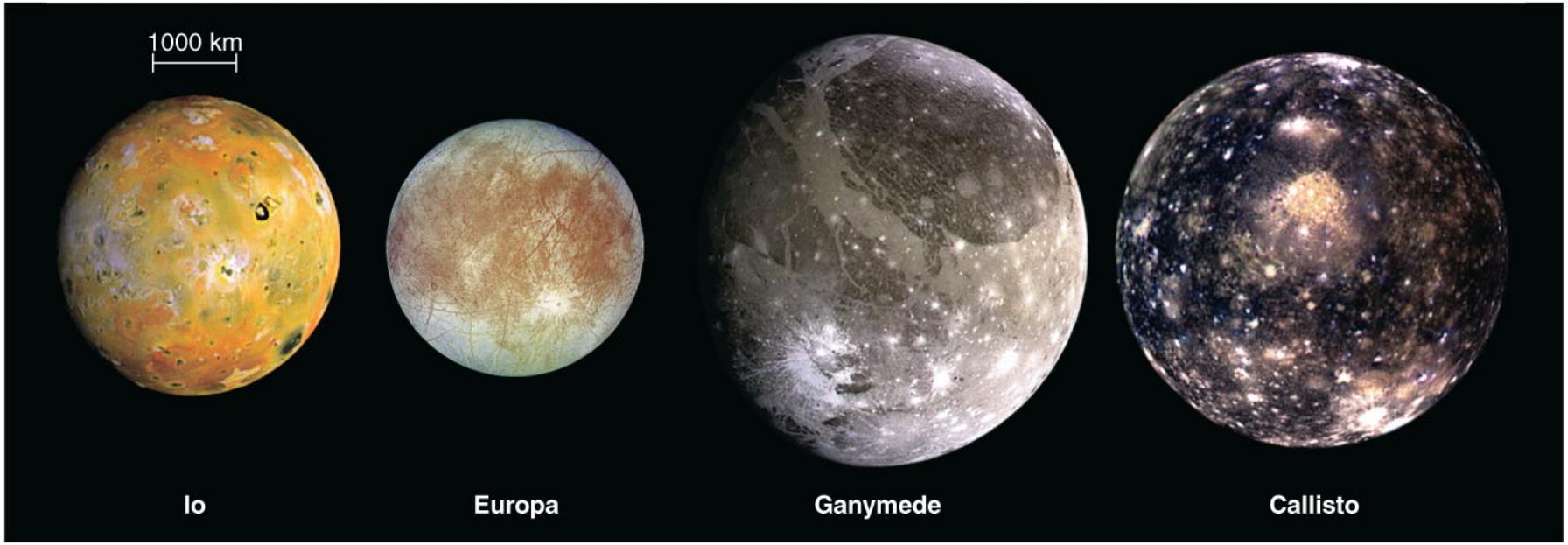
11.2 A Wealth of Worlds: Satellites of Ice and Rock

- Our goals for learning:
  - **What kinds of moons orbit the jovian planets?**
  - **Why are Jupiter's Galilean moons so geologically active?**
  - **What is remarkable about Titan and other major moons of the outer solar system?**
  - **Why are small icy moons more geologically active than small rocky planets?**

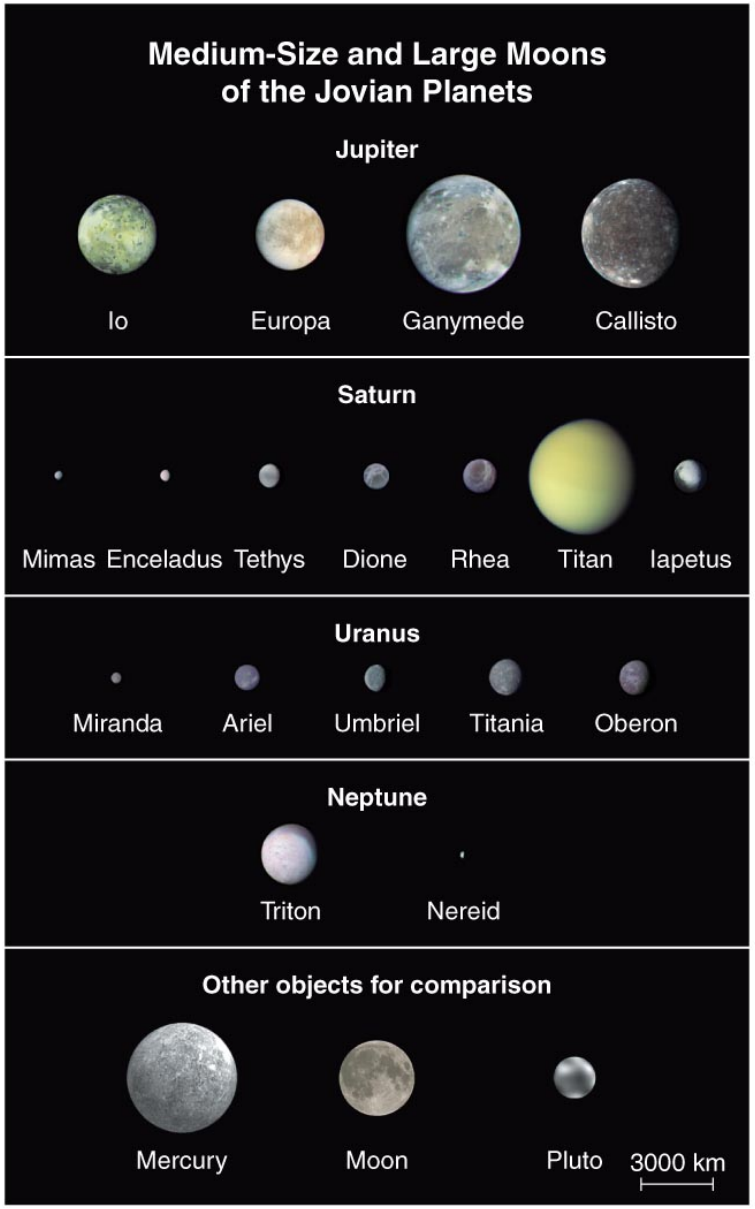
What kinds of moons orbit the jovian planets?



Sizes of Moons

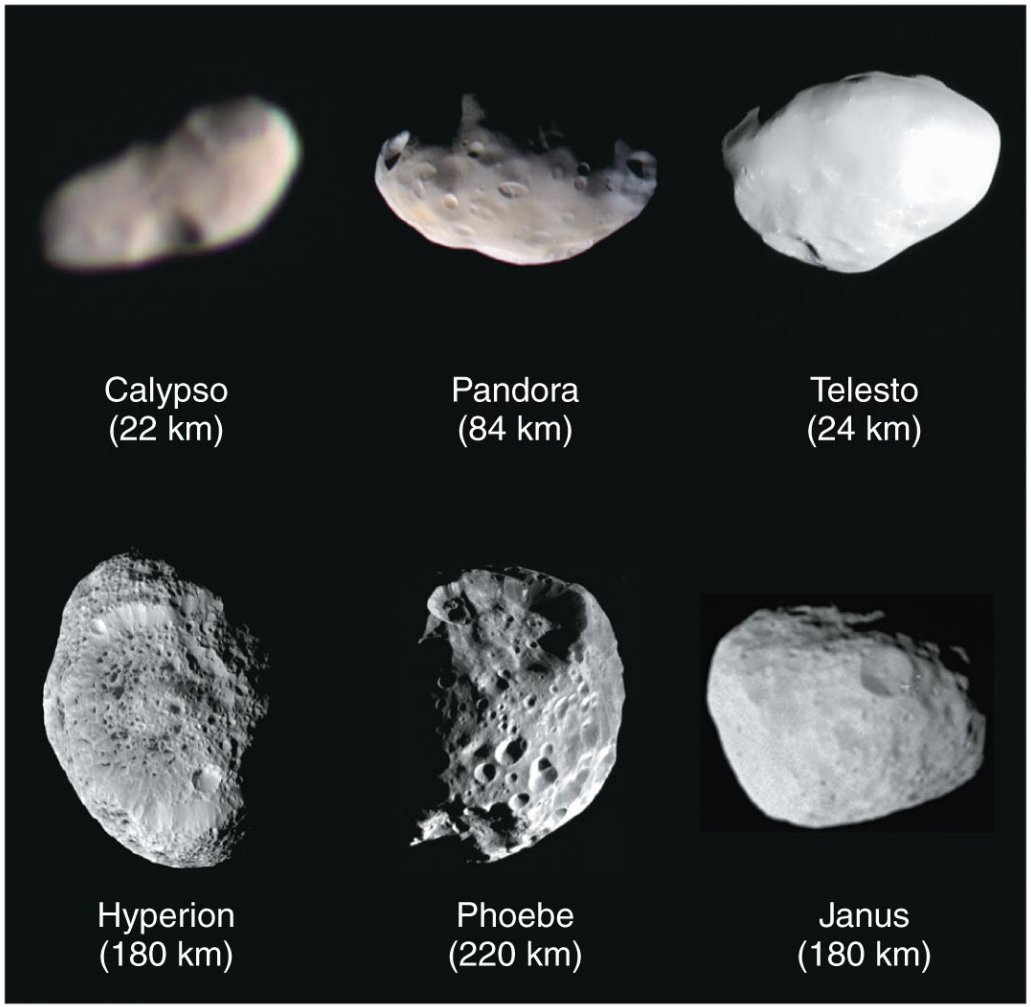
- Small moons (< 300 km in size)
  - No geological activity
- Medium-sized moons (300–1500 km)
  - Geological activity in past
- Large moons (> 1500 km)
  - Ongoing geological activity

Medium and Large Moons



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

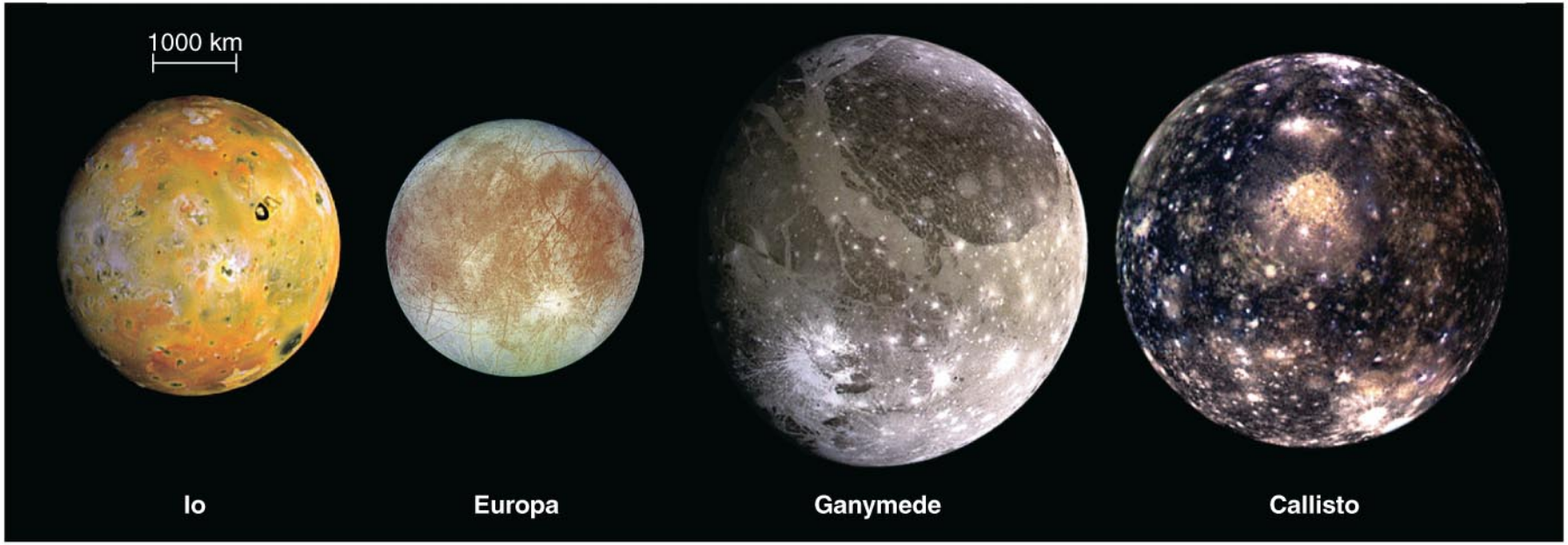
Small Moons



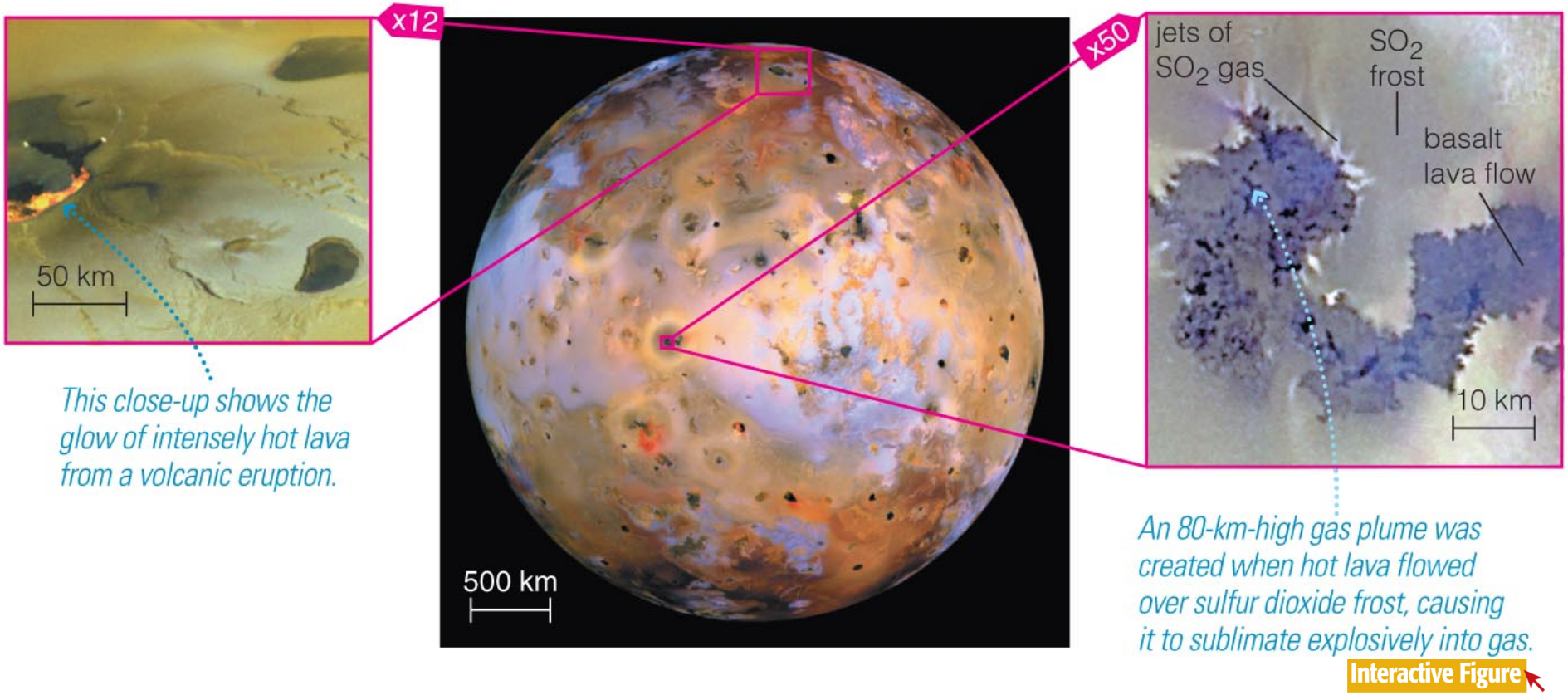
- These are far more numerous than the medium and large moons.
- They do not have enough gravity to be spherical: Most are "potato-shaped."

- They are captured asteroids or comets, so their orbits do not follow usual patterns.

Why are Jupiter's Galilean moons so geologically active?

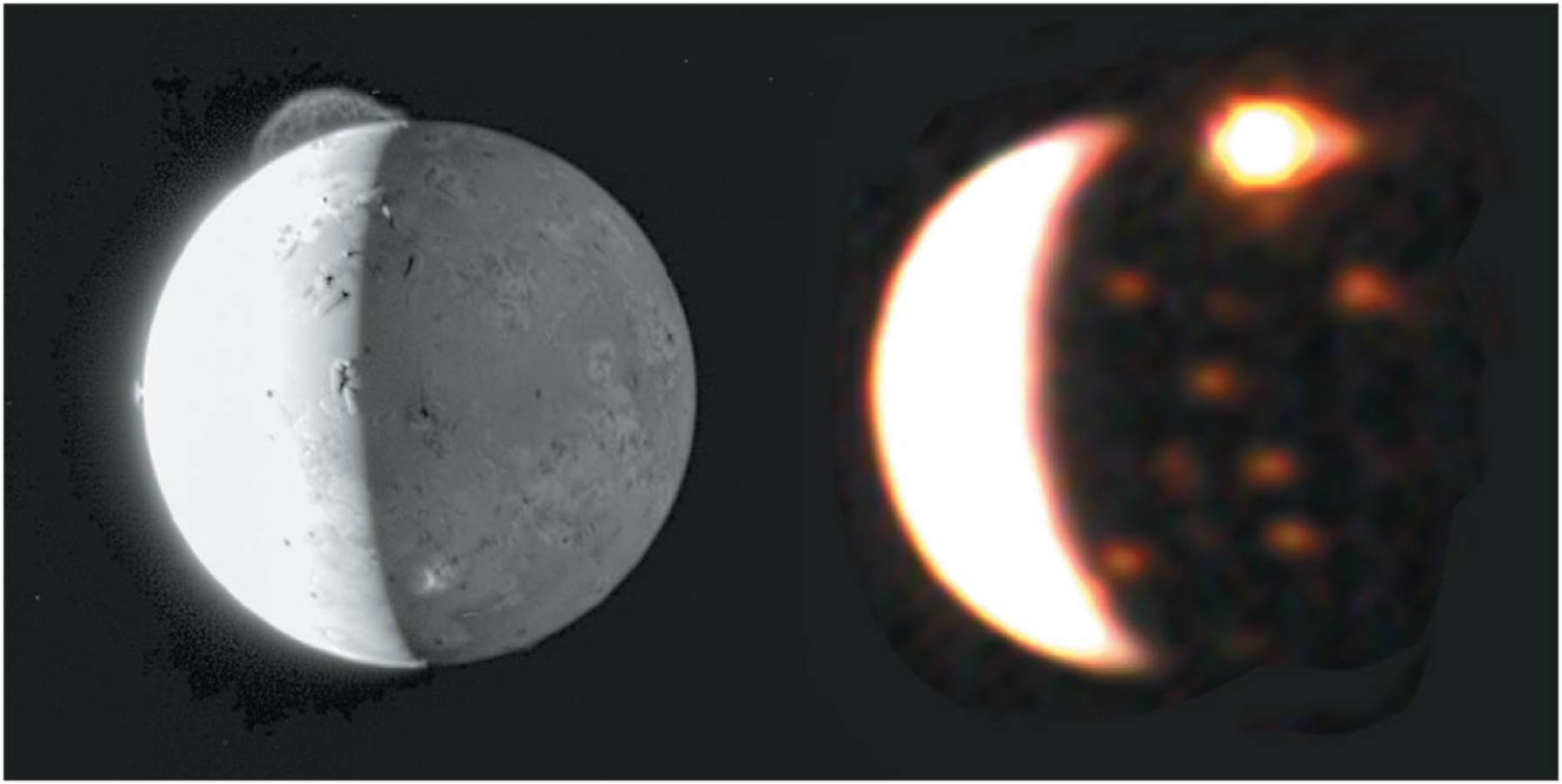


Io's Volcanic Activity



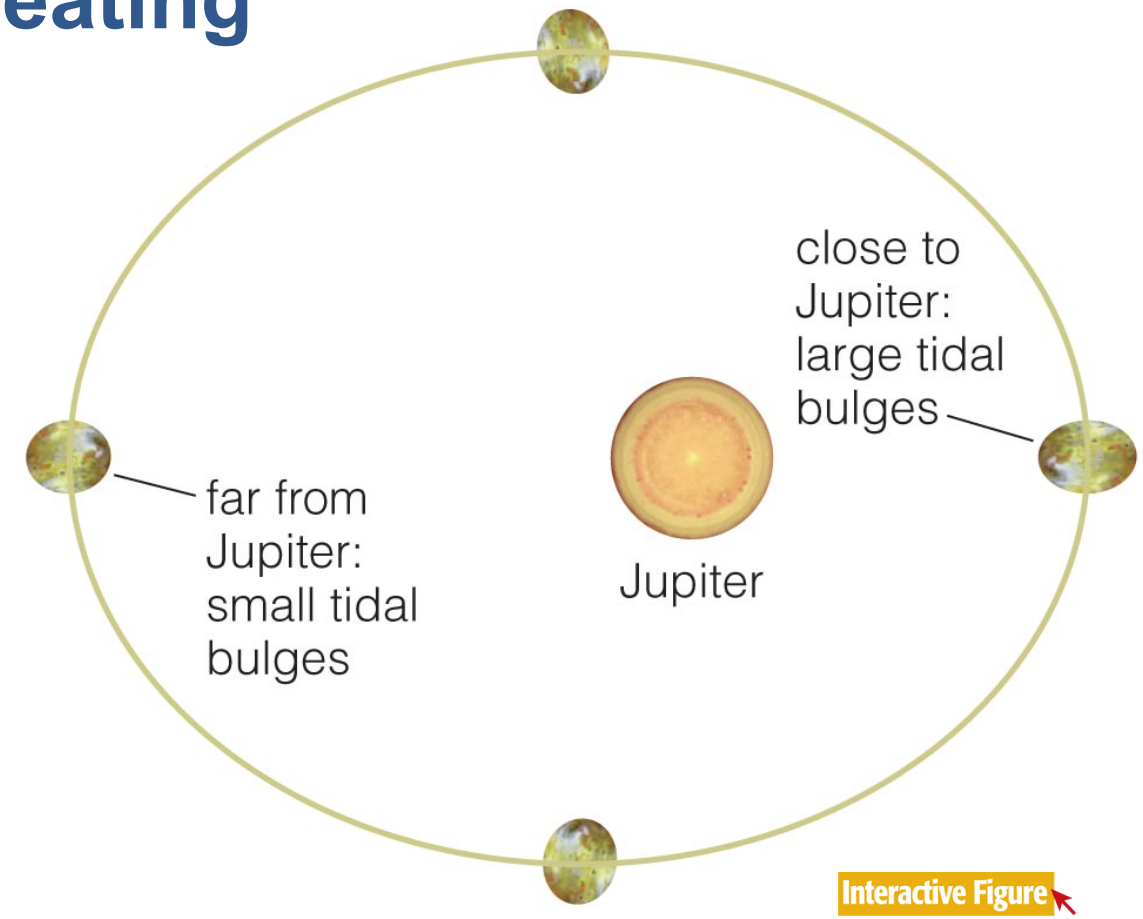
- Io is the most volcanically active body in the solar system, but why?

Io's Volcanoes



- Volcanic eruptions continue to change Io's surface.

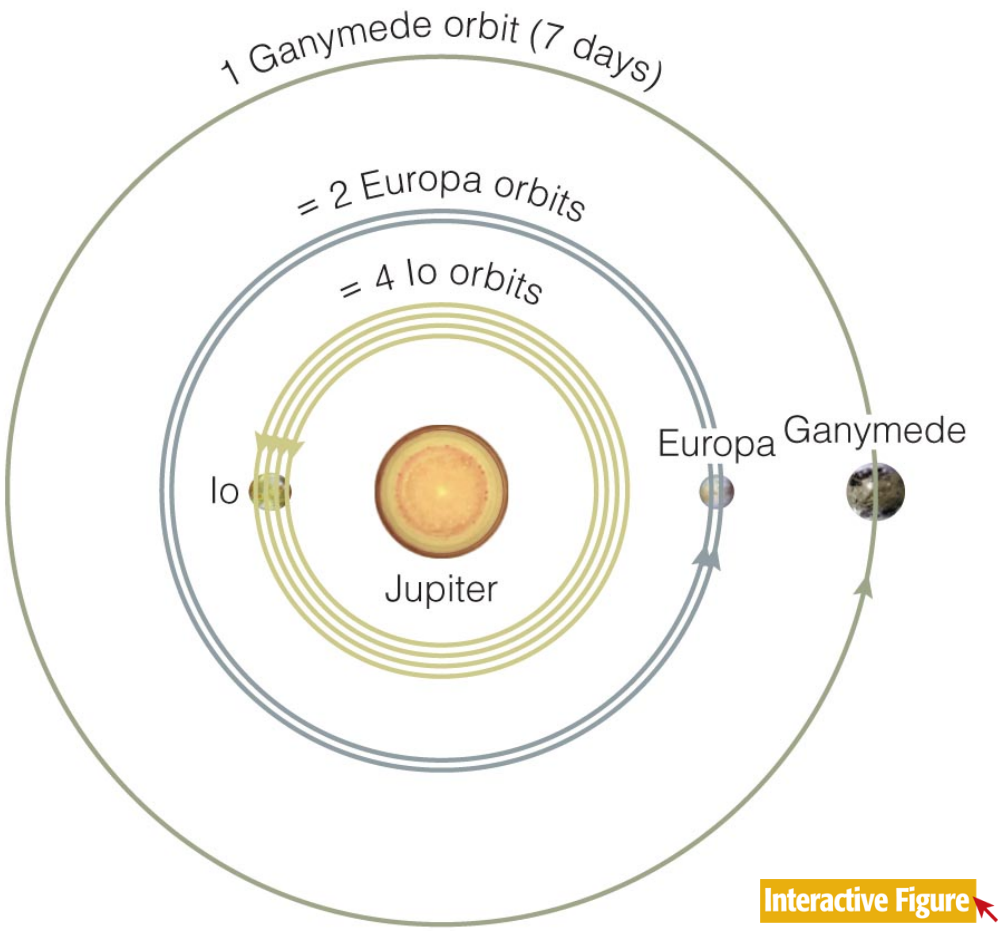
Tidal Heating



Io is squished and stretched as it orbits Jupiter.

But why is its orbit so elliptical?

Orbital Resonances



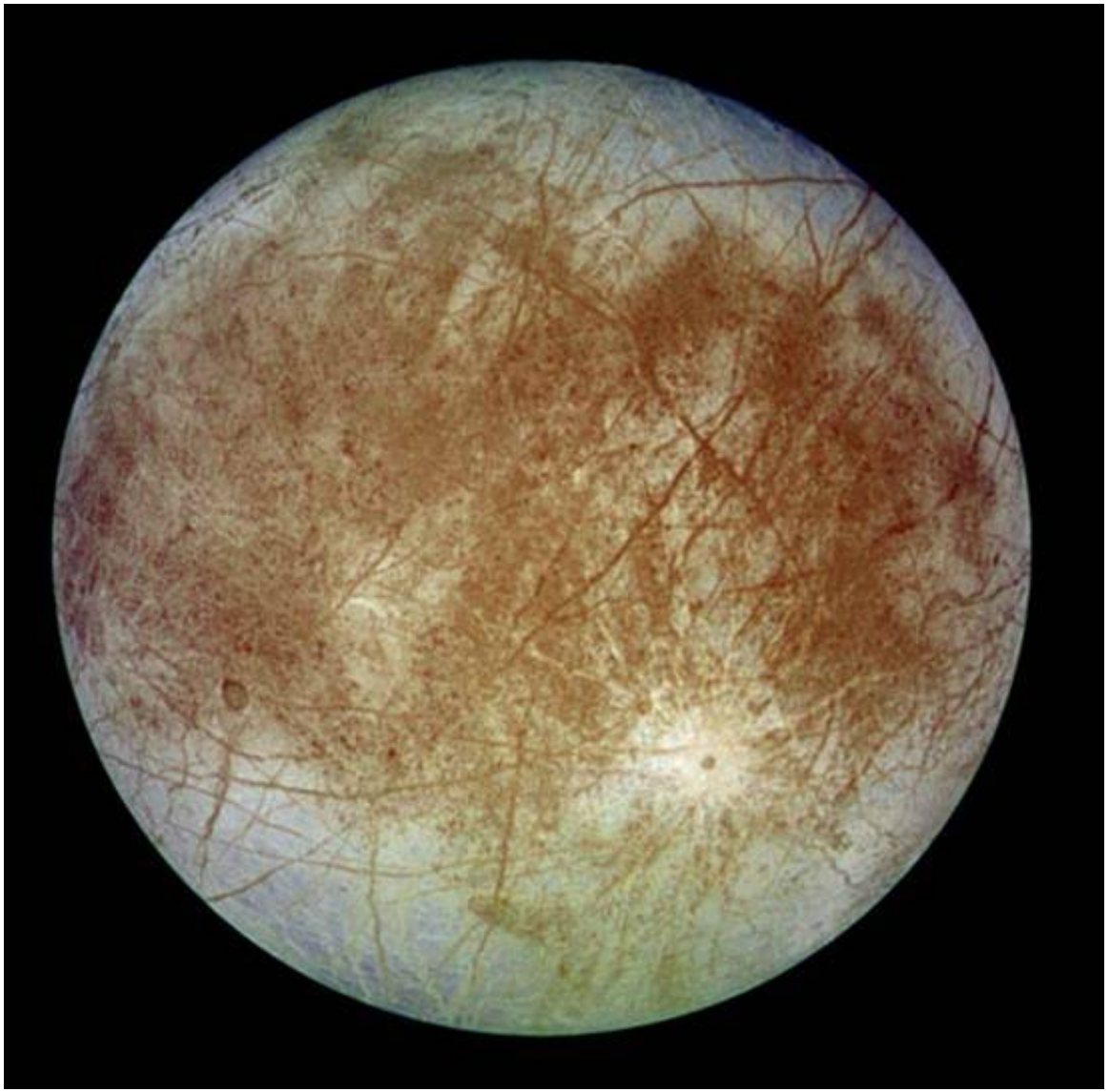
- Every 7 days, these three moons line up.
- The tugs add up over time, making all three orbits elliptical.

Heating of the Galilean Satellites

Early in the solar system's history, when the moons formed, they were heated by Jupiter releasing lots of energy due to gravitational contraction. This is why the inner moons are not just ice balls, but have a lot of rock as well.

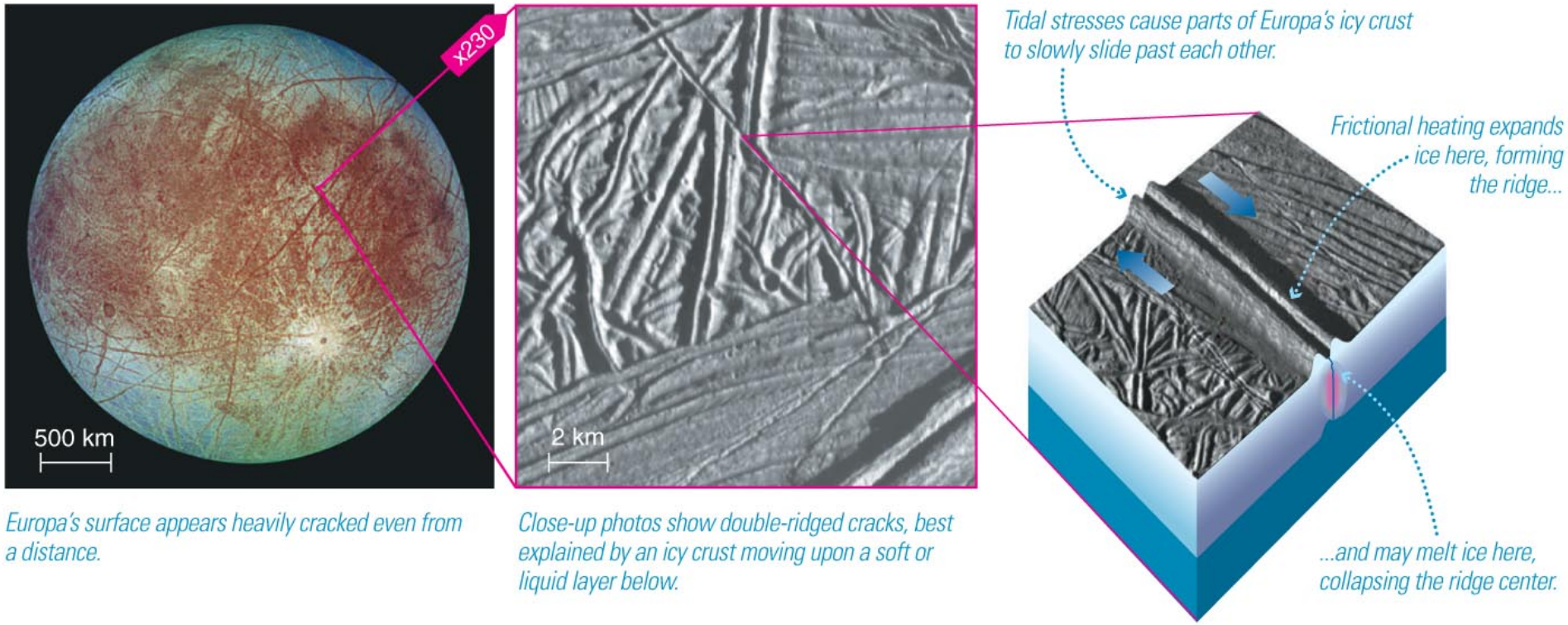
Today, Jupiter's contraction has mostly (but not completely) stopped, and moons' interiors are heated by tidal forces instead.

Europa's Ocean: Waterworld?



NASA/JPL/DLR

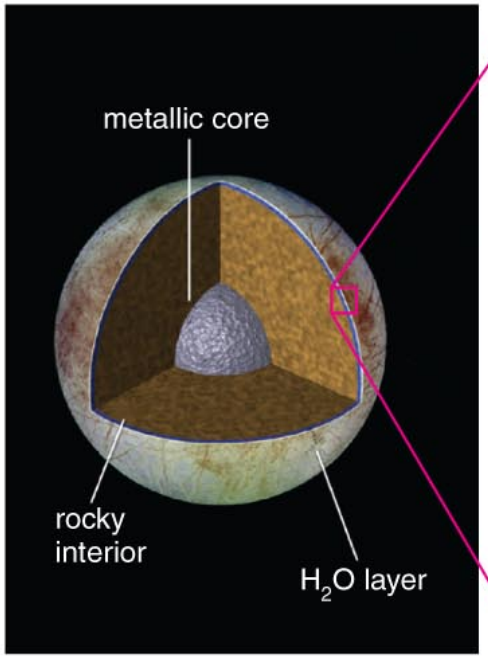
Tidal stresses crack Europa's surface ice.



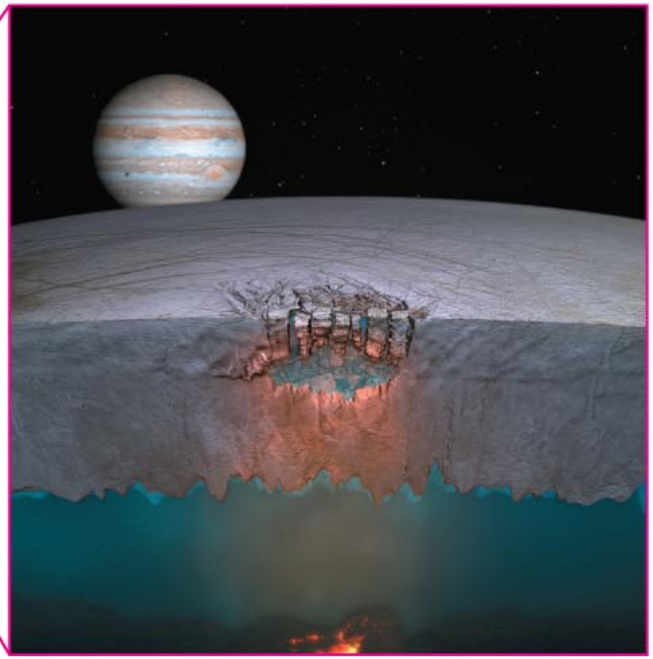
Europa's surface appears heavily cracked even from a distance.

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

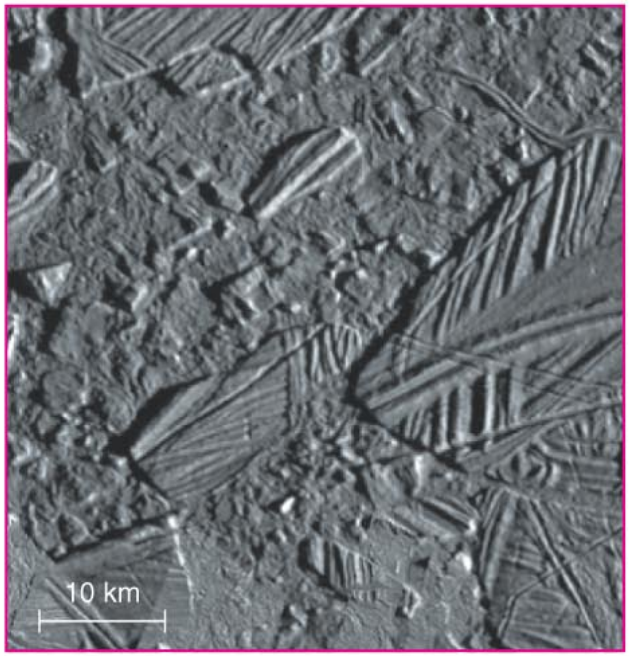
Europa's interior also warmed by tidal heating.



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

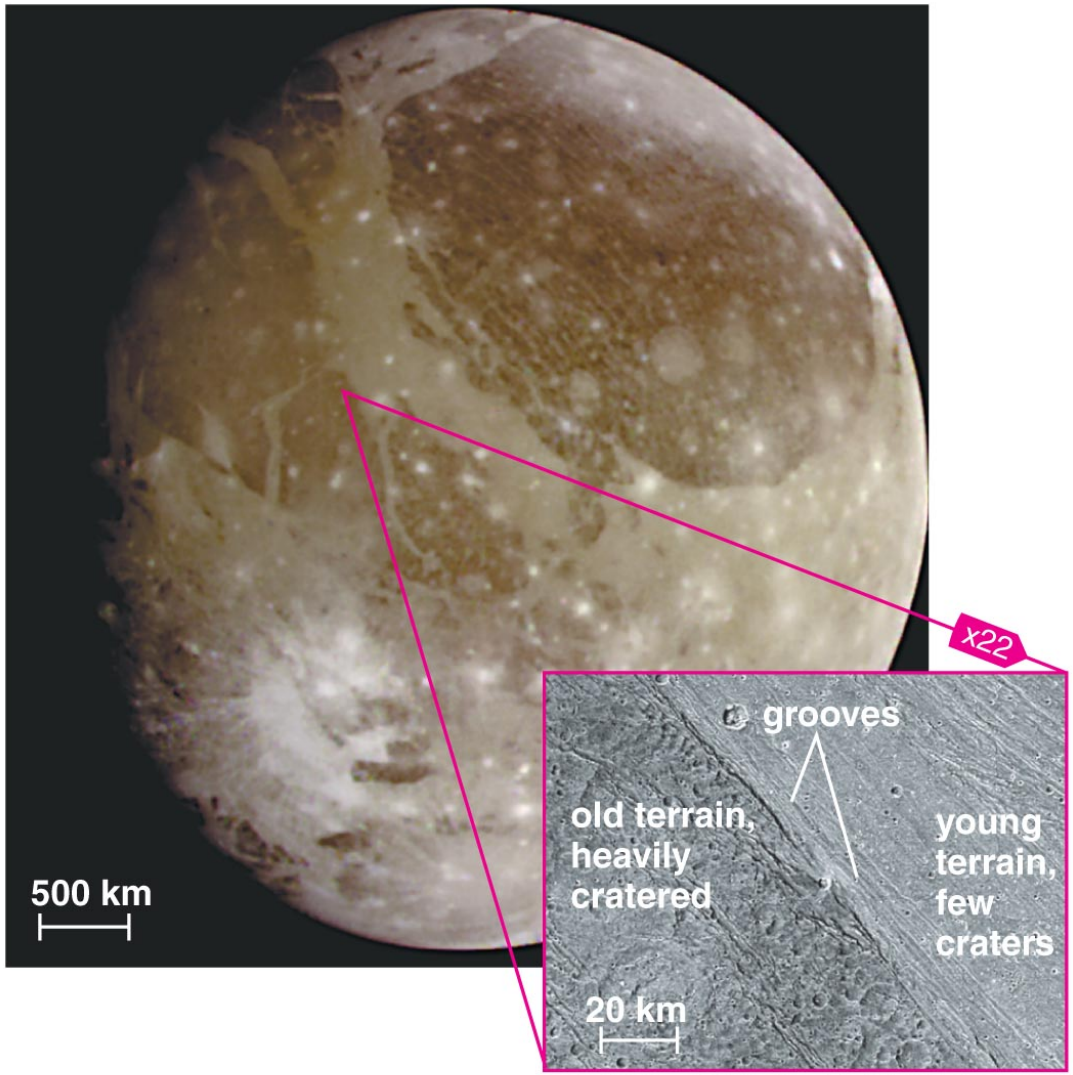


Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .



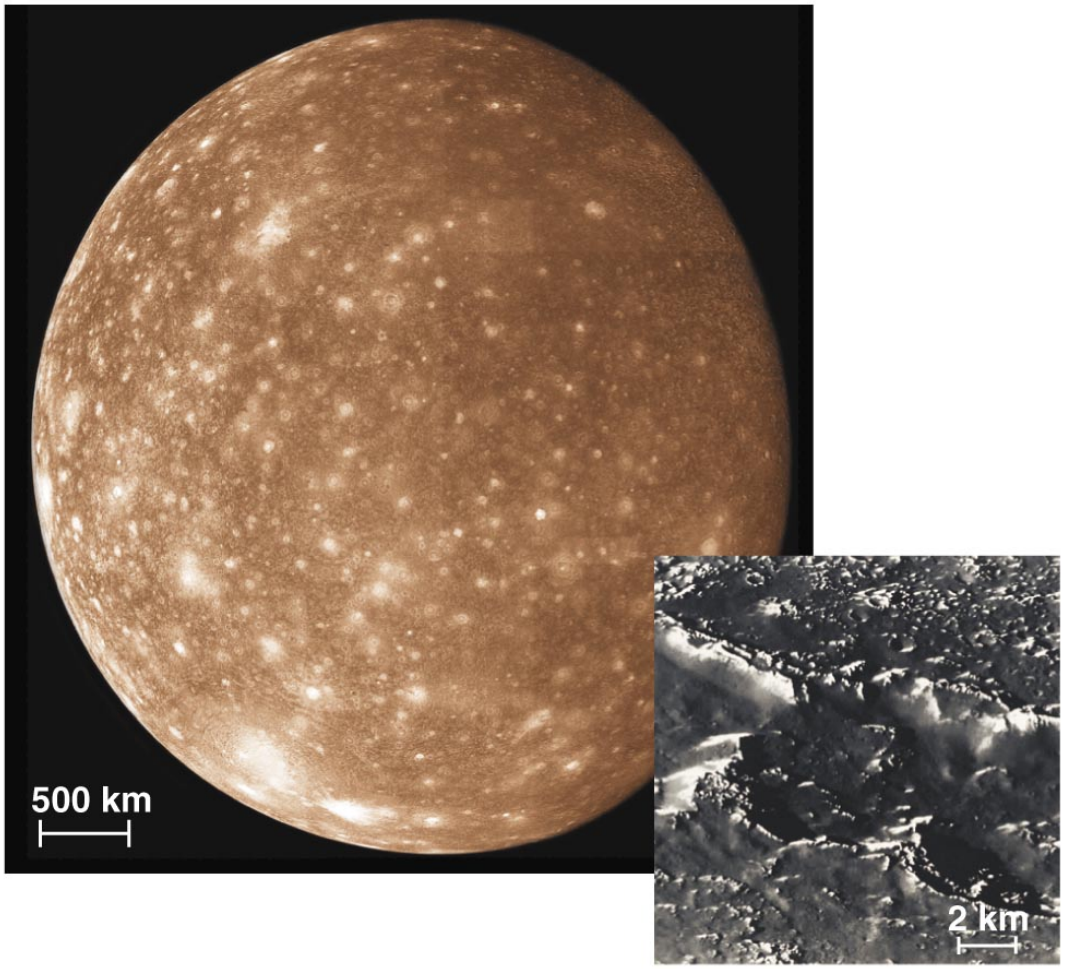
. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

Ganymede



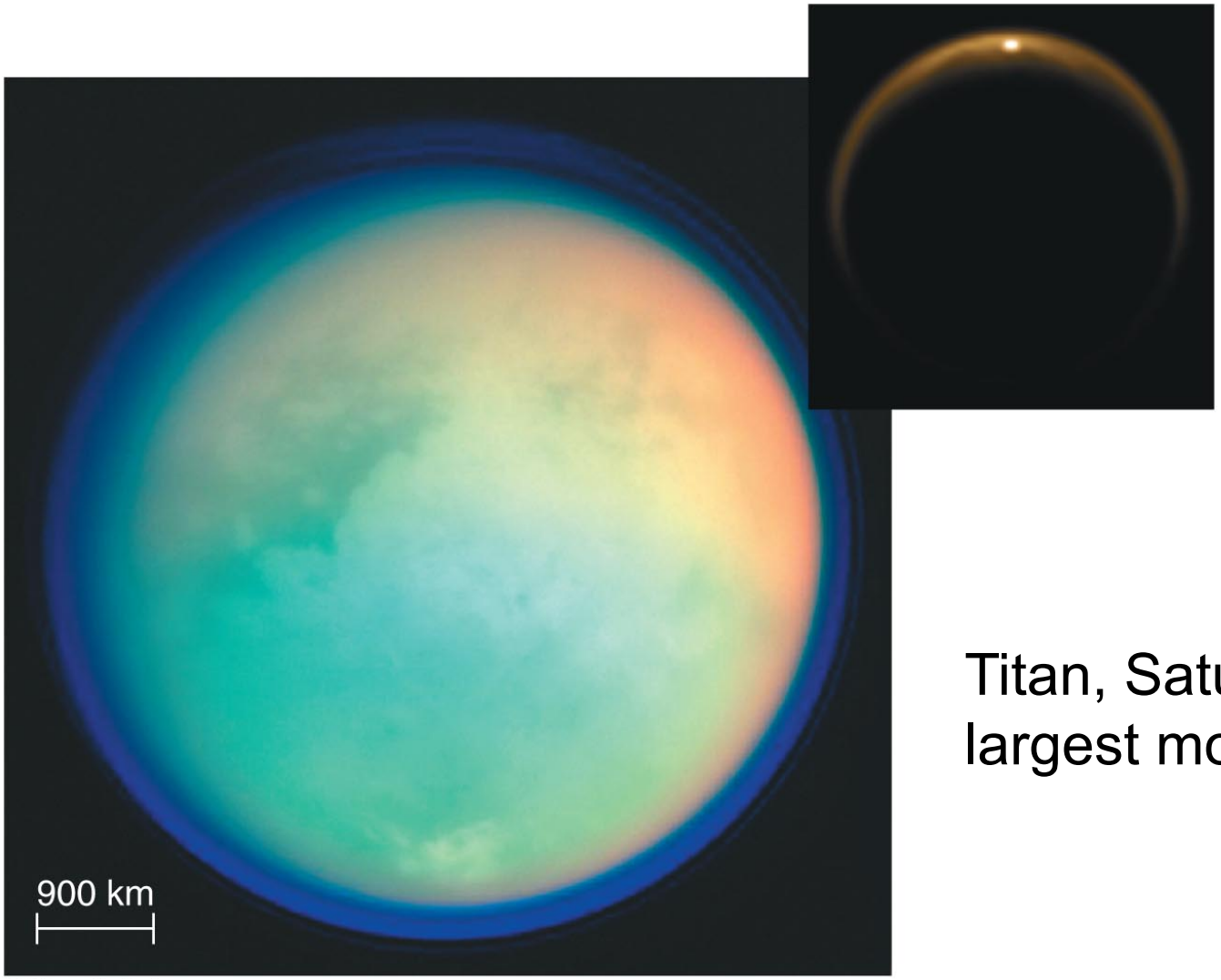
- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?

Callisto



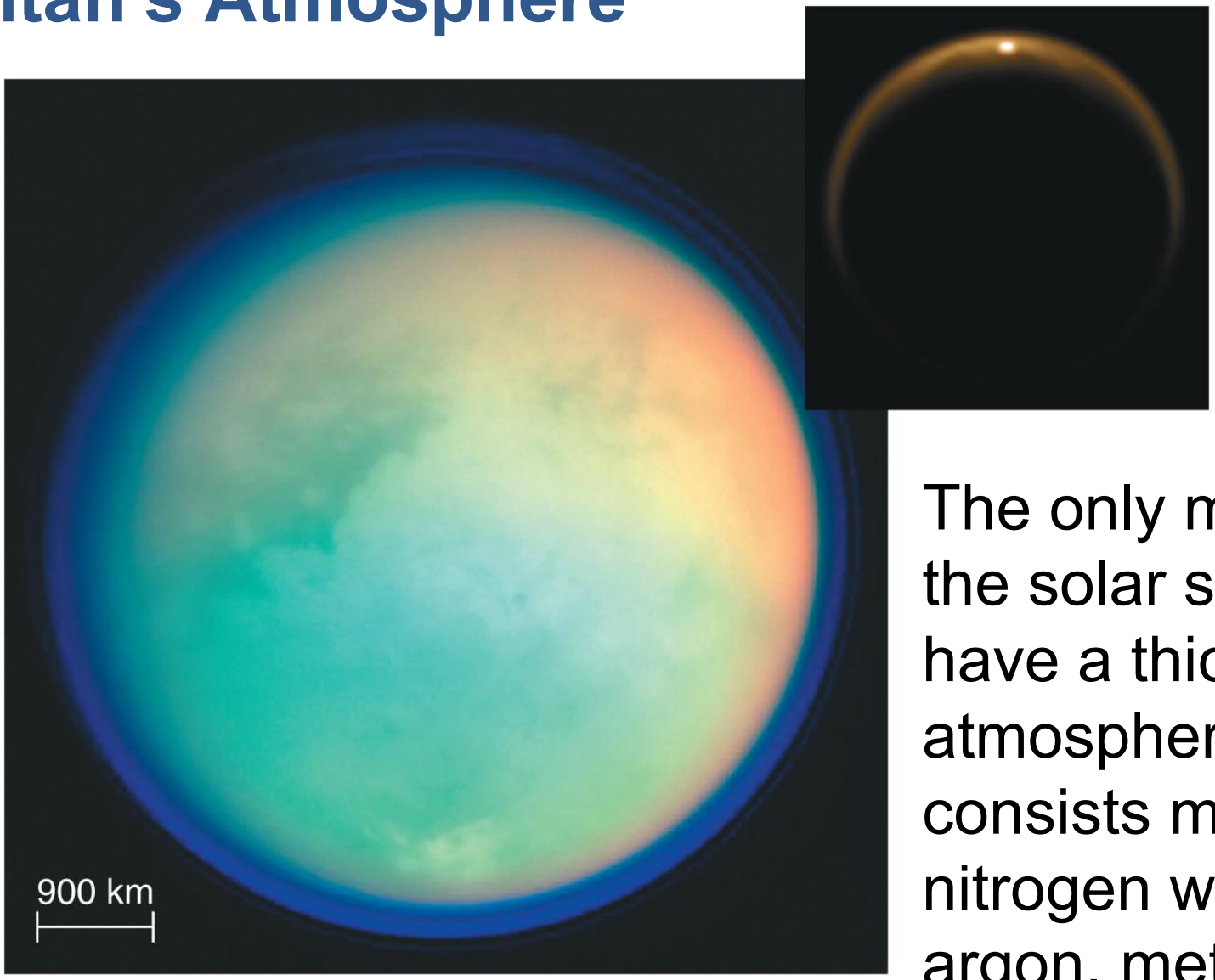
- "Classic" cratered iceball
- Not involved in the “resonance dance” with the other moons, so no tidal heating.

What is remarkable about Titan and other major moons of the outer solar system?



Titan, Saturn's largest moon

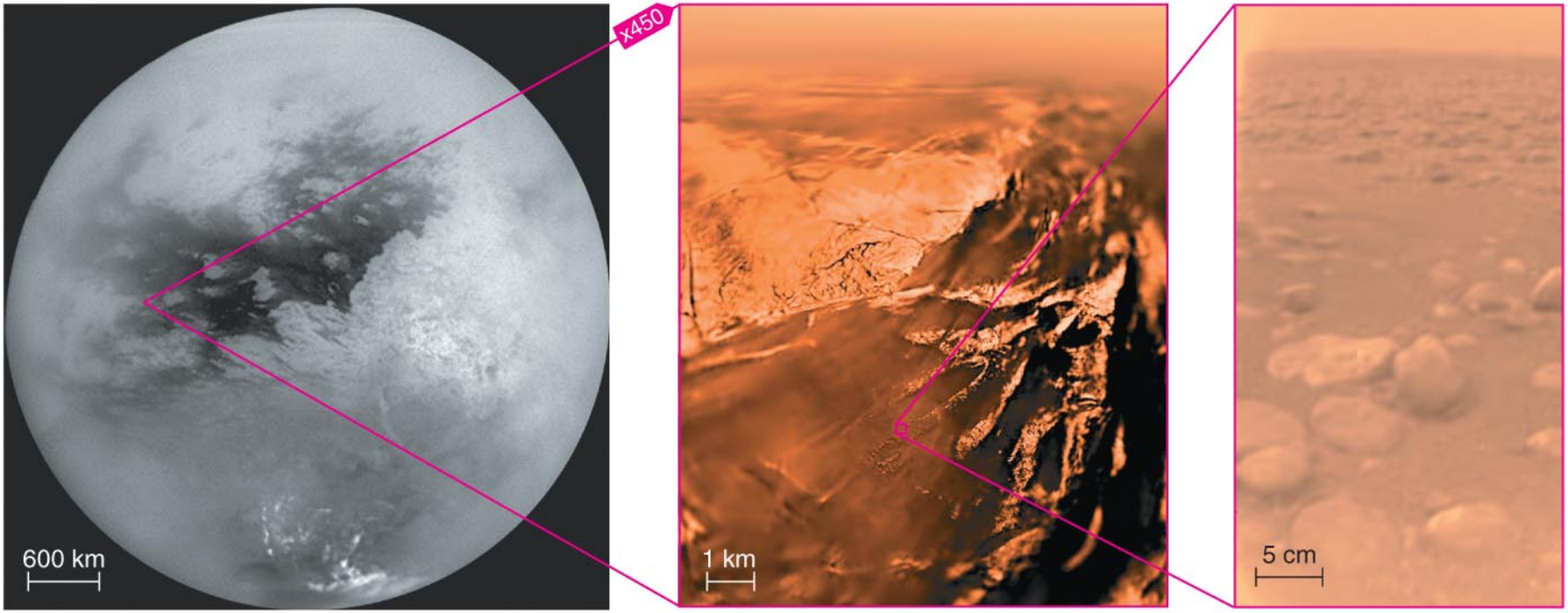
Titan's Atmosphere



Sunlight glinting off Titan

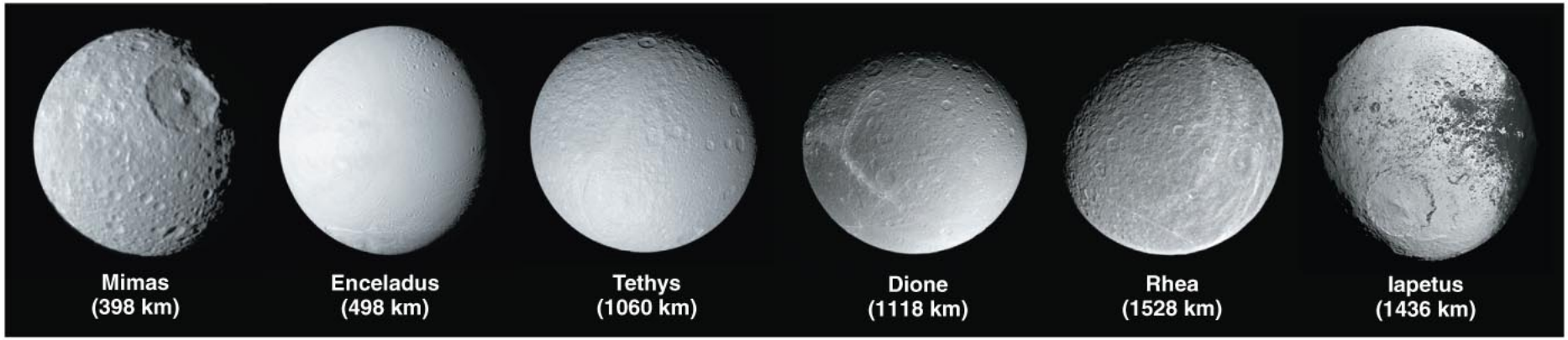
The only moon in the solar system to have a thick atmosphere. It consists mostly of nitrogen with some argon, methane, and ethane.

Titan's Surface



- Surface temp ~ -290 F.
- *Huygens* probe provided first look at Titan's surface in early 2005. Landing animation
- It found liquid methane and "rocks" made of ice.

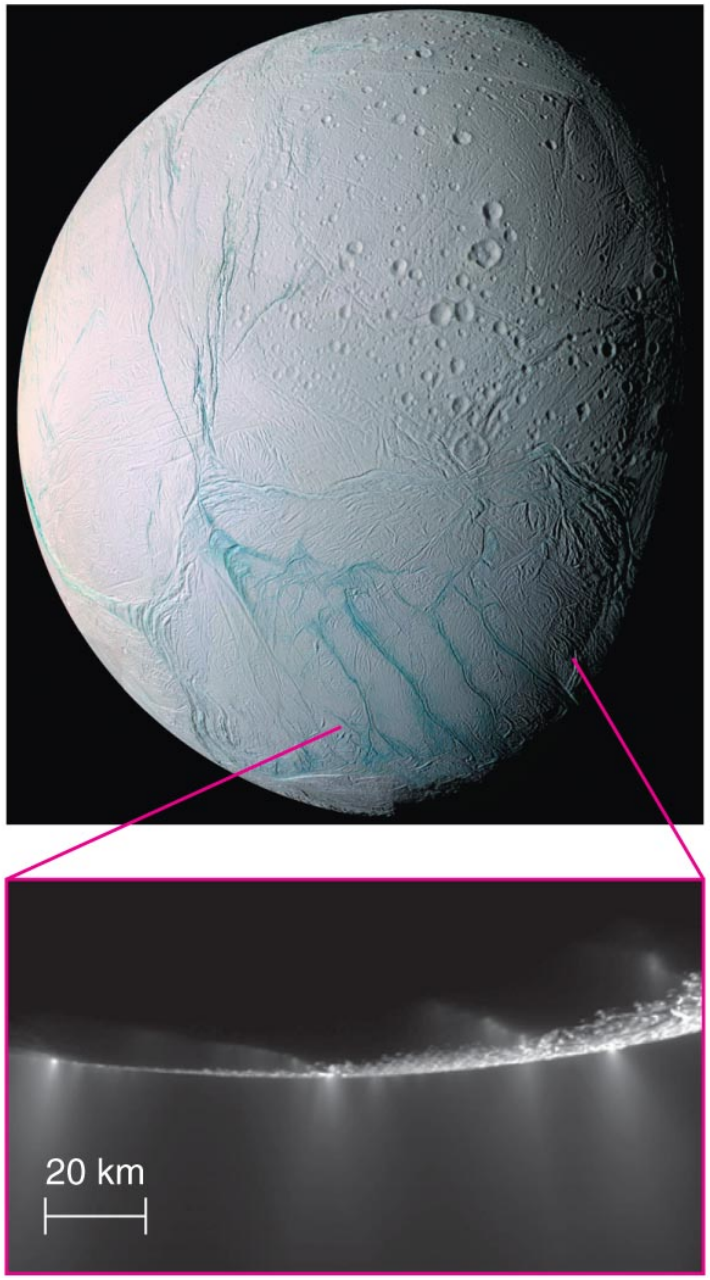
Medium Moons of Saturn



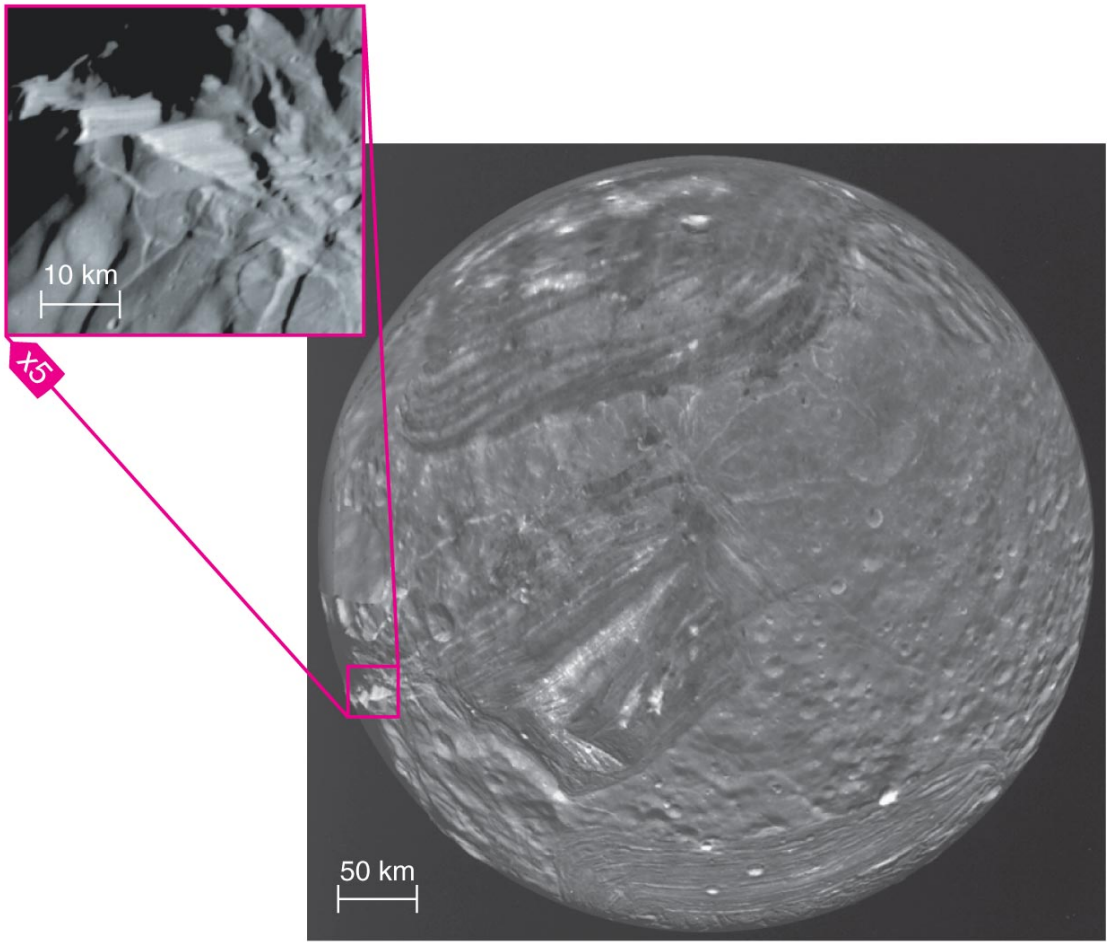
- Almost all of them show evidence of past volcanism and/or tectonics.

Medium Moons of Saturn

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

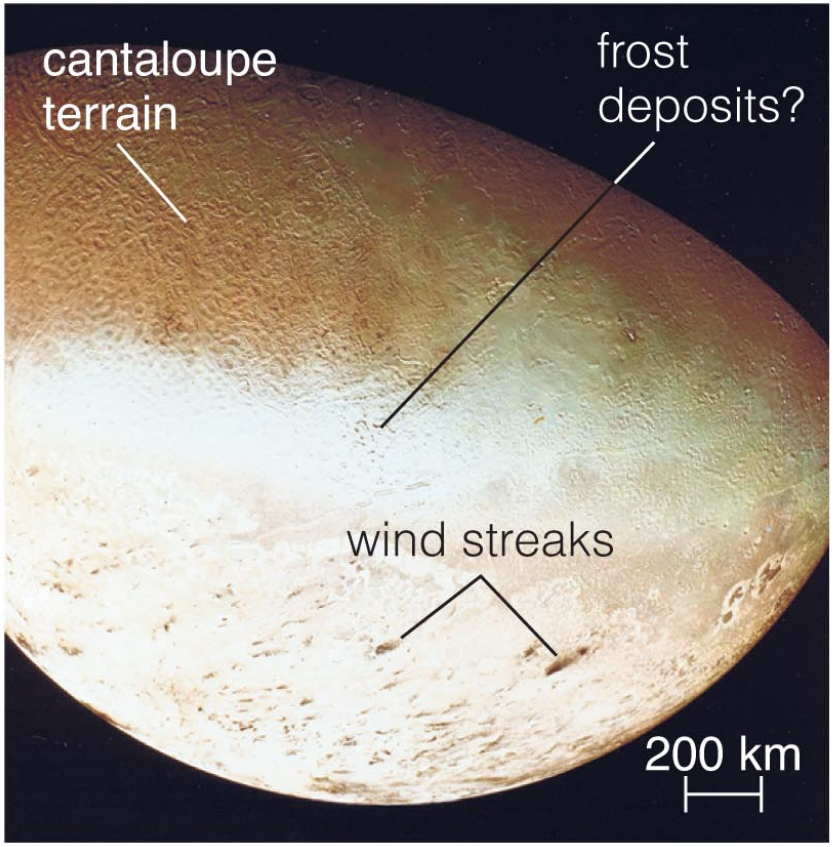


Medium Moons of Uranus

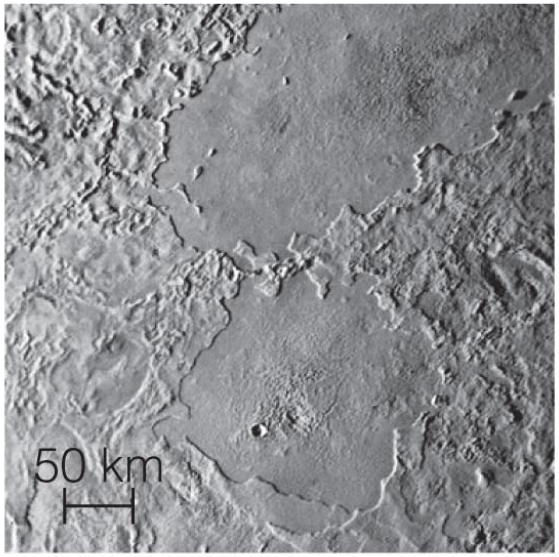


- They have varying amounts of geological activity.
- Miranda has large tectonic features and few craters (possibly indicating an episode of tidal heating in past).

Neptune's Moon Triton



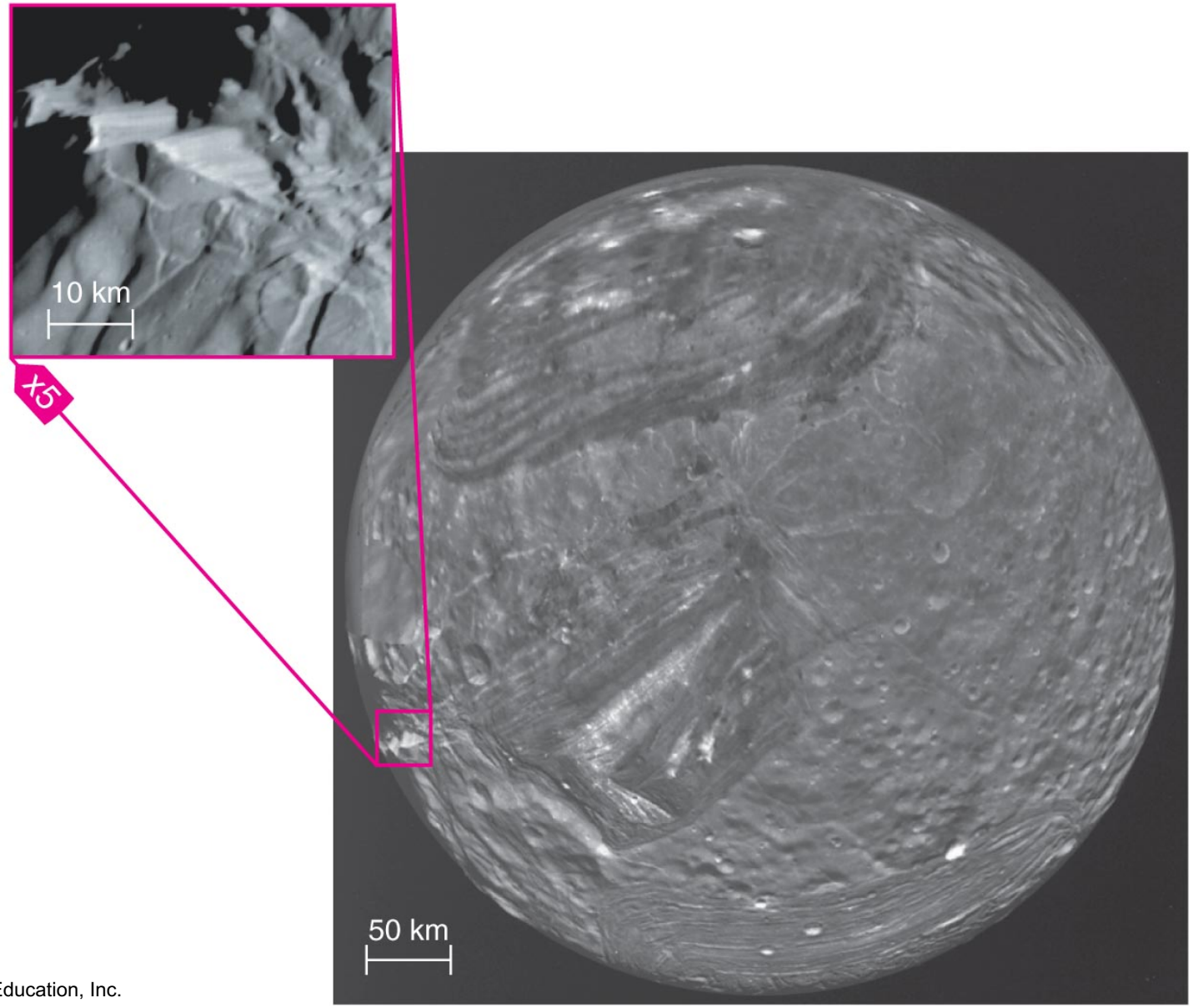
Triton's southern hemisphere as seen by *Voyager 2.*



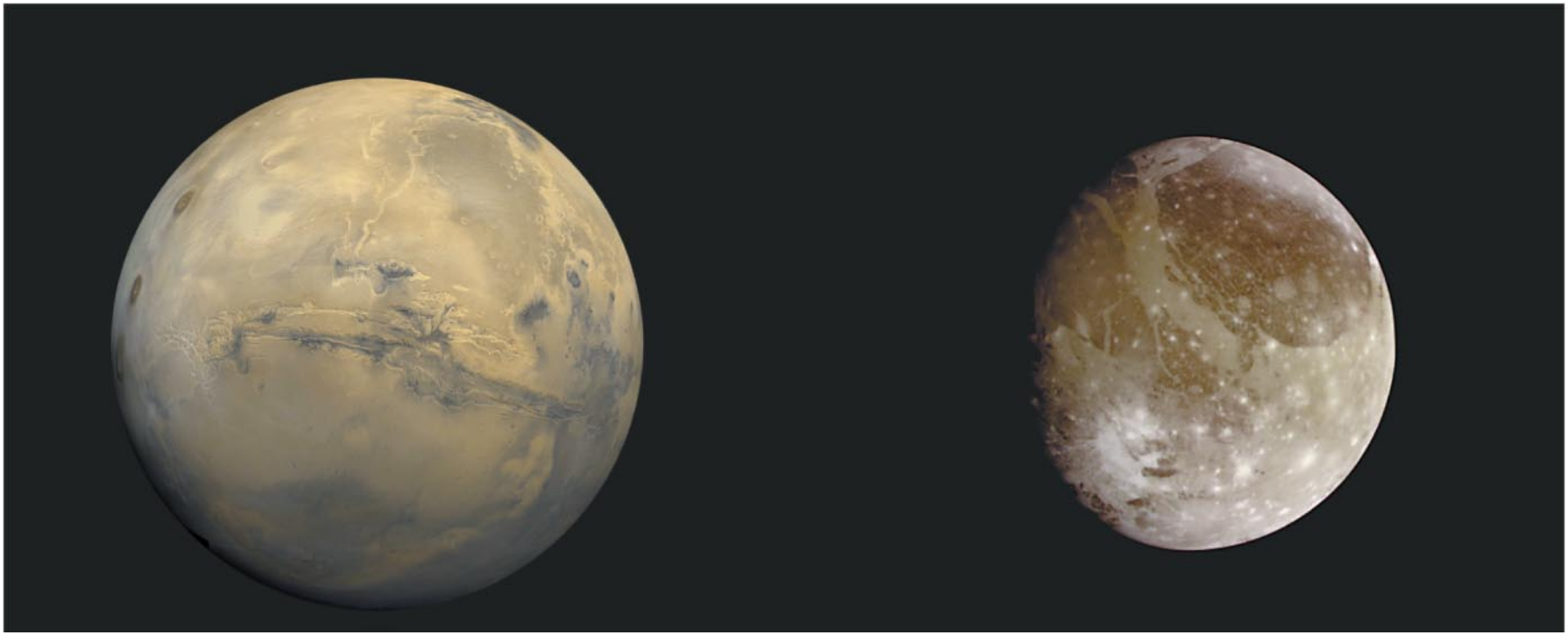
This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

- Similar to Pluto, but larger
- Evidence of past geological activity

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



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.

What have we learned?

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

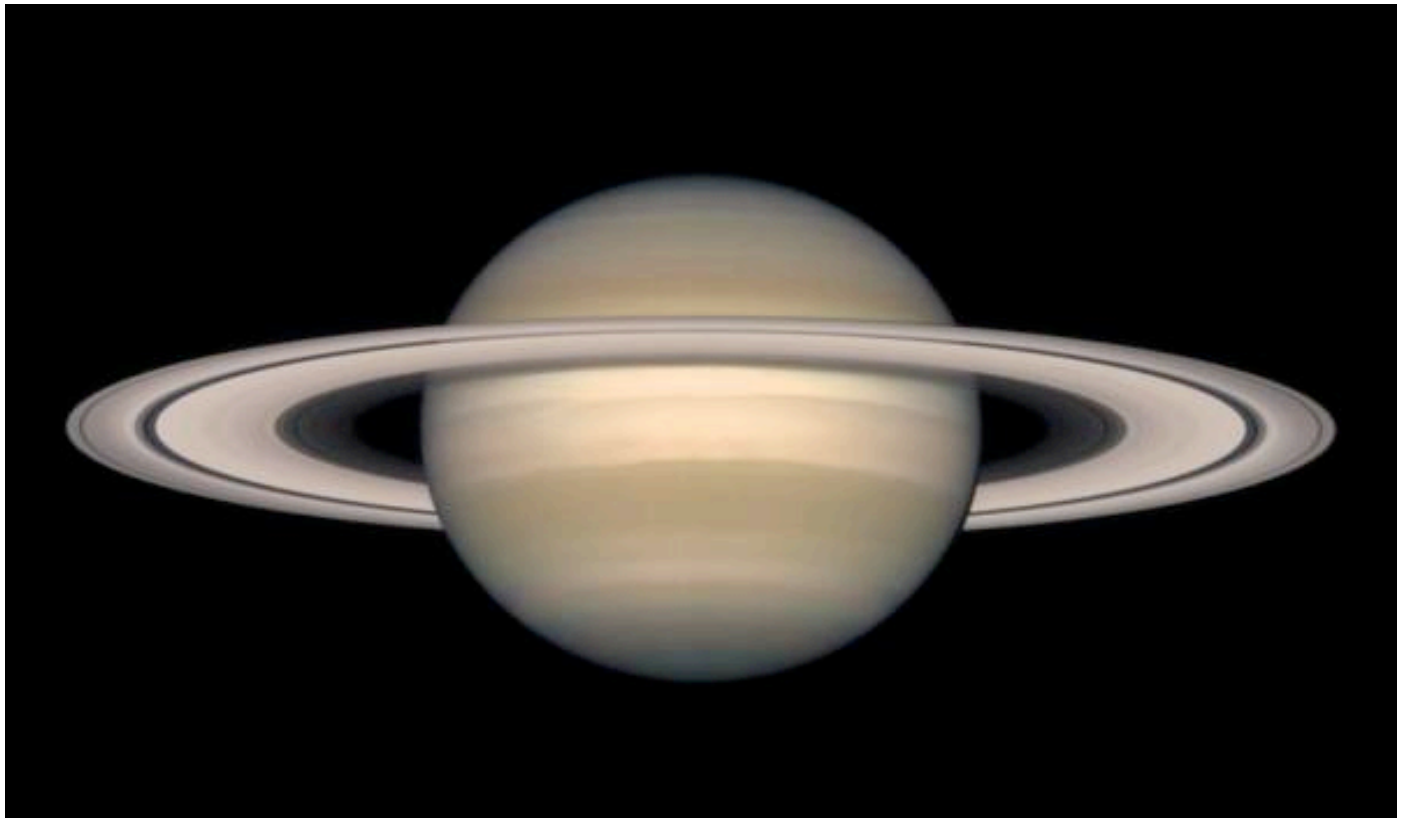
What have we learned?

- **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.

11.3 Jovian Planet Rings

- Our goals for learning:
  - **What are Saturn's rings like?**
  - **How do other jovian ring systems compare to Saturn's?**
  - **Why do the jovian planets have rings?**

What are Saturn's rings like?

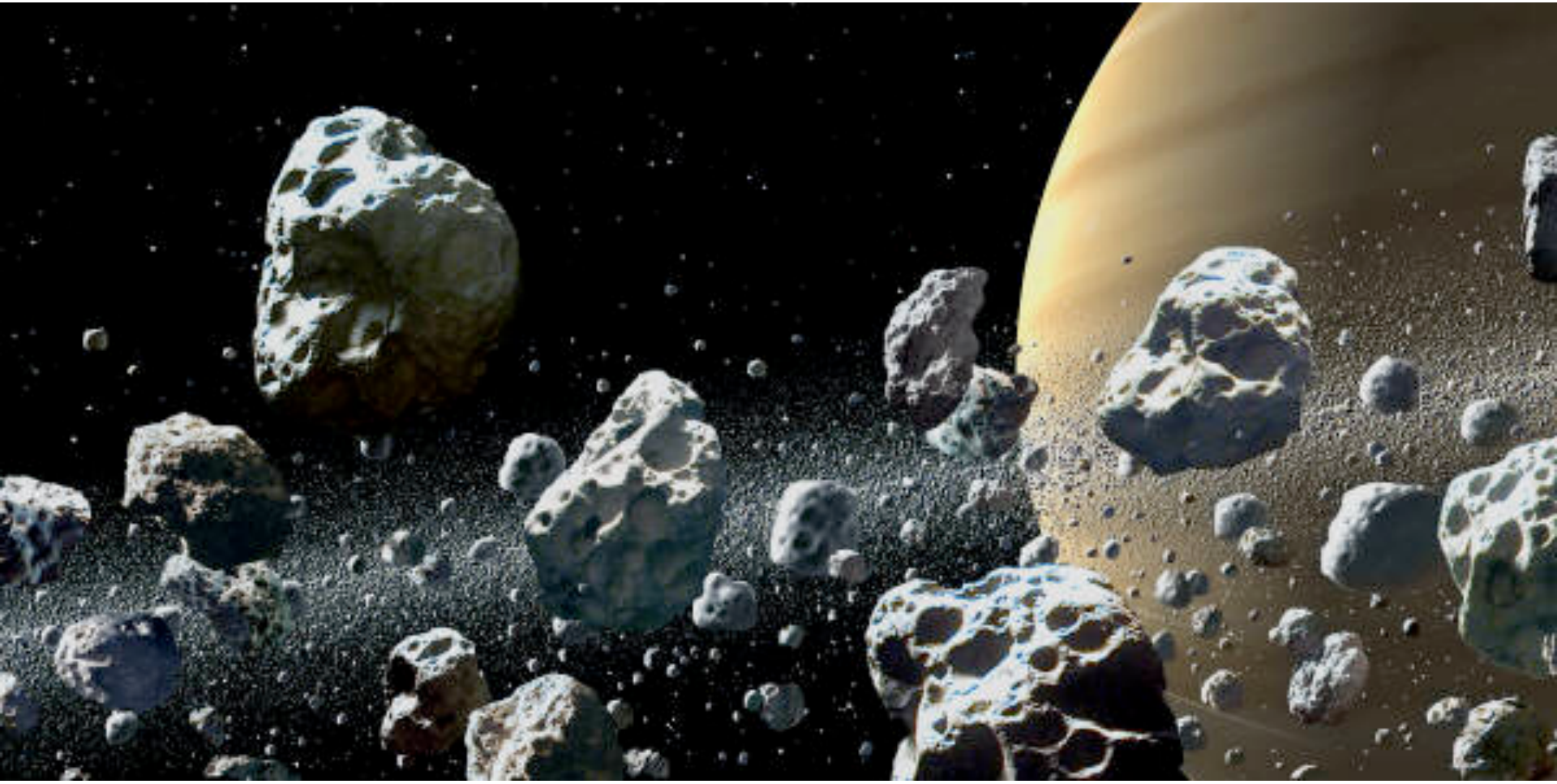


- They are made up of many small ice particles.
- They orbit around Saturn's equator.
- They are very thin (tens of meters thick).

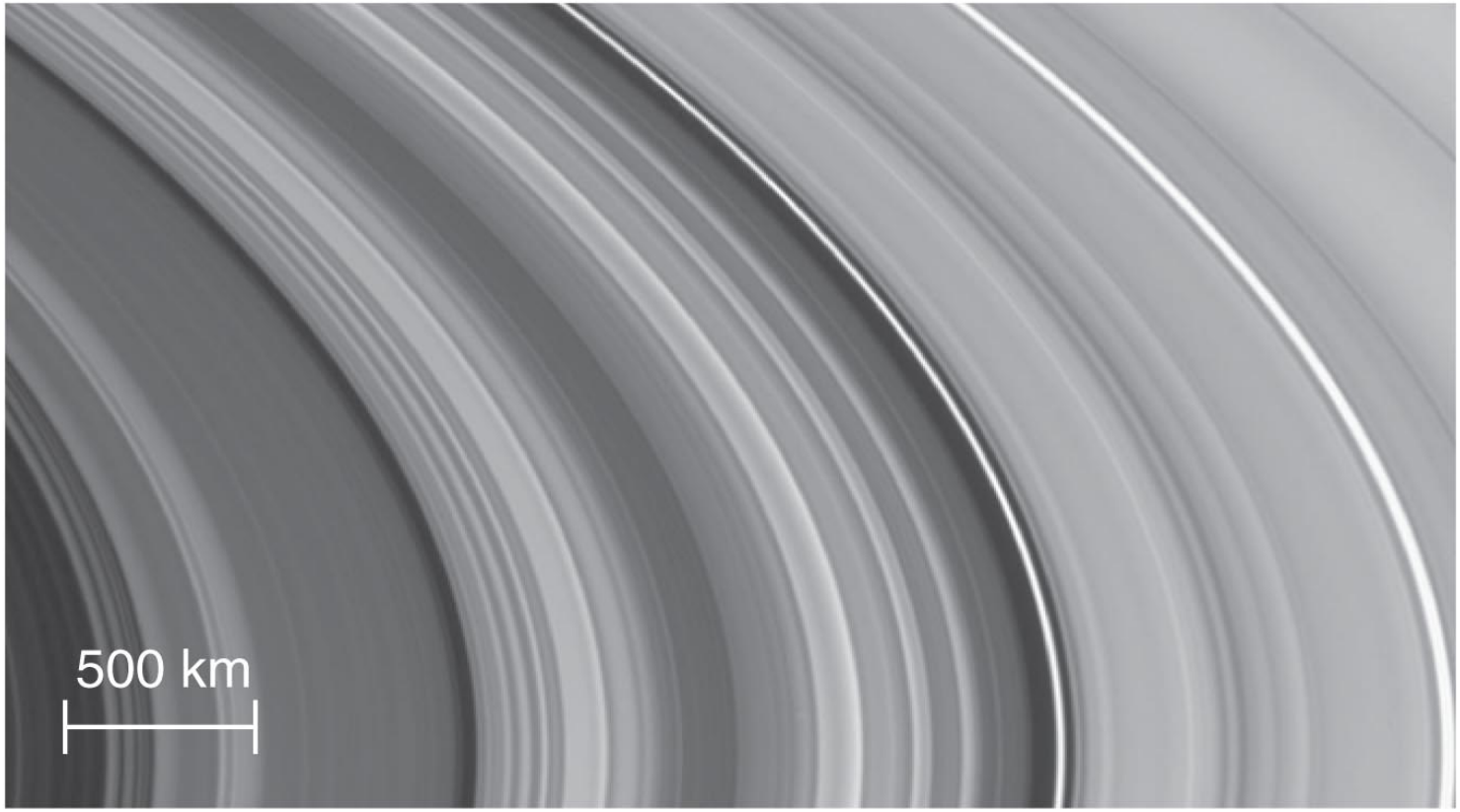
Interactive Figure

What are Saturn's rings like?

Artist's Conception of Rings Close-Up

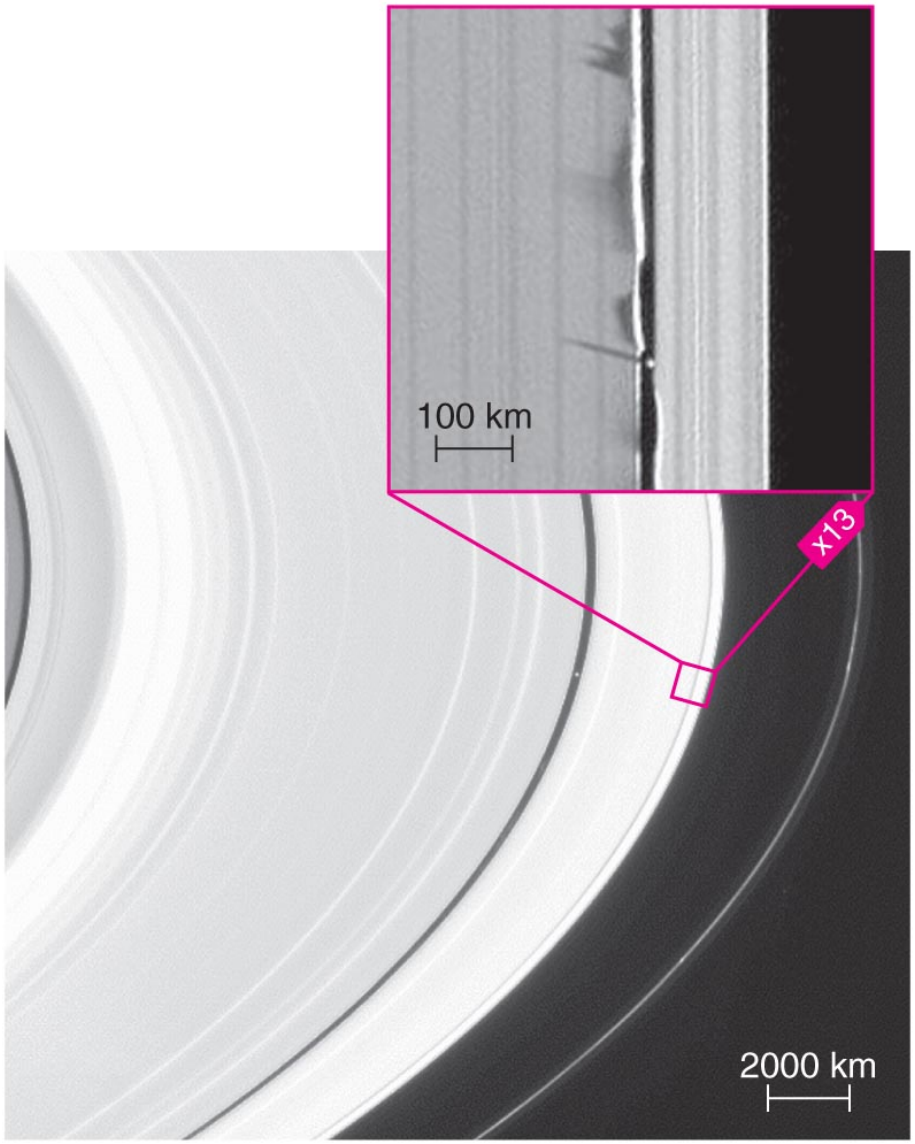


Spacecraft View of Ring Gaps



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

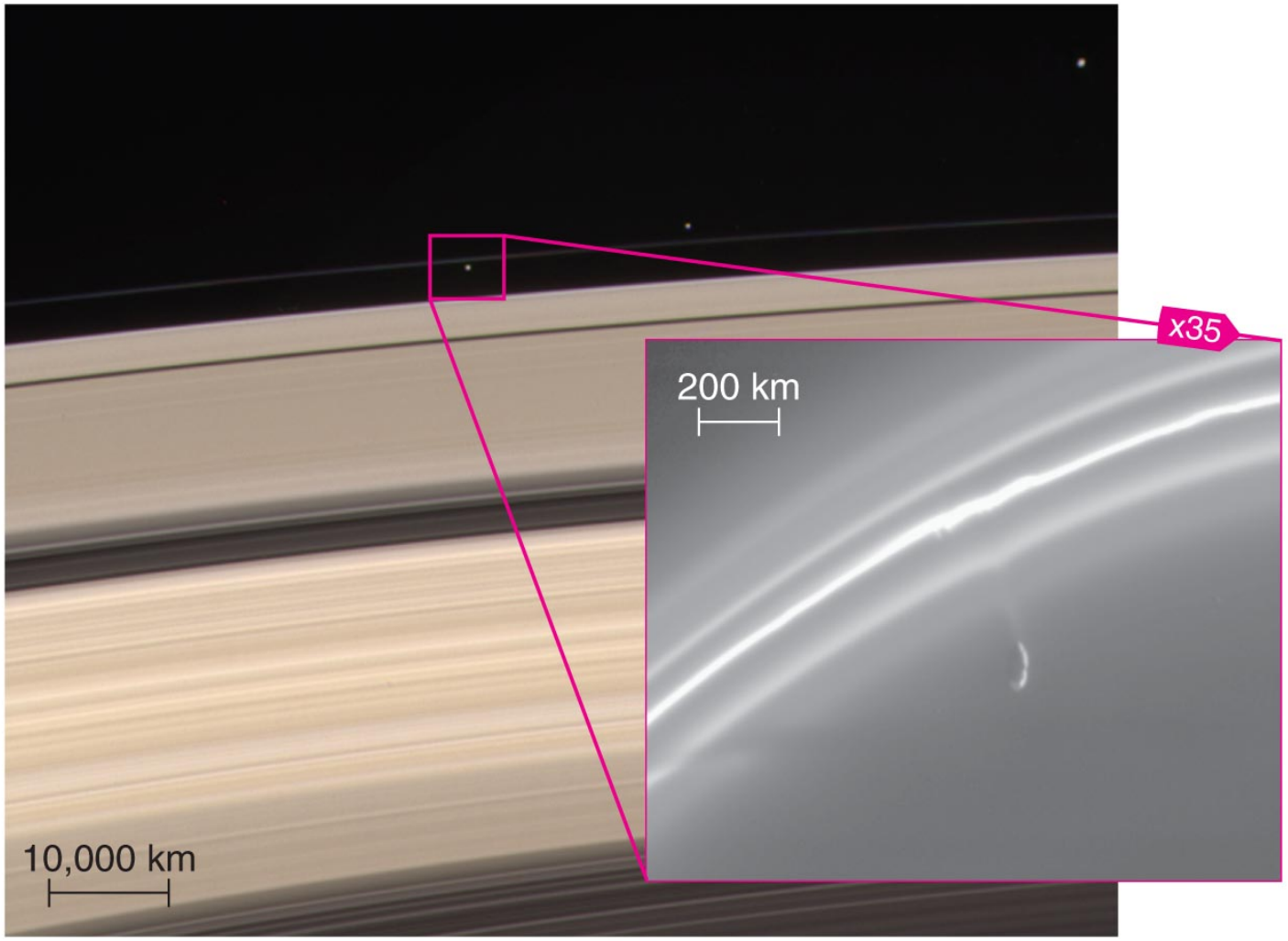
Gap Moons



a Some small moons create gaps within the rings.

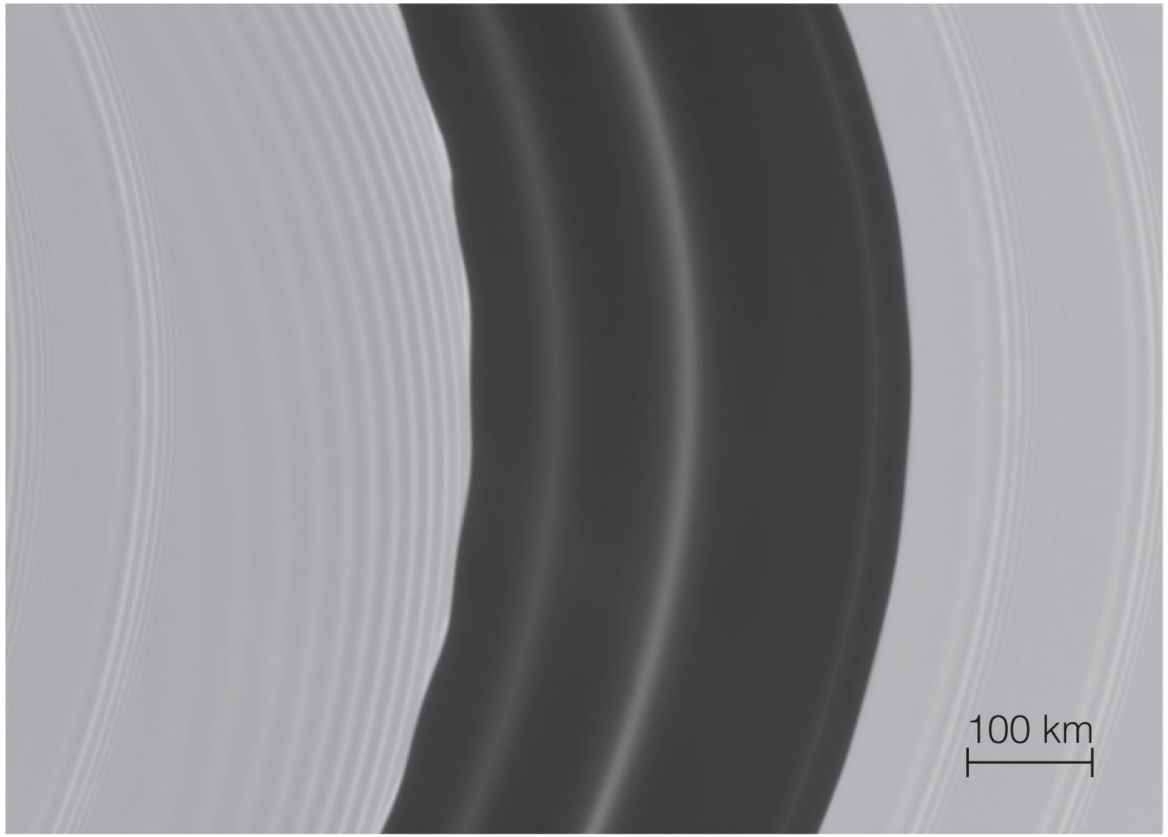
- Some small moons create gaps within rings.

Shepherd Moons



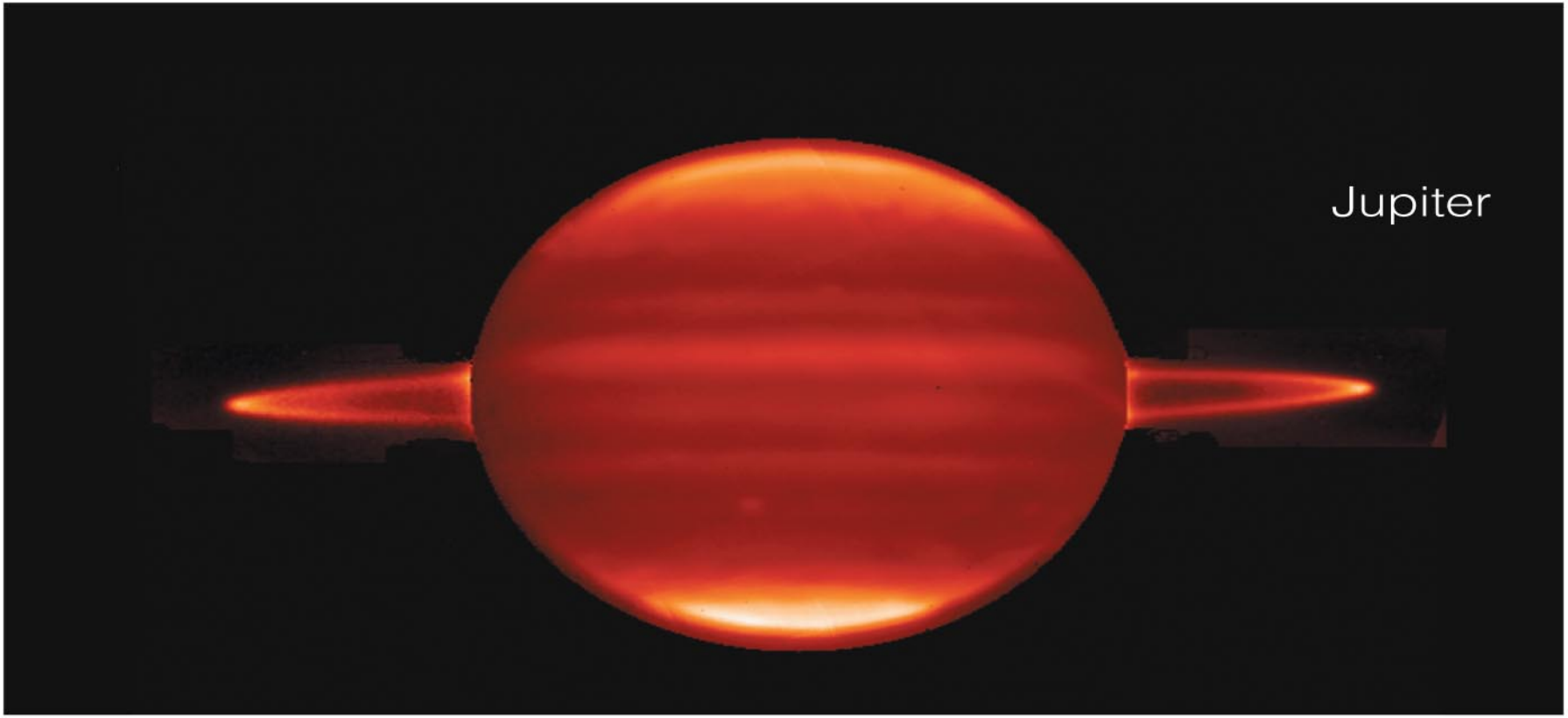
- A pair of small moons can force particles into a narrow ring.

Resonance Gaps

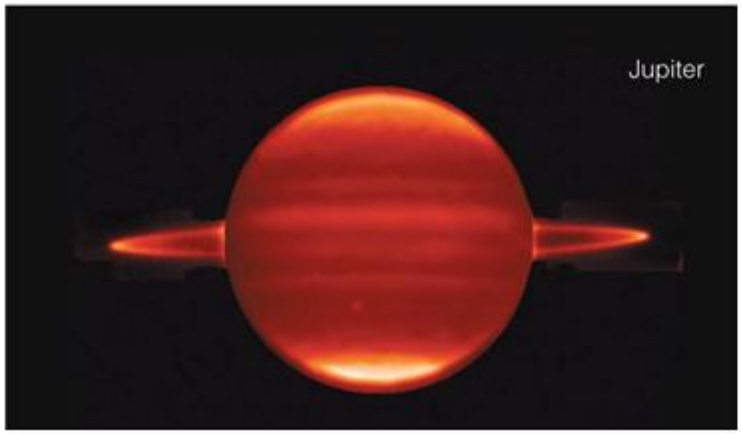


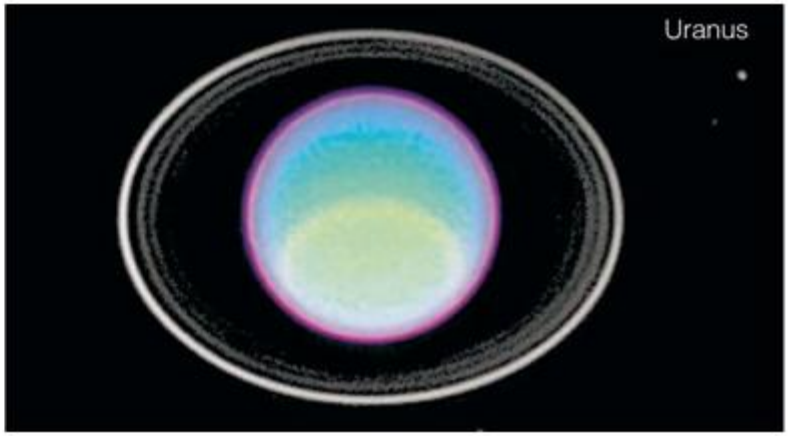
- Orbital resonance with a larger moon can also produce a gap.

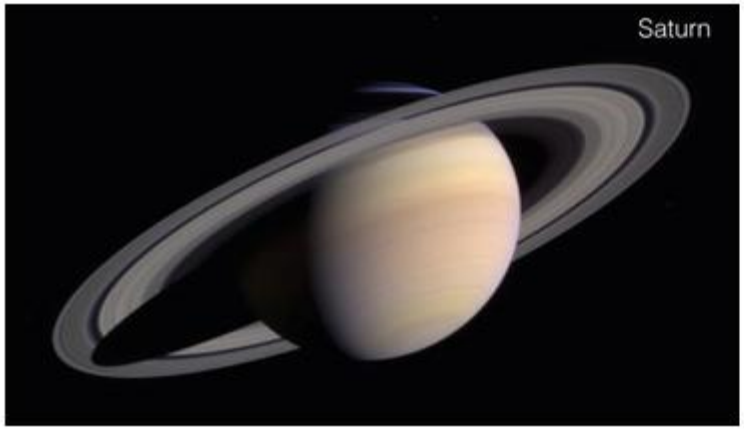
How do other jovian ring systems compare to Saturn's?

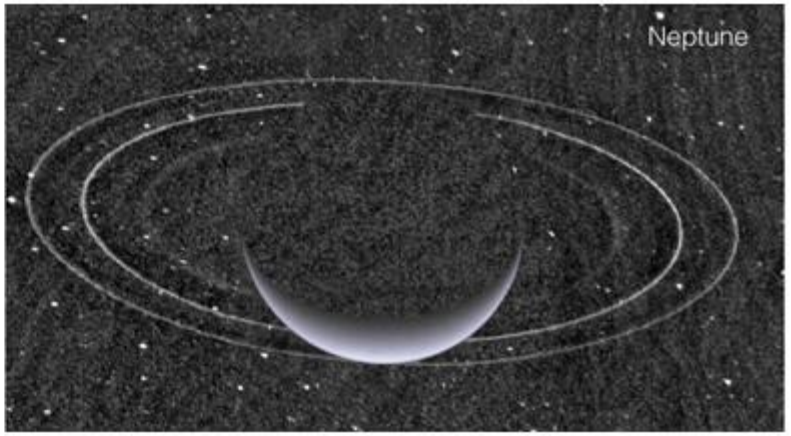


Jovian Ring Systems



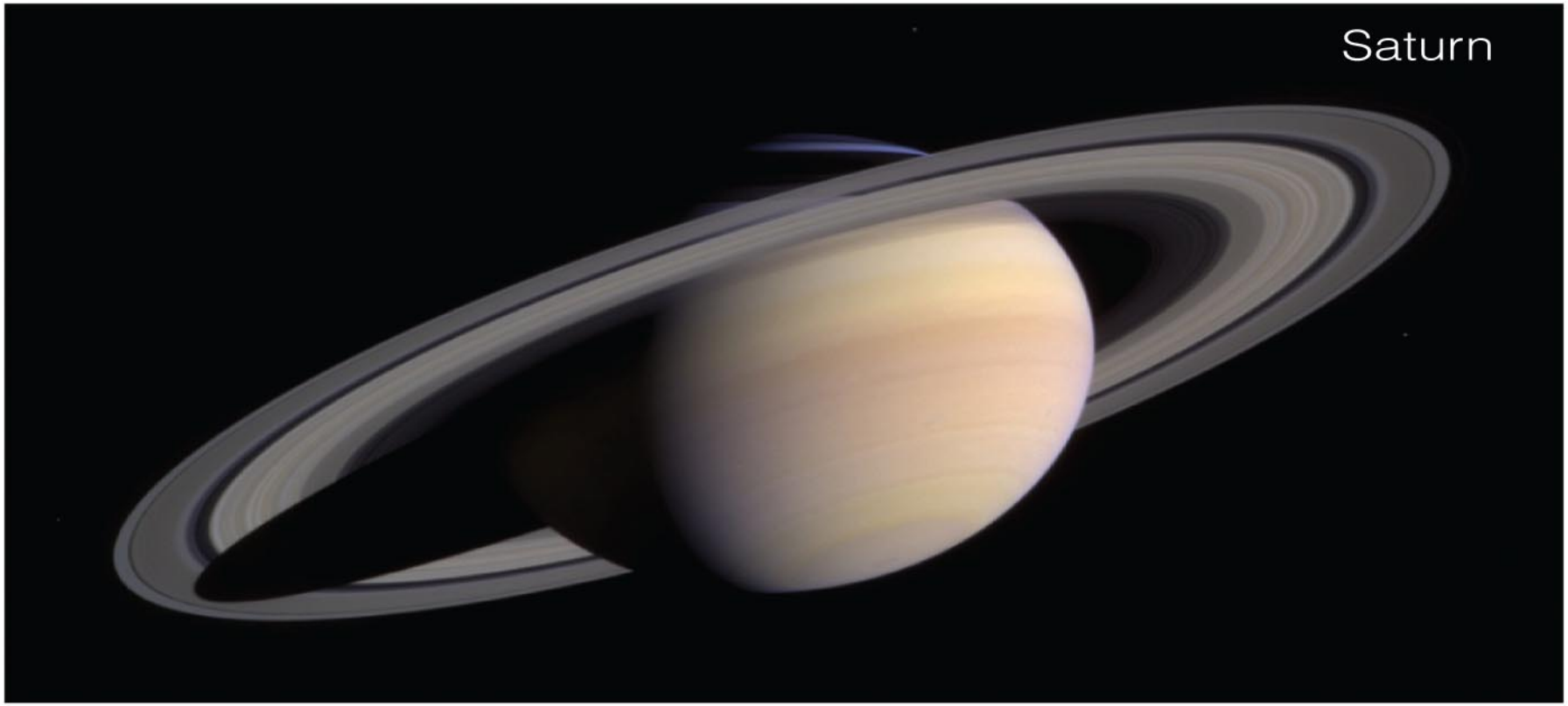






- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than Saturn.

Why do the jovian planets have rings?

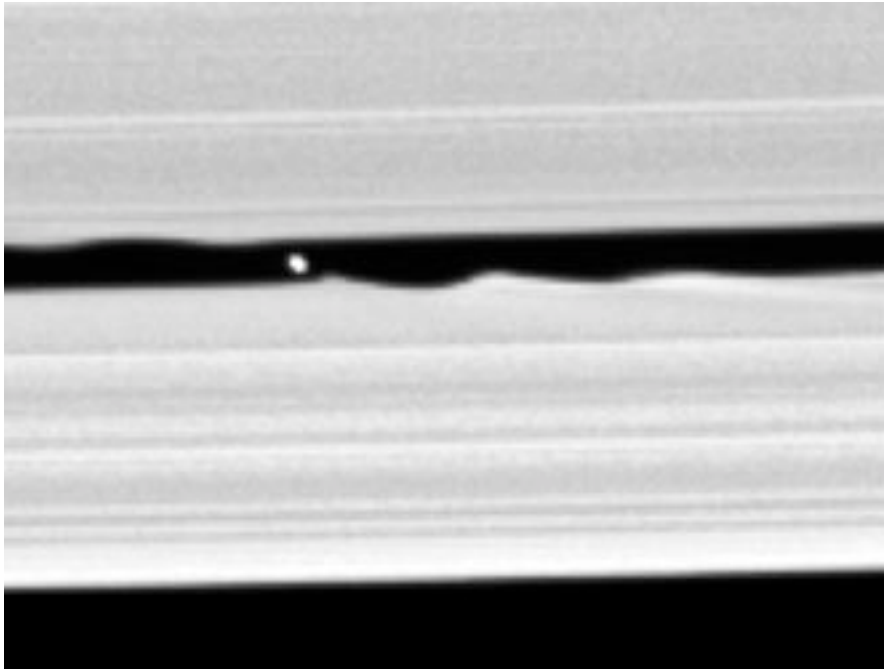


Why do the jovian planets have rings?

- A moon that broke apart long ago? Nope.
- A moon that failed to form? Nope.

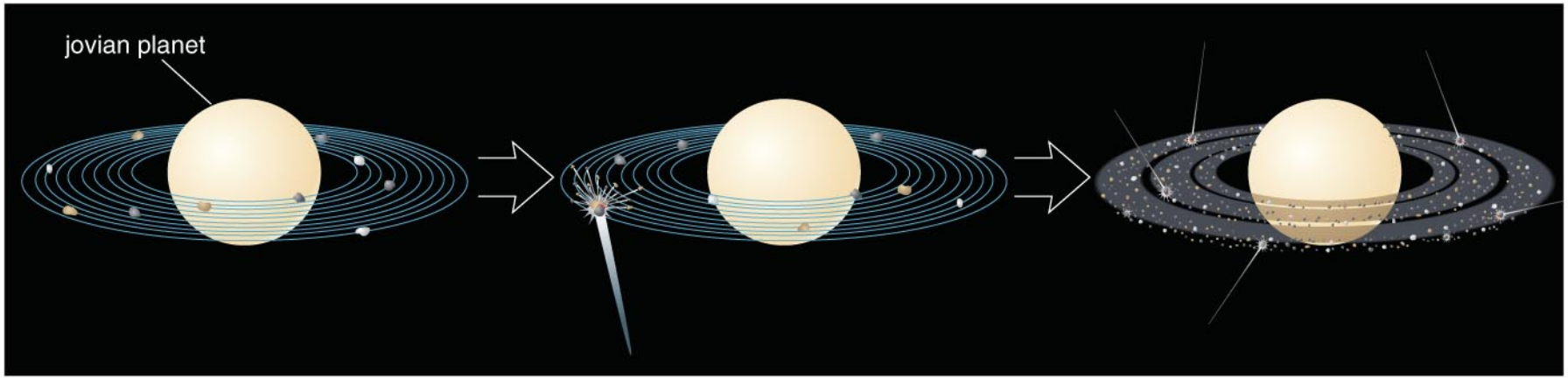
The lifetime of ring particles is much shorter than the age of the solar system, collisions would have turned them to dust.

So they must be continually being produced.



Impacts on the tiny moonlets constantly producing more ring material.

Ring Formation



- Jovian planets all have rings because they possess many small moons close in.
- Impacts on these moons are random. Big ones will produce more particles and brighter rings, until the particles are ground down.
- Saturn's incredible rings may be an "accident" of our time.

What have we learned?

- **What are Saturn's rings like?**
  - They are made up of countless individual ice particles.
  - They are extremely thin with many gaps.
- **How do other jovian ring systems compare to Saturn's?**
  - The other jovian planets have much fainter ring systems with smaller, darker, less numerous particles.
- **Why do the jovian planets have rings?**
  - Ring particles are probably debris from moons.