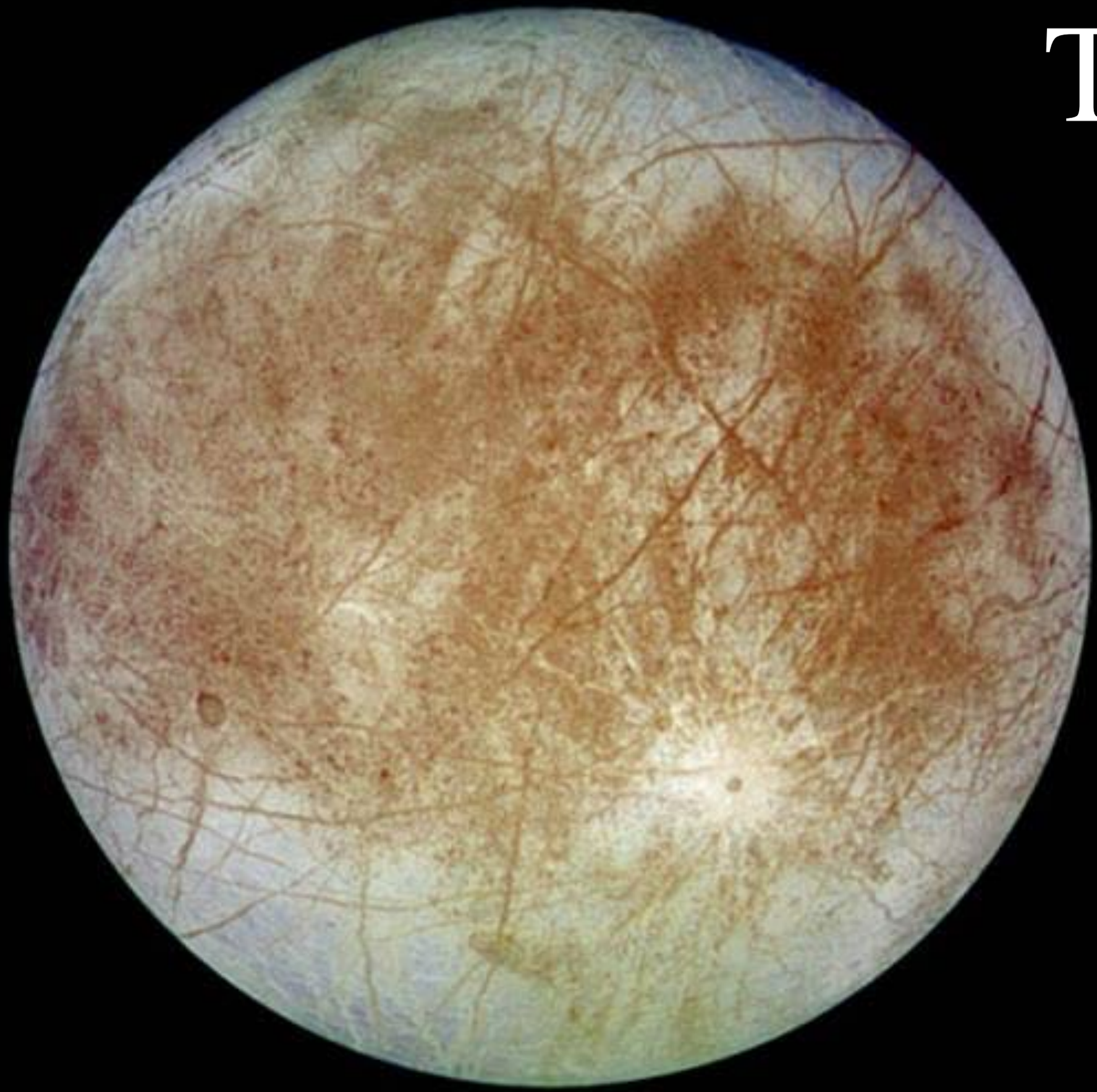


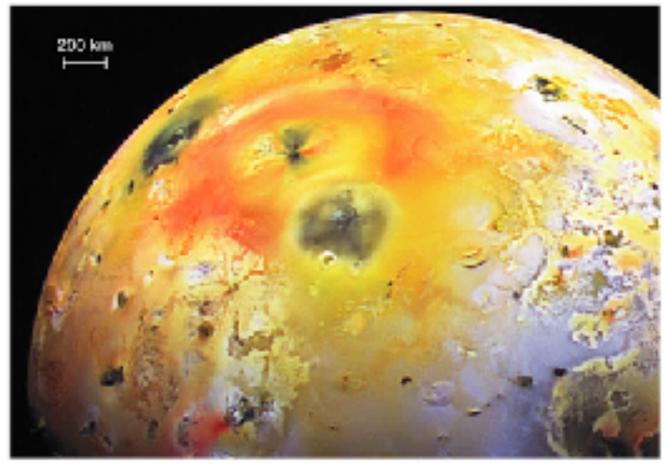
Today

- Moons of the solar system
- Rings

Events

- Homework 5
- Due next time

Io



H_2O

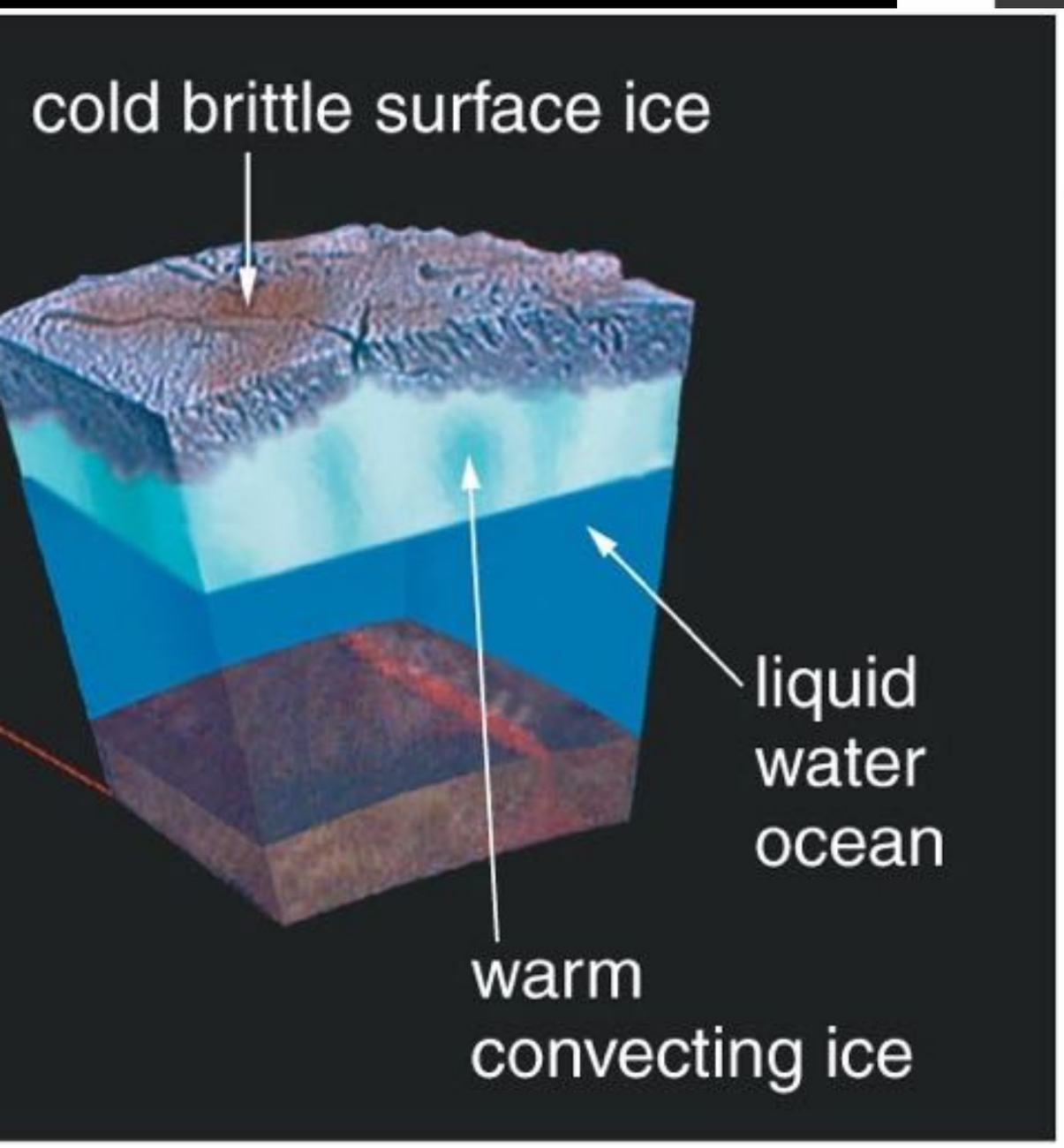
PAH

Lp

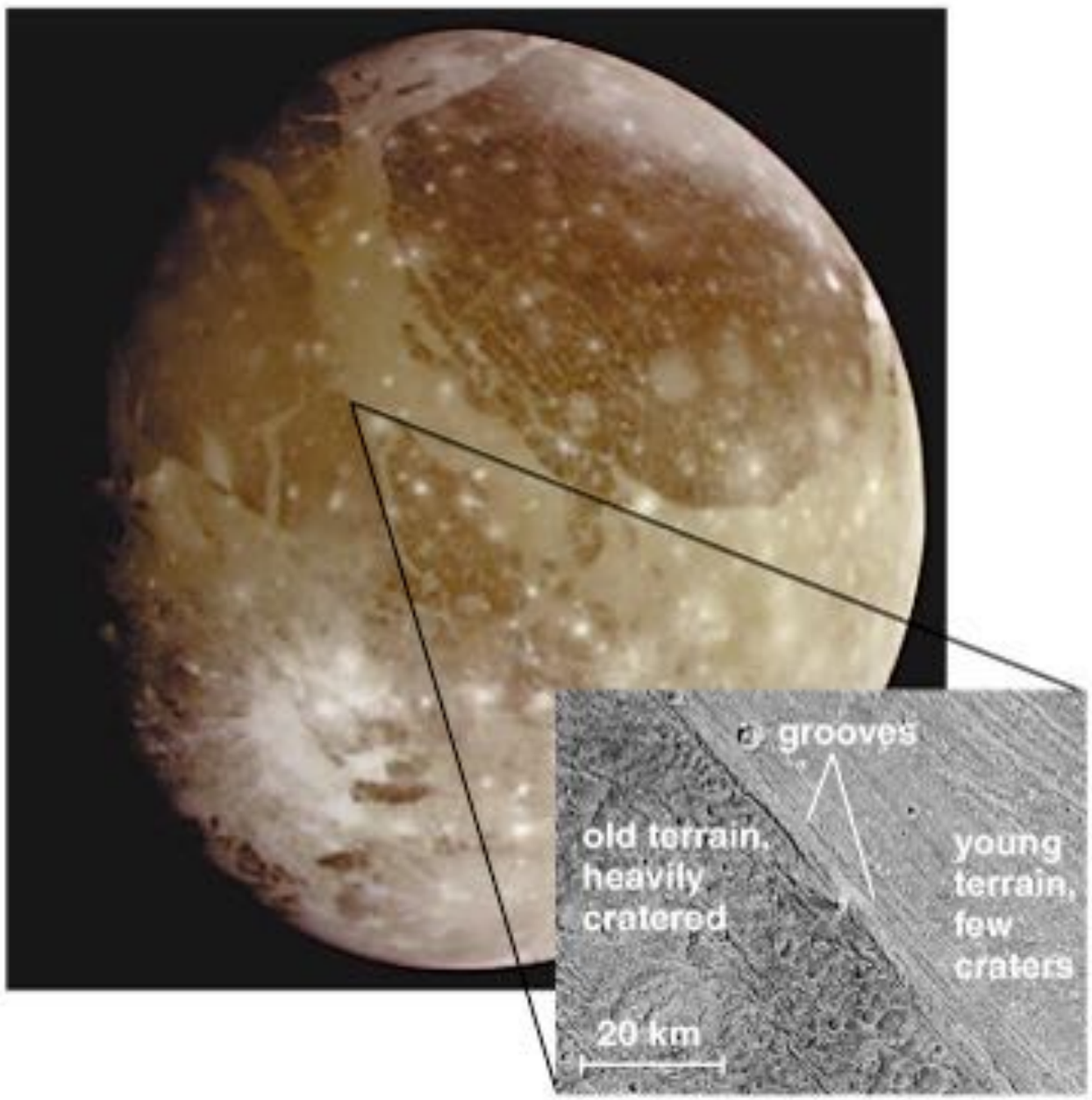
Ms

Monitoring Io shows many active volcanos

NASA
"Visions of the Future"
poster series

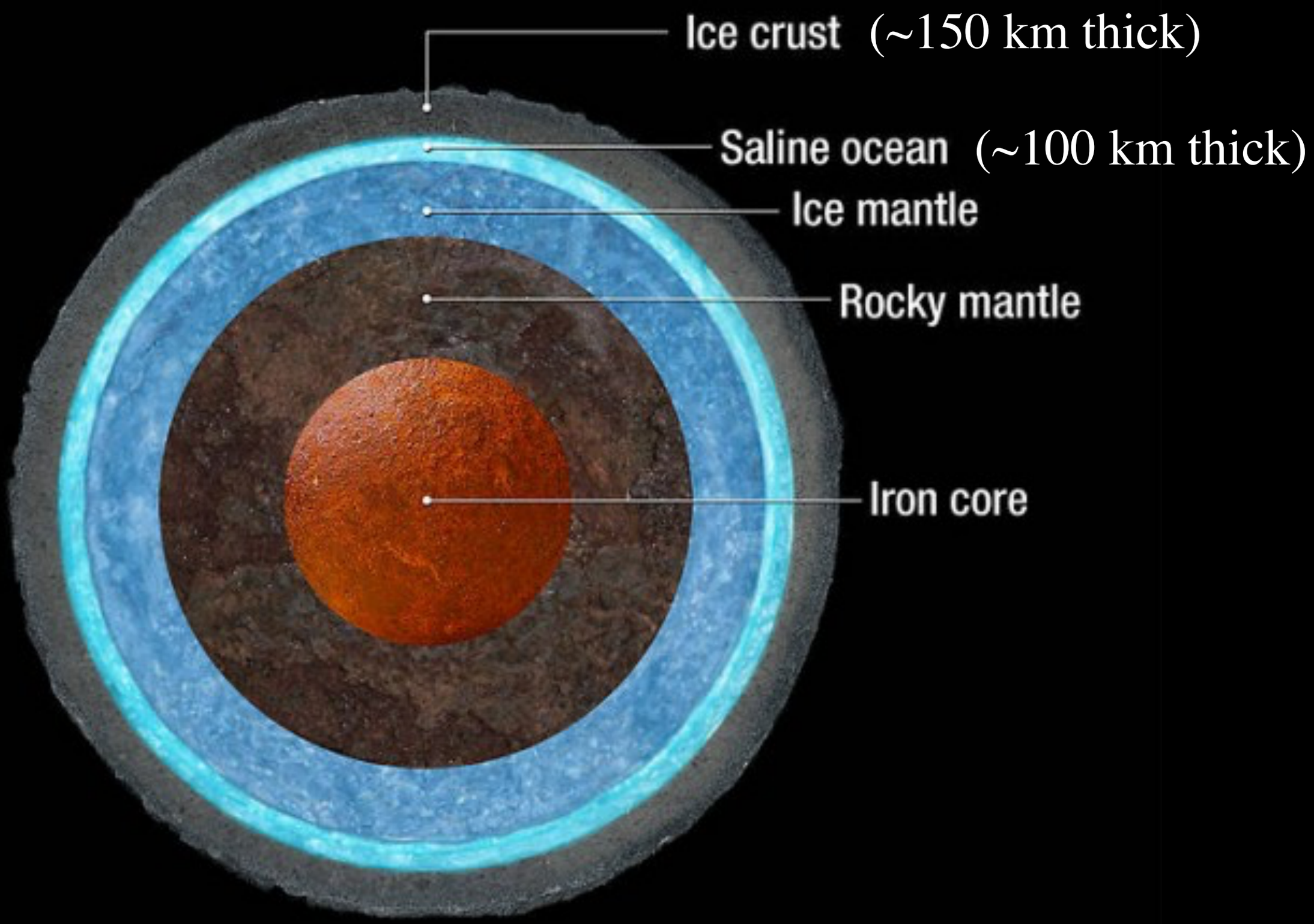


Ganymede

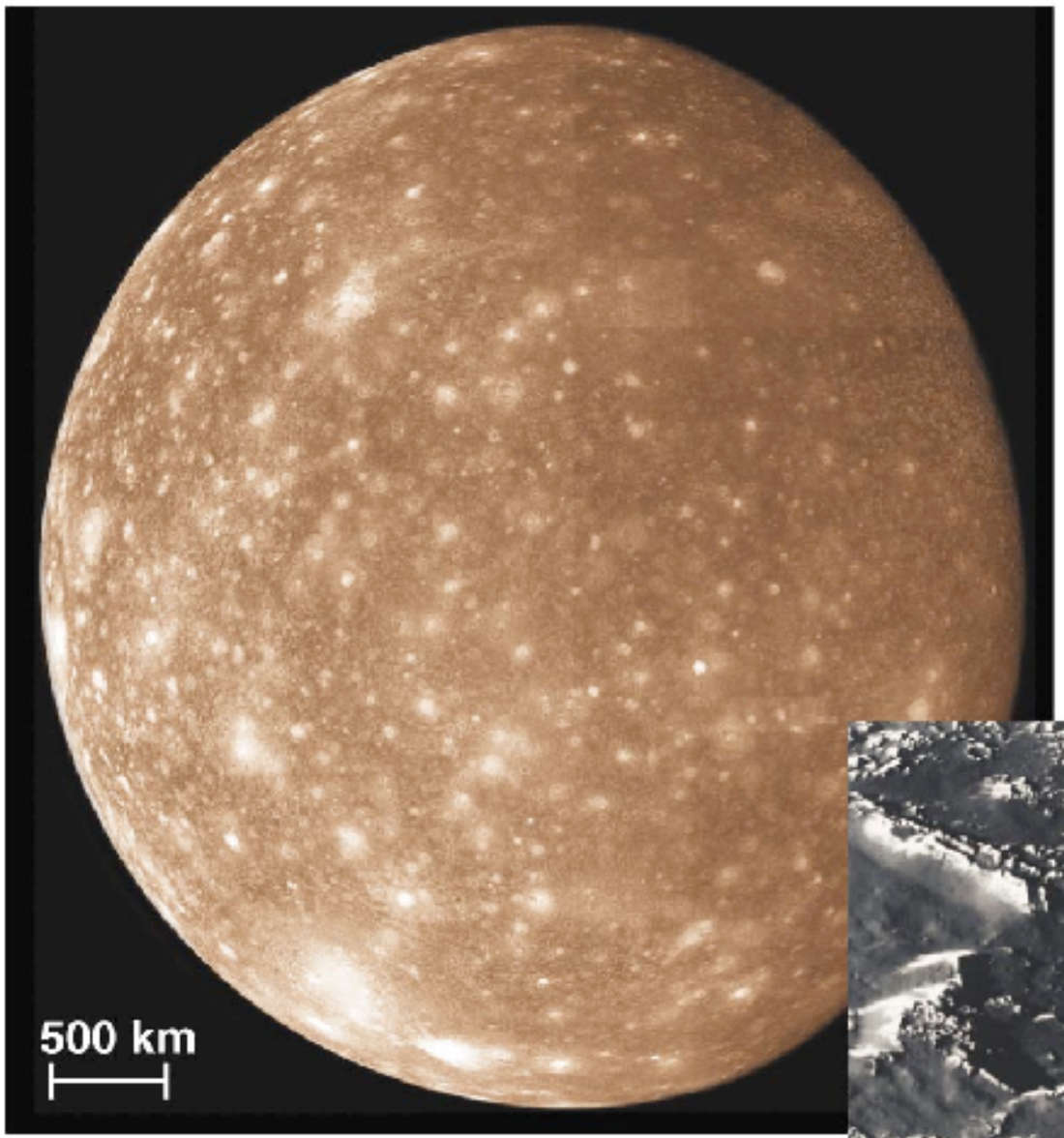


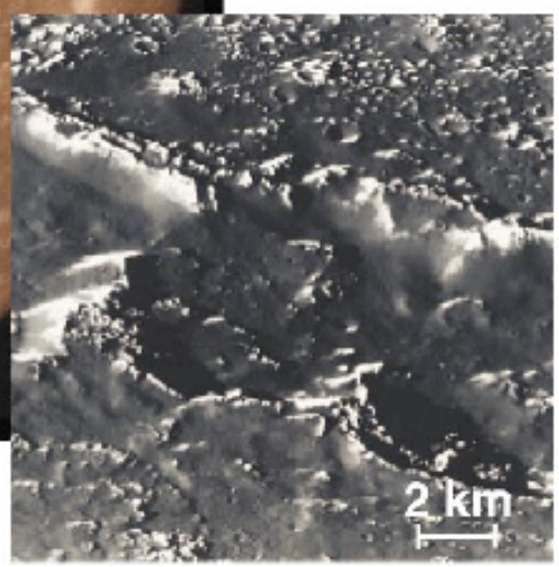
- Largest moon in the solar system
- Clear evidence of geological activity
- Salty ocean under thick crust of ice
- Tidal heating plus heat from radio-active decay?

Ganymede Interior



Callisto

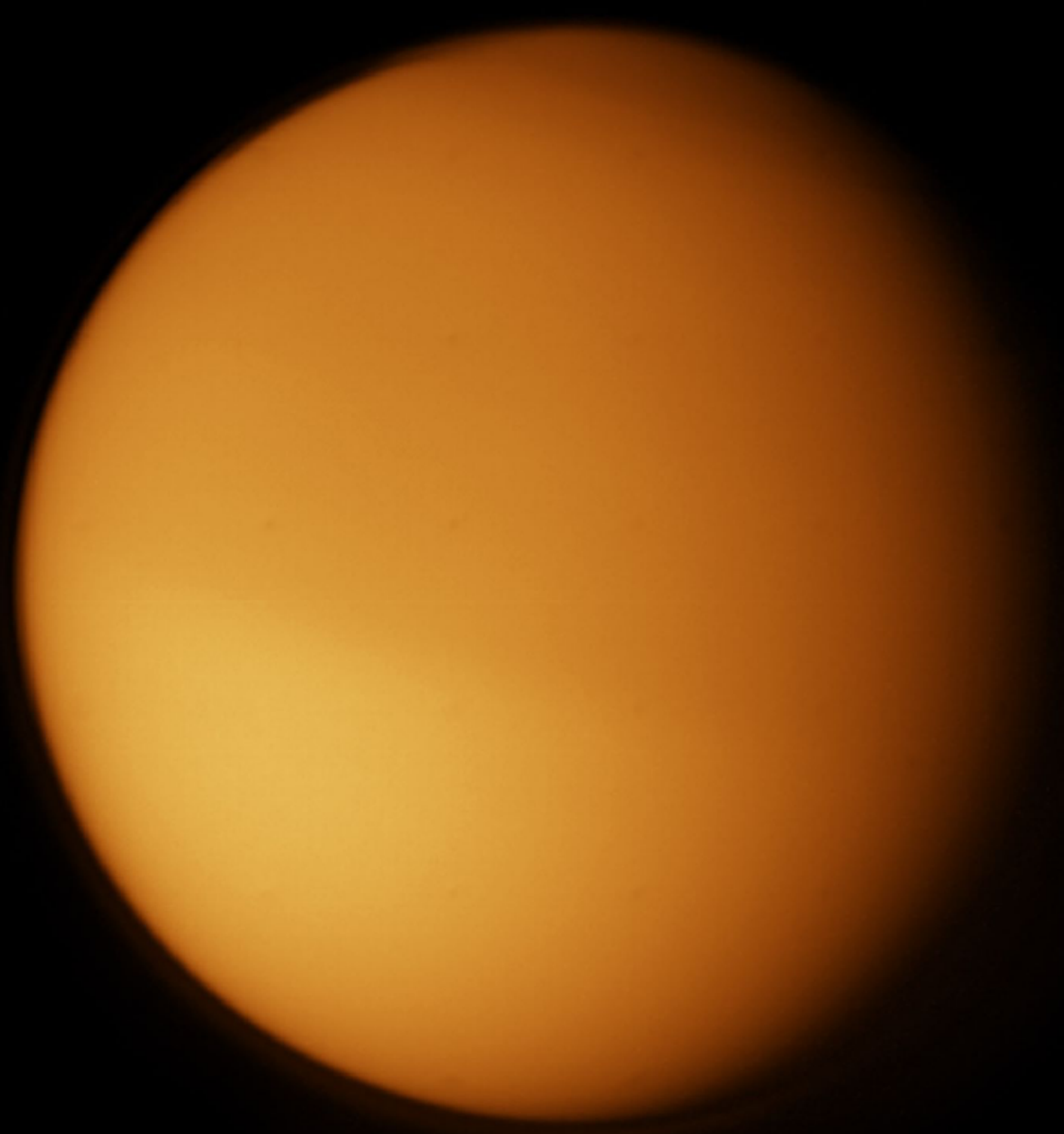




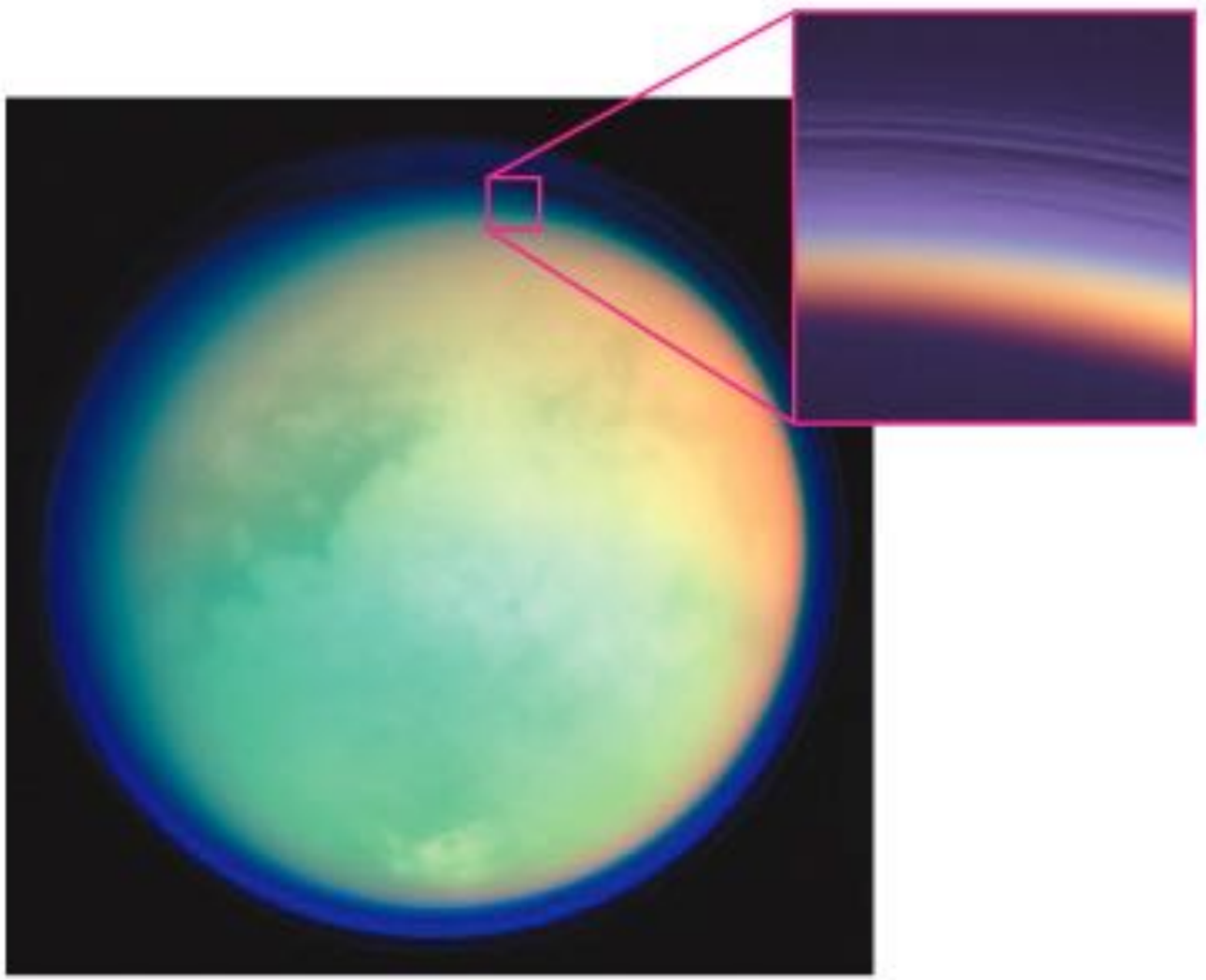
- "Classic" cratered iceball
- No tidal heating, no orbital resonances

Saturn

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

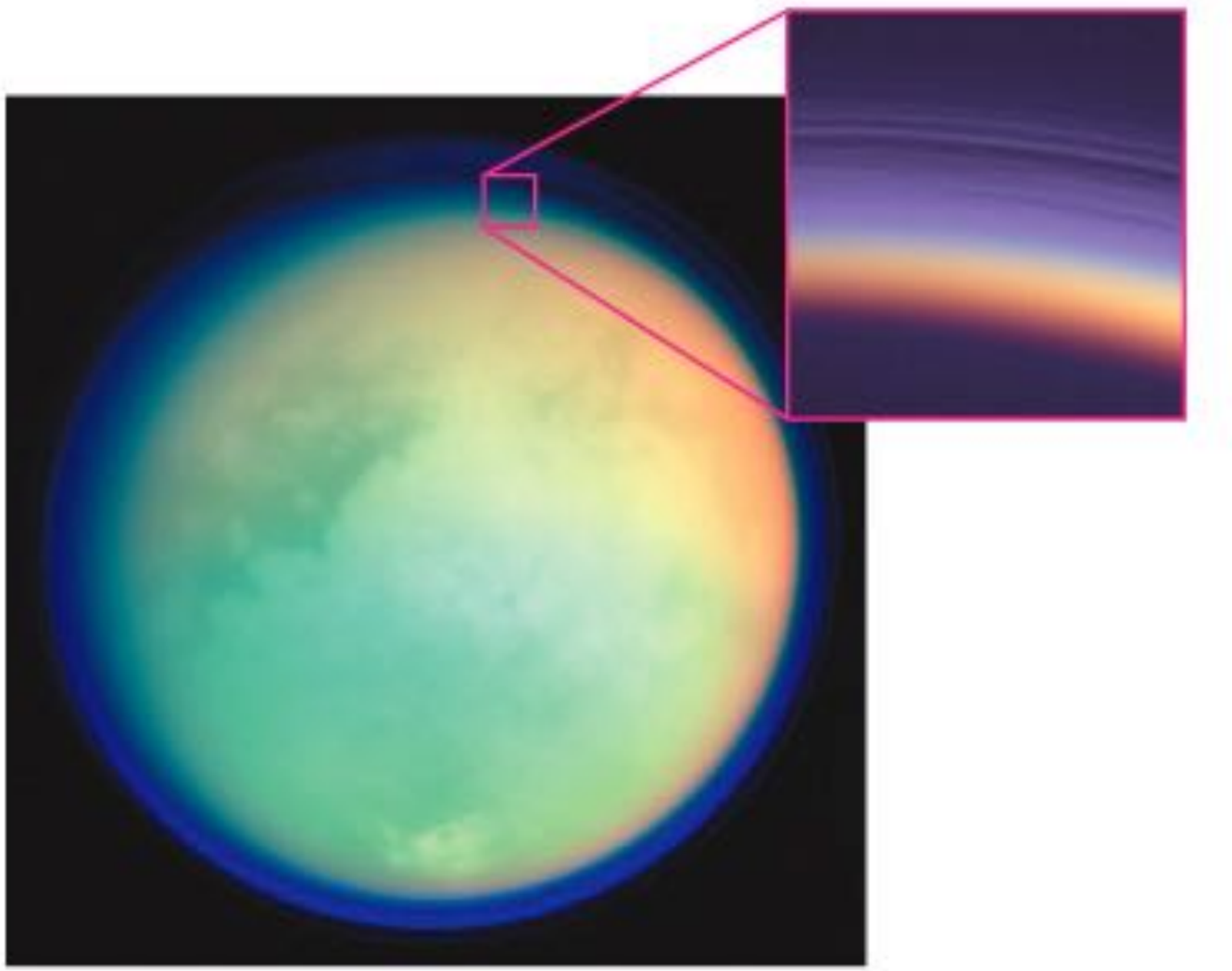


Saturn’s large moon Titan



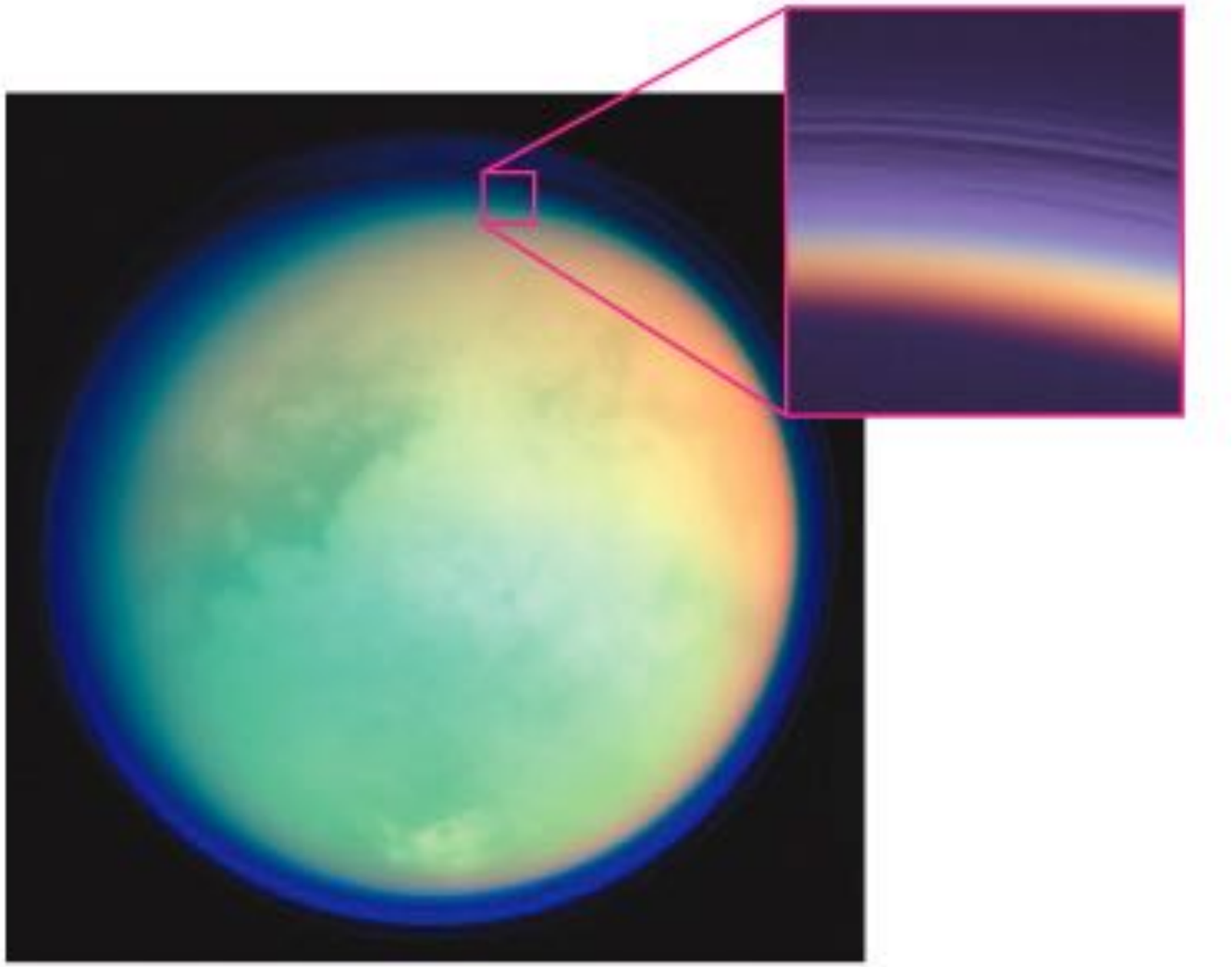
- Titan is the only moon in the solar system which has a thick atmosphere.
- It has a thick haze layer that obscures the surface at optical wavelengths.

Saturn's large moon Titan



- Atmospheric composition:
  - 90% N_2
  - 5% Argon
  - 5% CH_4 (methane)
  - other hydrocarbons
- Hazy

Saturn's large moon Titan

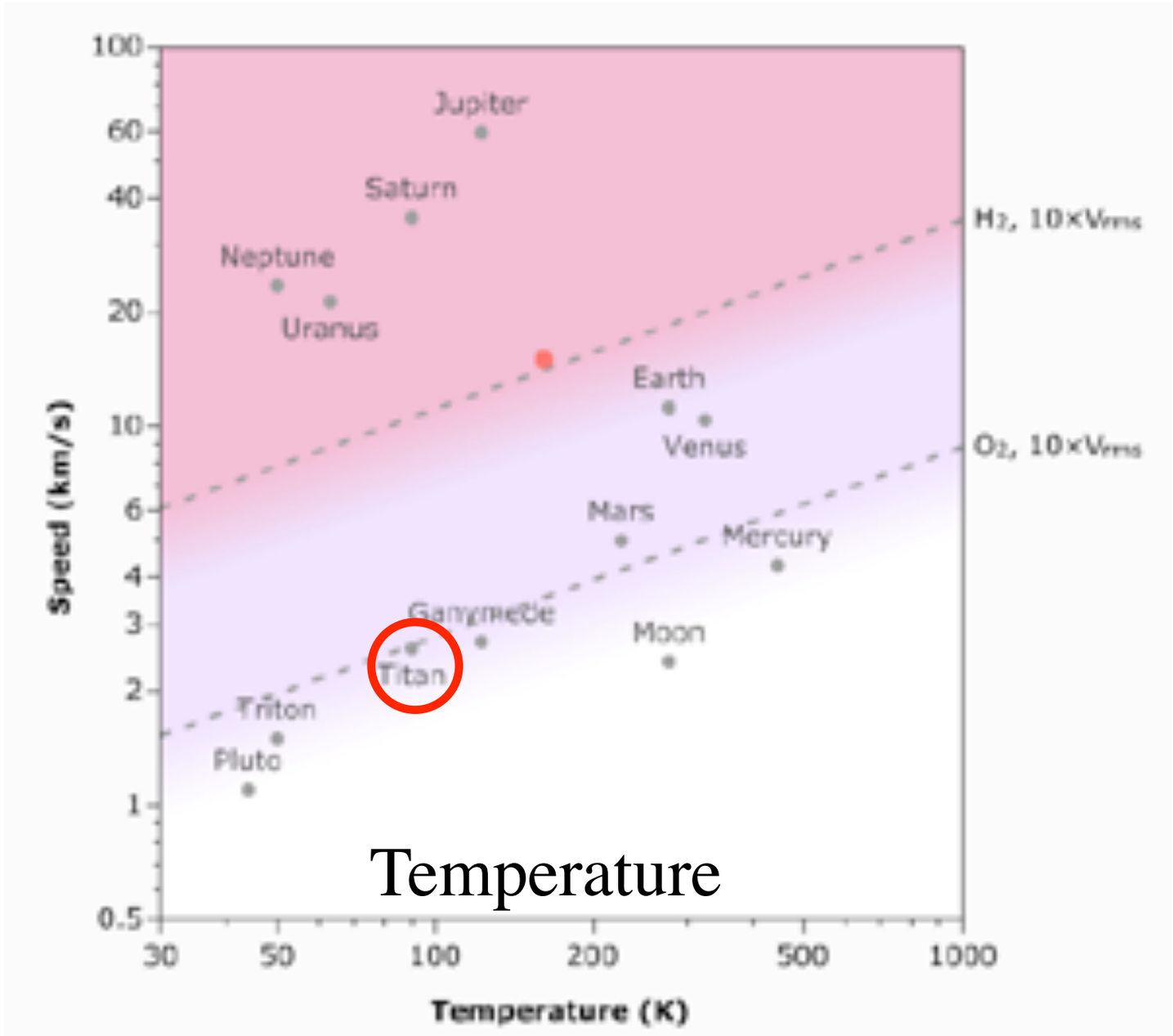


- Relative to Earth:
  - 1.5 Atm pressure
  - 4x denser
  - comparable total mass (1.2x)
  - more extended
    - due to lower gravity

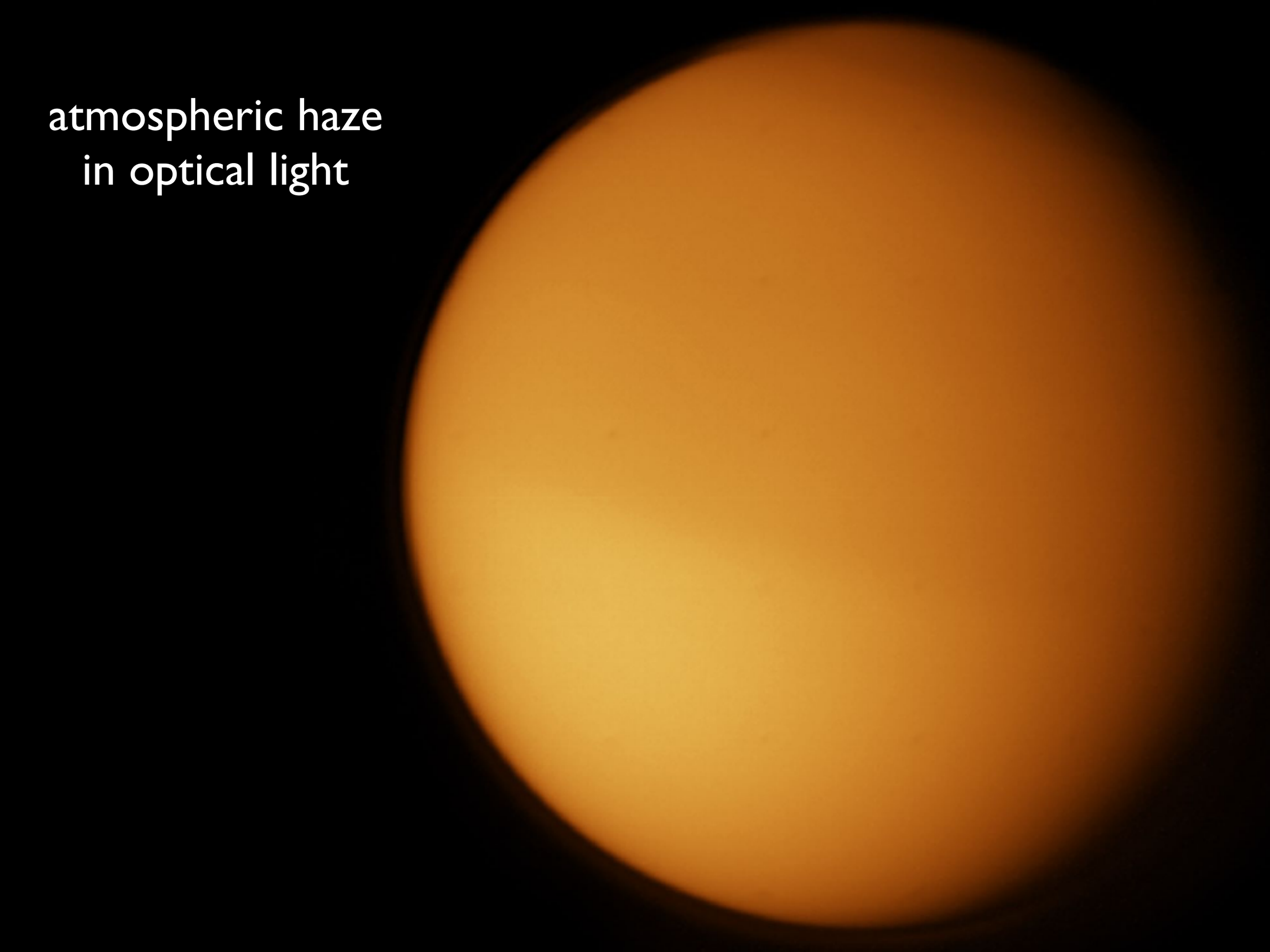
- Cold
  - -180^{o} C

Titan is

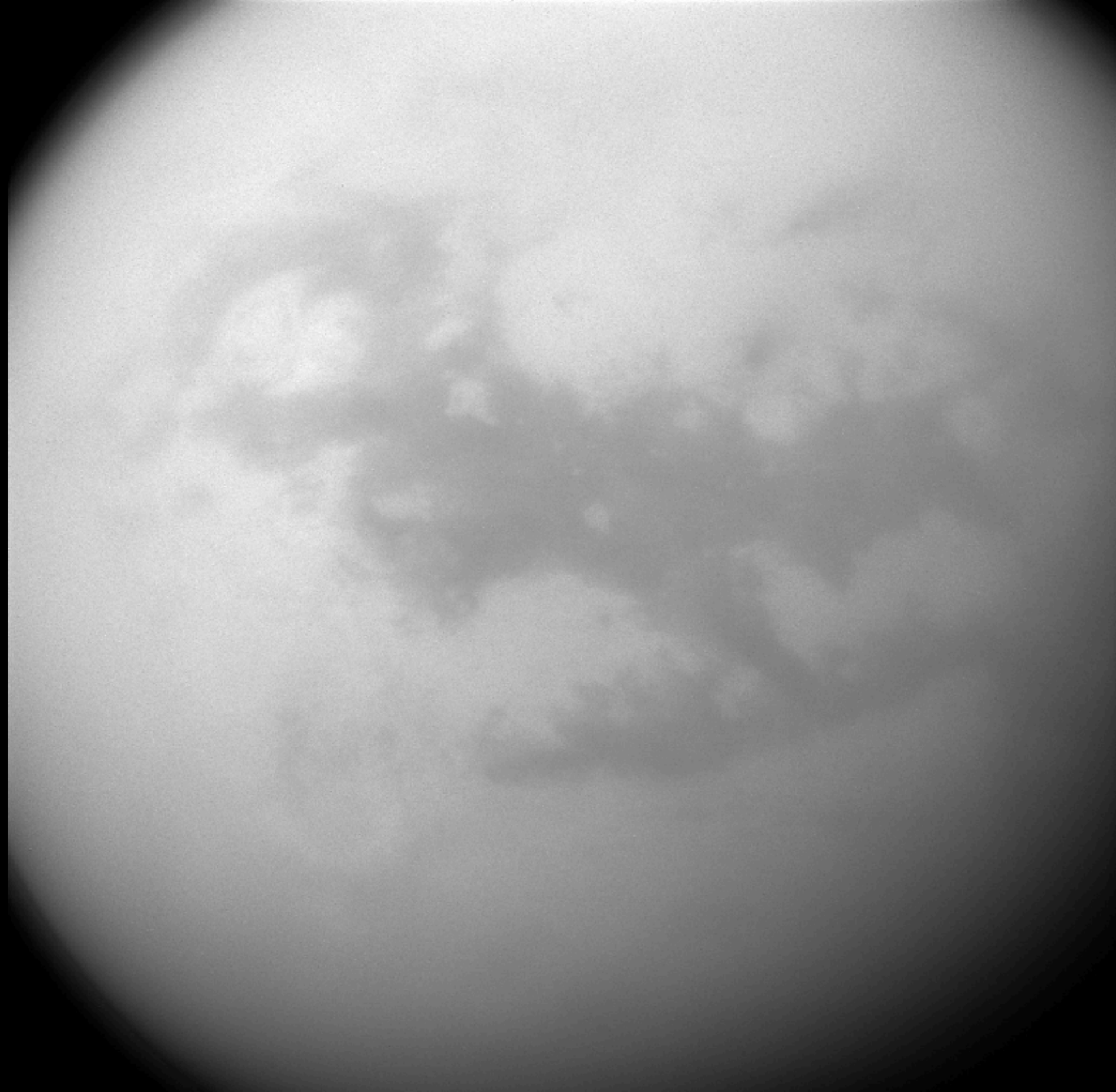
- Big for a moon, and
- cold - can retain an atmosphere



atmospheric haze
in optical light



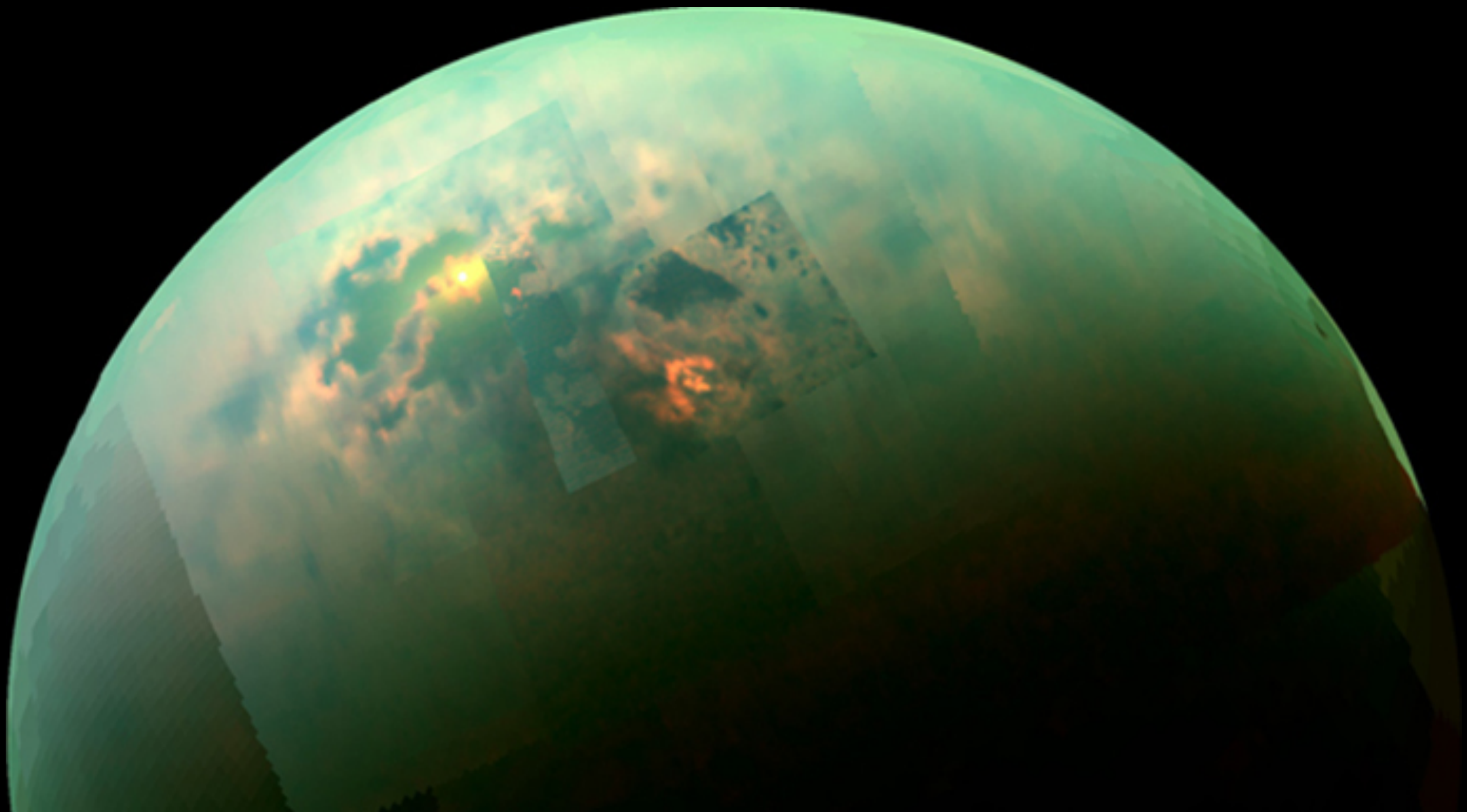
Underneath the atmosphere is terrain, including seas of liquid hydrocarbons



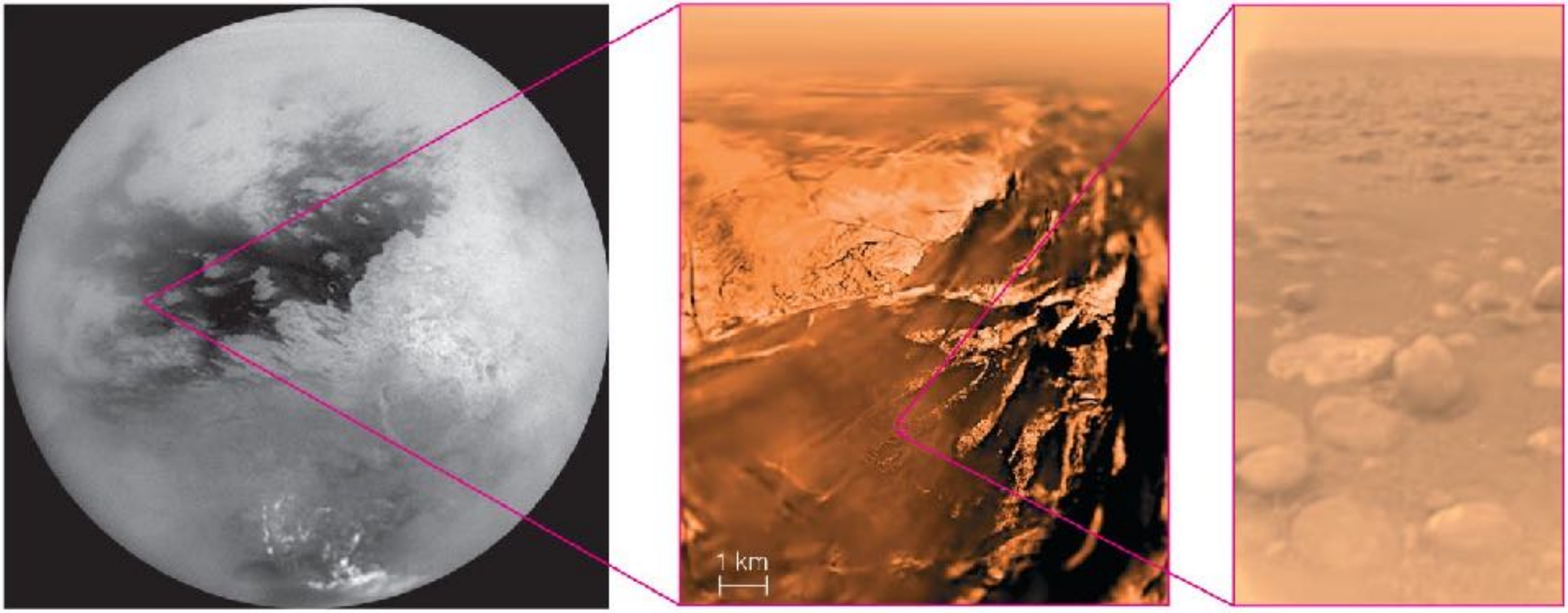
solid surface

liquid
methane

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.

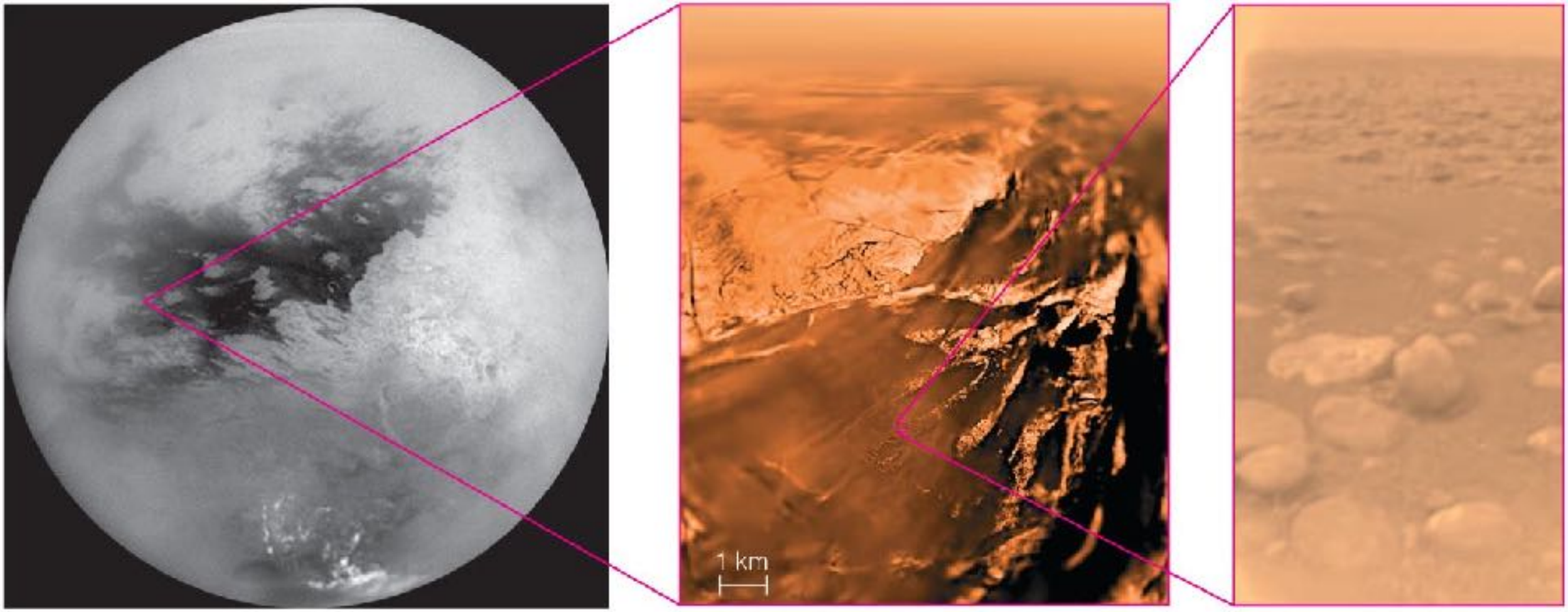
Huygens descent movie

https://www.youtube.com/watch?v=HtYDPj6eFLc

https://www.youtube.com/watch?v=YErUVO0FSS8

https://www.youtube.com/watch?v=bS9wlVsFlzA

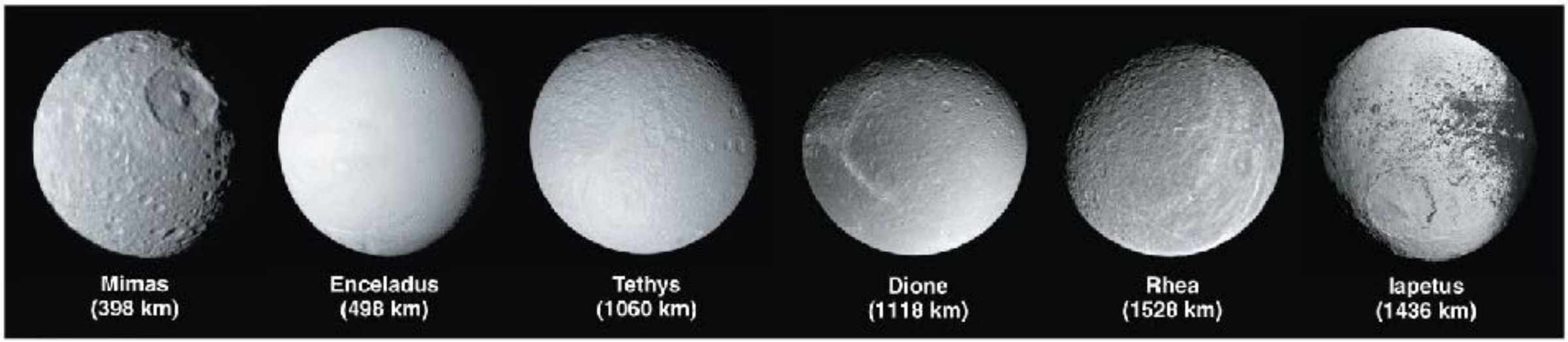
Titan's Surface



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

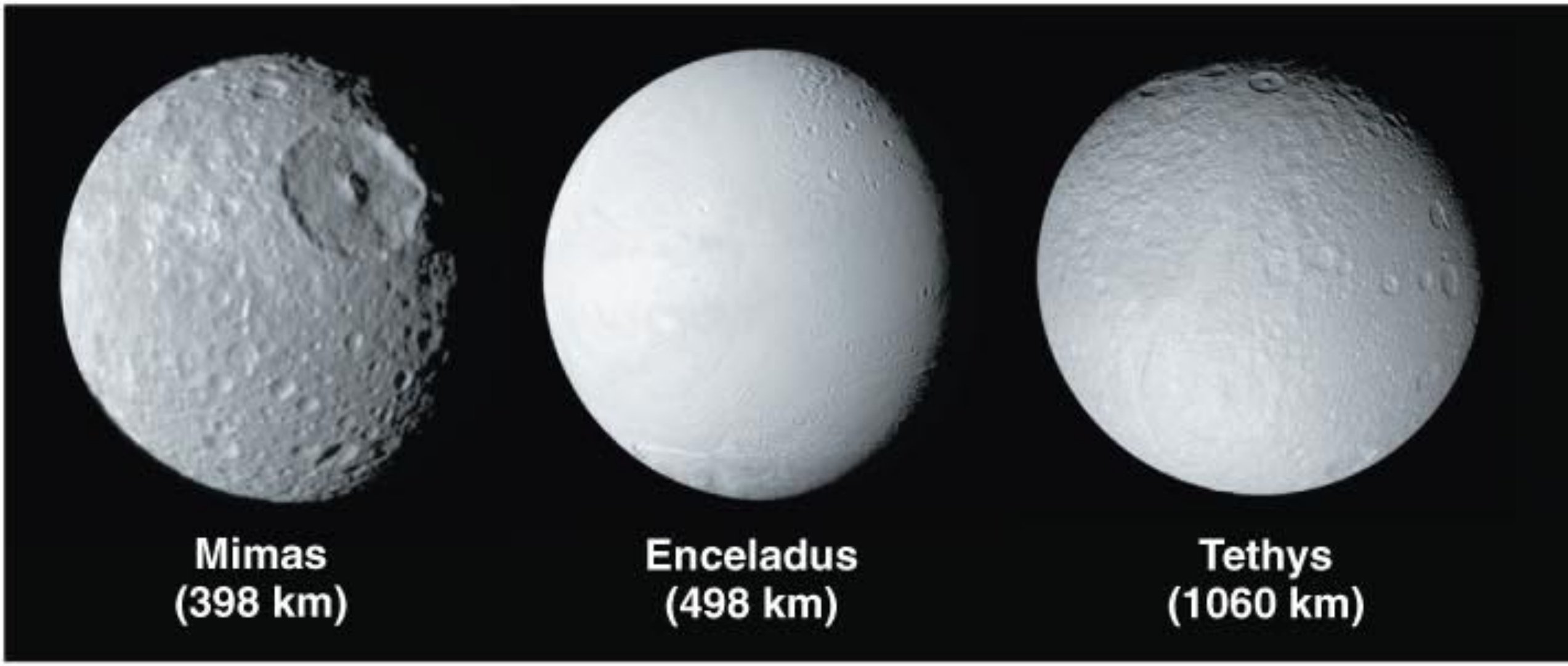
NASA
"Visions of the Future"
poster series

Medium Moons of Saturn



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

Medium Moons of Saturn

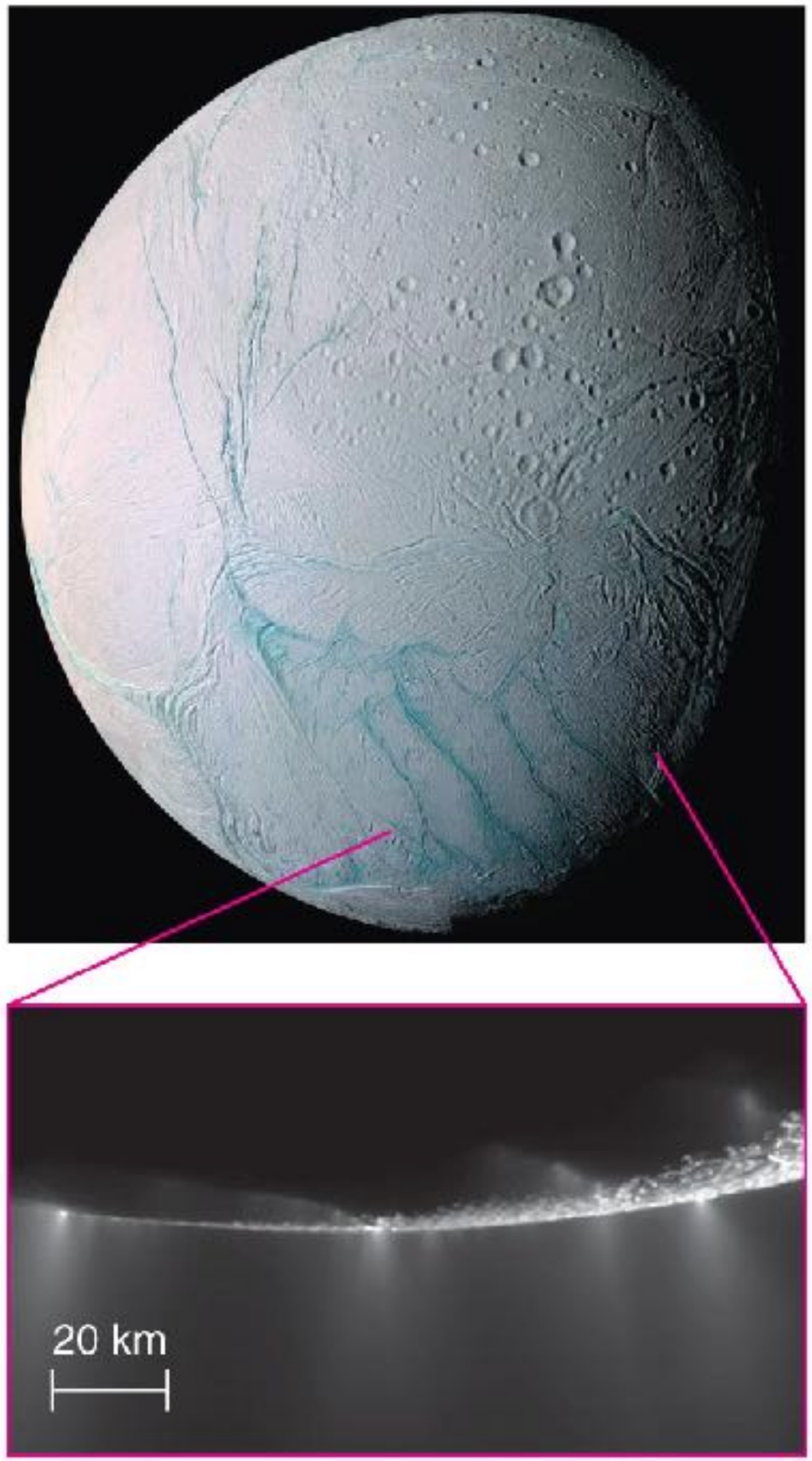


- Mimas has a big crater that makes it look like the Death Star.

Medium Moons of Saturn

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

- “Cryovolcanism - the “magma” is water.

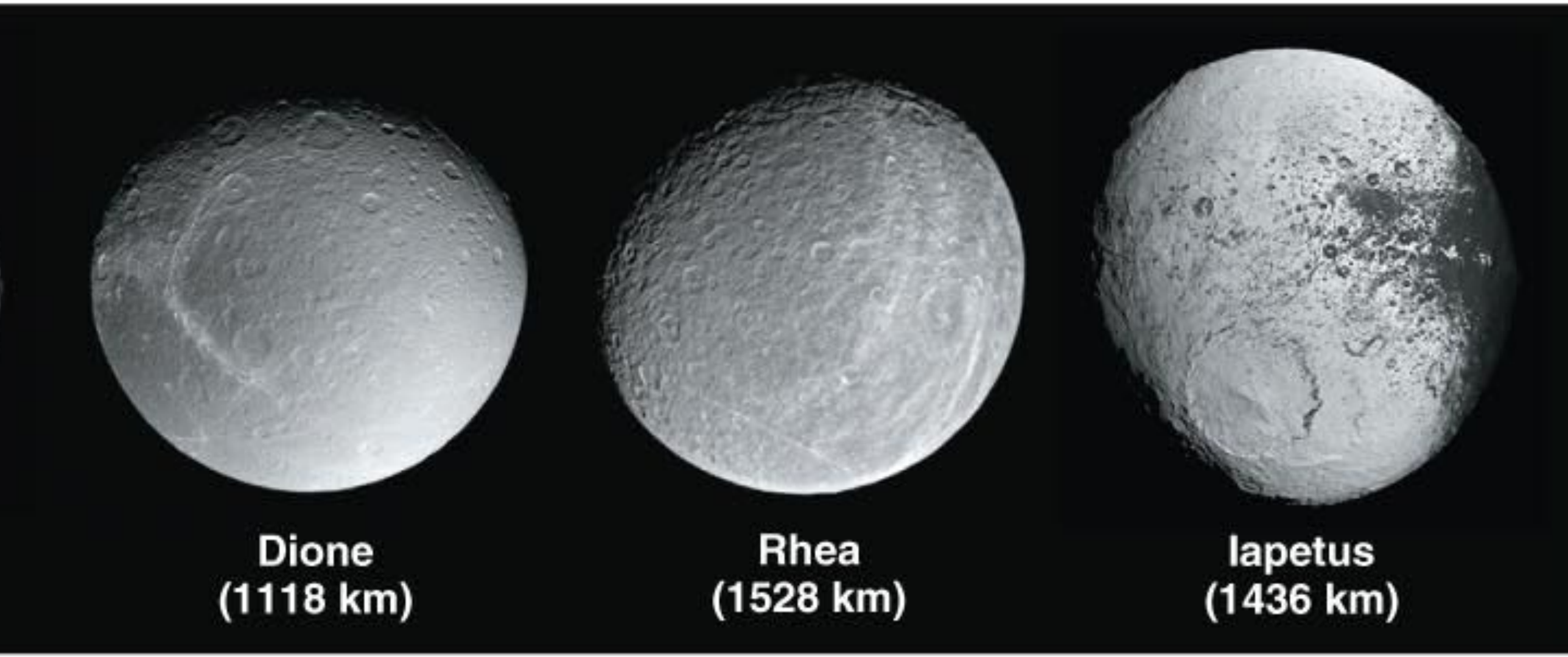


NASA
"Visions of the Future"
poster series

Apparently NASA artists think you'll need a cane.

In zero g.

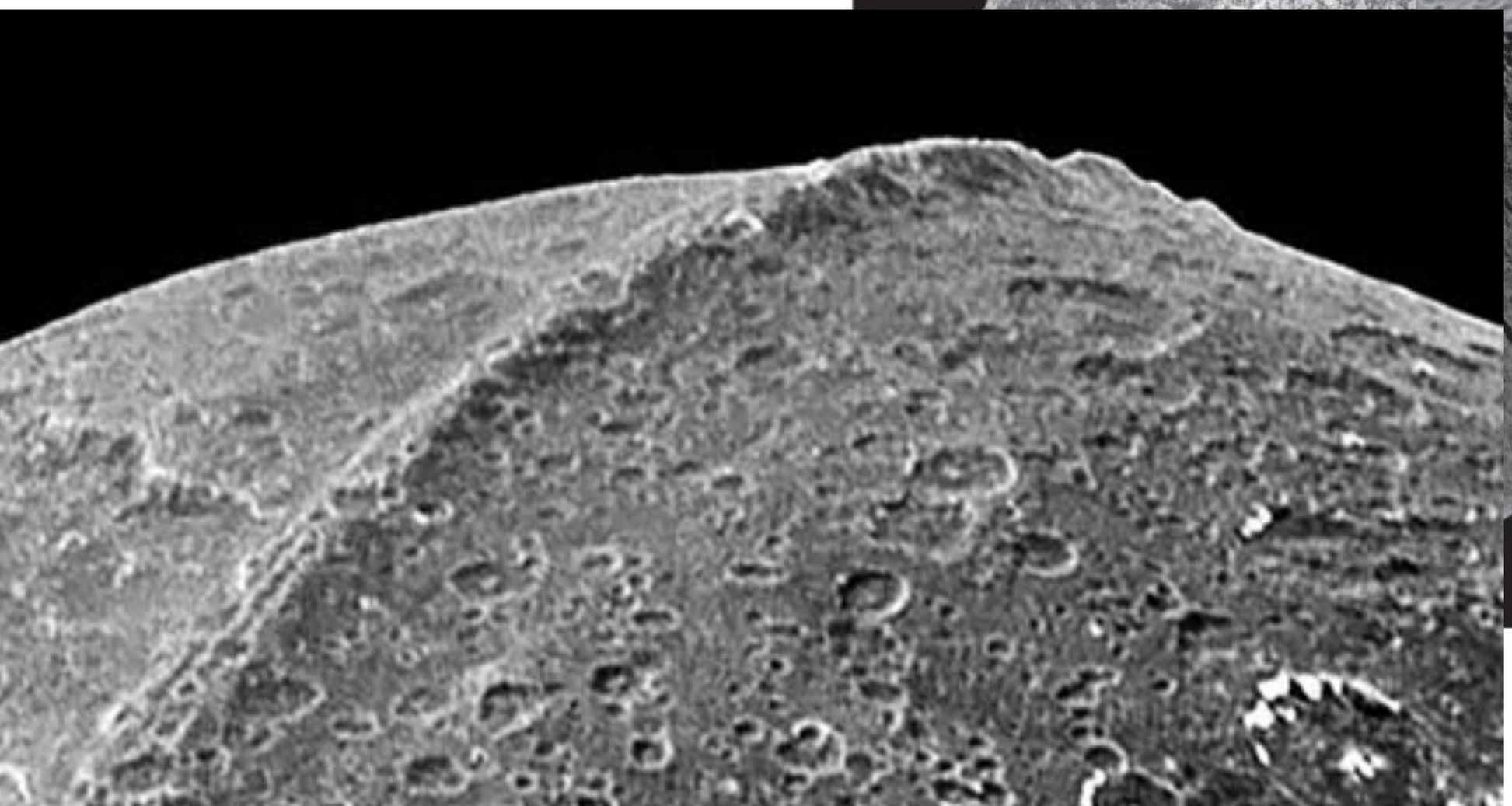
Medium Moons of Saturn



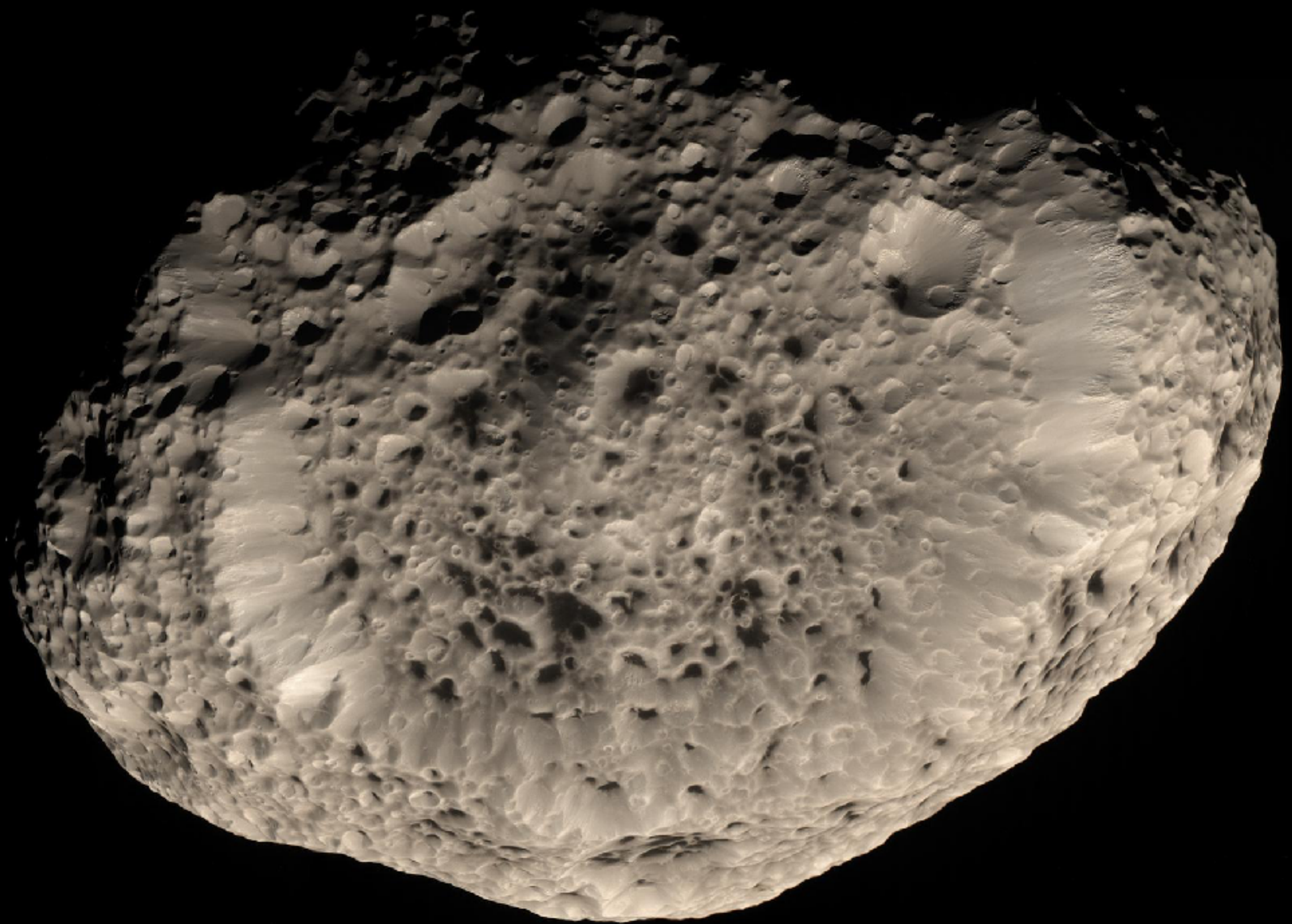
- Iapetus is dark on one side & bright on the other. It seems to have collected a goo of space debris emitted by Phoebe on the leading (dark) side of its orbit.

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

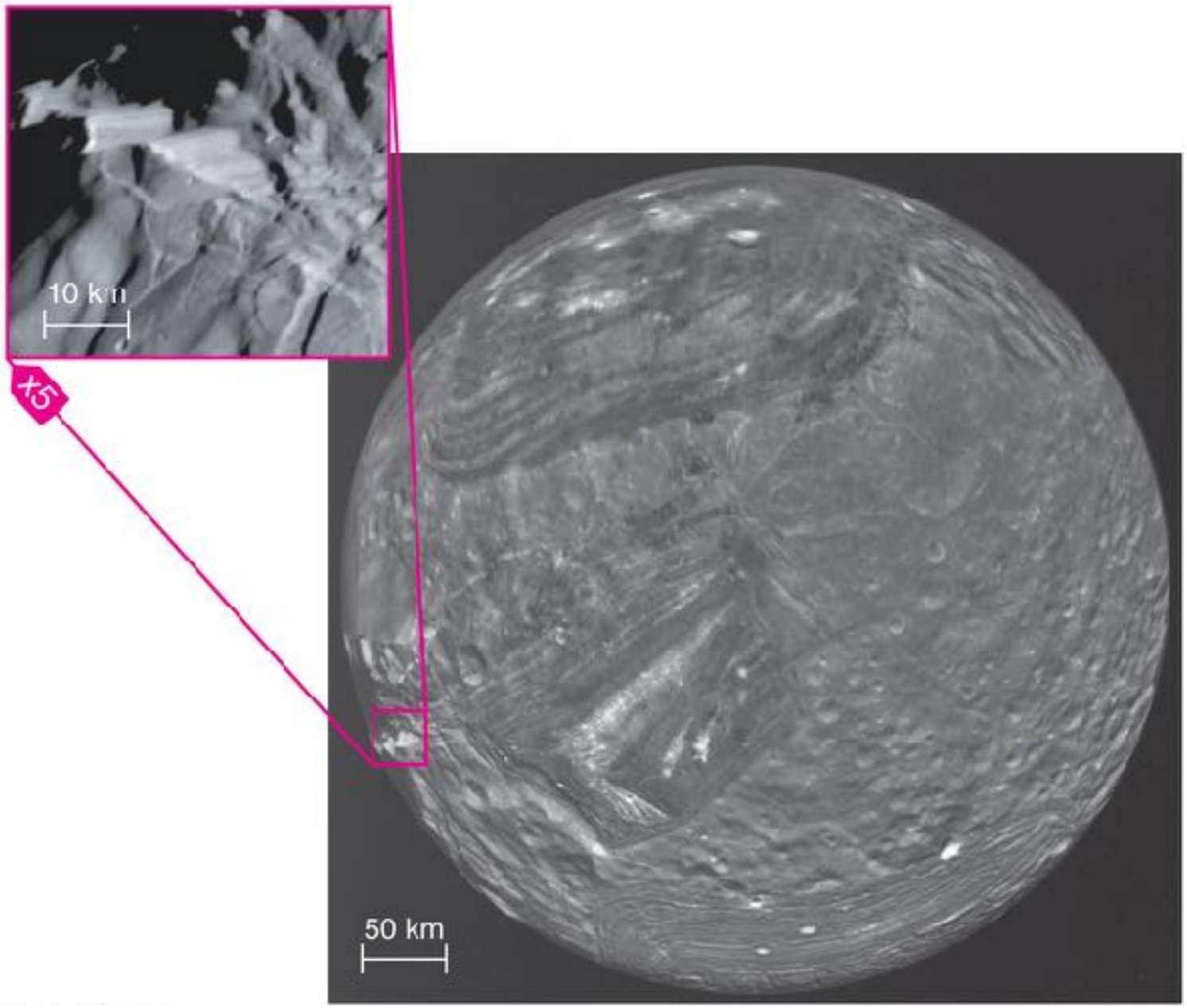
Oberon

Umbriel

Earth's Moon

Titania

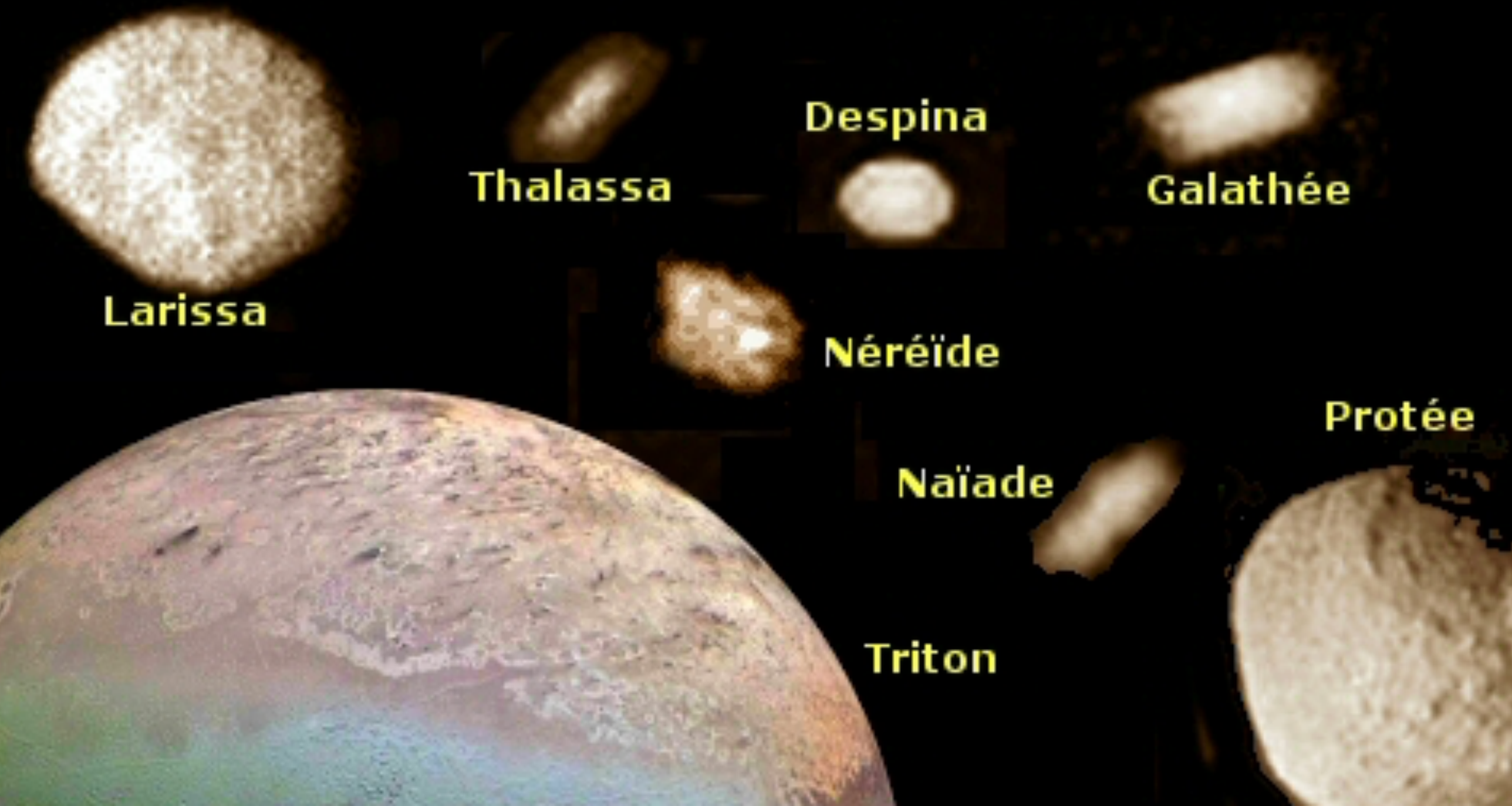
Medium Moons of Uranus



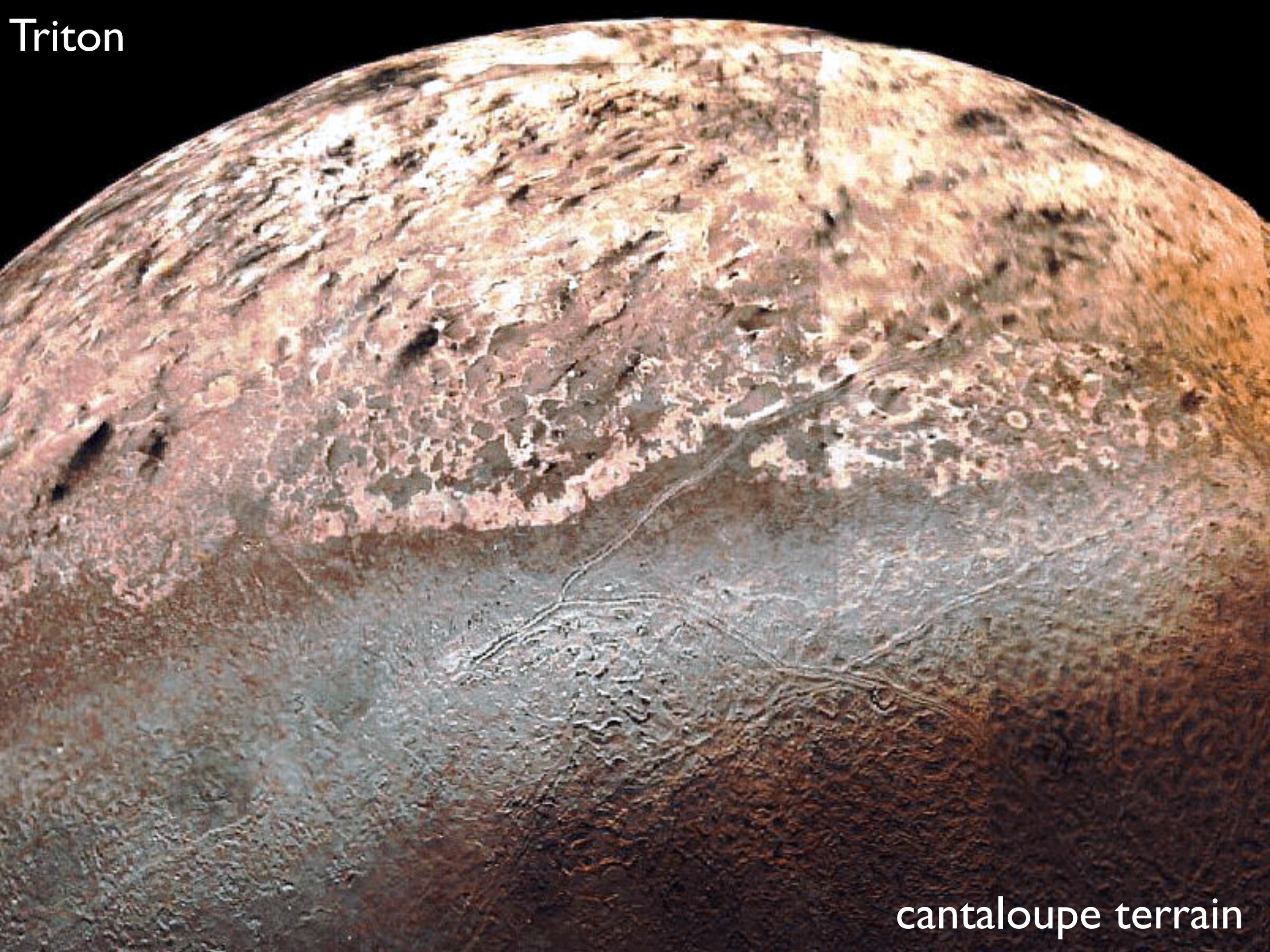
- They have varying amounts of geological activity.
- Miranda has large tectonic features and few craters (possibly indicating an episode of tidal heating in past).

https://www.youtube.com/watch?v=v6Bt7u-EQHM

Moons of Neptune

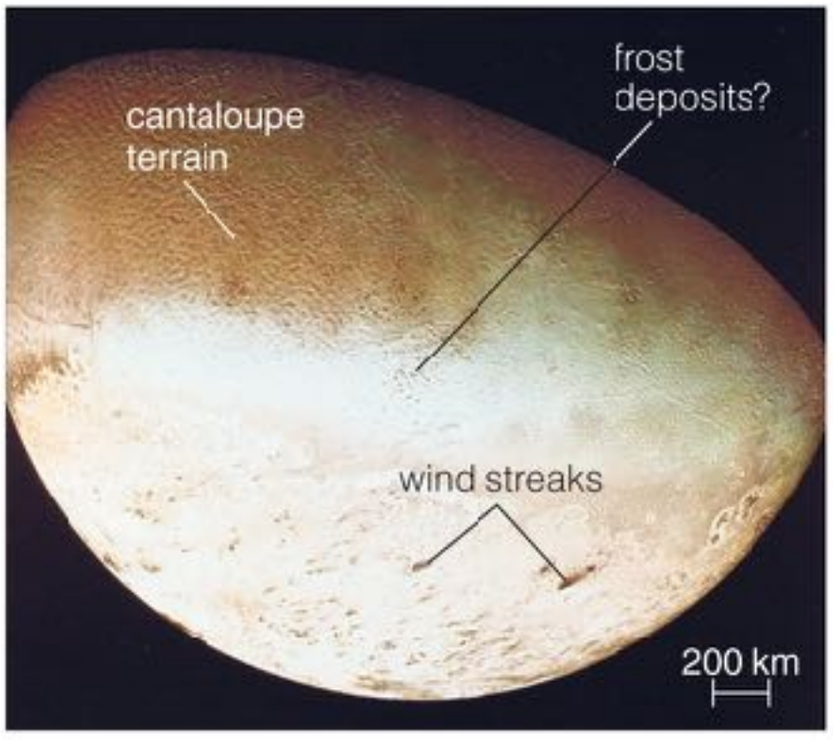


Triton



cantaloupe terrain

Neptune's Moon Triton

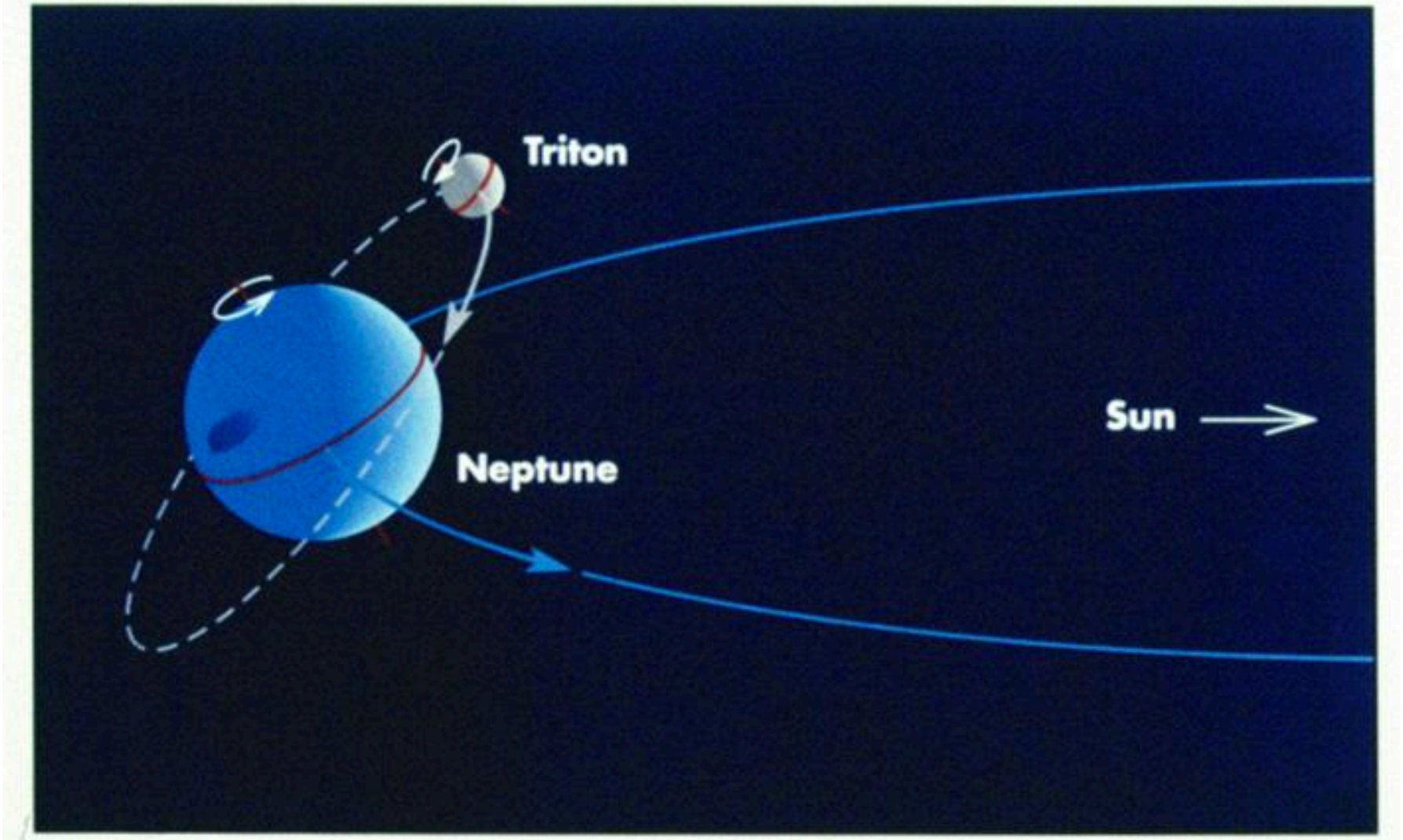


Triton's southern hemisphere as seen by *Voyager 2*.

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

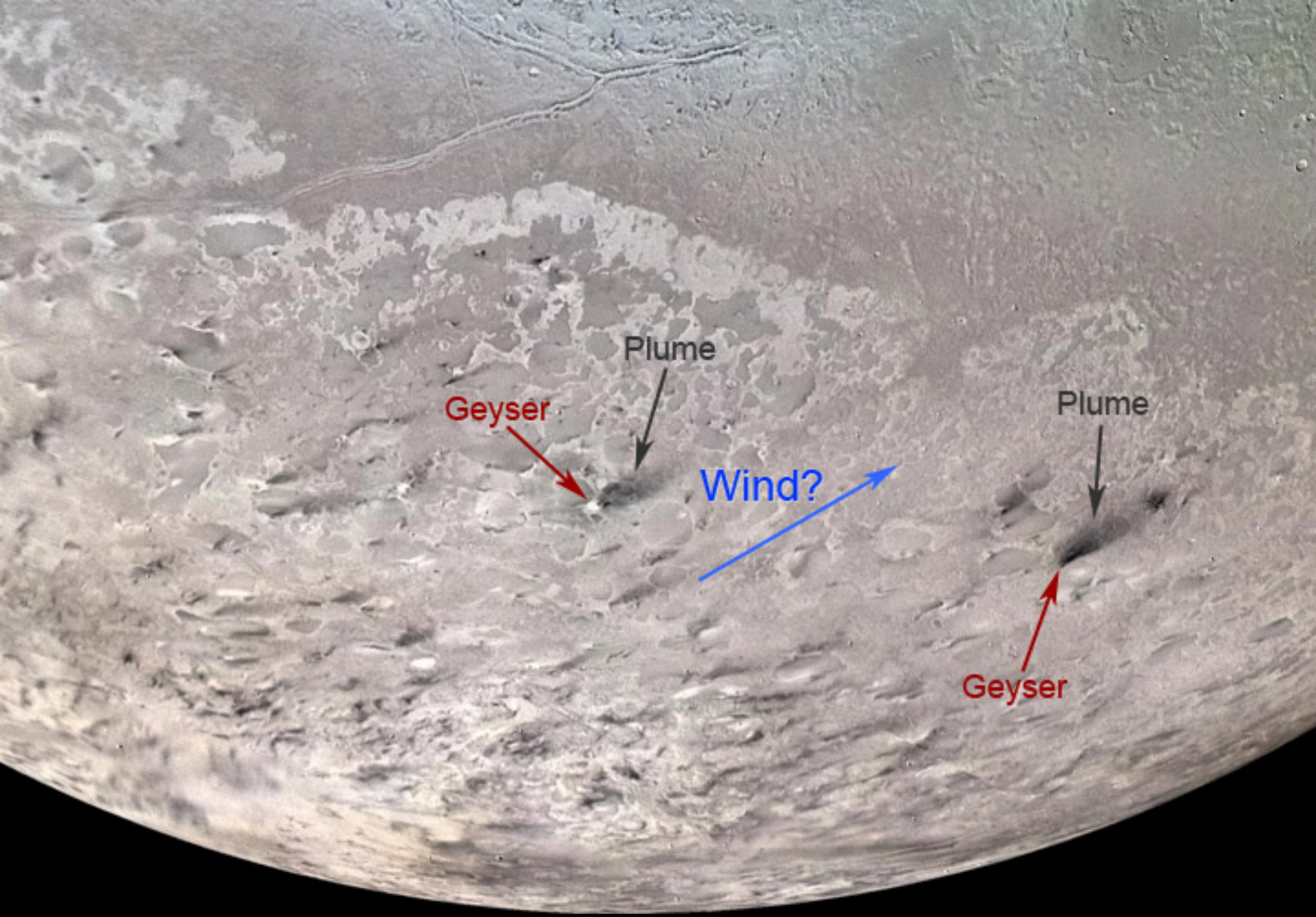
The occasional geyser, heated by sunlight, streaks the downwind terrain with dark material

- 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



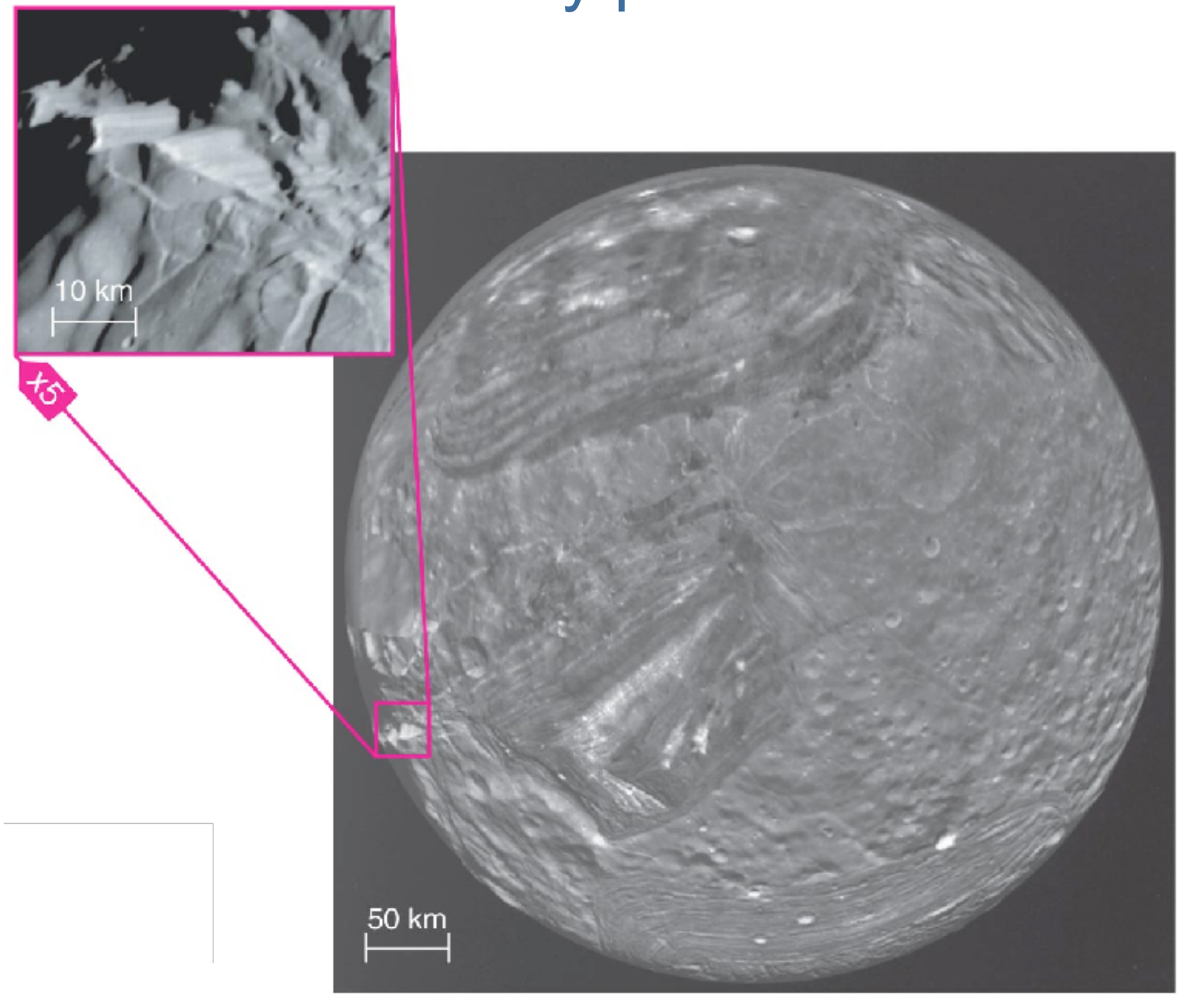
- tidally locked, like Earth's moon
- orbit is retrograde
- and highly inclined (40 degrees)
  - not stable
    - will eventually make rings!

https://vimeo.com/3852837

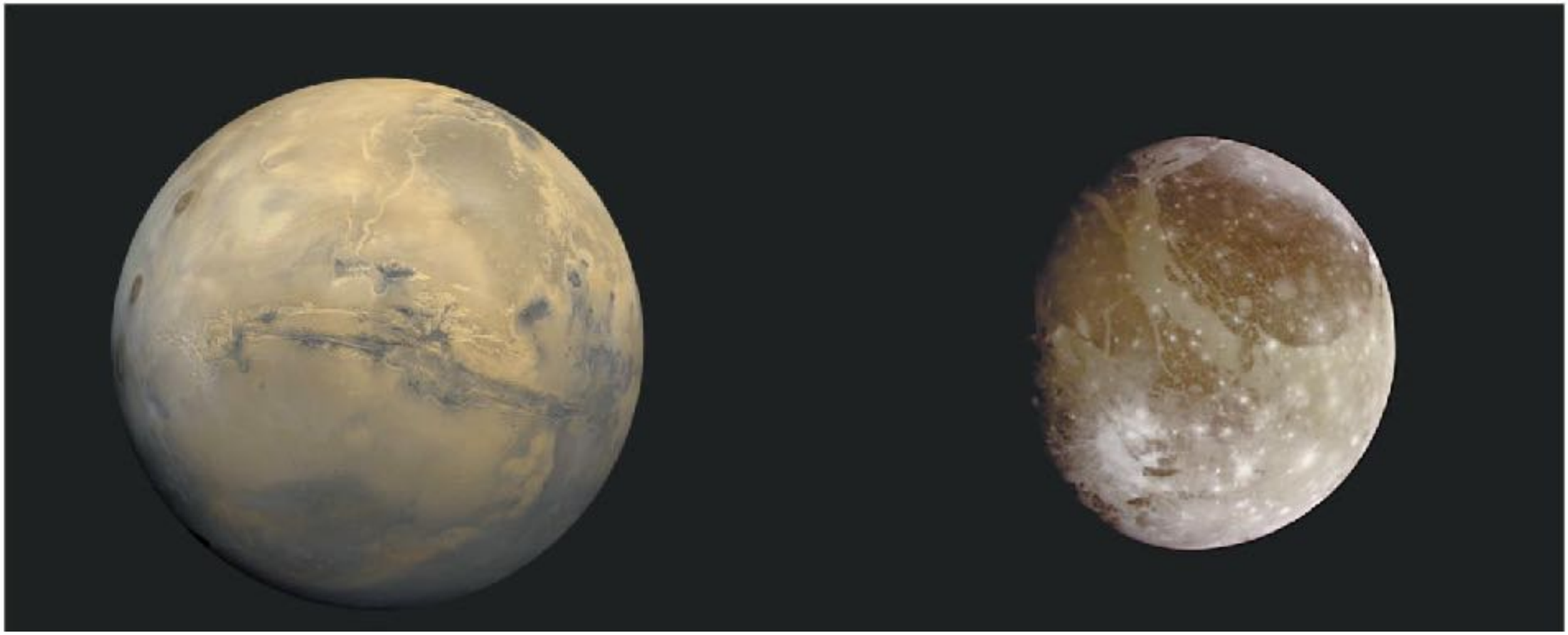


geysers

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



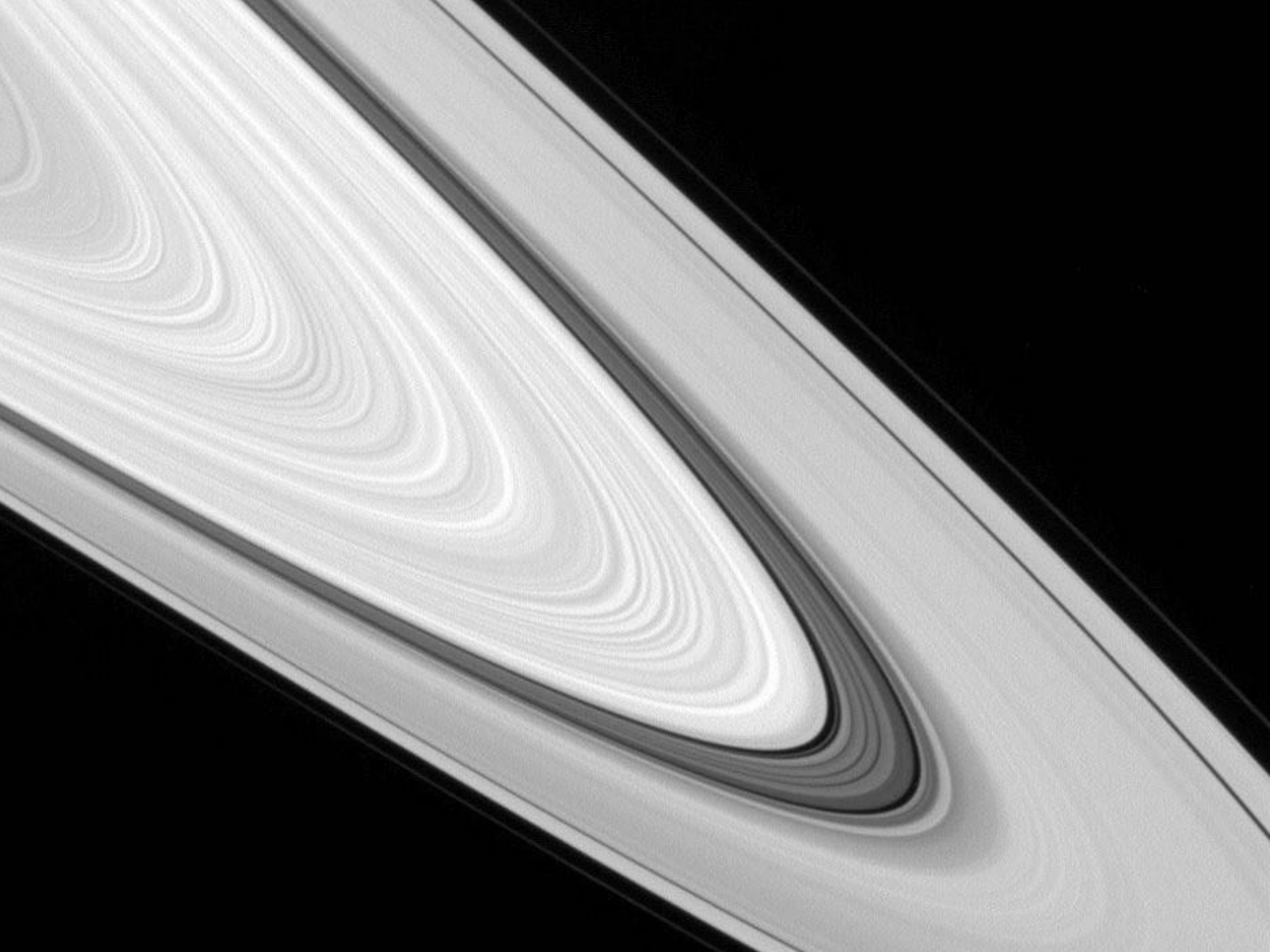
Rocky Planets versus Icy Moons



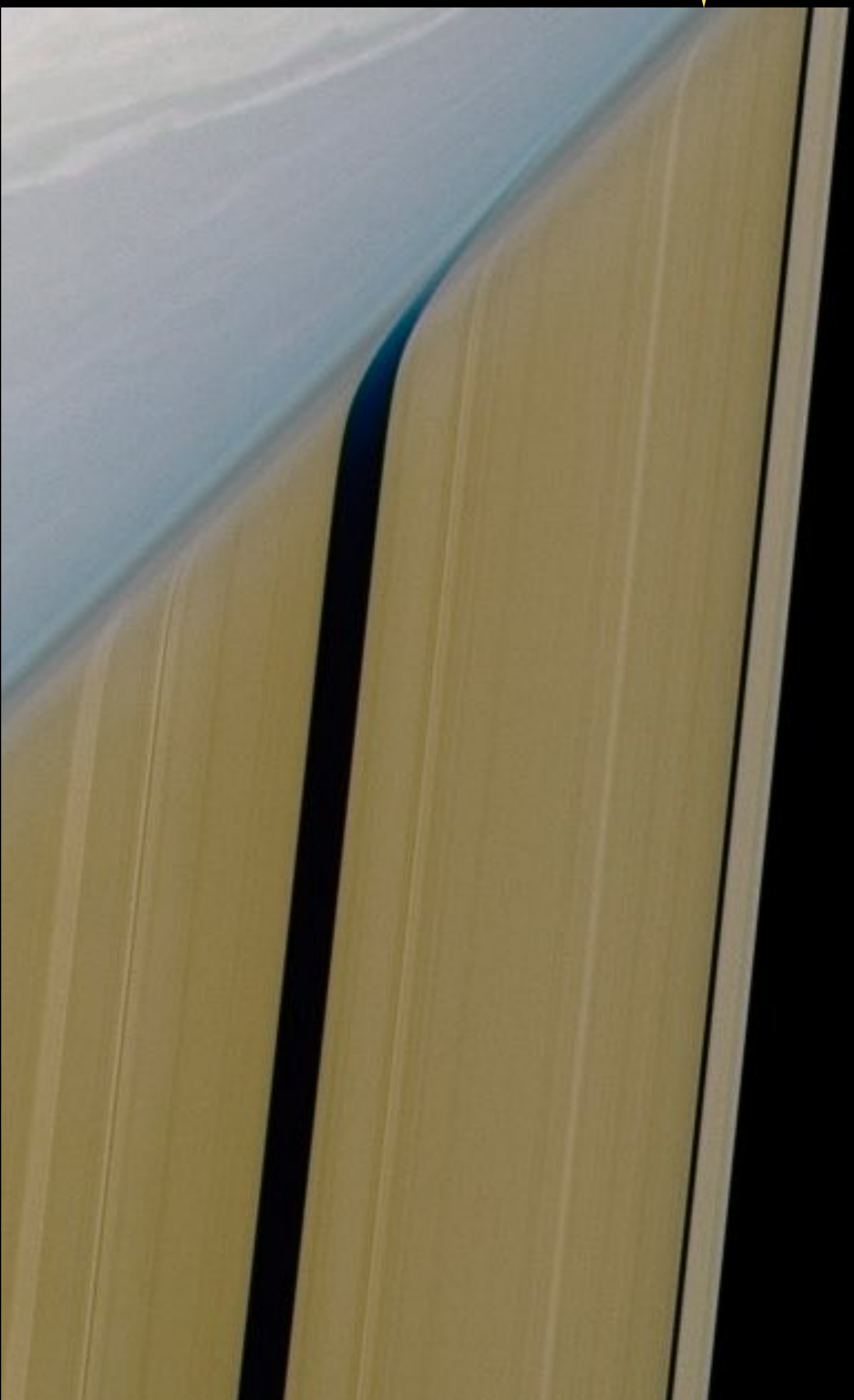
- Rock melts at higher temperatures.
- Only large rocky planets have enough heat for activity.

- Ice melts at lower temperatures.
- Tidal heating can melt internal ice, driving activity.

Saturn’s rings



Note refraction in atmosphere



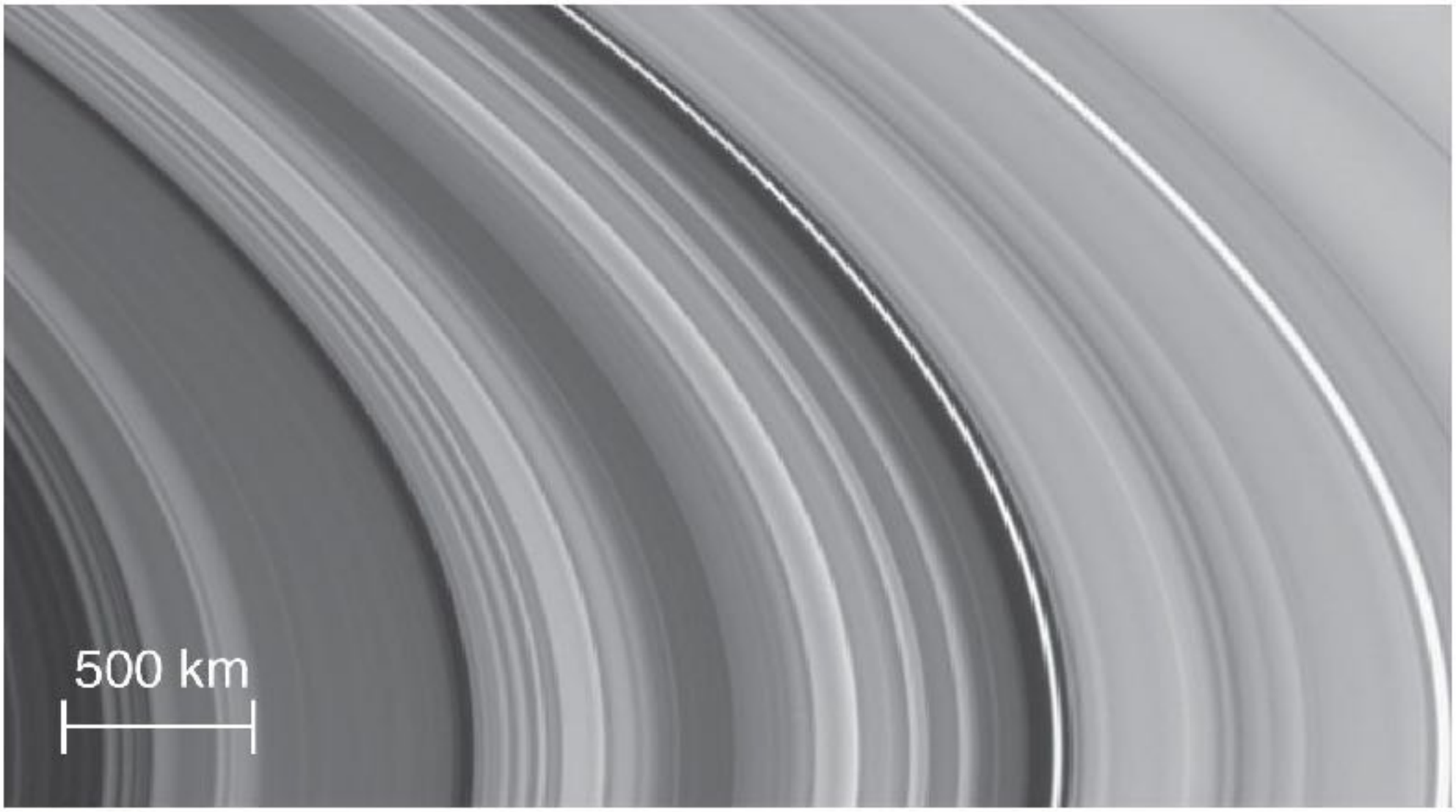
What are Saturn's rings like?

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

https://saturn.jpl.nasa.gov/resources/7628/

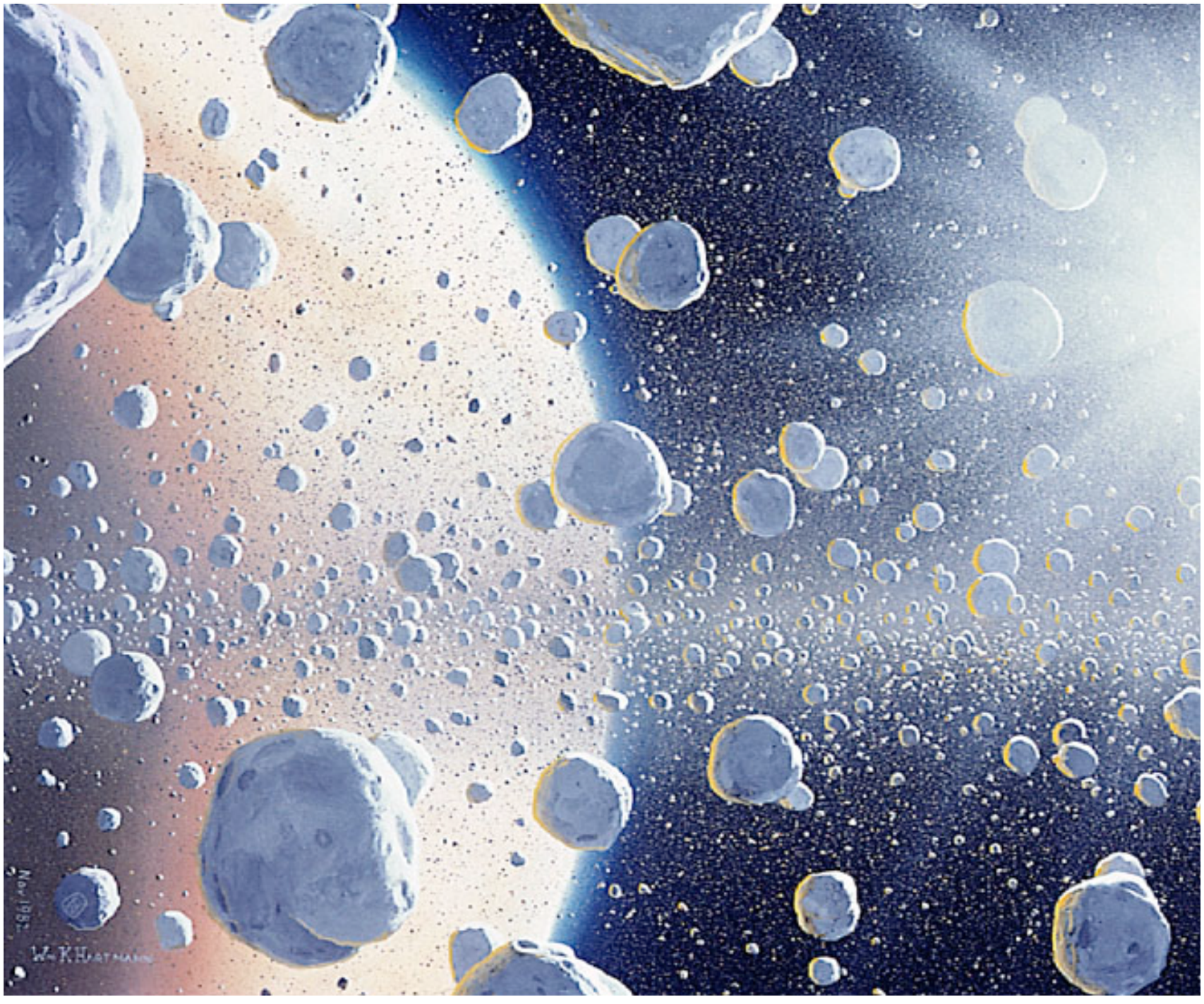
https://www.youtube.com/watch?v=xrGAQCq9BMU

Spacecraft View of Ring Gaps

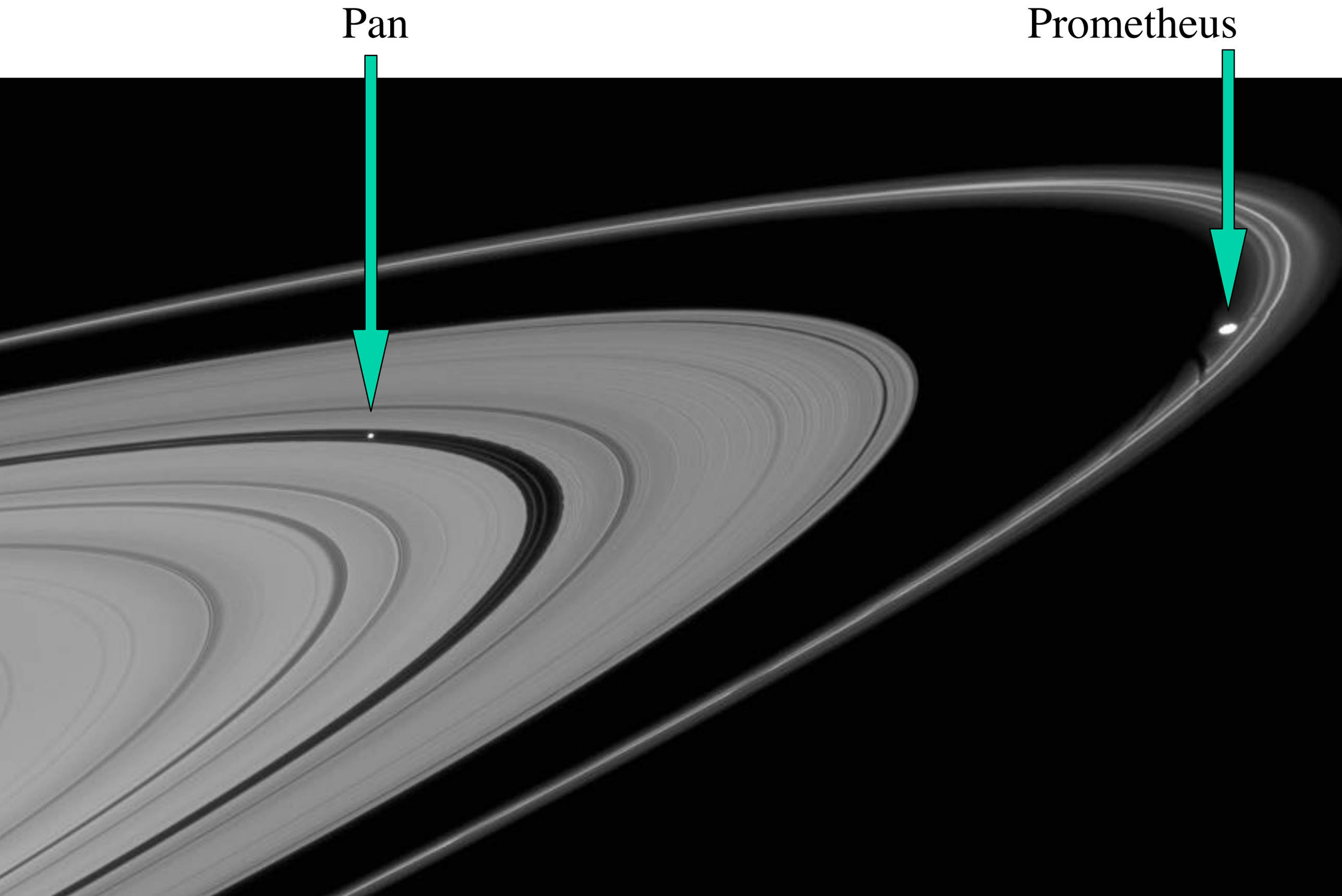


b This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.

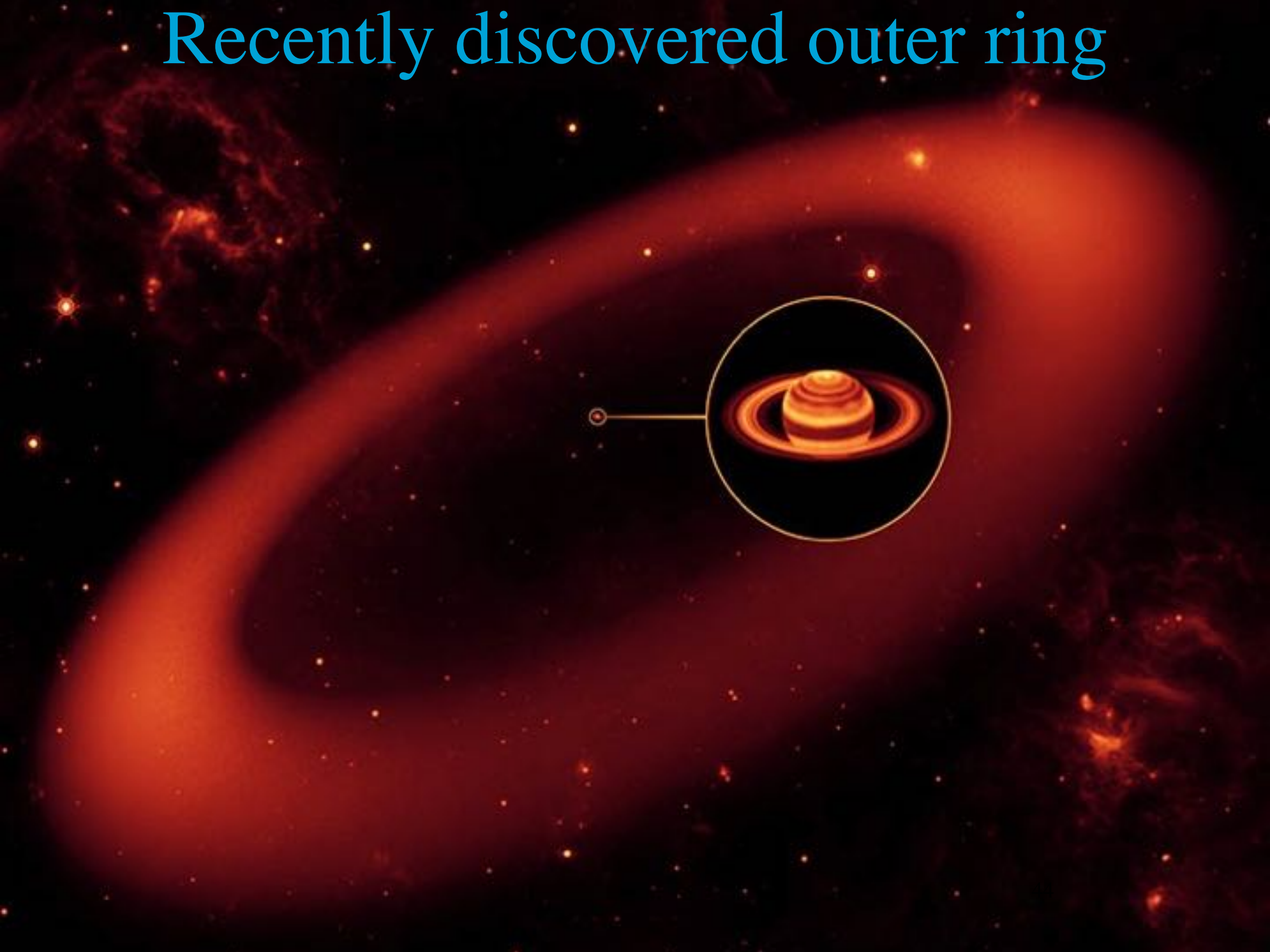
Artist’s Conception in Ring



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



Recently discovered outer ring



Saturn

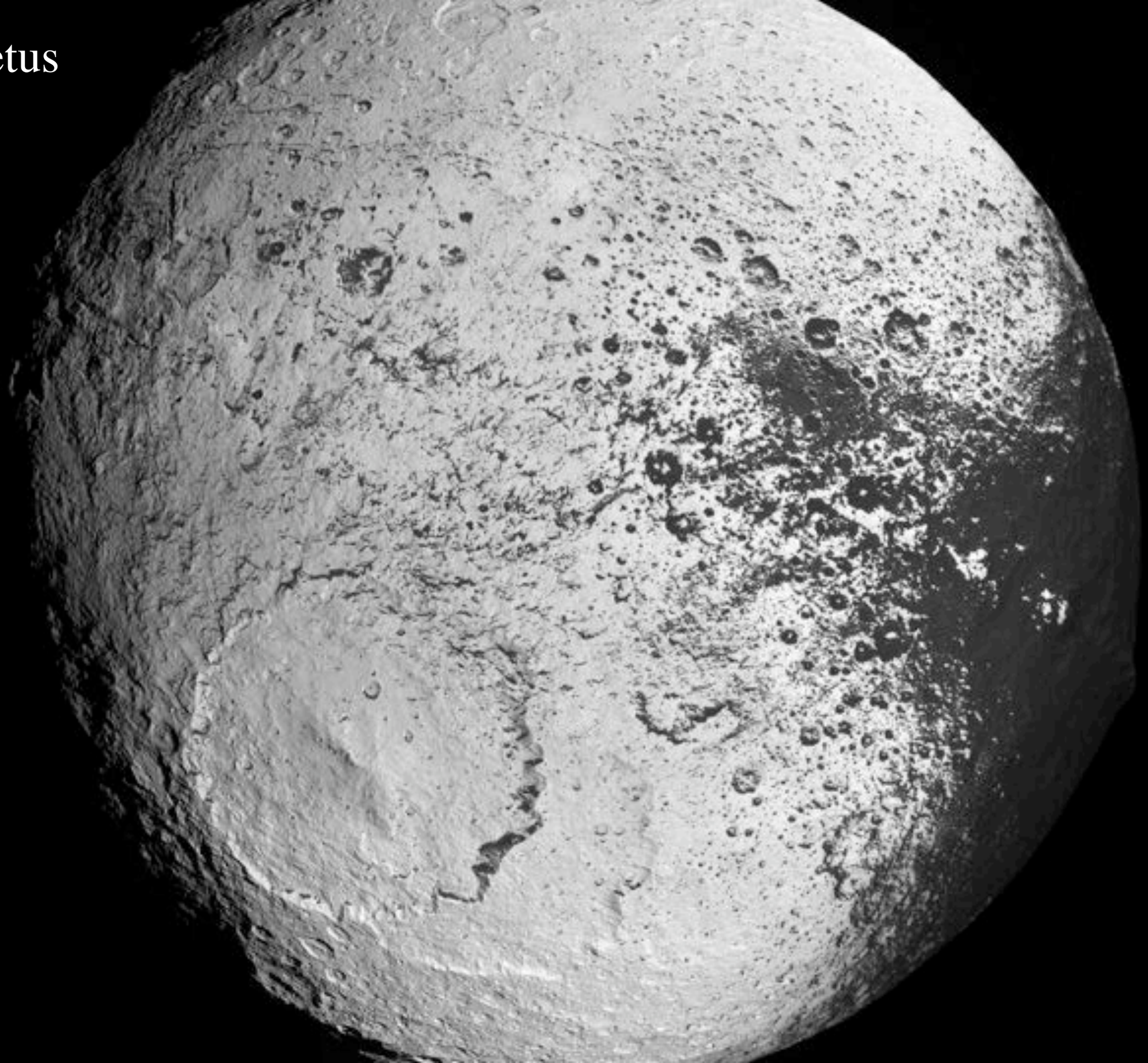
Phoebe

Titan

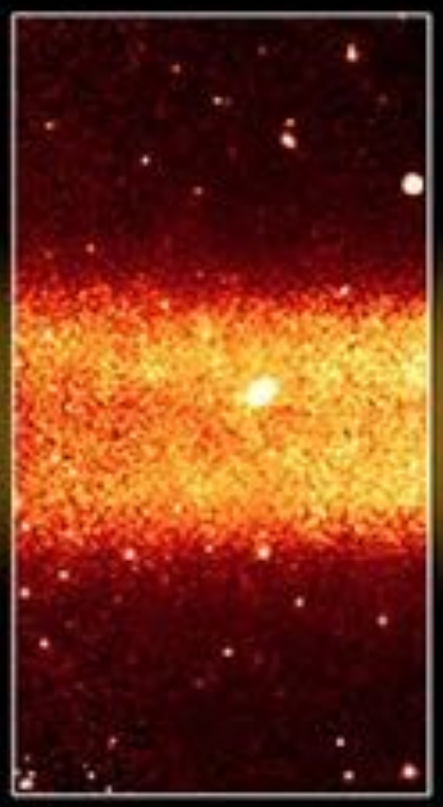
Iapetus

Saturn's Largest Ring

Iapetus



actual data



Dust Ring

Infrared View of Saturn's Largest Ring

NASA / JPL-Caltech / A. Verbiscer (Univ. of Virginia)

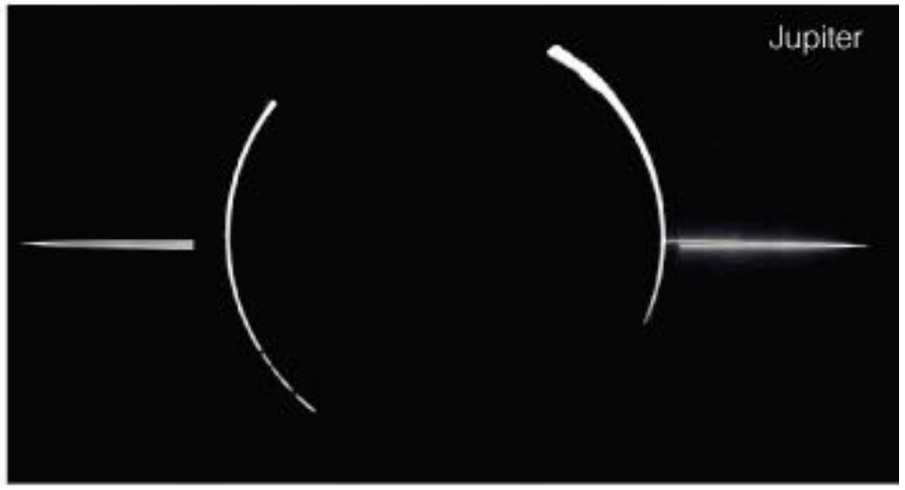
Spitzer Space Telescope • MIPS

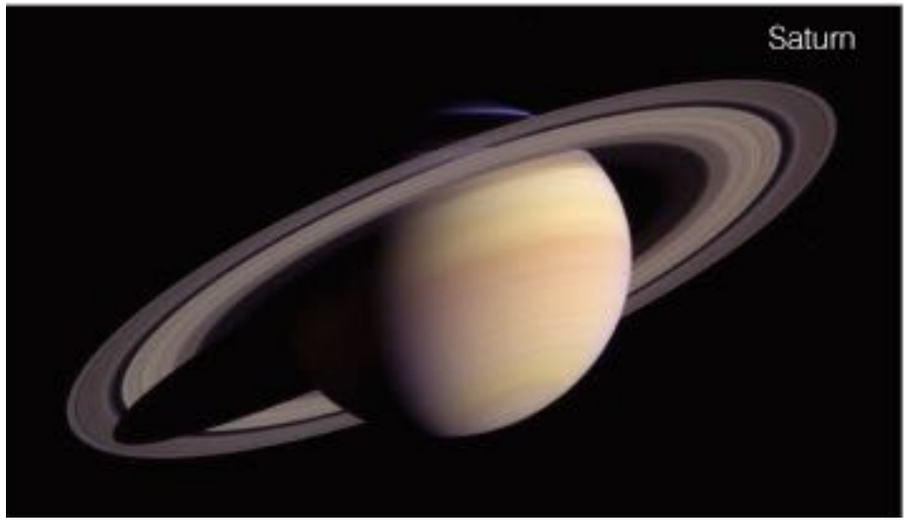
ssc2009-19a

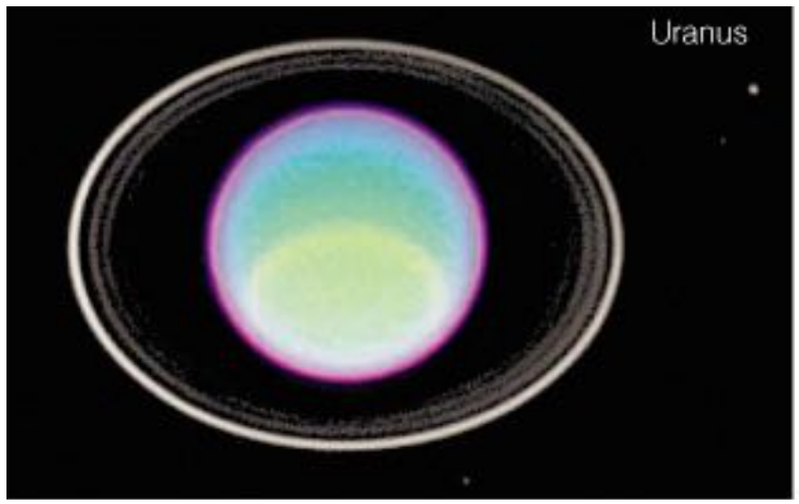
How do other jovian ring systems compare to Saturn's?

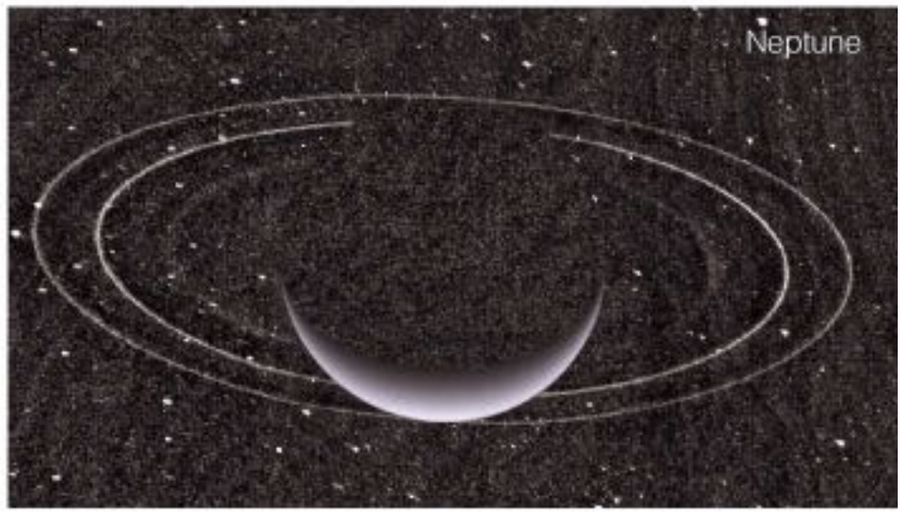
Jupiter

Jovian Ring Systems



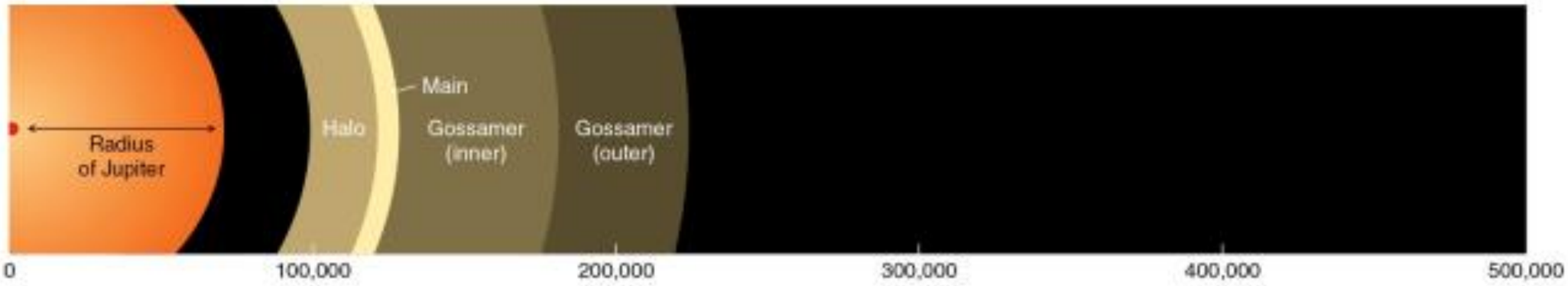




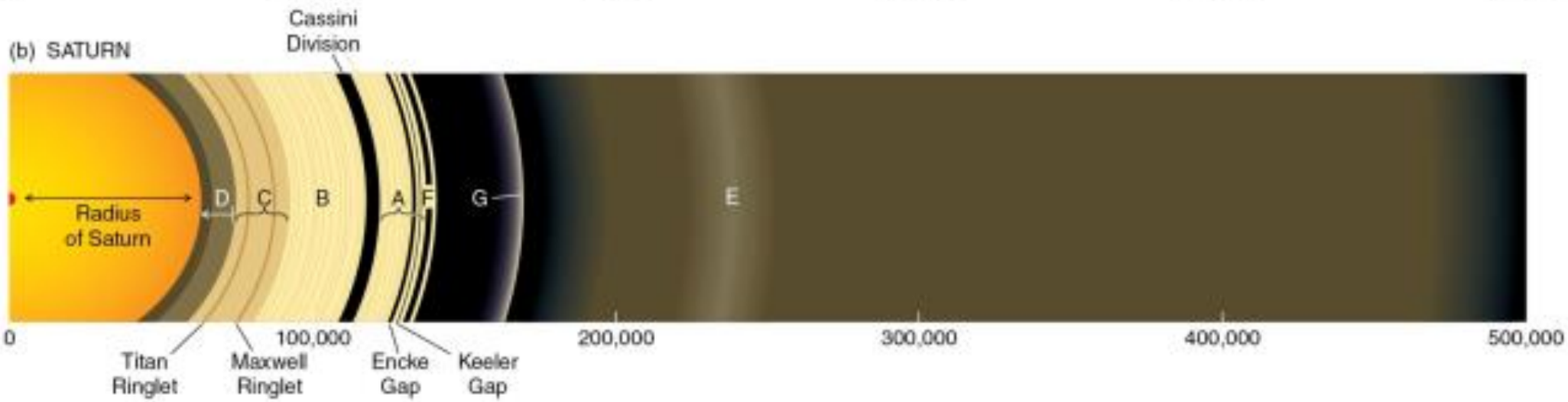


- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than does Saturn.
- Rings and moons ubiquitous around Jovian planets
  – like small solar systems.

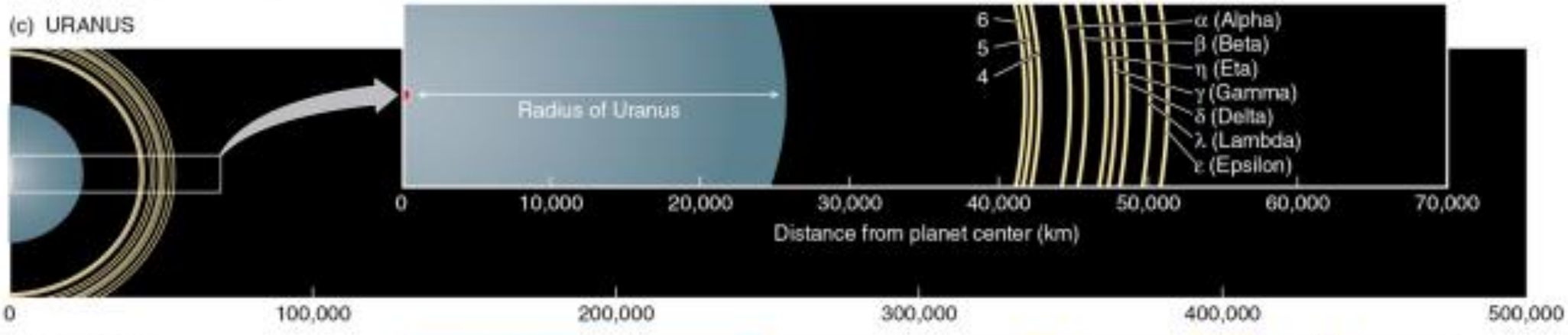
(a) JUPITER



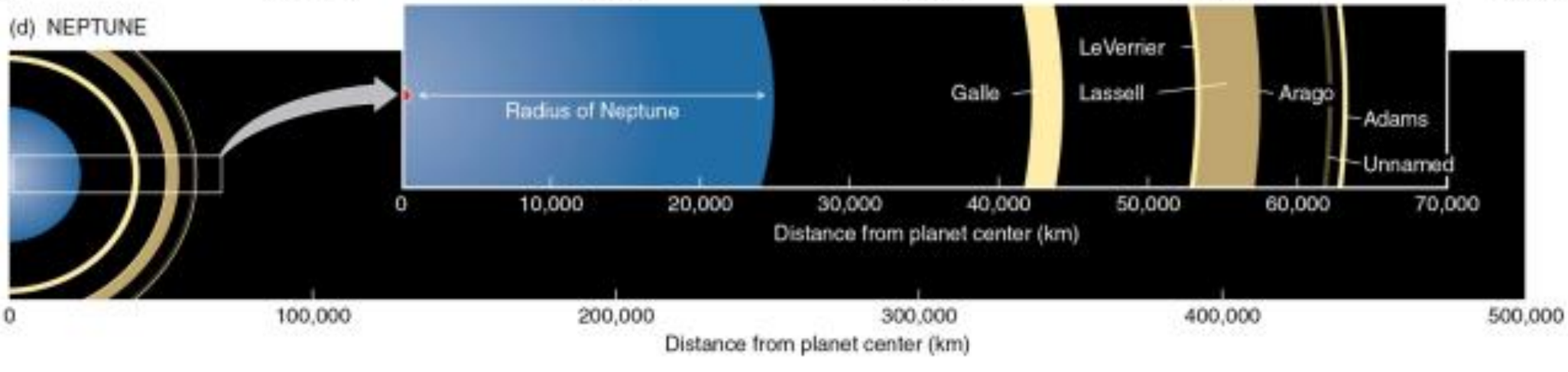
(b) SATURN



(c) URANUS



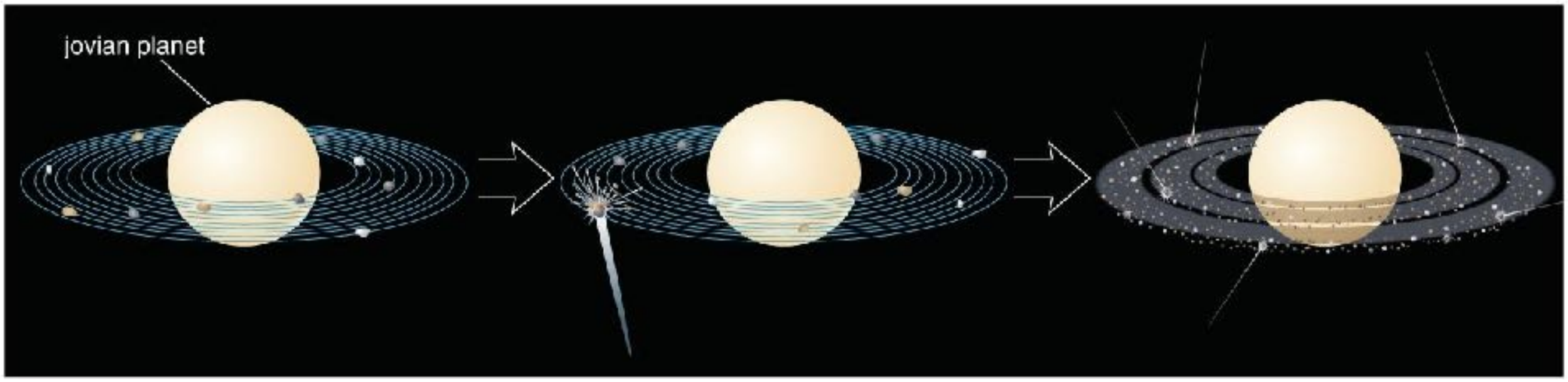
(d) NEPTUNE



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.

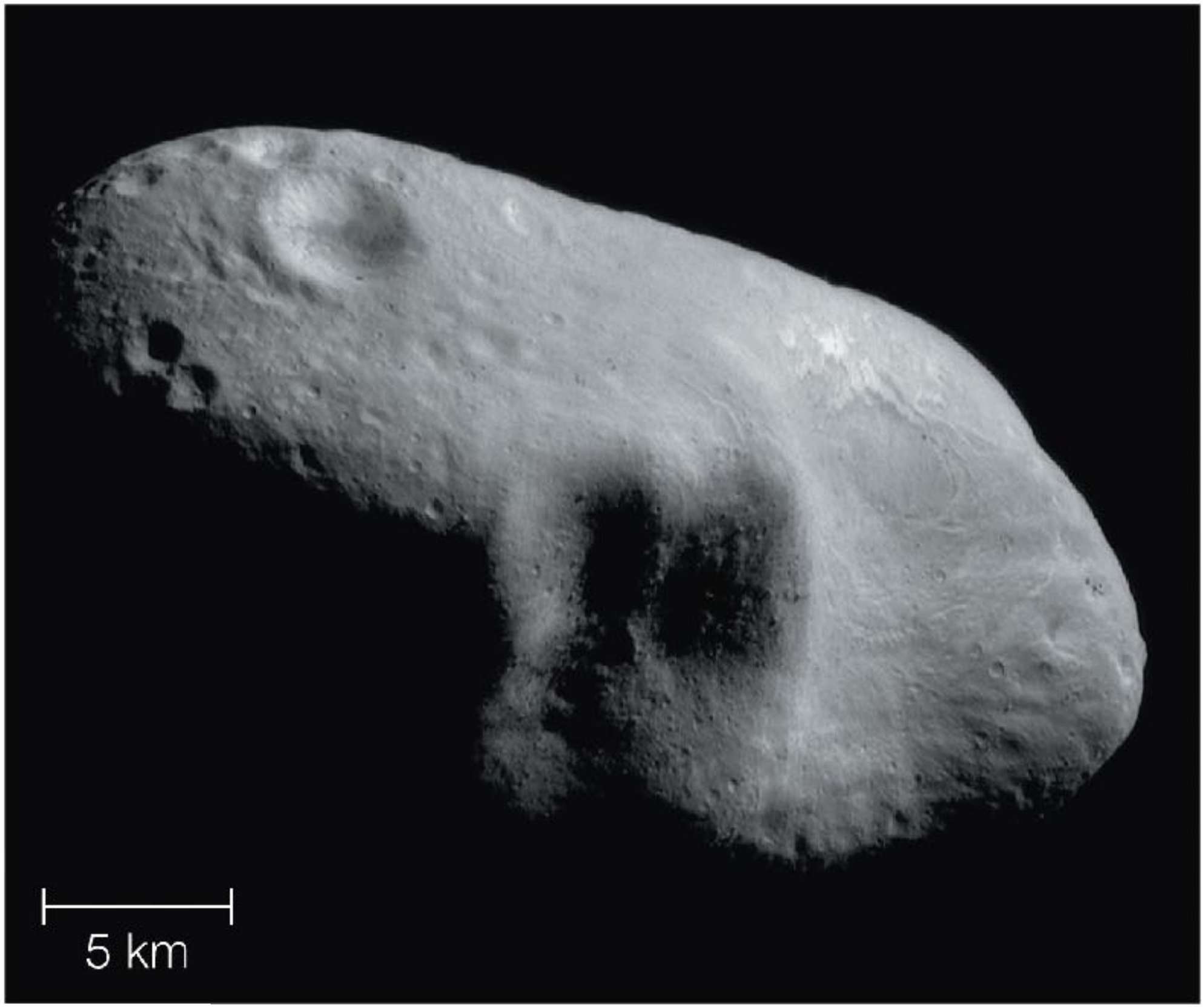
Ring Formation



- 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 as a result of any icy moon getting too close - inside the Roche limit
  - Roche limit: over/under line where tidal forces will rip a small body apart

Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

What are asteroids like?



Asteroid traversing sky due to orbital motion (time lapse)

Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- "Rubble Piles"
  – loose collection of rocks; not one big one.
- The largest is Ceres, diameter ~1,000 km.
- There are 150,000 in catalogs, and probably over a million with diameter >1 km.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.

Lots of small bodies, but not much mass.

Diameter, km

0.01

0.1

1

10

10^8

10^6

10^4

10^2

10^0

number

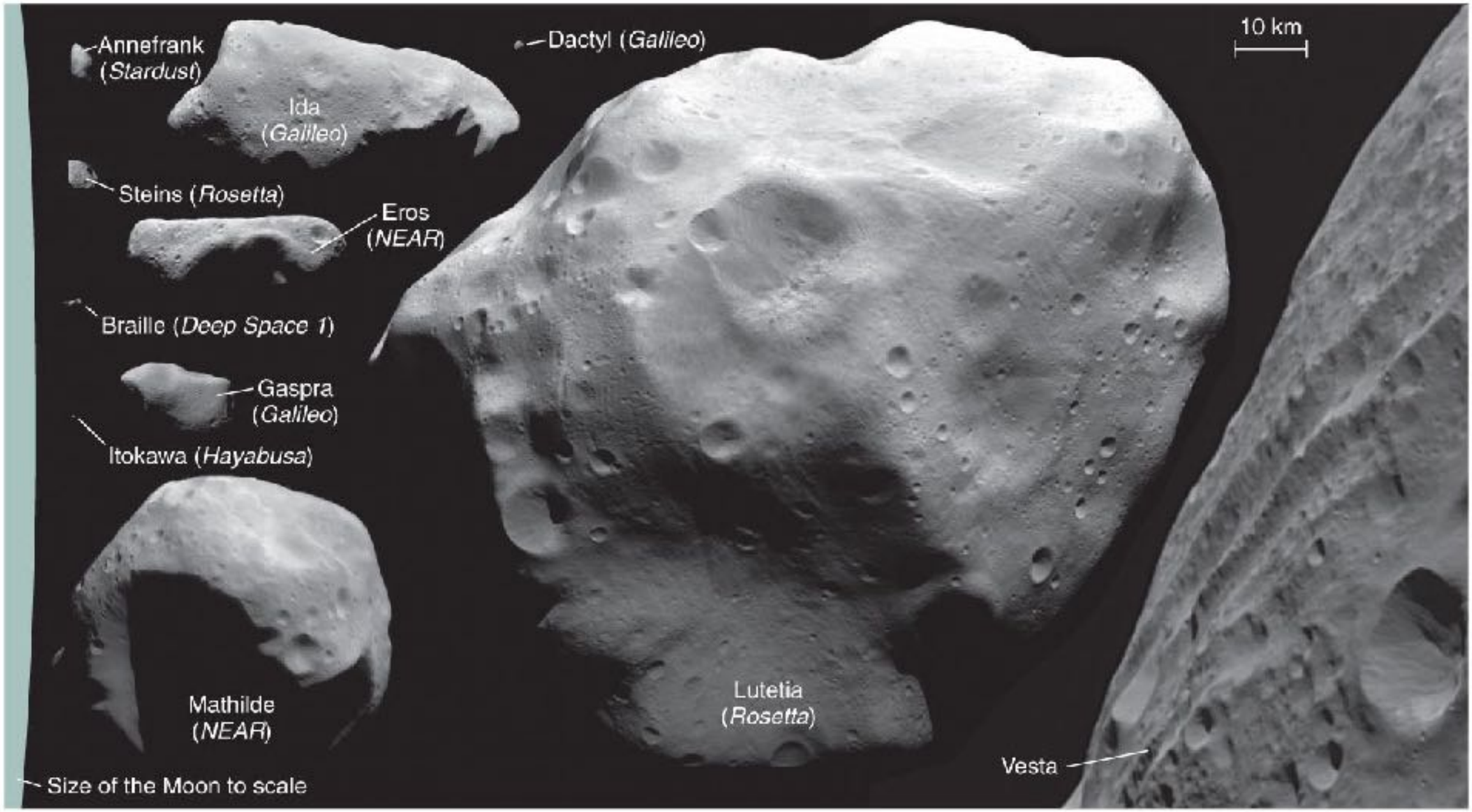
n (*H*)

Population estimate

Total discovered
to August 2014

30 28 26 24 22 20 18 16 14 12 10

H apparent brightness



- Asteroids are cratered and not round.