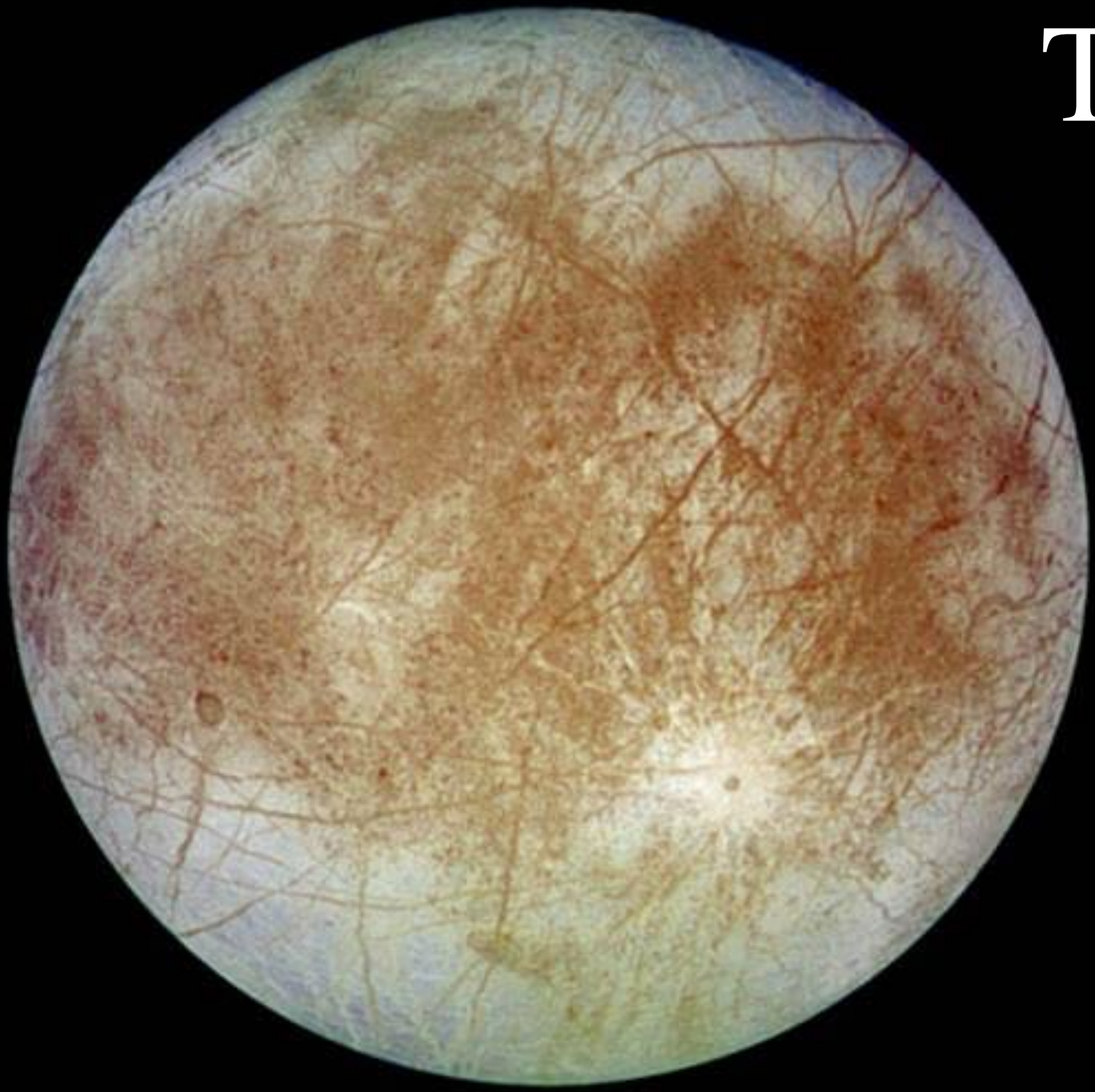


Today

- Moons of the solar system
- Rings

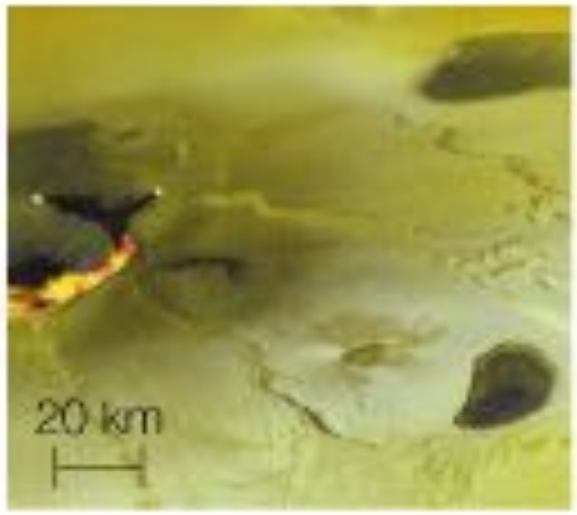
Events

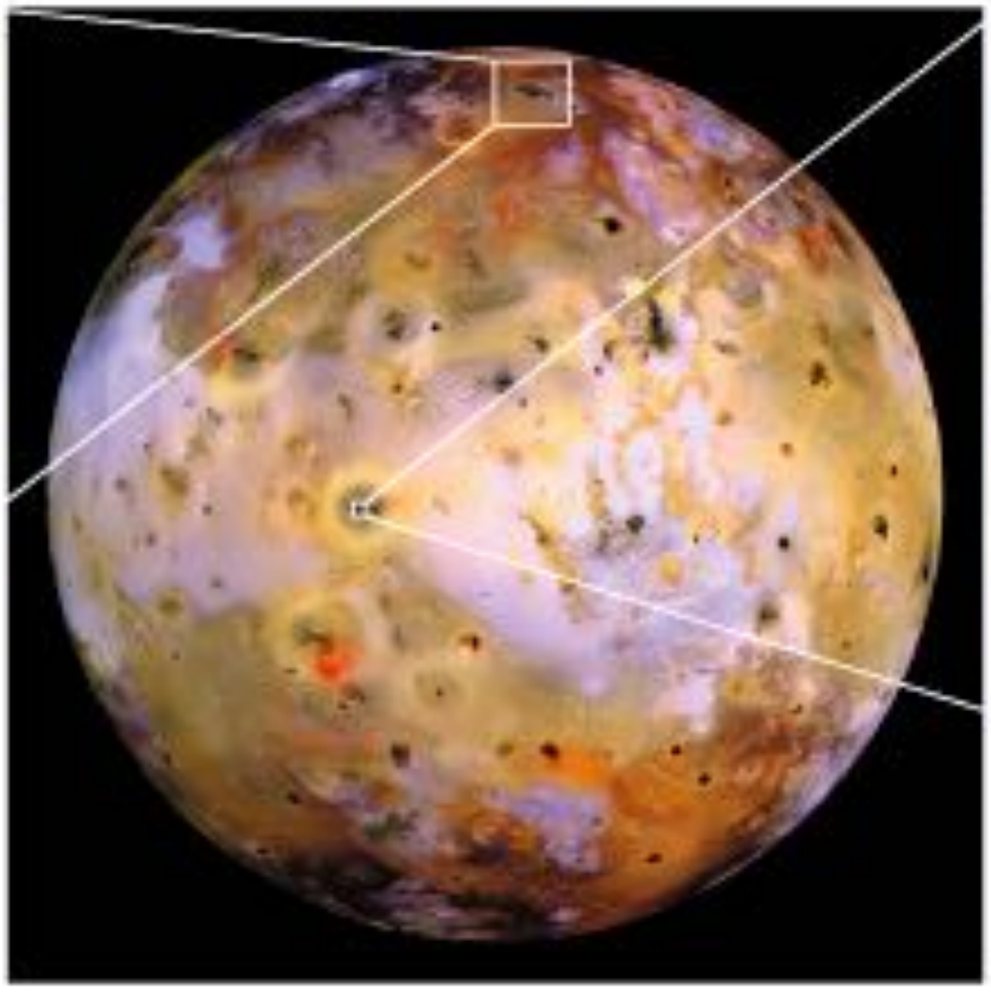
- Homework 5
- Due next time

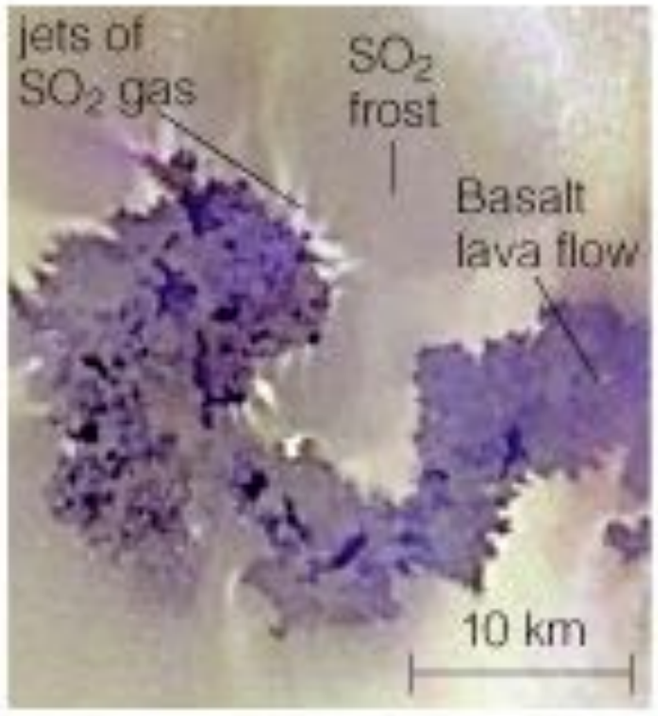
The moons of the Jupiter

Galilean moons of Jupiter
("Medici stars")

Io





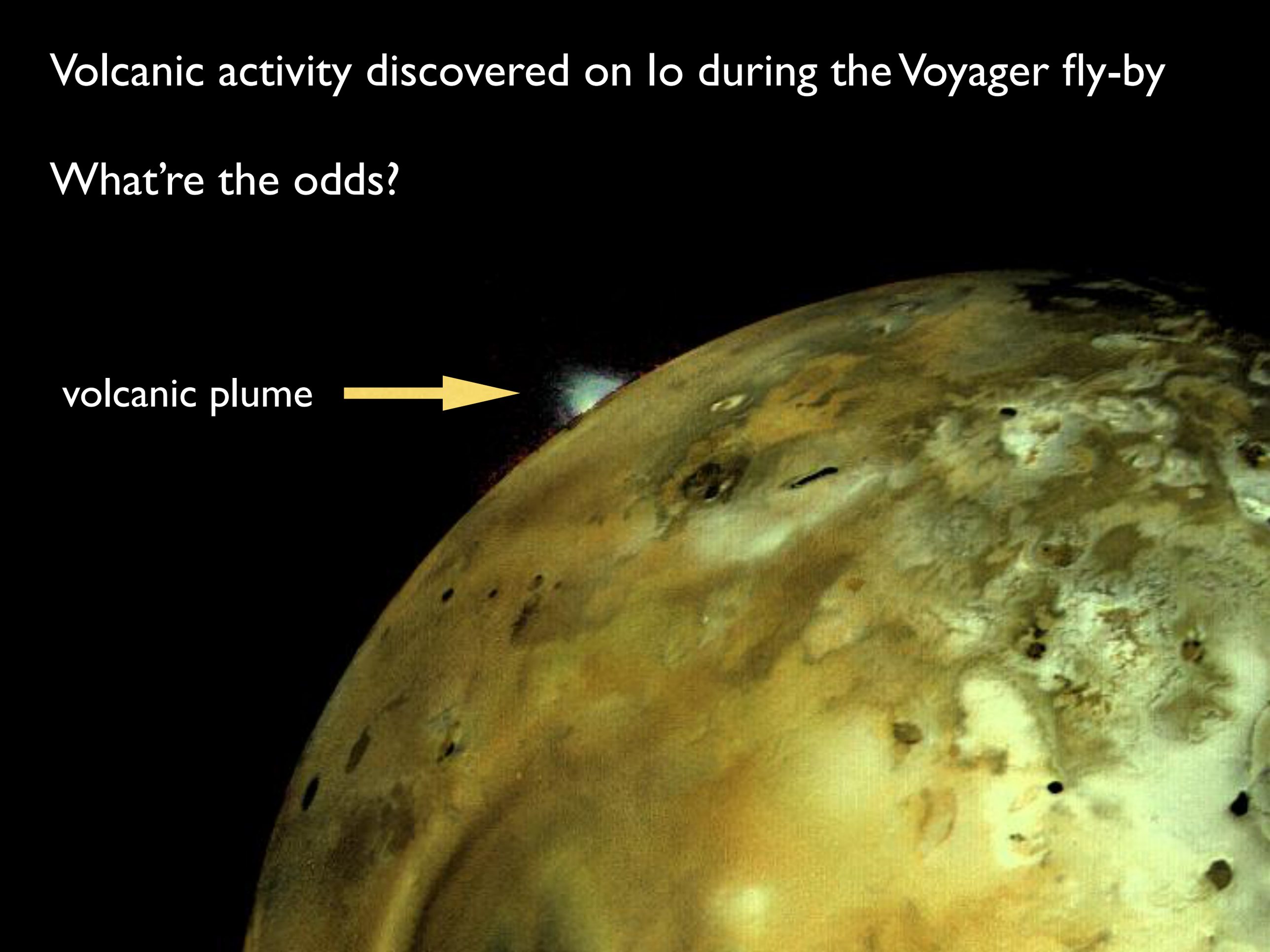


- Io is the most volcanically active body in the solar system.

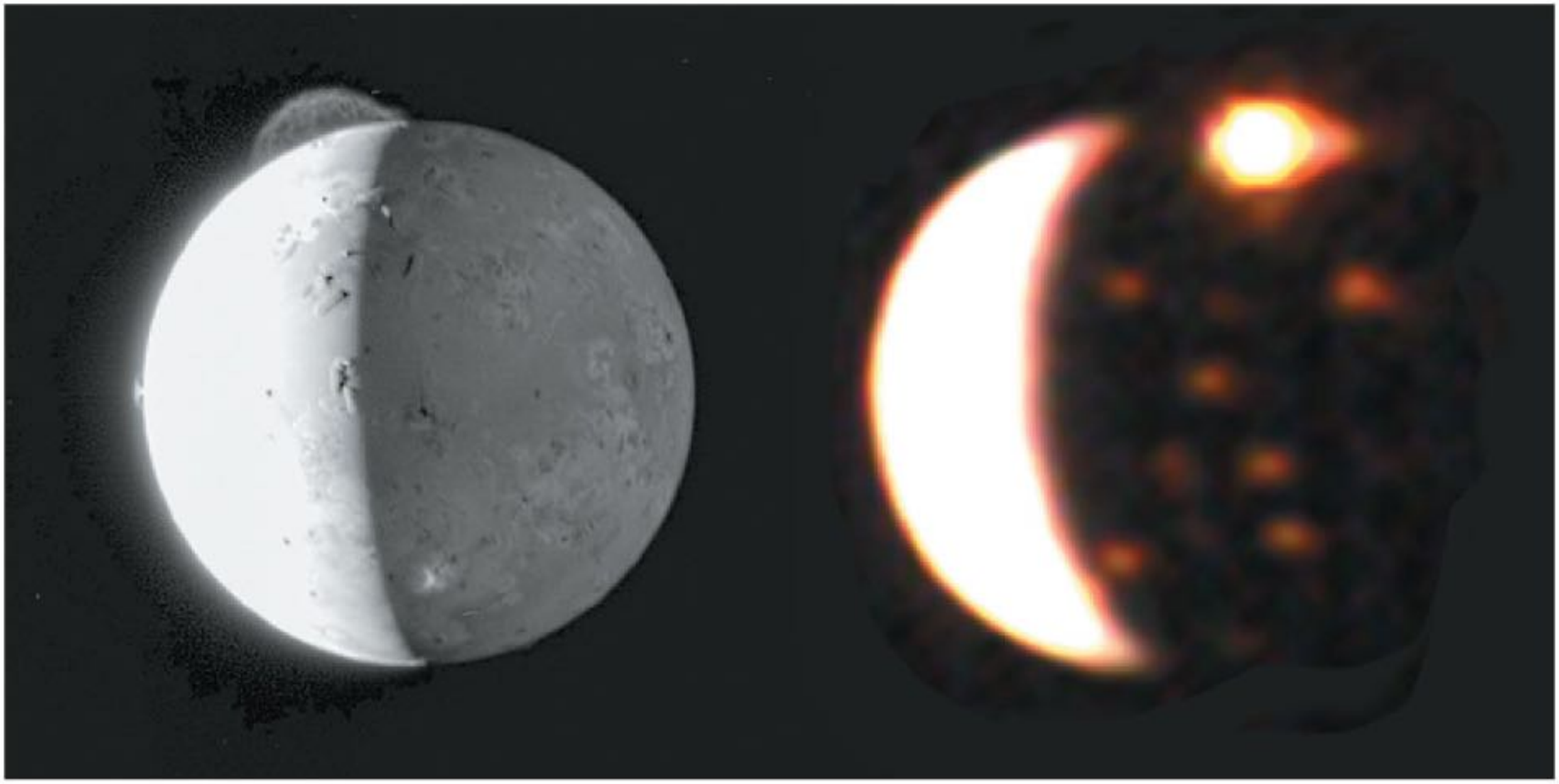
Volcanic activity discovered on Io during the Voyager fly-by

What're the odds?

volcanic plume



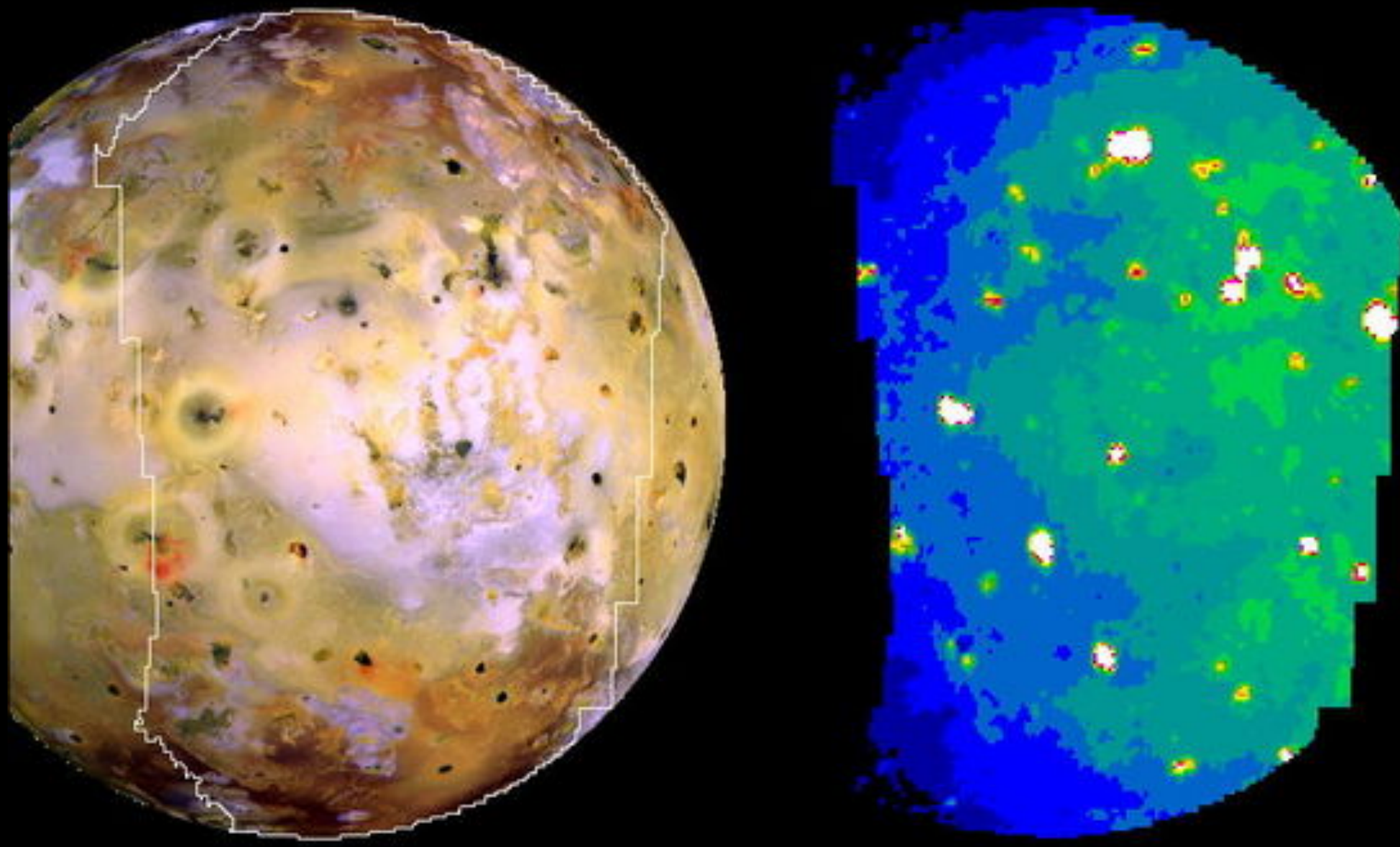
Io's Volcanoes



- Volcanic eruptions continue to change Io's surface.

optical

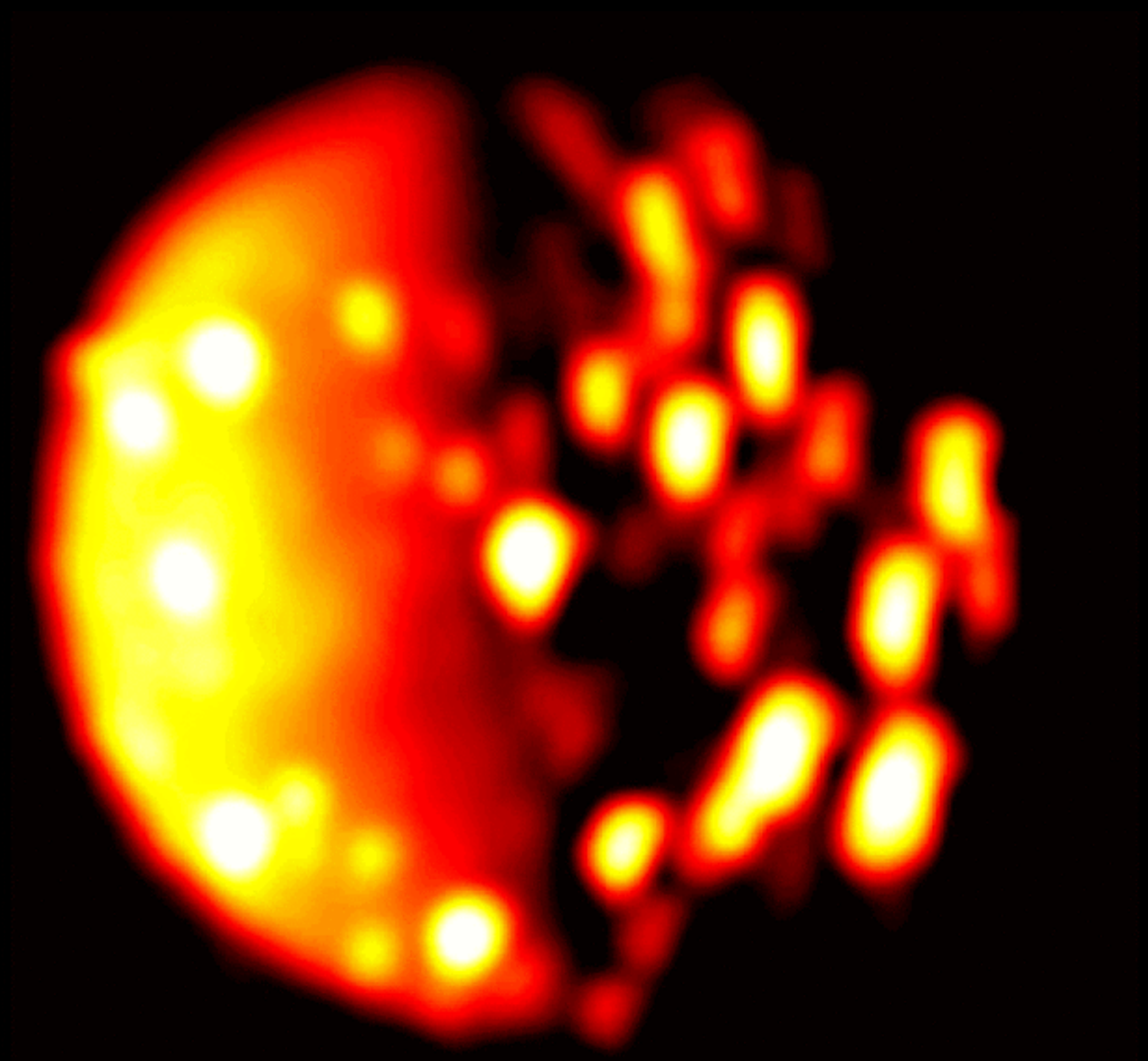
infrared



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

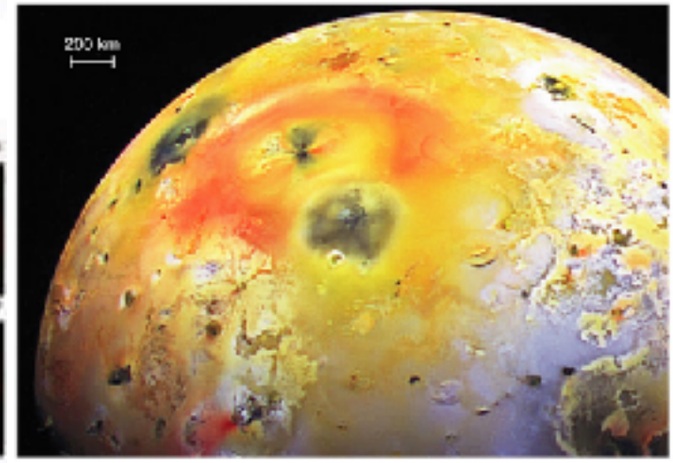
show interactive optical/IR image IF_11_17_IoVolcanoesIR

Infrared view of Io



The glowing spots are active volcanoes

Io



H_2O

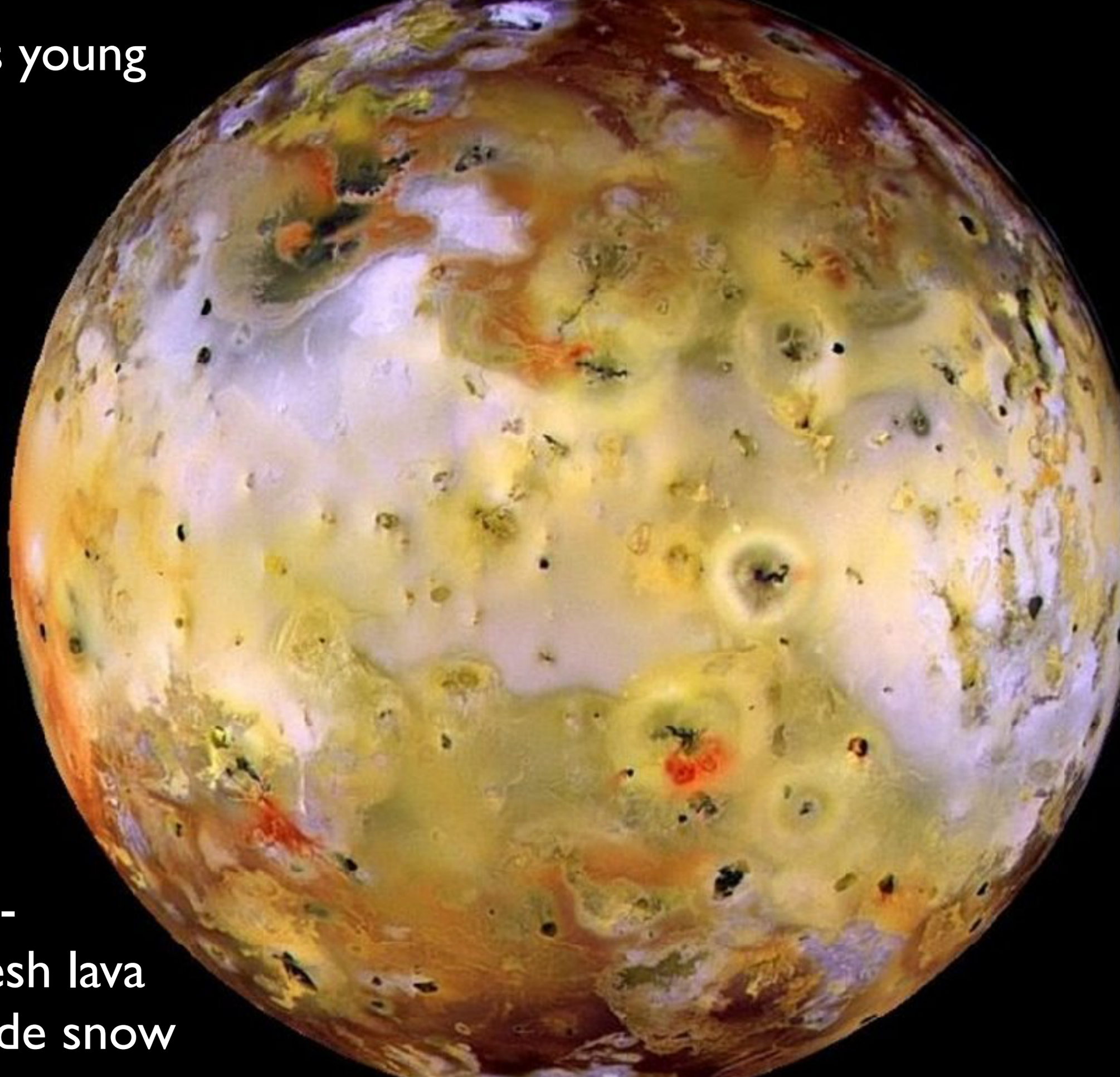
PAH

Lp

Ms

Monitoring Io shows many active volcanos

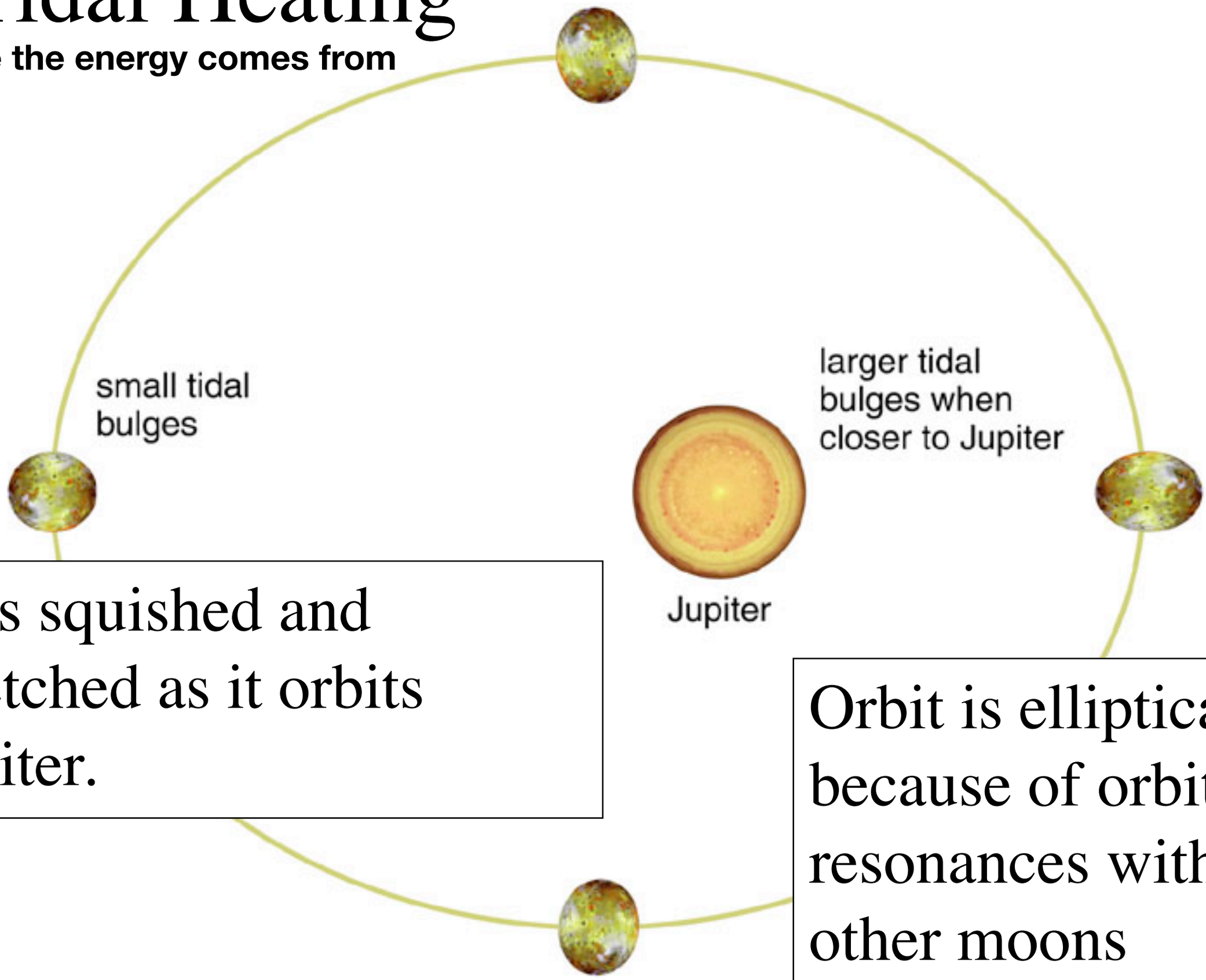
Io's surface is young



Constantly re-covered in fresh lava & sulfur dioxide snow

Tidal Heating

where the energy comes from

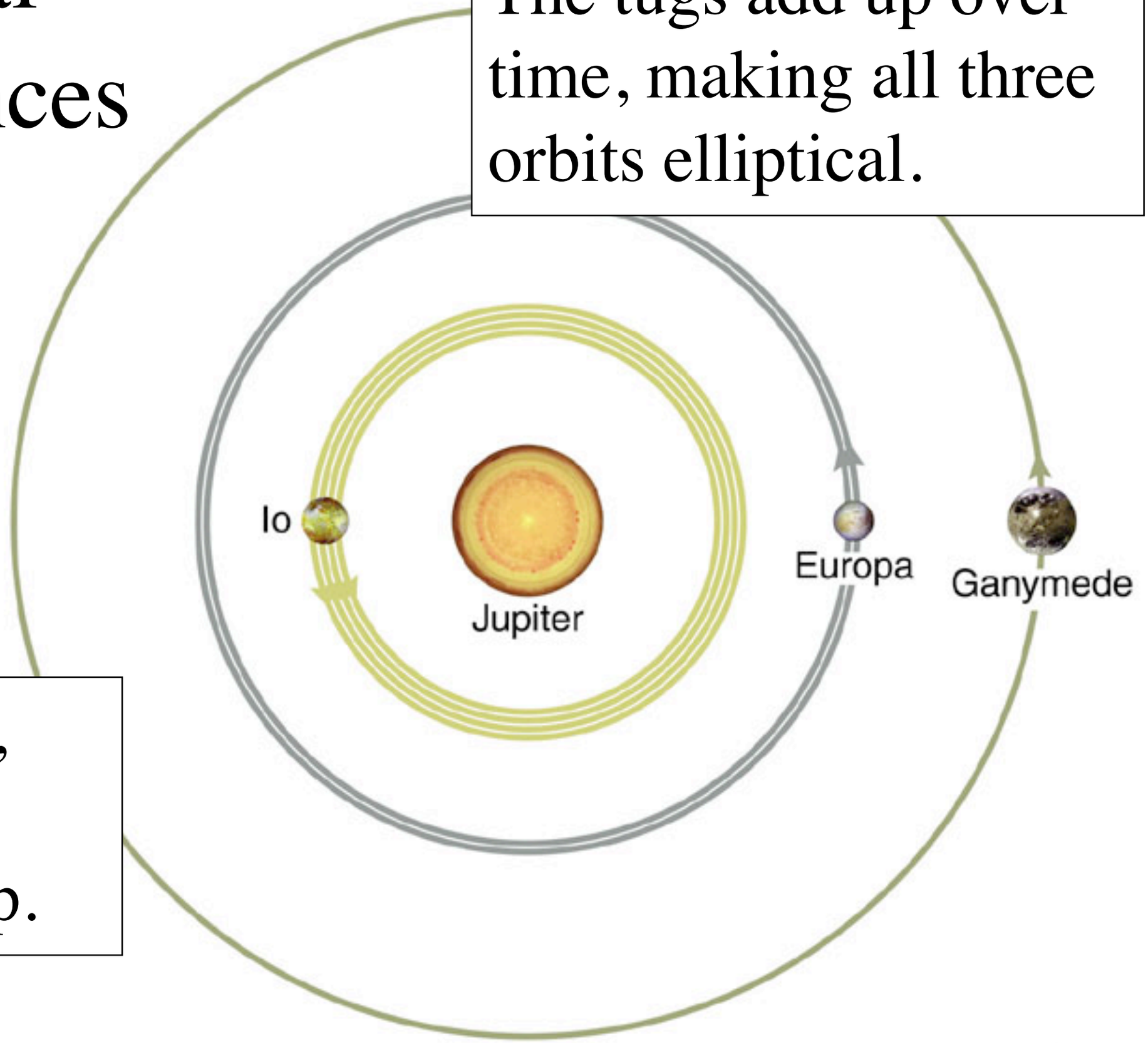


Io is squished and stretched as it orbits Jupiter.

Orbit is elliptical because of orbital resonances with other moons

Orbital Resonances

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

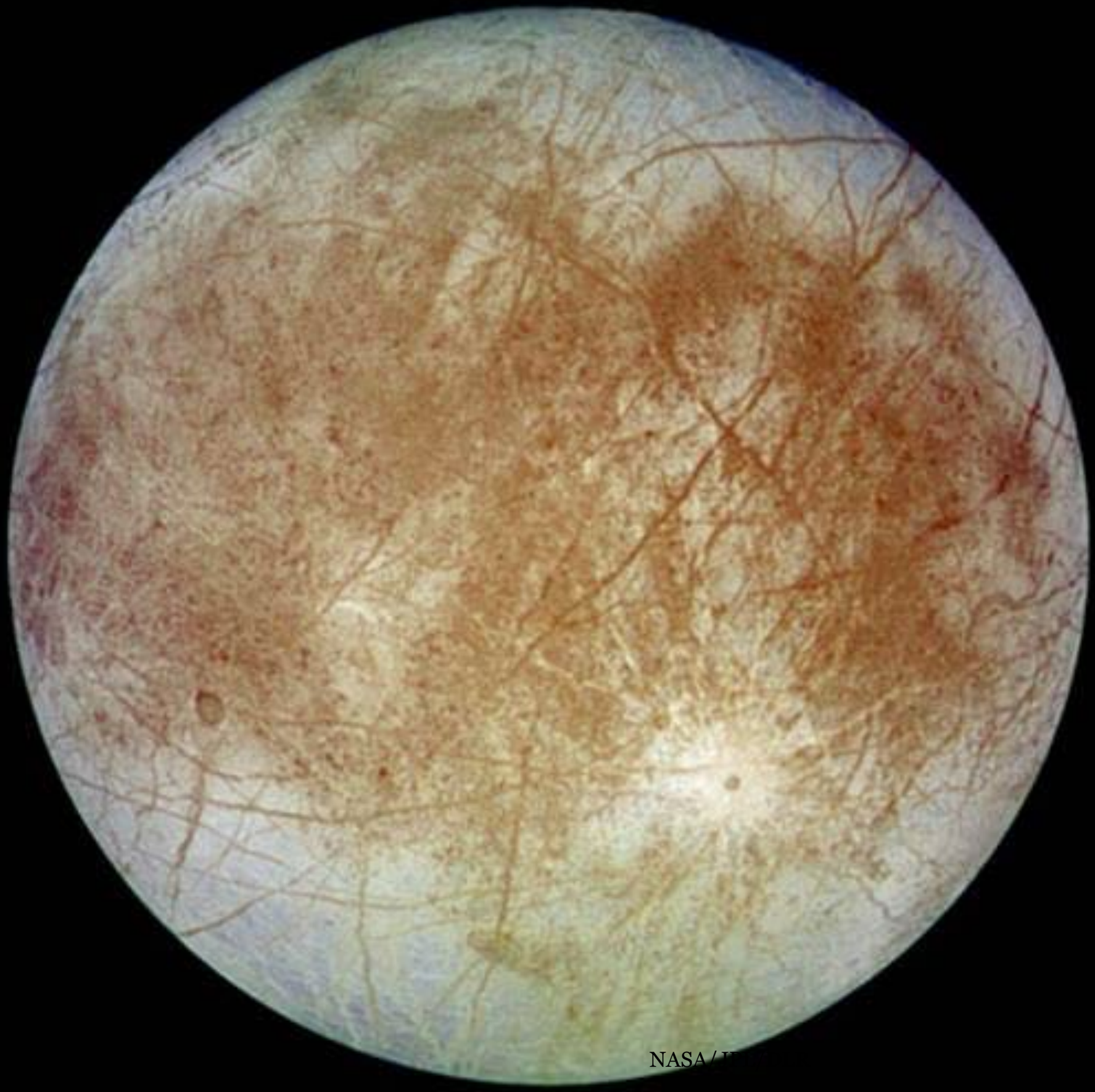


Every 7 days, these three moons line up.

IF_11_19_TidalHeatingResonance

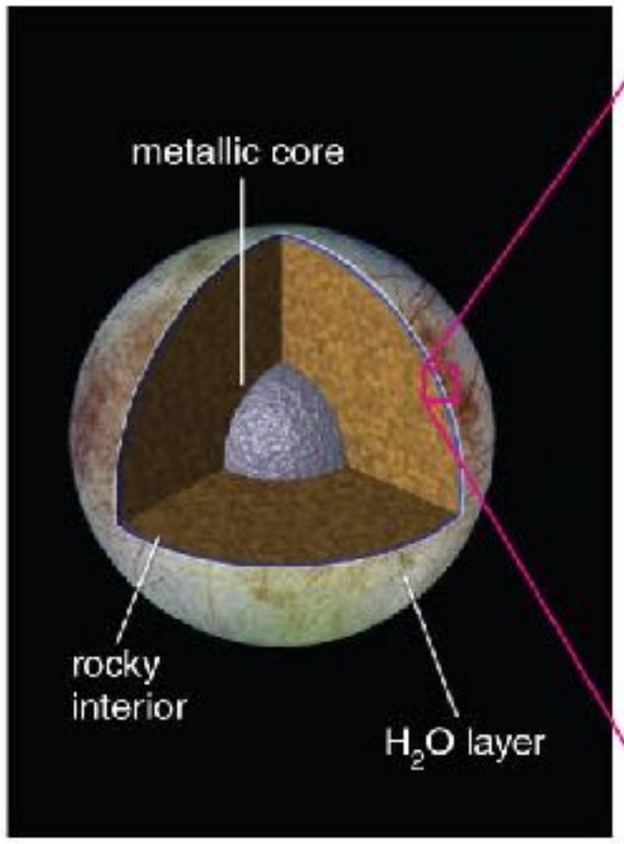
show interactive figure

Europa

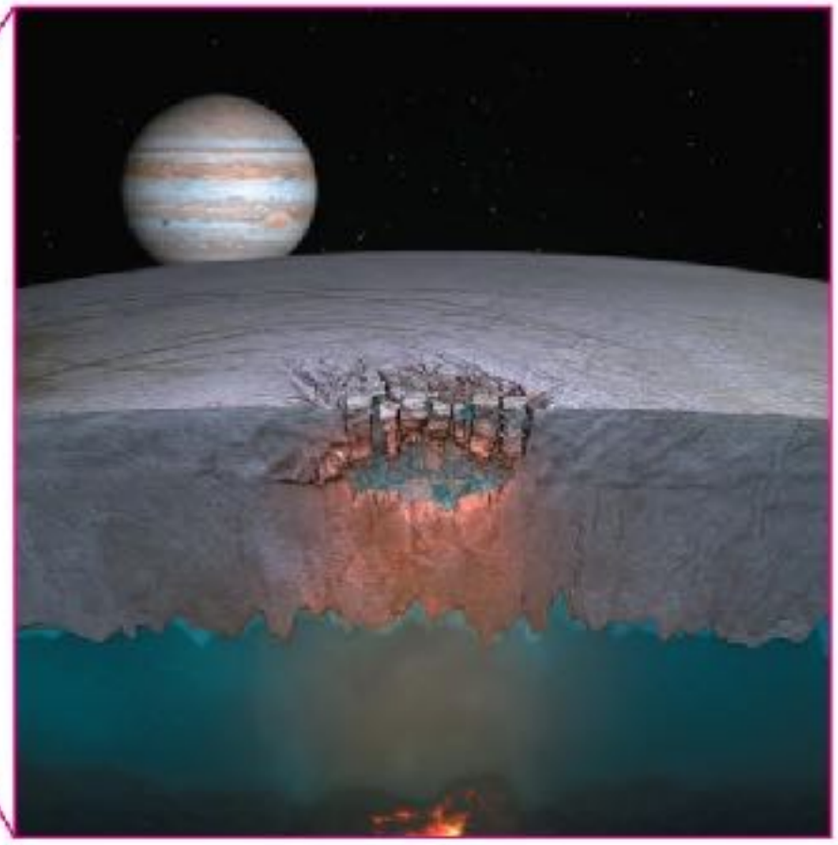


NASA /

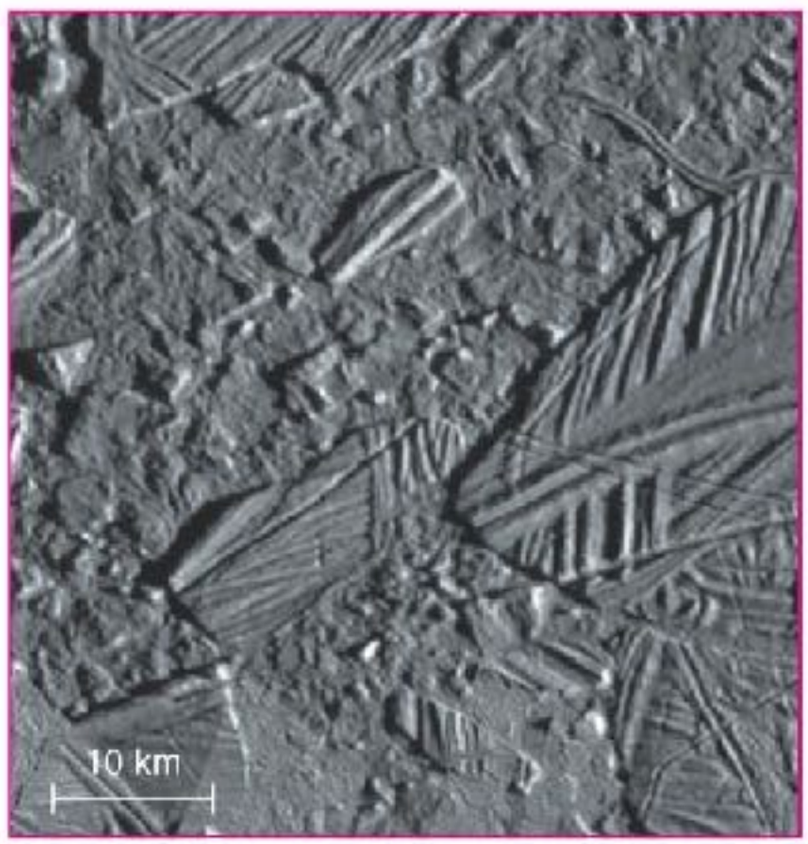
Europa's interior also warmed by tidal heating.



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.

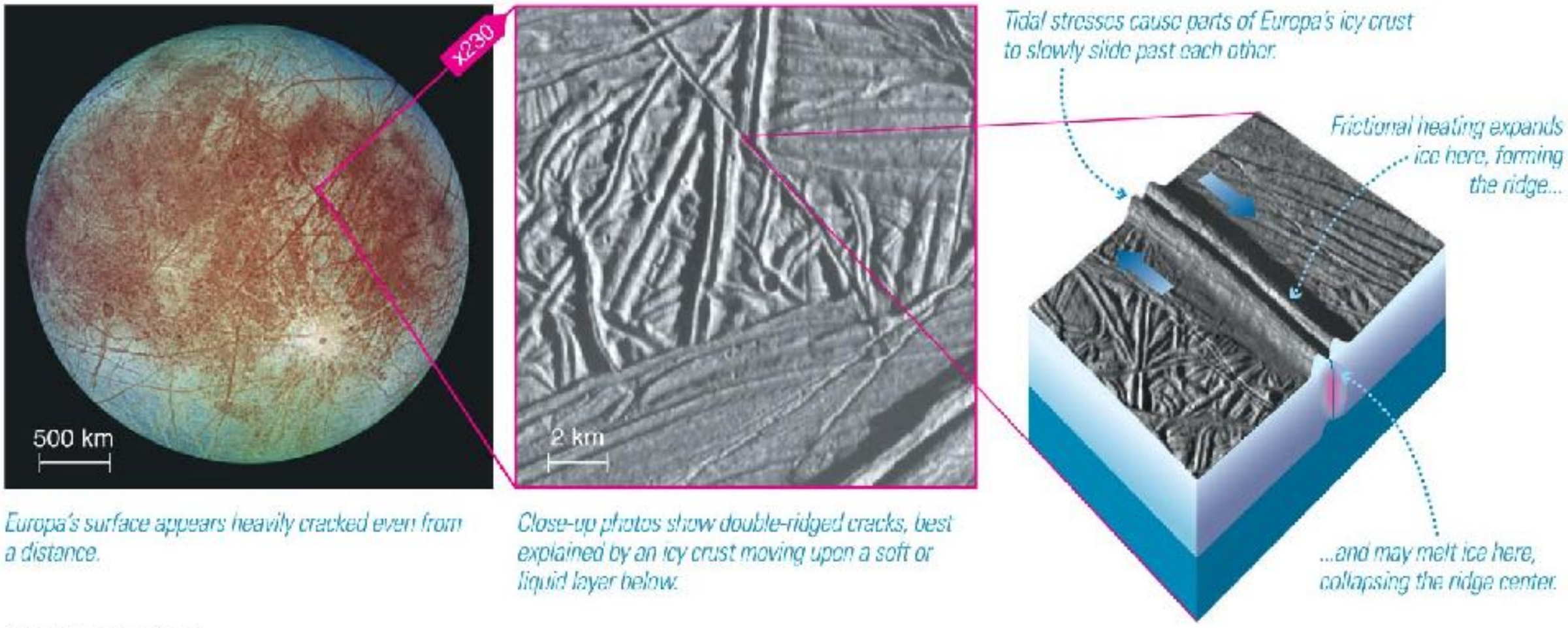
- **metallic core**
- **rocky mantle**
- **briny global ocean**
- **ice crust**

Ice crust stressed and sometimes melted from below…

… resulting in a jumbled terrain of broken ice sheets

Energy source: tidal heating again important, just not as strong as on Io

Tidal stresses crack Europa's surface ice.



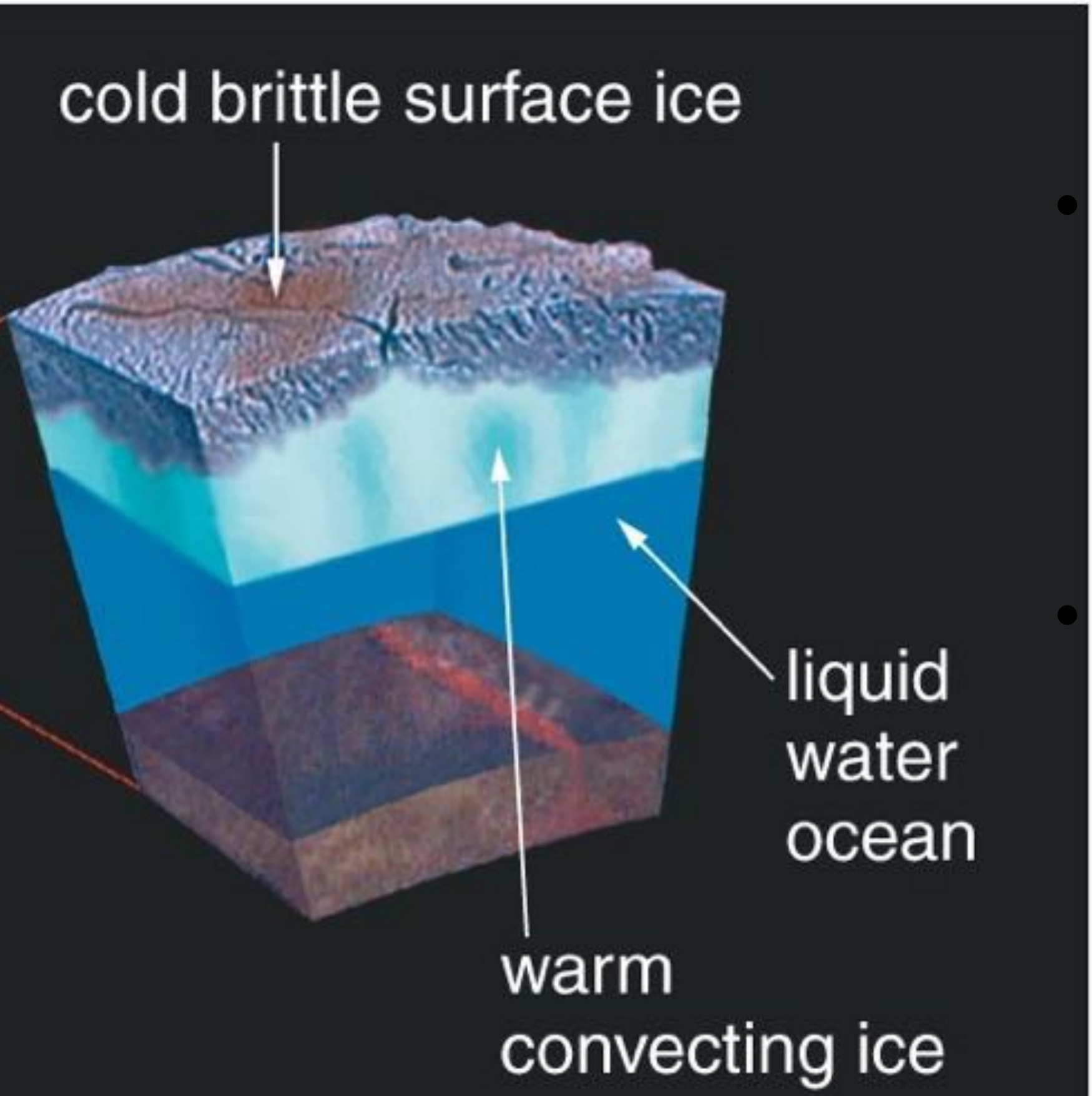
Europa's surface appears heavily cracked even from a distance.

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

- **metallic core**
- **rocky mantle**
- **briny global ocean**
- **ice crust**

Sometimes long tidal cracks and ridges form, a bit like fault lines on the Earth

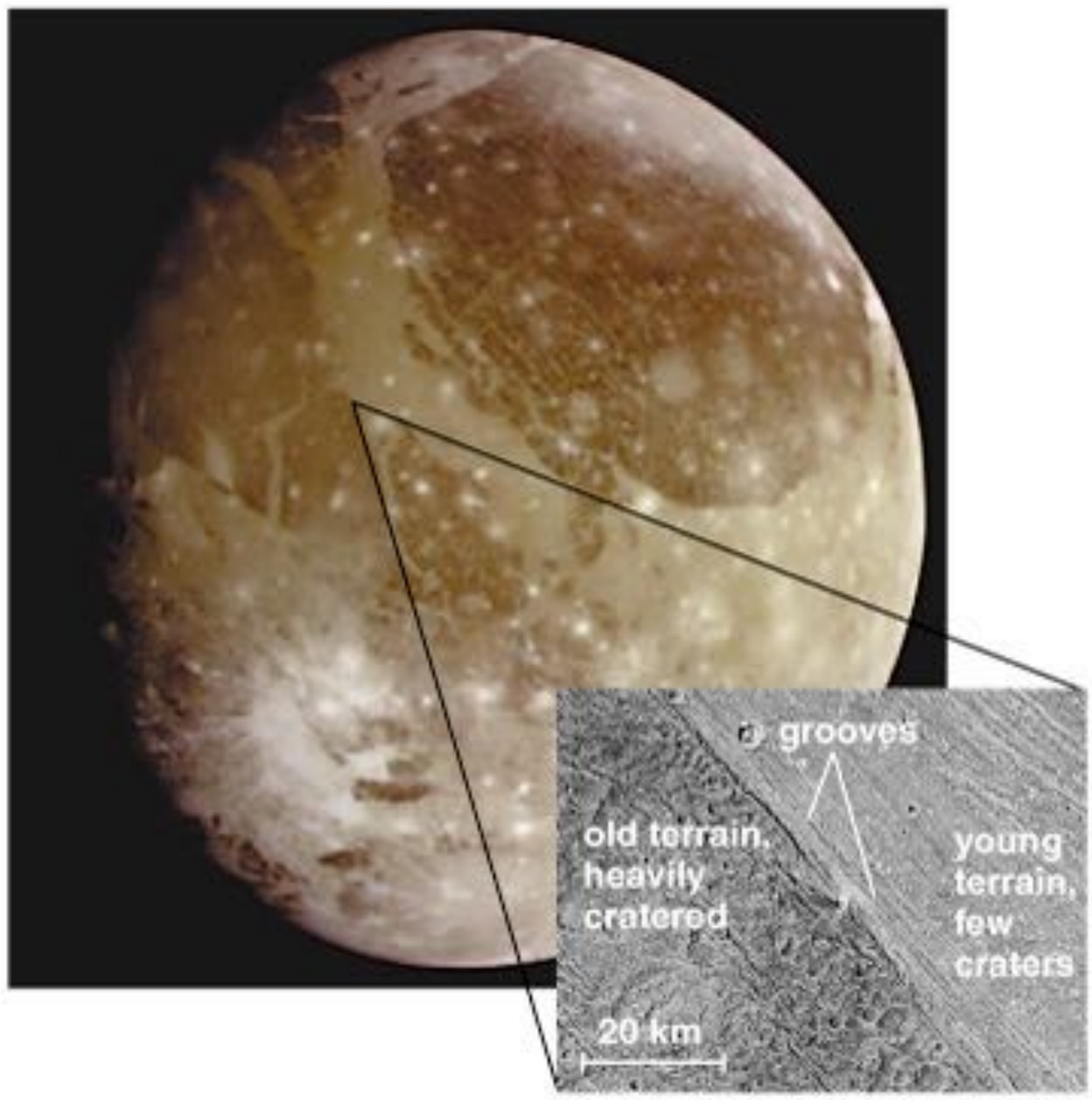
Energy source: tidal heating again important, just not as strong as on Io



Europa

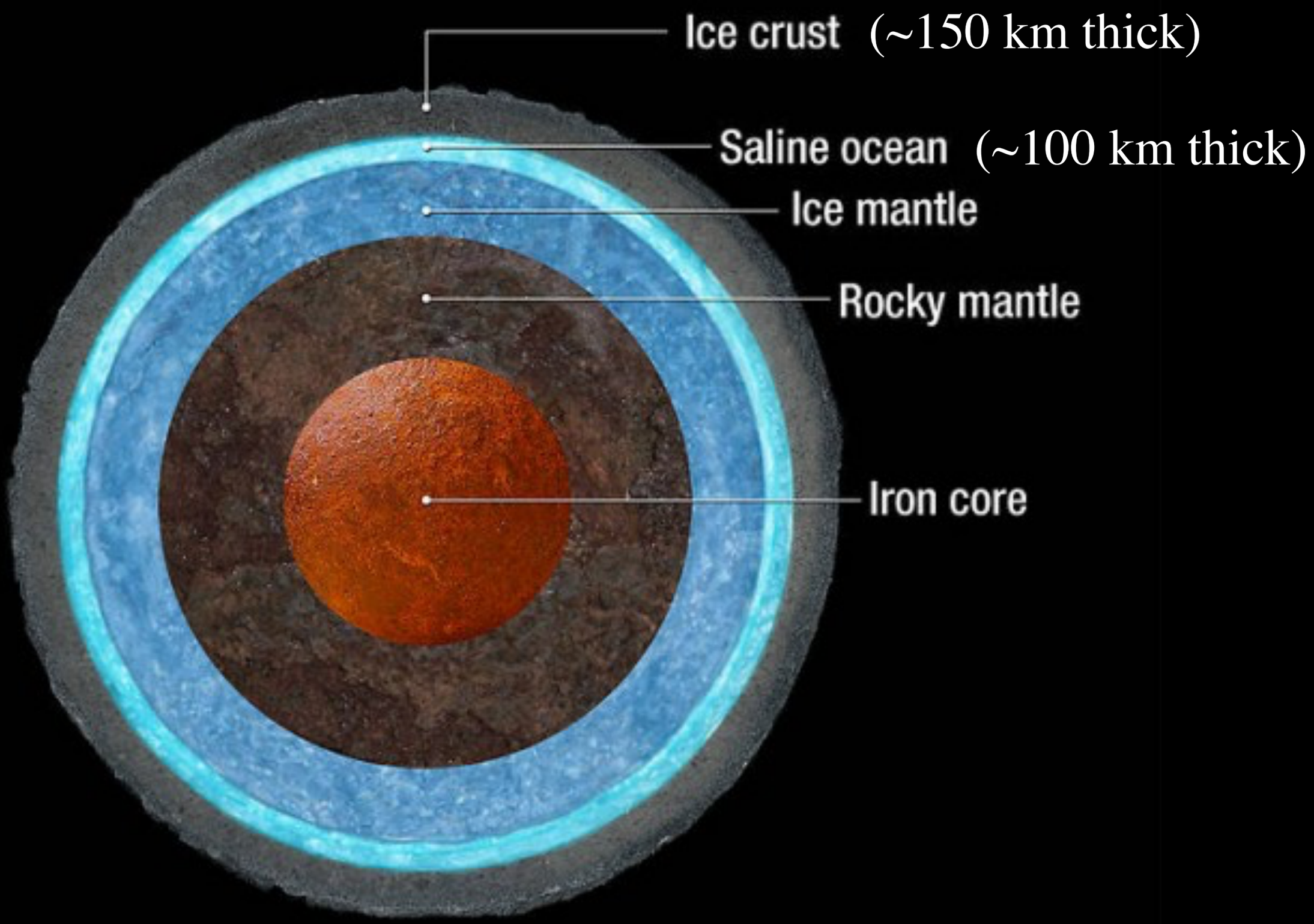
- Icy surface
  - cracks driven by tidal heating ("geological" activity)
- Liquid ocean beneath
  - popular spot to speculate about the potential for life

Ganymede



- Largest moon in the solar system
- Clear evidence of geological activity
- Salty ocean under thick crust of ice
- Tidal heating still important, but much less than on Io or Europa

Ganymede Interior



Phase diagram of water

Temperature

Pressure

0 K 50 K 100 K 150 K 200 K 250 K 300 K 350 K 400 K 450 K 500 K 550 K 600 K 650 K

1 TPa 100 GPa 10 GPa 1 GPa 100 MPa 10 MPa 1 MPa 100 kPa 10 kPa 1 kPa 100 Pa 10 Pa 1 Pa

10 Mbar 1 Mbar 100 kbar 10 kbar 1 kbar 100 bar 10 bar 1 bar 100 mbar 10 mbar 1 mbar 100 μbar 10 μbar

XI (hexagonal)

X

VIII

VII

VI

II

V

III

XV

IX

XI (ortho-rhombic)

Ic

Ih

100 K, 62 GPa

278 K, 2.1 GPa

355.00 K, 2.216 GPa

218 K, 620 MPa

272.99 K, 632.4 MPa

248.85 K, 344.3 MPa

256.164 K, 350.1 MPa

238.5 K, 212.9 MPa

251.165 K, 209.9 MPa

Critical point
647.096 K (373.946 °C), 22.064 MPa

Solid

Liquid

Vapour

STP
273.15 K (0 °C), 100 kPa

NTP
293.15 K (20 °C), 101.325 kPa

SATP
298.15 K (25 °C), 101.325 kPa

Earth

Mars

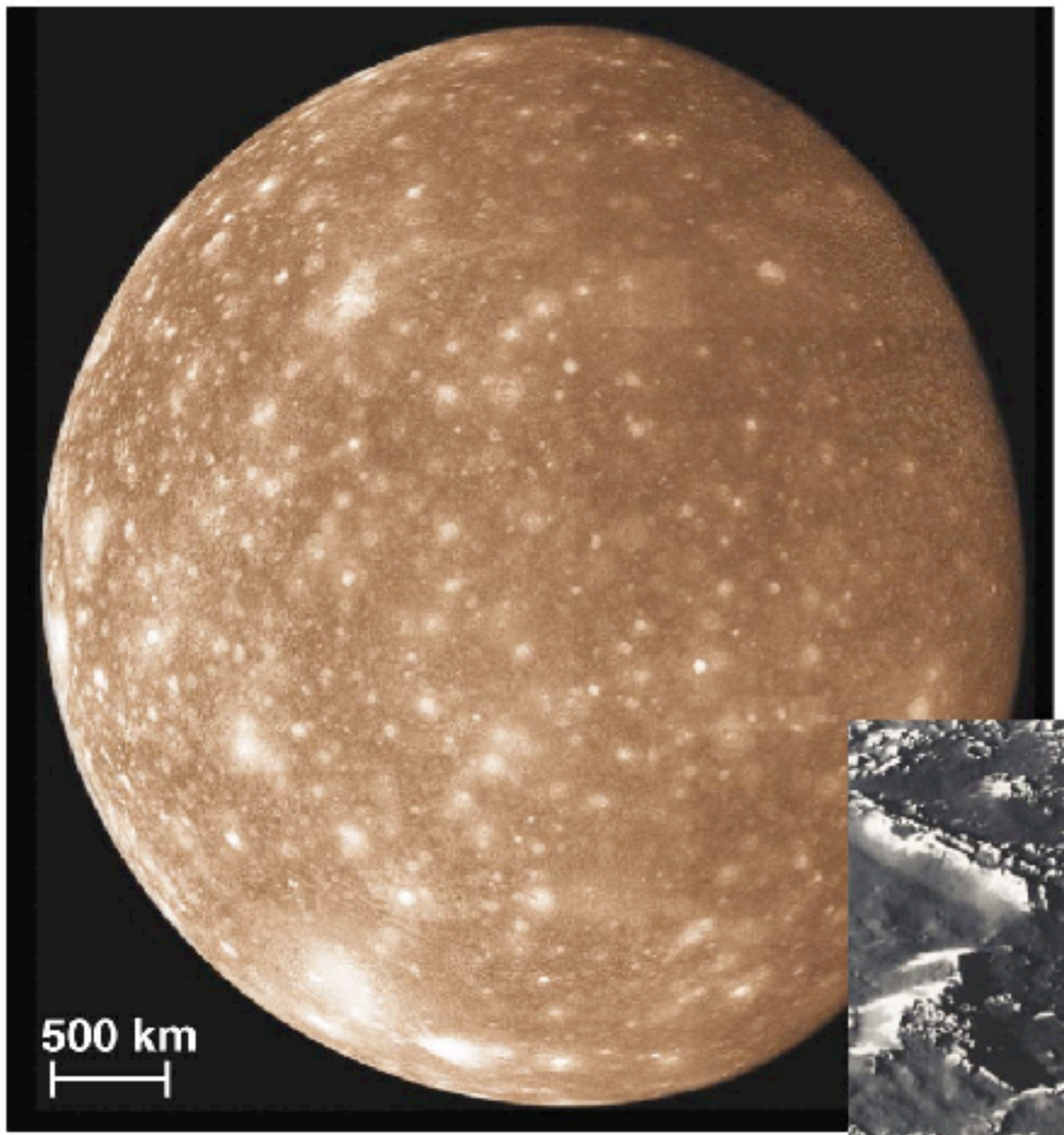
Freezing point at 1 atm
273.15 K (0 °C), 101.325 kPa

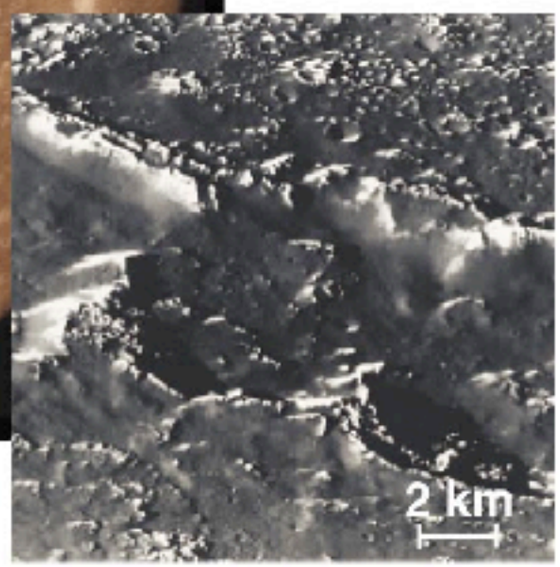
Boiling point at 1 atm
373.15 K (100 °C), 101.325 kPa

Solid/Liquid/Vapour triple point
273.16 K (0.01 °C), 611.657 Pa

-250 °C -200 °C -150 °C -100 °C -50 °C 0 °C 50 °C 100 °C 150 °C 200 °C 250 °C 300 °C 350 °C

Callisto



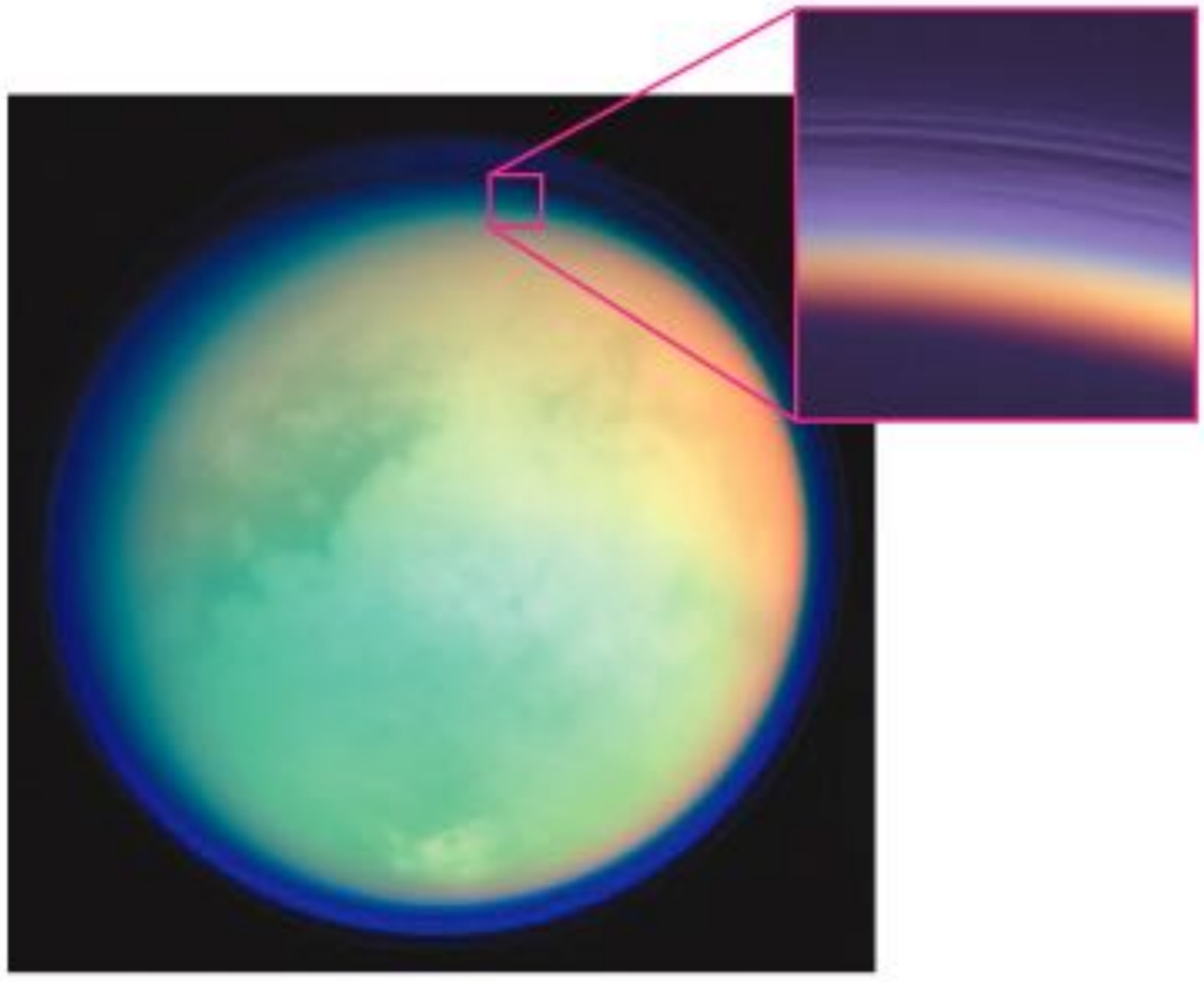


- "Classic" cratered iceball
  - very thick ice crust
- No orbital resonances
  - No tidal heating

Saturn's moons

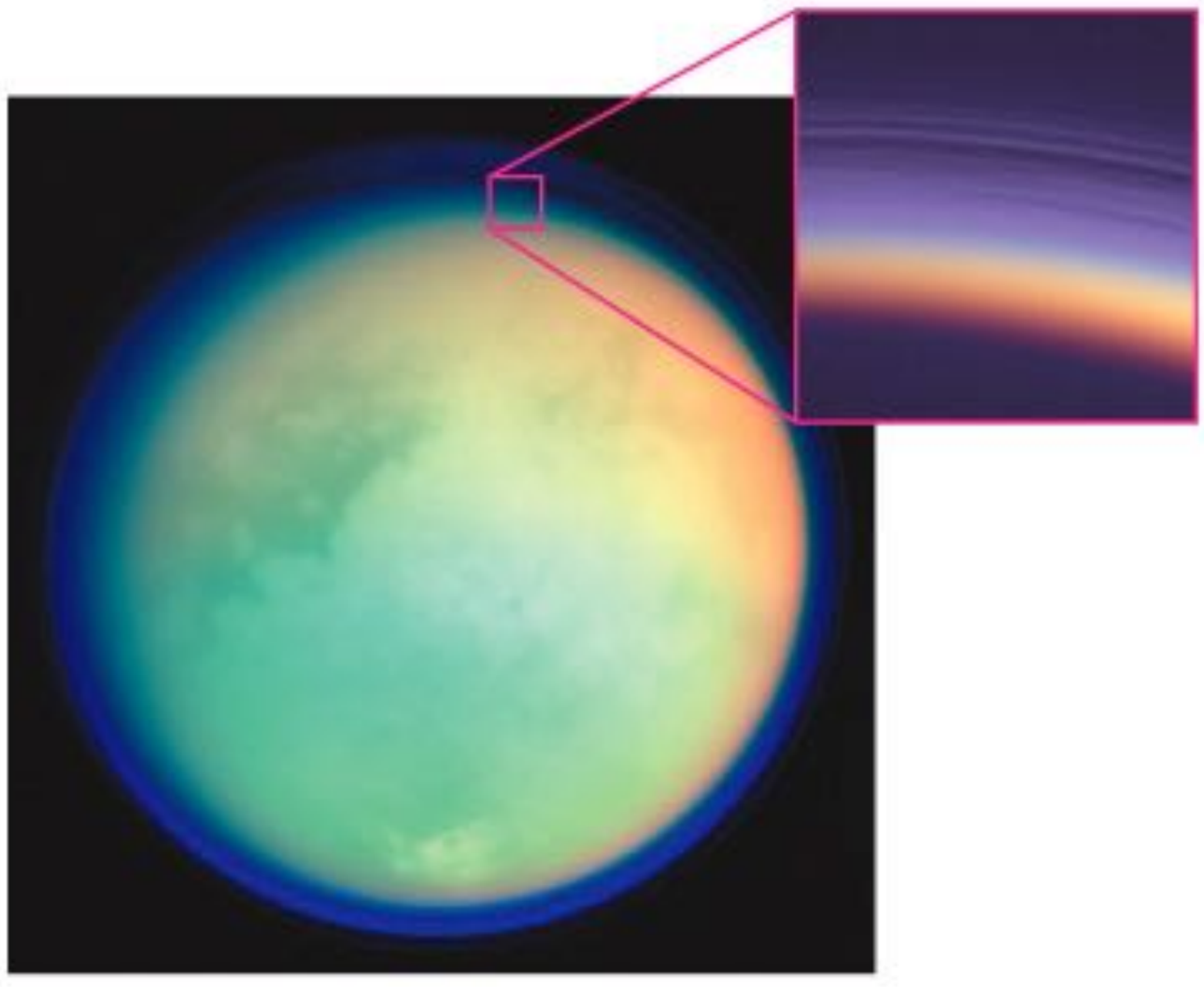
- Saturn has one large moon - **Titan**
- a large number of medium-sized and small moons
- Rings composed of many tiny icy moonlets

Saturn's large moon Titan



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

Saturn's large moon Titan

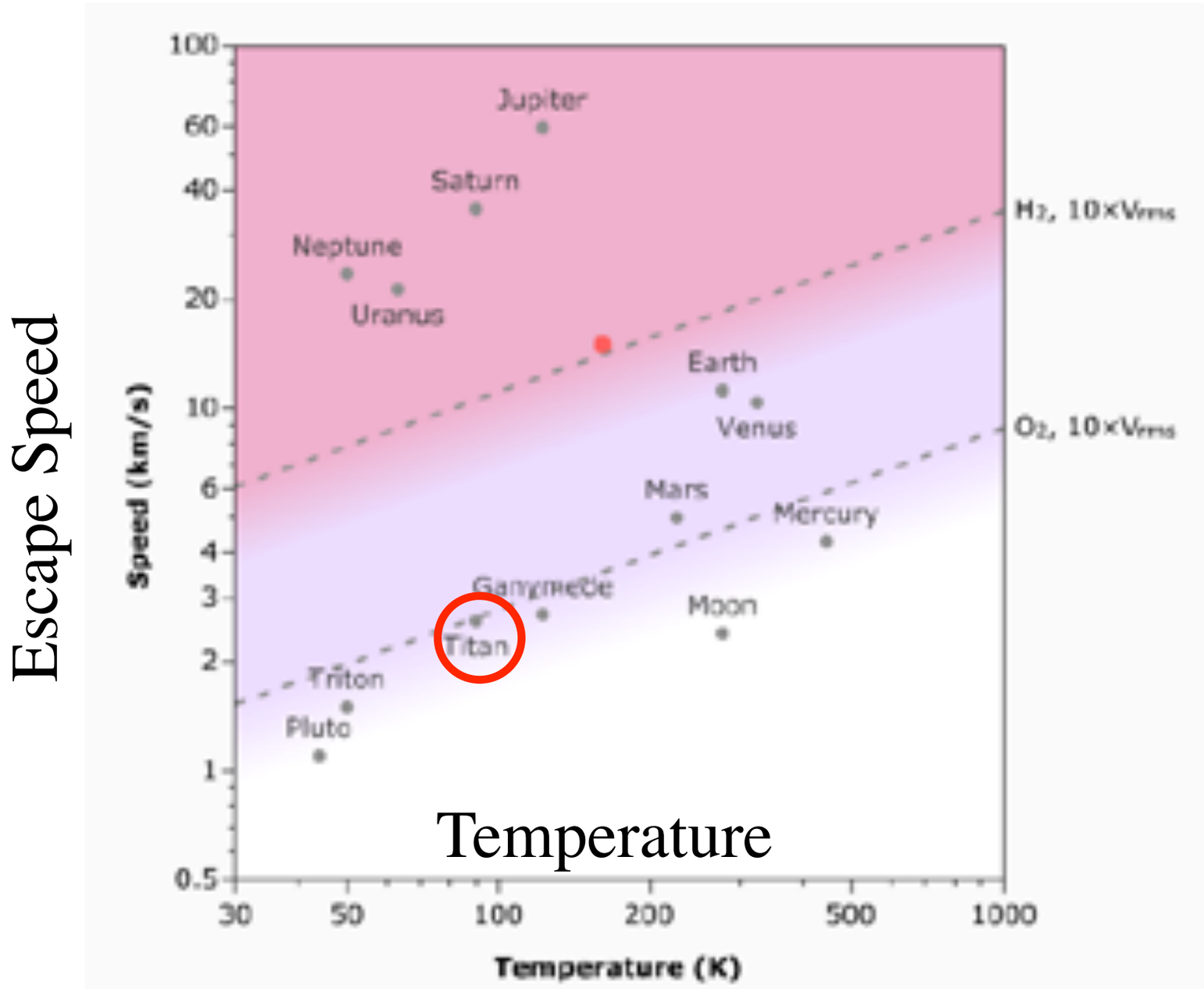


- Relative to Earth:
  - 1.5 Atm pressure
  - 4x denser
  - comparable total mass (1.2x)
  - more extended
    - due to lower gravity

- Cold
  - -180^{o} C

Titan is

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



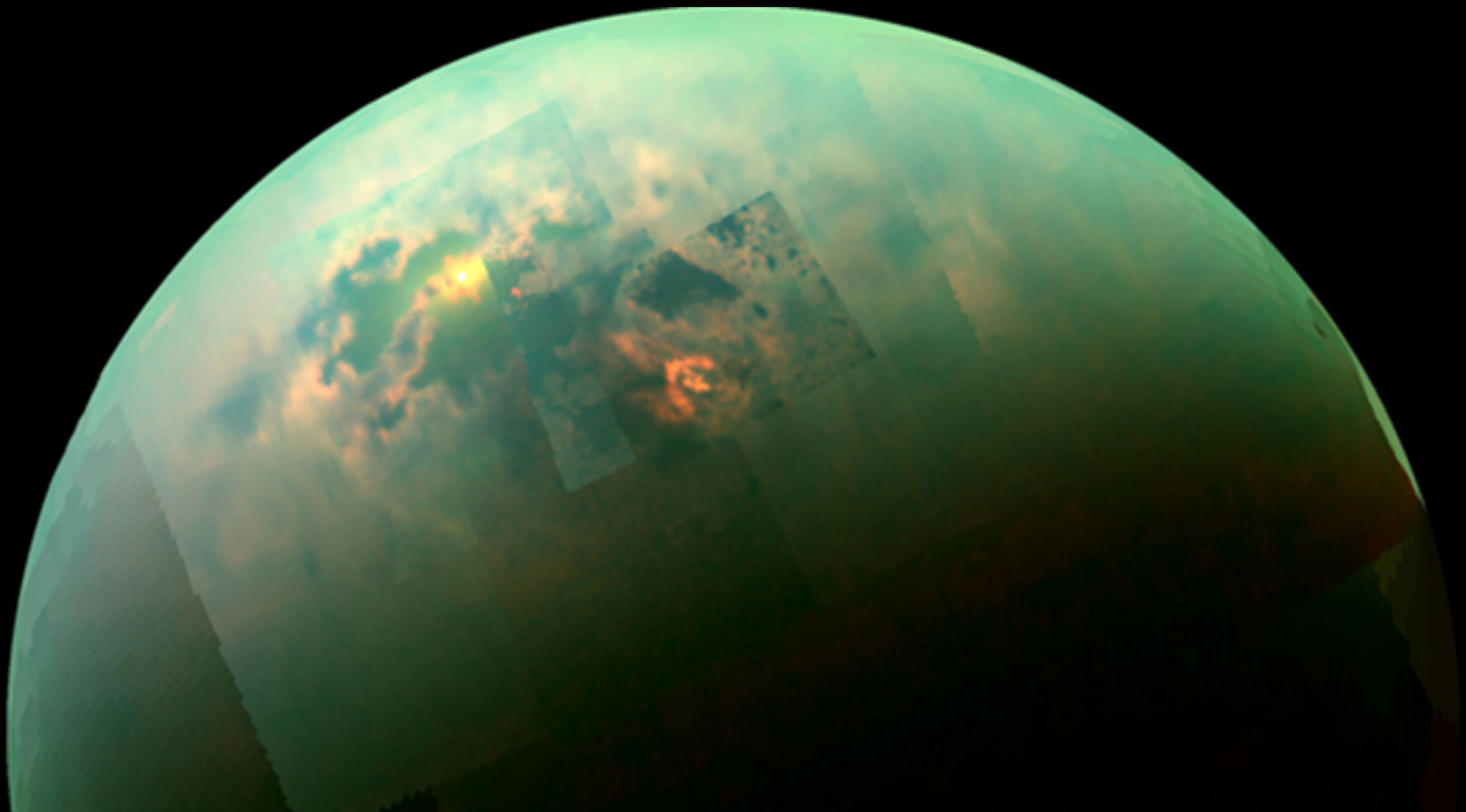
atmospheric haze
in optical light

Underneath the atmosphere is terrain, including seas of liquid hydrocarbons

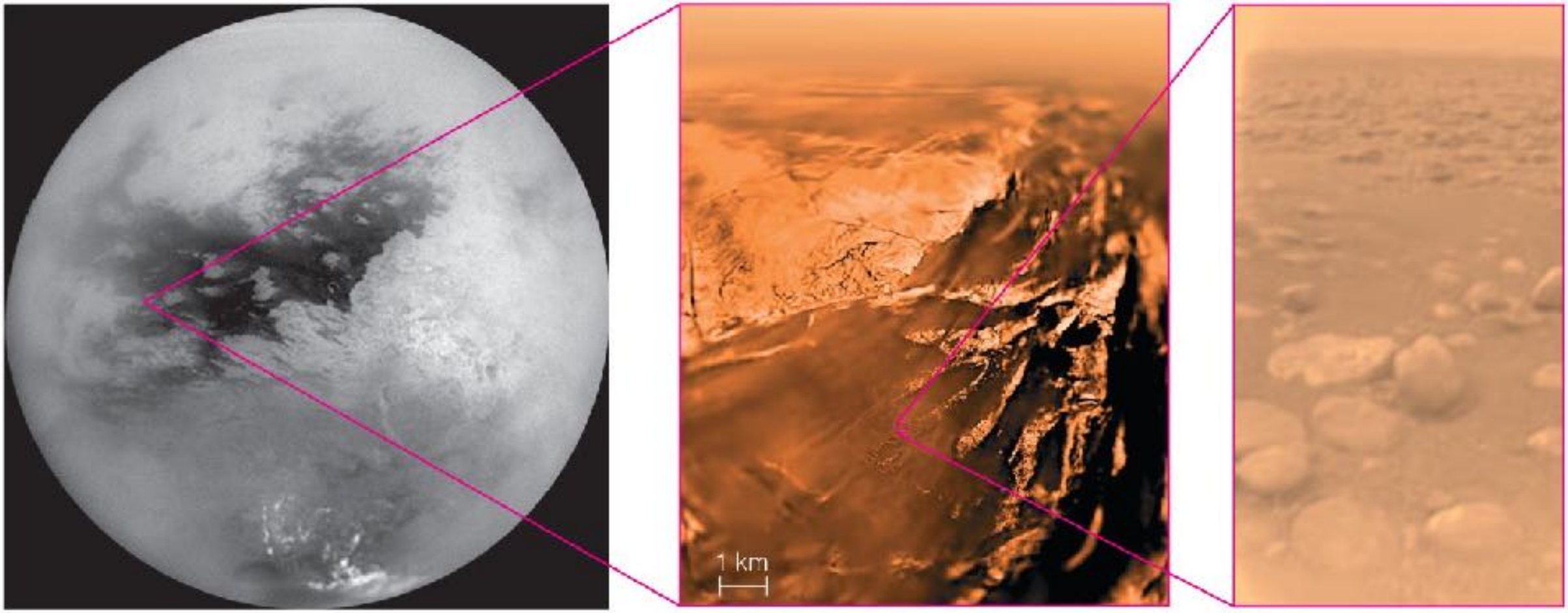
solid surface

liquid
methane

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



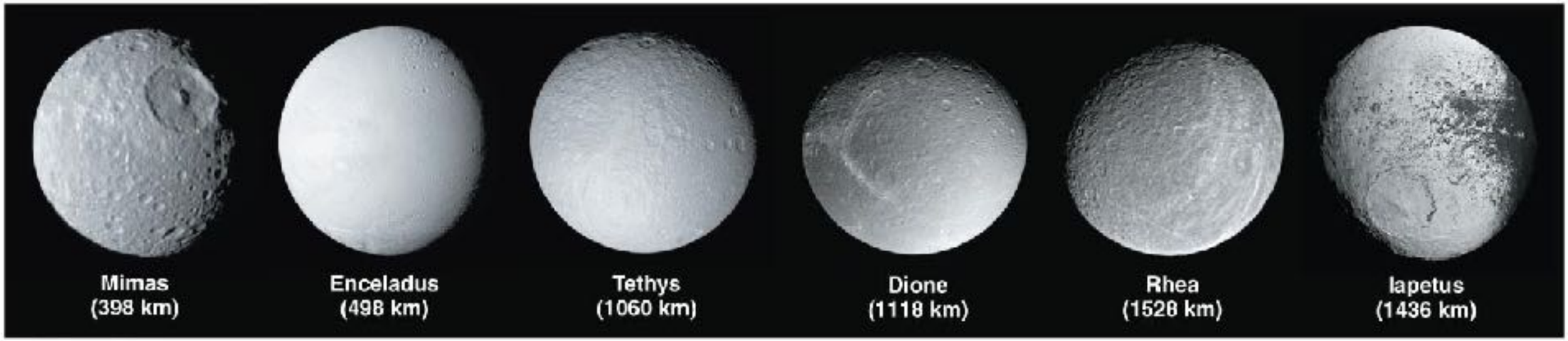
Titan's Surface



- 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

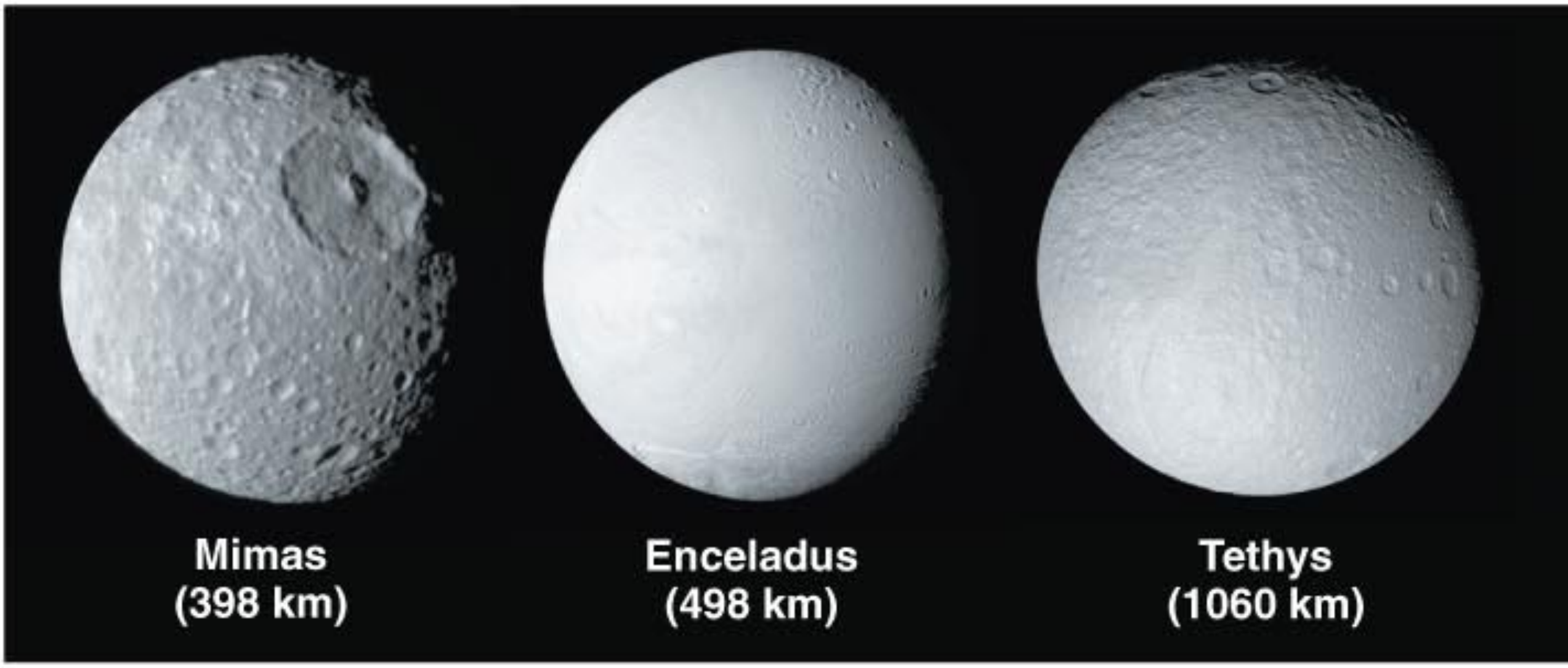
https://www.youtube.com/watch?v=YErUVO0FSS8
Bennett7th_201/11_lecture_ppt/IF_11_26_TitanLanding.htm

Medium Sized Moons of Saturn



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

Medium Moons of Saturn

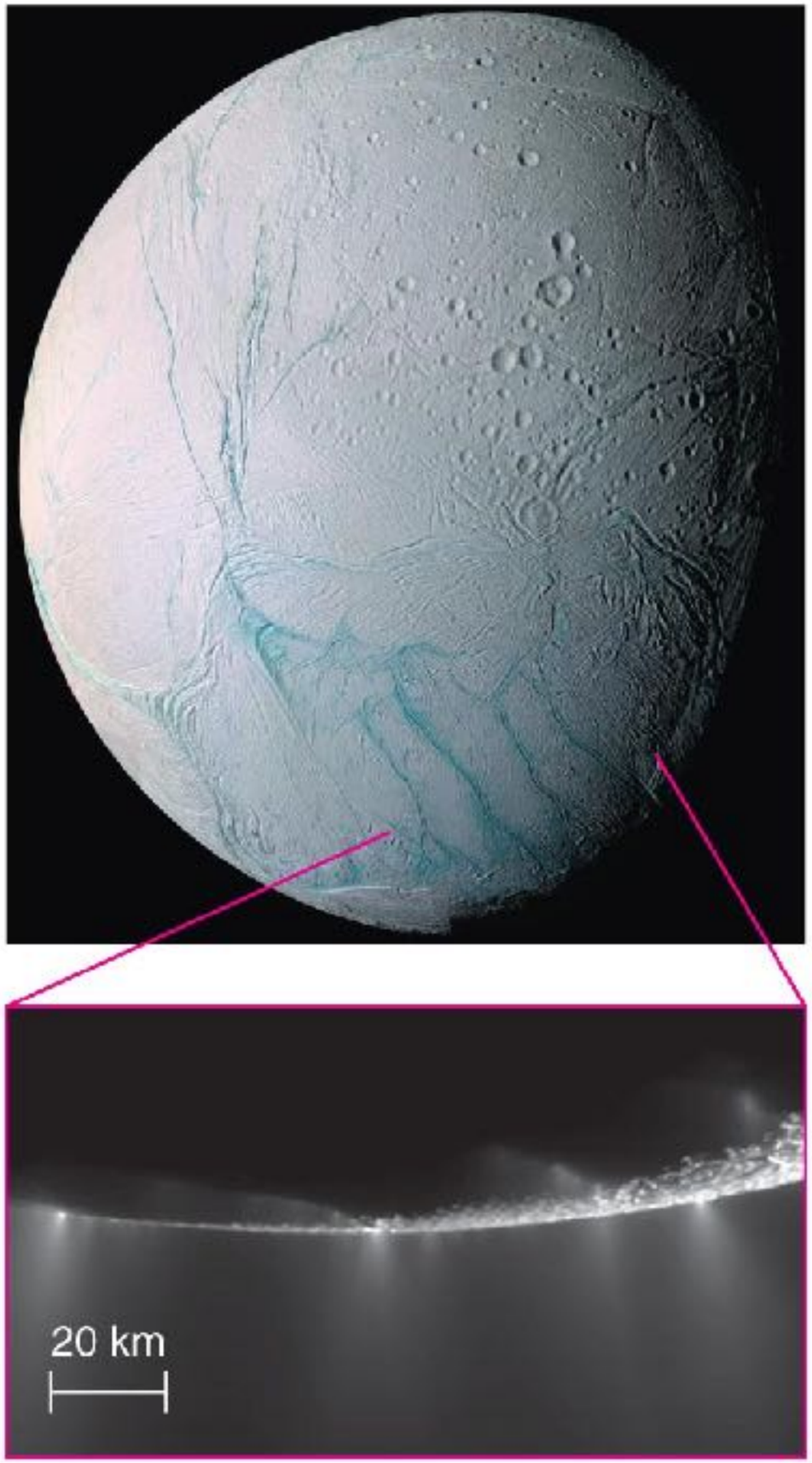


- Mimas has a big crater that makes it look like the Death Star.

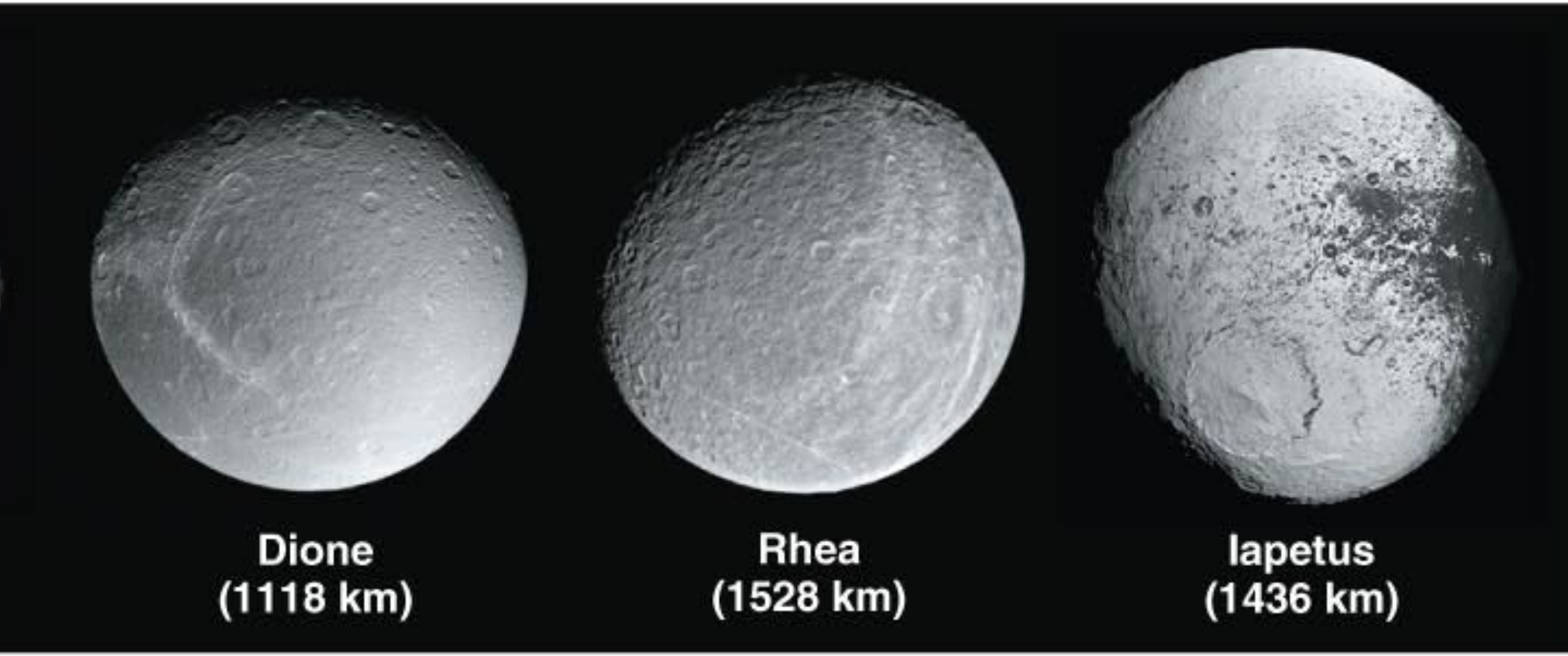
Medium Moons of Saturn

- Ice fountains of Enceladus suggest it has a subsurface ocean.

- “Cryovolcanism” - the “magma” is water.



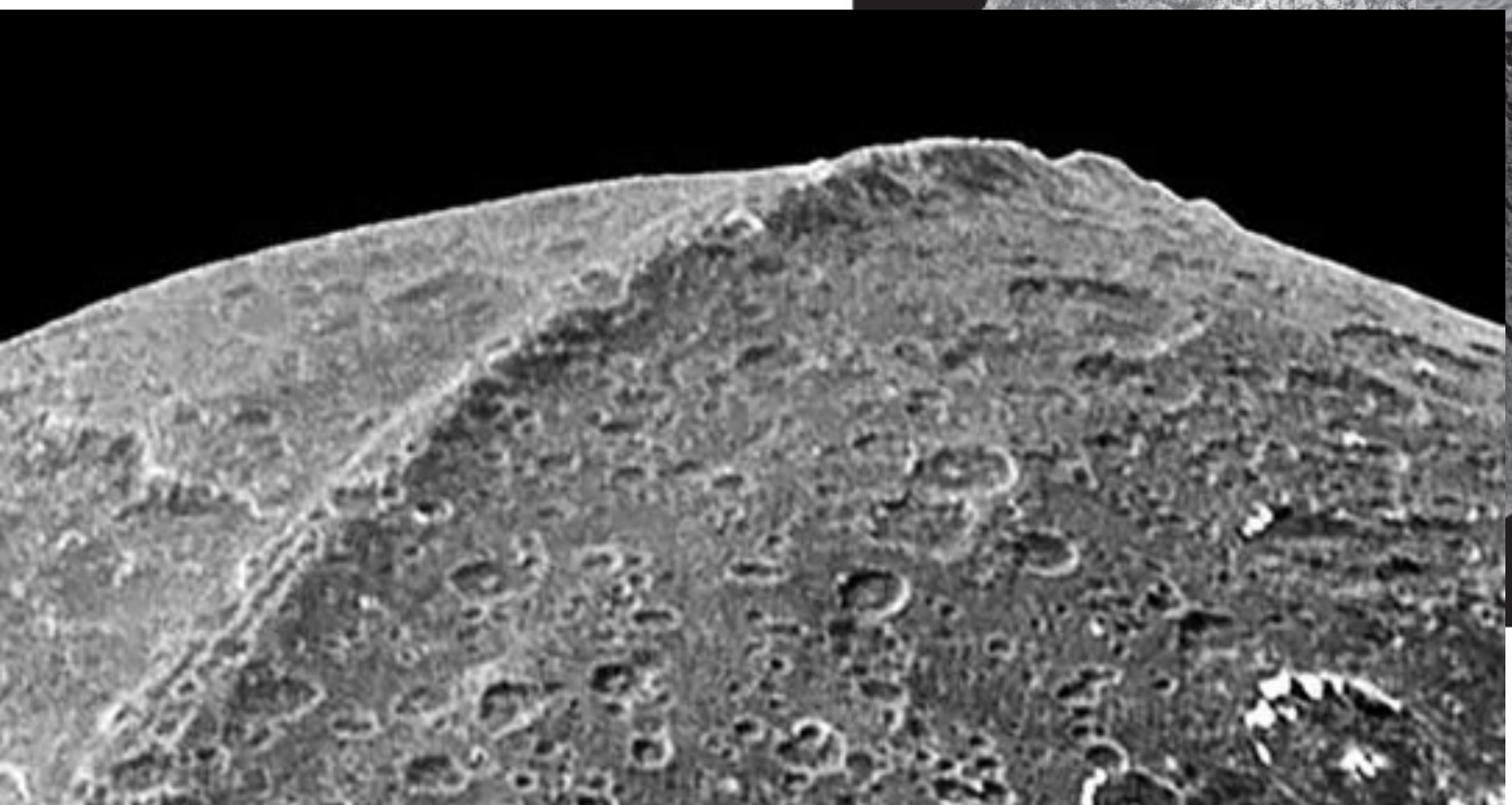
Medium Moons of Saturn



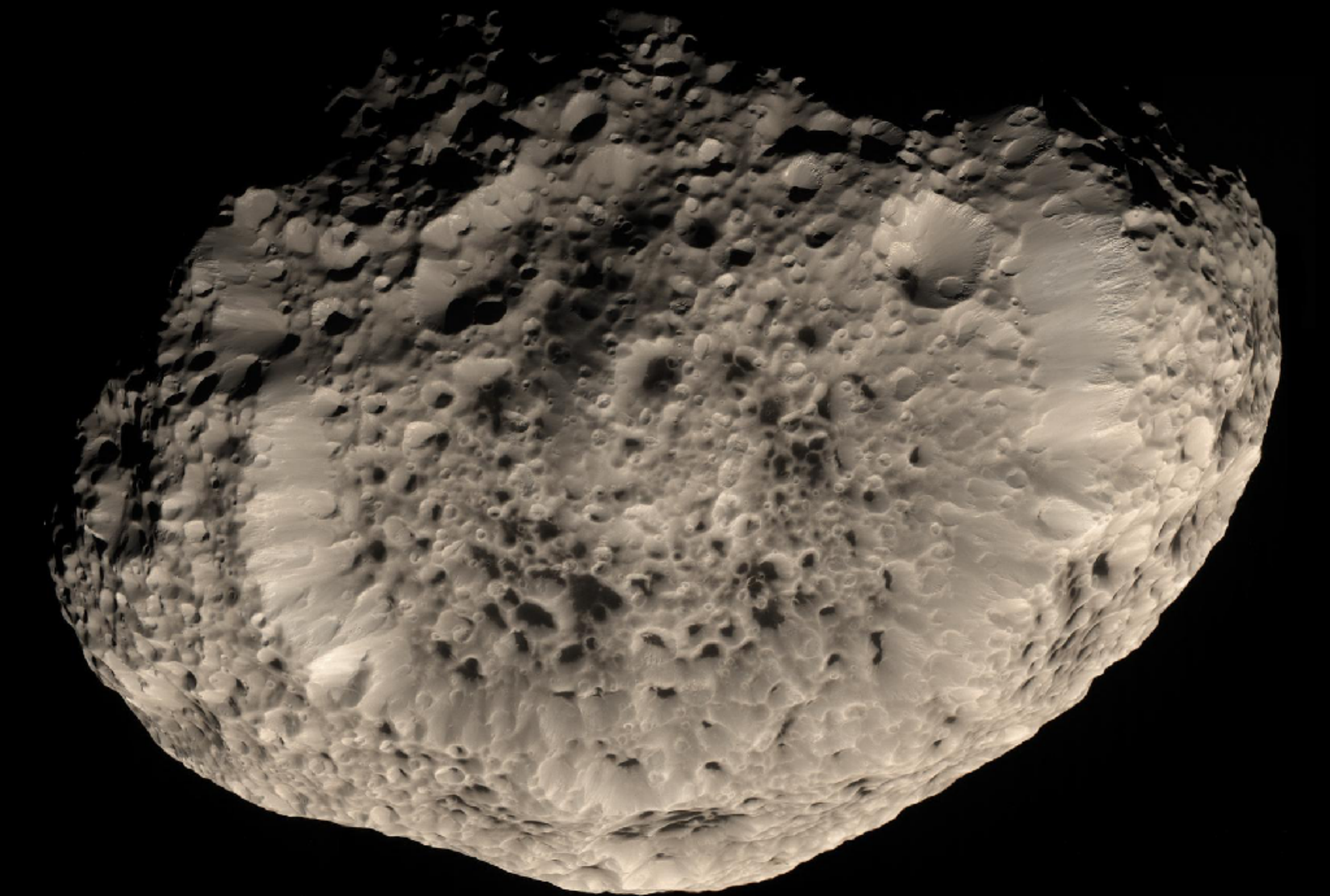
- Iapetus is dark on one side & bright on the other. It seems to have collected a goo of space debris emitted by Phoebe on the leading (dark) side of its orbit.

Medium Moons of Saturn

- Iapetus has a curious ridge around much of its equator

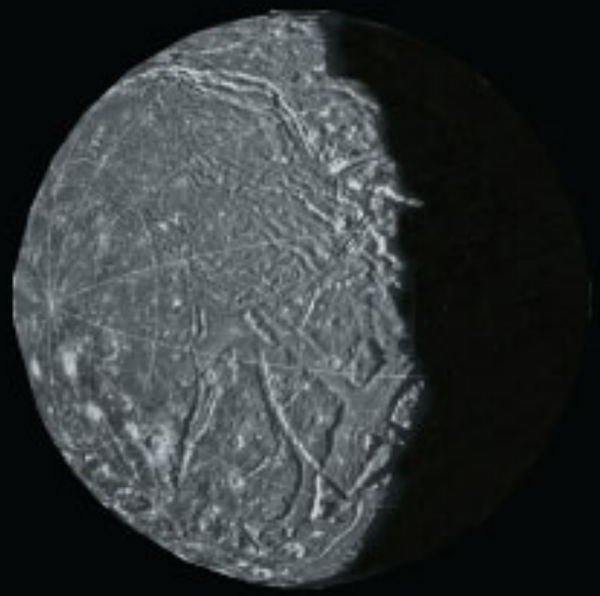


Small moons can also be weird. Hyperion looks like a sponge.



Moons of Uranus

Miranda



Ariel

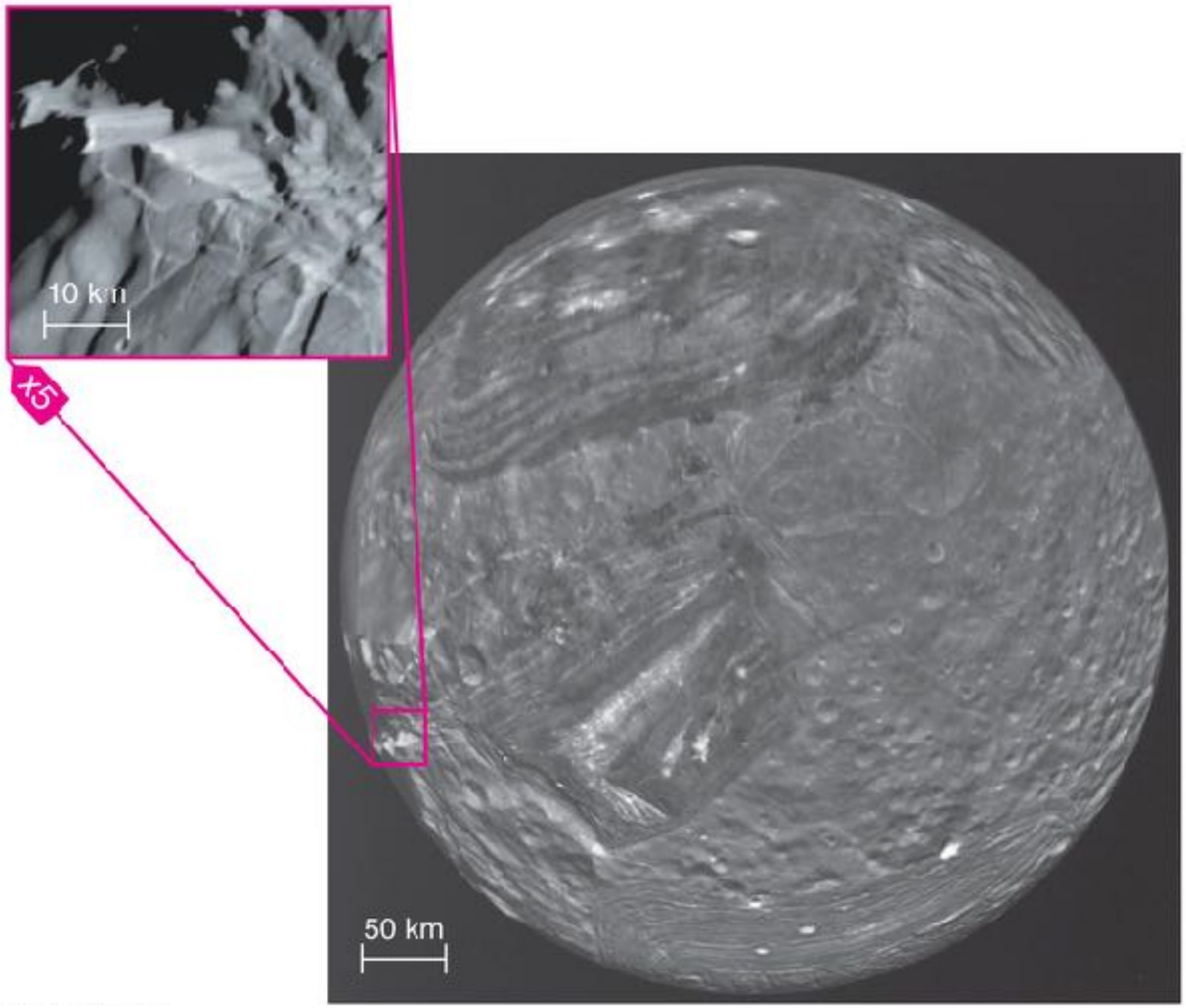
Oberon

Umbriel

Earth's Moon

Titania

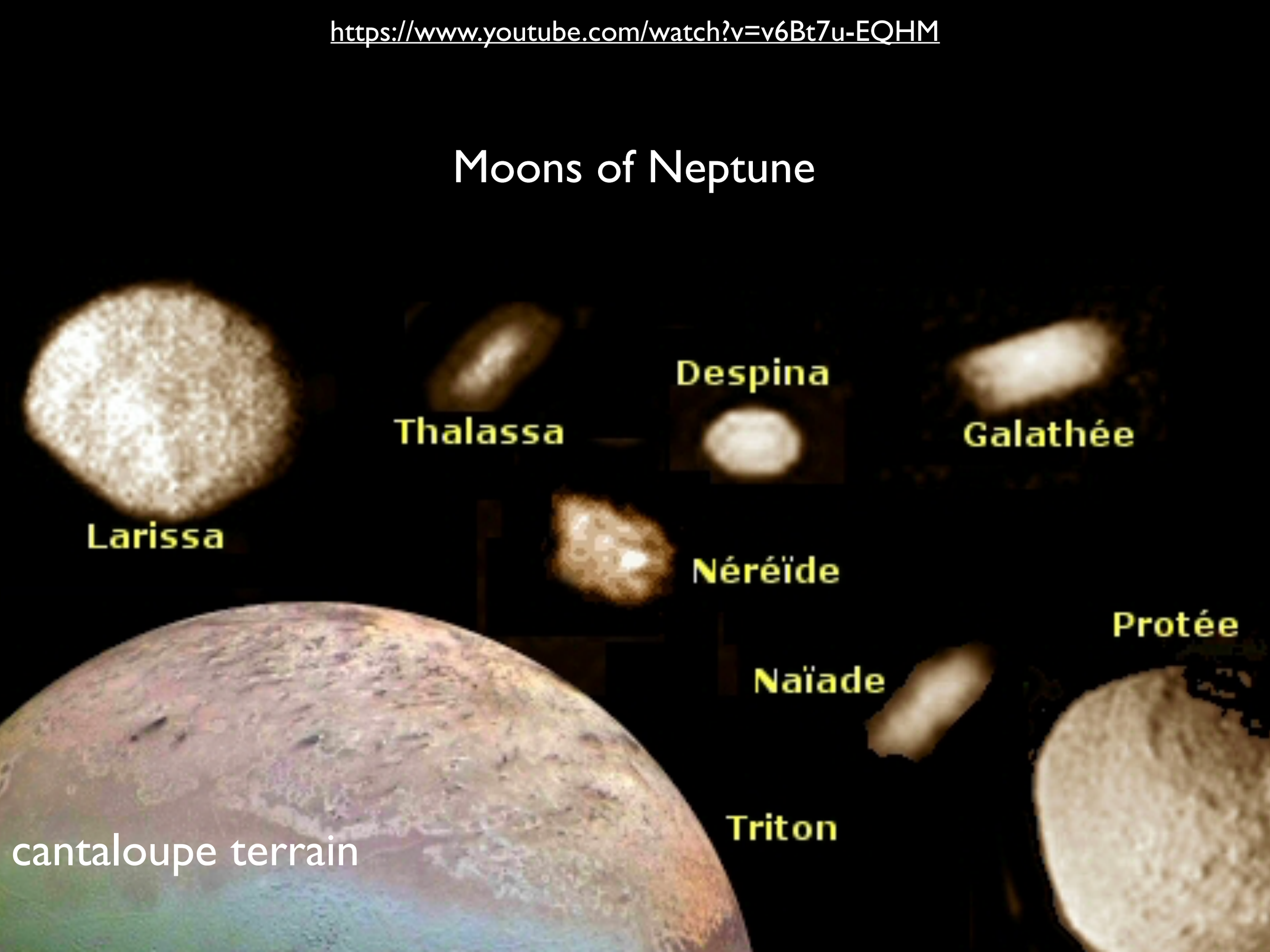
Medium Moons of Uranus



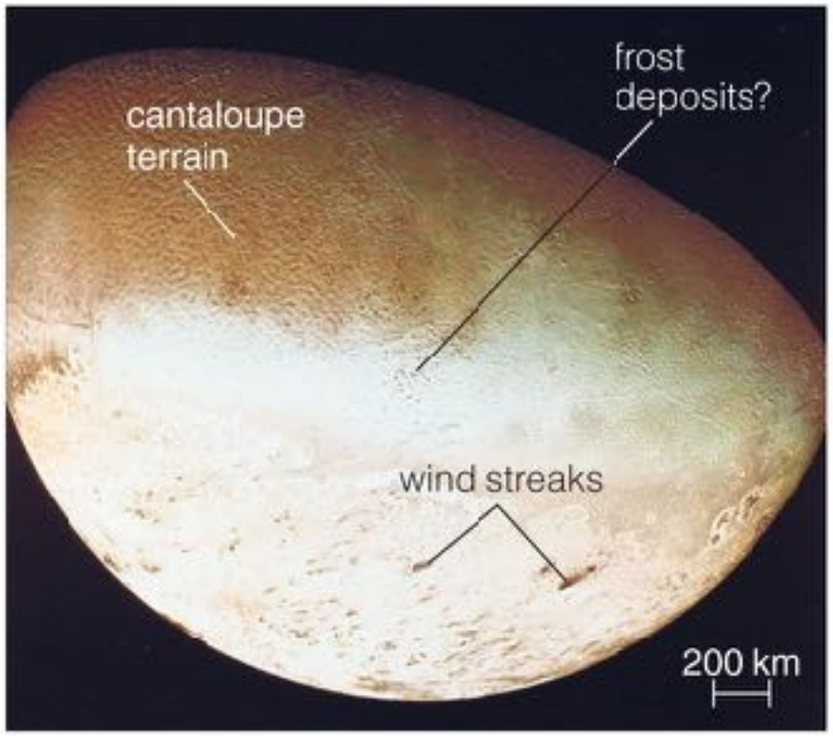
- They have varying amounts of geological activity.
- Miranda has large tectonic features and few craters (possibly indicating an episode of tidal heating in past).
- Frankenstein's moon

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

Moons of Neptune



Neptune's Moon Triton

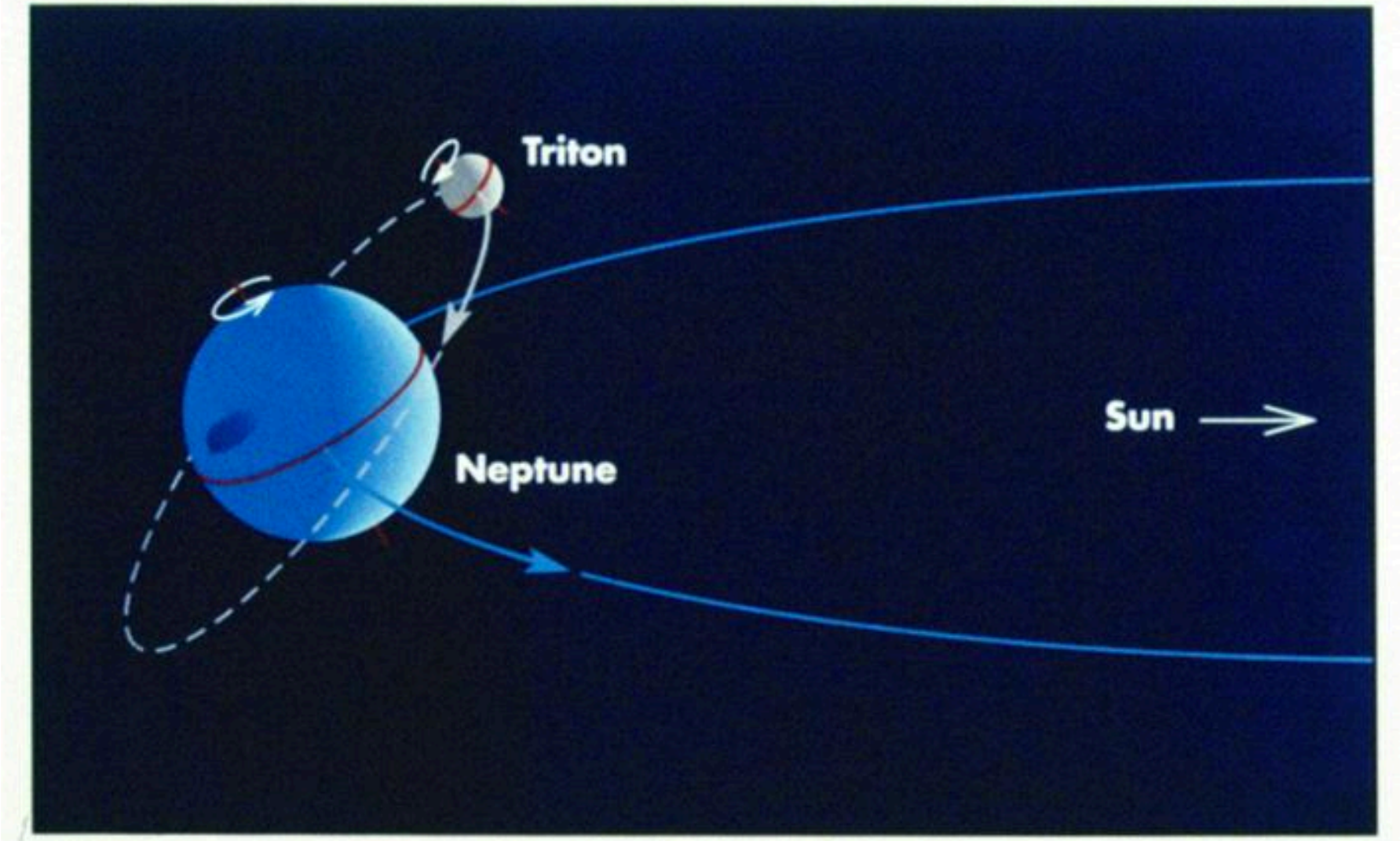


Triton's southern hemisphere as seen by *Voyager 2*.

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

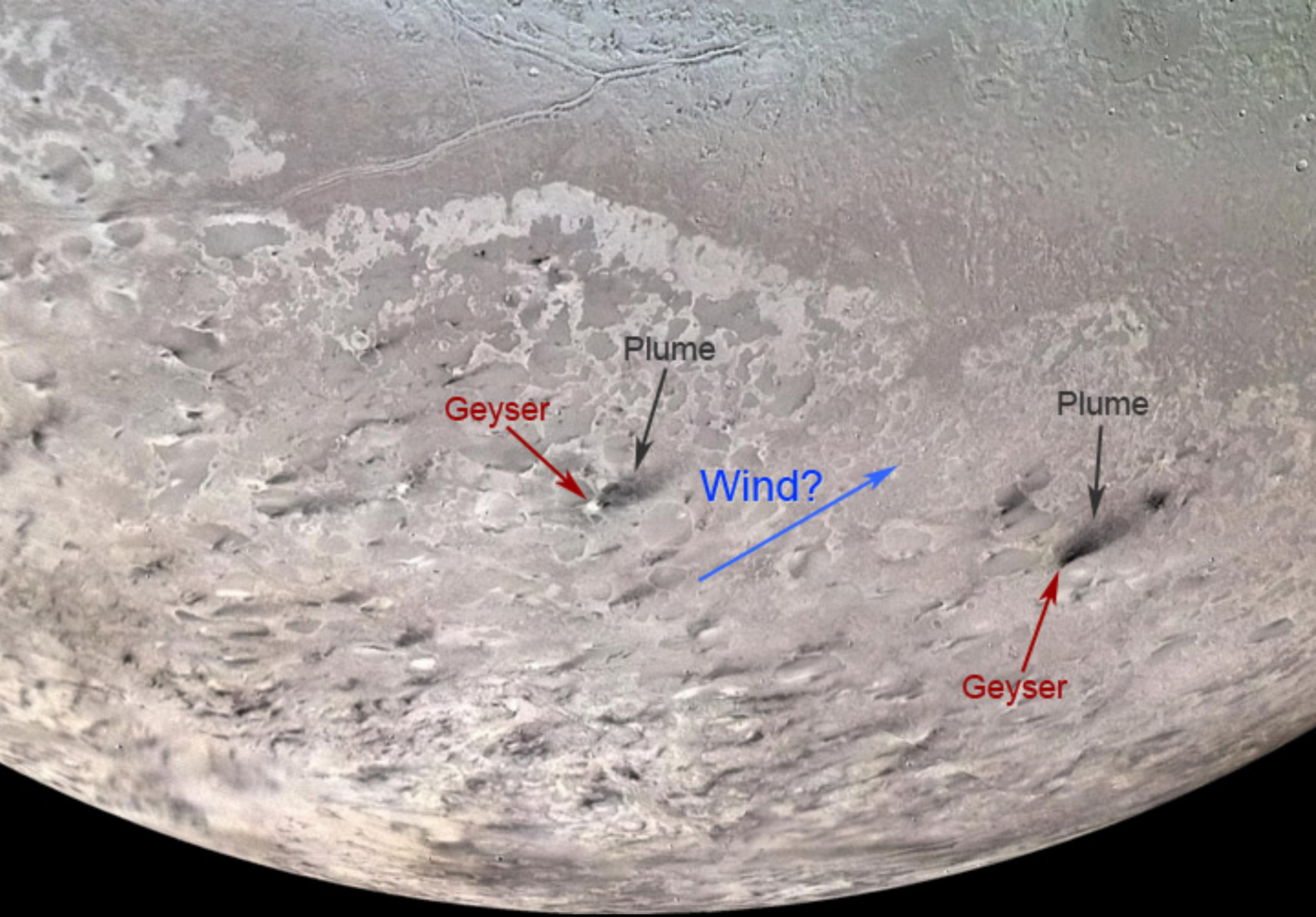
The occasional geyser, heated by sunlight, streaks the downwind terrain with dark material

- 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



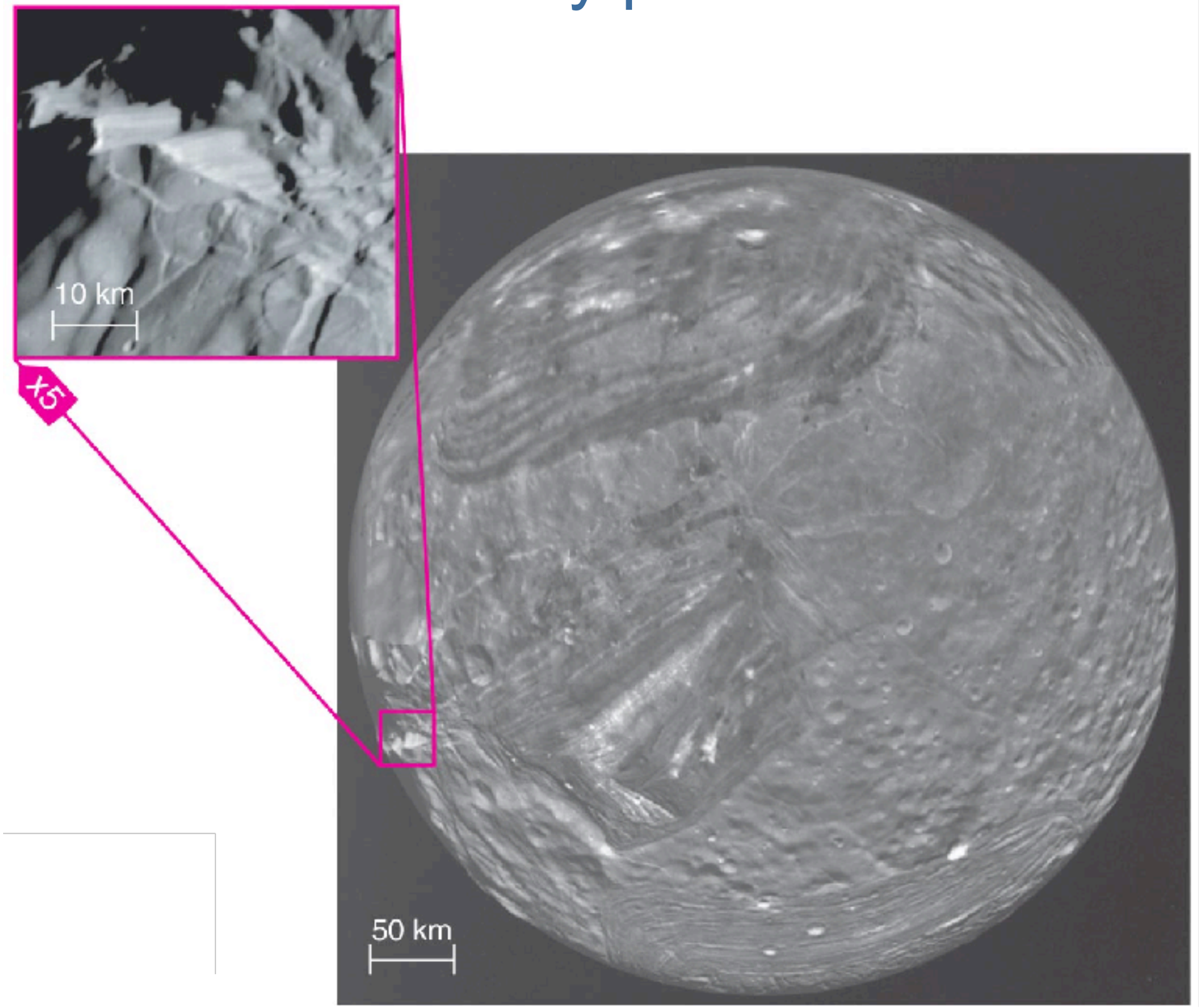
- tidally locked, like Earth's moon
- orbit is retrograde
- and highly inclined (40 degrees)
  - not stable - being pulled *in* by tides
    - will eventually make rings!

https://vimeo.com/3852837

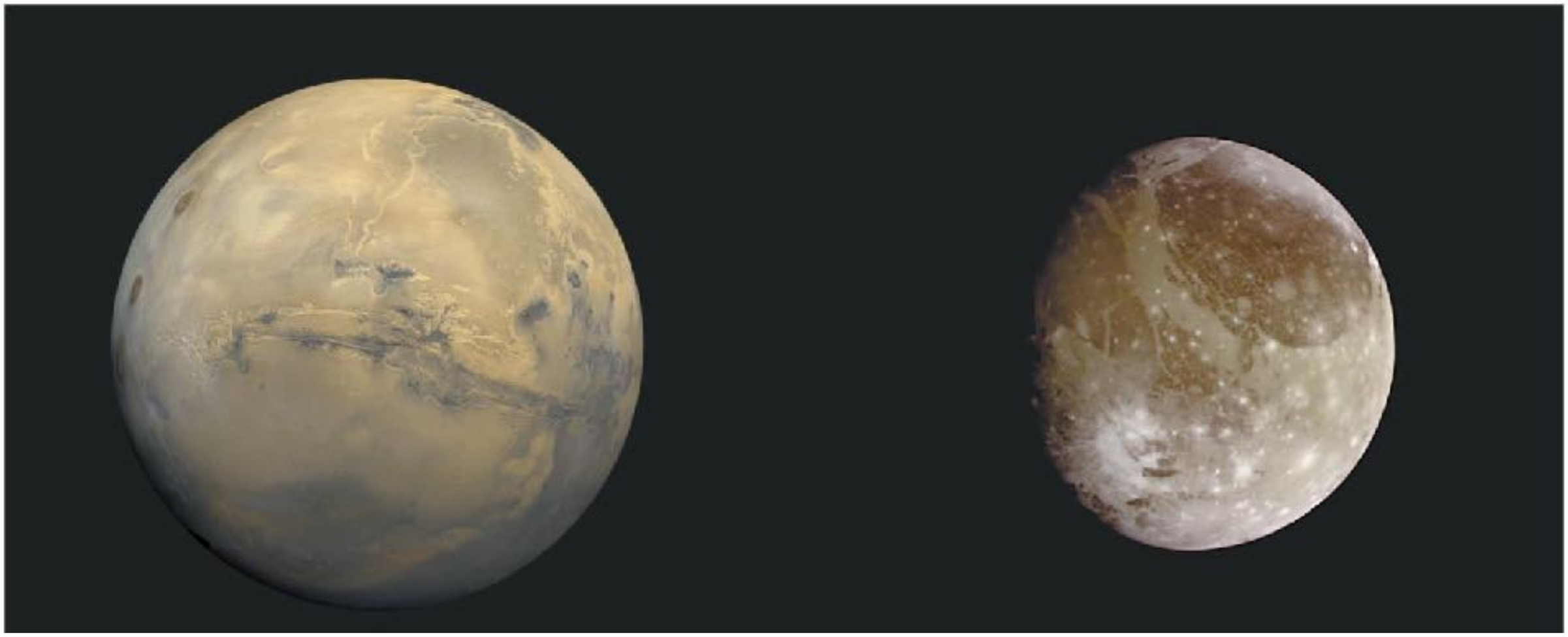


geysers

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.

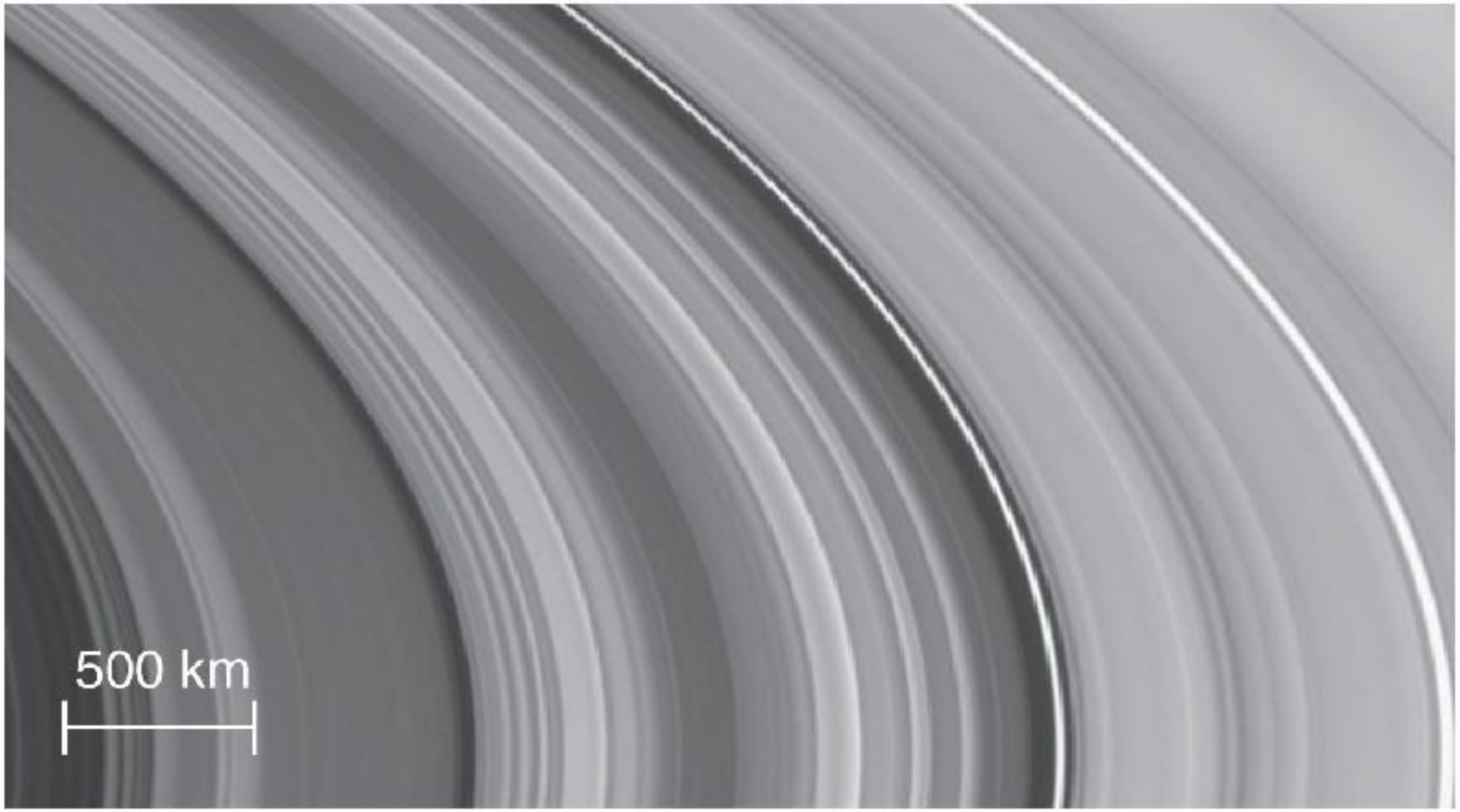
Saturn’s rings

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.

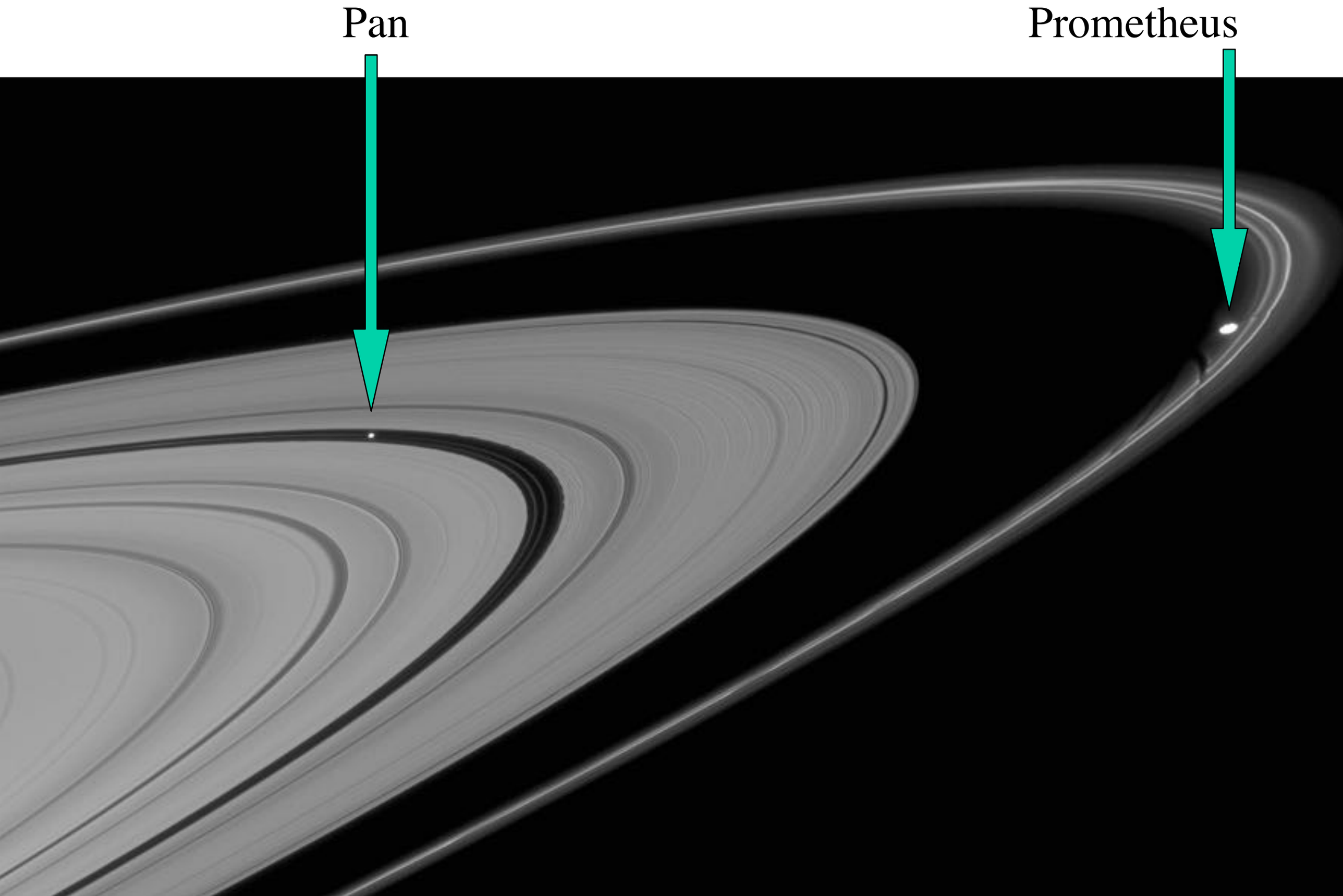
https://saturn.jpl.nasa.gov/resources/7628/

Spacecraft View of Ring Gaps



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

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



Saturn

Debris knocked loose from Phoebe creates a dust ring that tints the leading side of Iapetus

Phoebe

Titan

Iapetus

Saturn's Largest Ring

Iapetus

material accreted from
Pheobe dust ring