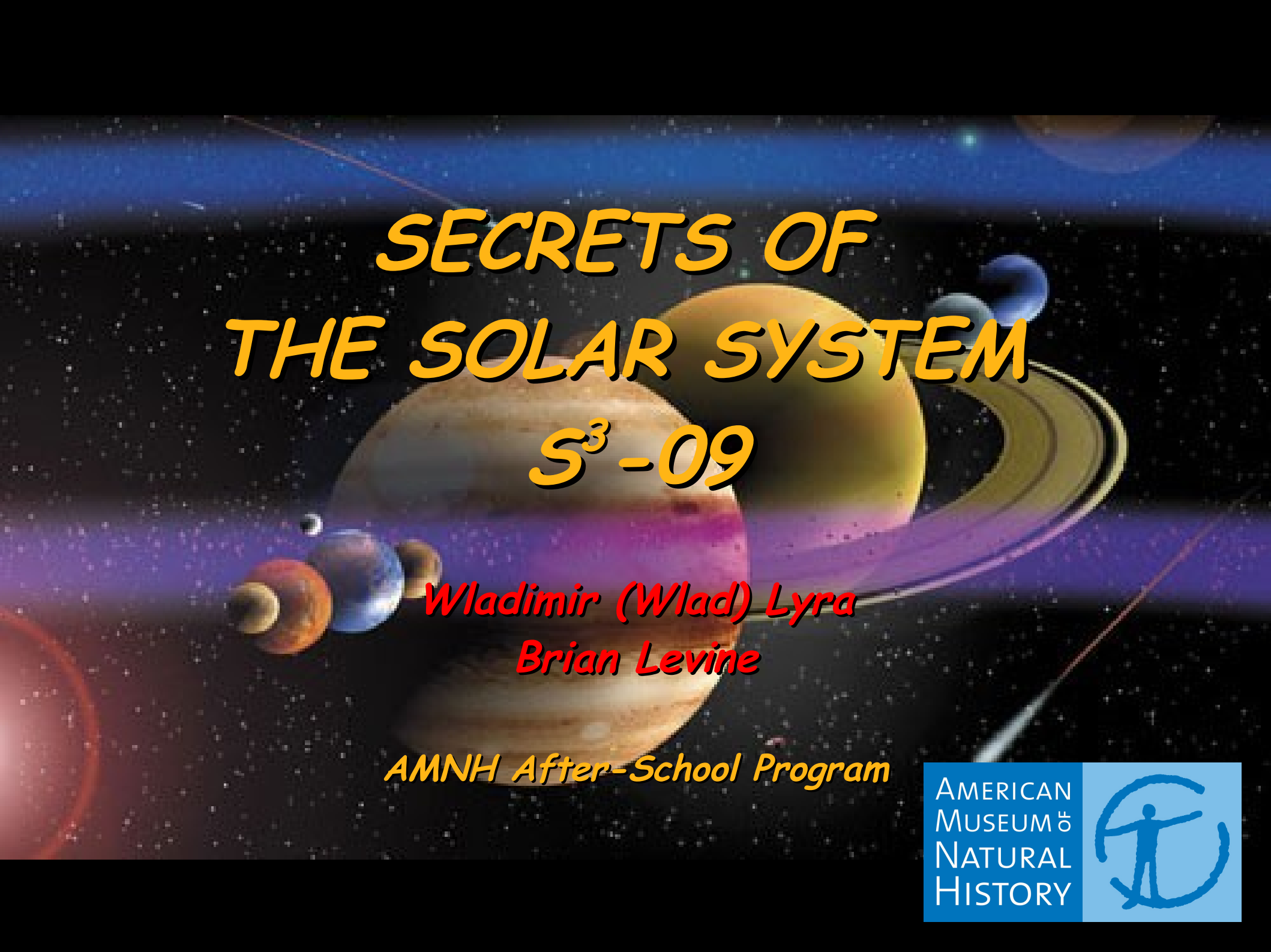


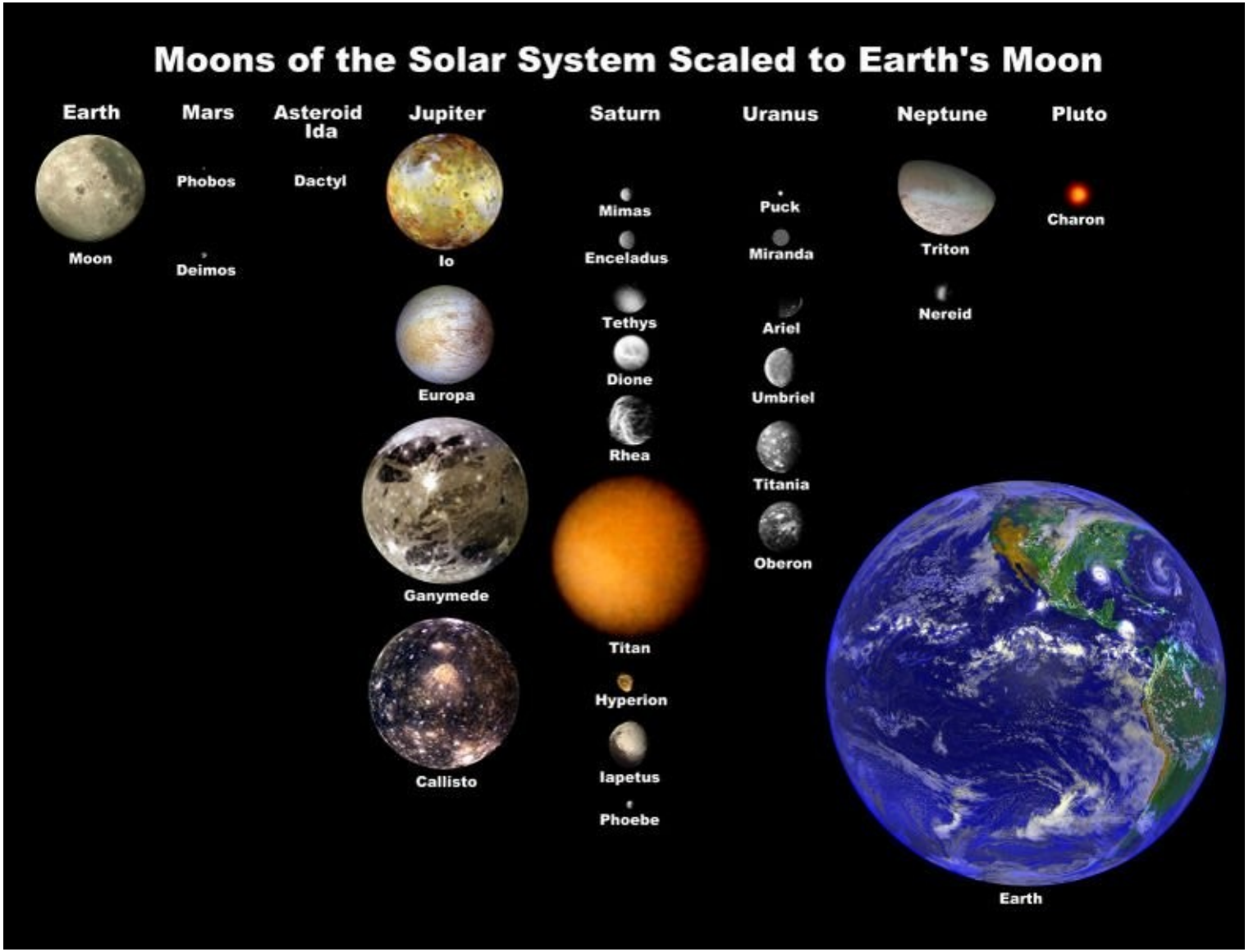
SECRETS OF THE SOLAR SYSTEM S^3-09

Wladimir (Wlad) Lyra
Brian Levine

AMNH After-School Program

American Museum of Natural History

Satellites of the Outer Planets

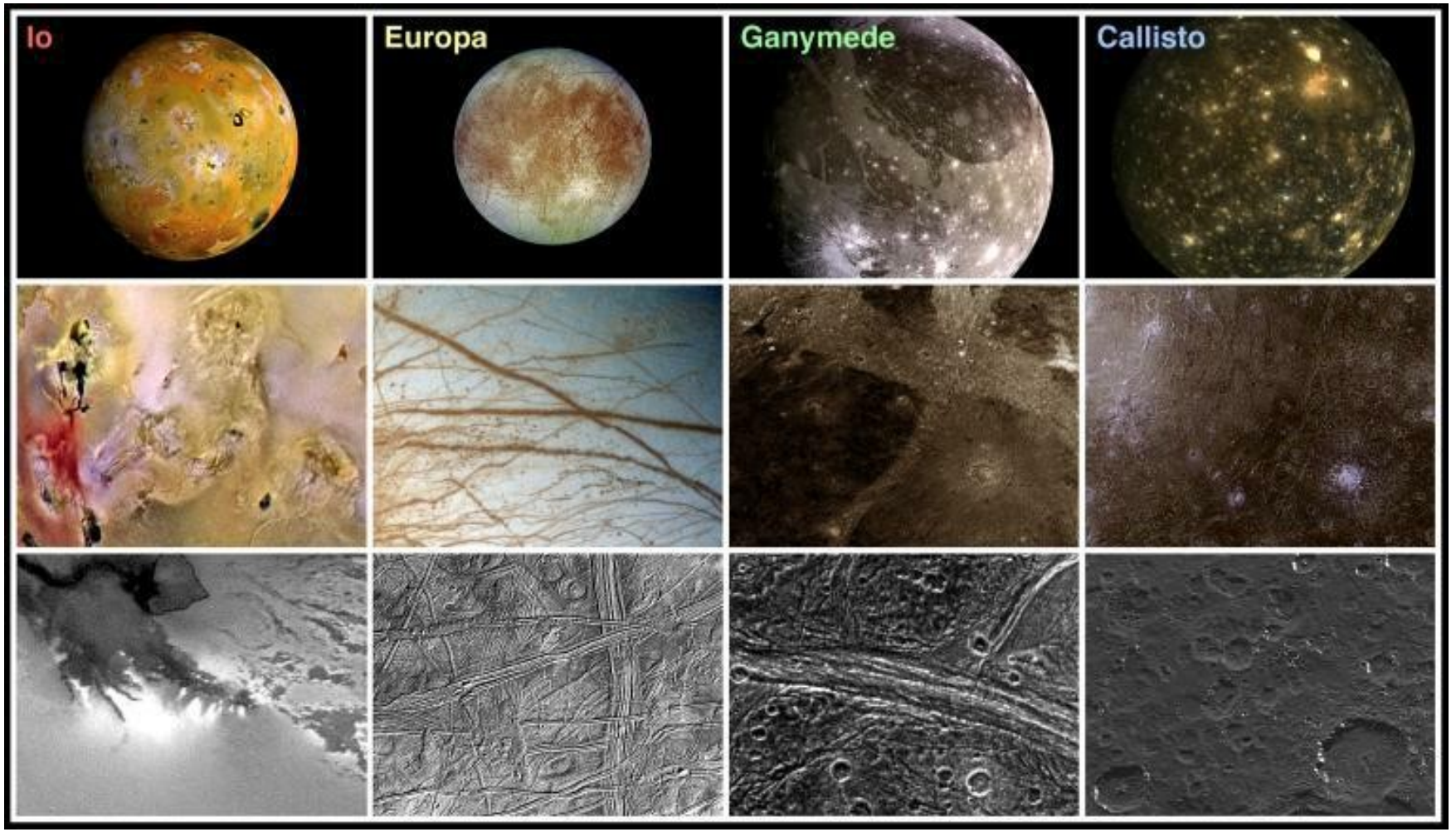


Size Comparison

Jupiter's family portrait

The Galilean Moons

Surfaces of the Galilean Satellites

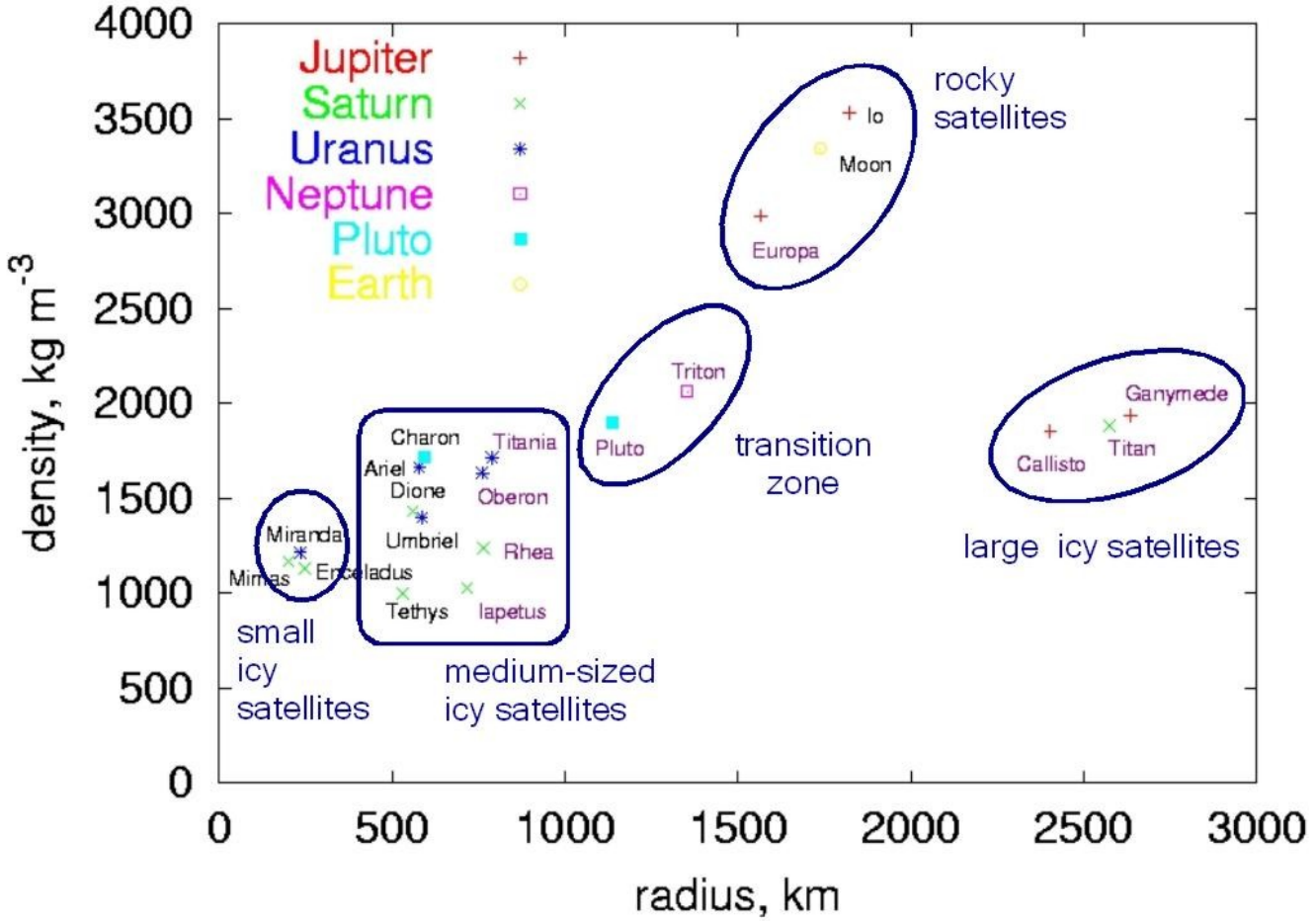


Young surfaces ◄——— ———► Old surface

(Geologically Active)

Radius-Density relation

Io and **Europa** are **rocky** satellites, like the Moon.
The other are mostly **icy**.

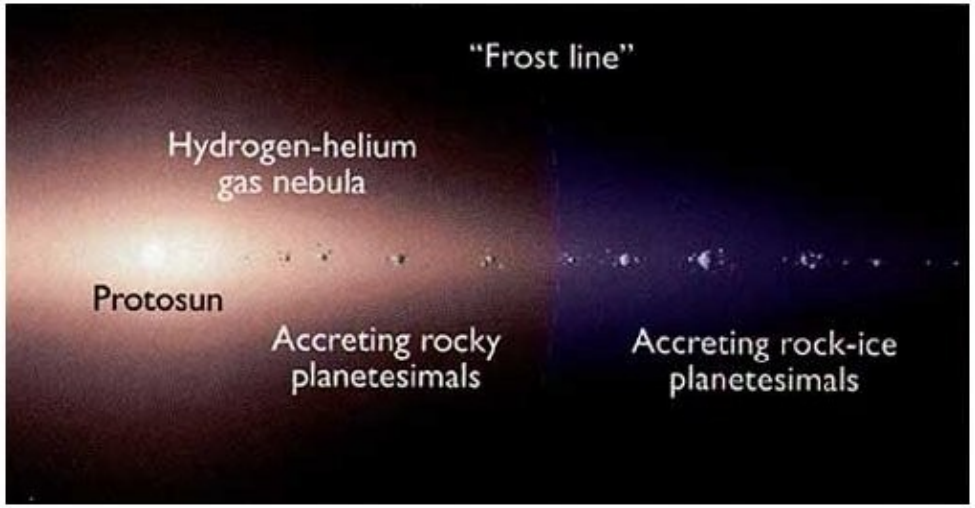


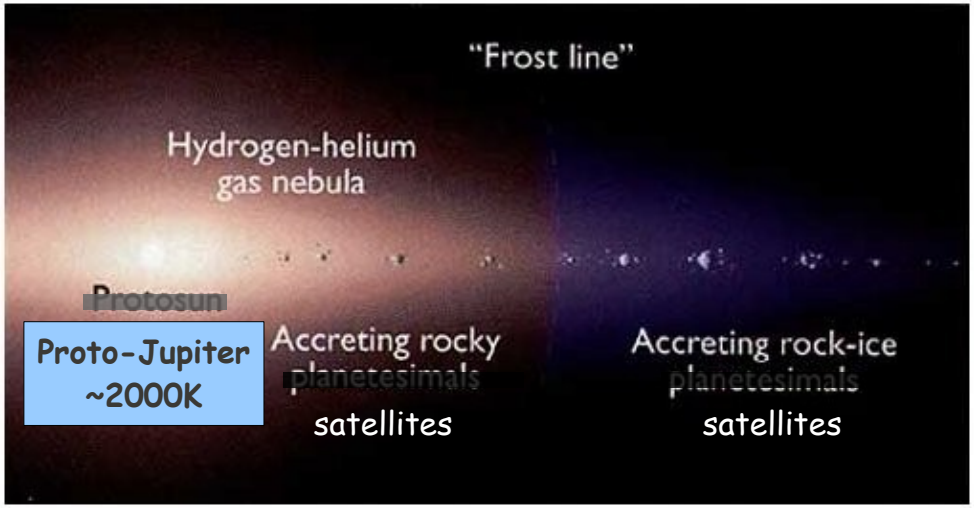
Satellite formation occurs in a
circum-planetary disk.

Scaled-down version of planet formation

Proto-Jupiter was very hot (~2000 K)

The proto-satellite disk had its own snowline

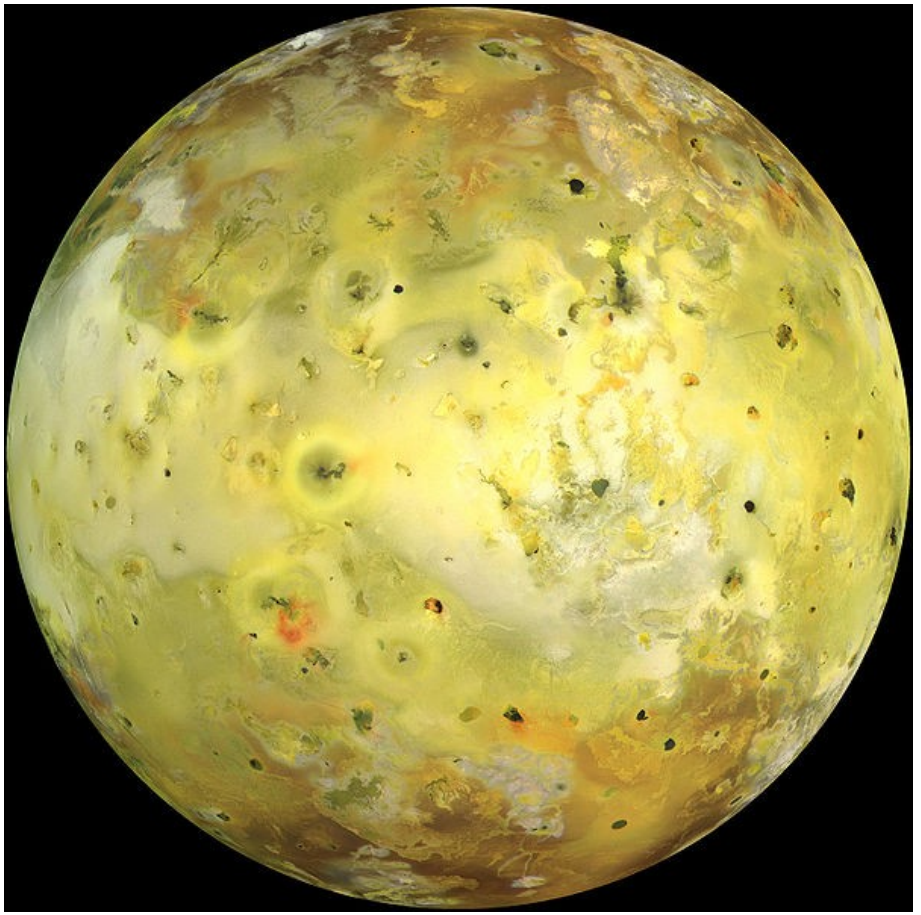




Rocky Io and Europa formed **inside** the snowline

Icy Ganymede and Callisto formed **beyond** the snowline

Io – Jupiter's Volcanic Moon



100 times more volcanic than Earth

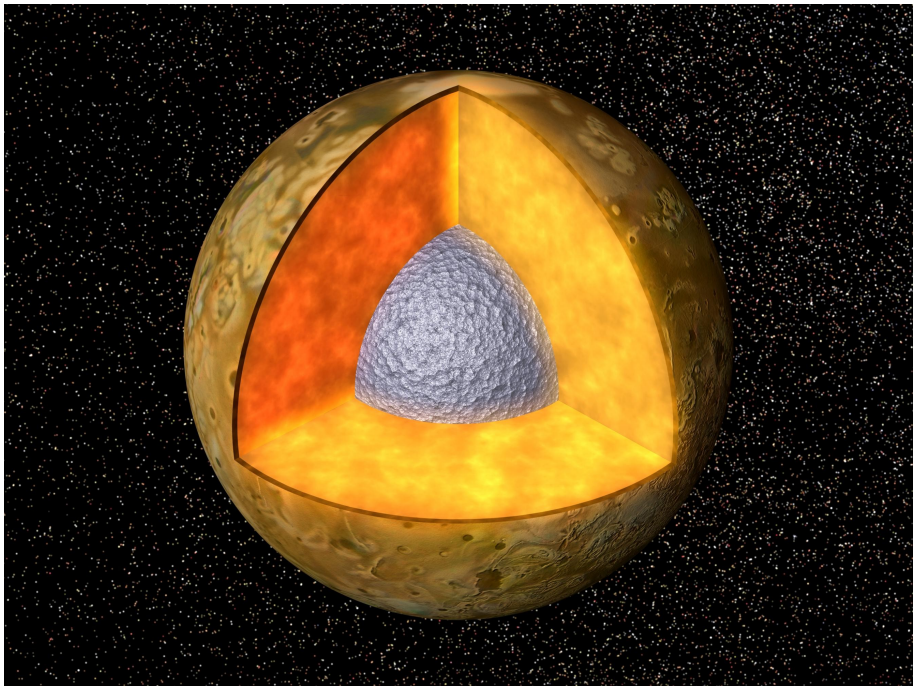
Ground temperature: 110K

Bright areas: Fresh sulfur frost

Yellow-Brown areas: older sulfur compounds

"Nowhere else in the Solar System
do volcanic processes so dominate everything we see
as on Io"

Io's interior



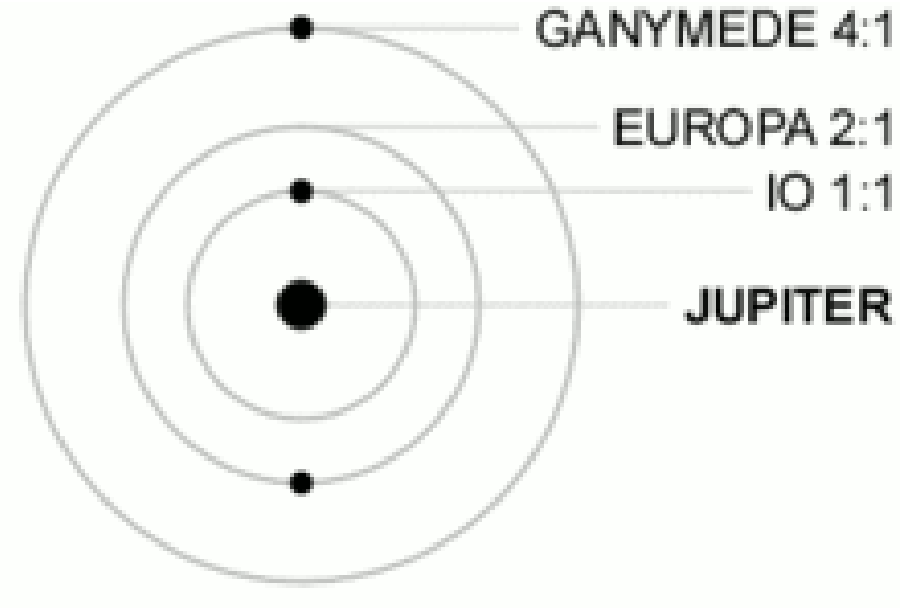
Thin silicate crust

Molten silicate interior

Iron rich core

Io is roughly the size of the Moon.
How does such a small body retain such a hot interior?

Laplace Resonance



Tidal Heating

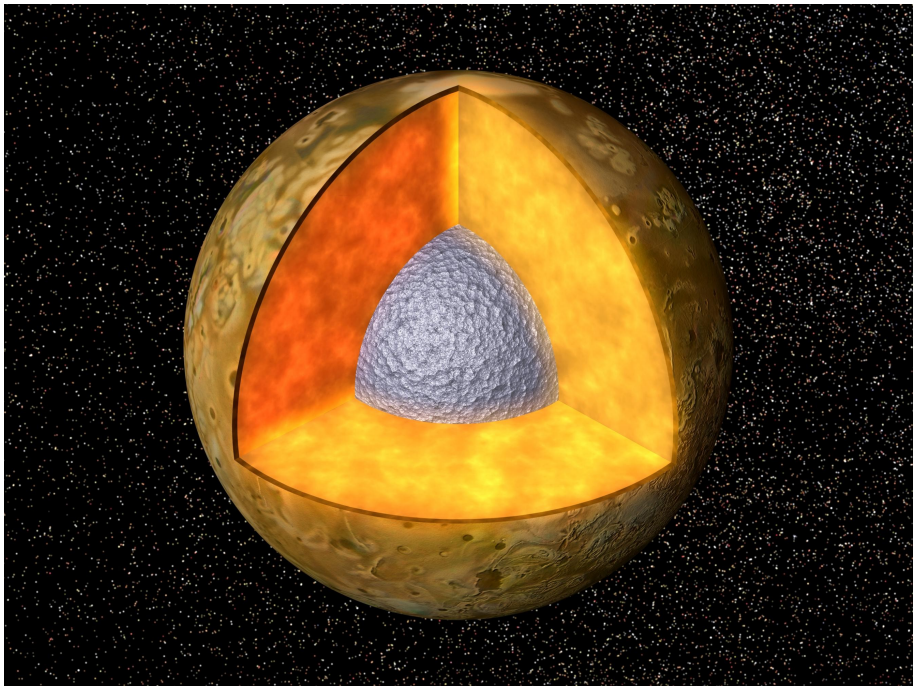
Periodic tug of Europa makes Io's orbit slightly elliptic (e ~ 0.004)

Difference in tidal bulge from closest to farthest from Jupiter:

100m

MASSIVE FRICTION!!!

Tidal heating keeps Io's interior molten

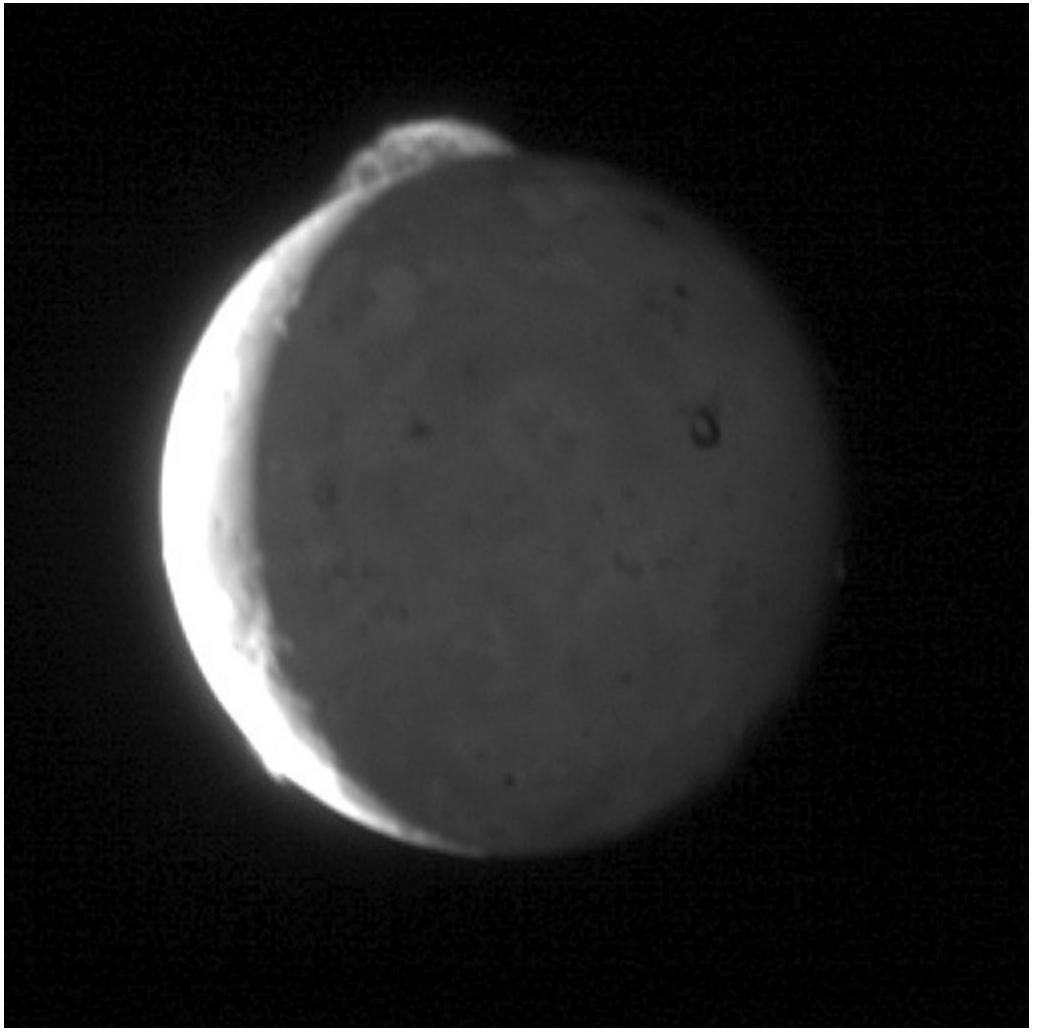


Thin silicate crust

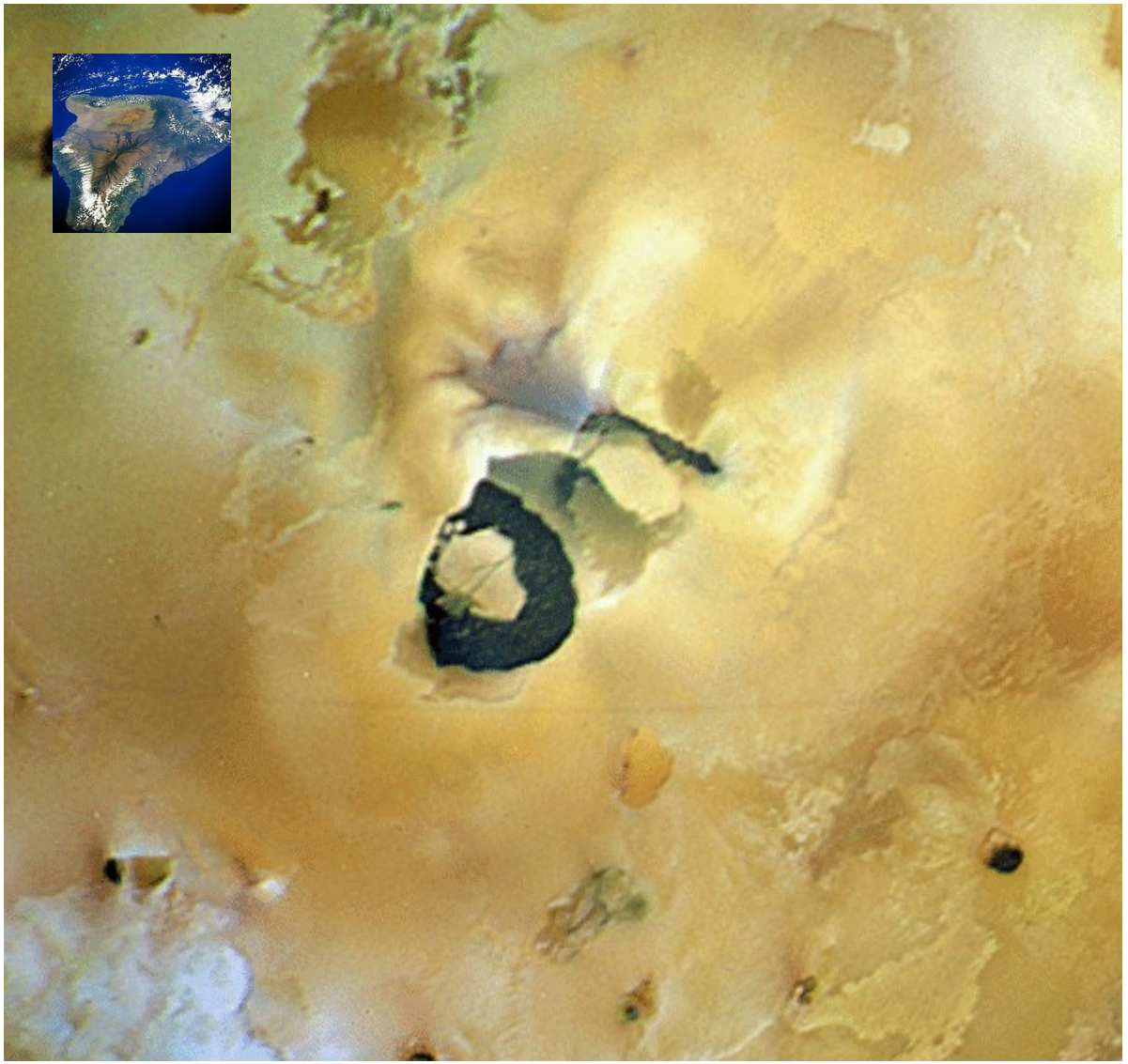
Molten silicate interior

Iron rich core

Io's Volcanoes

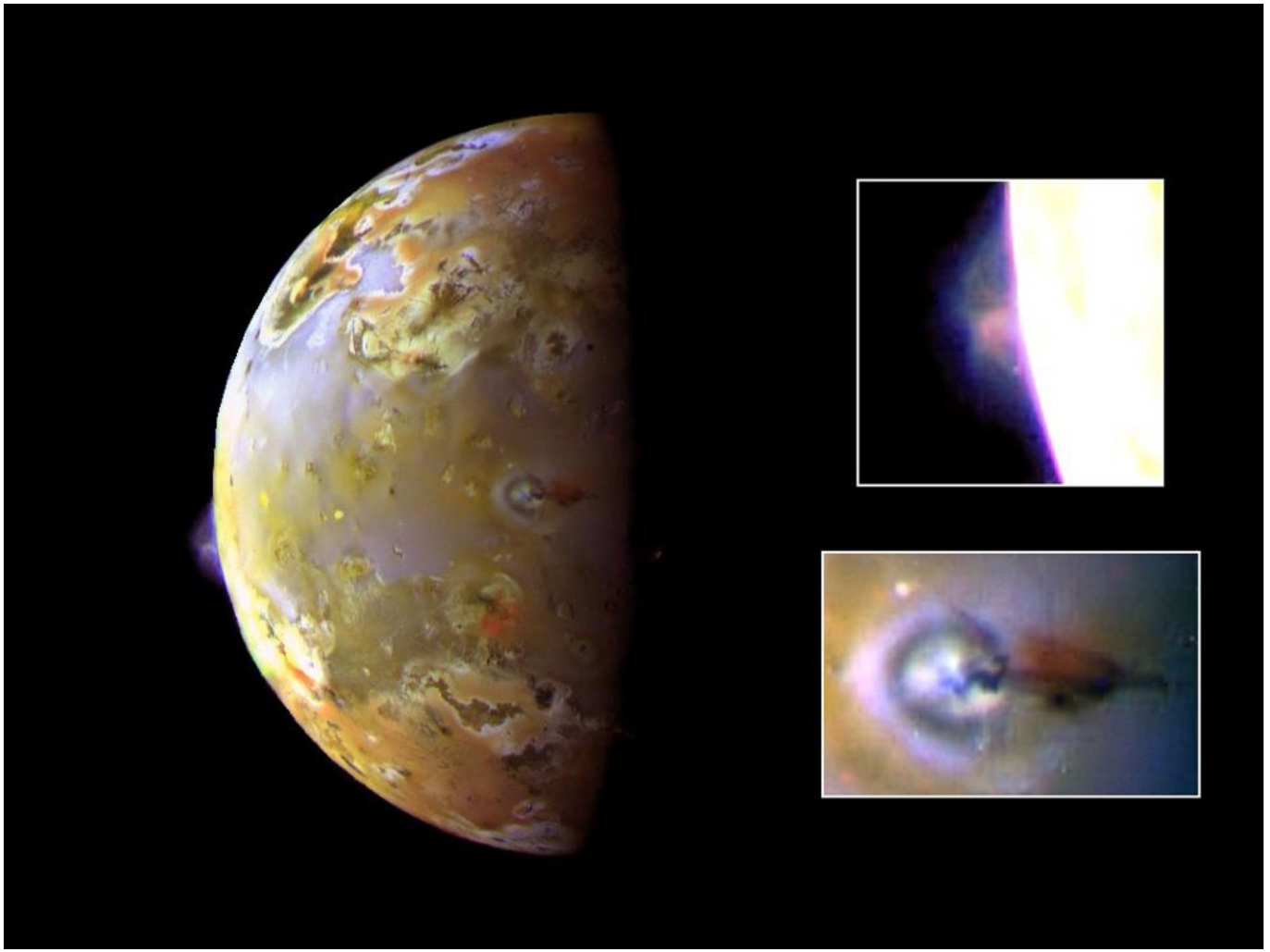


Io's Volcanoes

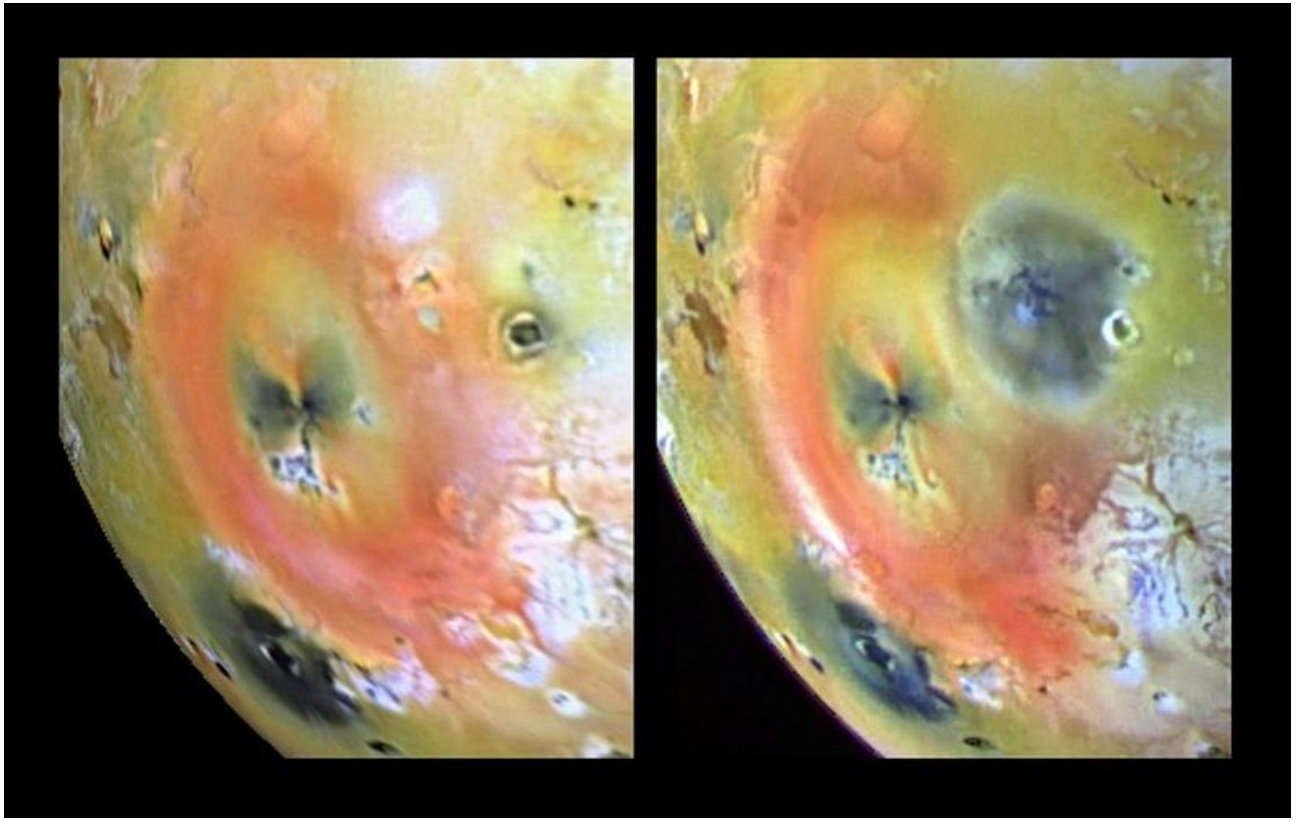


Loki

Active plumes



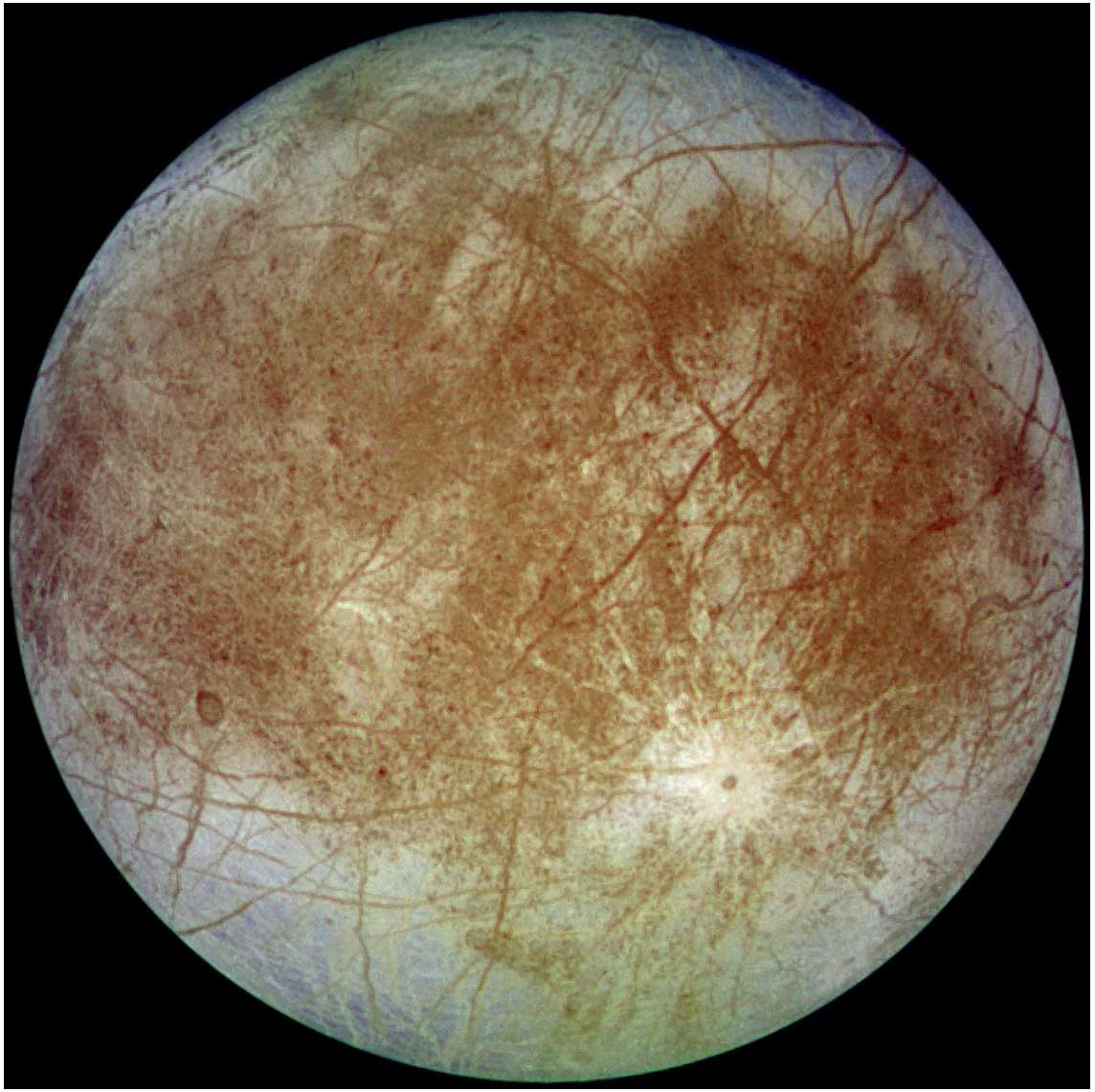
Io in action



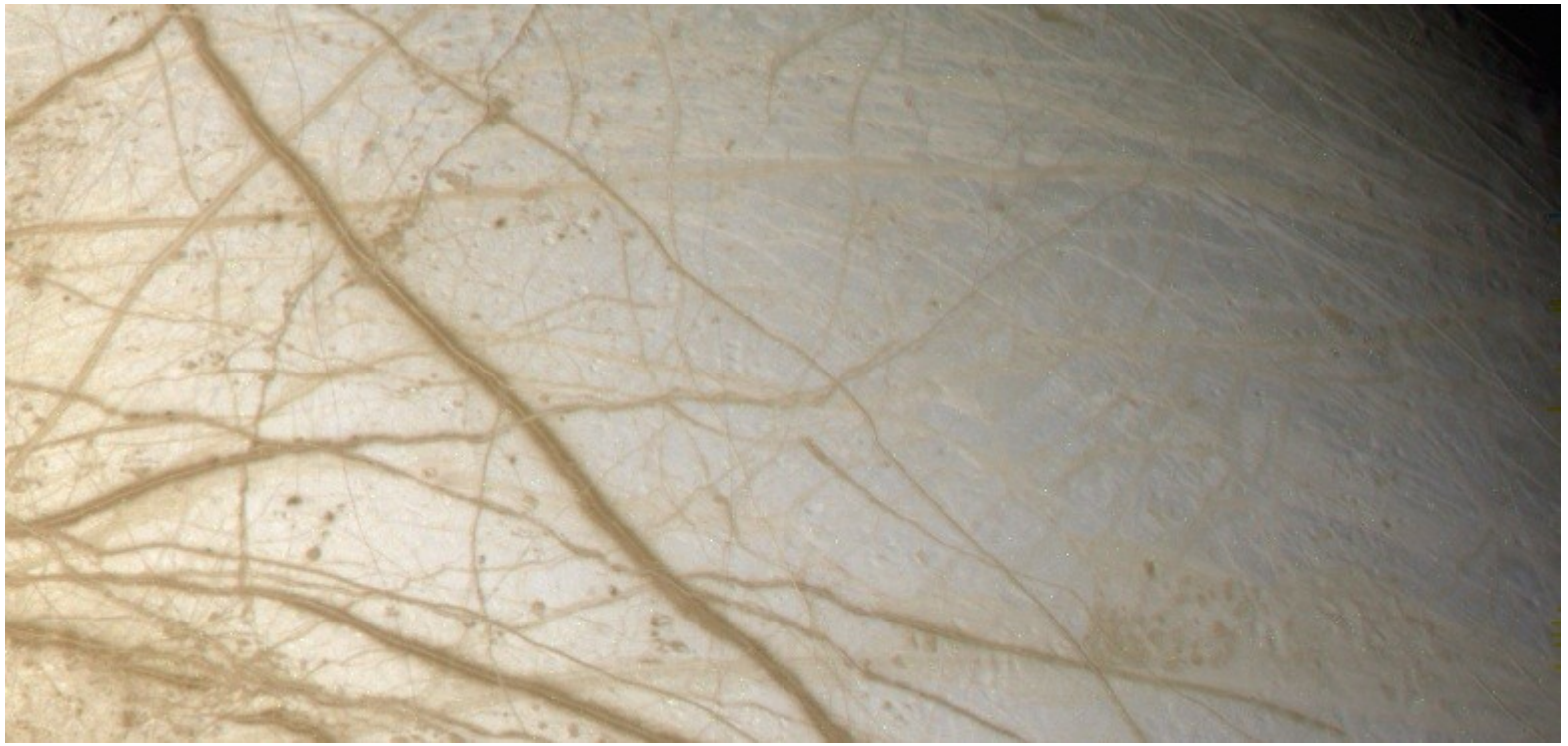
April 2007 September 2007

Surface of Io?

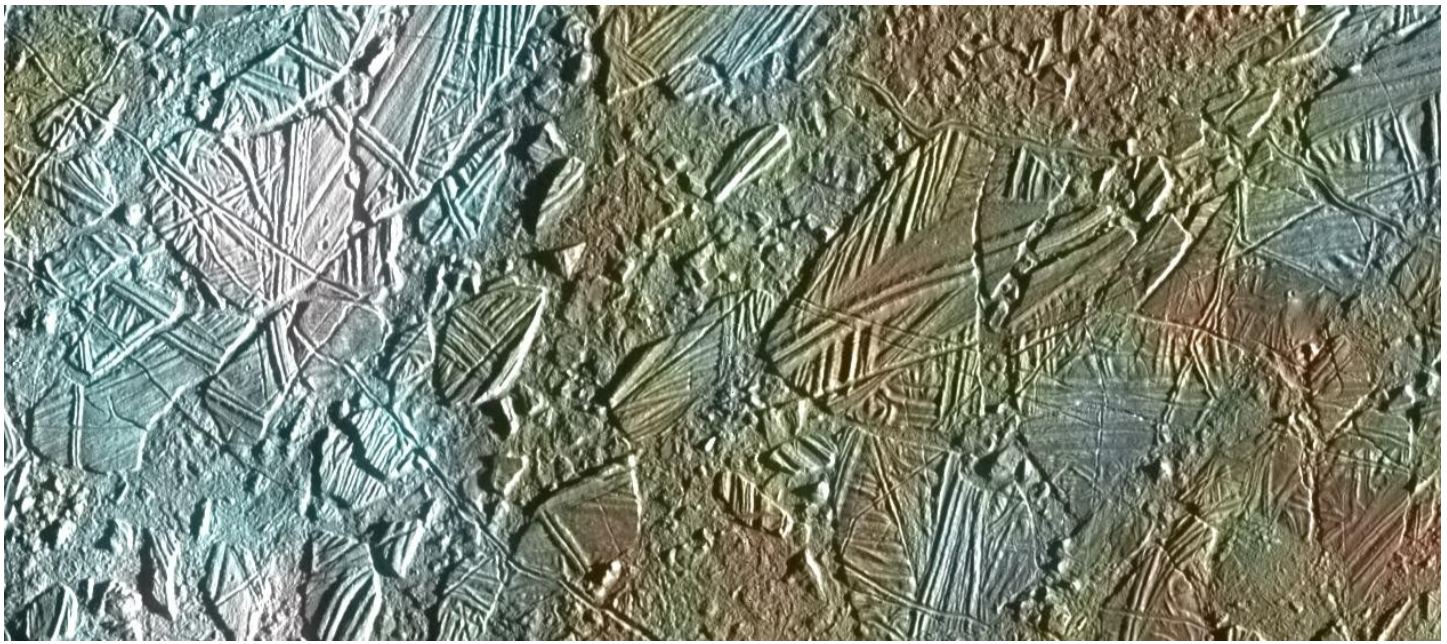
Europa



Ice Tectonics

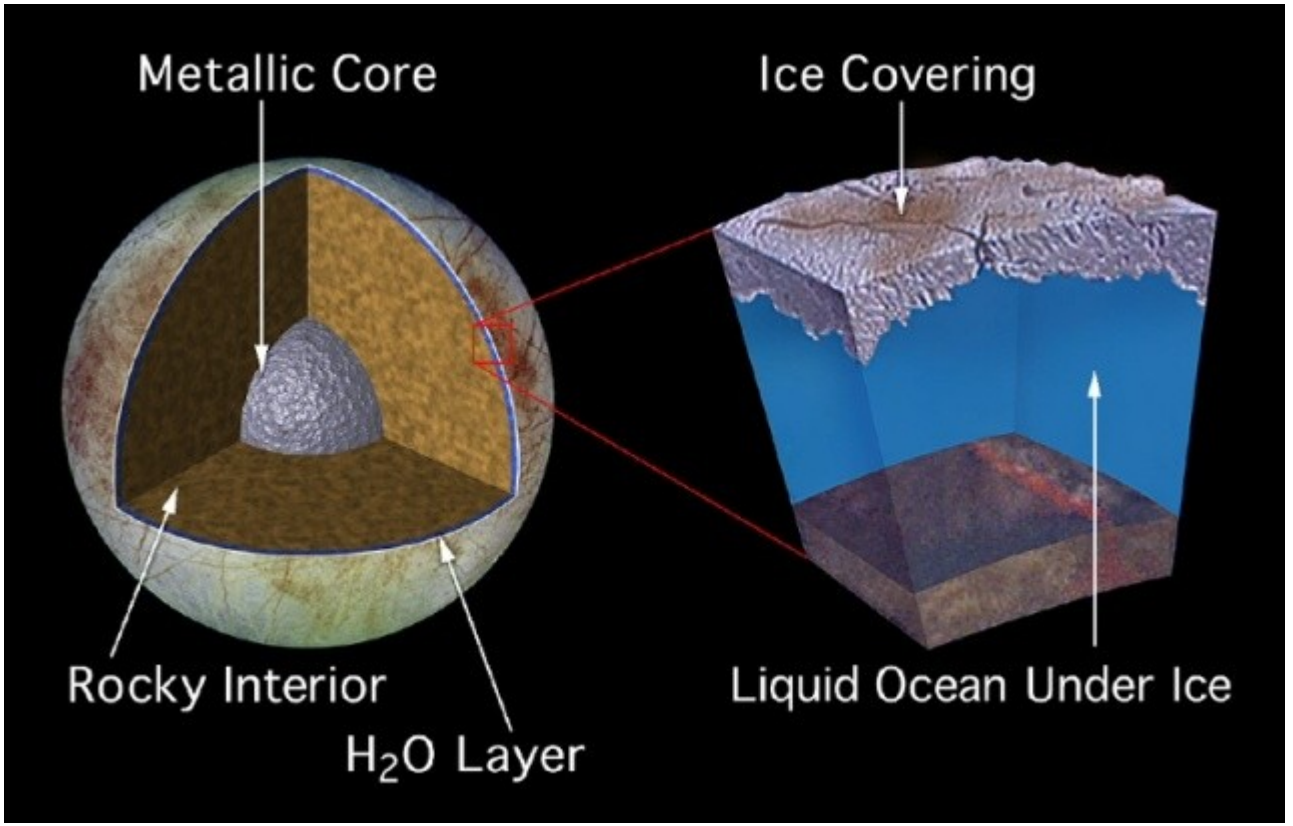


Surface features



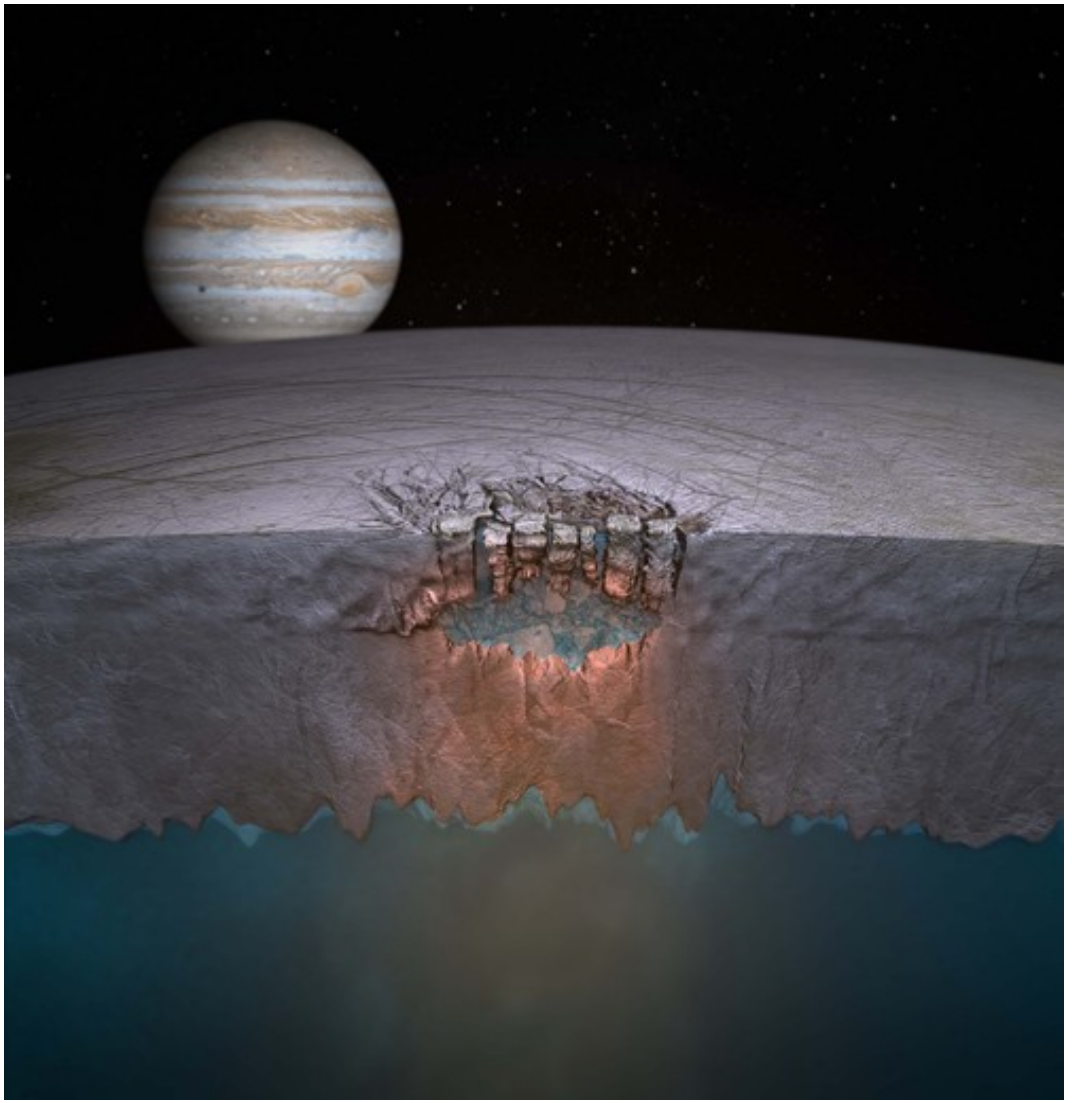
"Chaotic" terrain, as if subject to melting and refreezing

Europa Interior model

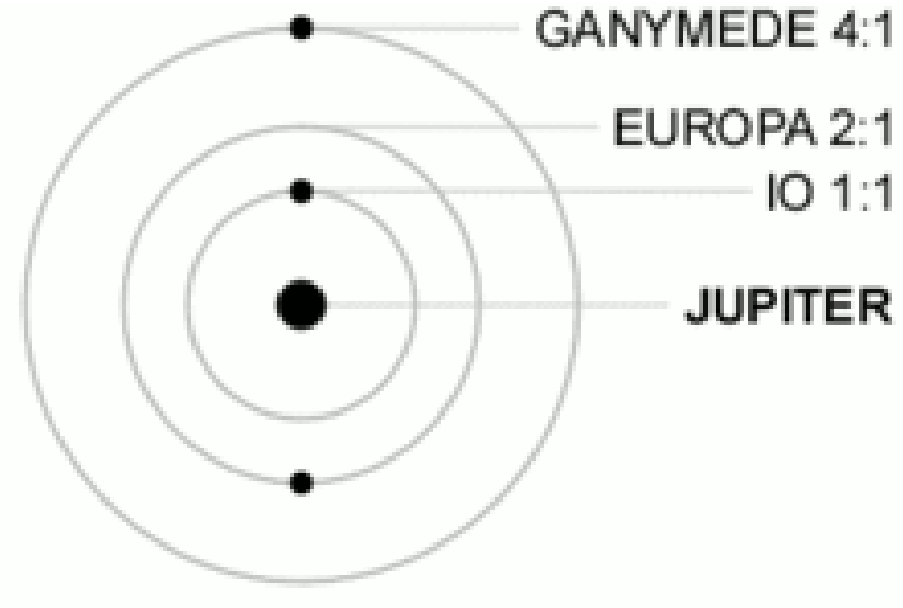


Icy crust floating on top of liquid ocean.
Very interesting for Life!

Sub-surface shallow lakes?

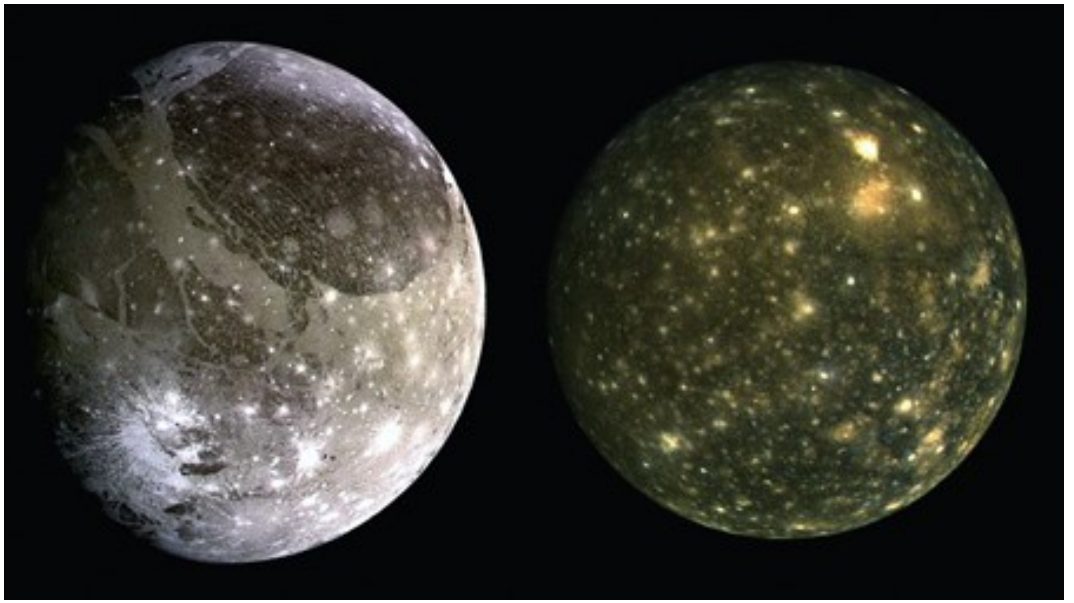


Laplace Resonance



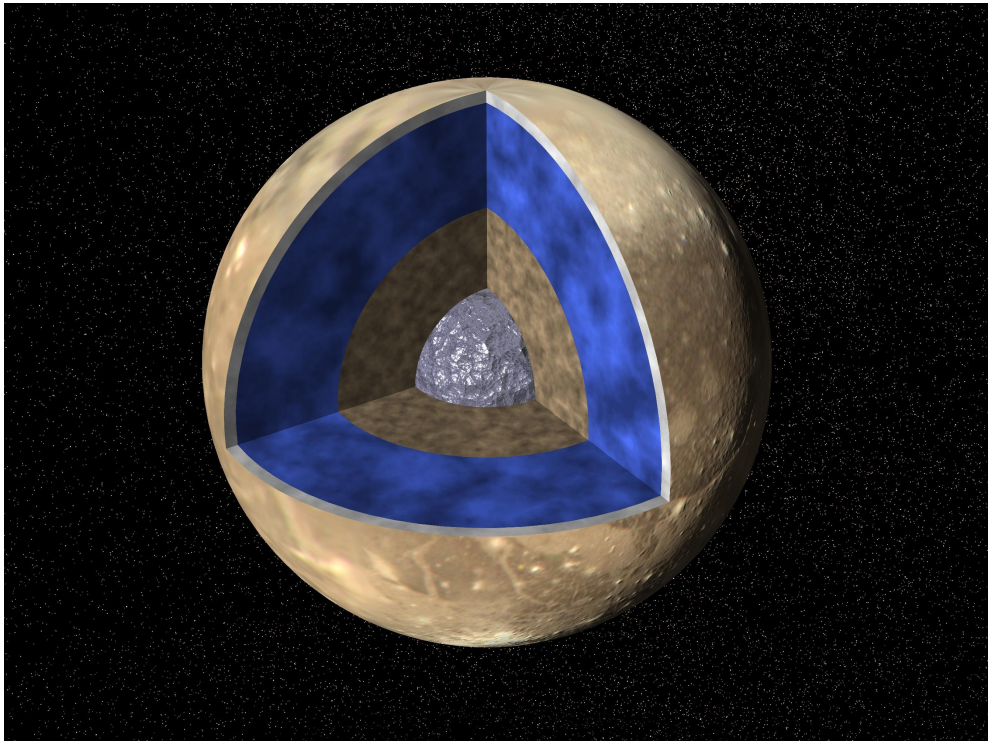
Ganymede and Callisto

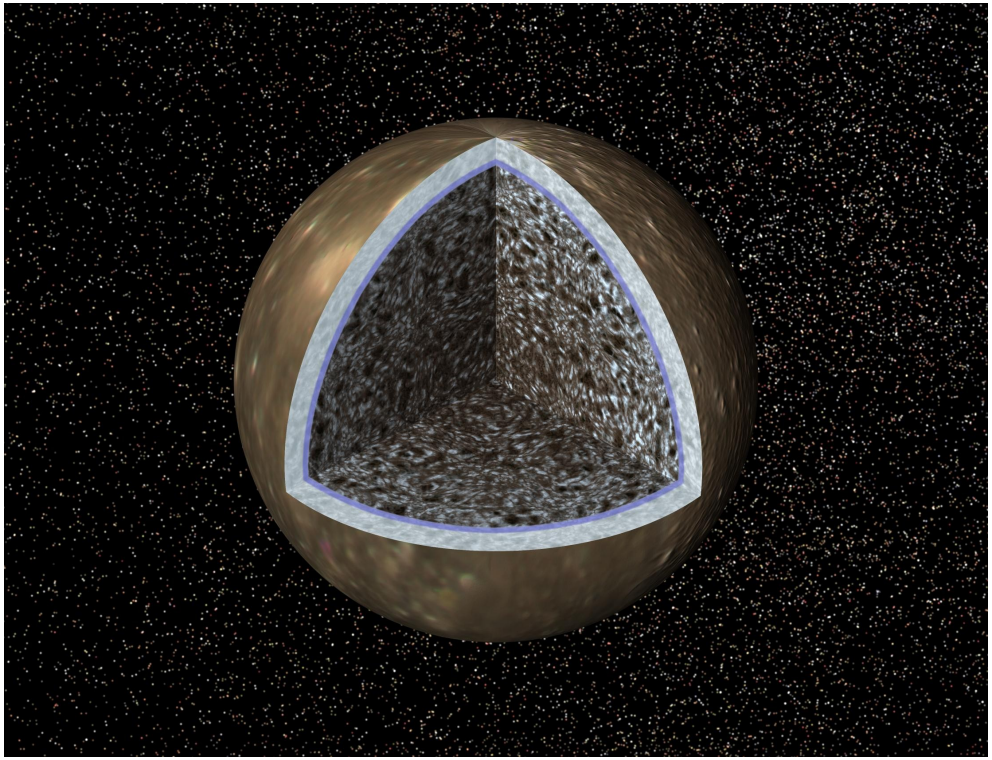
Sibling worlds in mass, radius, and composition
Yet so different!



Ganymede has two different terrains, old and young.
Callisto has a heavily cratered, old surface.

Ganymede and Callisto interiors





Fully differentiated body

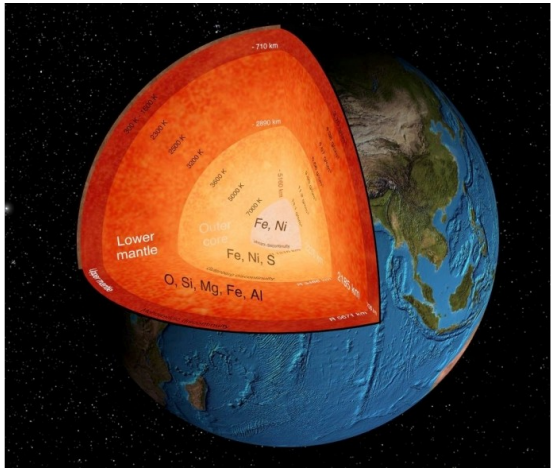
Slushy icy mantle

Undifferentiated body

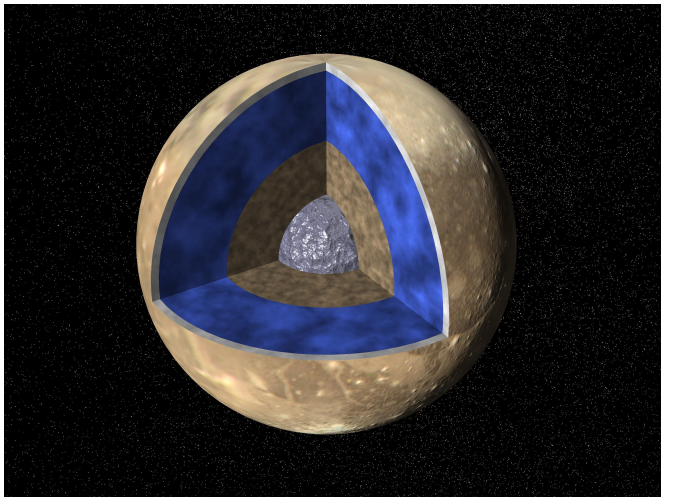
No substantial heat source

Callisto has never been molten.

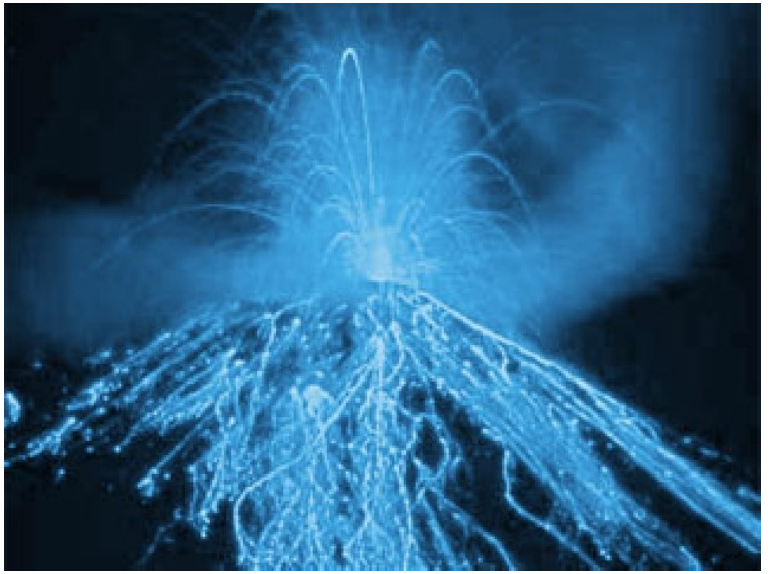
Cryovolcanism



Silicate mantle
Volcanoes expel molten rock (lava)



Slush-Icy mantle
Volcanoes expel molten ice (water)



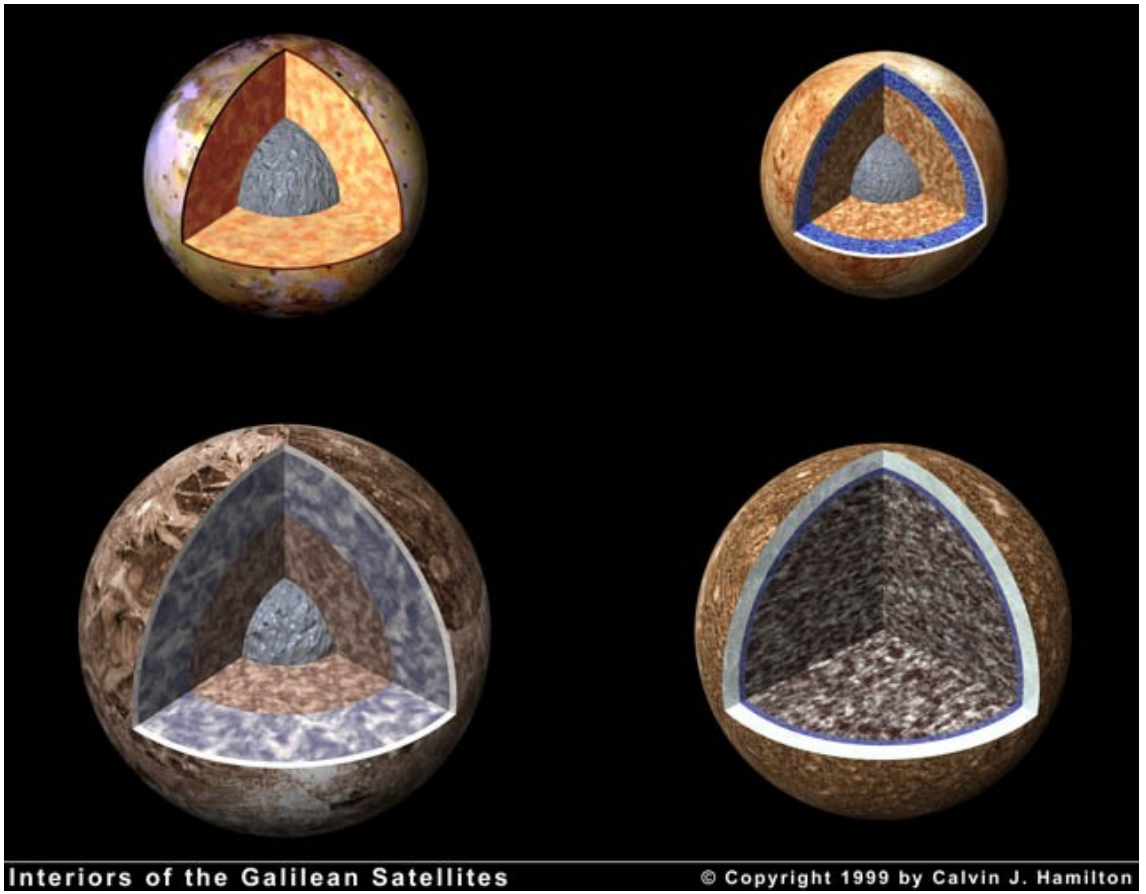
Ganymede's "Grooved Terrain"

On the rocky Moon
The 'maria' are basalts,
ancient lava flows.

On icy Ganymede
The 'maria' are ices,
ancient water flows.

Interiors

Quite active



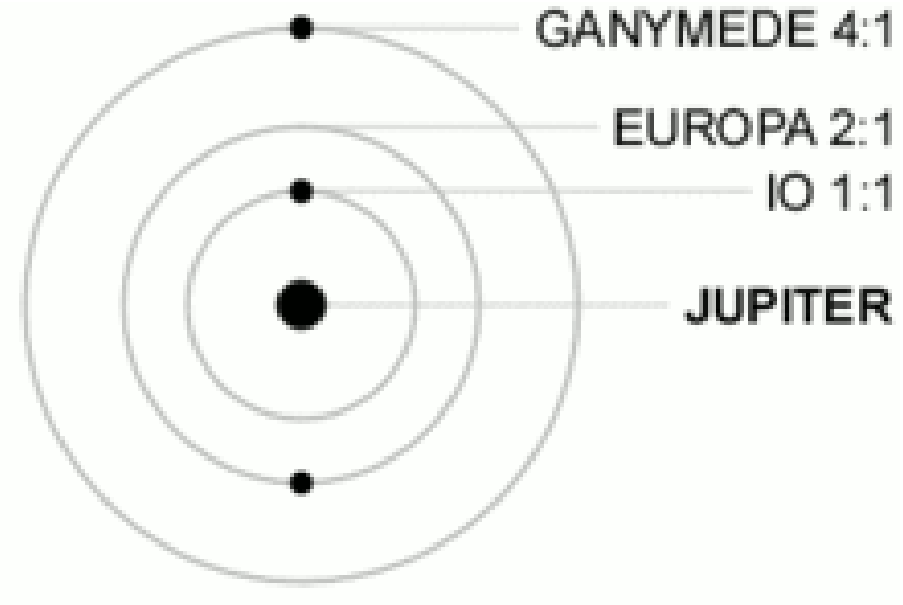
Active

So so...

Dead

Why?

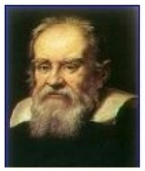
Ganymede and Callisto



Callisto is not part of the orbital dance.

No resonance, no eccentricity pumping, no tidal heating

Jupiter's Galilean Moons



Galileo Galilei in 1610 — were discovered by

Voyager Flyby & Galileo Orbiter Spacecraft — have been characterized by

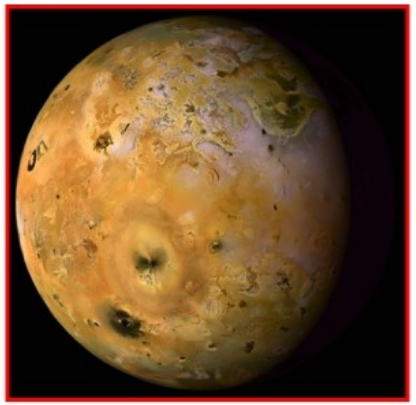
are: Large Enough to be Easily Observed via Telescope

keep: Same Face towards Jupiter as they Orbit — because: Rotational & Orbital Periods are Same — as case for: Earth's Moon

comprise:

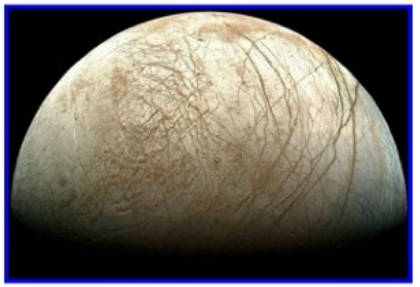
Innermost: Io

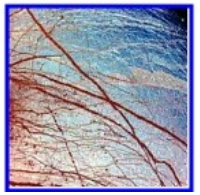
- has: ~3650 Km Diameter, Density 3.53 gm/cc, 1.769 days Period
- is: Rocky Silicate Body with Metallic Core
- LACKS: Ice Crust
- characterized by: Extraordinary Continuous Volcanic Activity
  - is caused by: Powerful Tidal Forces
    - result of: Jupiter's Powerful Gravitation
    - result of: 4:2:1 Orbital Resonance with Europa & Ganymede
    - together cause: Io's Surface to experience ~ 100m Tides
    - is result of: Frictional Heat Source
      - consequence of considered: Possible Abode for Microbial Life



2nd Inner: Europa

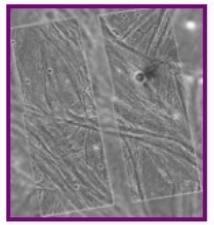
- has: ~3120 Km Diameter, Density 3.01 gm/cc, 3.551 day Period
- modelled as: Rocky Silicate Body with Metallic Core
- ~100 km Deep Ice Crust
  - has: Smooth Bright Surface
  - likely overlies: Ocean of Liquid Water





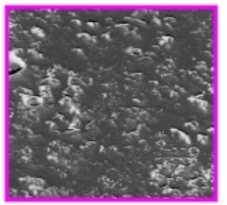
3rd Inner: Ganymede

- has: ~5262 Km Diameter, Density 1.94 gm/cc, 7.155 day Period
- modelled as: ~200 Km Deep Ice Crust, Rocky Silicate Body with Metallic Core
- ~200 Km Deep Ice Crust
  - likely overlies: Ocean of Liquid Water
  - characterized by: 2 Surface Types
    - are: Highly Cratered Ancient Dark Surface
    - are: Less Ancient Grooved & Ridged Surface

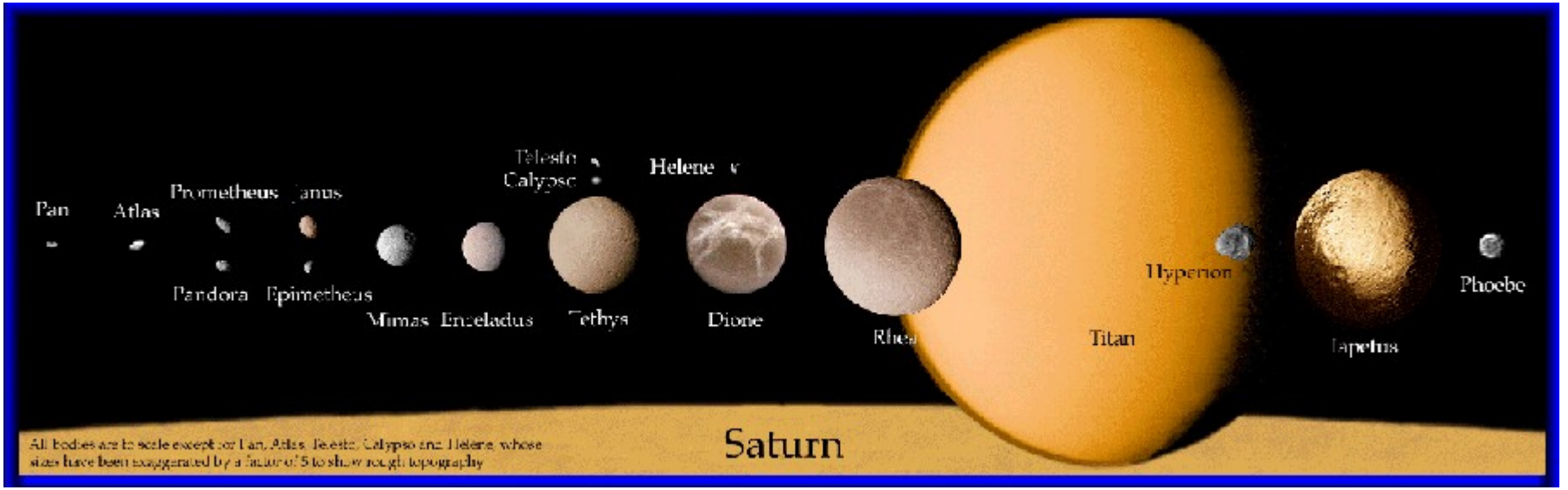


Outermost: Callisto

- has: 4820 Km Diameter, Density 1.83 gm/cc, 16.69 day Period
  - is NOT in: Orbital Resonance with Other Moons
    - is NOT subject to: Tidal Heating
- modelled as: Body made up of ~Equal Parts Rock and Ice with Metallic Core
- has: Heavily Cratered Ancient Surface
  - includes: 3000 km Basin: "Valhalla"



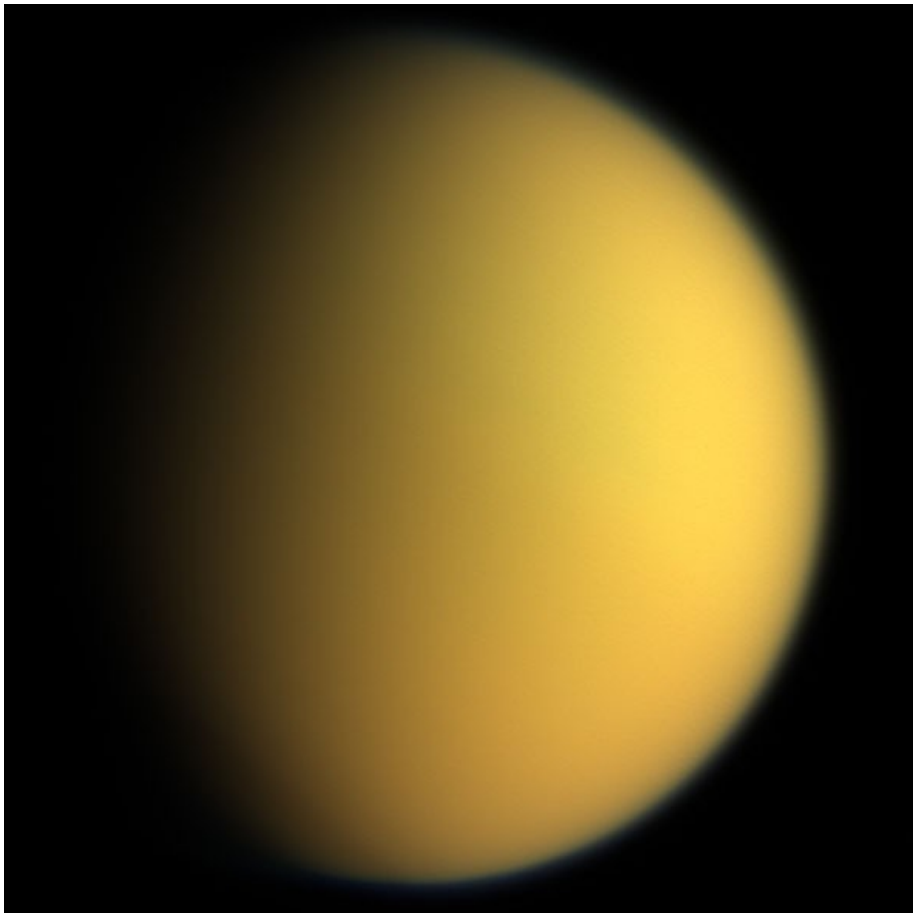
Saturn's Giant Moon



Second in size only to Ganymede, **Titan** is bigger than Mercury

The only satellite with a considerable atmosphere

Titan



Atmosphere!

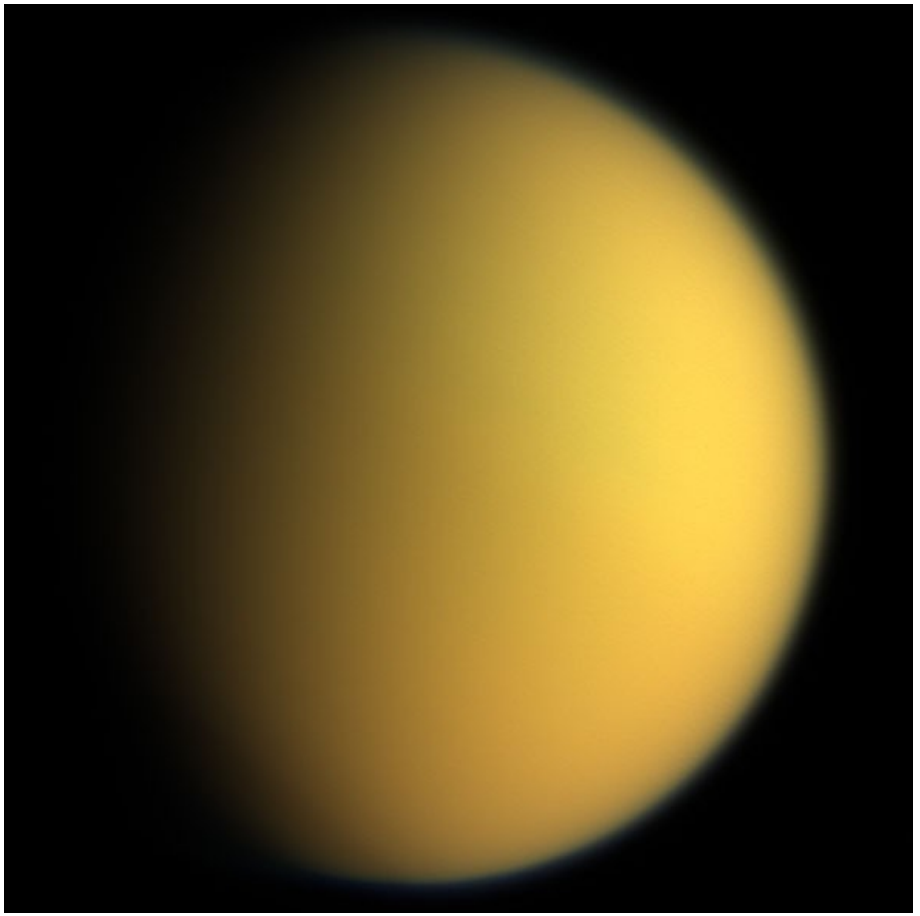
Makes sense...

It is colder than Ganymede: molecules travel slower.

Mostly nitrogen

100% covered in opaque orange haze
No view of the surface

Titan



Methane
triple point
~90K

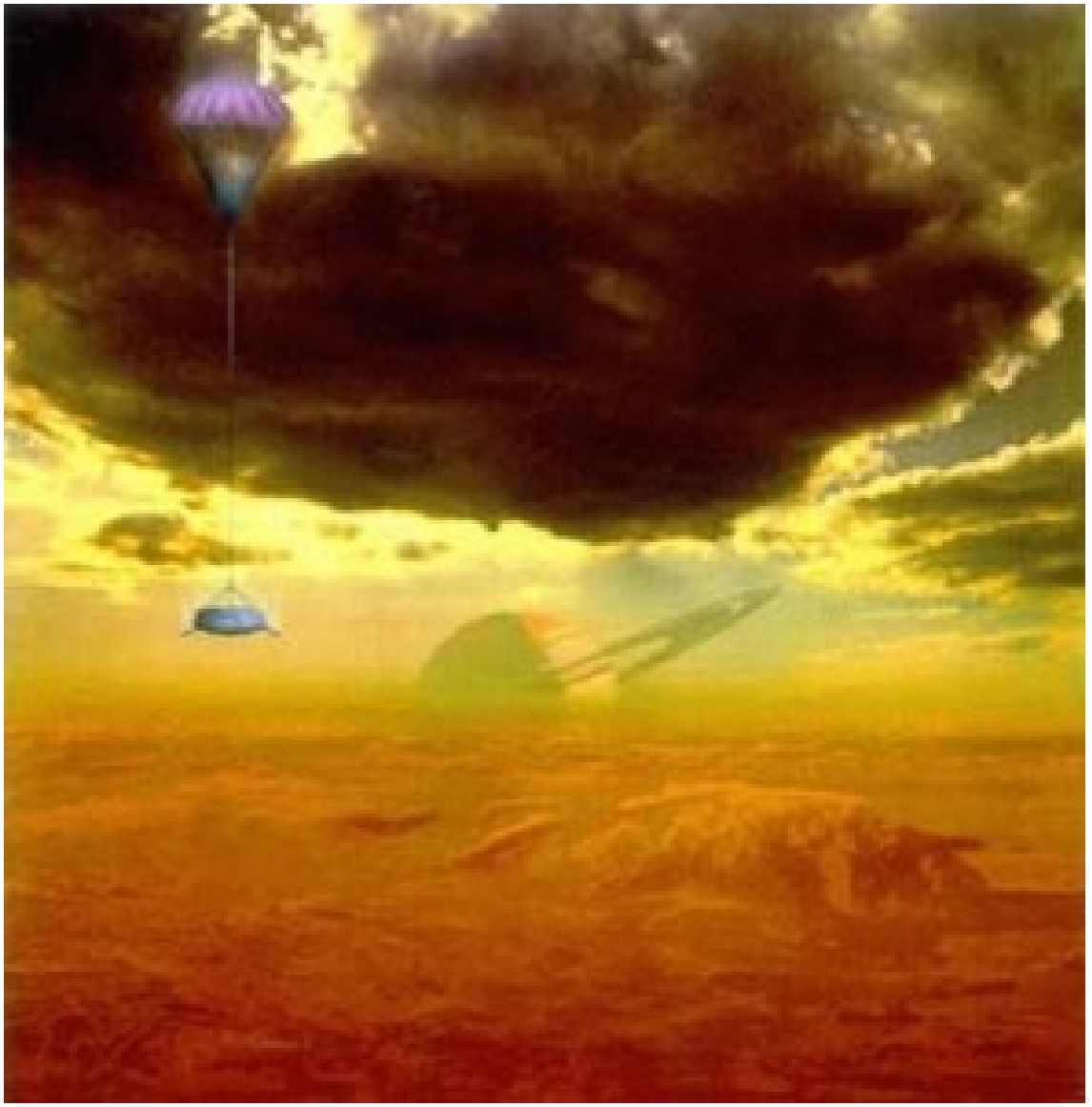
Titan's mean
temperature

~93K

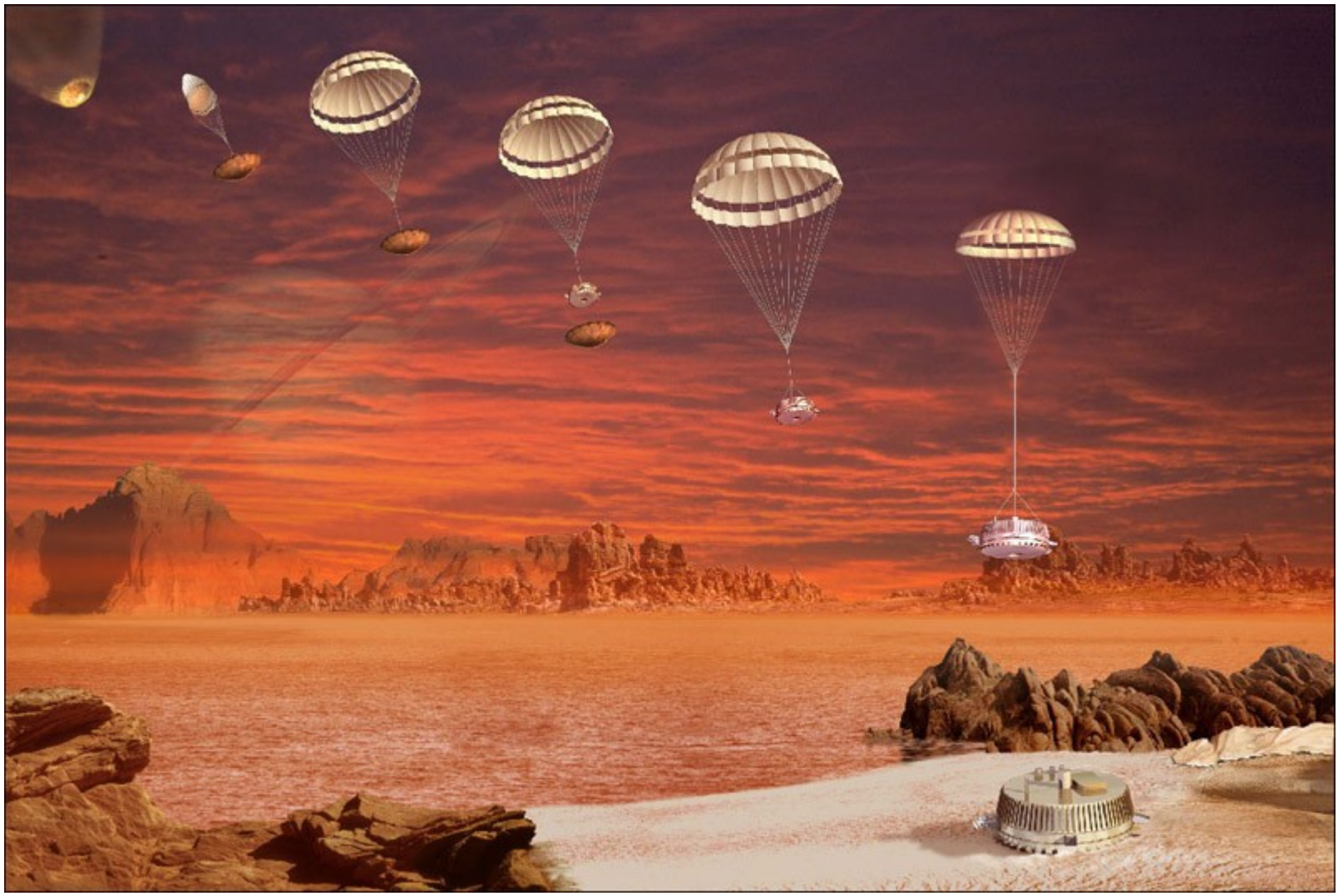
Methane in Titan should be like water on Earth!

Presence of liquid hydrocarbons highly likely.

Pre-Cassini speculations



Pre-Cassini speculations



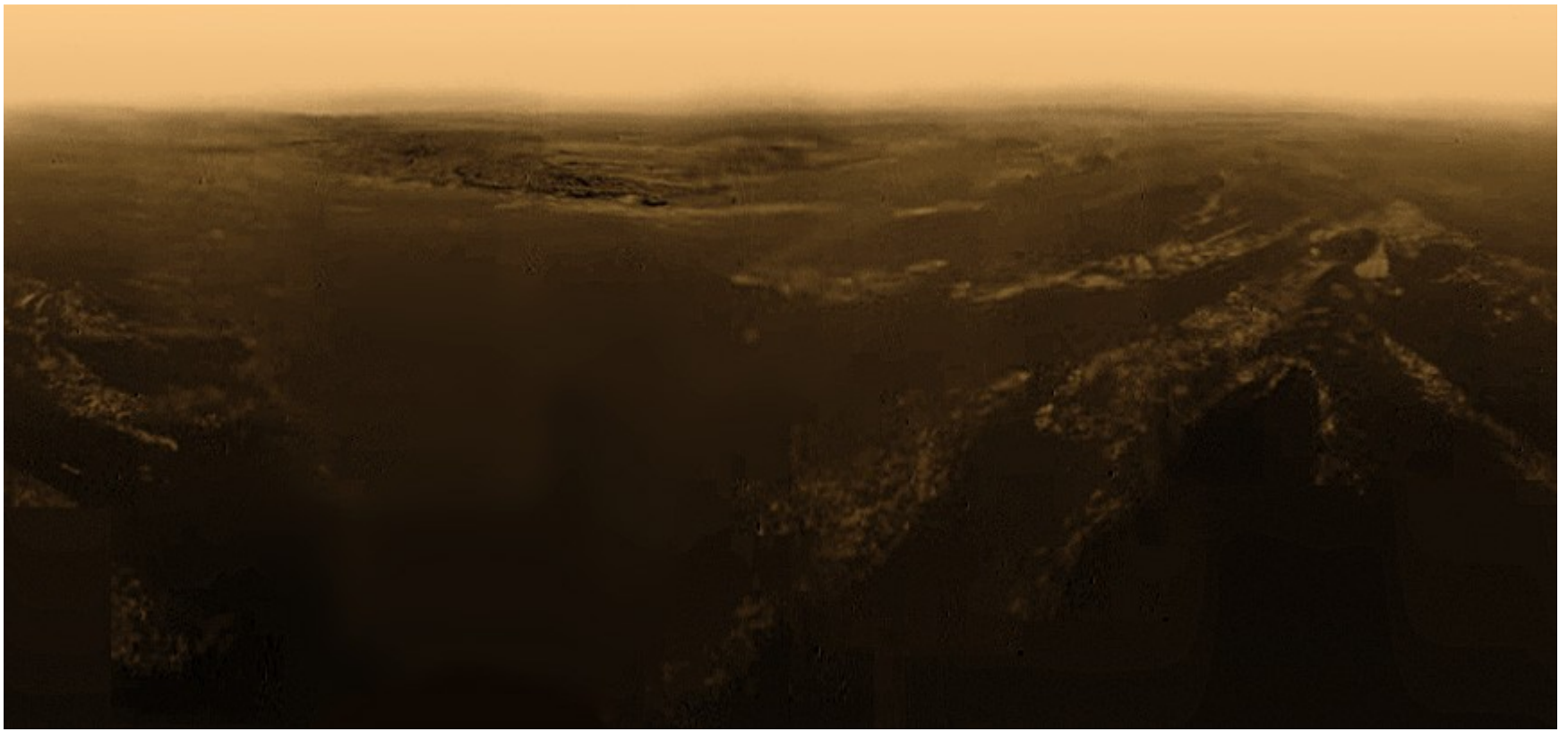
Pre-Cassini speculations

Titan

Radar image by Cassini

Huygens descent

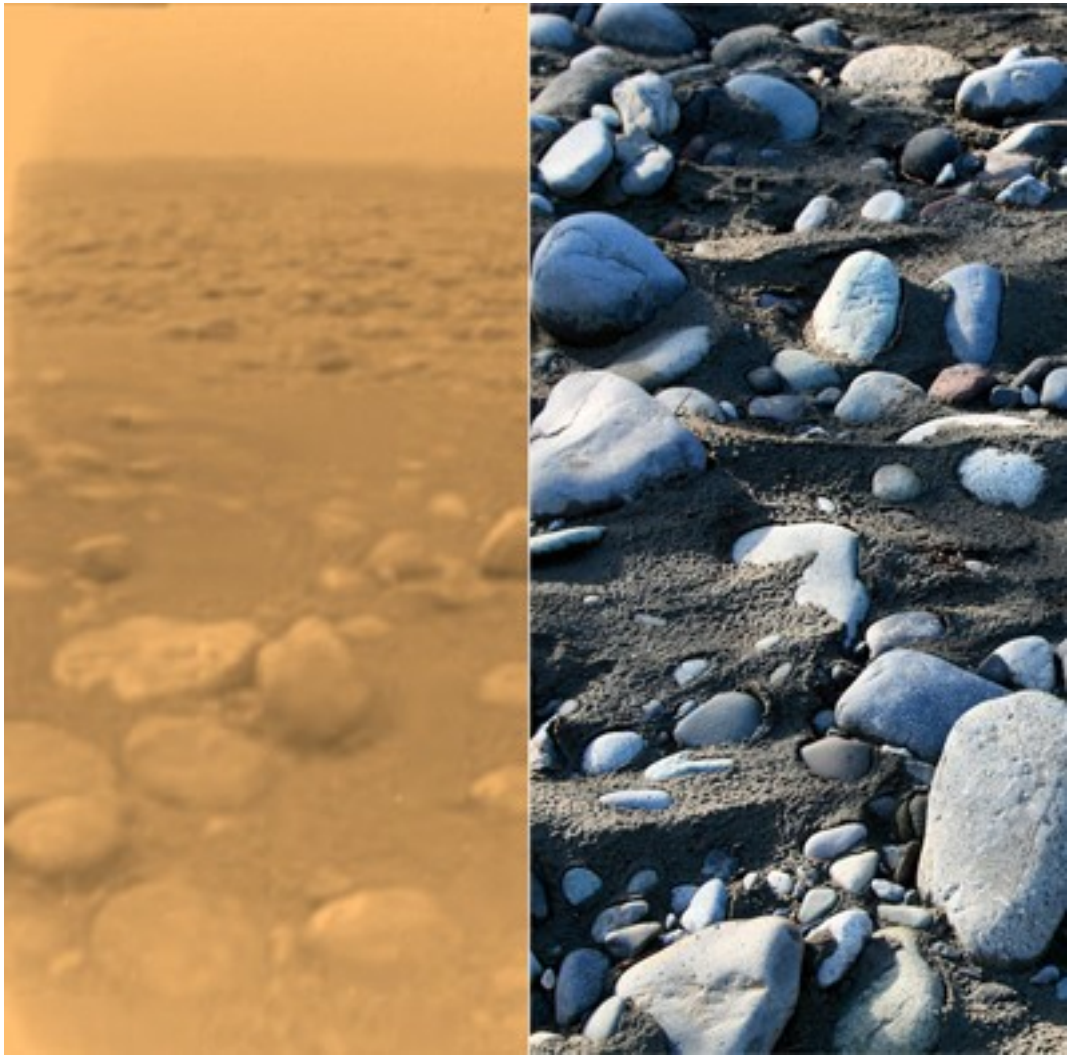
Huygens descent



Huygens landing site

Huygens landing site

Huygens landing site

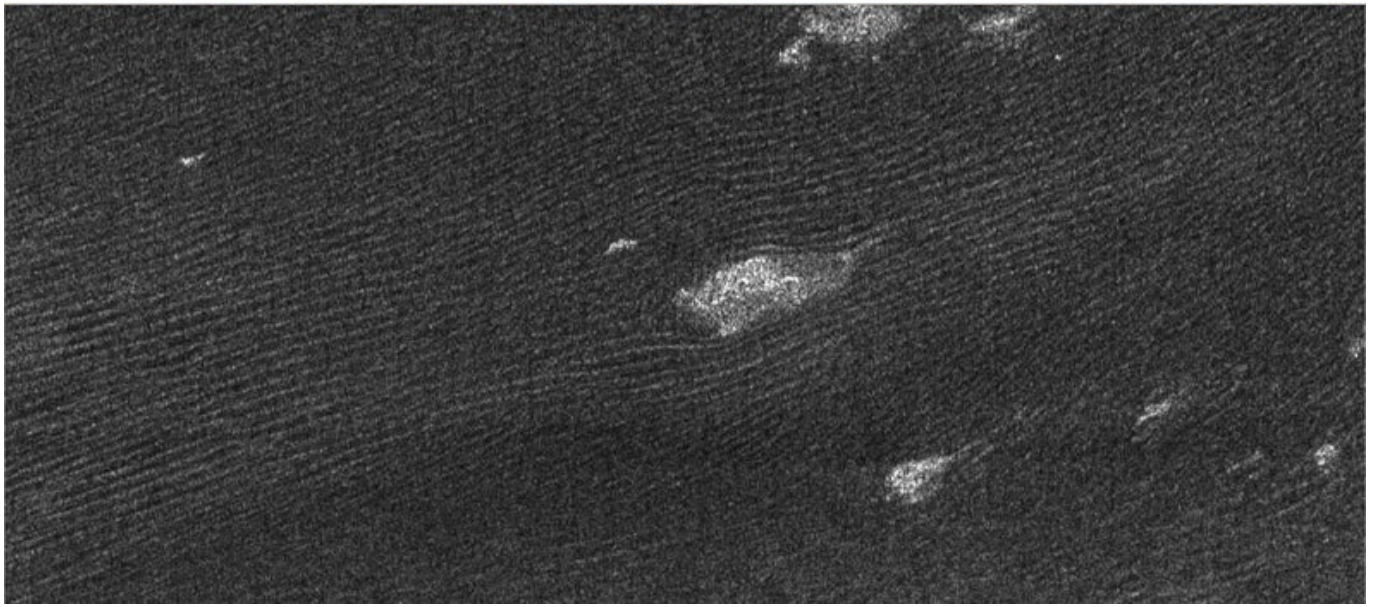


Titan Earth

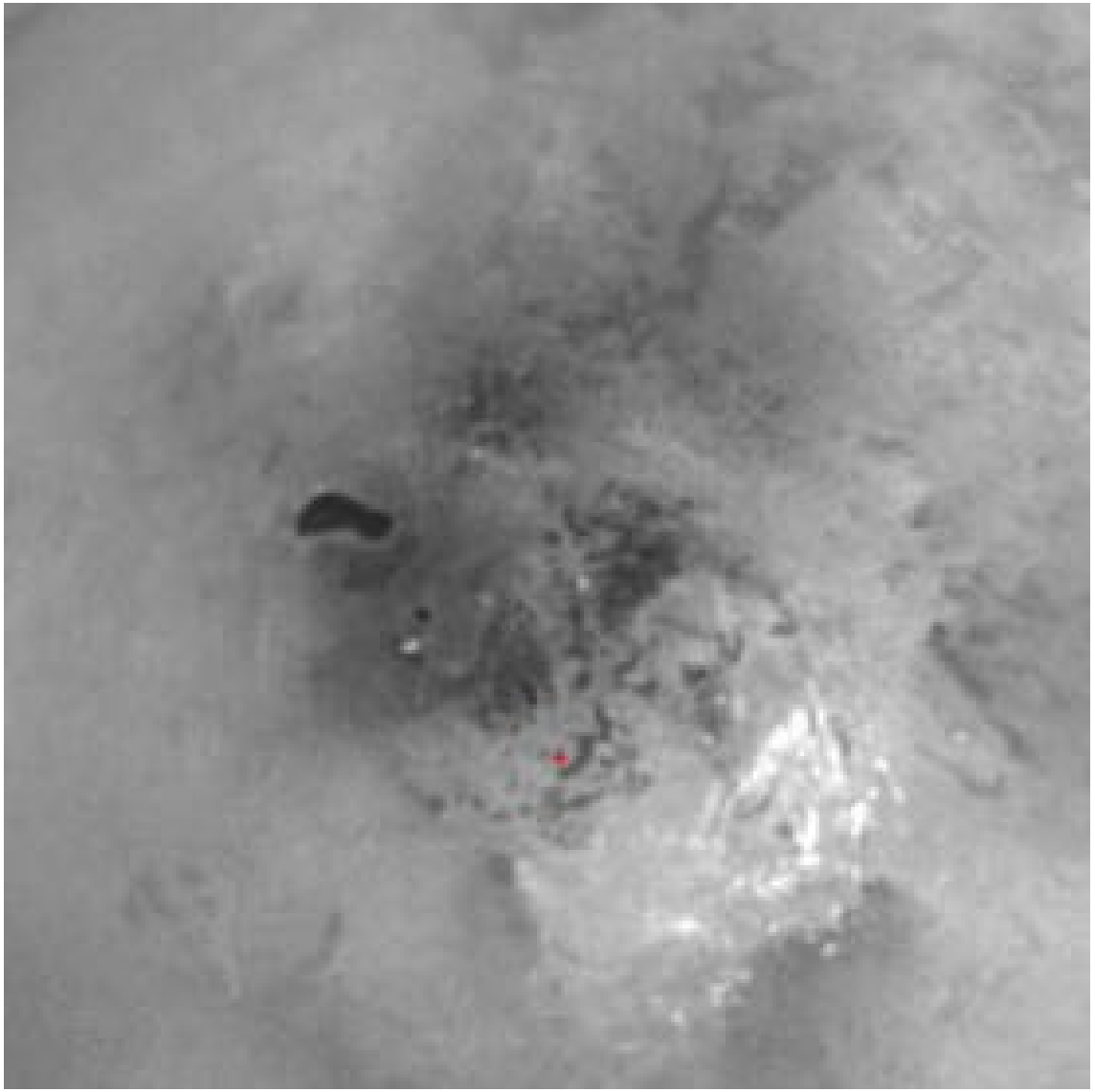
Titan Dunes

Earth

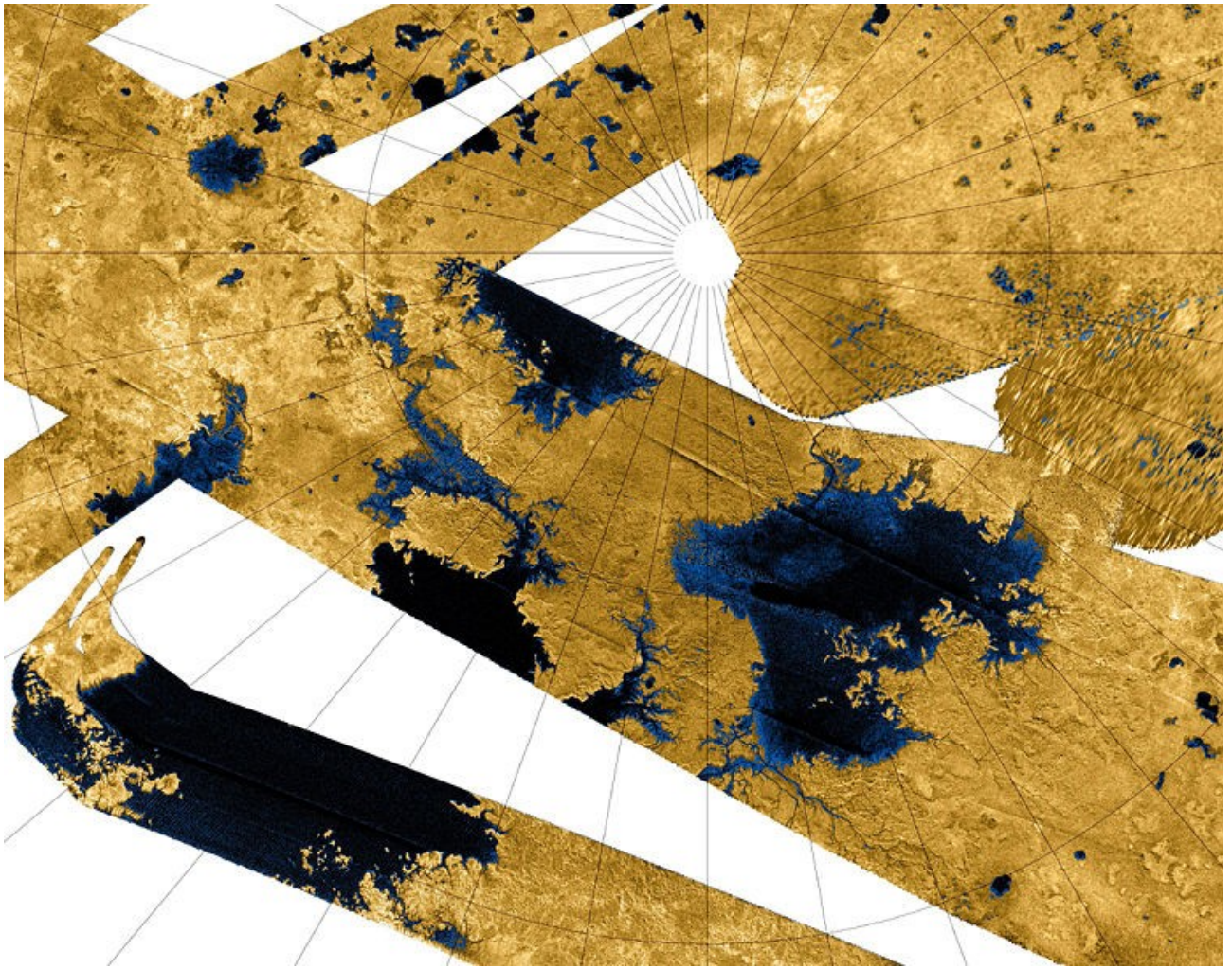
Titan



A little lake near the South Pole

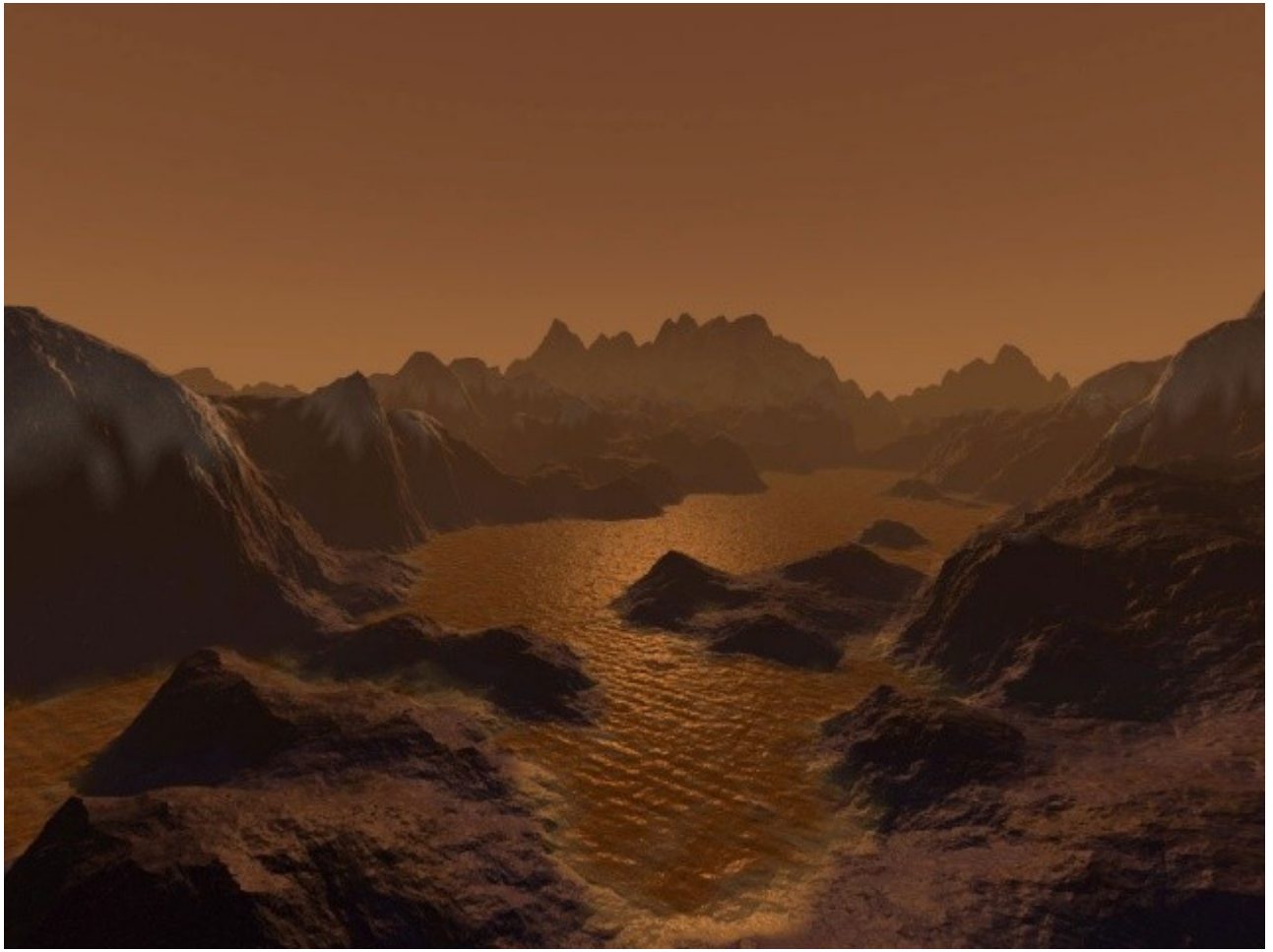


Lakes at last!

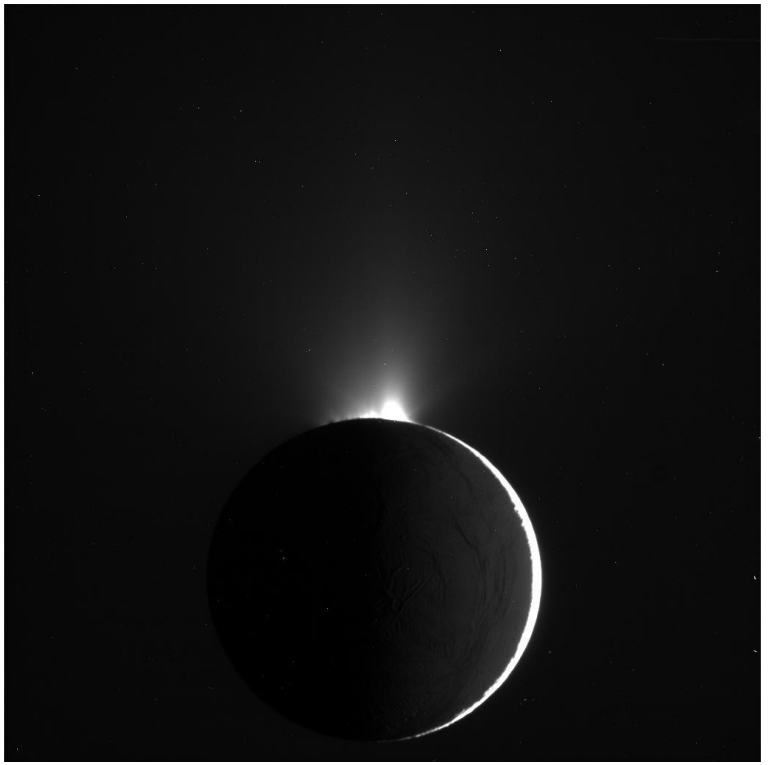


Lakes at last!

Lakes of Titan

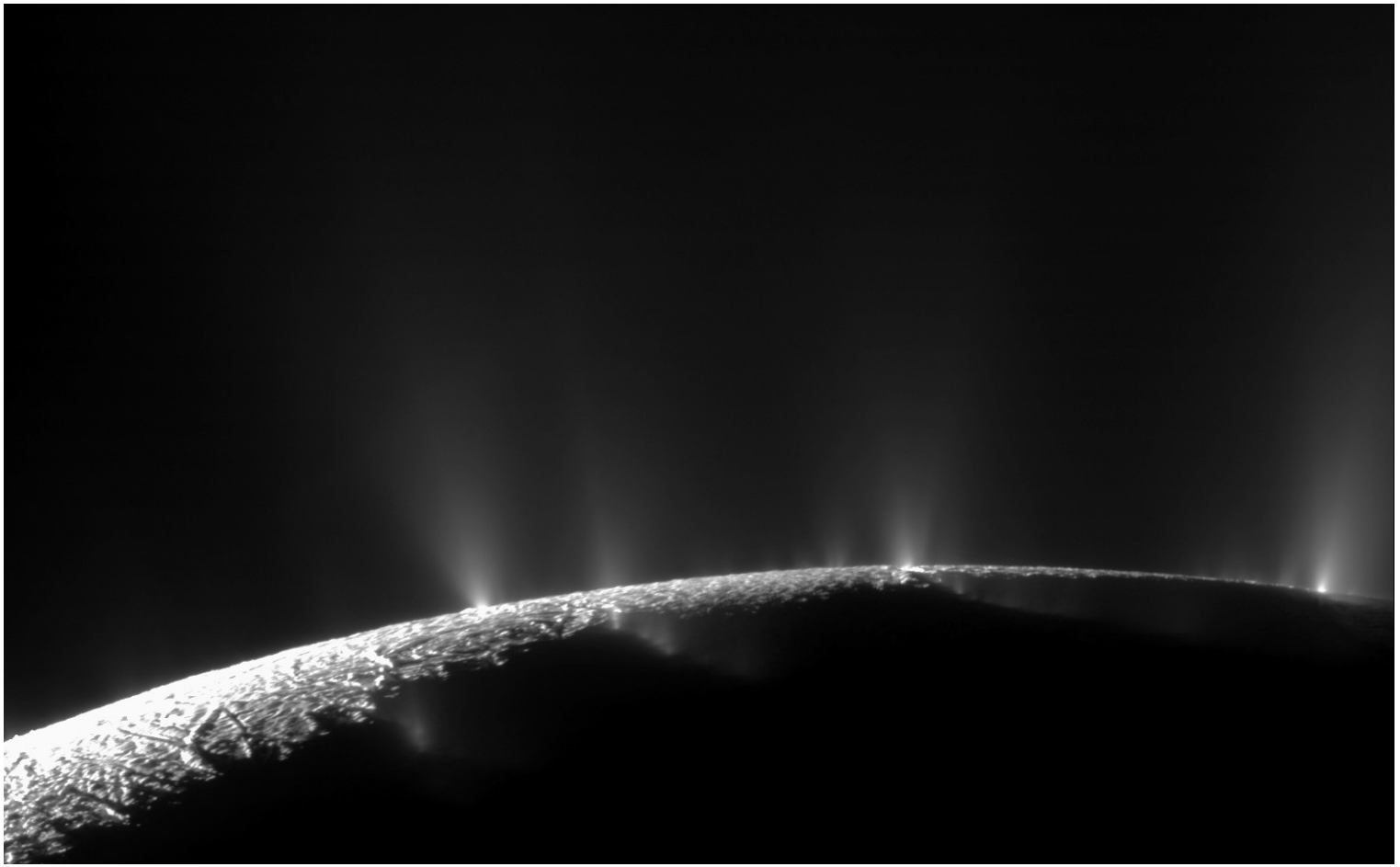


Enceladus



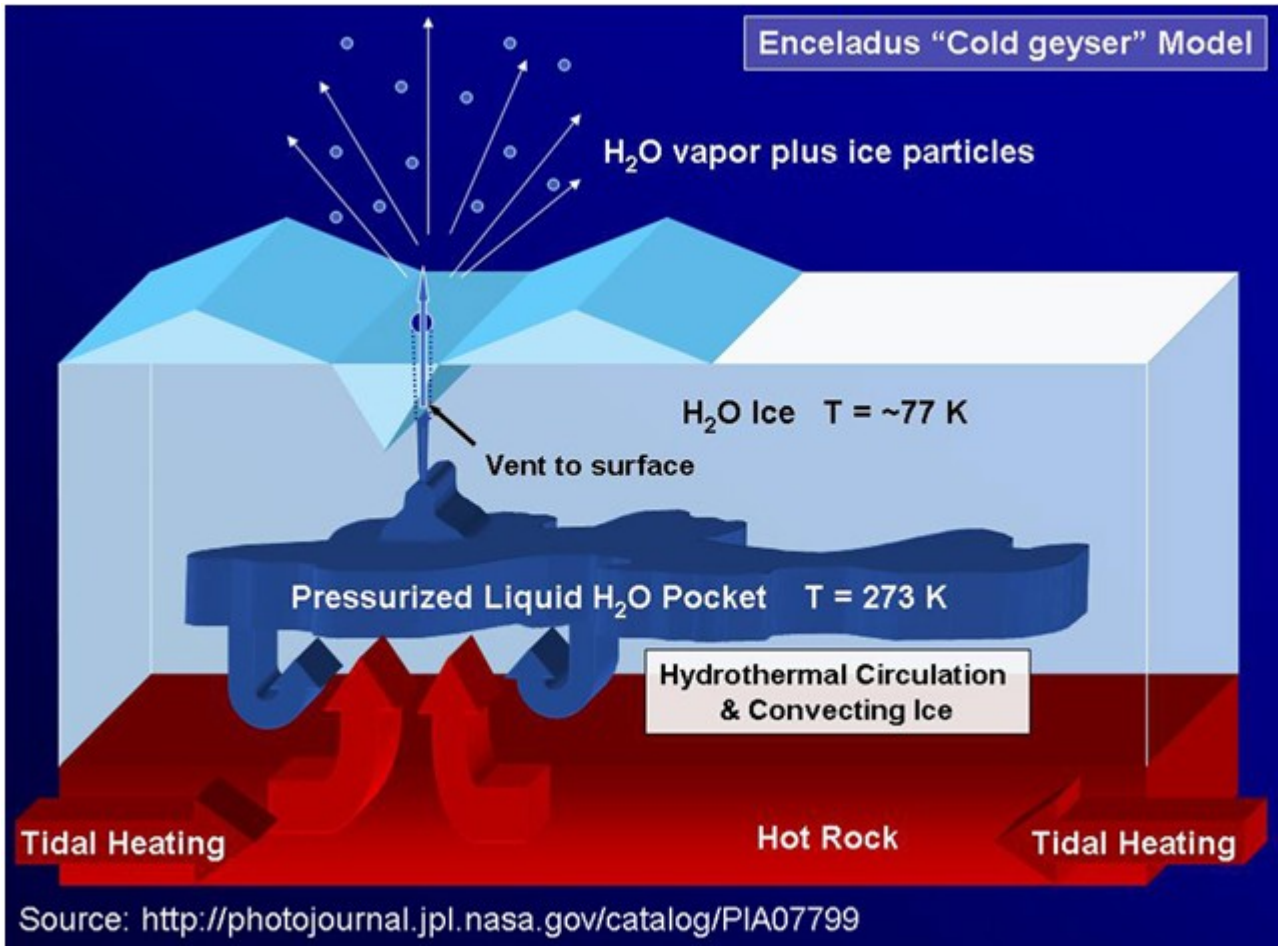
Plumes imaged by Cassini

Enceladus



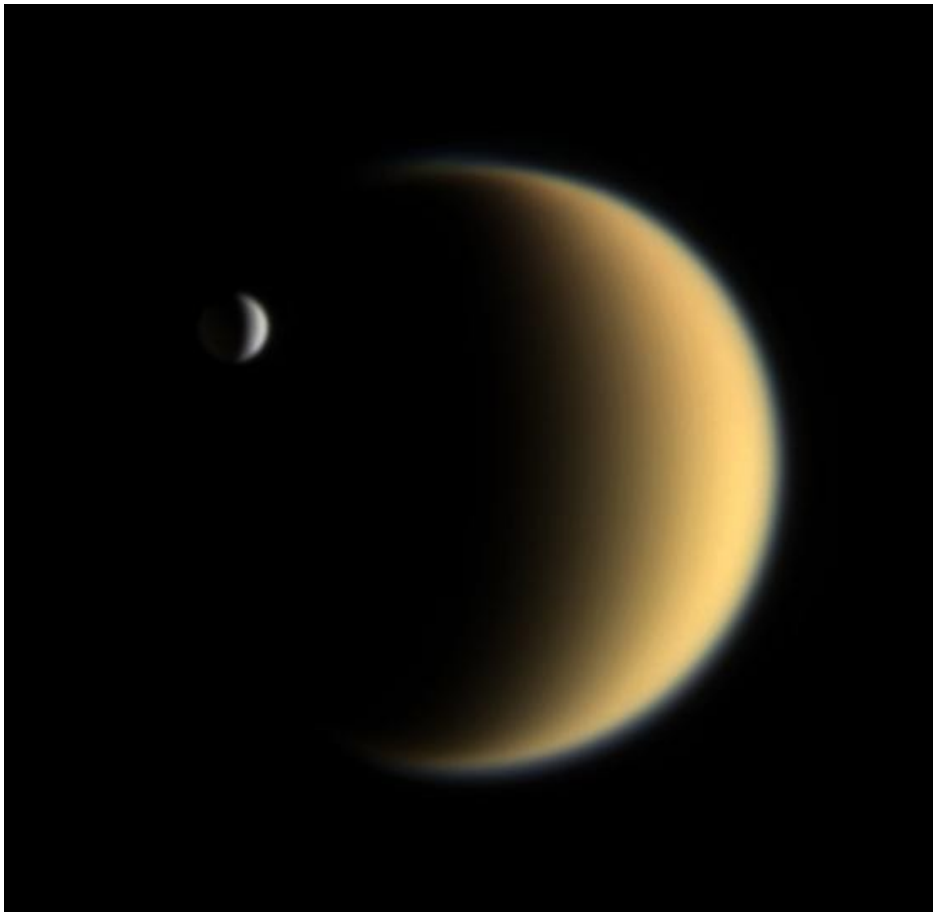
Close up of the plumes

Enceladus


Enceladus "Cold geyser" Model
H_2O vapor plus ice particles
H_2O Ice T = ~77 K
Vent to surface
Pressurized Liquid H_2O Pocket T = 273 K
Hydrothermal Circulation & Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating
Source: http://photojournal.jpl.nasa.gov/catalog/PIA07799

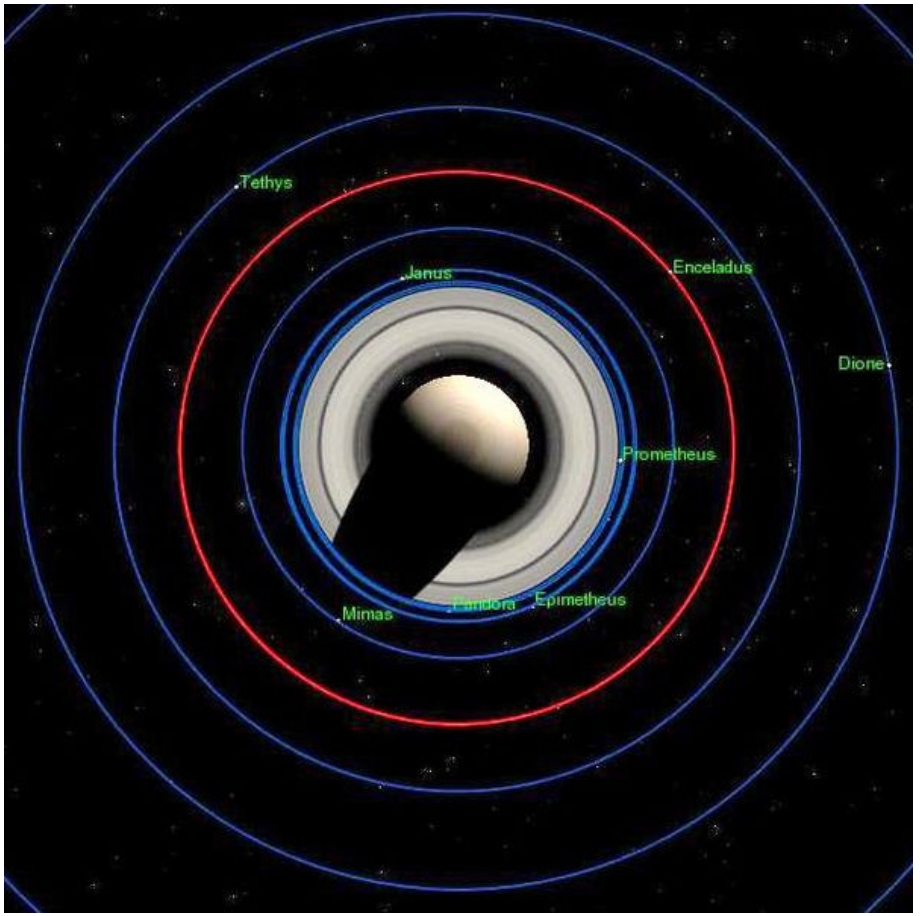
Enceladus

Enceladus and Titan



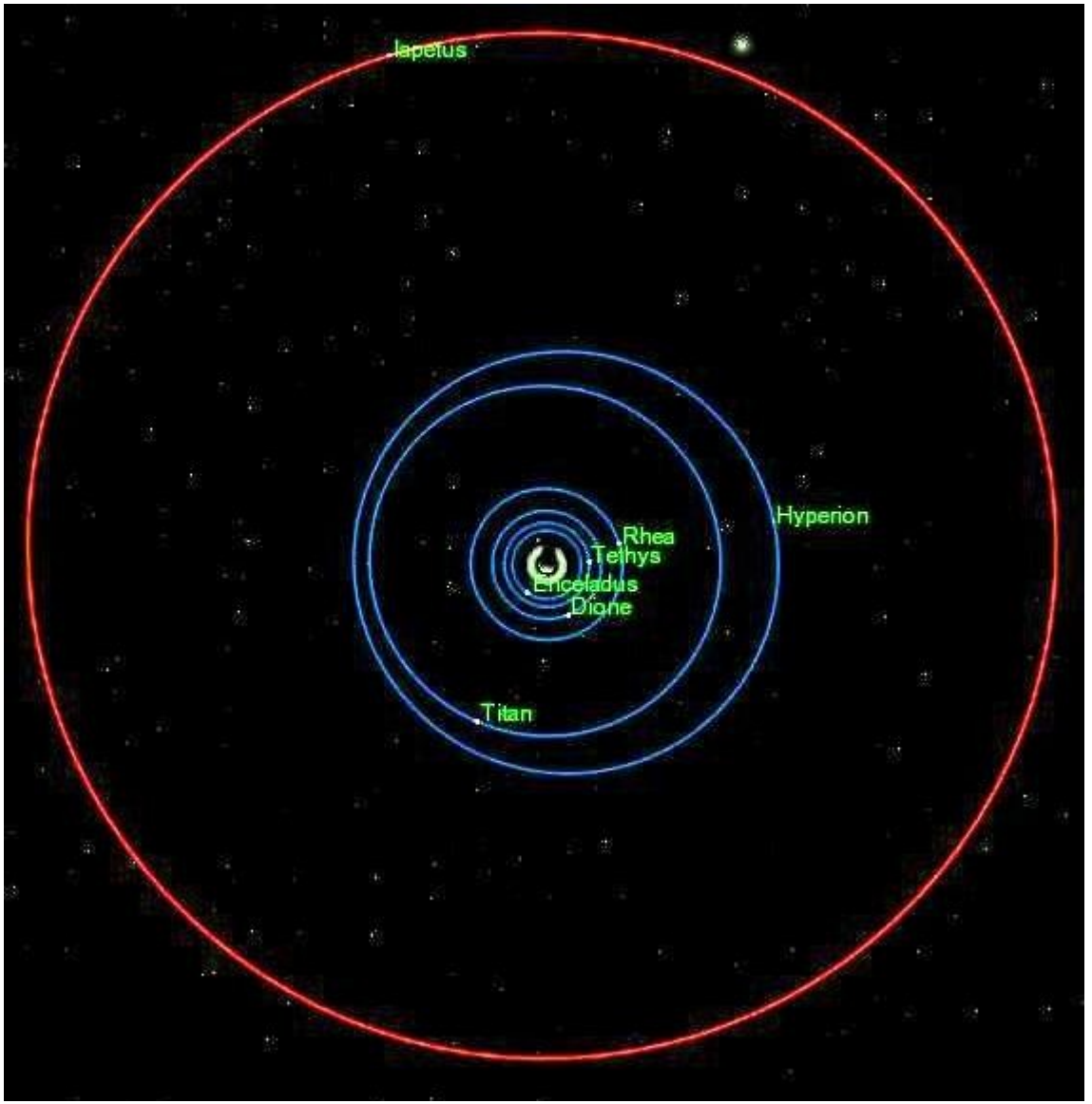
Such a small world!
How can it be active?

Tidal Heating!

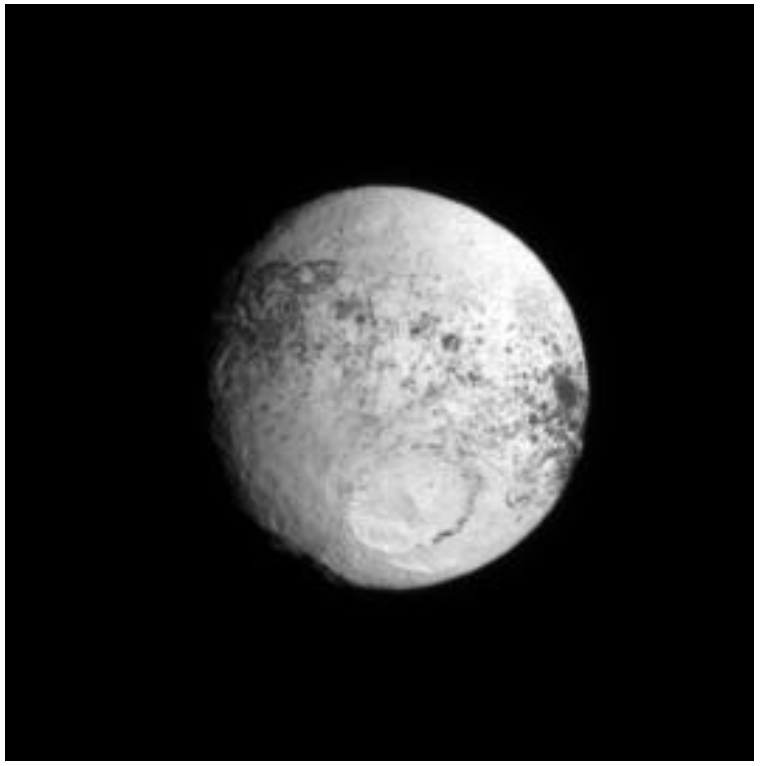


2:1 resonance with Dione
keeps Enceladus' orbit eccentric
(e ~ 0.004)

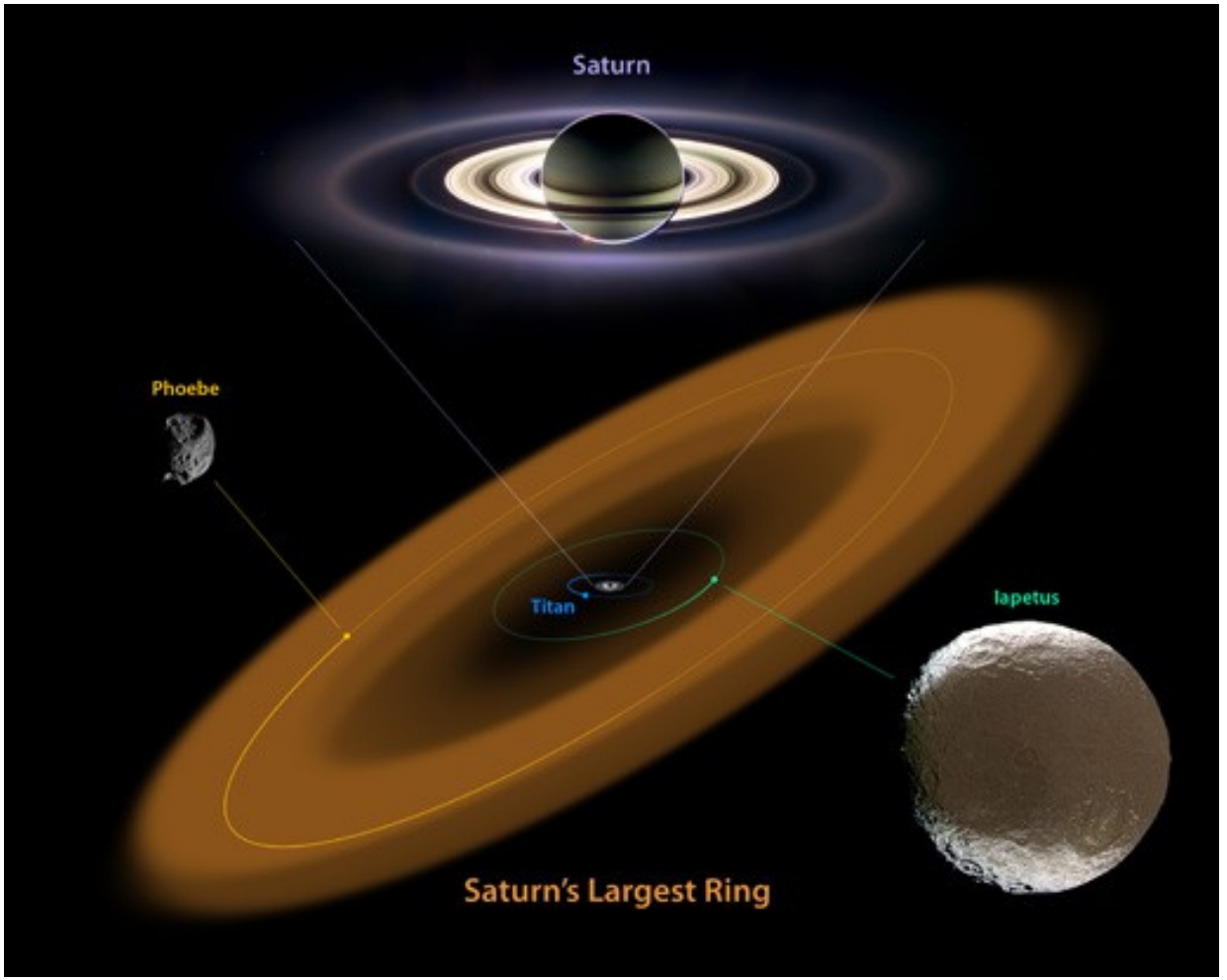
Iapetus



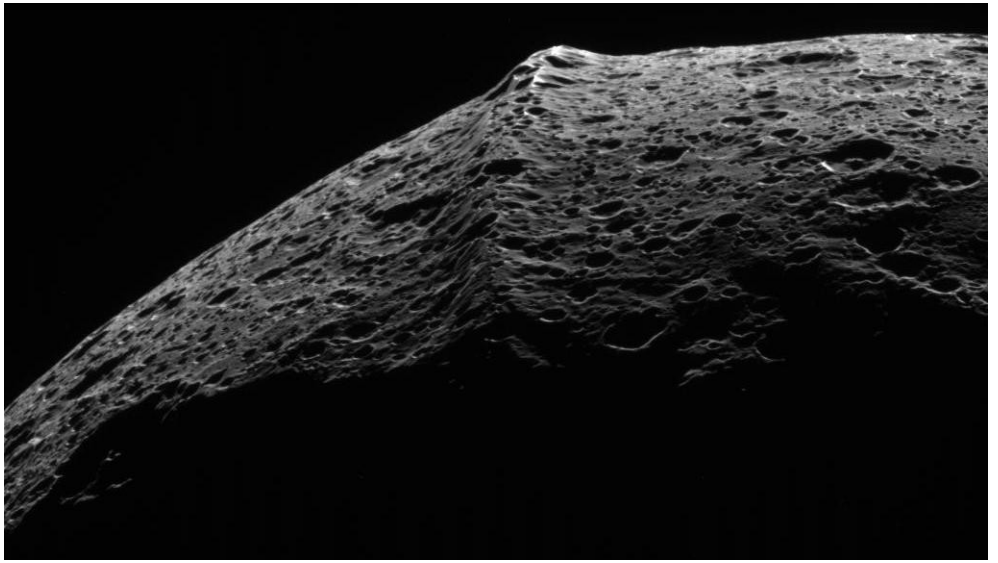
Iapetus' strikingly different hemispheres

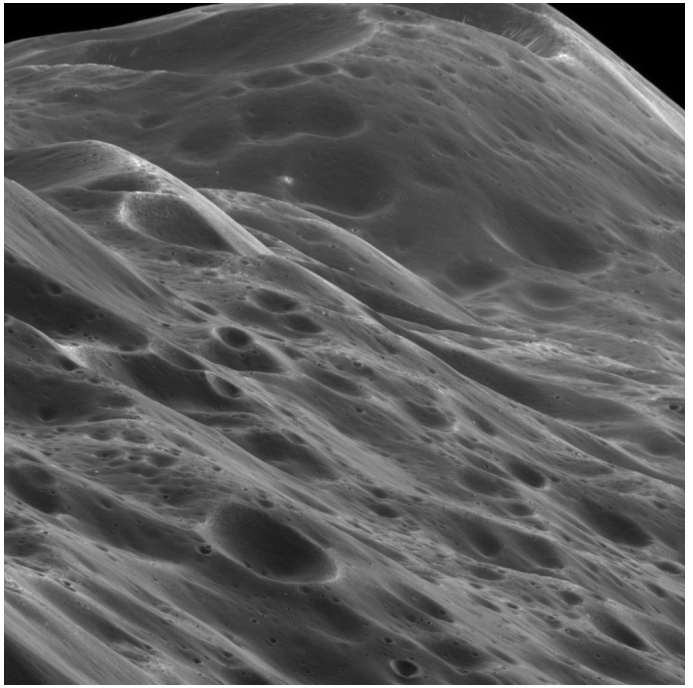


Debris from Phoebe

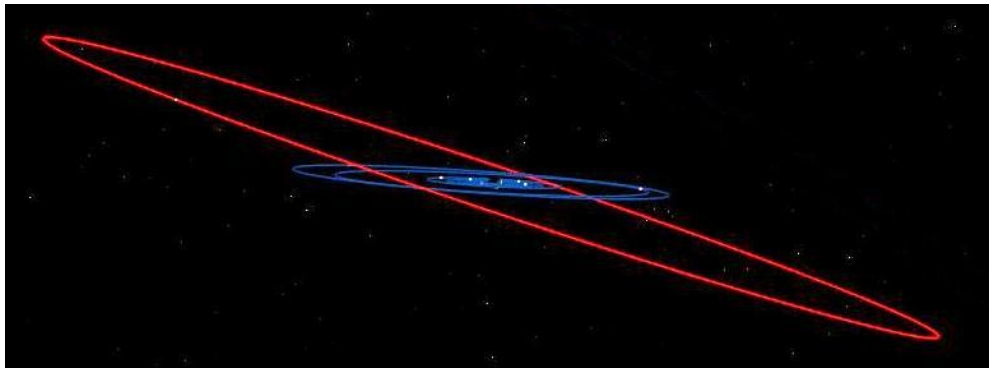


Iapetus' equatorial ridge





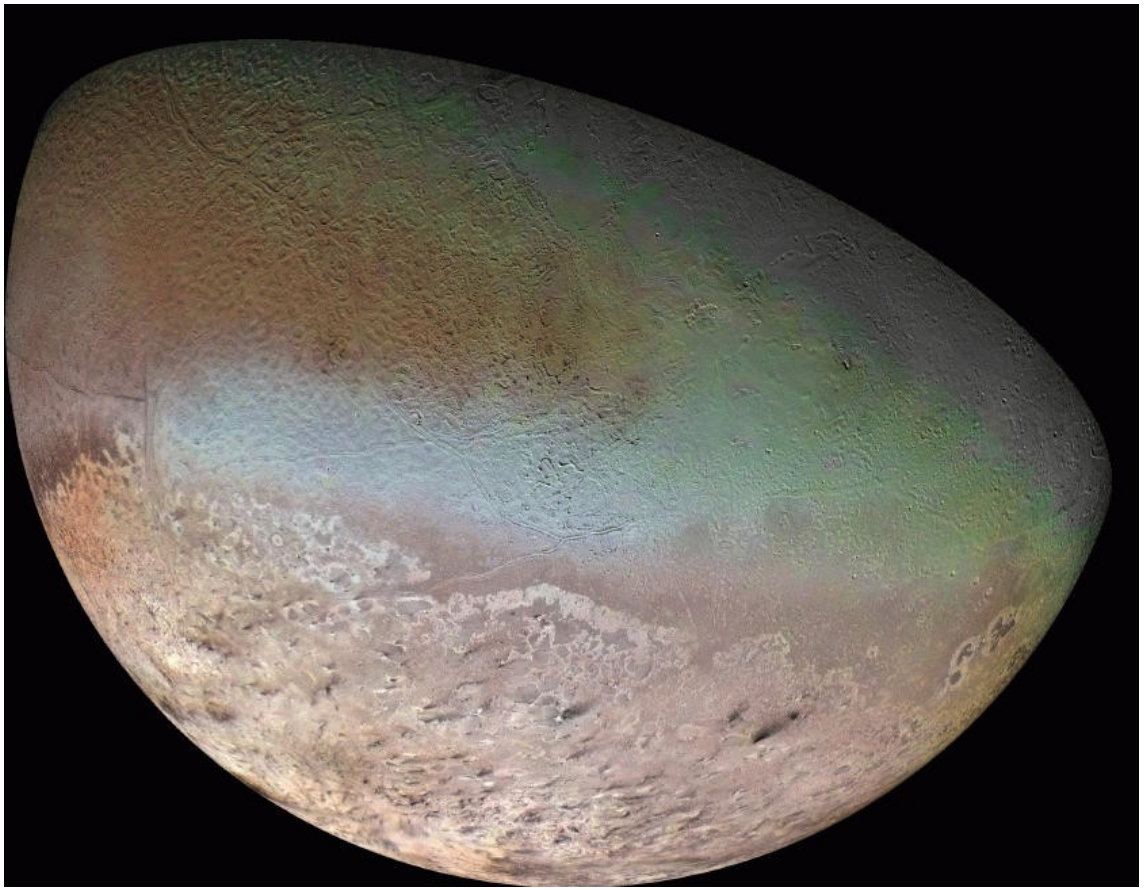
Iapetus: A moon with a view



Iapetus inclined orbit...

... allows for a clear view of the rings.

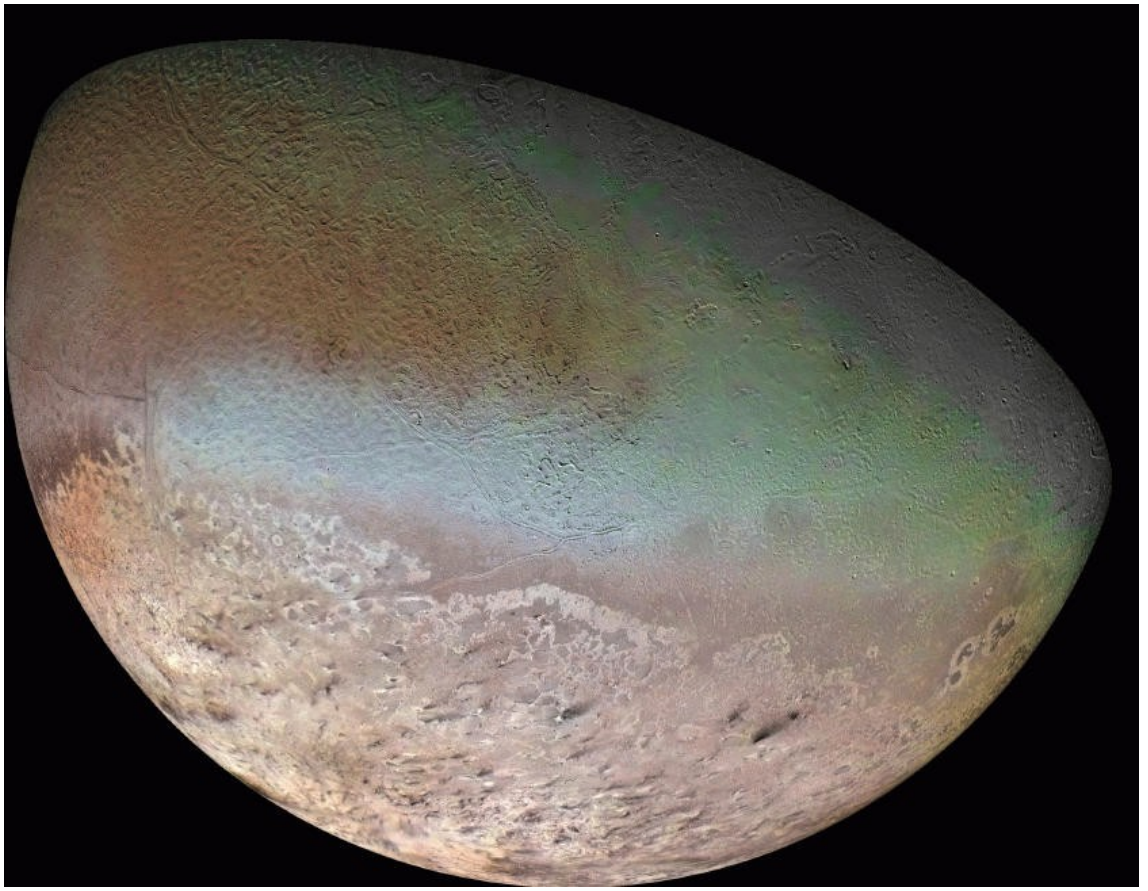
Triton – Neptune's large moon.



Frigid temperatures of 38K
All volatiles are either rock-solid or snow.

Yet, no craters. The surface is young.
Triton is geologically active !

Triton – Neptune's large moon.



Cantaloupe terrain

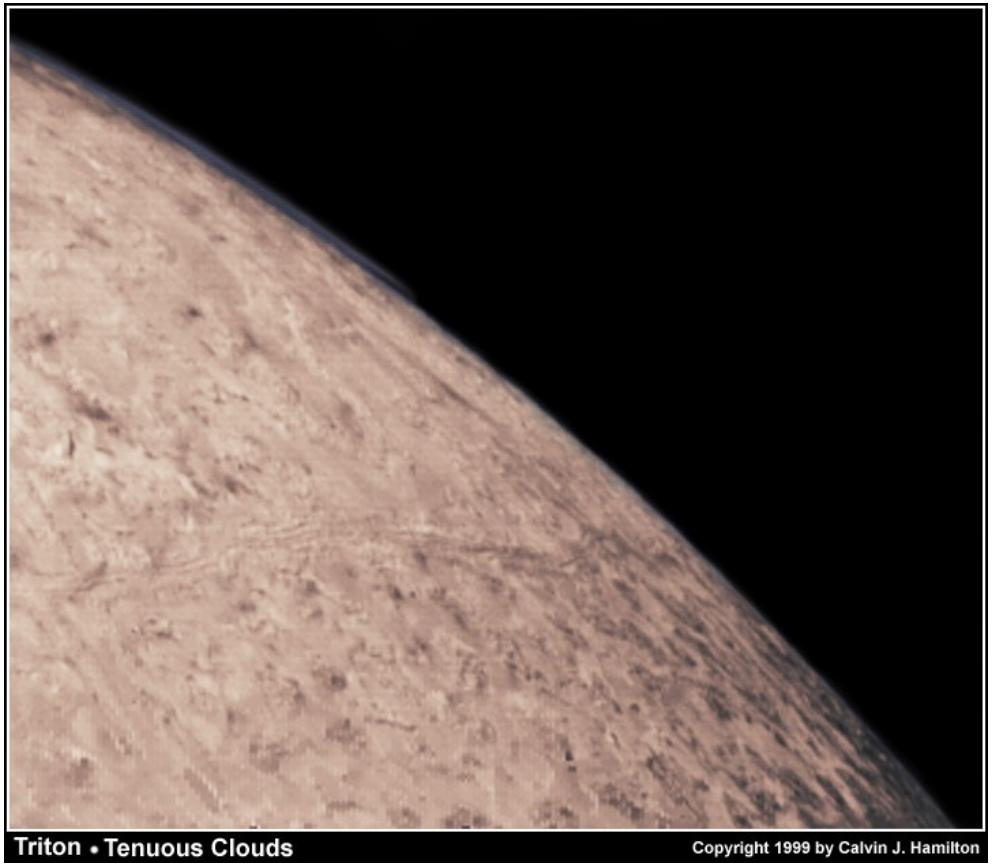
Dark streaks

Nitrogen snow

Frigid temperatures of 38K
All volatiles are either rock-solid or snow.

Yet, no craters. The surface is young.
Triton is geologically active !

Clouds on Triton



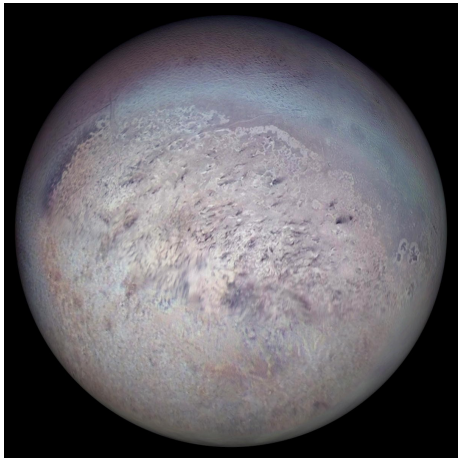
Nitrogen is near the sublimation point,
Forming a thin atmosphere

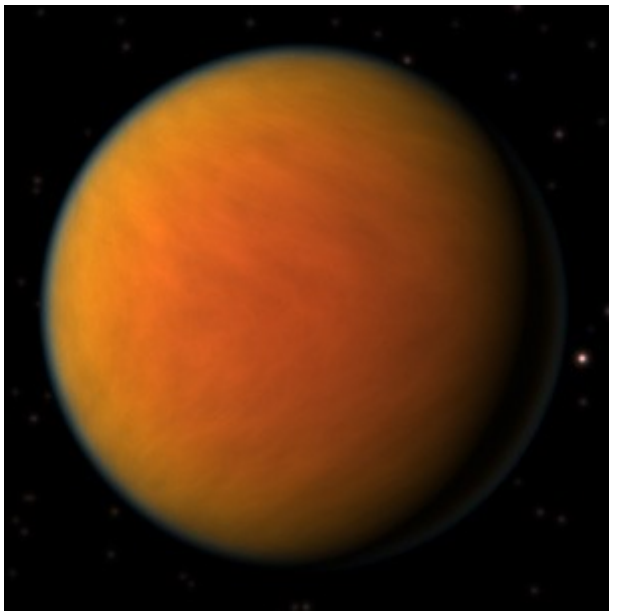
Dark streaks

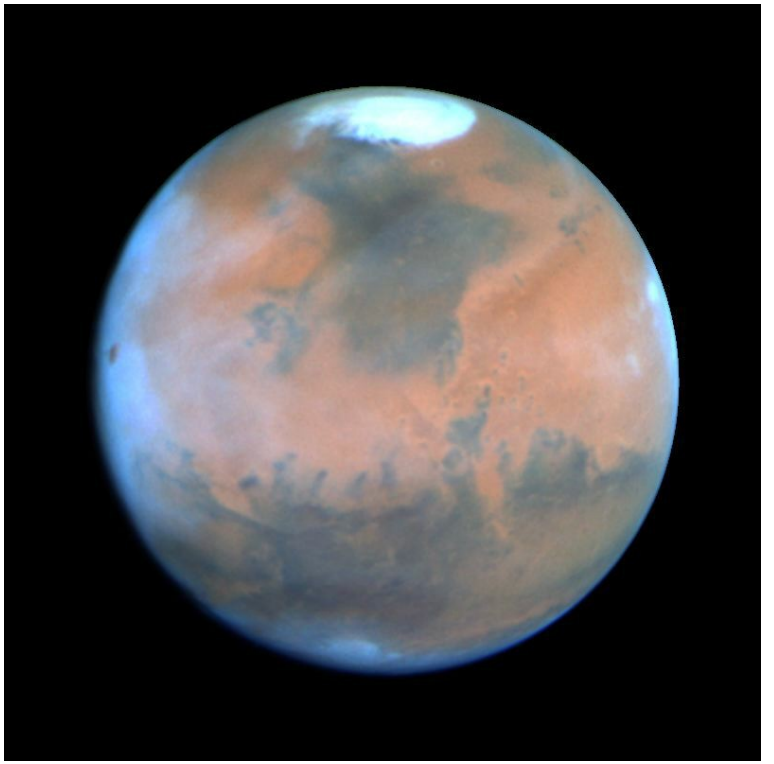
Geysers, caught by the wind

Powered not by tides,
But by solar heating
under the nitrogen snow.

Triton – Titan - Mars







These three worlds would look very much alike at the same distance from the Sun