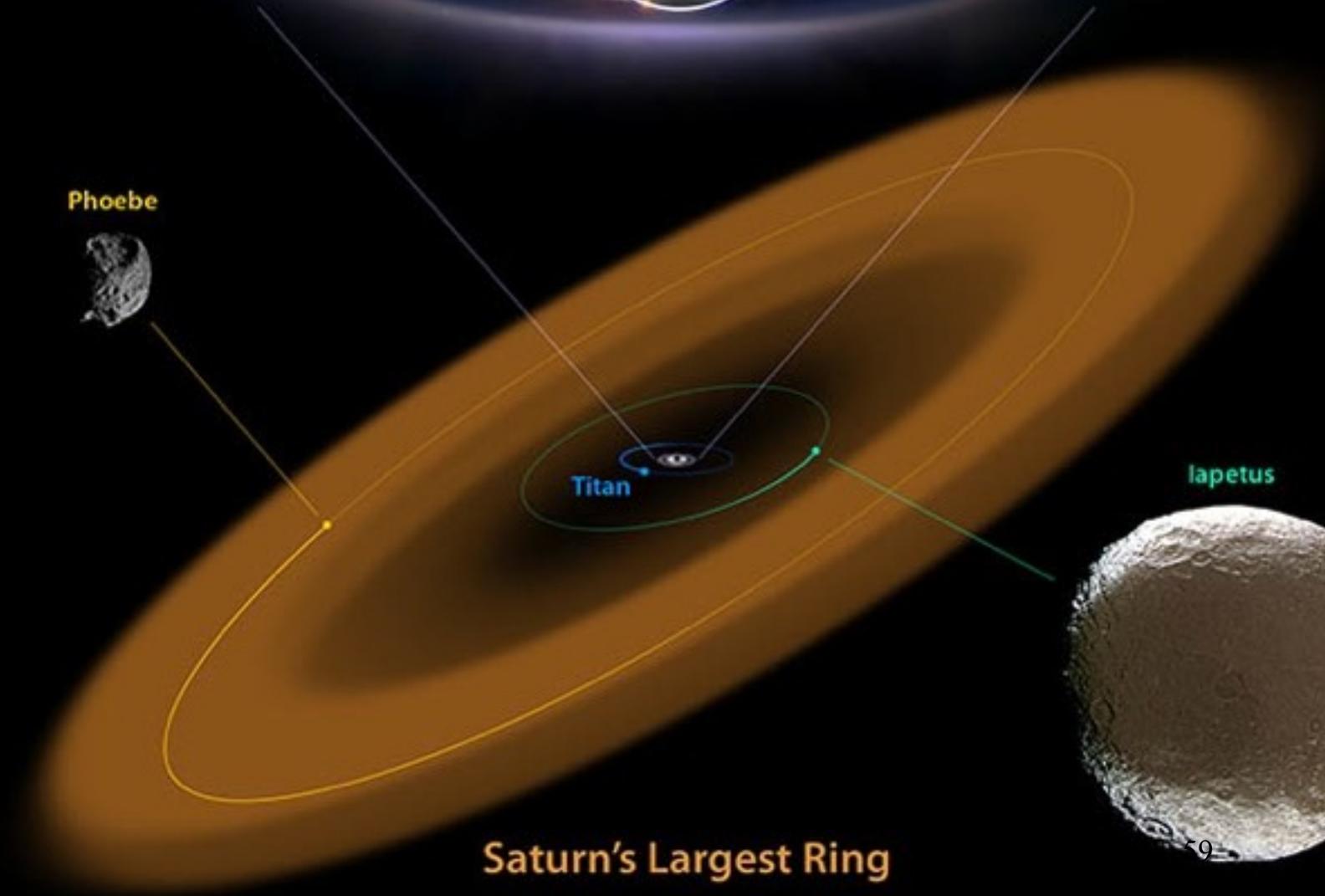


Titan

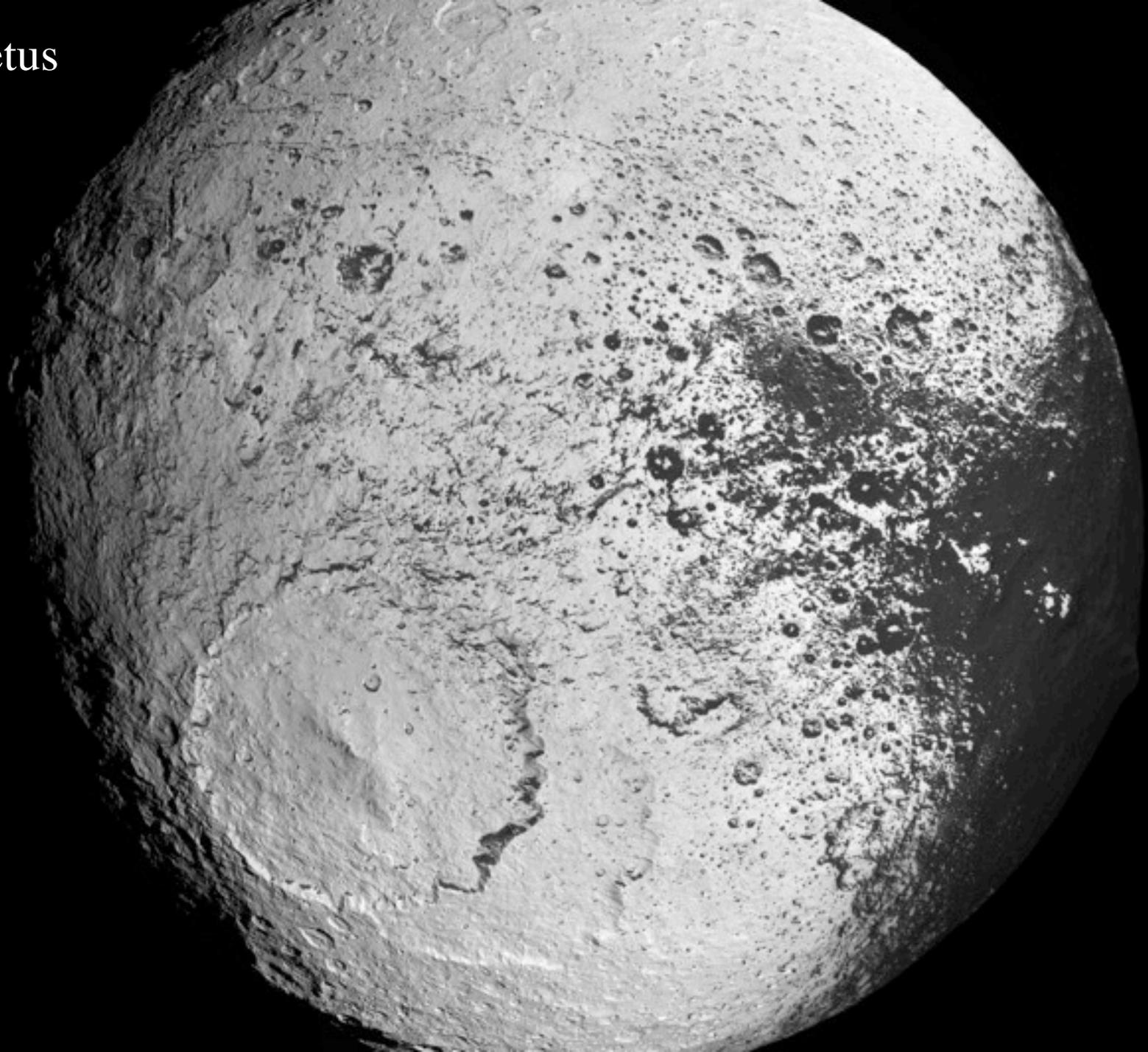
Iapetus



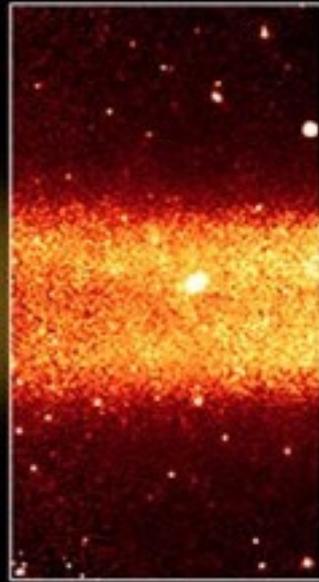
Saturn's Largest Ring



Iapetus



actual data



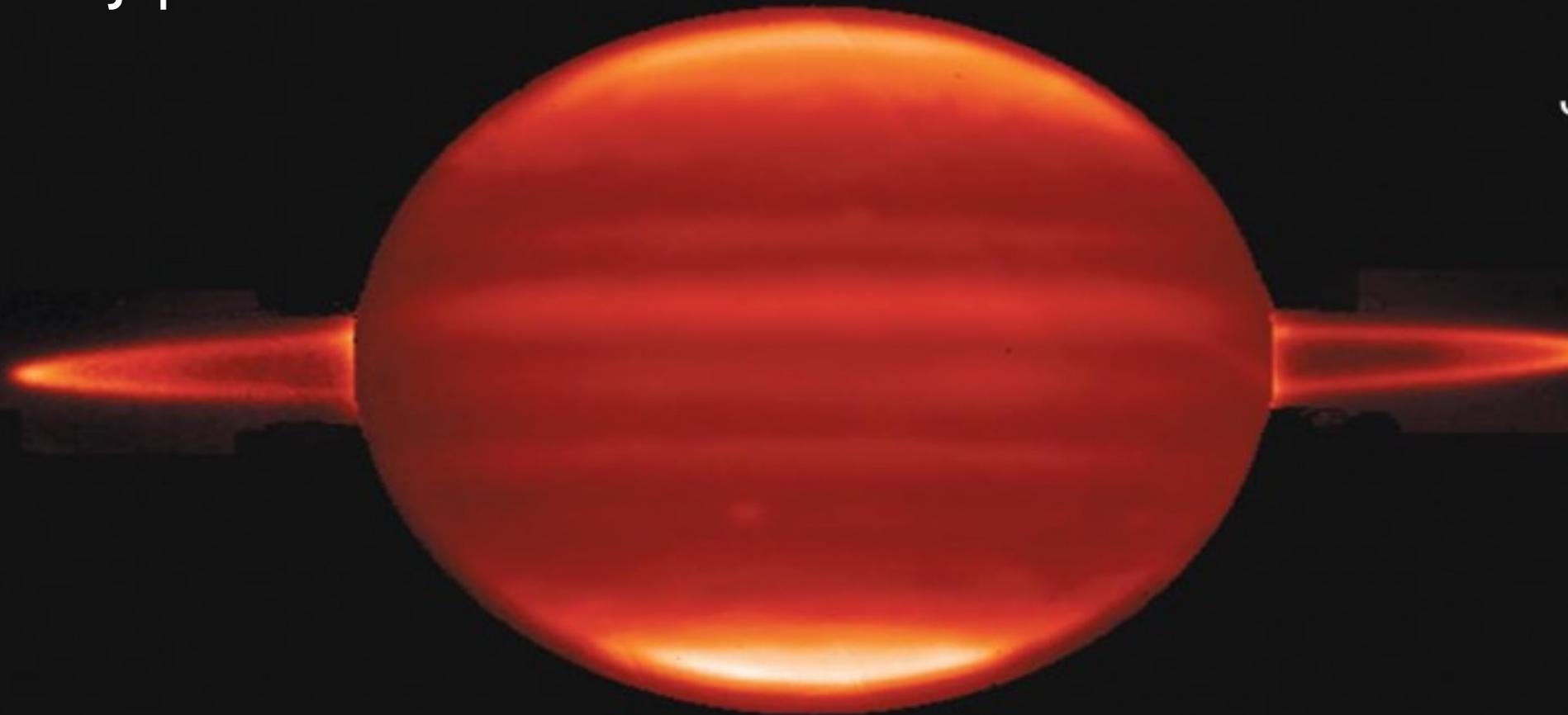
Dust Ring

Saturn

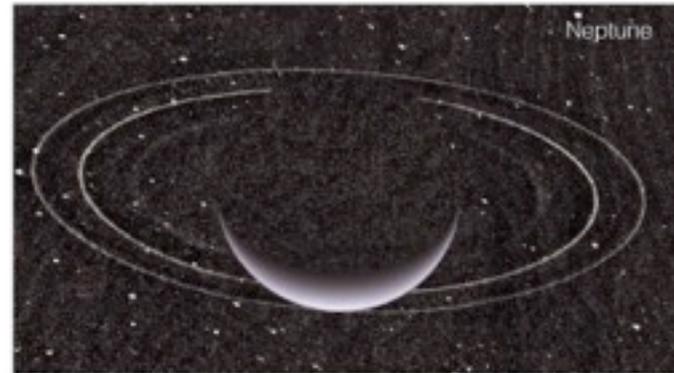
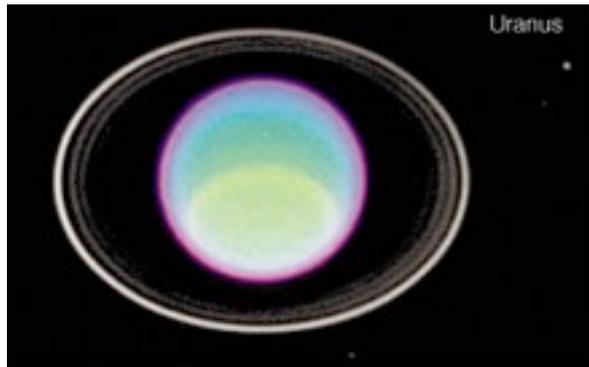
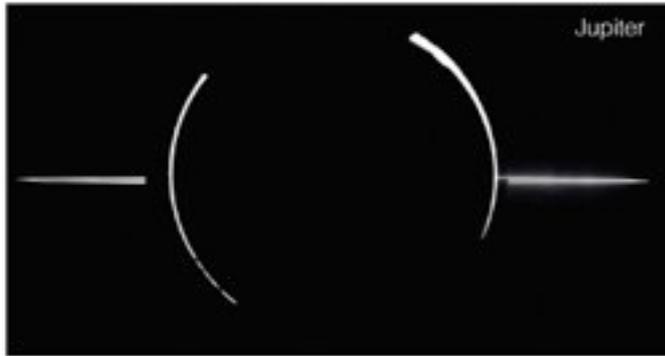


How do other jovian ring systems compare to Saturn's?

Jupiter



Jovian Ring Systems



- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than does Saturn.
- Rings and moons ubiquitous around Jovian planets
 - like small solar systems.

Rings are short-lived yet ubiquitous

- Rings form from dust created in impacts on moons orbiting the Jovian planets.
- There must be a continuous replacement of tiny particles.
 - The tiny particles that make up the rings are subject to non-gravitational forces (photon pressure, solar wind) that push them out of orbit.
- The most likely source is impacts with jovian moons.
 - The dust emitted by Phoebe is an example of ring building in progress.

Ring Formation



- Jovian planets all have rings because they possess many small moons close in.
- Impacts on these moons are random.
 - rings come and go
- Saturn's incredible rings may be an "accident" of our time.
 - i.e., a recent ice-shattering event