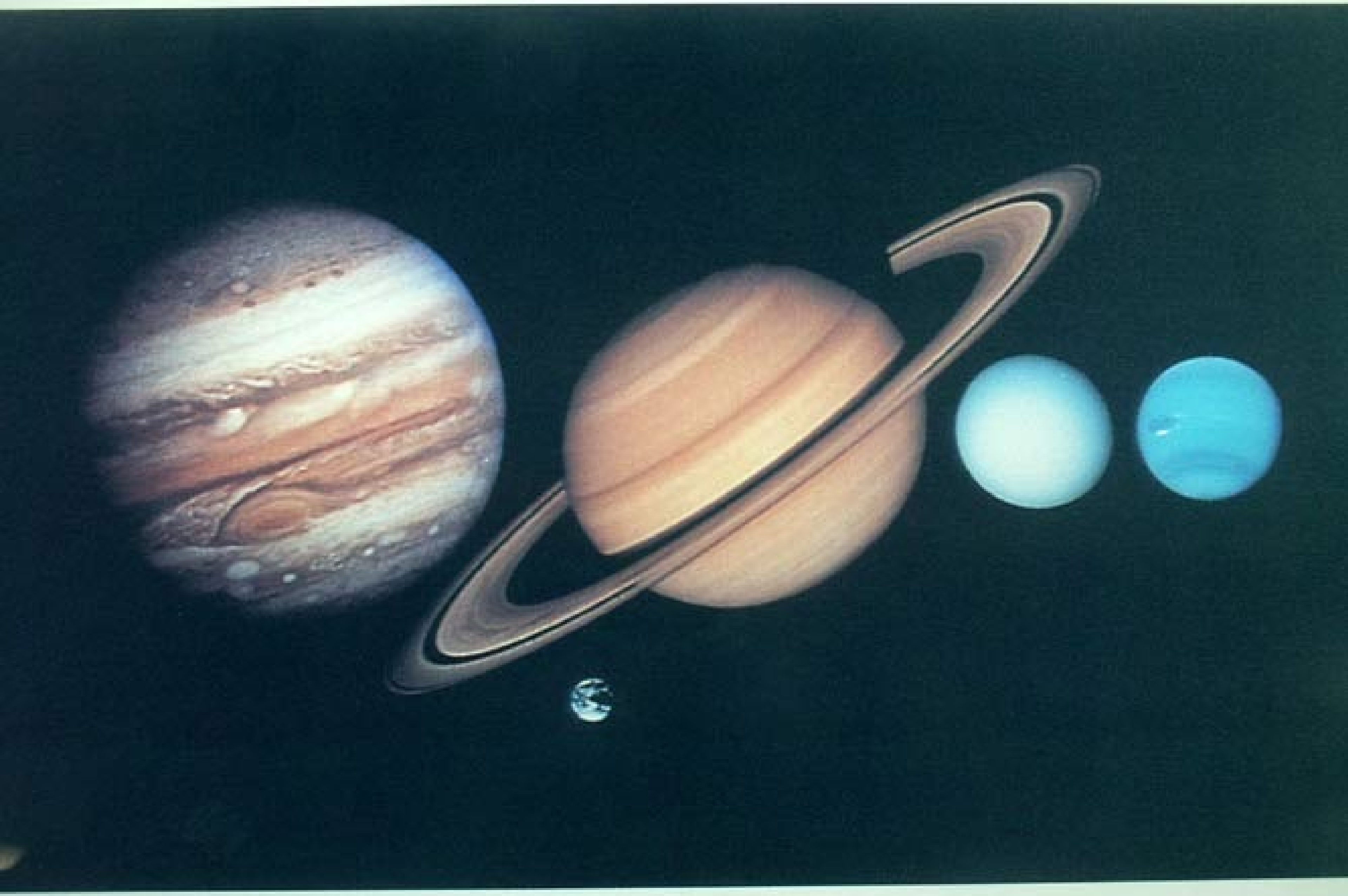
Chap 11: The Jovian Planet Systems

- TOTALLY different planets than our familiar next door neighbors
- They formed beyond the frost line – so **ices** could form and **seed** the early stages of agglomeration. There's a lot more ice-type raw material than rock-type raw material, and they stick together much easier when they're already solids, so planet formation is easier and quicker, and so you get bigger planets!

Key Points – Chap 11: Jovian Planets and Moons

- Jupiter & Saturn both emit more heat than they receive from sun, know why
- Virtually all moons of all planets are tidally locked; same face towards planet at all times
- All outer planets have rings, which decay over ~few hundred million years, inside tidal Roche Limit
- Young rings=water ice, older rings=dust
- Cloud tops; condensations of ammonia on Jupiter and Saturn, and of methane in Uranus and Neptune.
- Tidal friction heats Io, Europa, Titan, Enceladus, and to a smaller extent, the other moons.
- Rapid rotation and conducting interior -> magnetic field
- Rapid rotation, strong Coreolis force and more banded atmosphere, especially seen on Jupiter
- Outermost moons of some Jovians; some orbit backwards: must be captured asteroids or KBO's.
- Titan – remarkable hydrologic cycle involving methane, not water like on Earth
- Neptune has the highest winds in the solar system: over 1000 mph



Retaining an Atmosphere

- Molecules or atoms moving fast enough can leave the planet’s upper atmosphere and gravity will not be strong enough to bring them back. Each planet has an “escape velocity”. For Jupiter it is ~60 km/sec, nearly 6 times that of Earth
- Molecules will be more likely to be retained if they are:
- -- cold
- -- in strong gravity (*i.e.* high mass planet)
- -- are heavy molecules (e.g. CO_2, N_2, not H_2 or He)

How a Planet Retains an Atmosphere

- ***Surface gravity*** must be high enough and
- ***surface temperature*** must be low enough, that the atmosphere molecules don't leak away during the 4.6 billion years since formation.
- Also, Jovian Planets are so distant and so cold, they formed from seeds of ice, MUCH more common than rocky seeds
- Net Result: Jovian planets are mostly made of light atoms from accretion of ices
- Jovians have strong enough gravity to retain even lightweights like hydrogen and helium (H and He). And since these are THE most abundant atoms – these planets are massive and nearly all H and He.

Remember the three ways a planet loses atmosphere: First… leakage

Lighter molecules move faster, because on average ***Kinetic Energy is higher at higher temperatures***

- Recall $(\frac{1}{2})\mathbf{m}\langle v^2\rangle = (3/2)\boldsymbol{k}T$ where **m** is the mass of the particle (atom or molecule) moving at velocity **v**, in a medium of temperature **T**
- So for a given temperature, higher mass particles will have lower velocity
- Molecules are continually bouncing off of each other and changing their speed, but if the average speed is higher, the odds are higher that during the colliding, it may escape the planet's gravity.

So the lighter gases may leak away more quickly over time

- **Hydrogen and Helium = 97%** of the mass of the solar nebula, and these are the lightest and easiest molecules to lose.
- ***But they are NOT lost by Jupiter, Saturn, and to some extent Uranus and Neptune. Mass is high, gravity is high, escape velocity is high, and temperature is low so molecular velocities, even H_2 and He, are also low. Low enough they don't leak away***

Surface Gravity vs. Earth's

- Mercury = 0.37 and v_e = 4.3 km/sec
- Venus = 0.88 and v_e = 10.3 km/sec
- Earth = 1.00 and v_e = 11.2 km/sec
- Moon = 0.165 and v_e = 2.4 km/sec
- Mars = 0.38 and v_e = 5.0 km/sec
- **Jupiter = 2.64 and v_e = 59.5 km/sec**
- **Saturn = 1.15 and v_e = 35.6 km/sec**
- **Uranus = 1.17 and v_e = 21.2 km/sec**
- **Neptune = 1.18 and v_e = 23.6 km/sec**
- Pluto = 0.4 and v_e = 1.2 km/sec

The second way to lose atmosphere…

Impact Cratering: Big comets and asteroids hitting the planet will deposit a lot of kinetic energy which becomes heat, blowing off a significant amount of atmosphere all at once.

- This is not much of an issue for the outer planets, who have high gravity and very high atmosphere mass, so even a big impact is unlikely to unbind much atmosphere

The third way to lose atmosphere: weak magnetic field

- Recall, a magnetic field will deflect incoming charged particles (cosmic rays and especially the solar wind) and prevent them from “sandblasting” away, bit by bit, the atoms and molecules in your atmosphere
- This is not an issue for the Jovian planets – they’ve all got strong magnetic fields, and huge atmospheres which could handle a little “sand-blasting” by the solar wind even if not.

The Outer Planets: Hydrogen/Helium Giants

- 97% of early solar nebula was hydrogen and helium, roughly the composition of the outer planets
- Cold temperatures, high mass allow these light atoms to be held by gravity for these 4.6 billion years
- Rocky cores surrounded by deep layers of H, He, and ices.
- Uranus and Neptune are colder and smaller; less H_2 and He and more ice (probably mostly water ice) mantles

Jupiter and Saturn: Thick H_2 and He atmospheres. Uranus and Neptune: thick layers of ice topped by thin H_2 and He atmospheres. All have rocky cores roughly the size of Earth

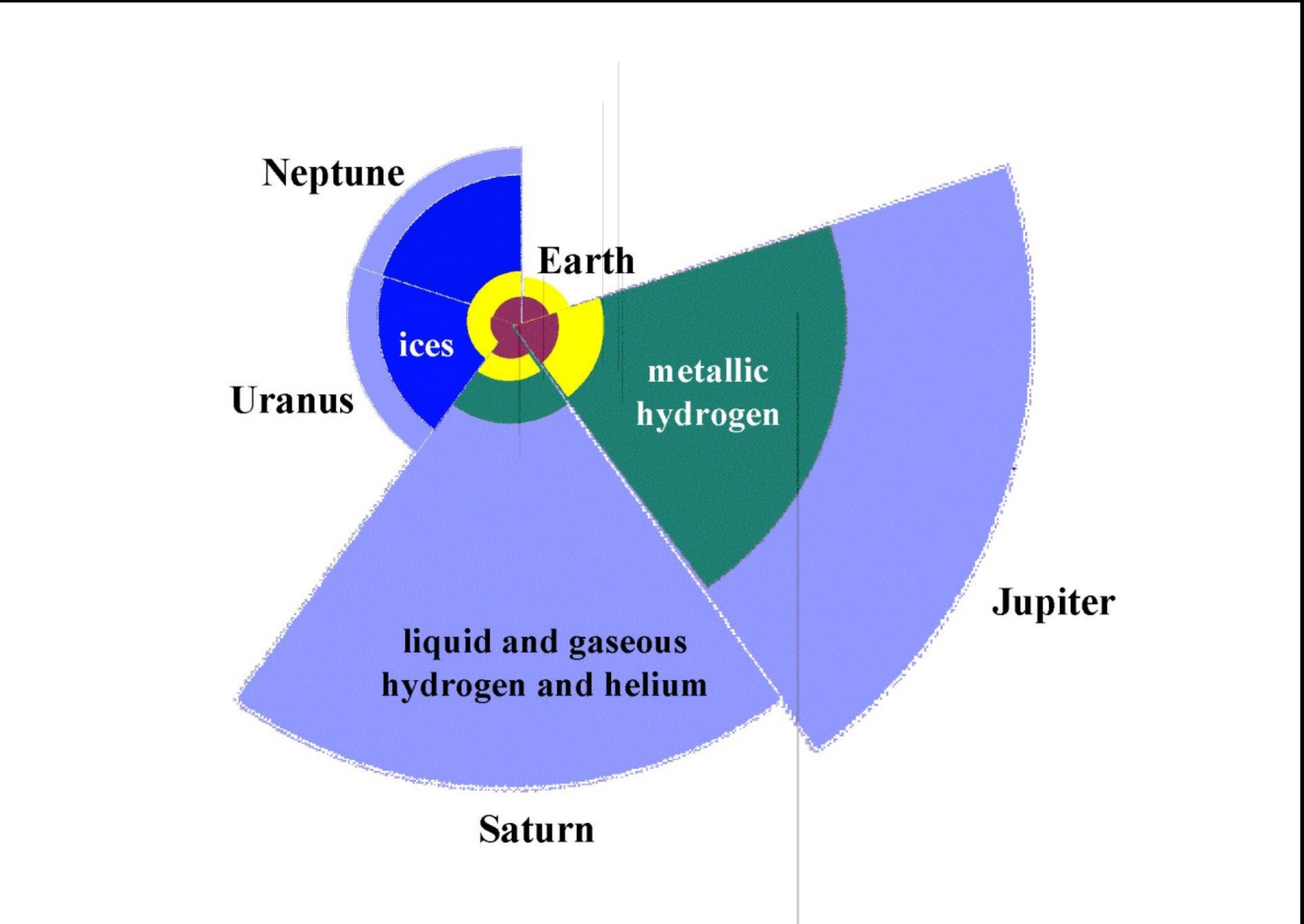
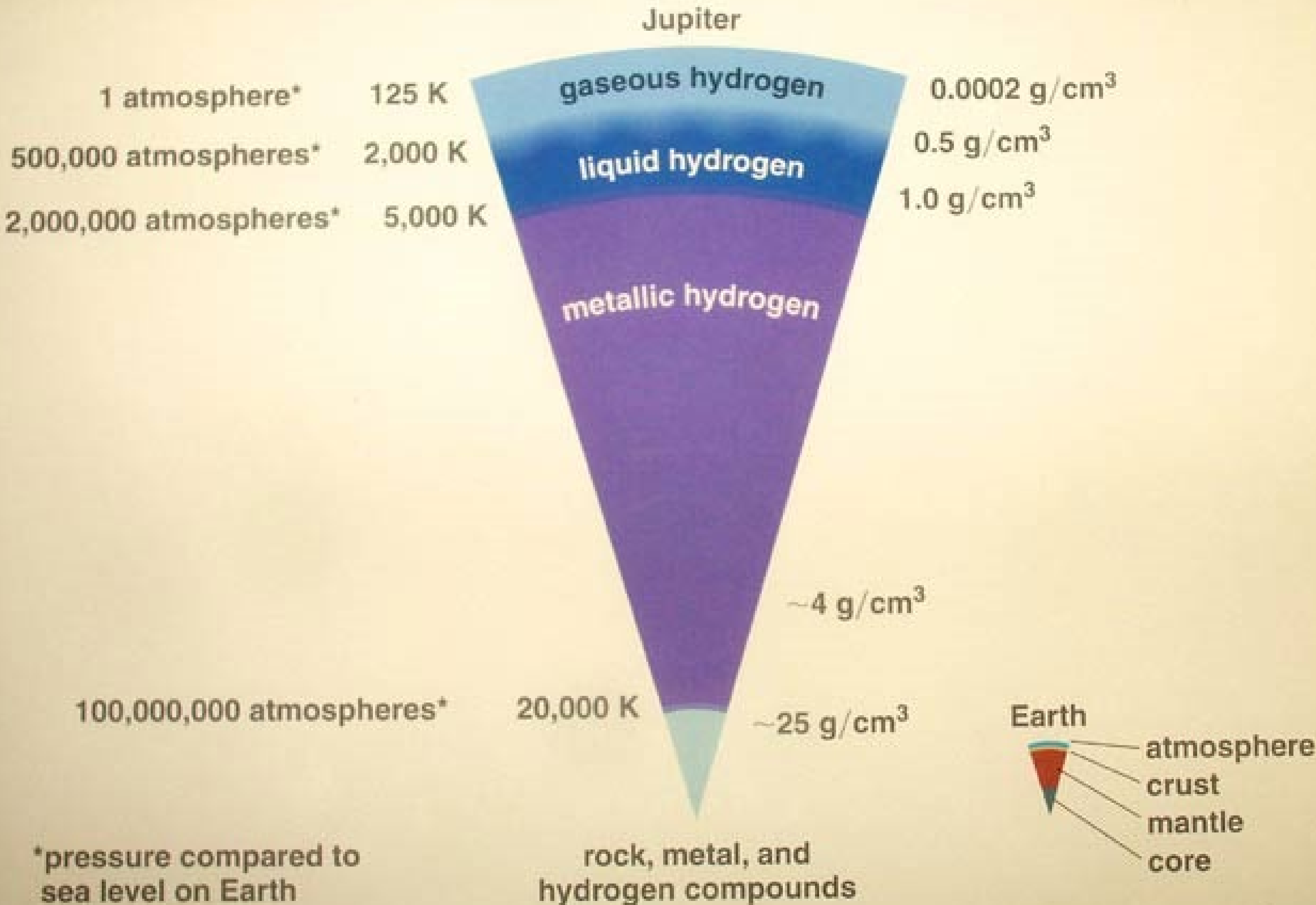
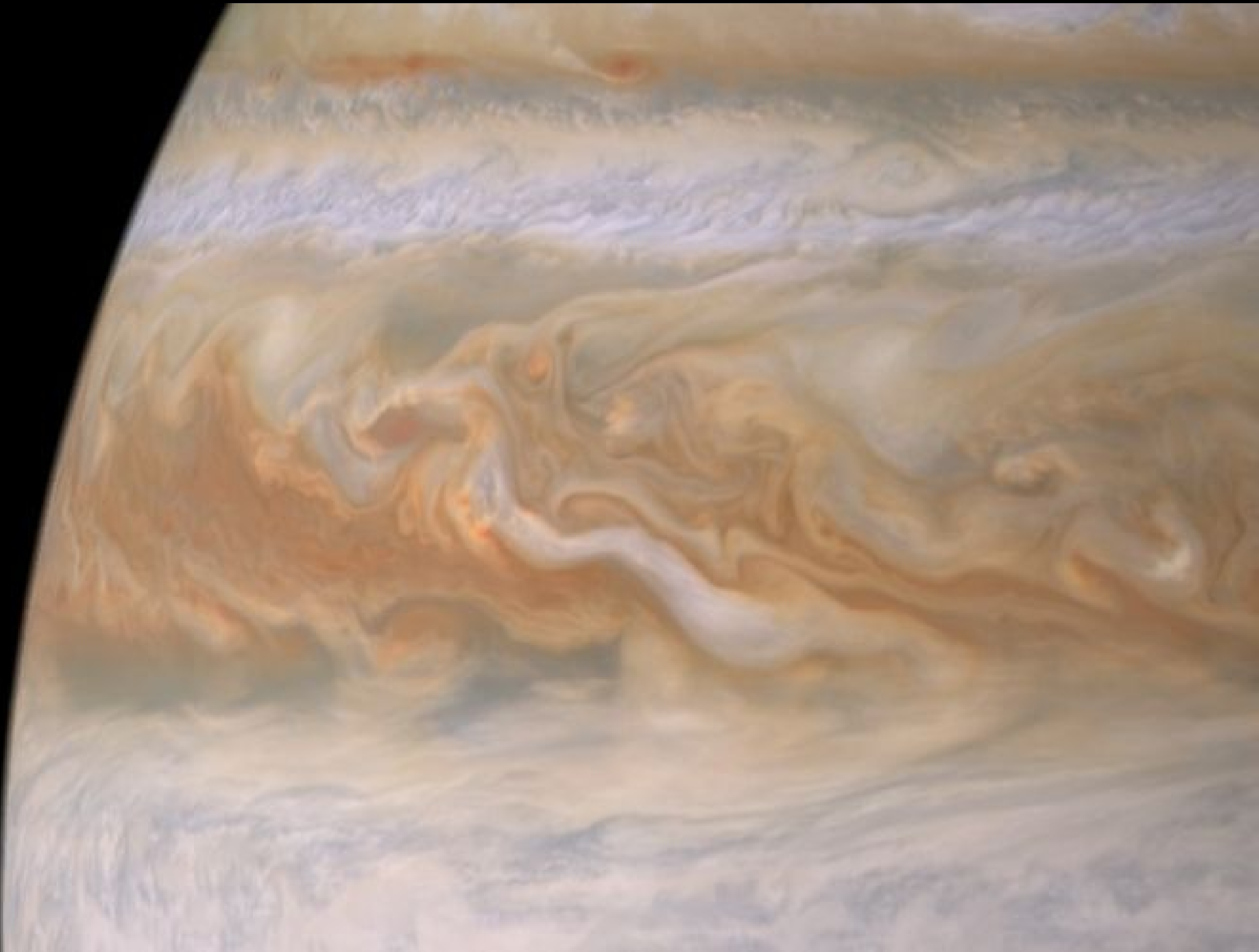


Figure 9.2 Internal structure: Jupiter vs. Earth



Jupiter is a Stormy Planet

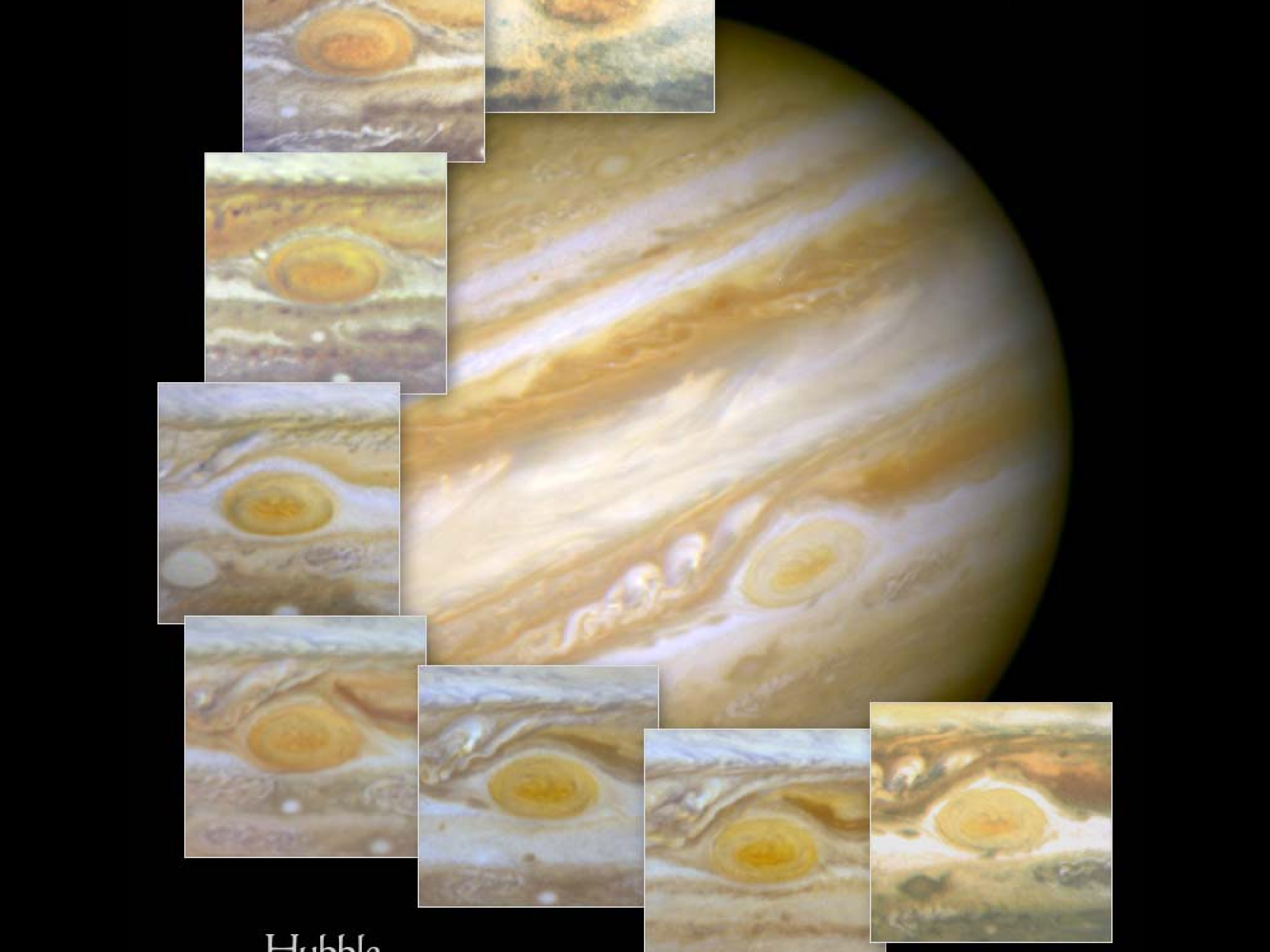
- High temperatures deep inside mean strong convective flow in the atmosphere.
- The rapid rotation (“day” = 12 hrs) and large diameter means very strong velocity gradient from equator to poles.
- So, strong Coriolis force, making atmospheric motions turn into circulations – like hurricanes
- Result is lots of big storms…
- Amazingly detailed 3min video from **Juno Mission passing over Jupiter**



The Great Red Spot

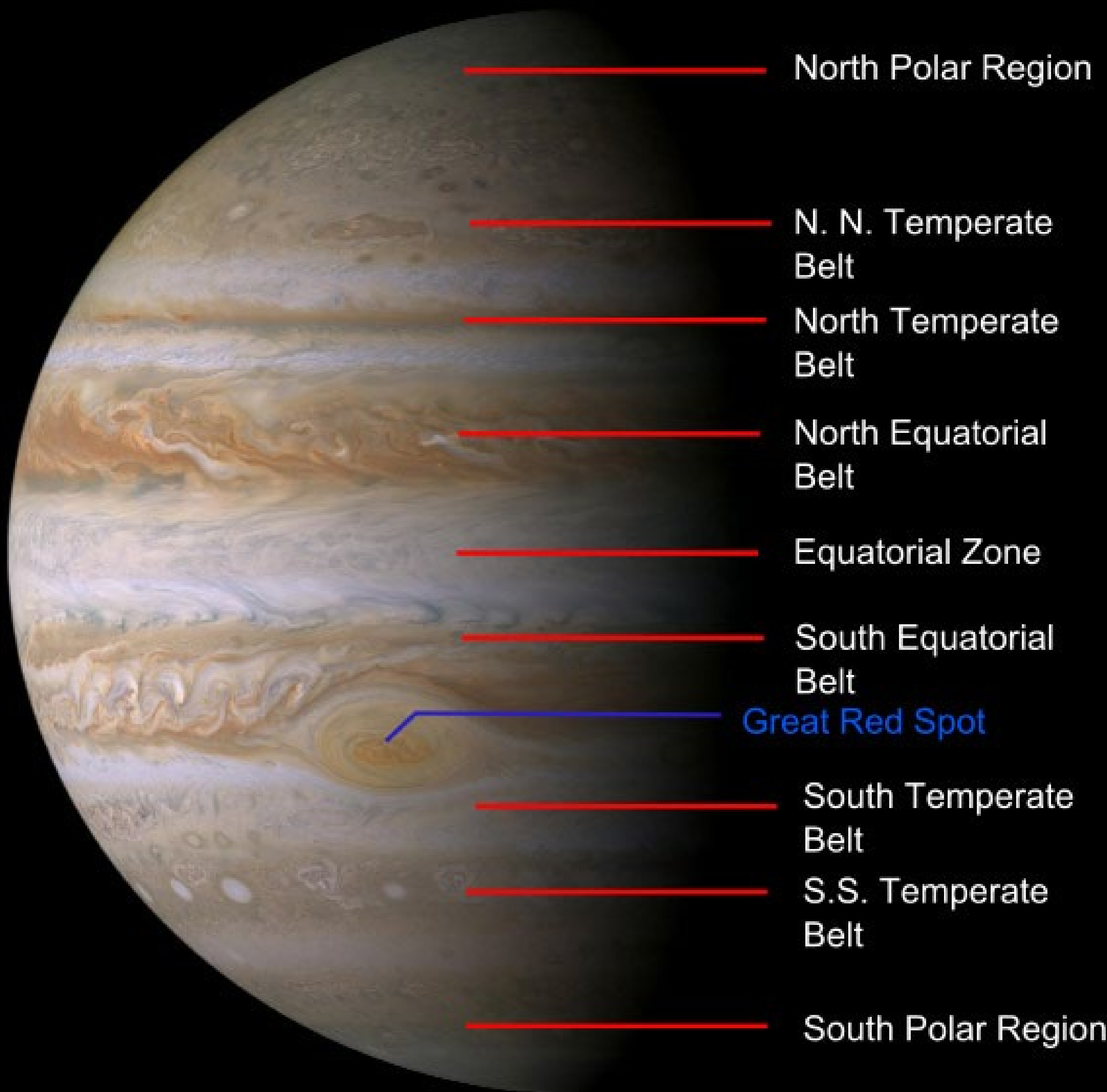
- As big as 3 Earth’s side-by-side
- This is a high pressure anti-cyclone
- Jupiter’s storms usually last months or maybe a year or so, but the Great Red Spot has been on Jupiter since we first put a telescope on it to see, 400 years ago.

Jupiter's Great Red Spot and Other Storms


Hubble

Jupiter is 12 times the diameter of Earth and Rotates in half the time of the Earth

- This means the equatorial velocity is 24x the Earth's and the velocity difference from pole to equator is also 24x the Earth's, but since the diameter of Jupiter is 12x Earth's, the actual gradient of velocity per mile on the surface, at a given latitude, is only 2x the Earth's, and so is the Coreolis Force.
- Still, it's enough to make for stronger storms, and more atmospheric bands than Earth. We have only 3 bands per hemisphere: the Hadley (tropical), Ferrel, and Polar cells. Jupiter has 9 bands

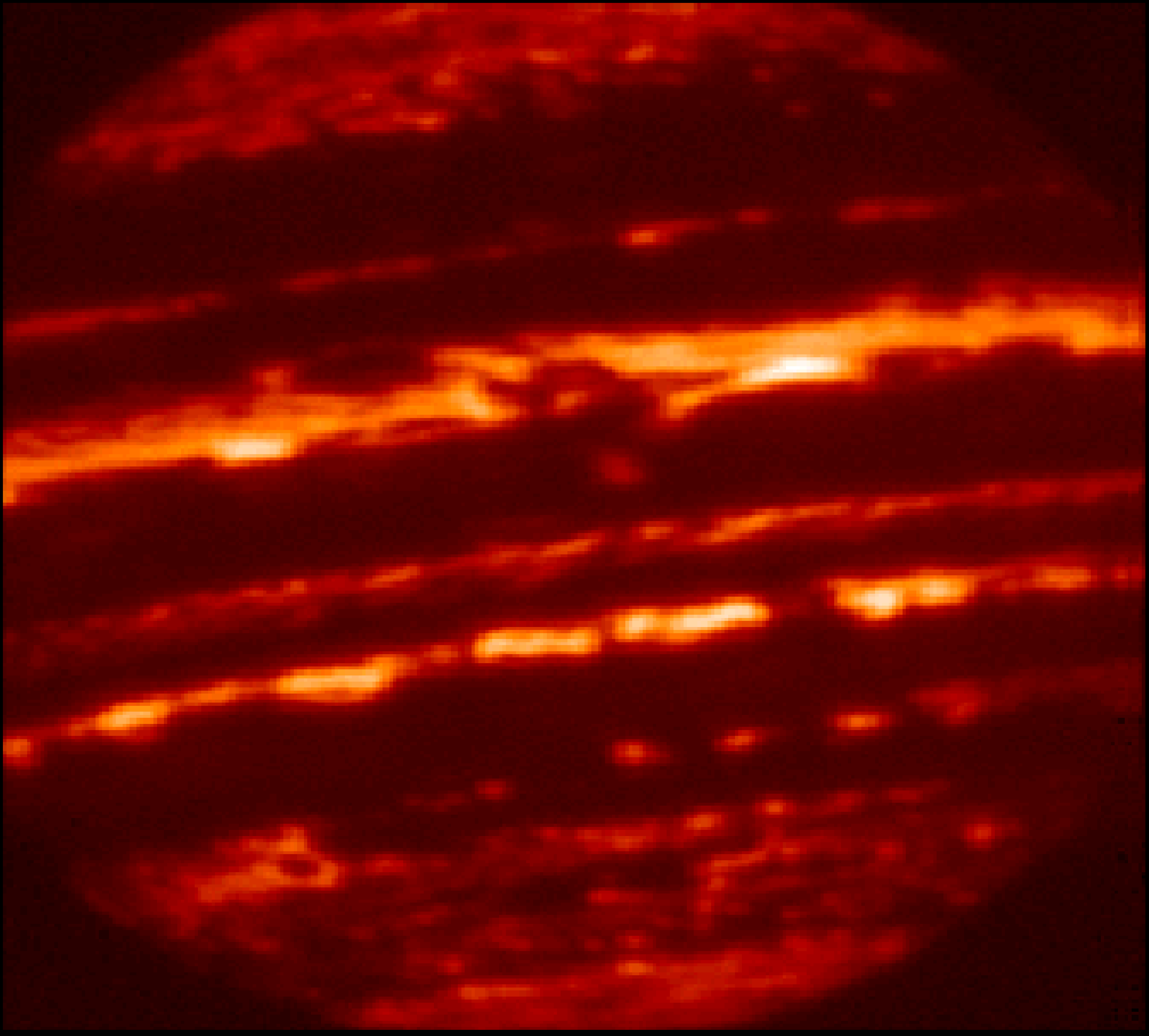

North Polar Region
N. N. Temperate Belt
North Temperate Belt
North Equatorial Belt
Equatorial Zone
South Equatorial Belt
Great Red Spot
South Temperate Belt
S.S. Temperate Belt
South Polar Region

Cloud Band Structure

- Darker “belts” are descending air, lighter colored “zones” are rising air. A rising + adjacent falling area = one “band”
- Rising air – cooling, condensing clouds. Whitish clouds have ammonia crystals
- Descending air – warming, evaporating clouds and allowing a deeper view into warmer layers.
- Storms – cyclones or anti-cyclones caused by strong Coriolis Force.
- Anti-cyclones tend to be larger, and cyclones tend to be smaller.

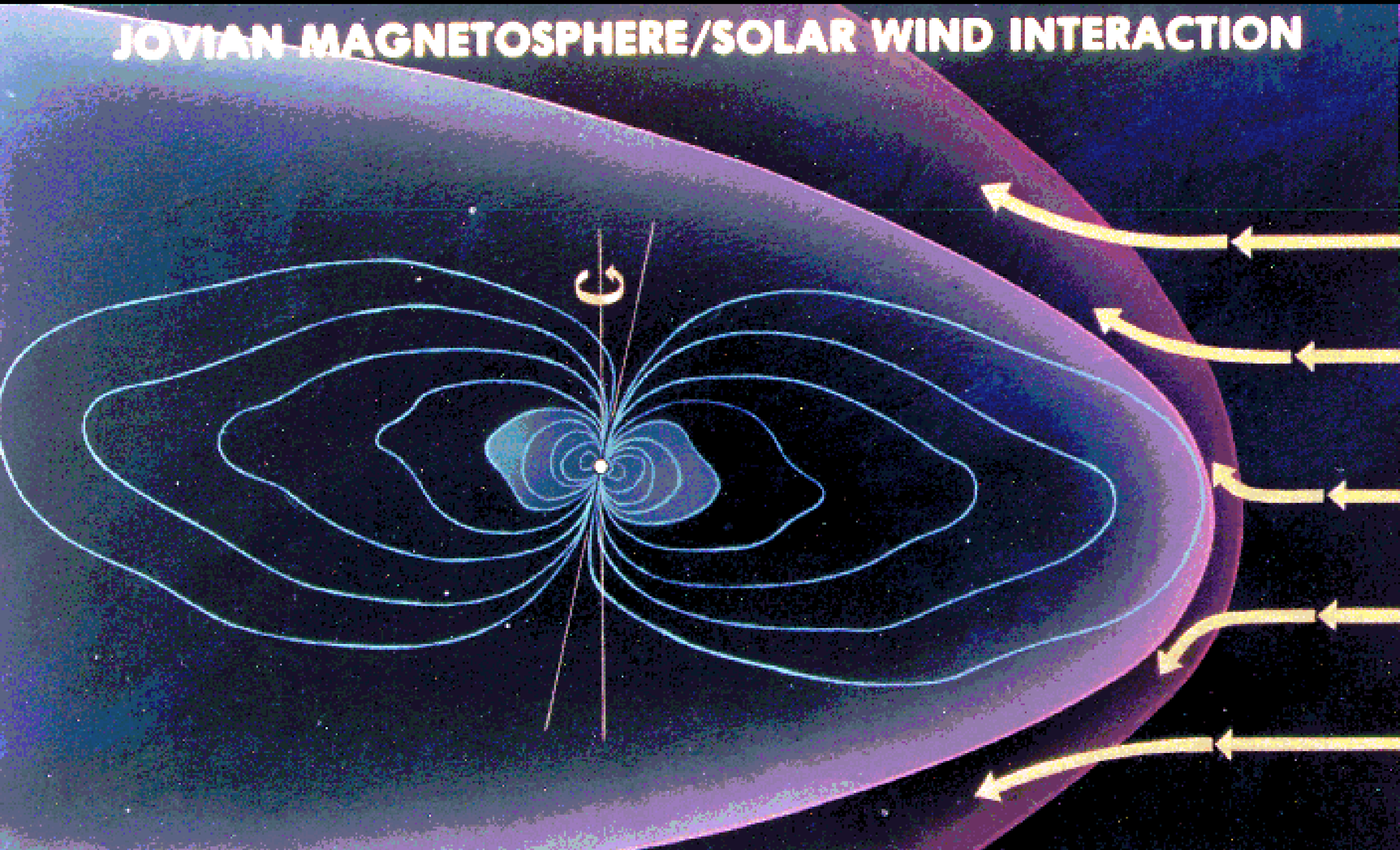
Jupiter gives off more heat than it receives from the sun. It's HOT under that cold atmosphere top

- Why? Heat of formation takes a LONG time to dissipate, but mainly its because it is still slowly collapsing, converting gravitational potential energy into heat
- You can see the hotter layers in infrared pictures…



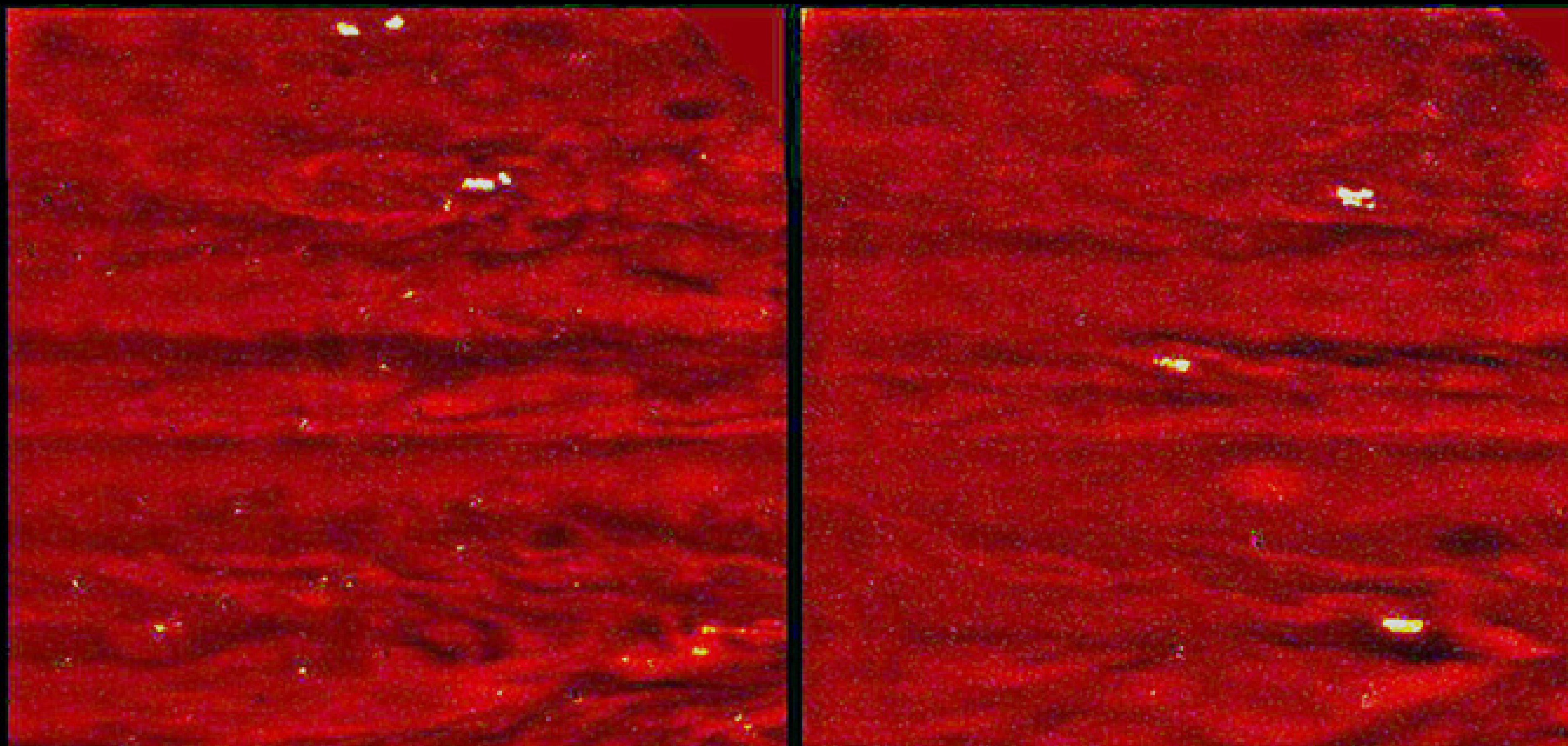
Jupiter Has the Right Ingredients for a Strong Magnetic Field…

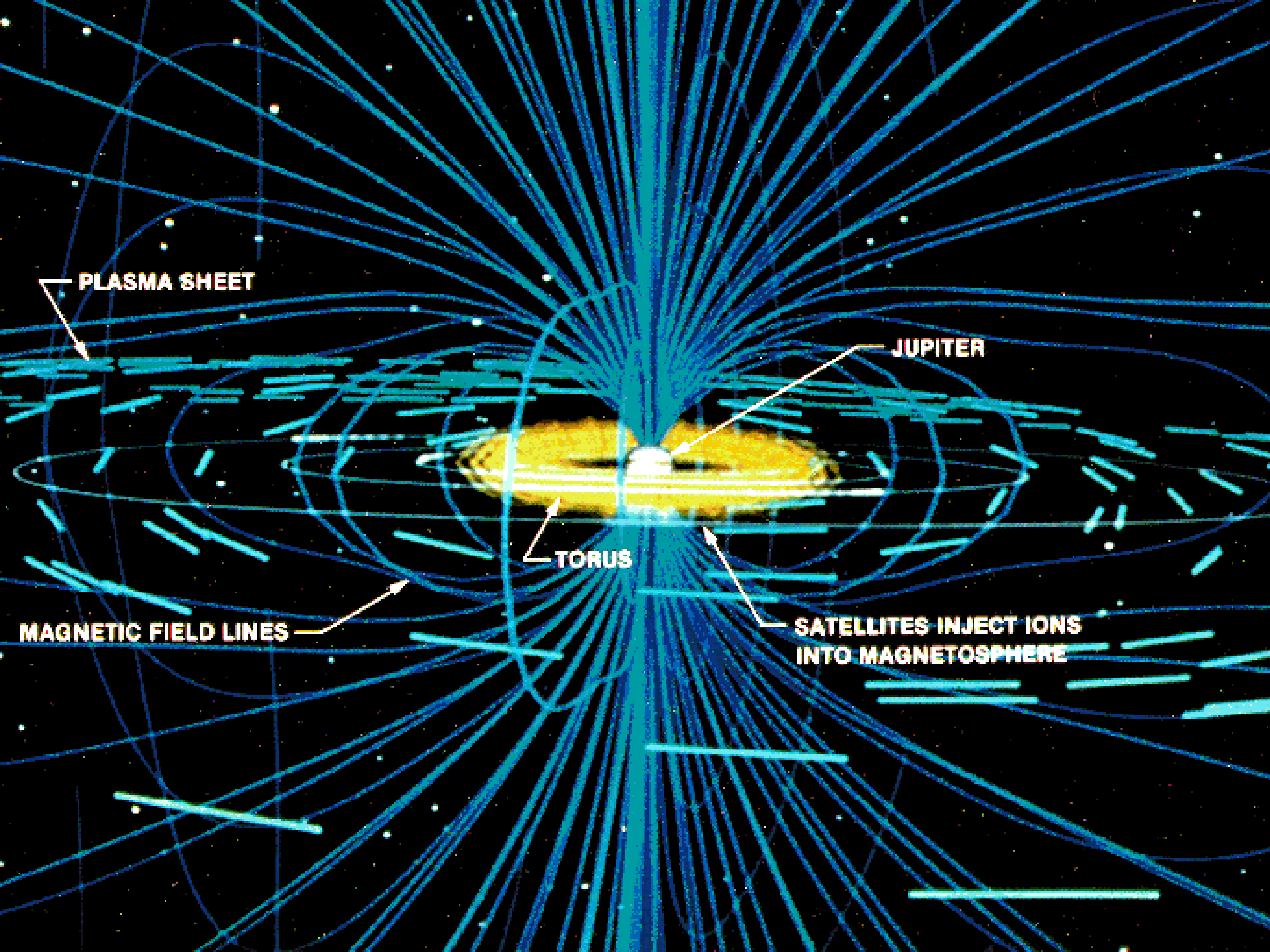
- Rapid rotation
- Hot interior and strong temperature gradient driving convection of…
- An electrically conducting interior – in this case, liquid hydrogen under so much pressure it behaves like a metal.
- The result – the most powerful magnetic field of any planet – by far.

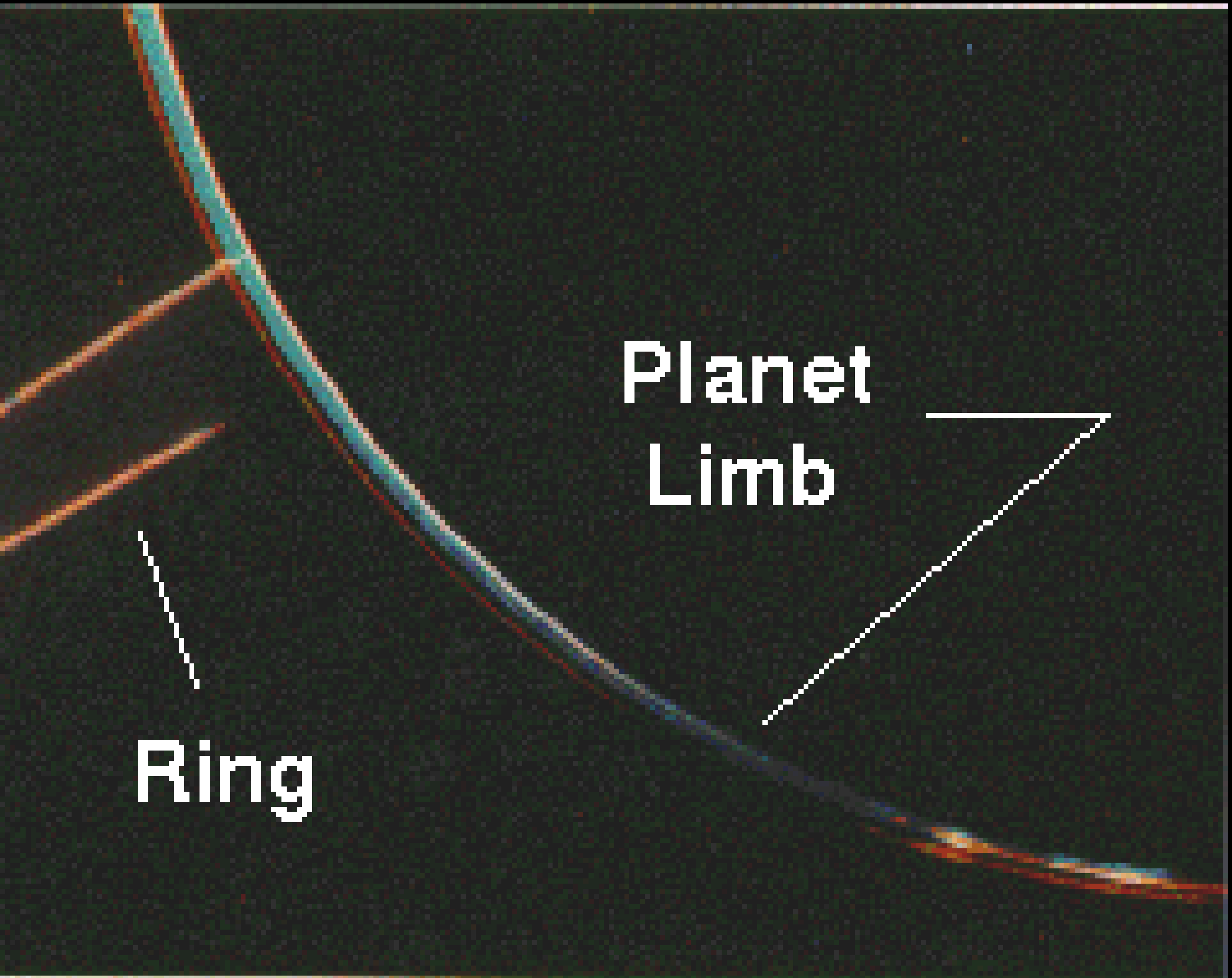

JOVIAN MAGNETOSPHERE/SOLAR WIND INTERACTION

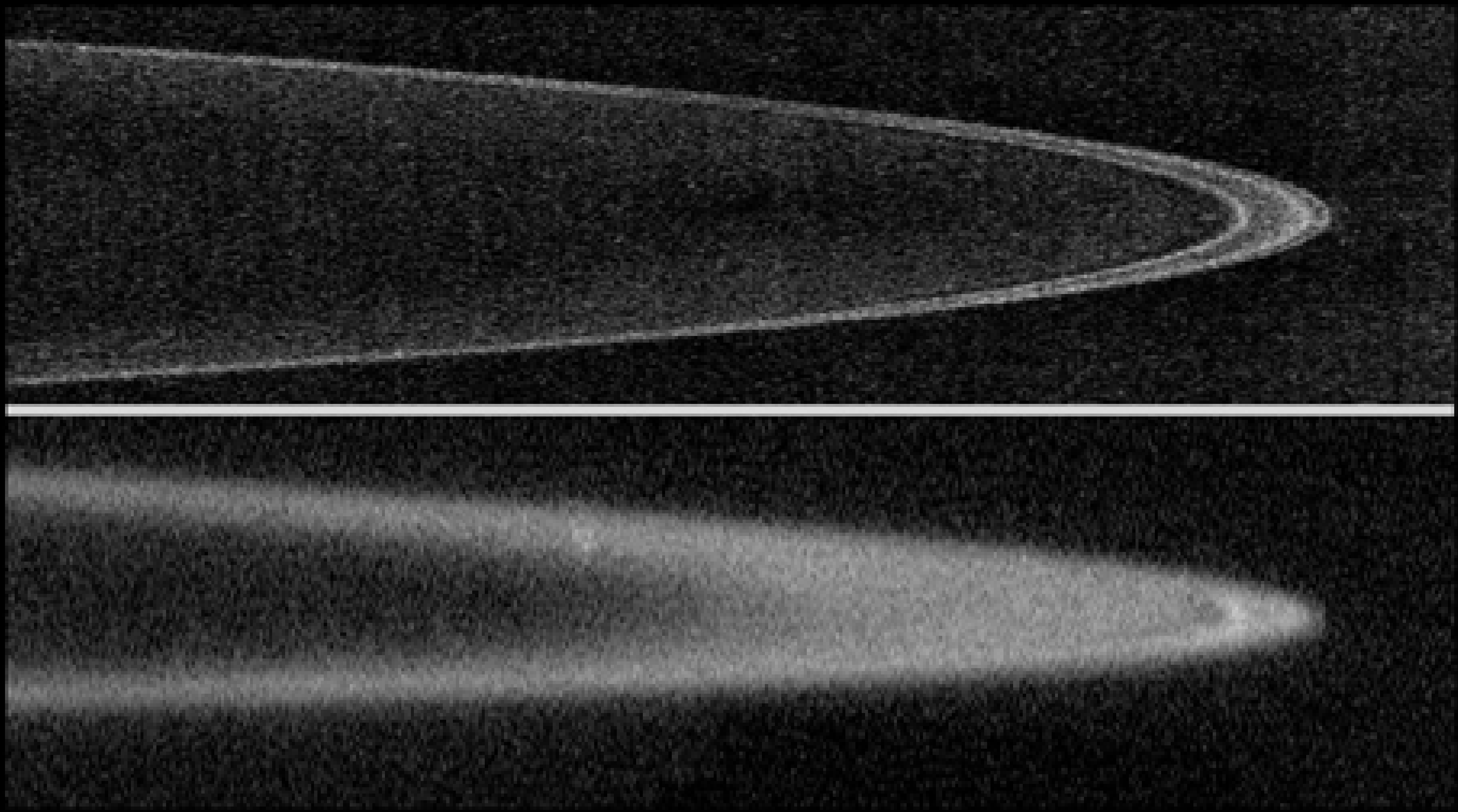
Jupiter's Aurora

The strong convection leads to Lightening

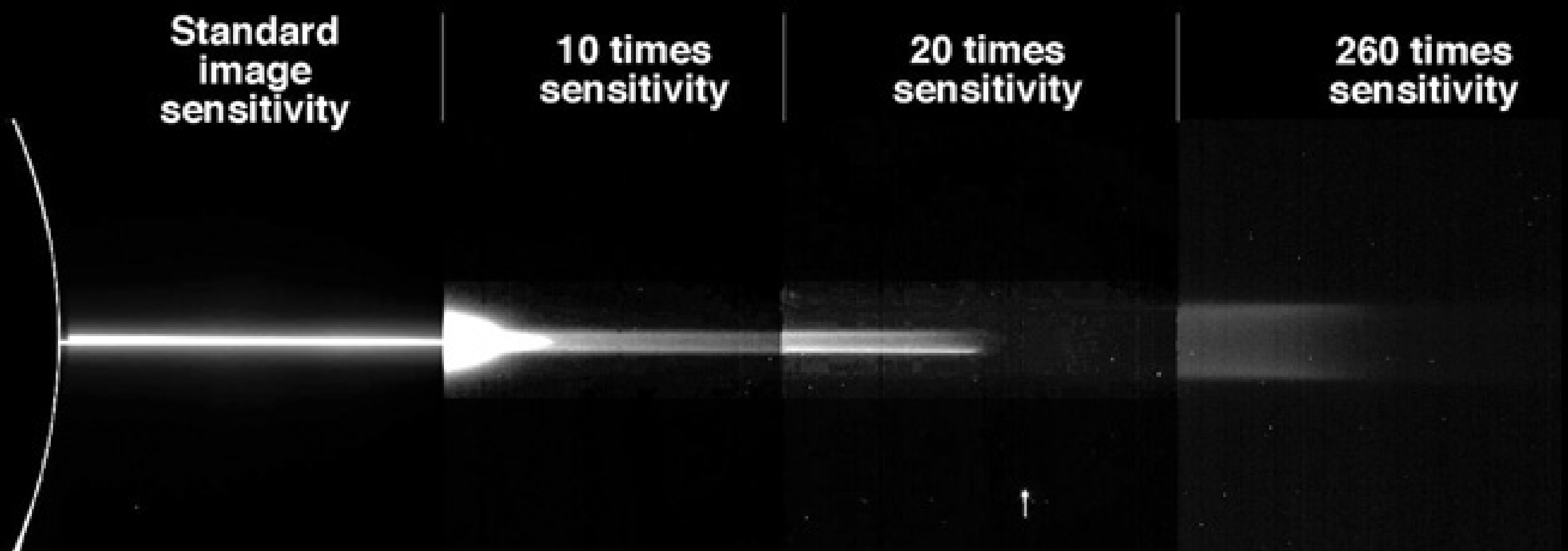



PLASMA SHEET
JUPITER
TORUS
MAGNETIC FIELD LINES
SATELLITES INJECT IONS
INTO MAGNETOSPHERE


Planet
Limb
Ring



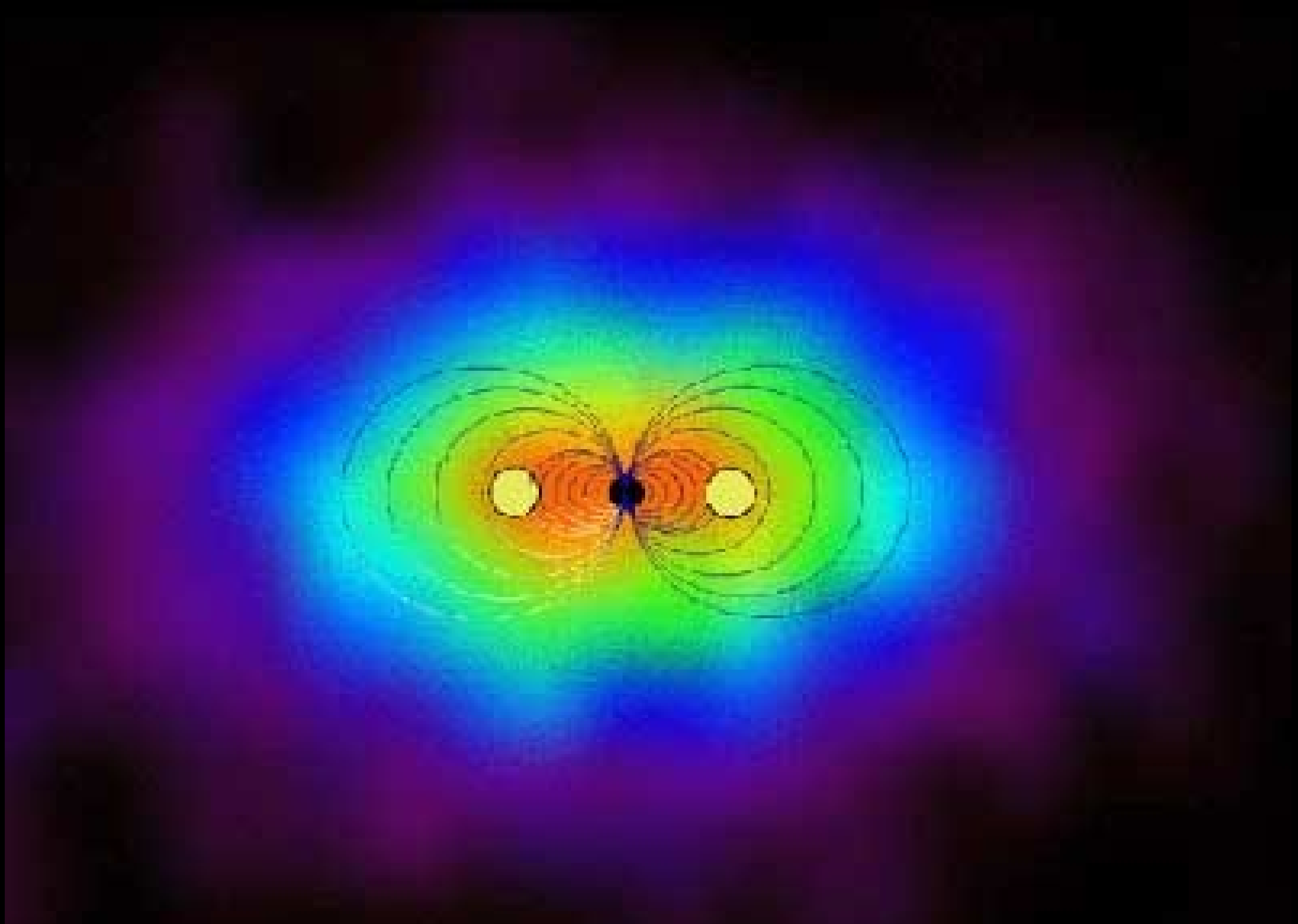
Jupiter's Ring, Seen Edge-on



Origin of Jupiter's Ring?

- Might be the remnants of a comet (icy dirtball) that was captured into an orbit and the ices eroded away by the ions trapped in the magnetic field
- But current thinking is that it's material launched into orbit around Jupiter by Io's volcanoes. The ring is made up of micron-sized particles, like volcanic ash.

A Radio Image, Showing Spiraling Solar Wind Electrons Caught in Jupiter's Powerful Magnetic Field

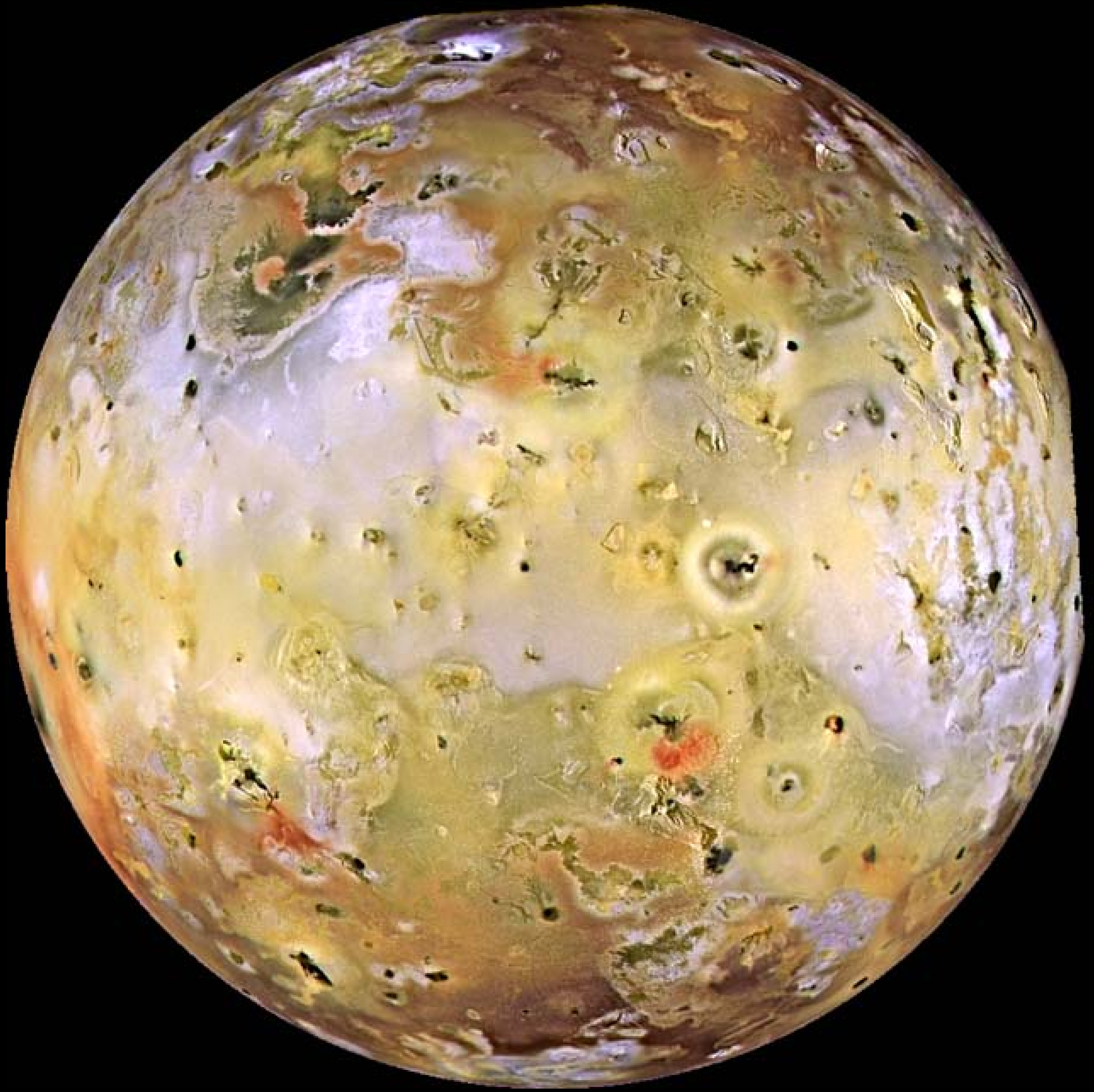


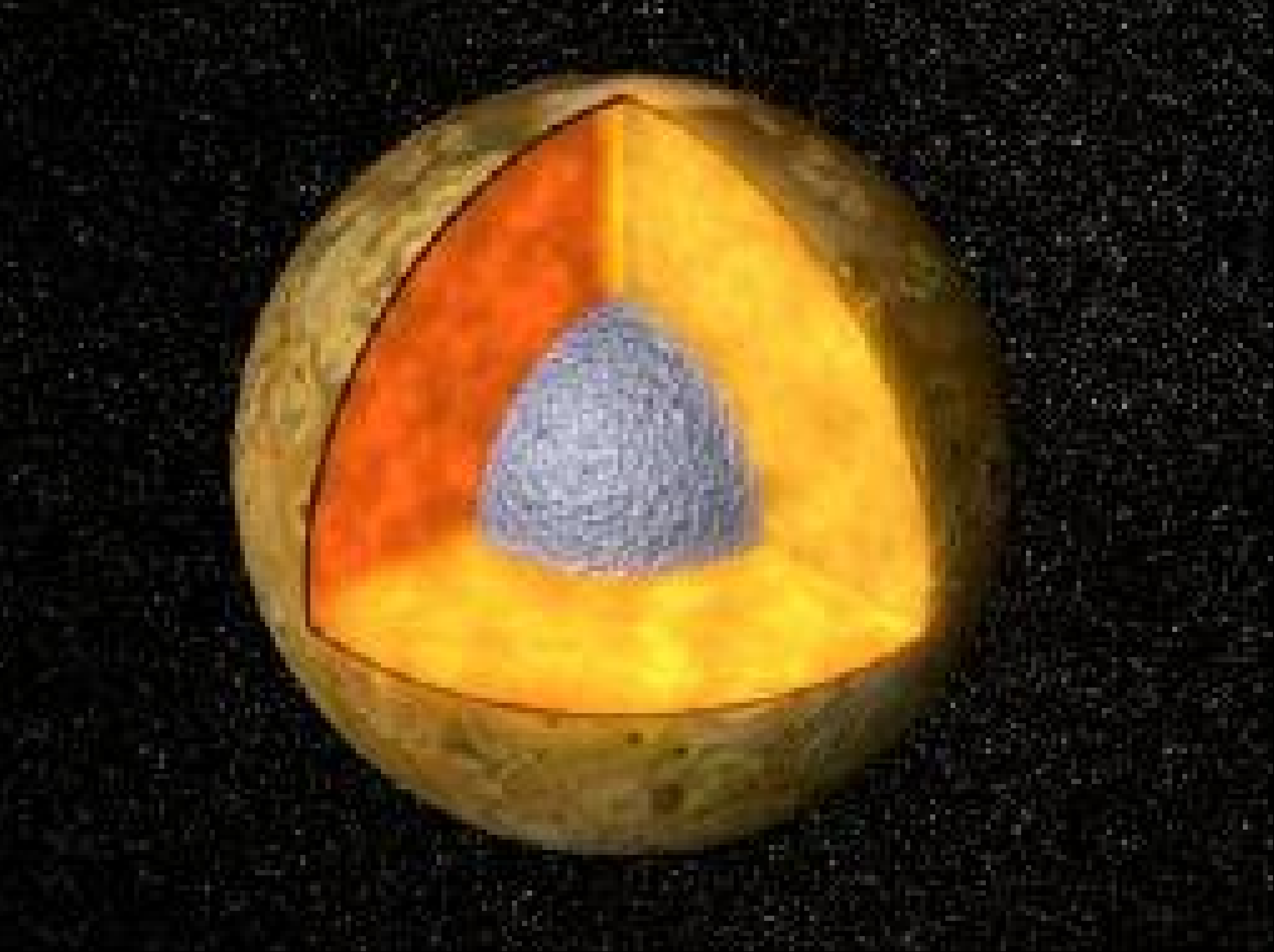
Jupiter's Moons – 80 at last count

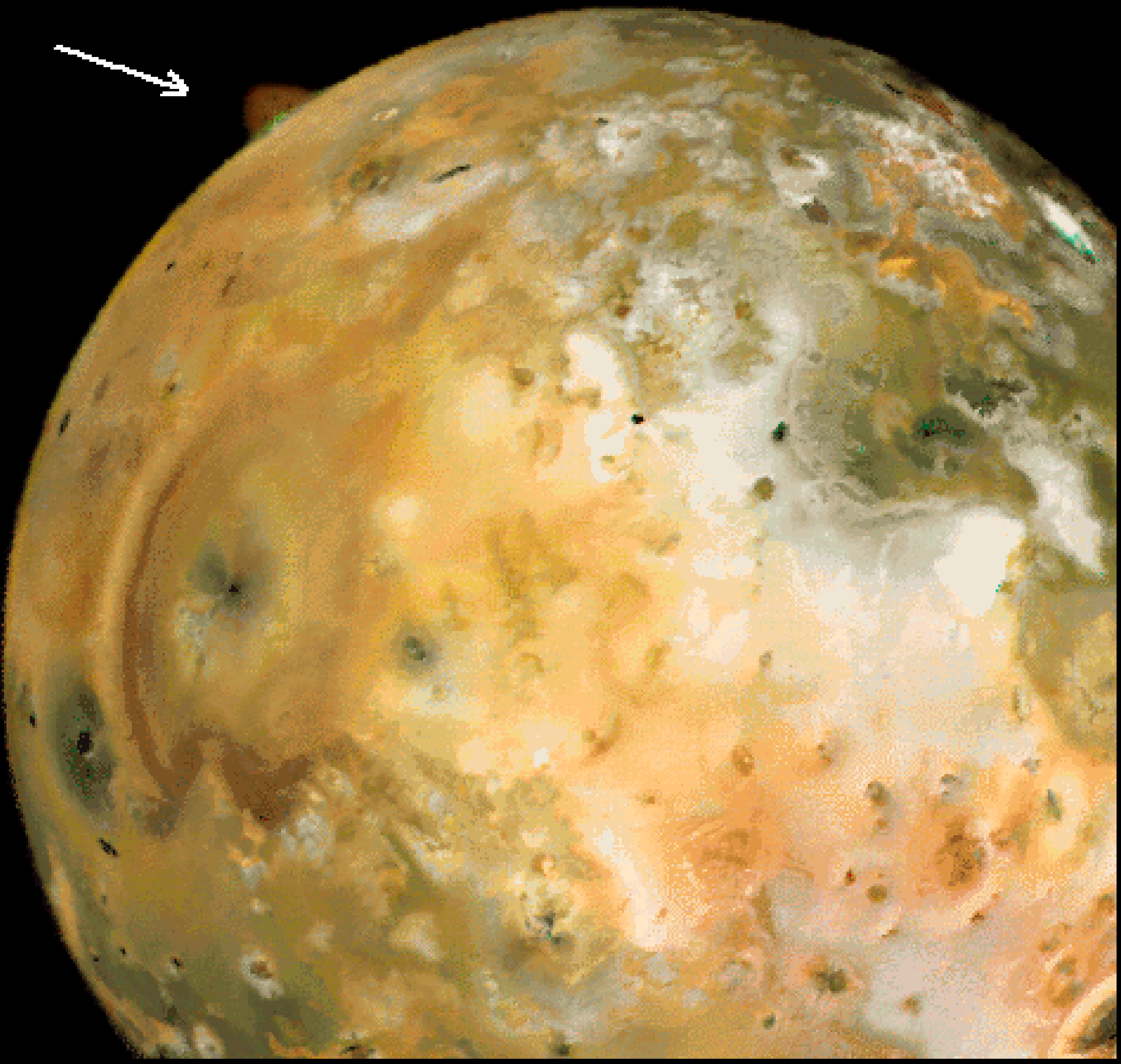
- The 4 big ones are roughly the size of our own moon – 1500 – 3000 miles across
- From closer to farther, they are: Io, Europa, Ganymede and Callisto
- Io's orbit is a bit elliptical, and only a couple of Jupiter diameters away from Jupiter – this has a huge effect on the properties of this little moon

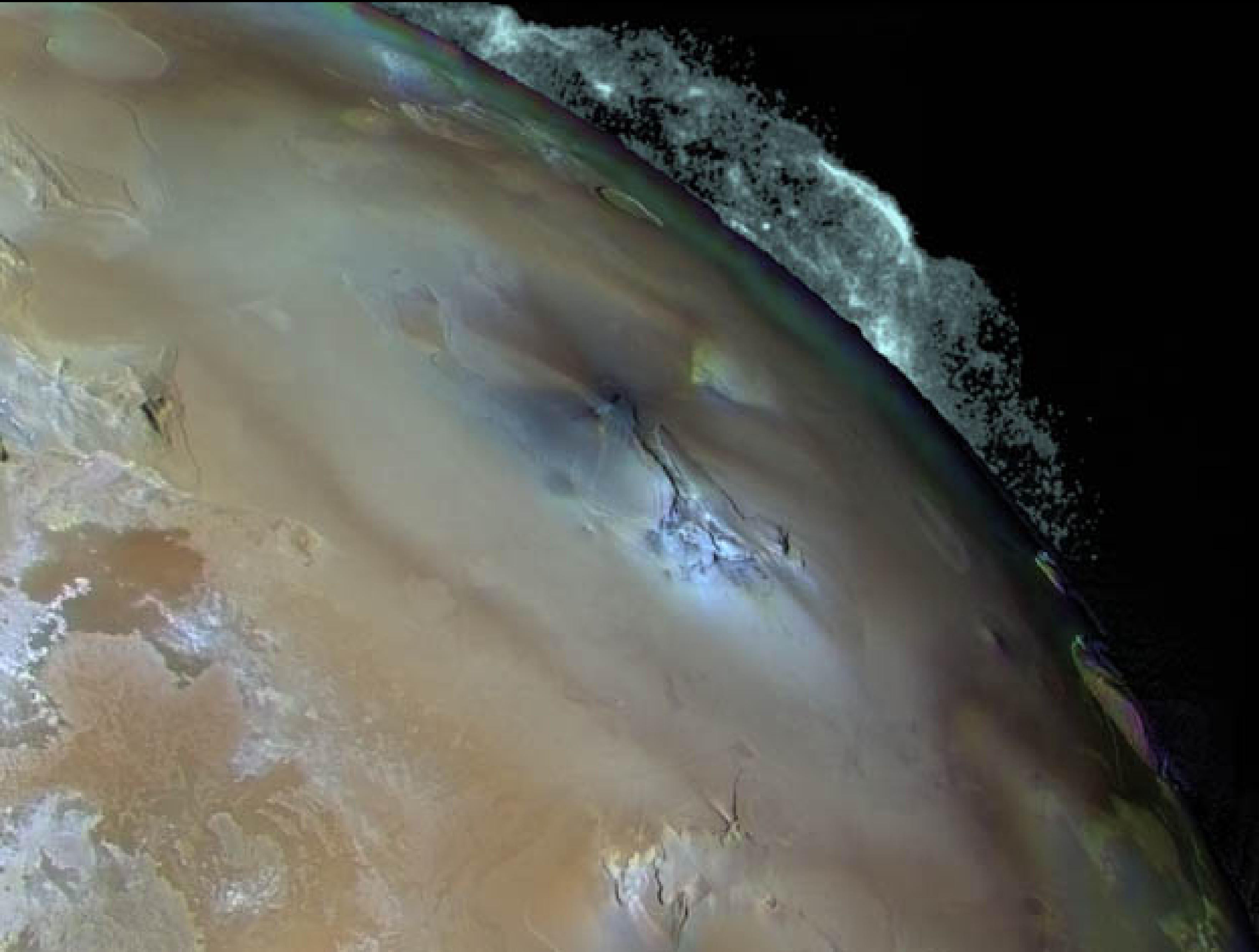
Jupiter's Huge Gravity and the Closeness of Io means Io Experiences Strong Tidal Stretching

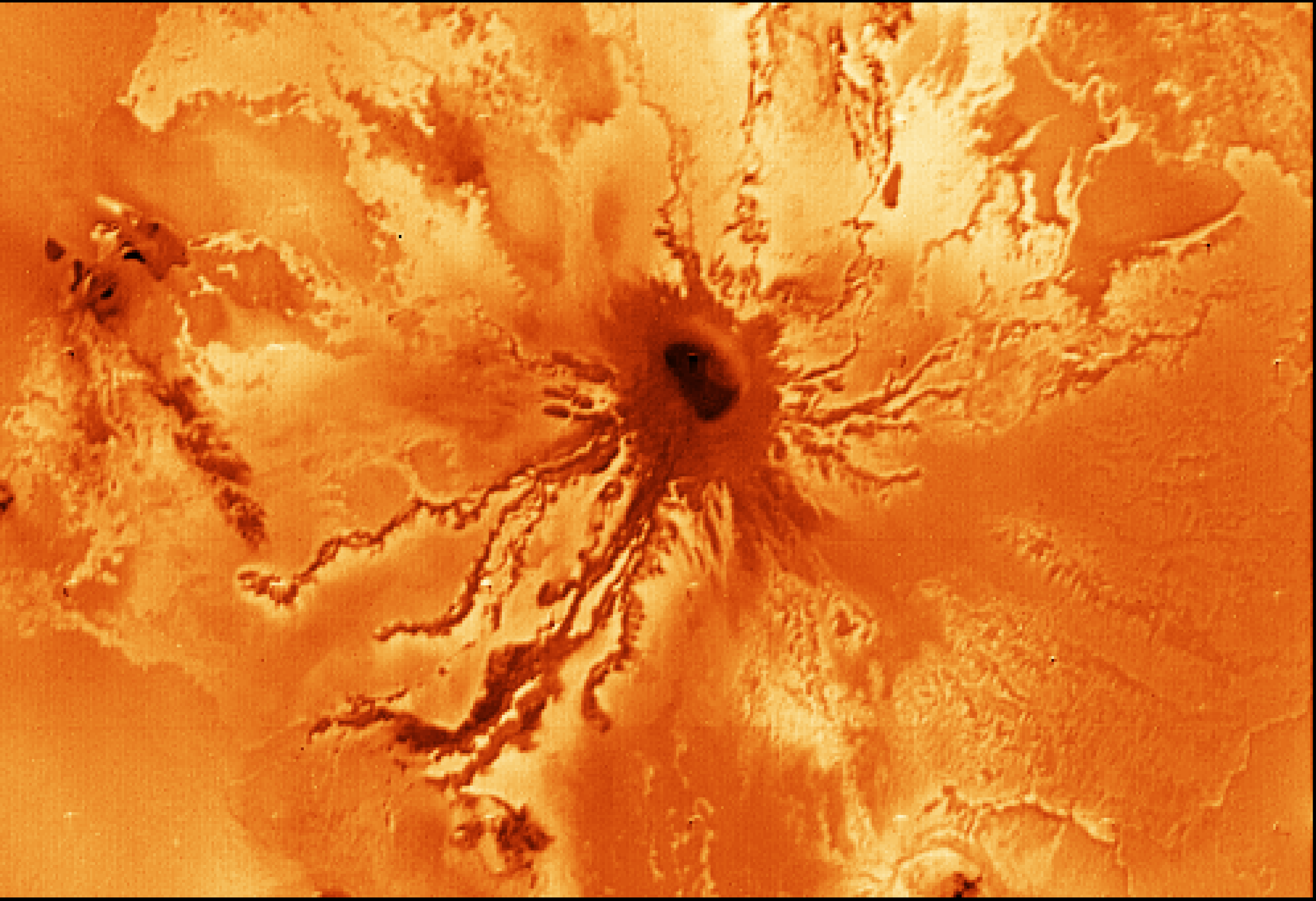
- This tidal force varies from weaker to stronger as Io goes from closer to farther from Jupiter in its slightly elliptical orbit. This rhythmic squeezing and stretching of the moon heats the interior – ***tidal friction***
- It's surprisingly effective. The volcanoes have vent temperatures of 2000F, melting sulfur, a relatively light element that is rich in the upper layers, and vaporizing any water or other icy materials.

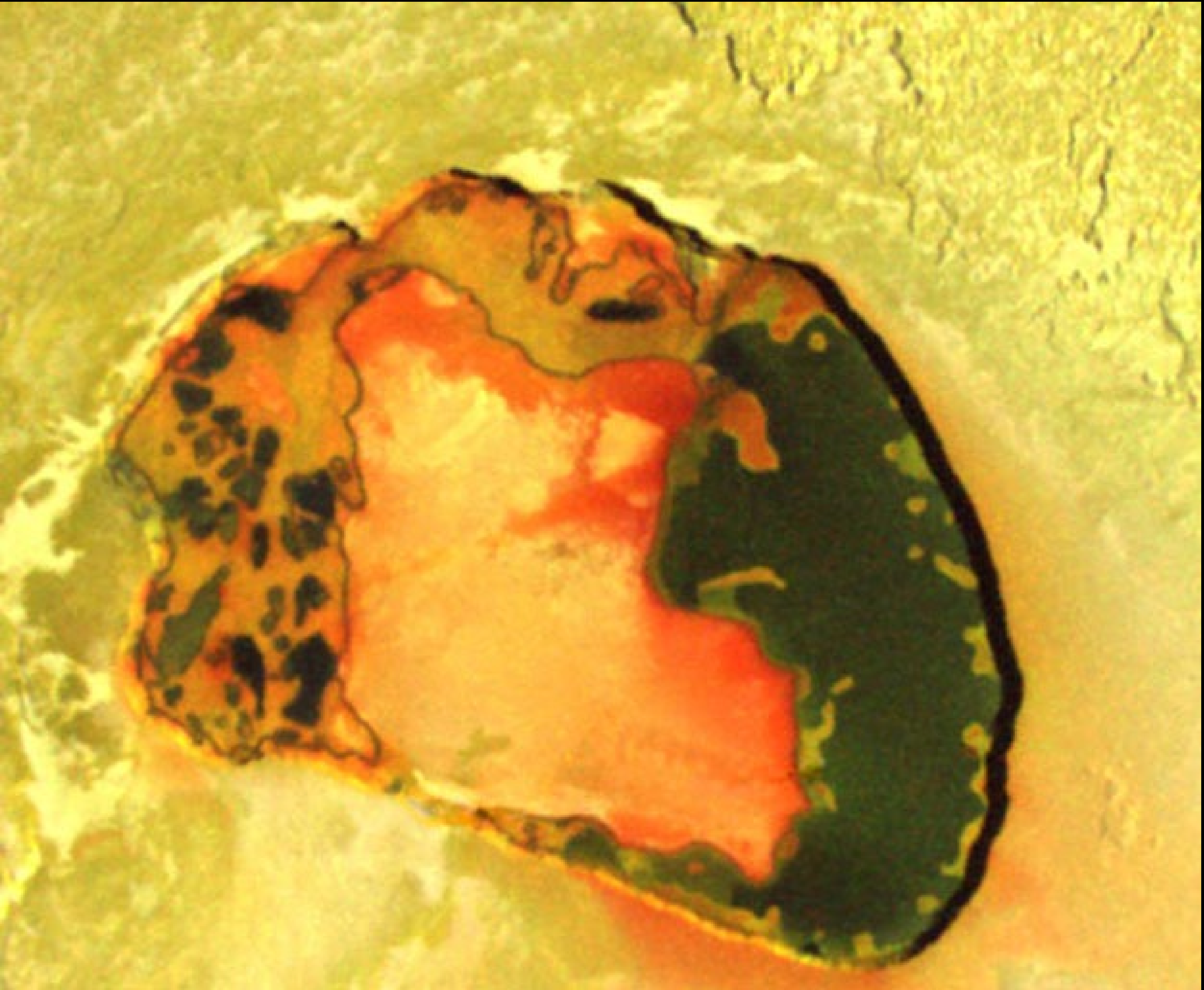


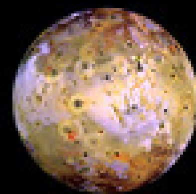






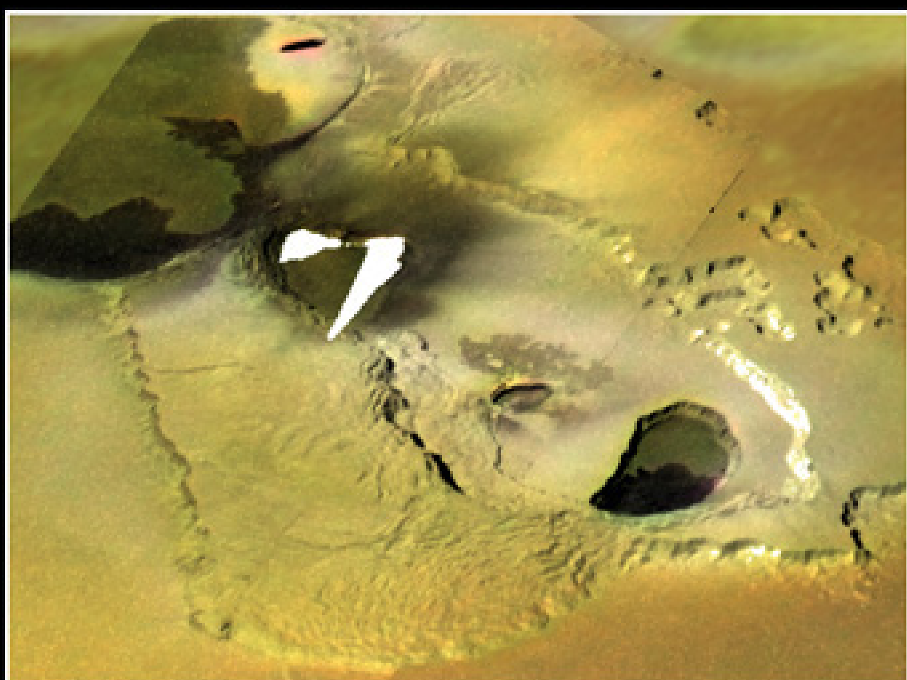




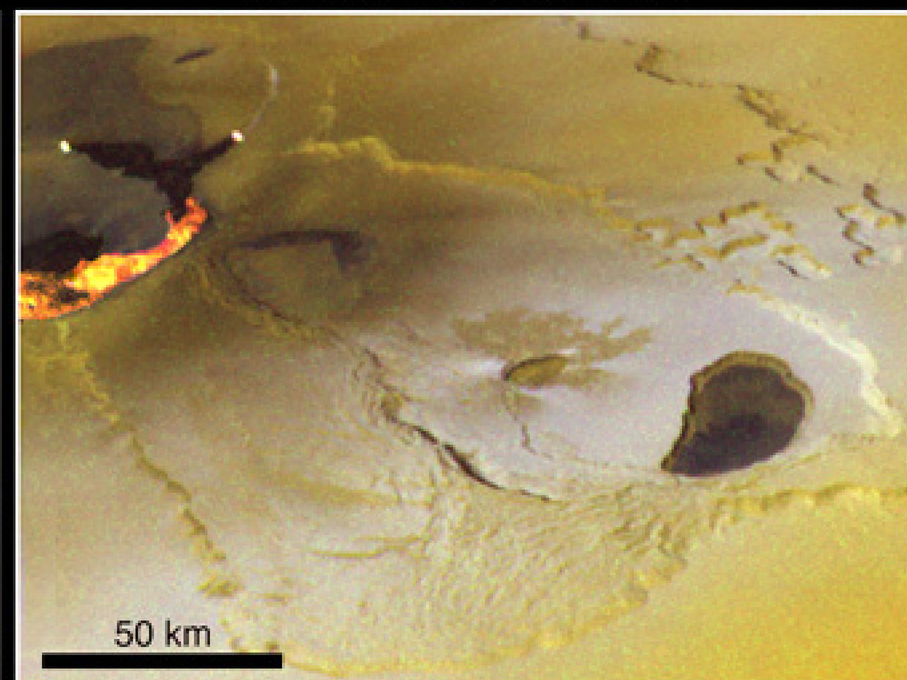


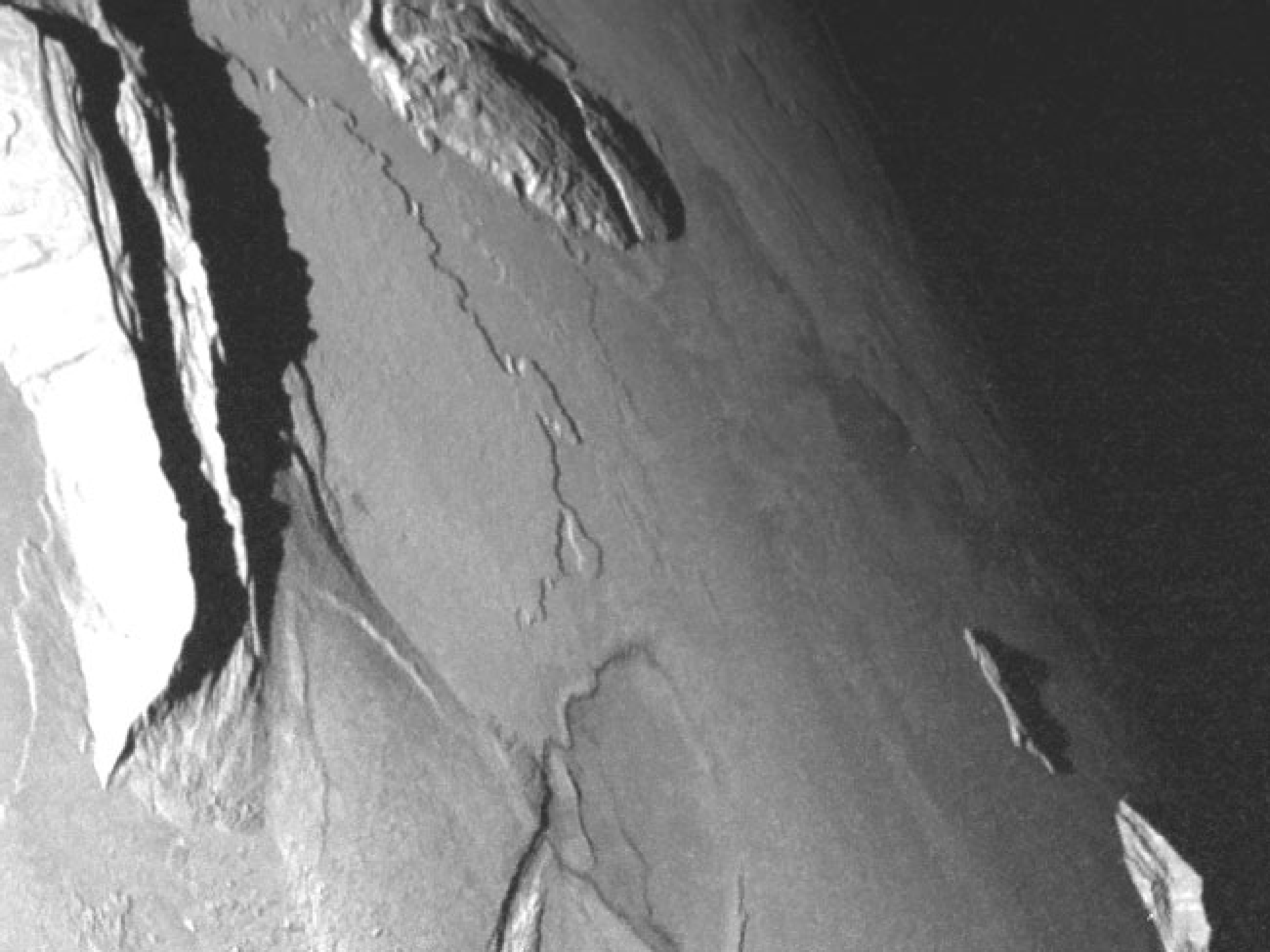
Io — Tvashtar Catena

I25 (26 Nov 1999)
+ C21 low-resolution color



I27 (22 Feb 2000)
visible wavelength data
+ IR data of active lava flow



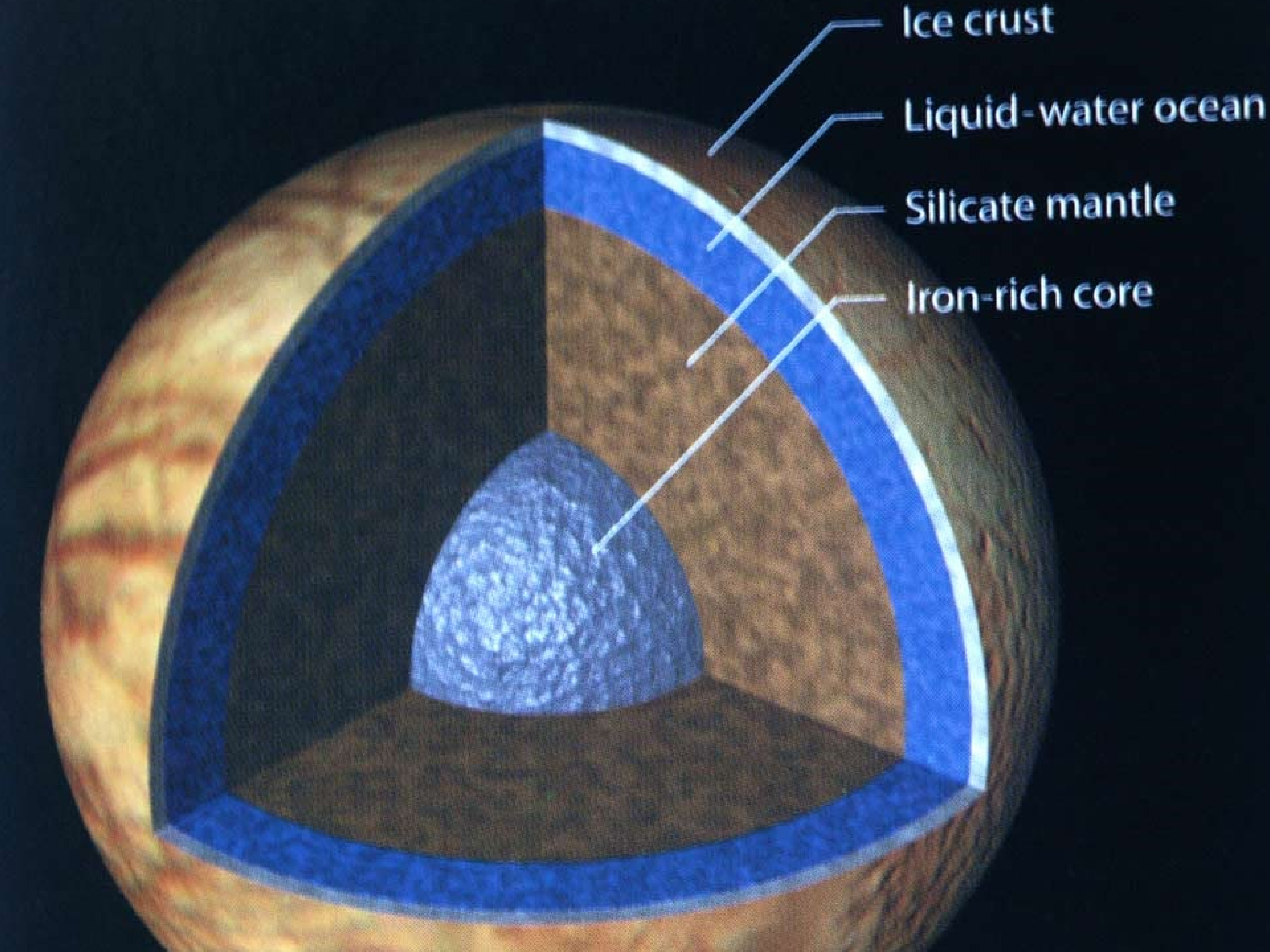


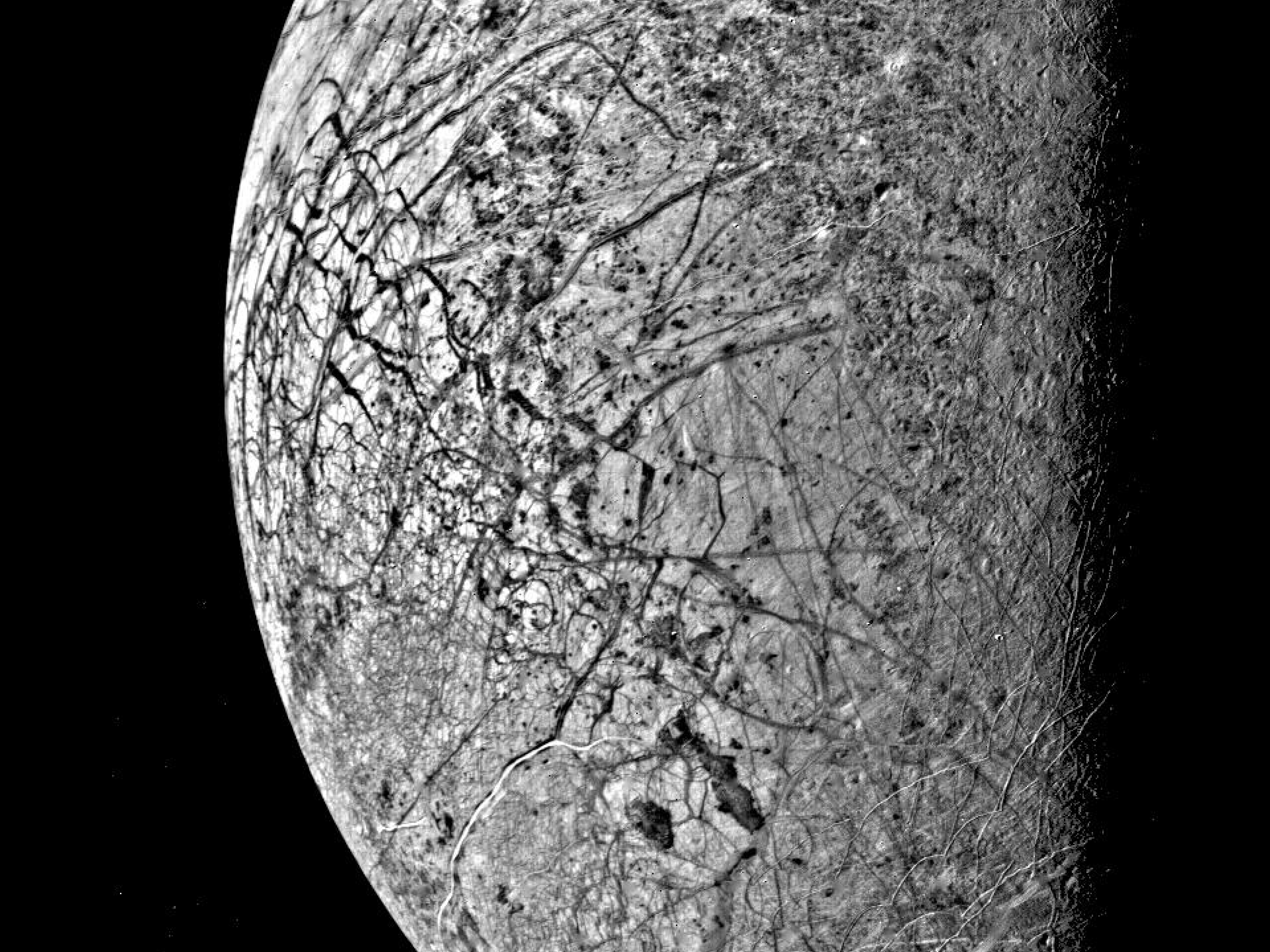
Summary on Io

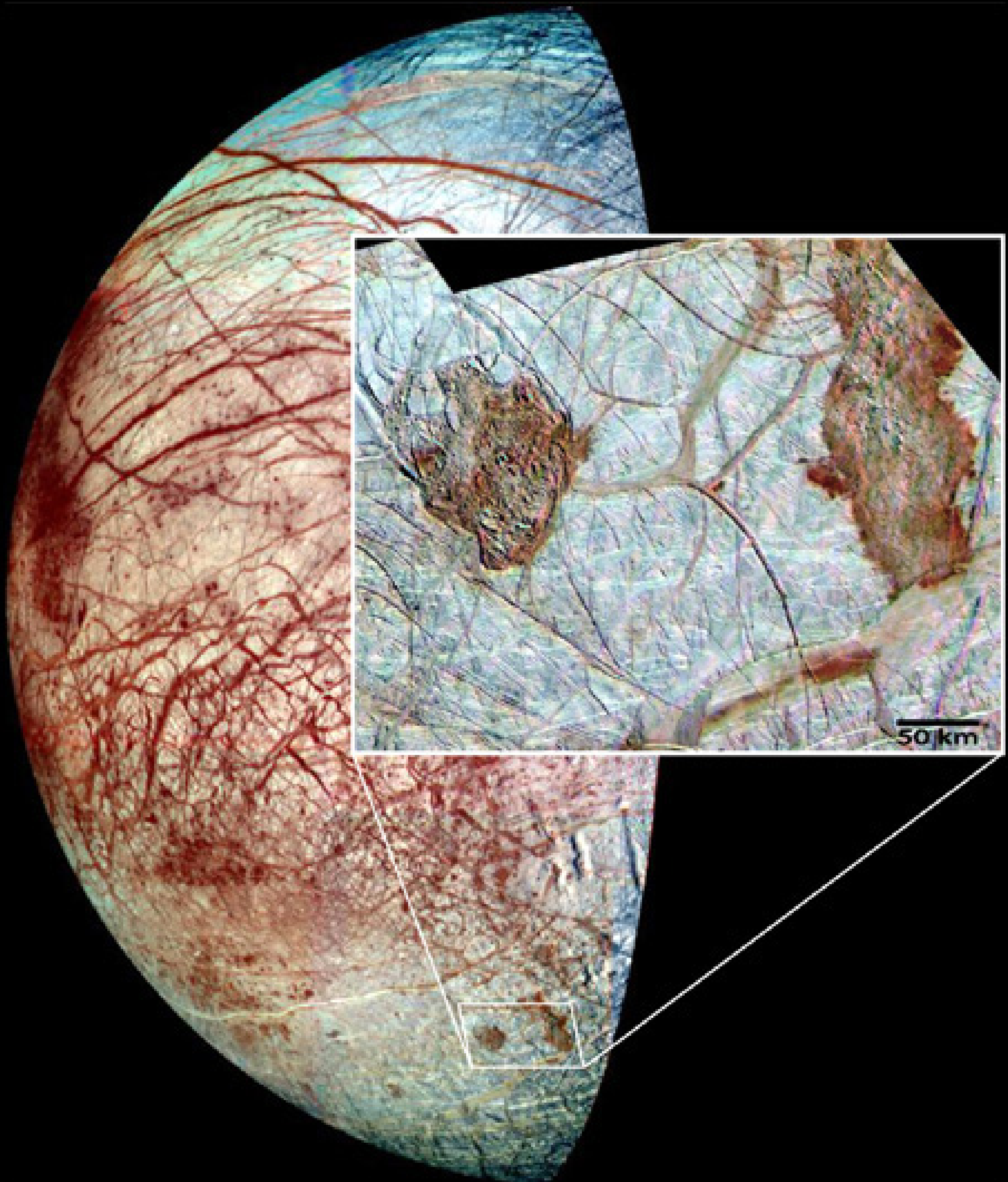
- Io is stretched more, then less, then more, then less…etc. for each and every 42hr orbit.
- This converts orbital kinetic energy into thermal energy, heating the interior above the melting point of sulfur (239F or 115C), and it burbles up through cracks to make volcanoes.
- Constant volcanic eruptions quickly fill in all craters that may have existed
- Volcanic particles can escape Io's weak gravity. And eventually friction decays the orbit and the material settles onto Jupiter, coloring its clouds.
- **We suspect Io's initial watery surface boiled away from the tidal heating, hence Io is smaller than the other 3 Galilean Moons**

Europa – Also Tidally Heated, But Less So

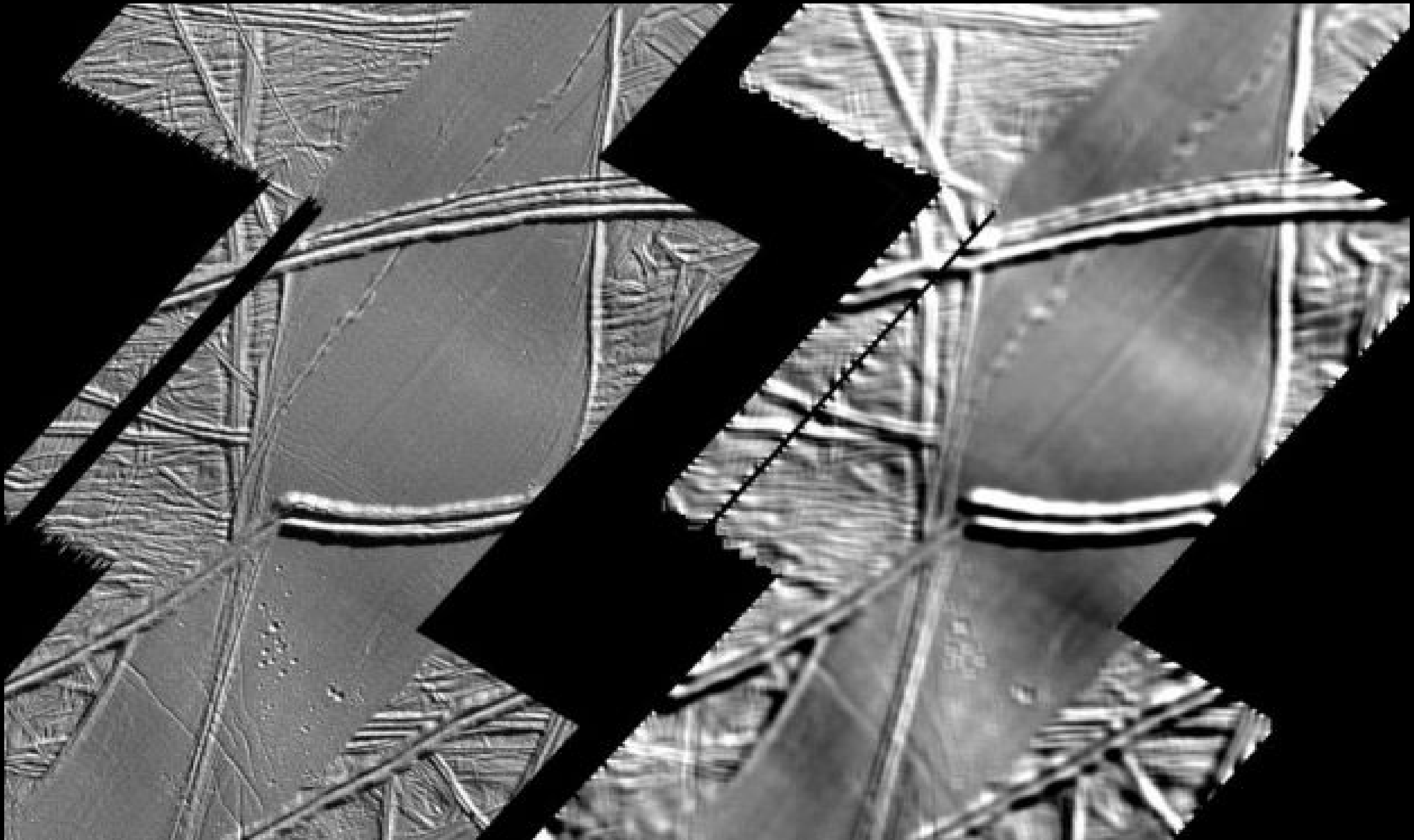
- But not so hot as to evaporate water away. Water is a very common molecule.
- Europa is an Arctic world of salt water covered by ice
- Cracks show characteristics of salt-water pressure ridges
- Intriguing… salt water ocean warm enough to support life, is what the evidence suggests…. What might be lurking down there??

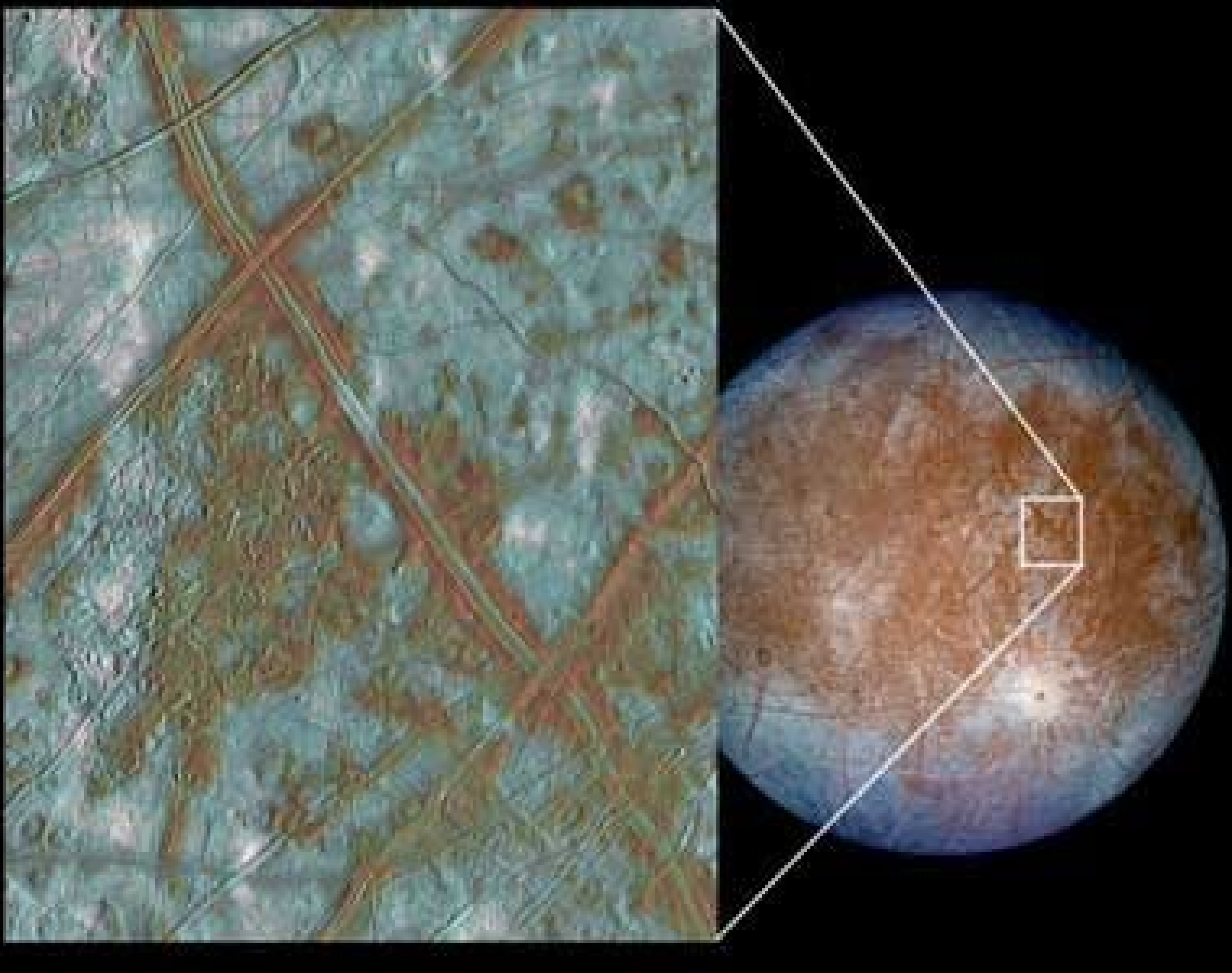

Ice crust
Liquid-water ocean
Silicate mantle
Iron-rich core

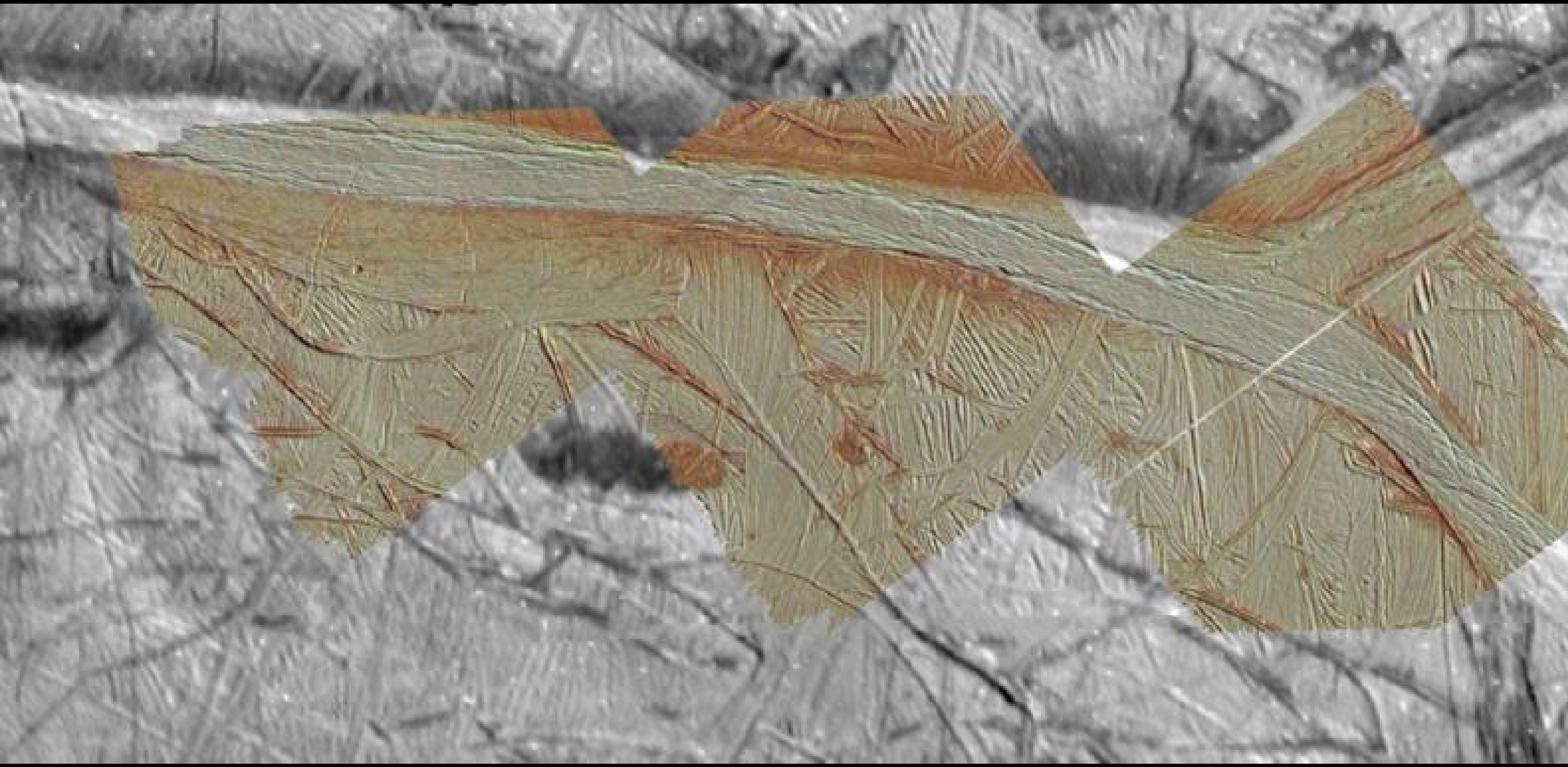



50 km

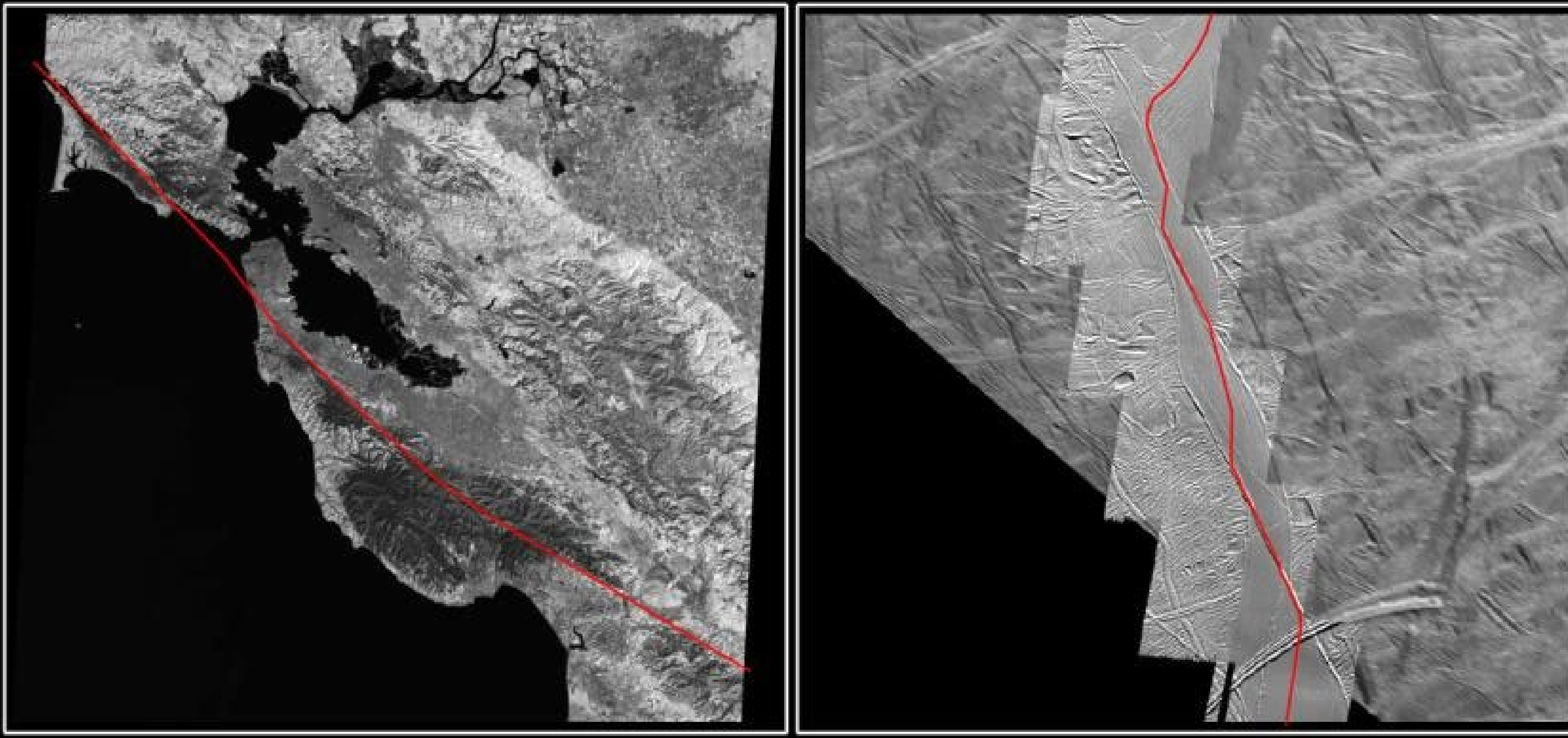
Pressure Ridges, Sharpened by Image Processing. The Reddish Color Likely Mineral Salts Evaporite



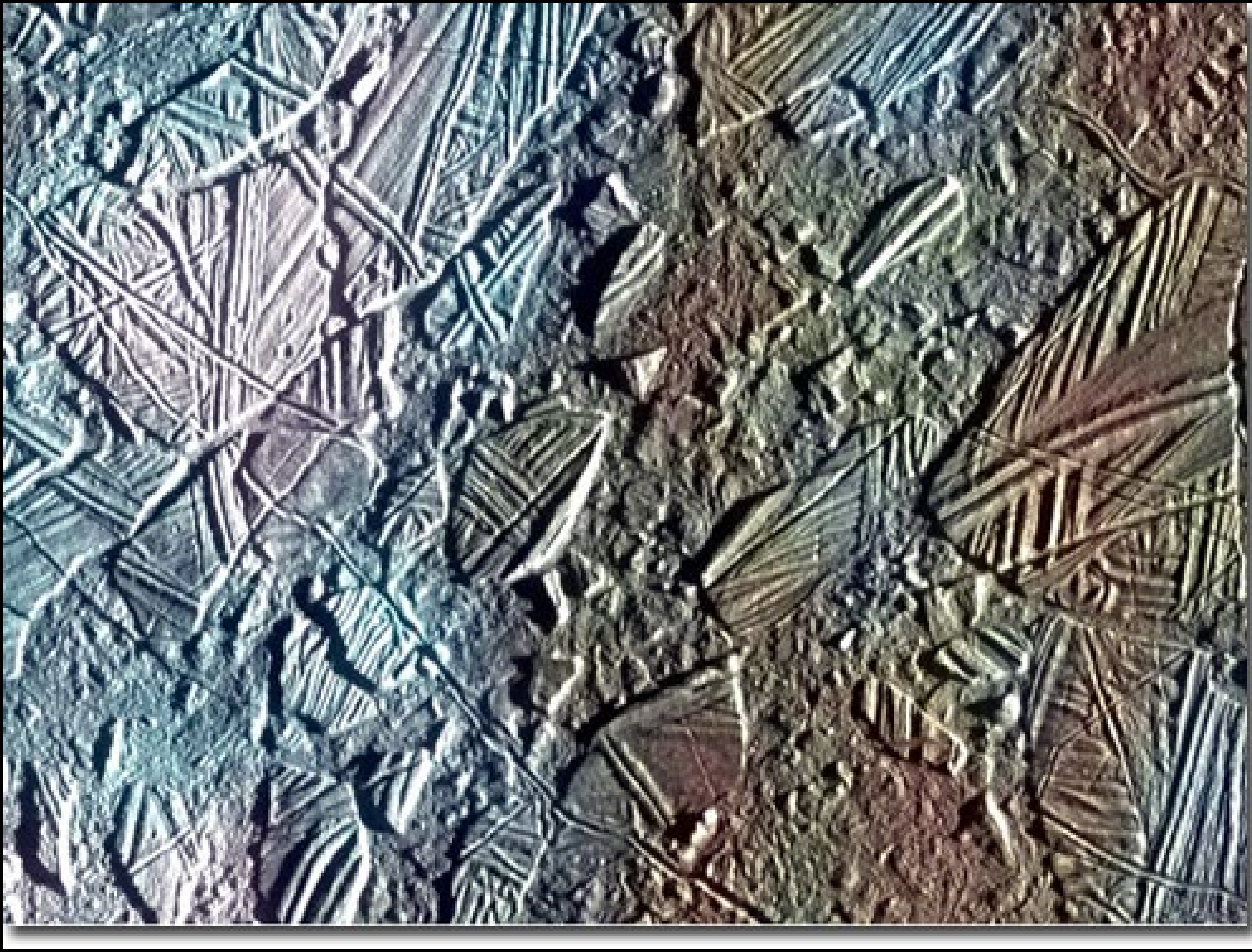




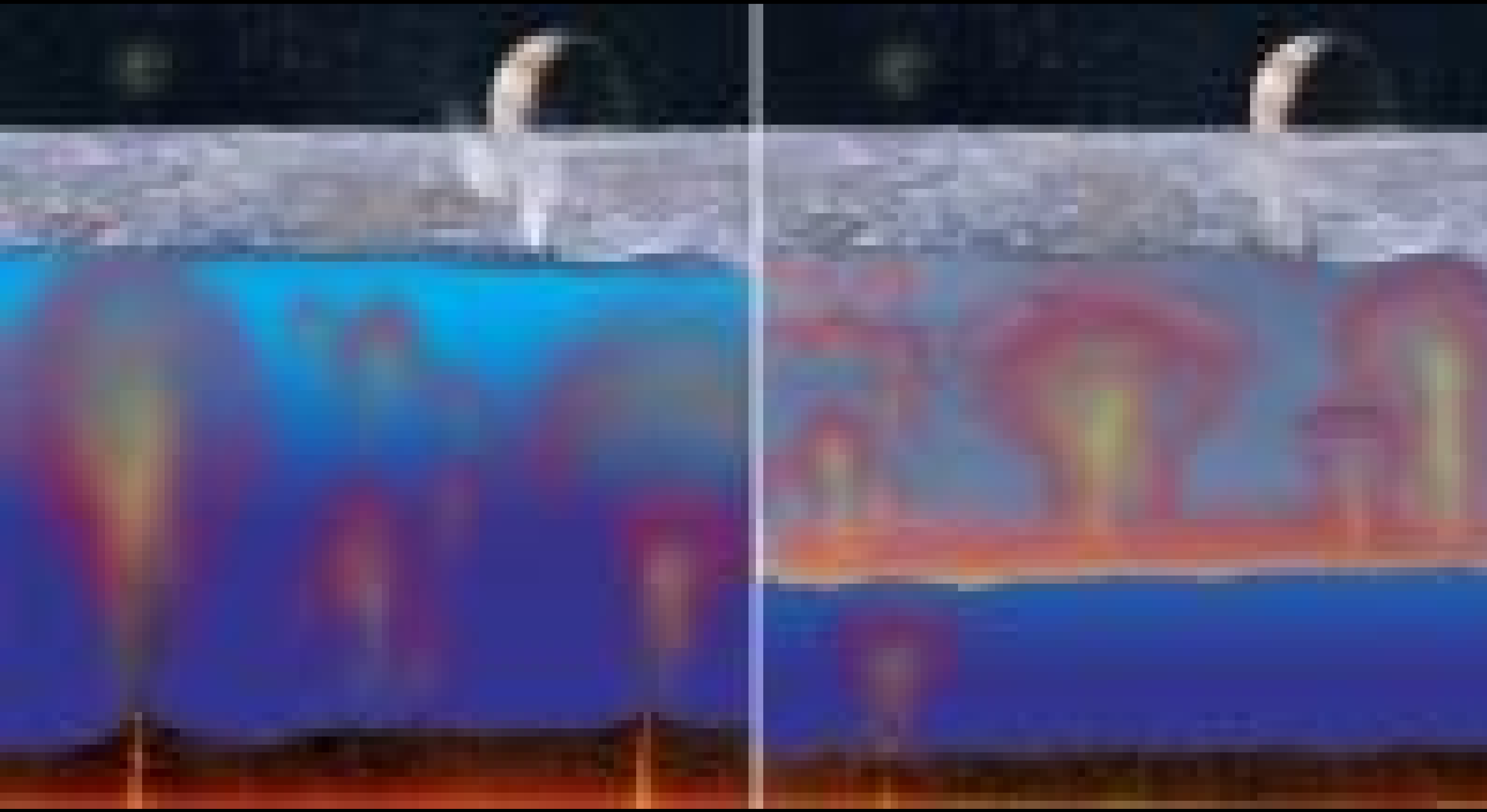
Strike-Slip Faults: Earth *vs.* Europa



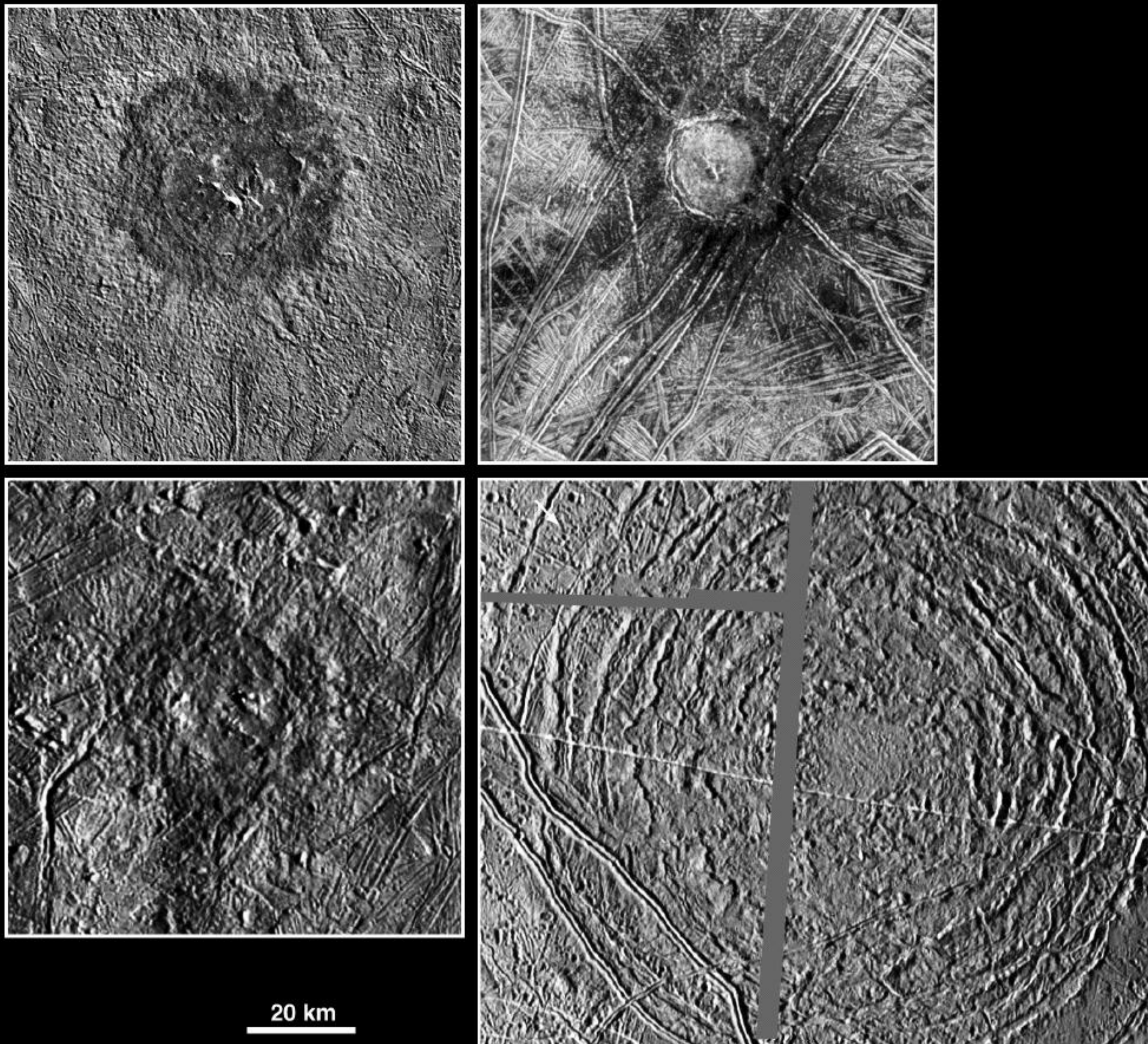
Ice Floes in Repeatedly Thawed/Frozen Sea?



A Suggested model for Europa - Thermal Vents from the Hot Core Drive Convection in the Ocean, Driving “Tectonics” in the Ice Crust?



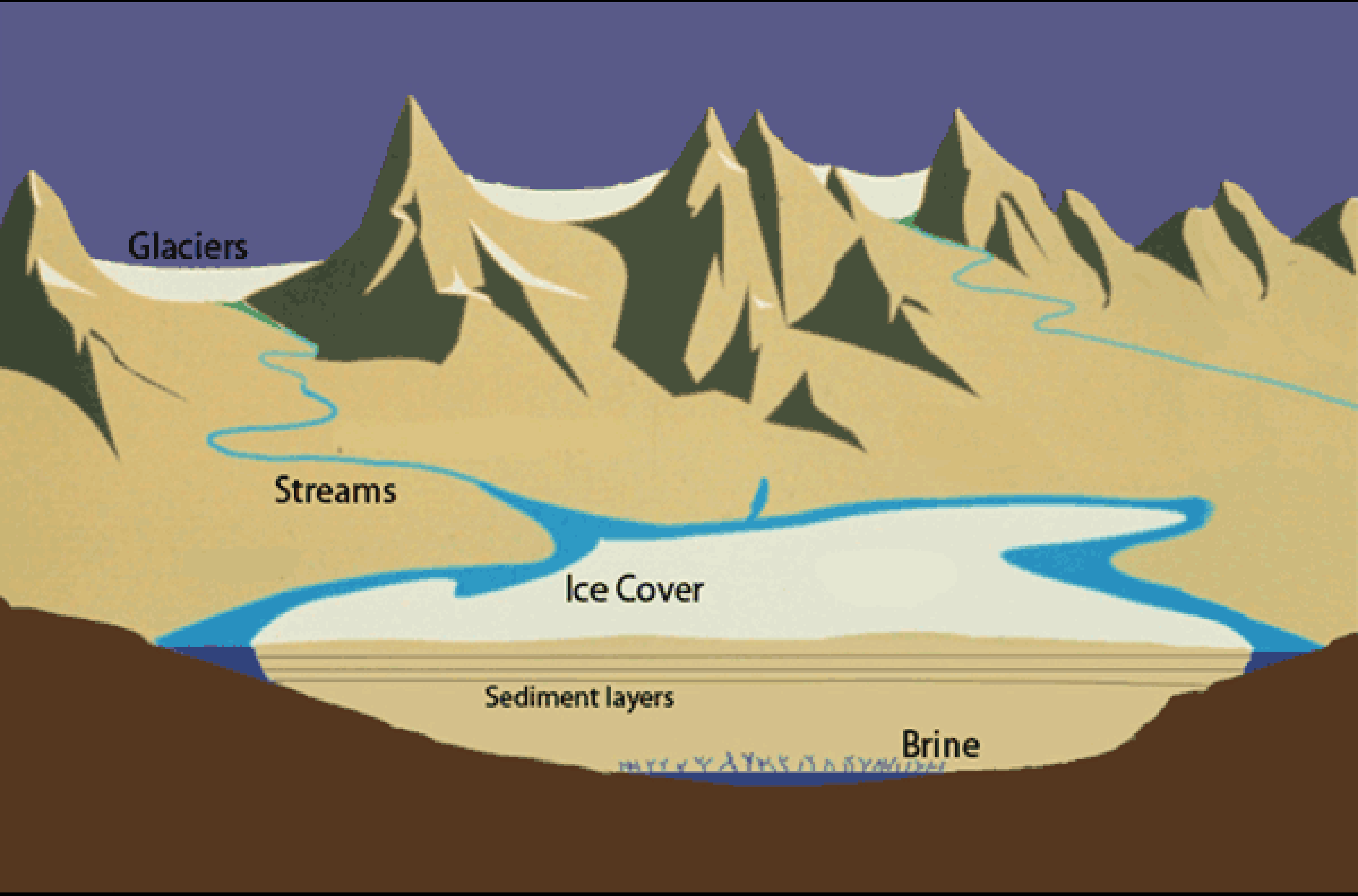
Impact Craters in the Ice



Antarctica's Lake Vida – closest analogue to Europa? There's briney water at the bottom of the lake, isolated from the surface.

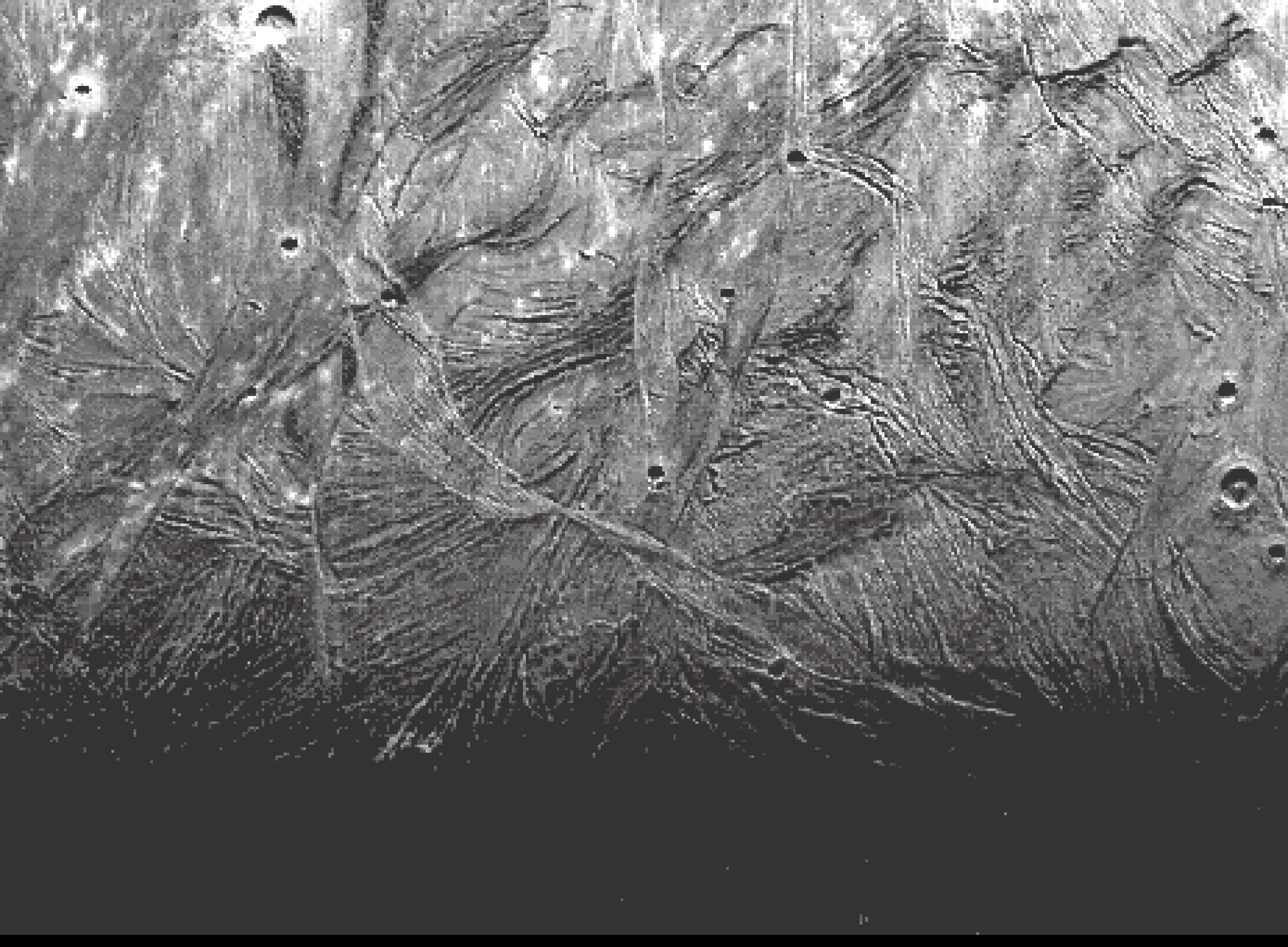
Lake Vida: A frozen Lake with a Thin layer of brine water at the bottom

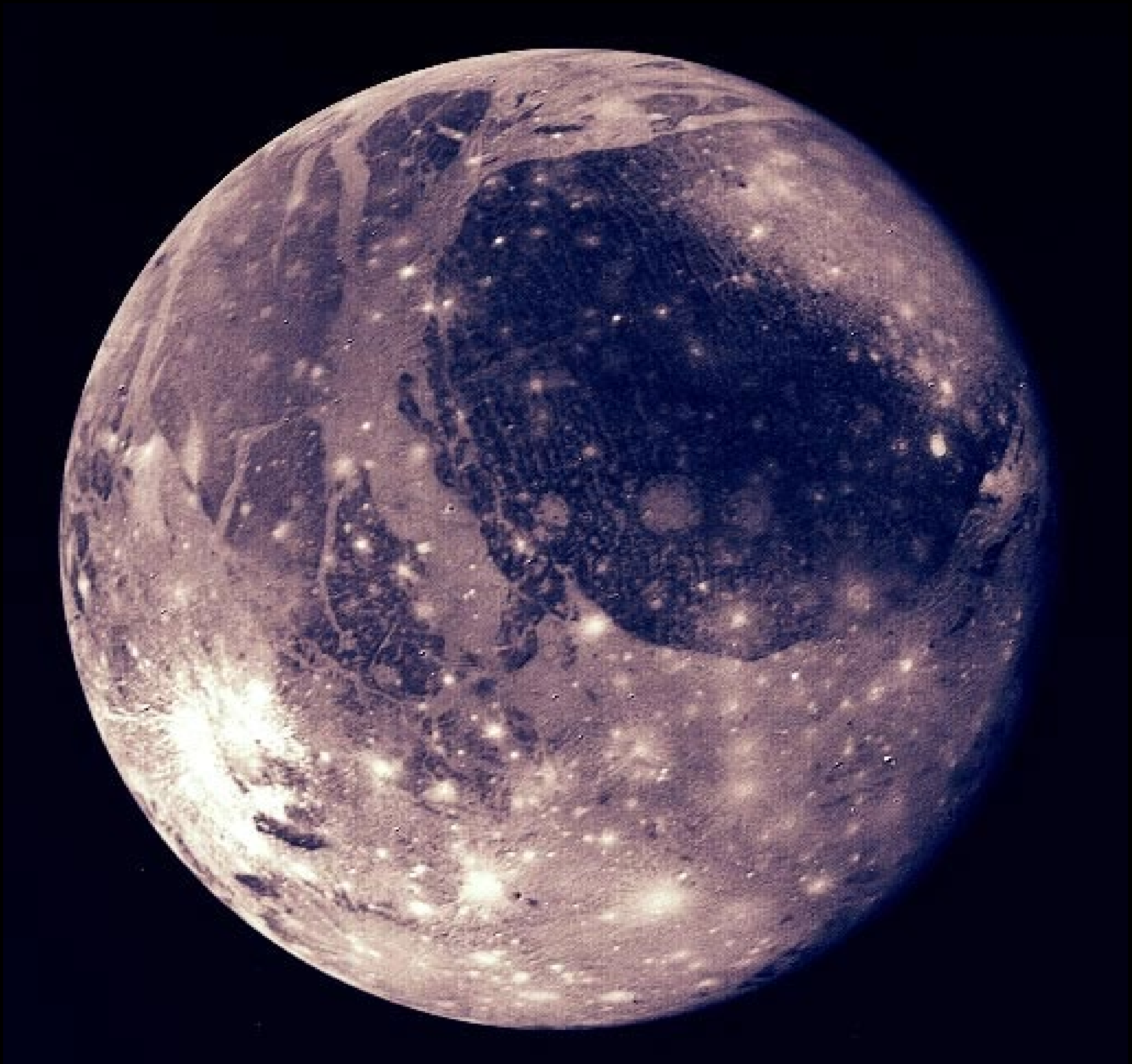
And: The brine layer turns out to be rich in bacterial life!

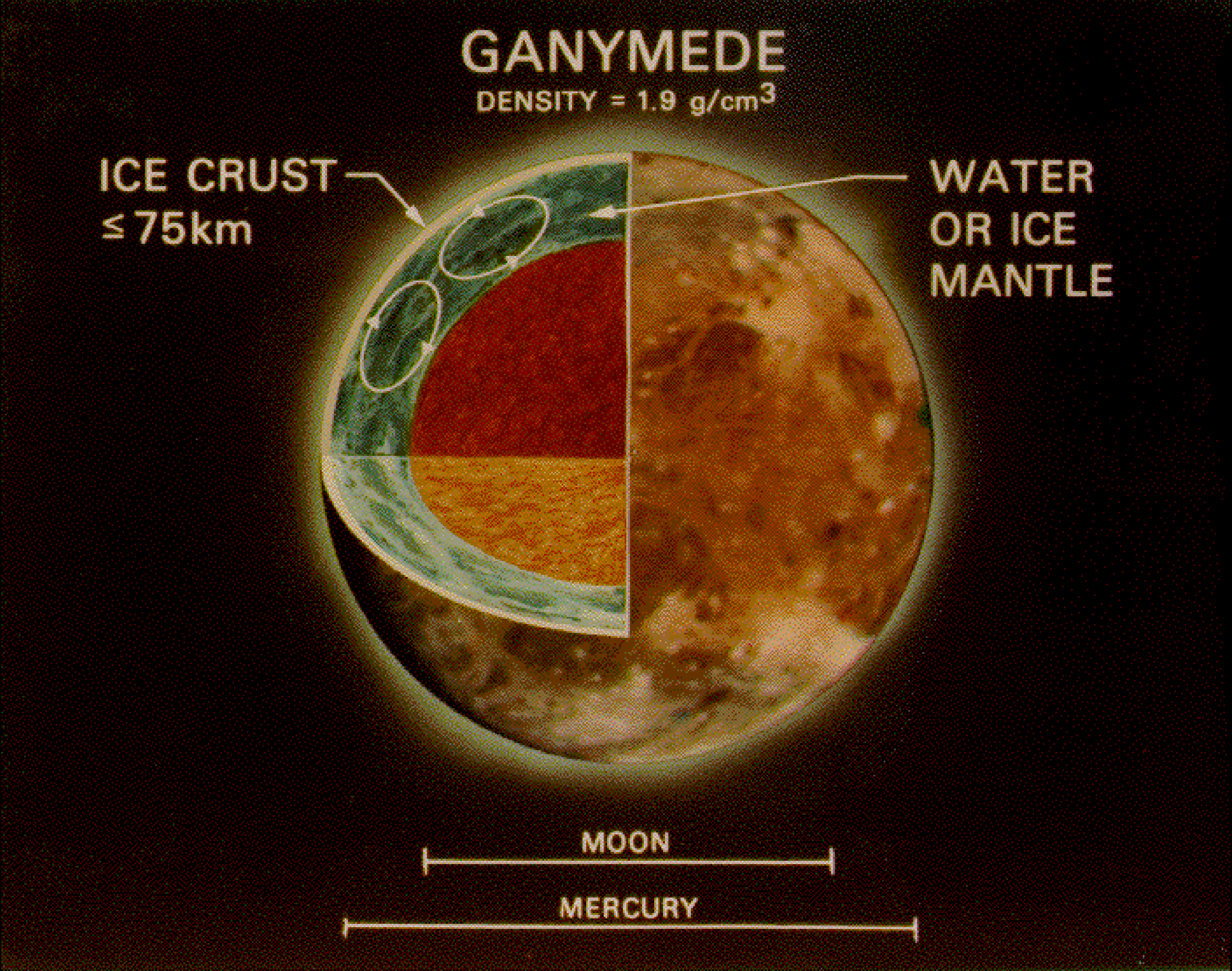


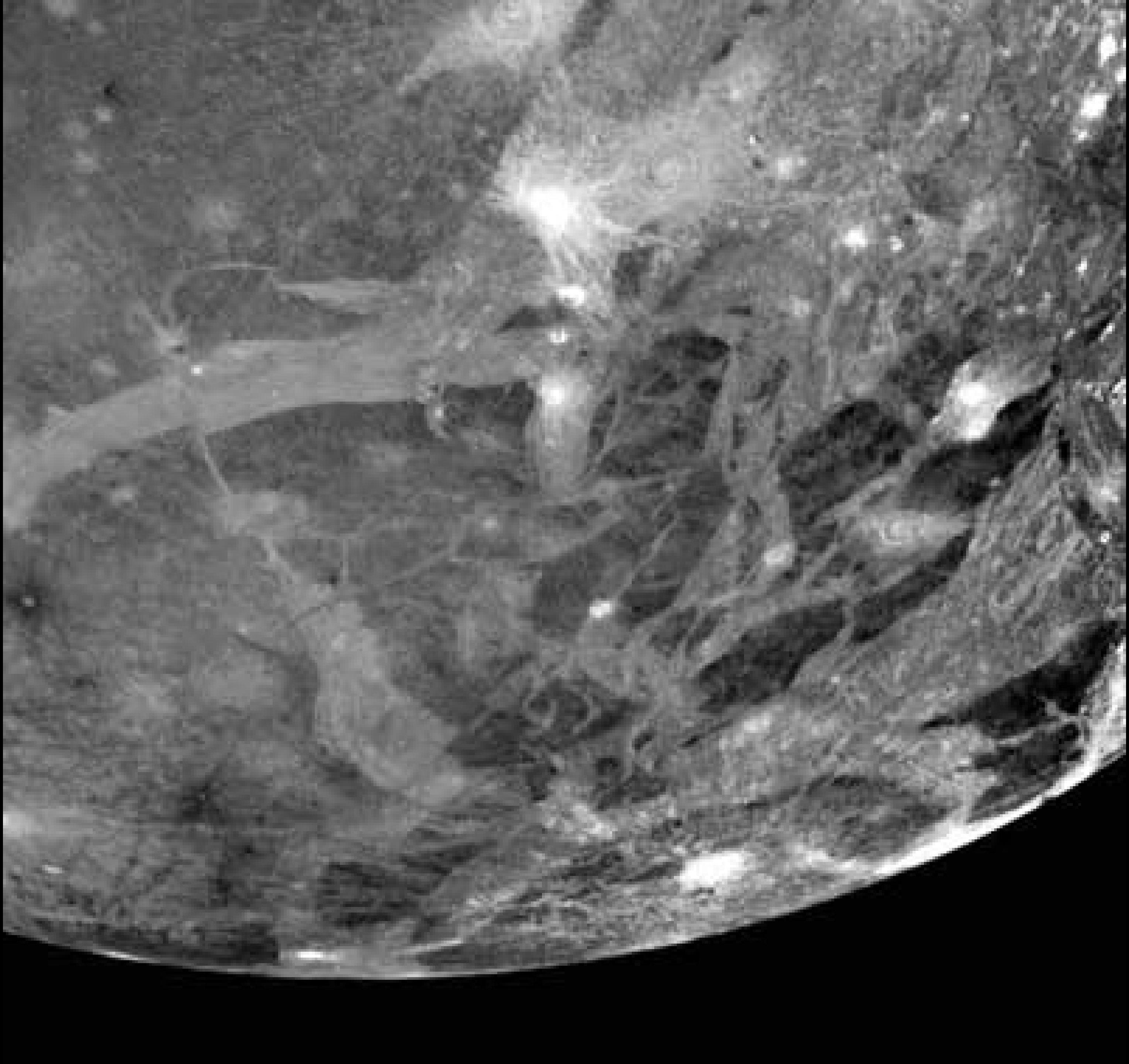
Ganymede…

- Farther from Jupiter; less tidal heating.
- But bigger than any other moon in the solar system, bigger than Mercury (3200 miles)
- This helped it retain some heat, and tidal heating is still able to make an ice/slush layer deep under the surface ice
- Not believed to be tectonically active now, but was in the distant past… see these wrinkles?



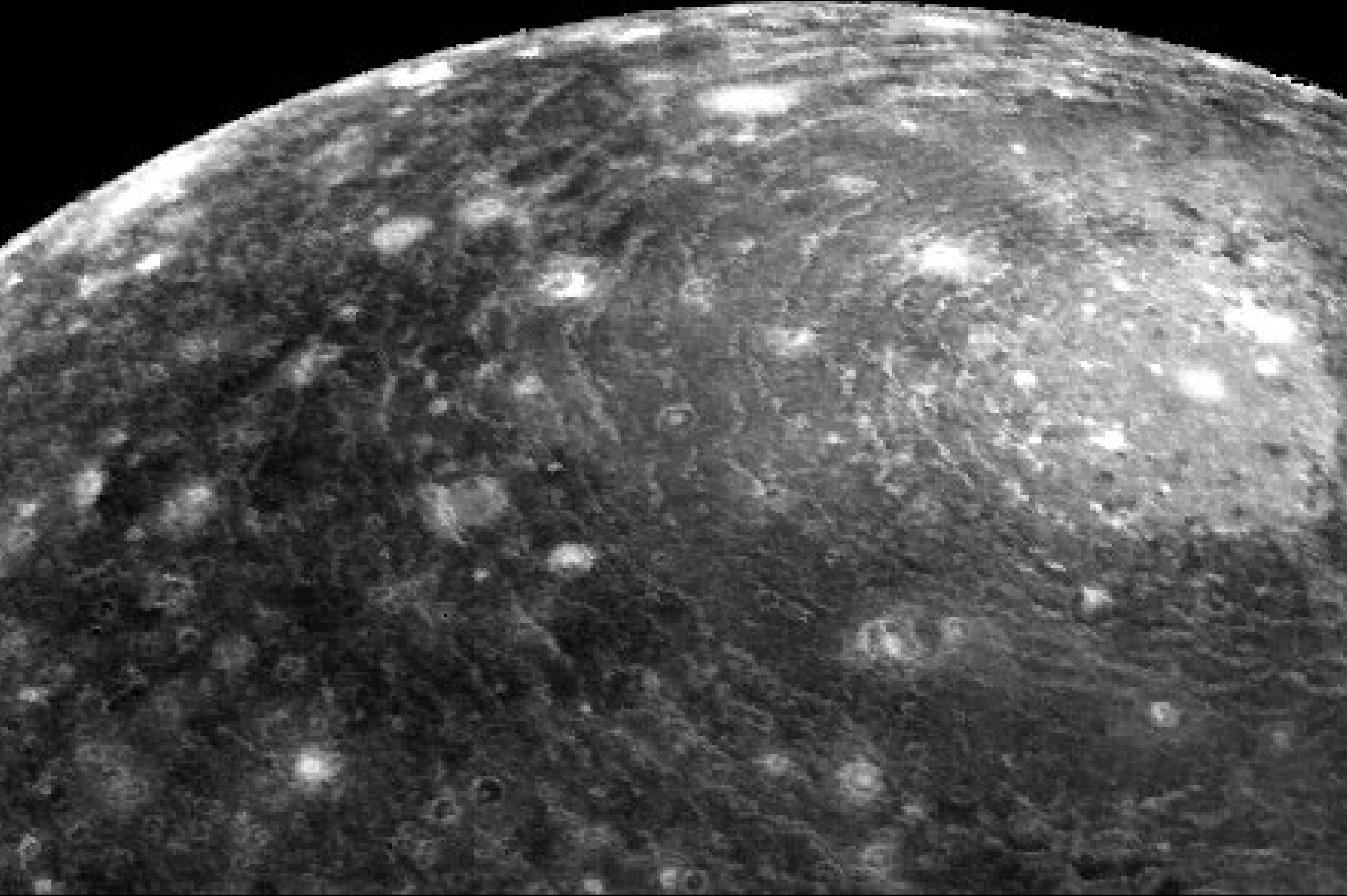


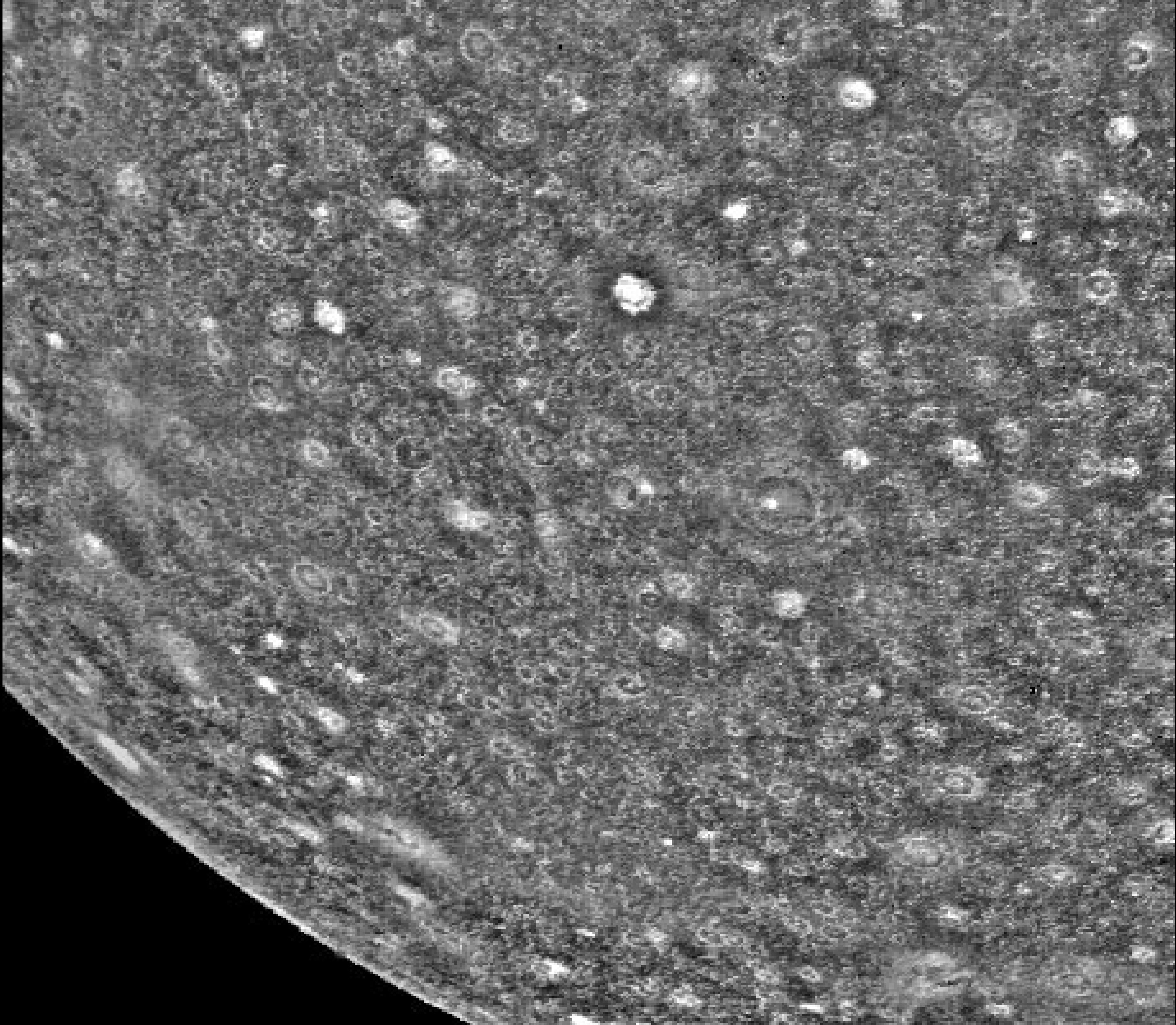

GANYMEDE
DENSITY = 1.9 g/cm3
ICE CRUST
≤ 75km
WATER
OR ICE
MANTLE
MOON
MERCURY

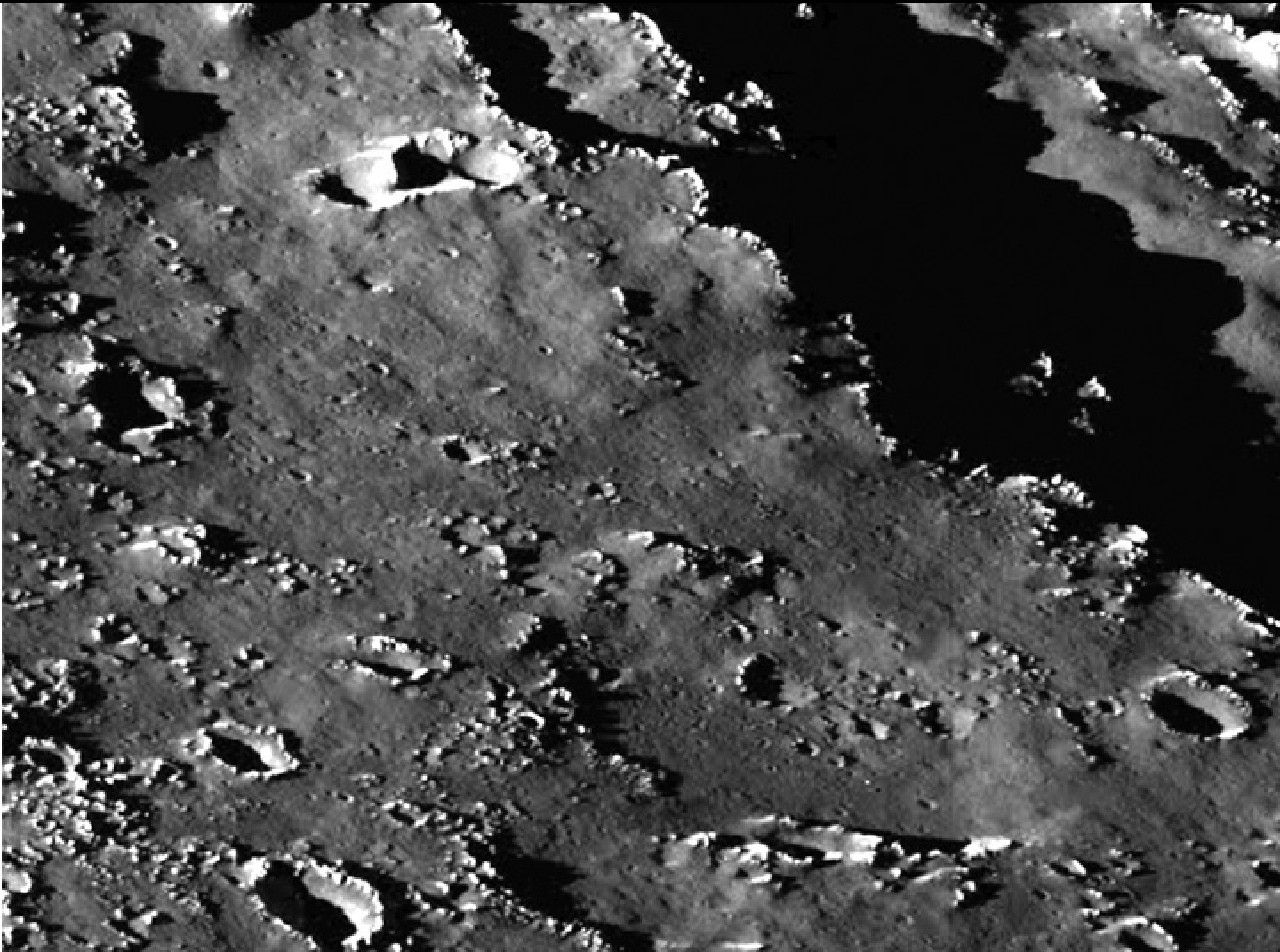


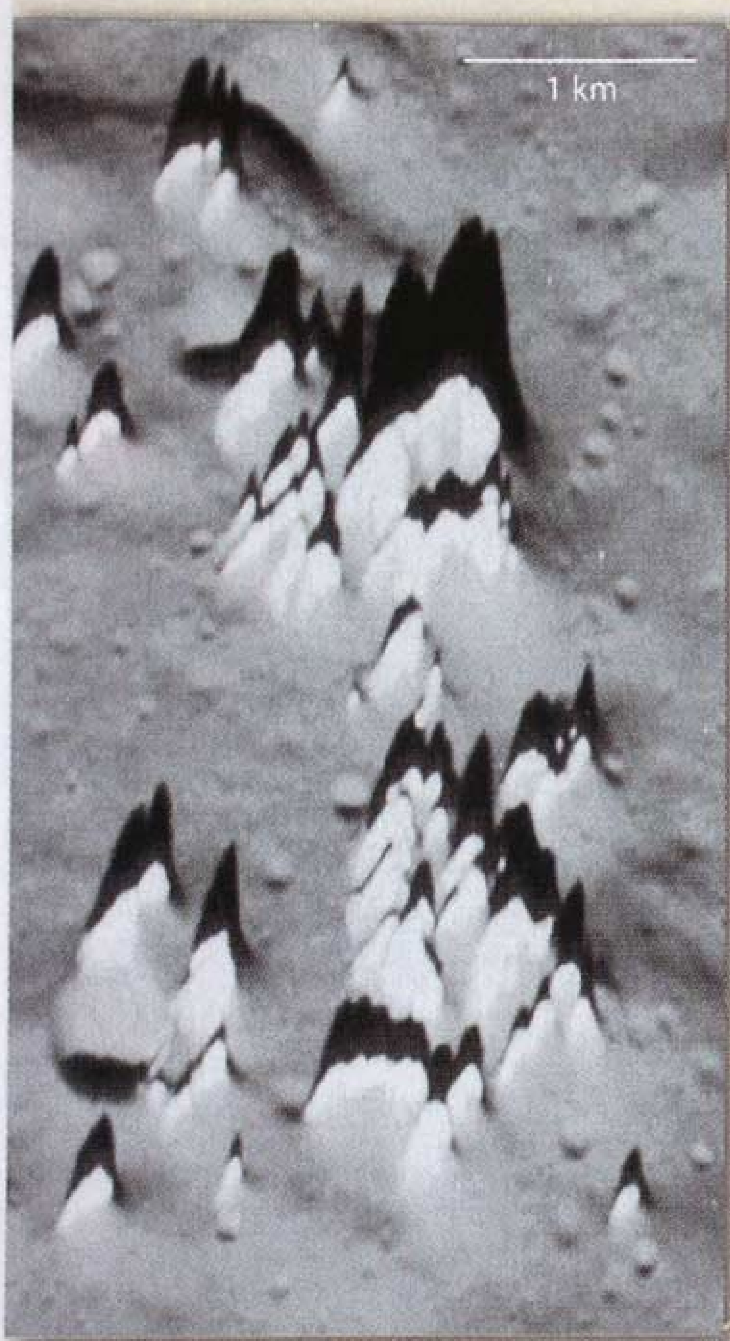
Callisto – Last and Farthest of the Galilean Moons

- Note the ancient surface, which you can tell because of the many impact scars.
- Tidal friction goes as $1/r^3$, and this far from Jupiter (4.5 times farther than Io), so…
- Callisto experiences only 1% of the tidal heating as Io.
- Not enough to melt water ice.



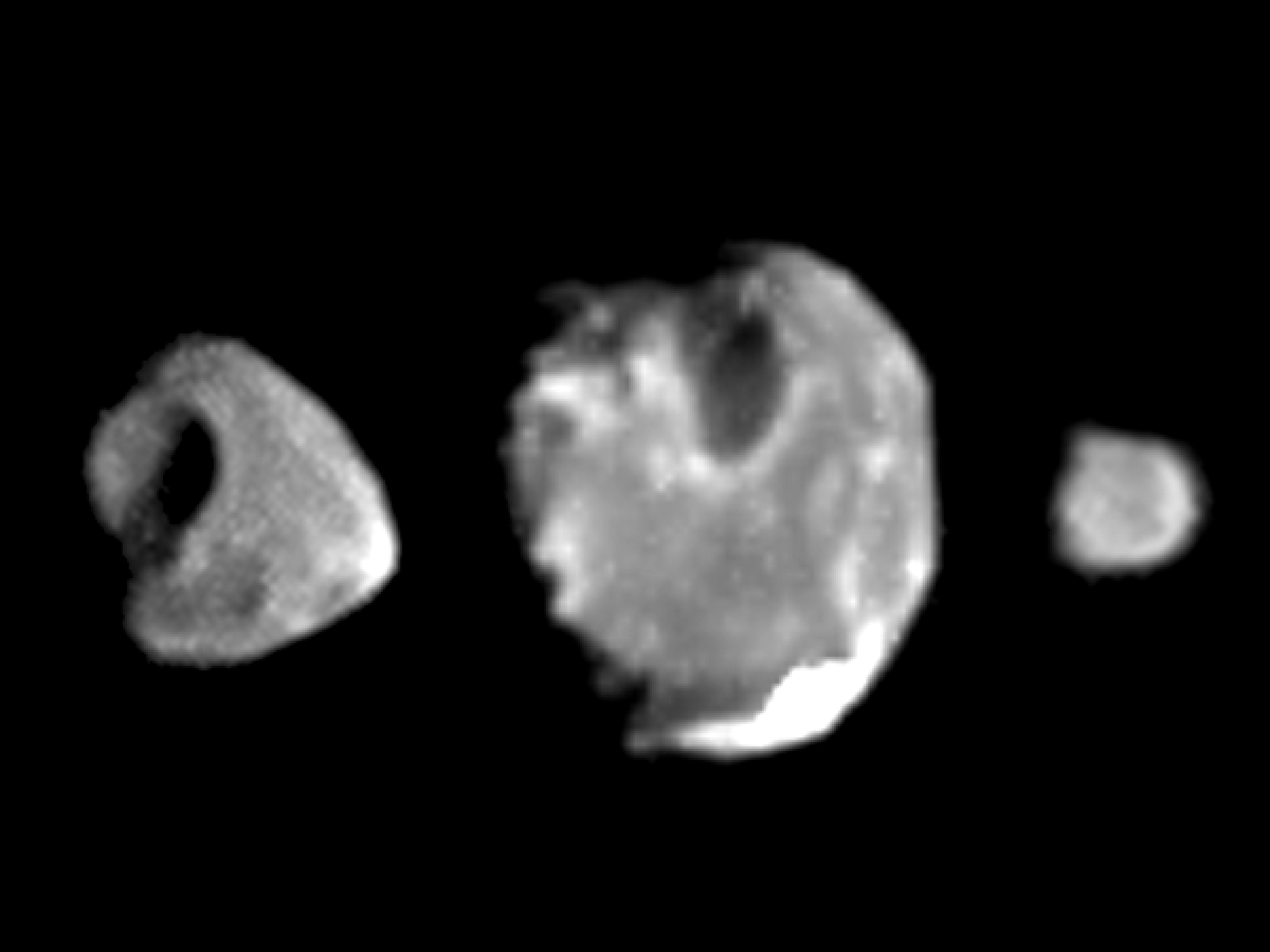






The Ice Spires of Callisto

A casual glance at spacecraft images of Jupiter's moon Callisto reveals a dingy gray world devoid of the exotic geology found on neighboring Ganymede, Europa, and Io. But when NASA's Galileo orbiter swooped to within 140 kilometers of Callisto's surface last May 25th, the spacecraft captured views of a flat, lightly cratered plain from which jut hundreds of whitish spires 80 to 100 meters high. This close-up view resolve few meters and clearly shows dark aprons of dust draped arounc bases. According to geologist James E. Klemaszewski (Academic R the stark protrusions appear to consist of dirty ice that is grad Left behind to dribble downslope are the dust and rock that onc Why the region has eroded to leave these peaked hills — as topped mesas — remains a mystery. Perhaps the area was on blocks of icy rubble thrown out from the 1,700-km-wide Asga north. In any case, Klemaszewski says, these peaks are "continu gradually disappear." Images courtesy Arizona State University.



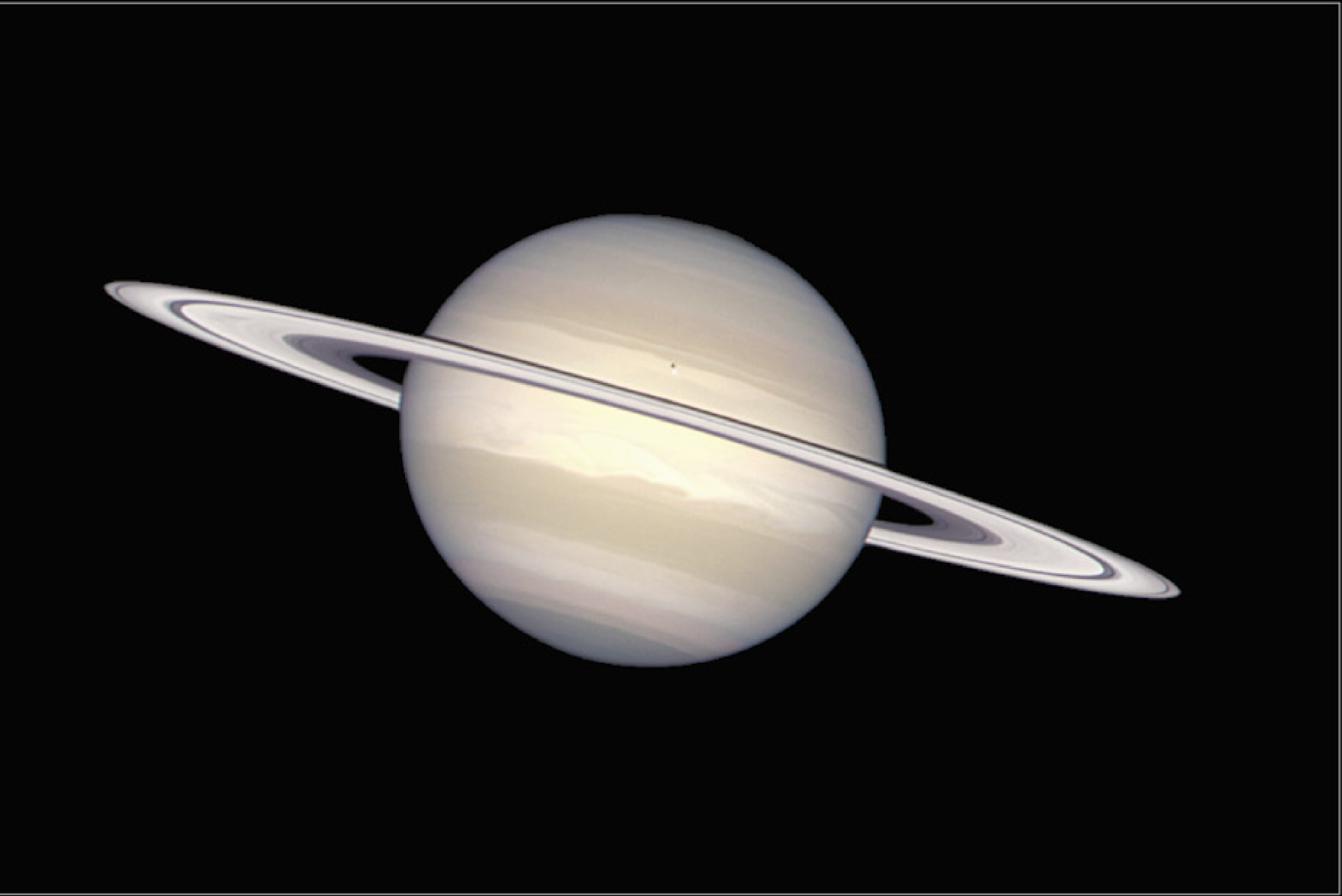
Saturn

- Slightly smaller than Jupiter, but much less massive. Not enough mass (gravity) to compress the hydrogen into a thick liquid layer like Jupiter
- So, it’s mostly a gaseous hydrogen and helium atmosphere
- Most obvious feature – very reflective and massive rings

Rings, and the Roche Limit

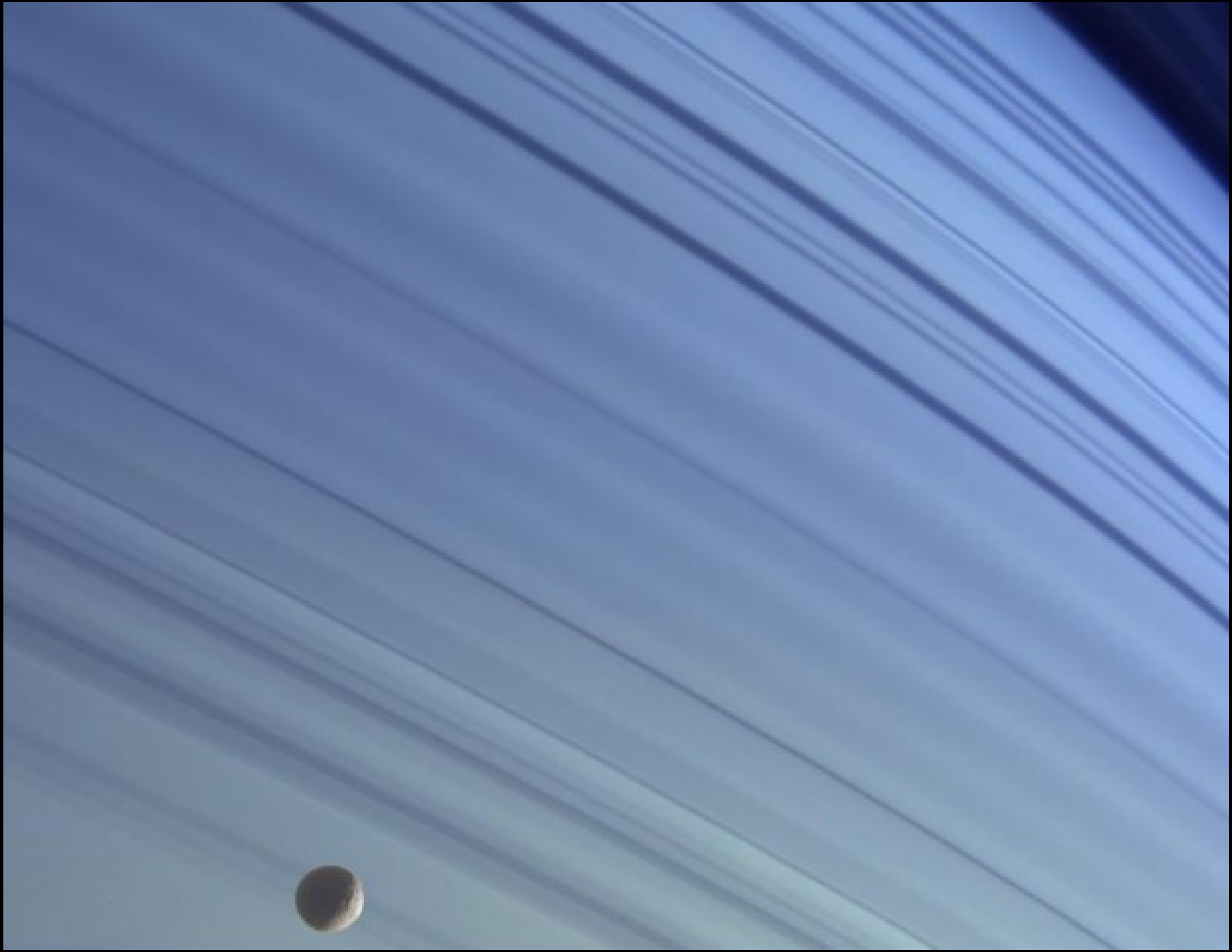
- If a moon is too close to a large gravity source, the tidal stretching can exceed the self-gravity and the moon will be pulled to pieces.
- All the outer planets' ring systems are inside this Roche Limit, including Saturn's.
- **If you want your moon to be safe, keep it far from its parent planet!**

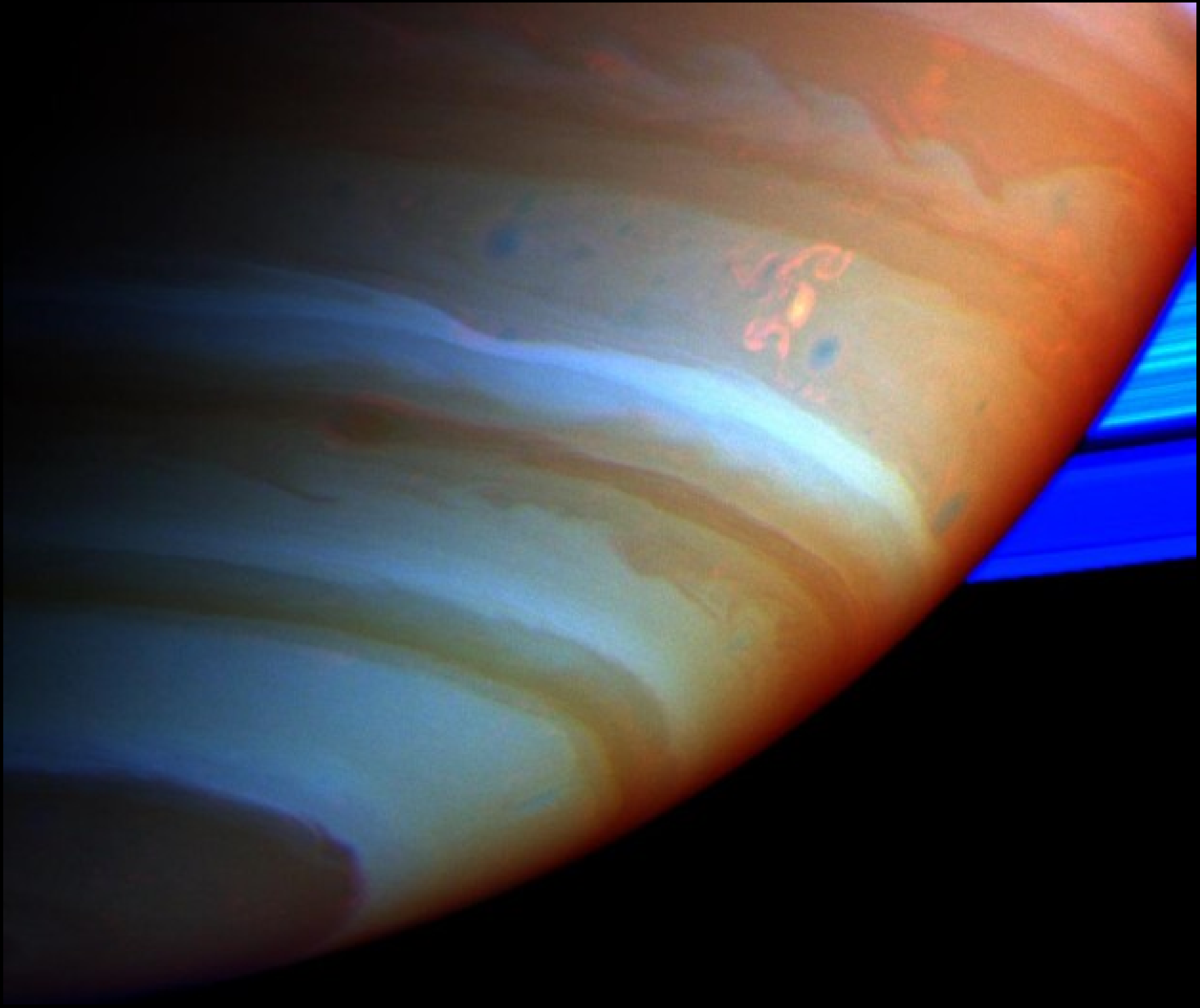
aturn

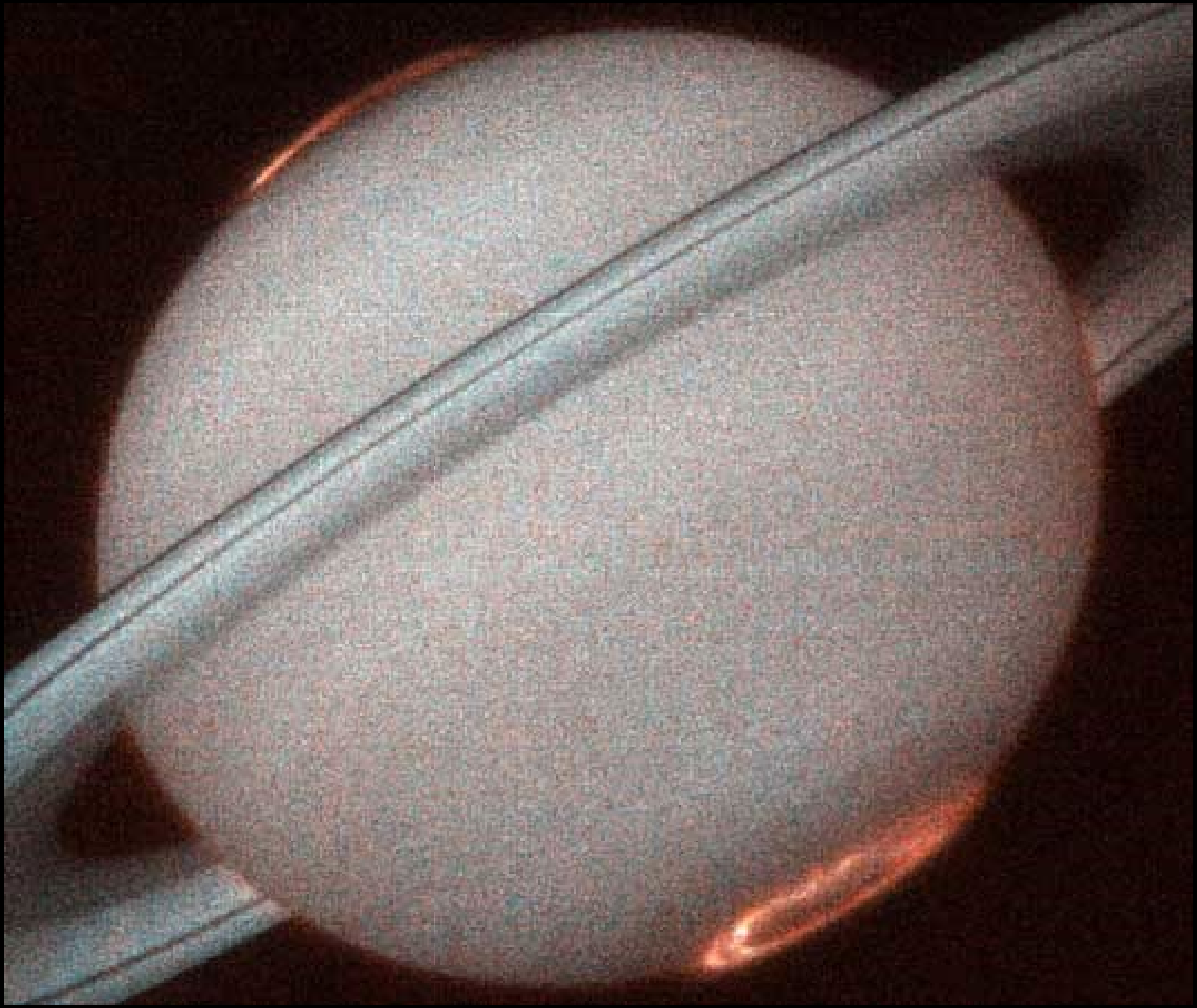


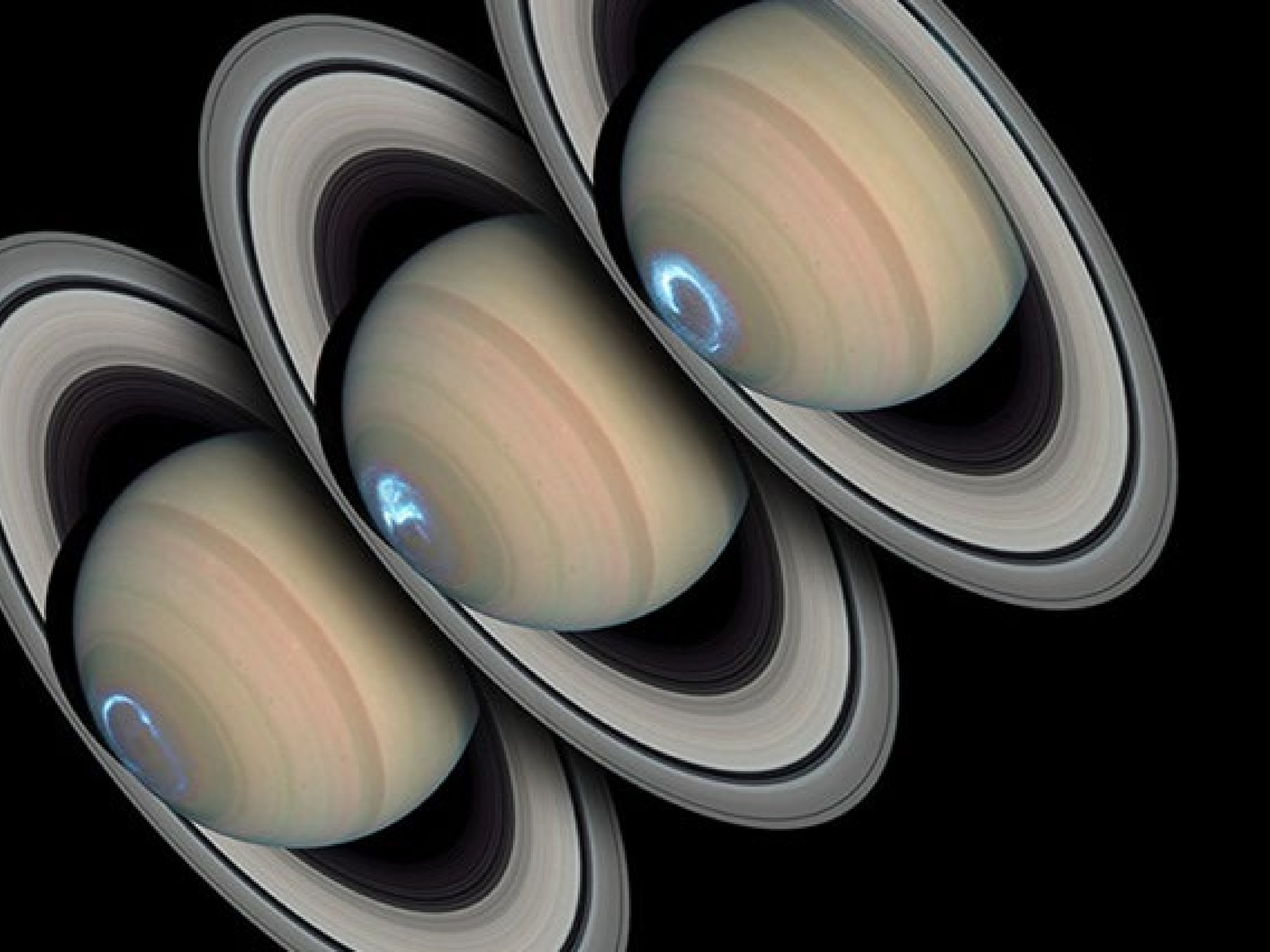
Hubble Heritage

Saturn's ring system is an awe-inspiring telescopic sight to novice and veteran observers alike. However, there may be more here than mere beauty. Amateurs have an opportunity to solve a long-standing observational mystery. Courtesy NASA and the Hubble Heritage Team (Space Telescope Science Institute and the Association of Universities for Research in Astronomy).

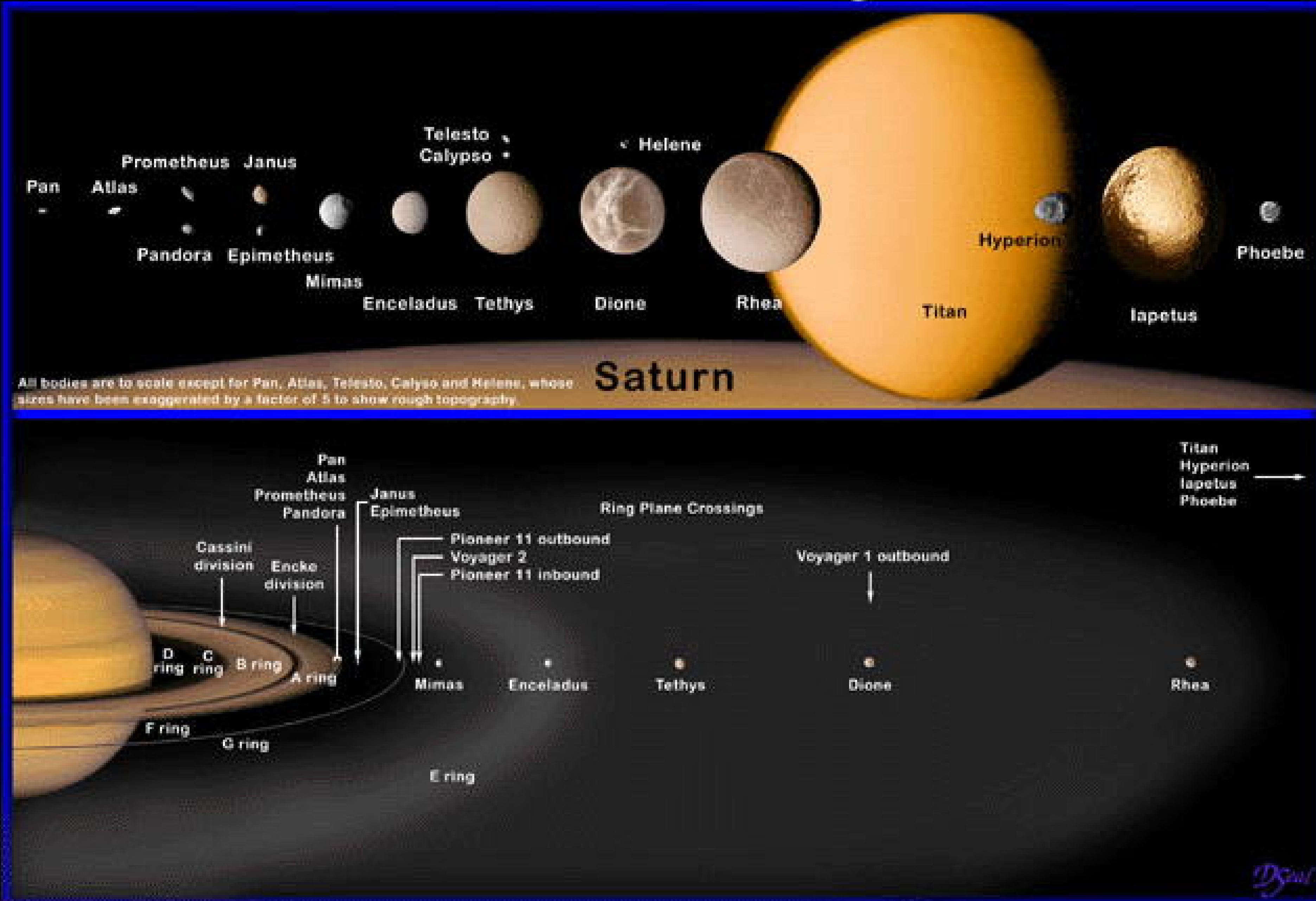








Saturn's Satellites and Ring Structure

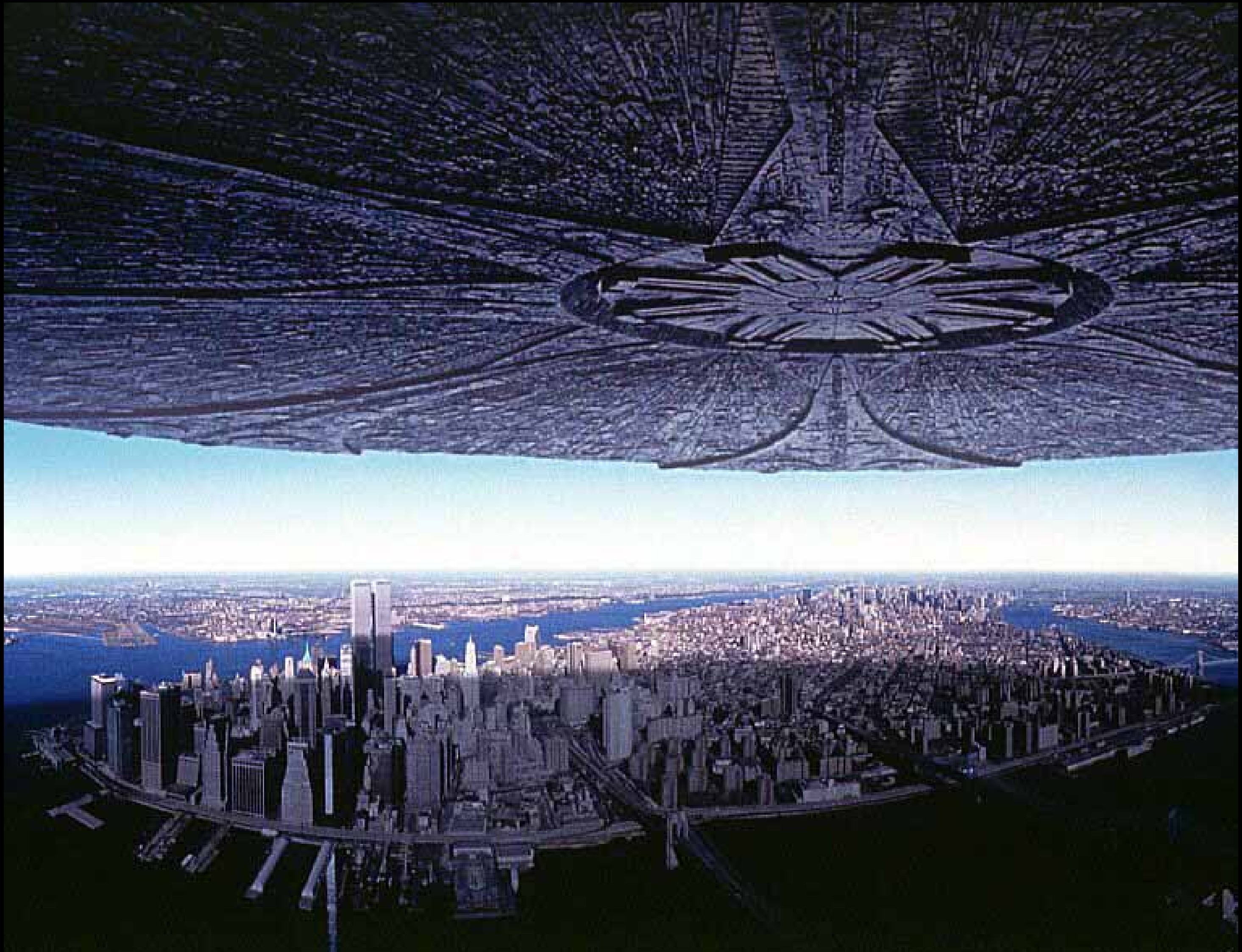


Pan: Only 17 Miles Across; About the Same as Those Giant Flying Saucers in "Independence Day"

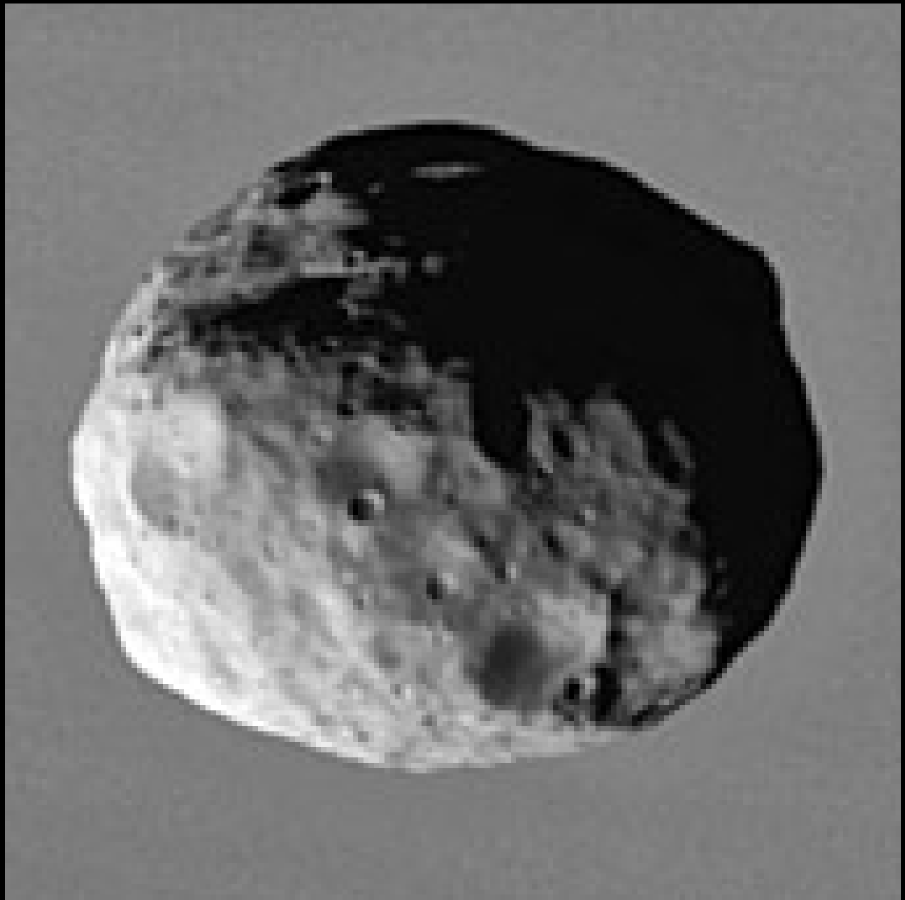
Close to Pan is Atlas: Also 17 Miles Across…. Disturbingly Similar in Appearance

There's a whole SQUADRON Out There!

OMG, is This …How it Ends?



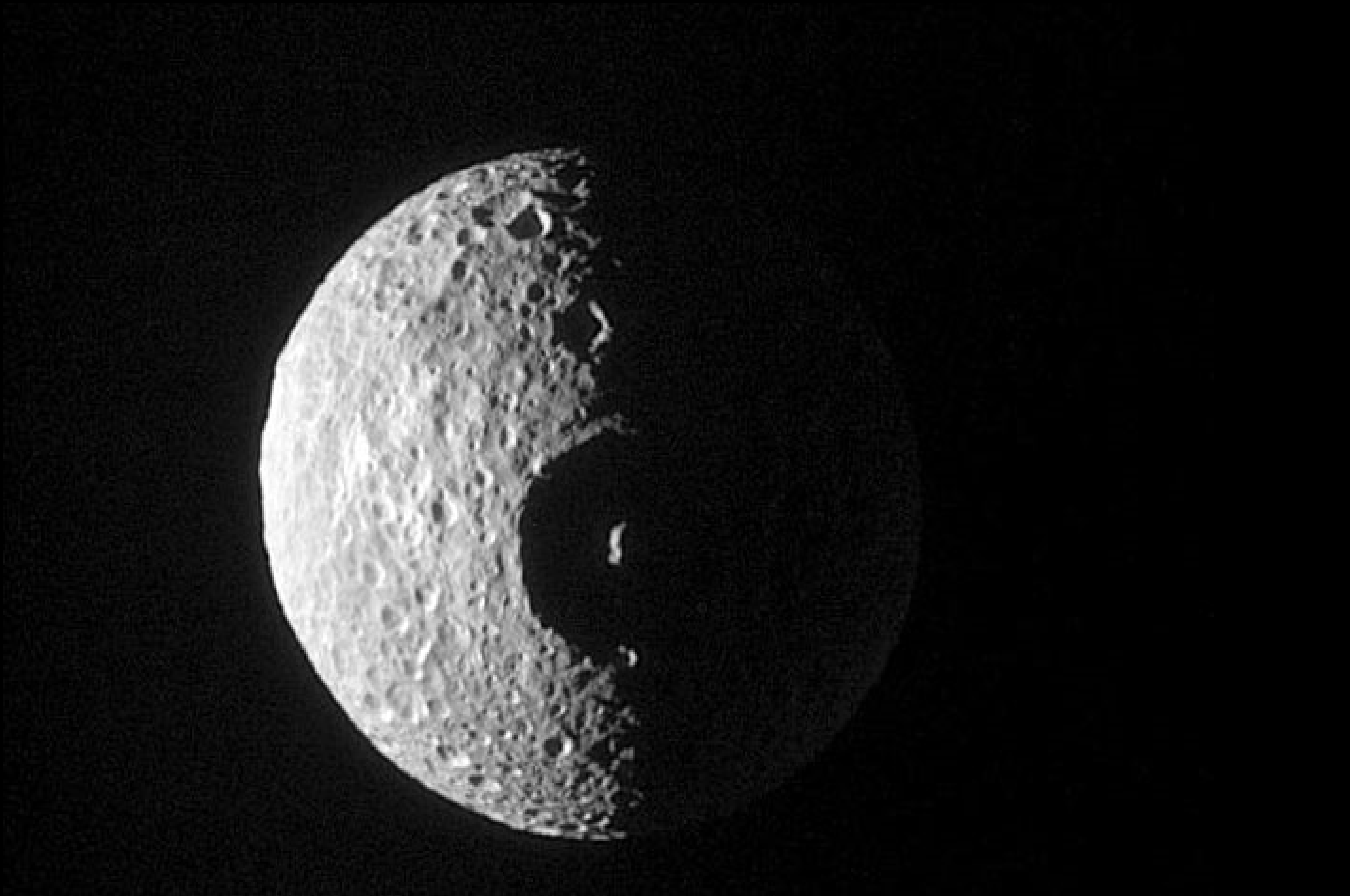
Janus: 111 miles across. Its orbit is within the outer Ring of Saturn, and just 50 km inside the orbit of Epithemus



Epithemus: Old surface, too tiny to feel tidal forces. Janus and Epithemus may have once been a single object, tidally disrupted.

Mimas - The Death Star Moon !

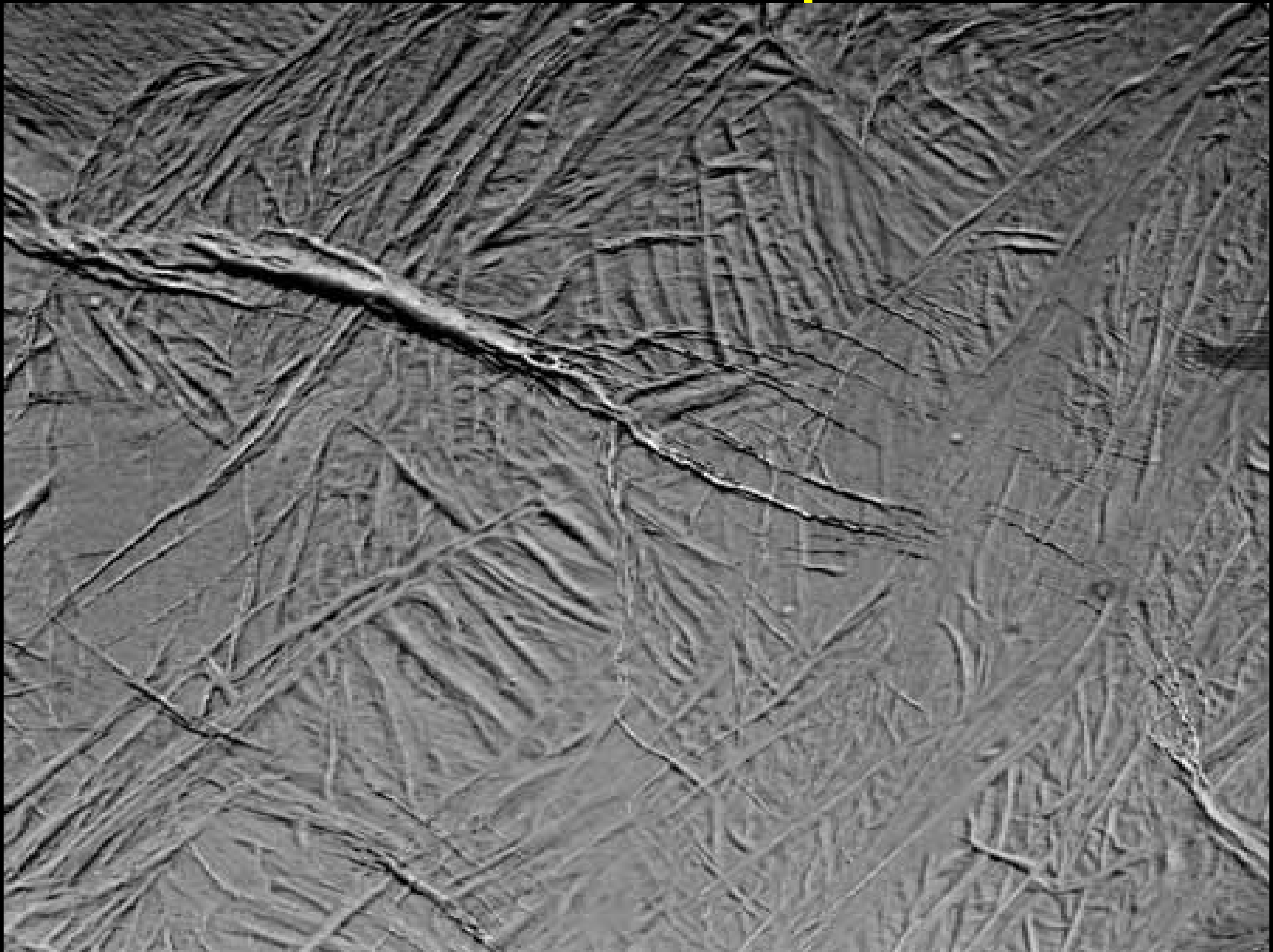
Mimas: only 240 miles across – too small to feel much tidal stress. Ancient surface, no evidence of tidal heating or cracks

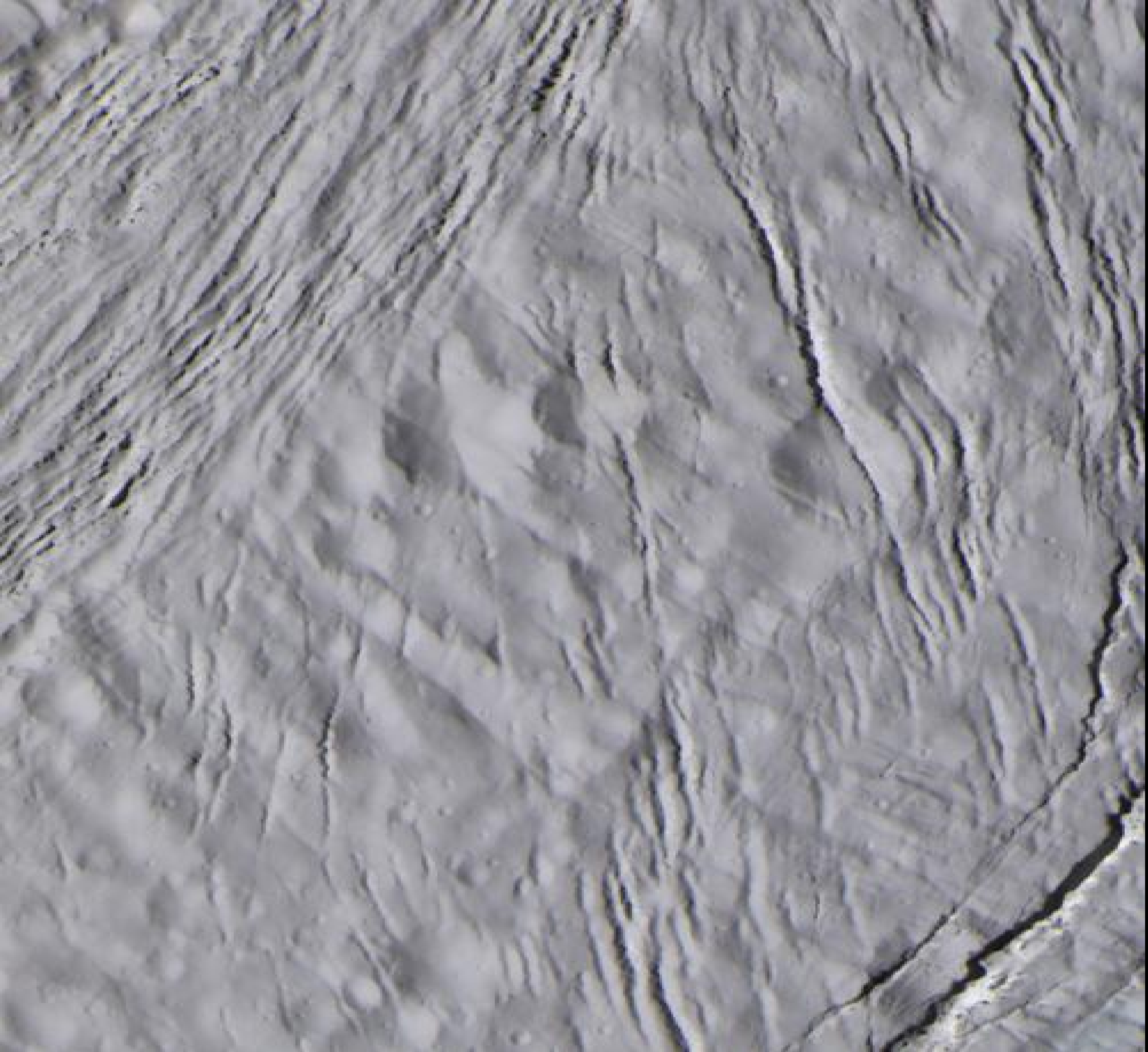


Enceladus- 313 miles across, big enough to feel some tidal stress and heating: **Liquid water ocean under the South Pole, from tidal heating**

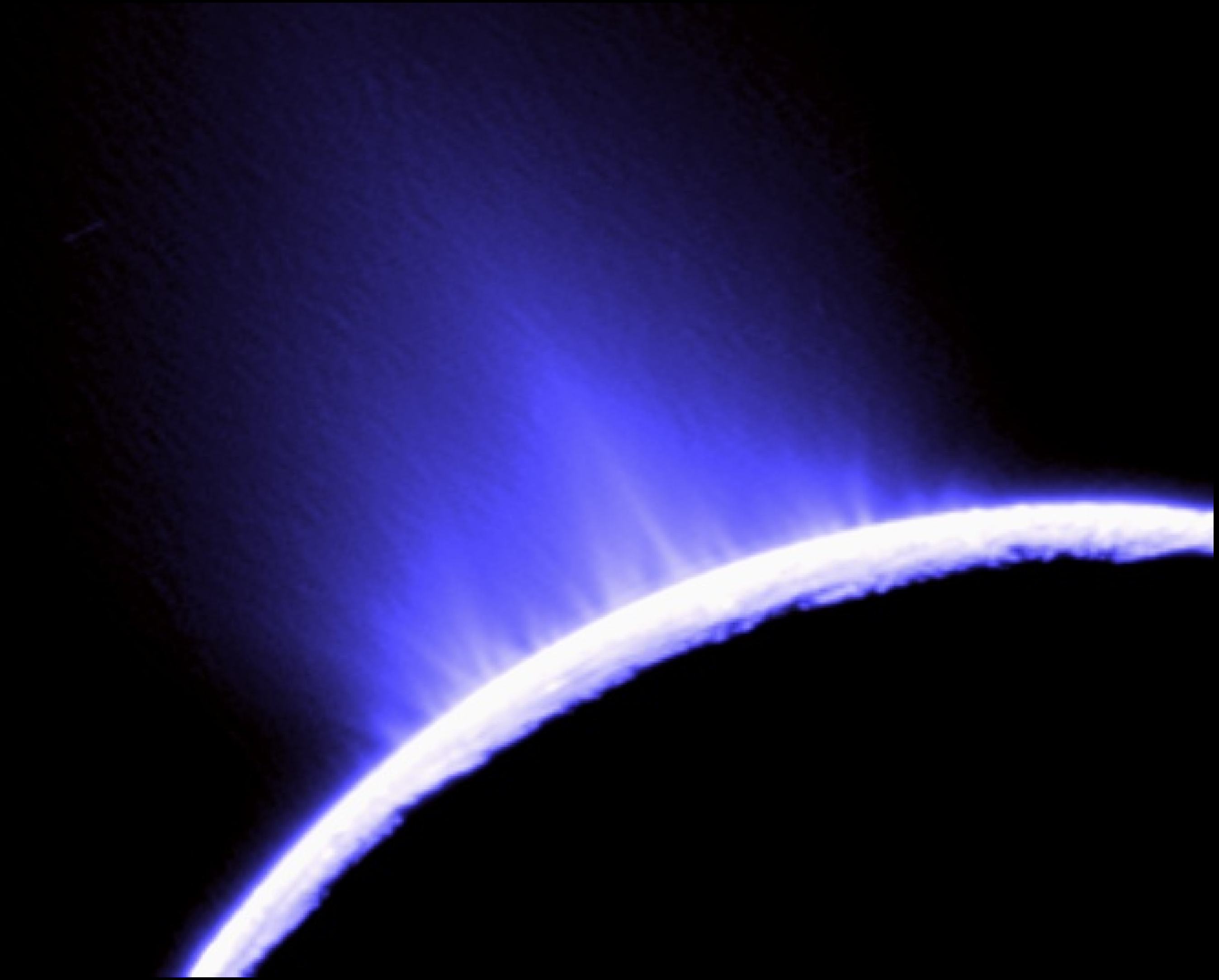
Enceladus: Tidal cracks on an icy old surface

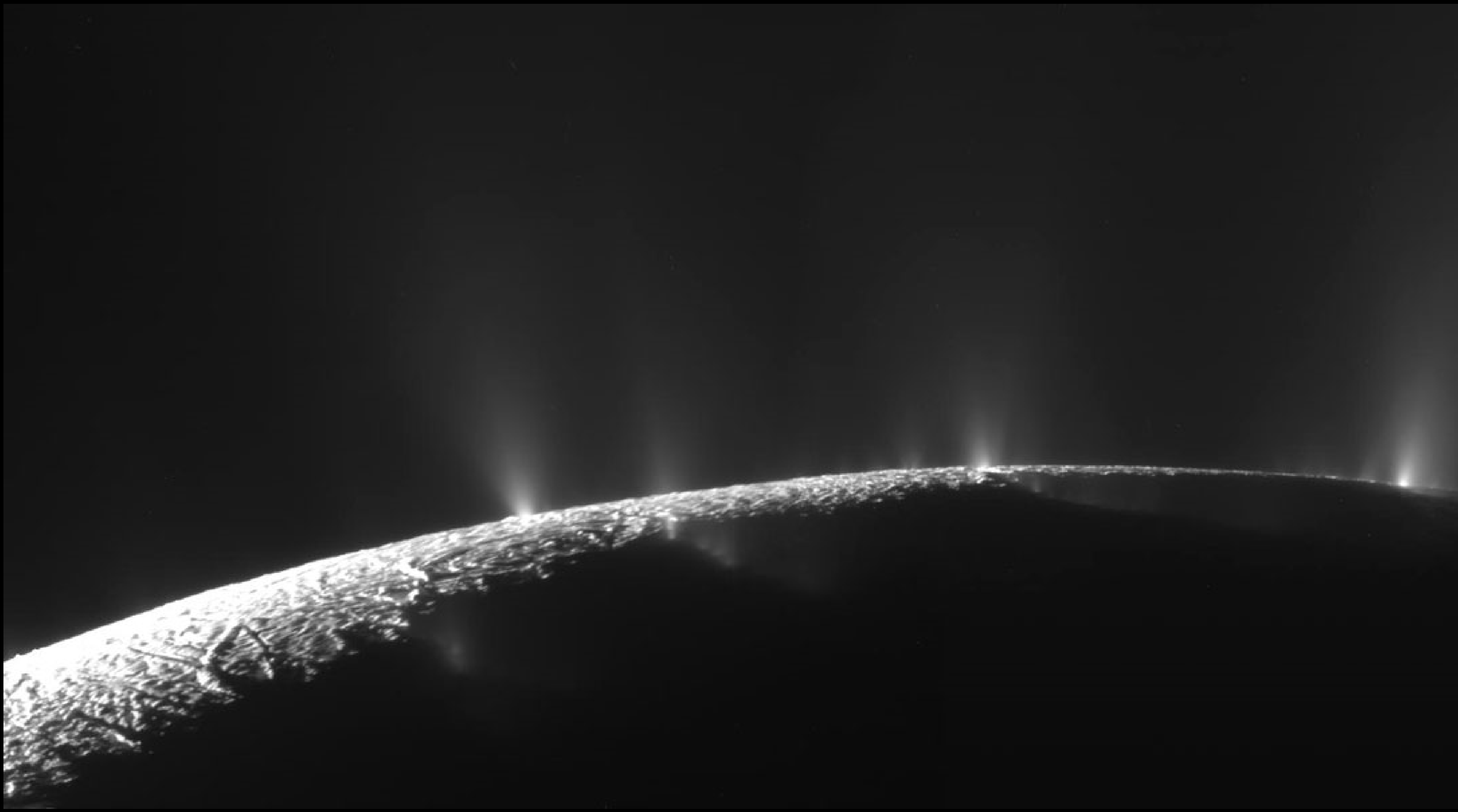
Enceladus; tidal stress fractures are episodic





Enceladus' geysers of water, turning instantly to snow





Subterranean Ocean on Enceladus

- It's got liquid water in an environment protected from the solar wind and solar UV.
- **Enceladus is judged by many astronomers to be the most likely harbor of life beyond Earth! Water is shallower than on Europa.**

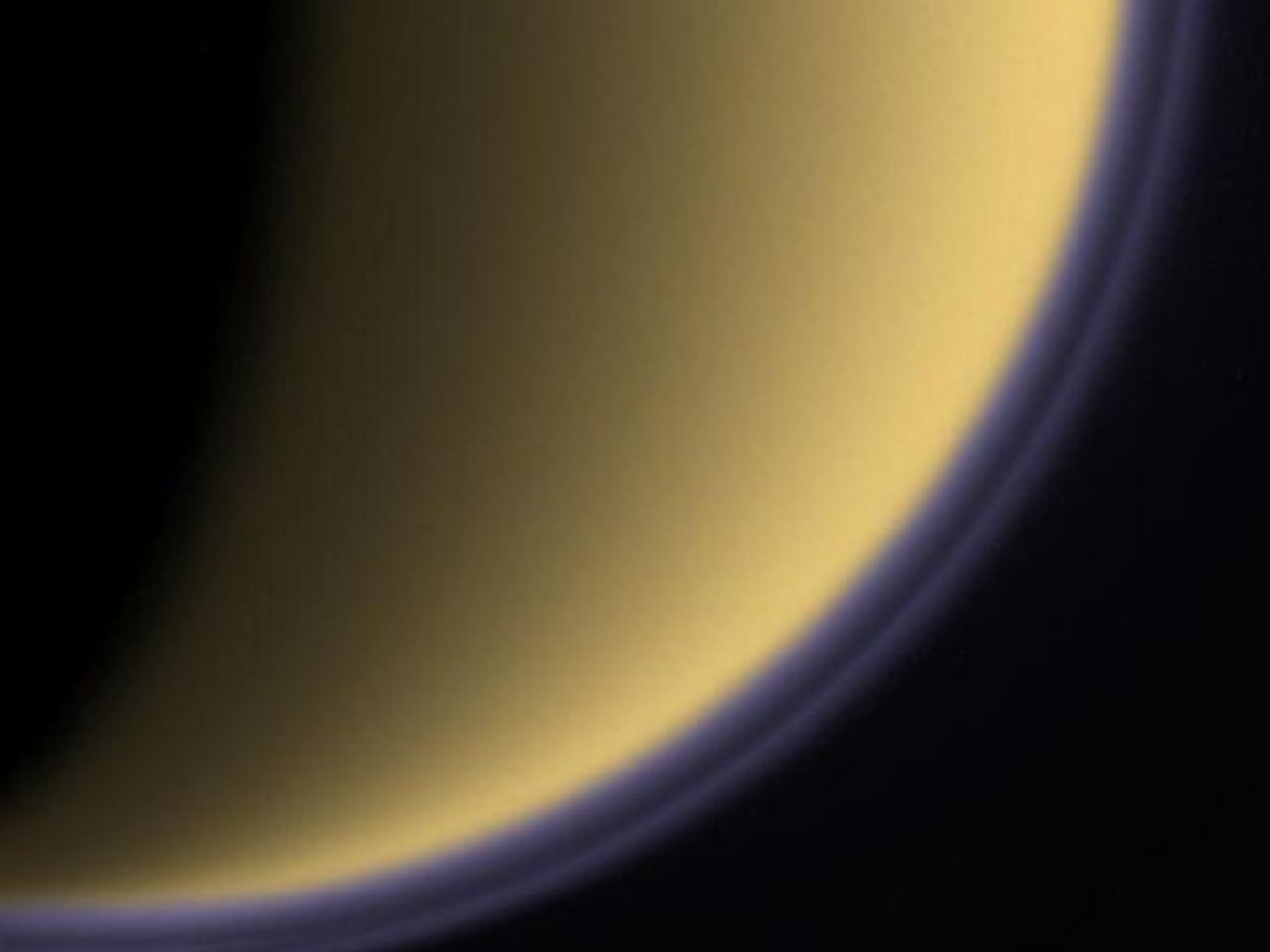
Dione: Old Surface. Less Tidal Heating. Some Cracks looking fairly fresh, but no Geysers

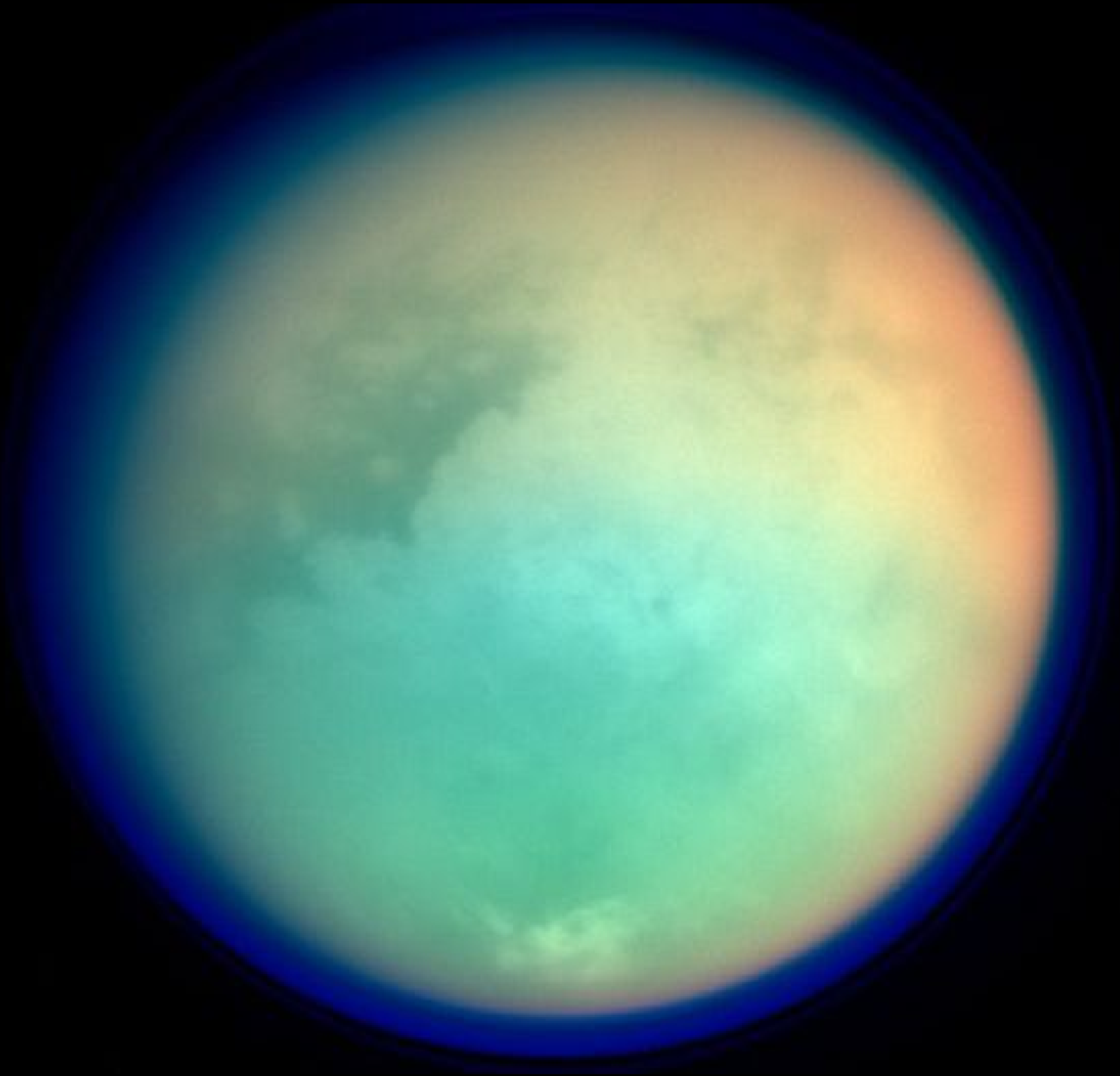
Rhea: Old icy surface. Signs of ancient cracks but long inactive? Farther from Saturn, less tidal stress

Titan – Only Moon in the Solar System with a Real Atmosphere

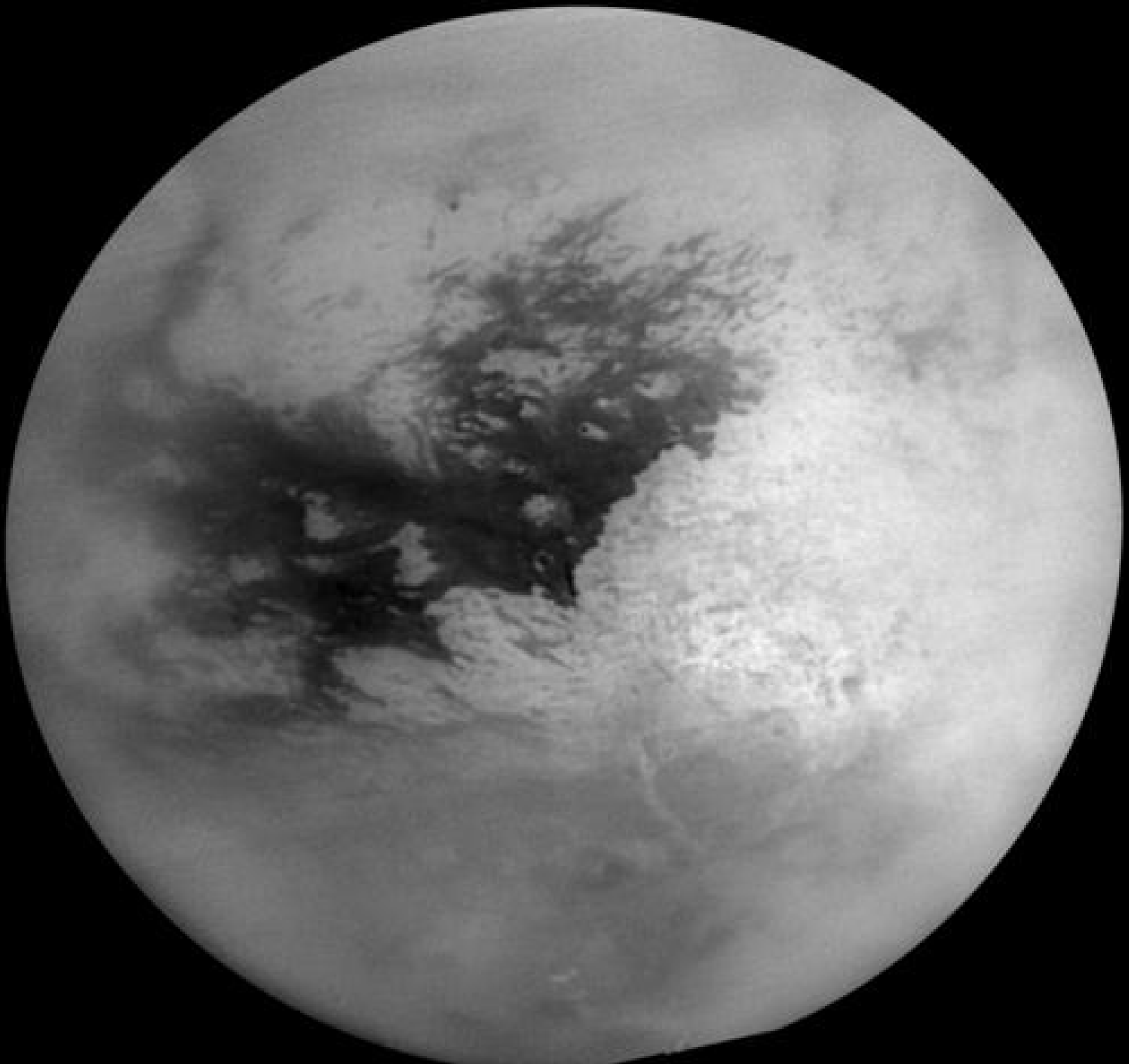
- 3000 miles across, significant gravity, can hold an atmosphere of heavy molecules…
- Not a wonderful atmosphere, though
- Unless you like…. **Smog**!
- Actually, mostly Nitrogen (like Earth), but with hydrocarbons making a large photochemical smog component.
- Atmospheric pressure is just like Earth!
- **Like a very cold Los Angeles, at -180 C**
- Bummer, Dude!

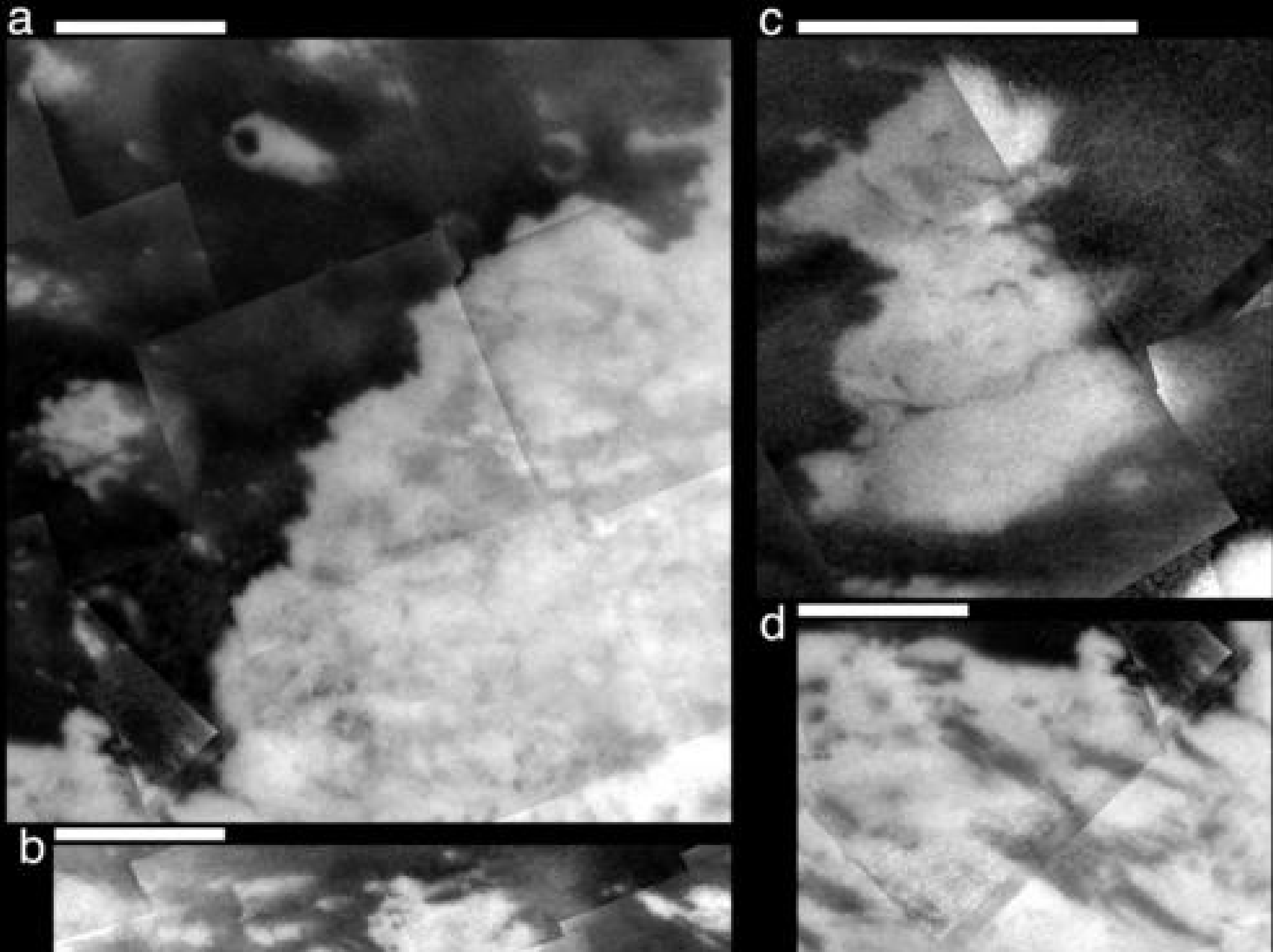
Photochemical Smog





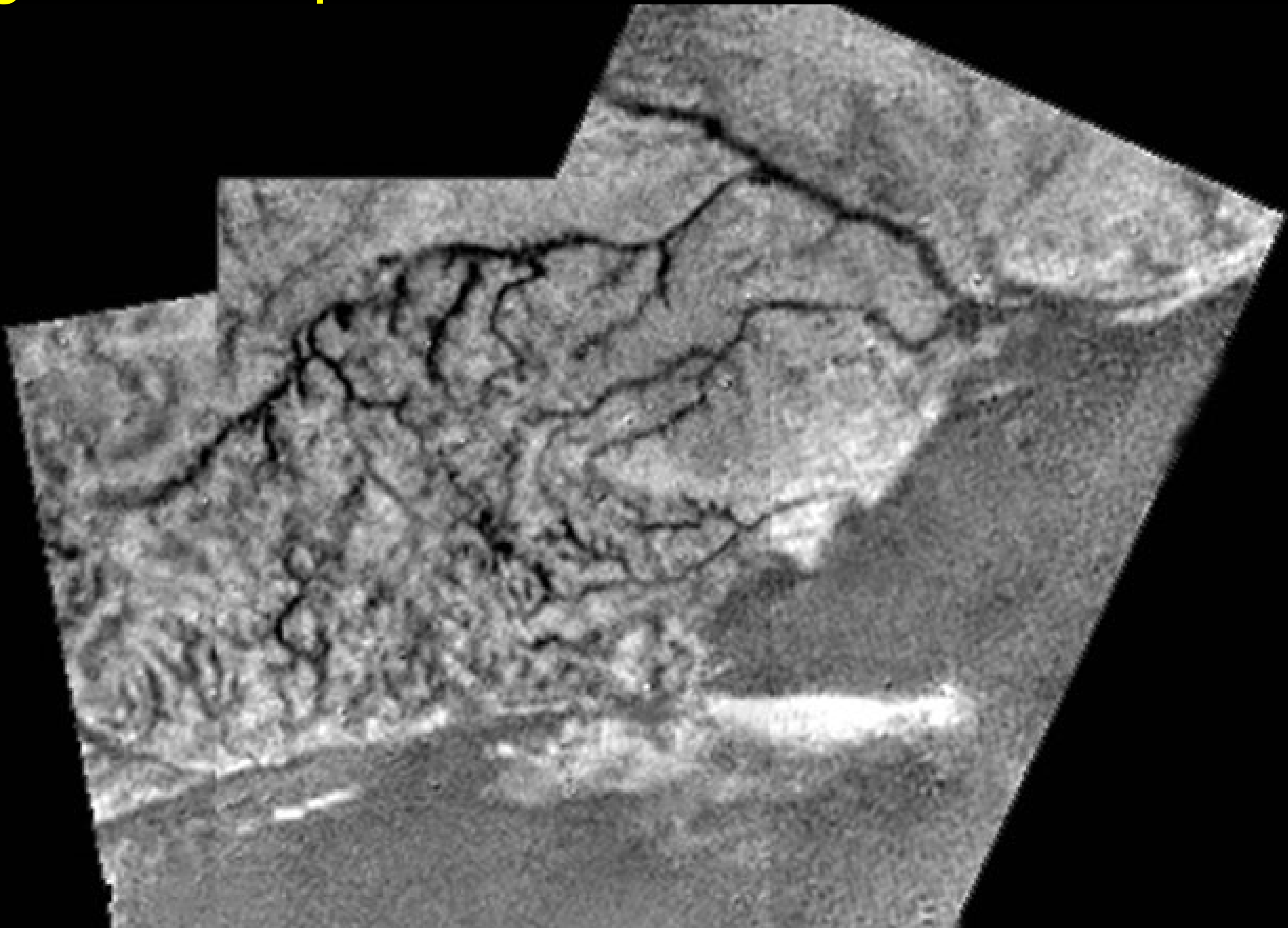
Oceans and Lakes of Methane/Ethane



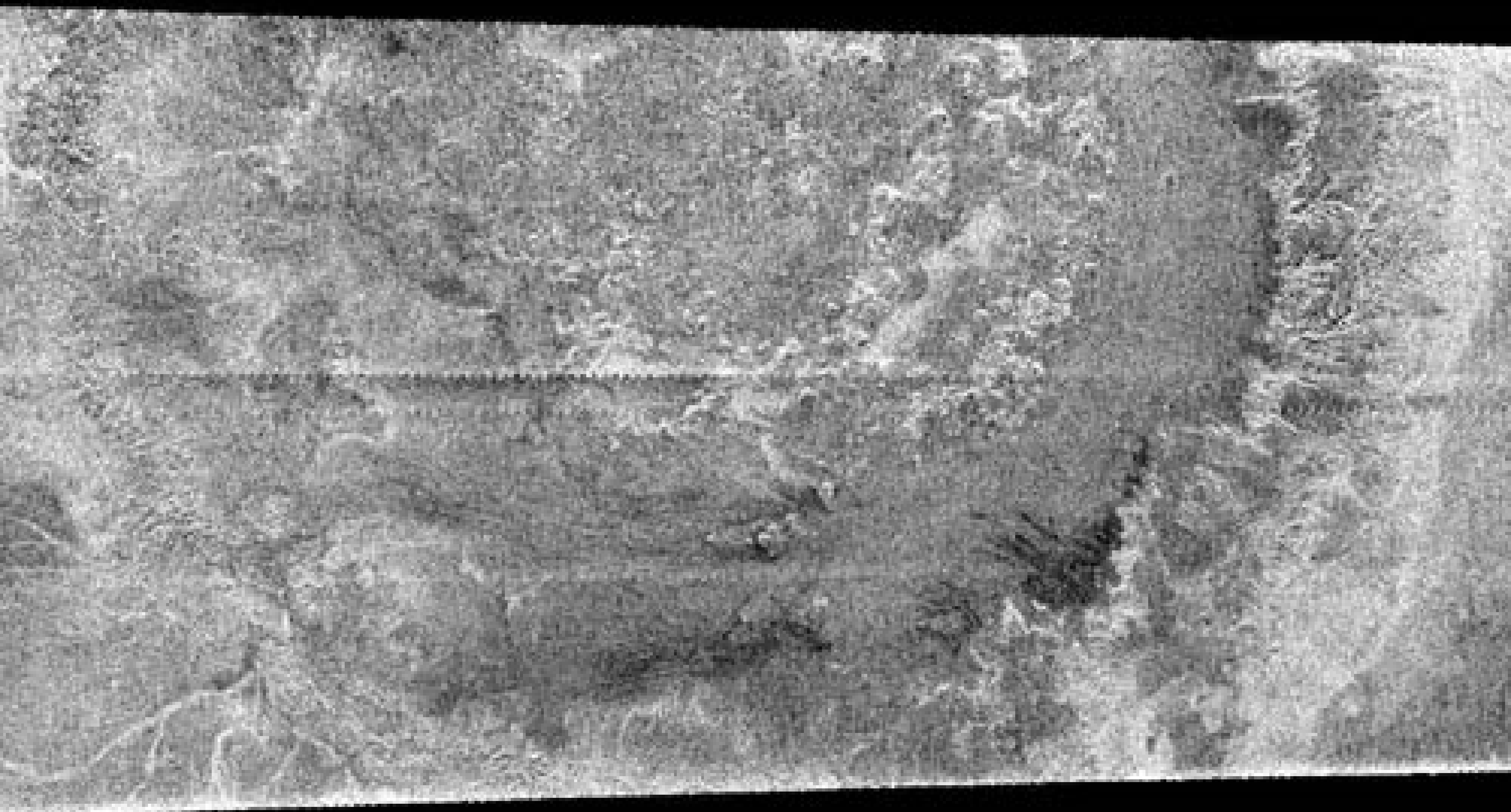


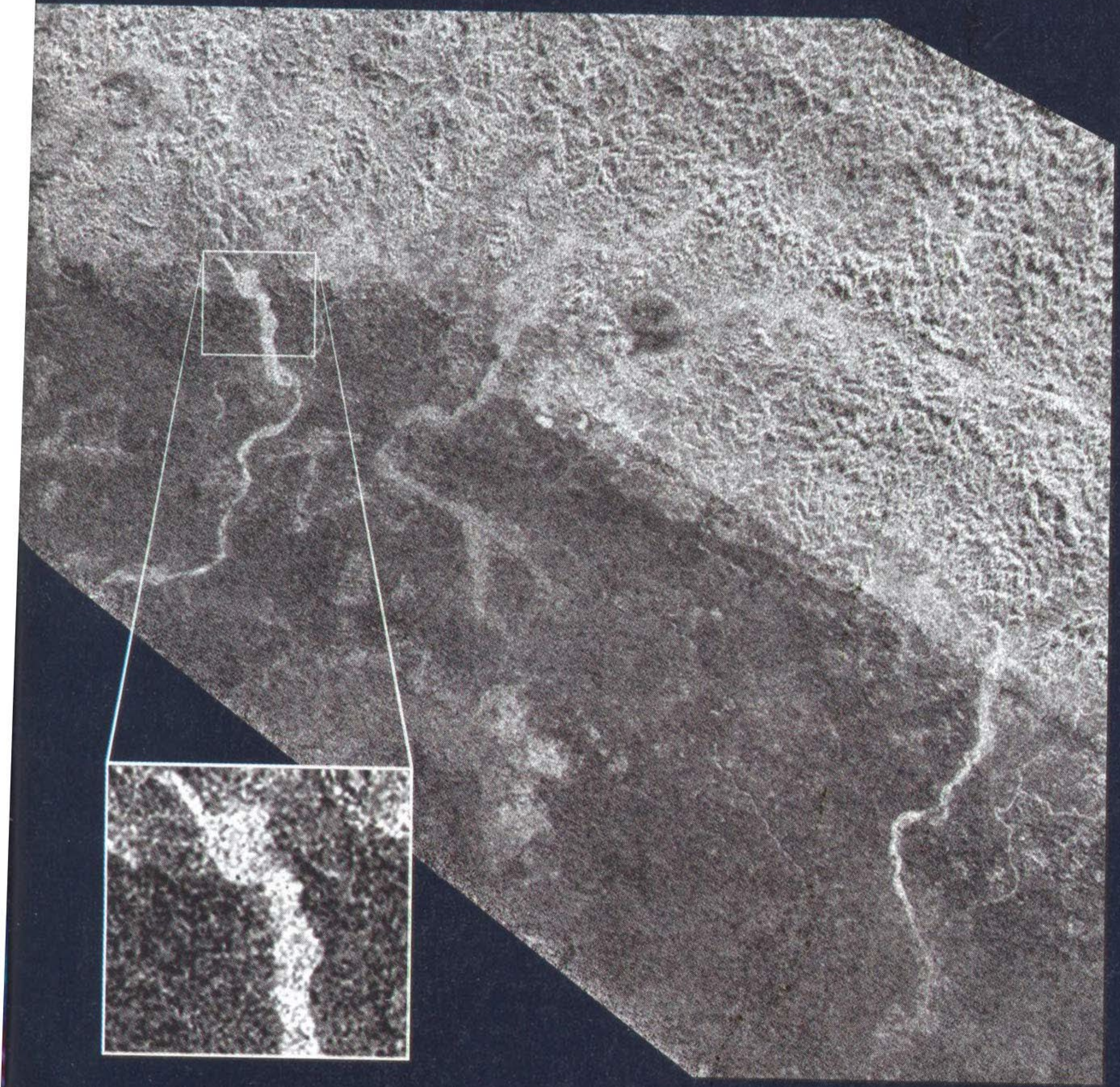
a
b
c
d

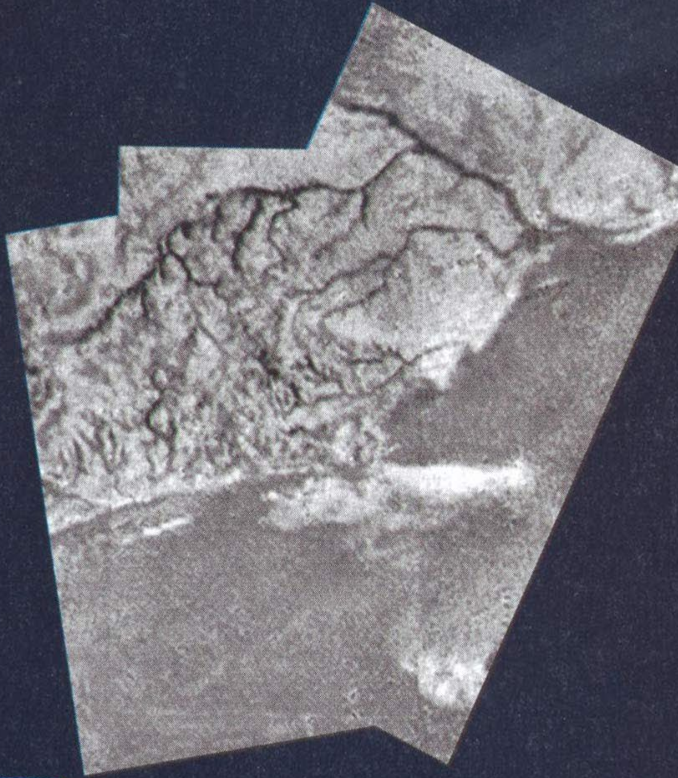
Canyons made by Rivers of Methane, coastlines on an Ocean of Methane; A hydrologic Cycle of Organic Compounds, not water like on Earth



An impact crater on an icy Titan continent

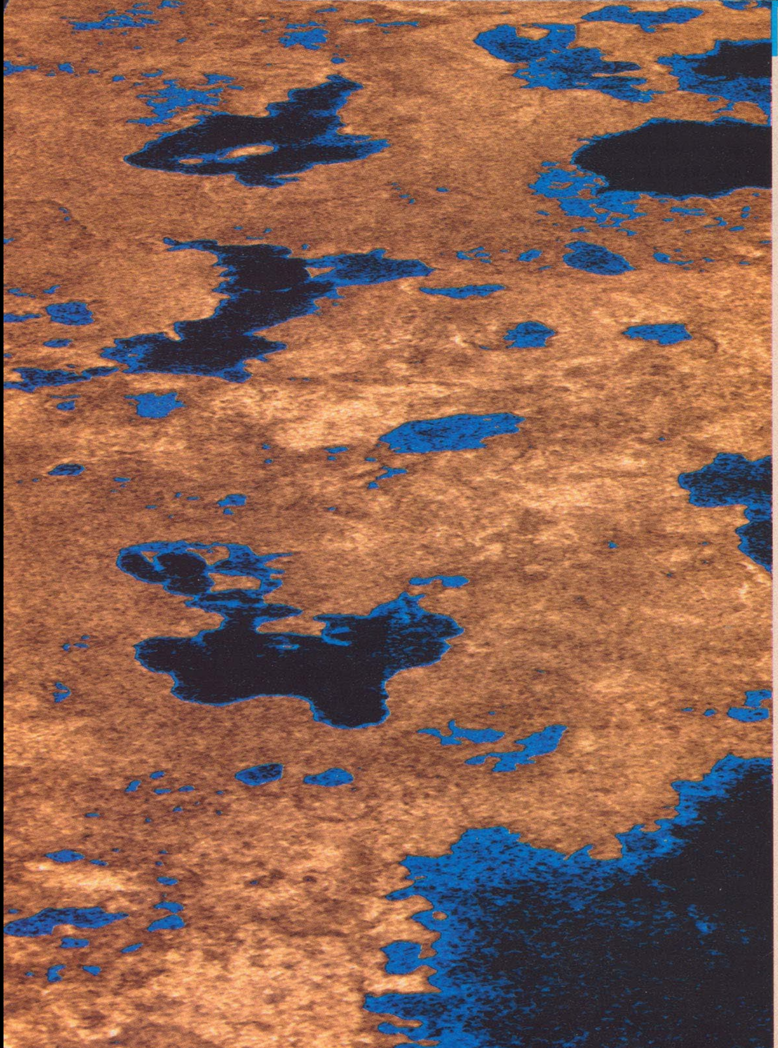




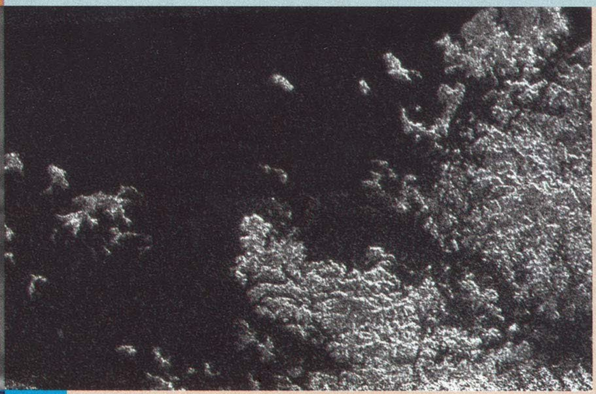


RIVERBEDS *Left:* Cassini's radar instrument has found dry riverbeds all over Titan. The channels come in all sizes and in both smooth and rough textures. They were presumably carved by liquid hydrocarbons running downhill. *Right:* As Huygens parachuted to Titan's surface, its descent camera imaged dark channels flowing into what appears to be a dry lakebed. The channels are currently dry, but they indicate recent fluvial activity fed by rainfall.

Stream-
rounded rocks,
on a dry lake
bed on Titan



NASA / JPL / SPACE SCIENCE INSTITUTE



NASA / JPL

LAND OF LAKES ***Left and above:*** **Cassini's radar has revealed numerous flat, smooth features, mainly at high northern latitudes, which scientists have interpreted as lakes. This view has been confirmed by recent spectral analysis. Titan and Earth are the only bodies in the solar system to have liquid bodies on their surface. The colors in the left image represent radar reflectivity, not what you'd see.** ***Above left:*** **Cassini imaged Ontario Lacus in near-infrared light. This feature is similar in size and shape to Lake Ontario, and is located near Titan's south pole. Recent spectral observations have confirmed the presence of liquid ethane.**

NASA / JPL

Splish, Splash

Huygens didn't see any surface puddles because, we now realize, it landed in Titan's equivalent of a vast desert. There are big pools of liquid on the surface — but they're in the polar regions. Cassini first spotted clusters of dark polar patches in 2005, and they've tantalized our science team ever since.

Initially the evidence for true hydrocarbon lakes was circumstantial. They appear really dark in both radar scans and infrared images. The radar result is consistent with nearly mirror-smooth surfaces that reflect Cassini's radar emissions away from the spacecraft and out into space. The infrared darkness implies that clear liquid extends so far down that photons of light are absorbed before they can scatter off suspended particulates.

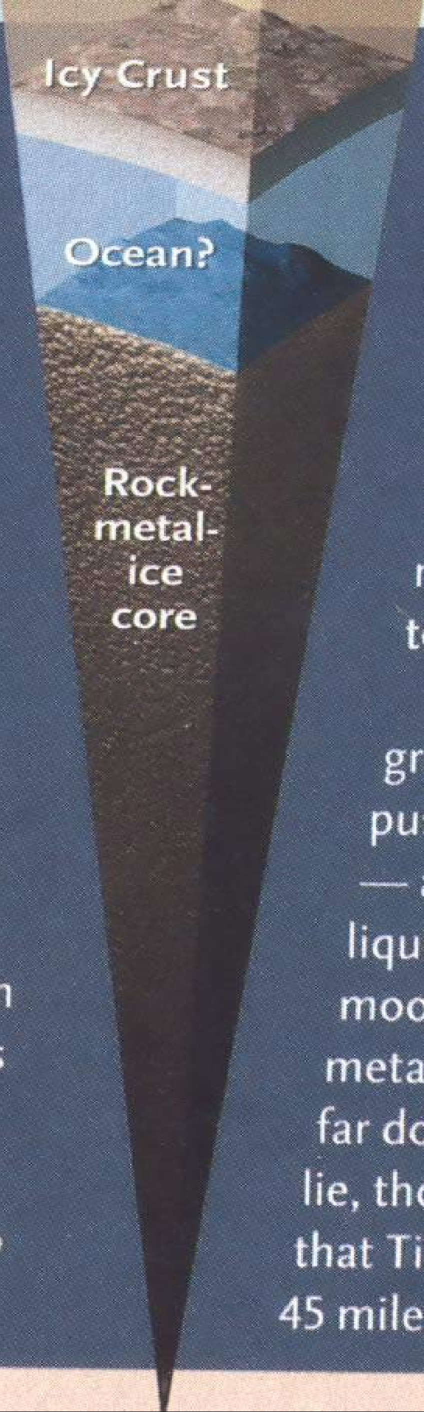
The lake hypothesis reached its splash point last December, when Cassini's Visual and Infrared Mapping Spectrometer (VIMS) got a good look at a conspicuous dark region near the south pole known as Ontario Lacus. VIMS analyzed the feature's reflectivity between 2 and 5 microns, infrared wavelengths at which the atmosphere is transparent. A handful of absorption lines match the ones expected for liquid ethane — finally, we had our long-sought "smoking gun" for fluid-filled reservoirs (November issue, page 19).

Close-ups of Ontario Lacus from that flyby also reveal what may be mudflats and a surrounding bathtub ring.

The Spin on Titan

Last year, Titan threw Cassini's radar scientists a real curve. They were unable to match up surface features wherever one of the instrument's long image swaths overlapped another. The coordinates of a given surface feature could be off by up to 25 miles (40 km) from one swath to the next.

The team had assumed that Titan's obliquity (axial tilt) was zero. If instead the pole could drift by nearly a half degree, the observations fit together much better. Yet even with the revised polar tilt, the radar images continued to show offsets of up to 2 miles — and they were getting larger. Incredibly, the moon's spin seemed to be speeding up!



Tides from Saturn should force Titan to keep one hemisphere constantly facing the planet, just as the Moon's near side always faces Earth. Motions within Titan's dense atmosphere can affect the spin rate slightly, but not if they have to tug the moon's entire mass.

The only way to explain the growing mismatch is if the winds push only on Titan's icy crust — and that's only possible if a liquid-water mantle separates the moon's crust from its rock-and-metal core. We're not yet sure how far down this lubricating layer might lie, though the radar team estimates that Titan's ice crust might be about 45 miles thick.

AN ABODE FOR LIFE?

Titan's surface abounds with organic molecules and water ice, but its frigid temperatures offer bleak prospects for life. At Titan's –290°F (–179°C) surface temperatures, chemical reactions slow to a crawl, limiting the ability of complex molecules to form. But Titan's interior is warm enough to sustain liquid water. Given the plethora of life's building blocks on Titan, scientists cannot rule out the possibility that the moon harbors biological activity deep underground.

Iapetus

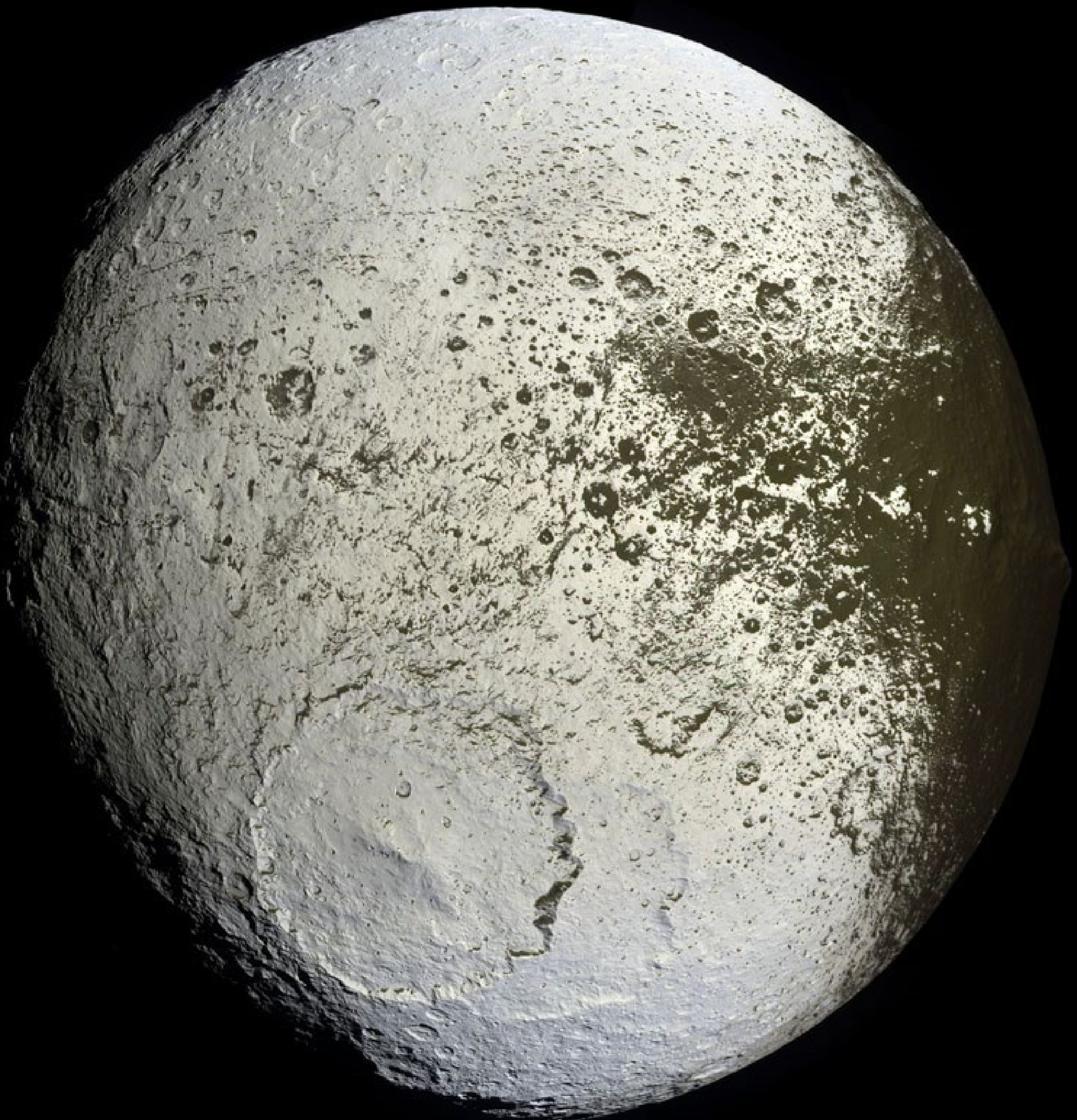
- We’ve known since the first telescopes that something was weird about this moon. It was 3x brighter when seen on one side of Saturn compared to when it’s on the other side.
- Clearly, one side must be very reflective, and the other side very dark
- And too, the moon must be tidally locked with Saturn, so it keeps the same fact towards Saturn always
- This last was not a surprise; virtually all moons in the solar system do this, including our own. The tidal braking time scale is much less than the 4.5 billion years since the beginning
- **Iapetus has a “Dark Side” and a “Bright Side”**

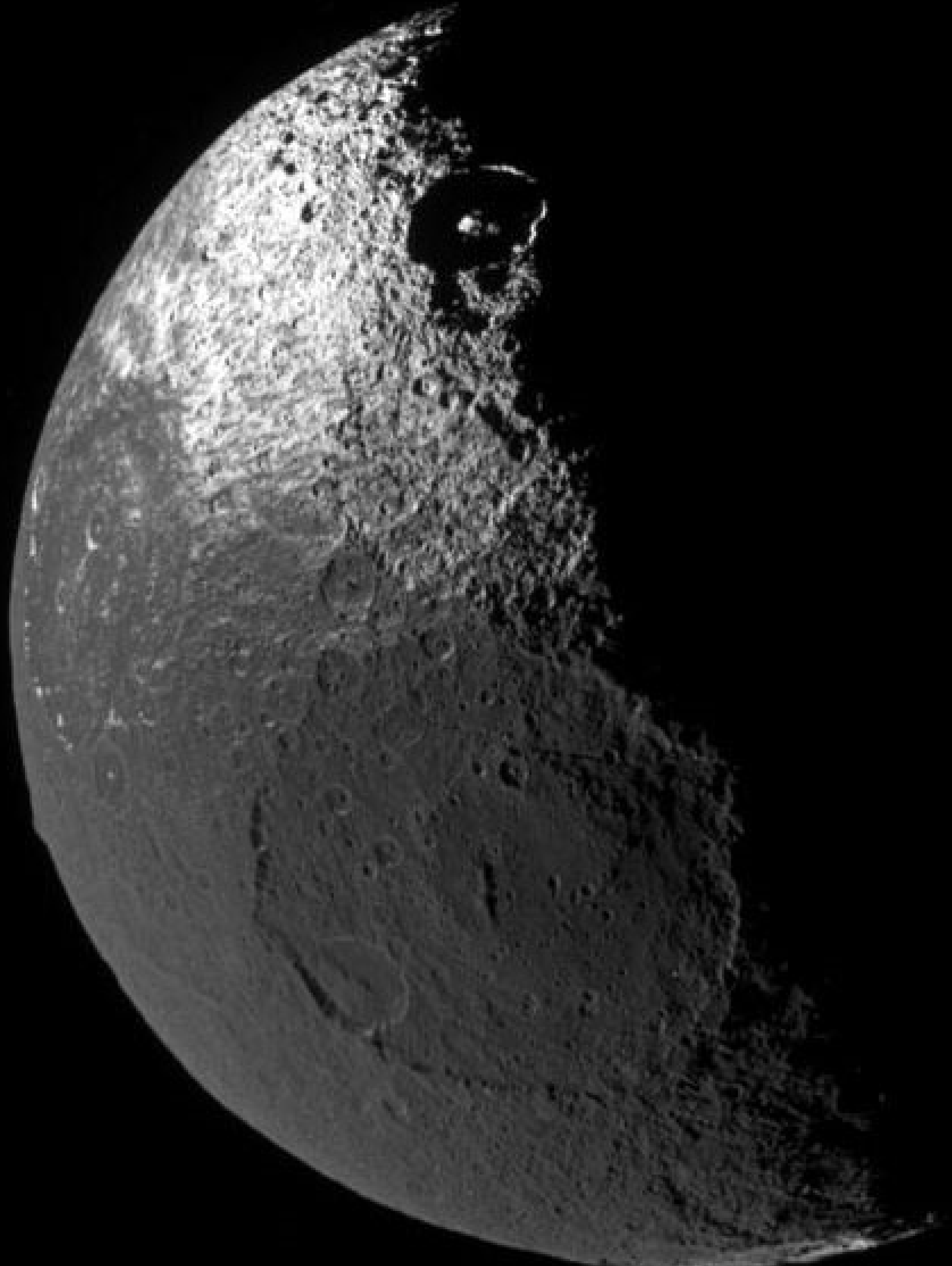
And, it's got a large mountain range along the Equator most of the way around the circumference. It looks like one of those old-fashioned toilet tank floats

Or, more tastefully, a walnut

The “Walnut Ridge” on the Equator

The other hemisphere is icy and bright

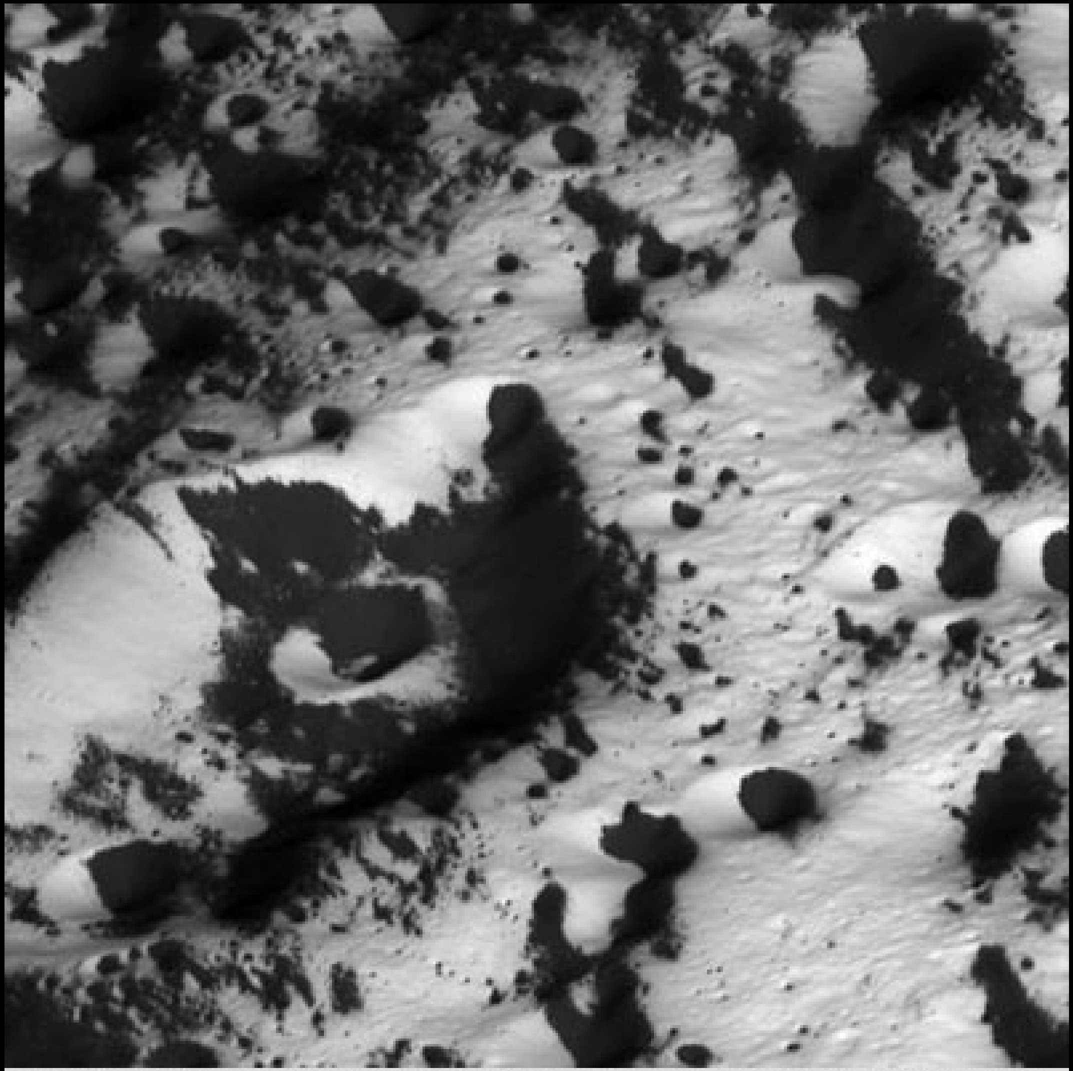




“You Don’t Know the POWER of the Dark Side!”

- **Dark material** is lag (residue) from the sublimation (evaporation) of water ice on the surface of Iapetus, possibly darkened further upon exposure to sunlight
- Iapetus has the **warmest daytime** surface temperature and **coldest nighttime** temperature in the Saturnian system even before the development of the color contrast; about 25 Fahrenheit difference
- So ice preferentially sublimates from the **Dark side**, and freezes in deposits in the Bright Side, especially at the even colder poles.
- Over geologic time scales, this would further darken the Dark Side and brighten the rest of Iapetus, creating a ***positive feedback thermal runaway process*** of ever greater contrast in albedo, ending with all exposed ice being lost from the Dark Side.
- Over a period of one billion years at current temperatures, dark areas of Iapetus would lose about 20 meters of ice to sublimation, while the bright regions would lose only 0.1 meters, not considering the ice transferred from the dark regions.

The trailing side is covered with water ice and carbon dioxide ice

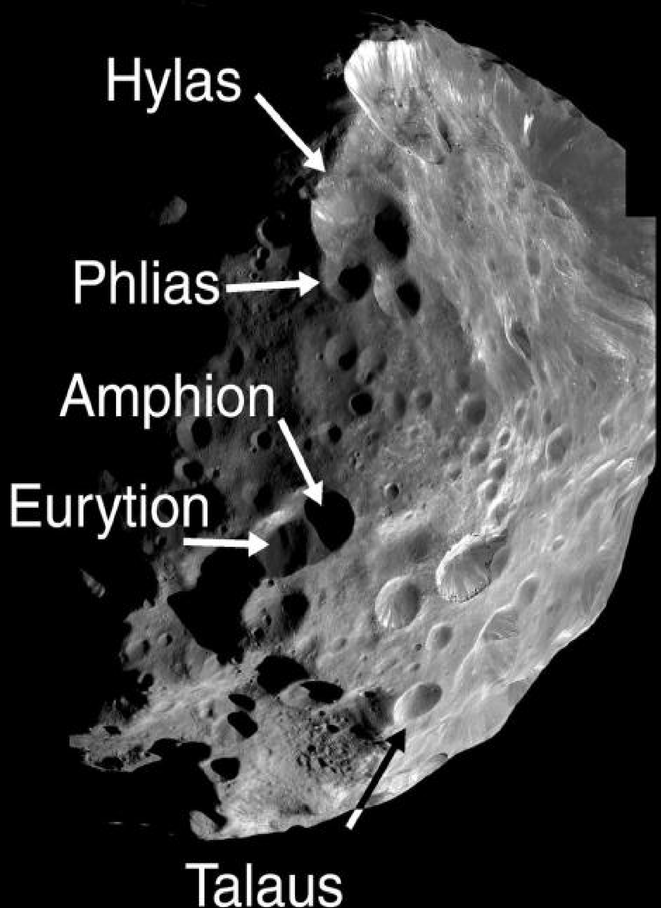


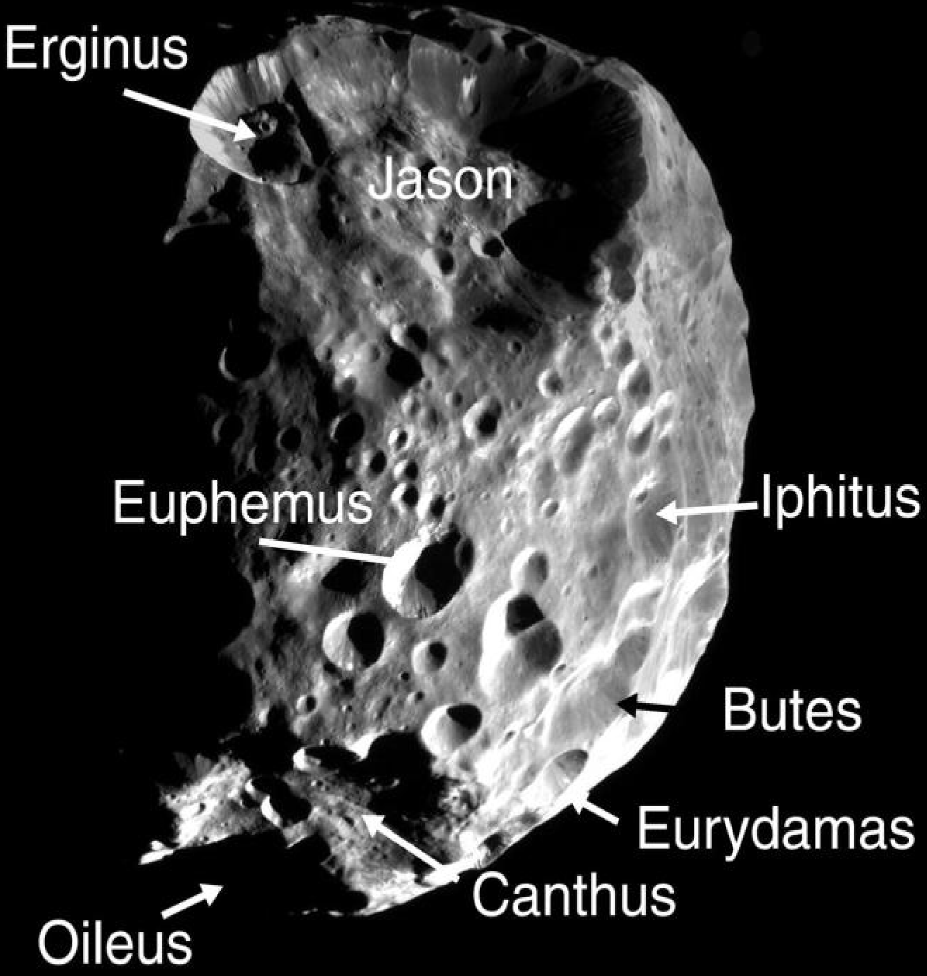
Cassini image shows terrain in the transition region between Iapetus' dark leading hemisphere and its bright trailing hemisphere. Image courtesy of NASA/JPL/Space Science Institute.

Hyperion – The SpongeBob Moon! (animation)

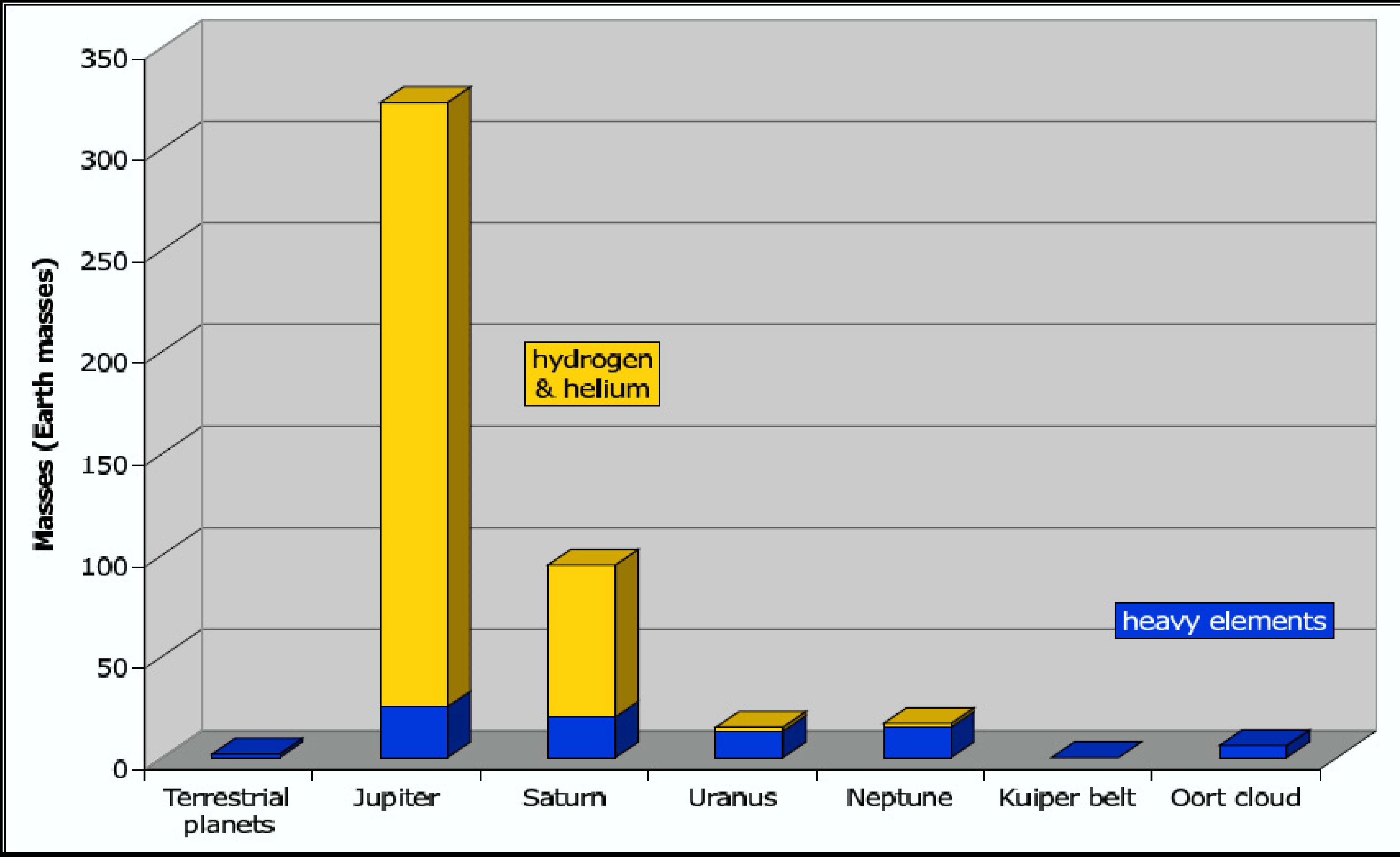
- Hyperion’s dark spots are made of hydrocarbons, and the white material is mostly water ice, but a bit too of CO2 “dry ice”.
- The dark hydrocarbons absorb more sunlight and heat, and melt (sublimate, really) their way down into the ice, making the dimpled surface.

Outer moon Phoebe; Nothing’s going on our there, ancient surface, cratered.





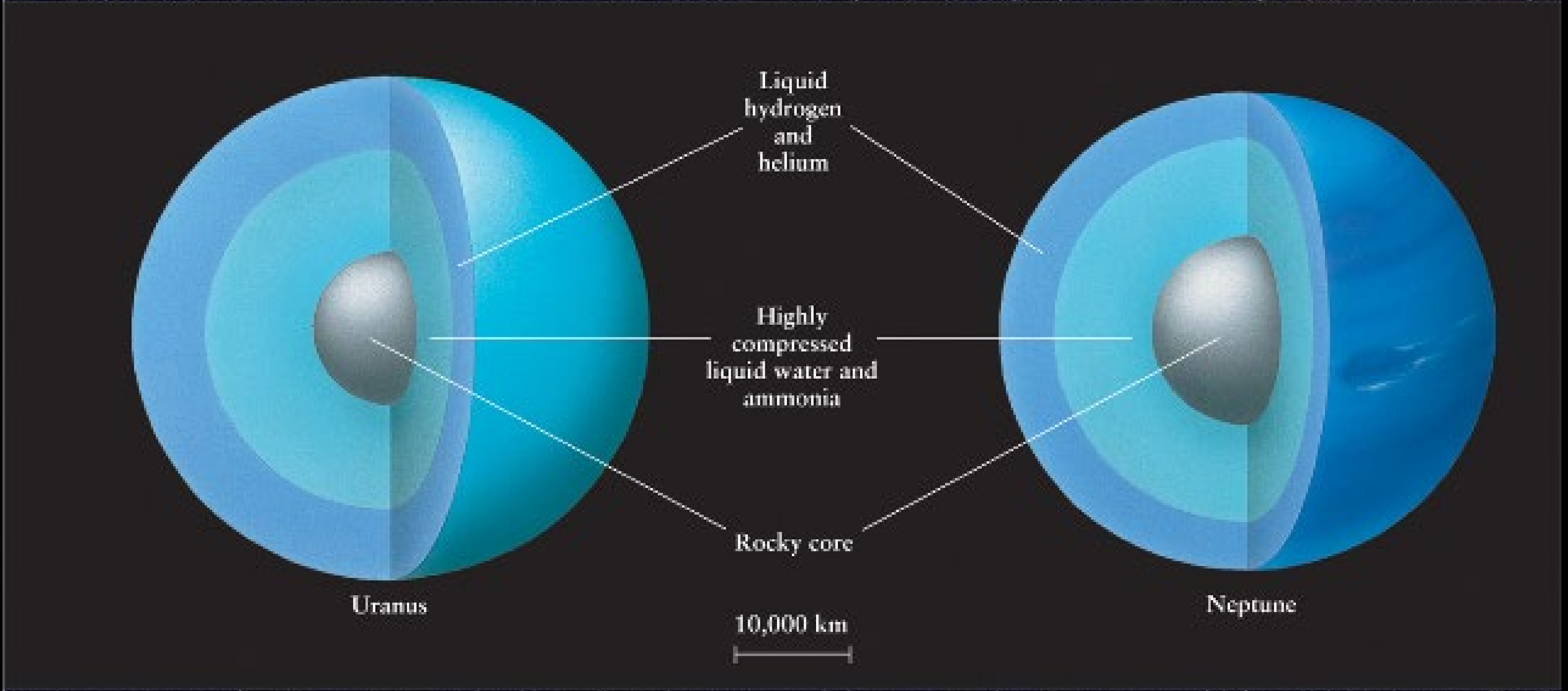
Unlike Jupiter and Saturn, the mass of Uranus and Neptune is dominated by heavy elements



Uranus

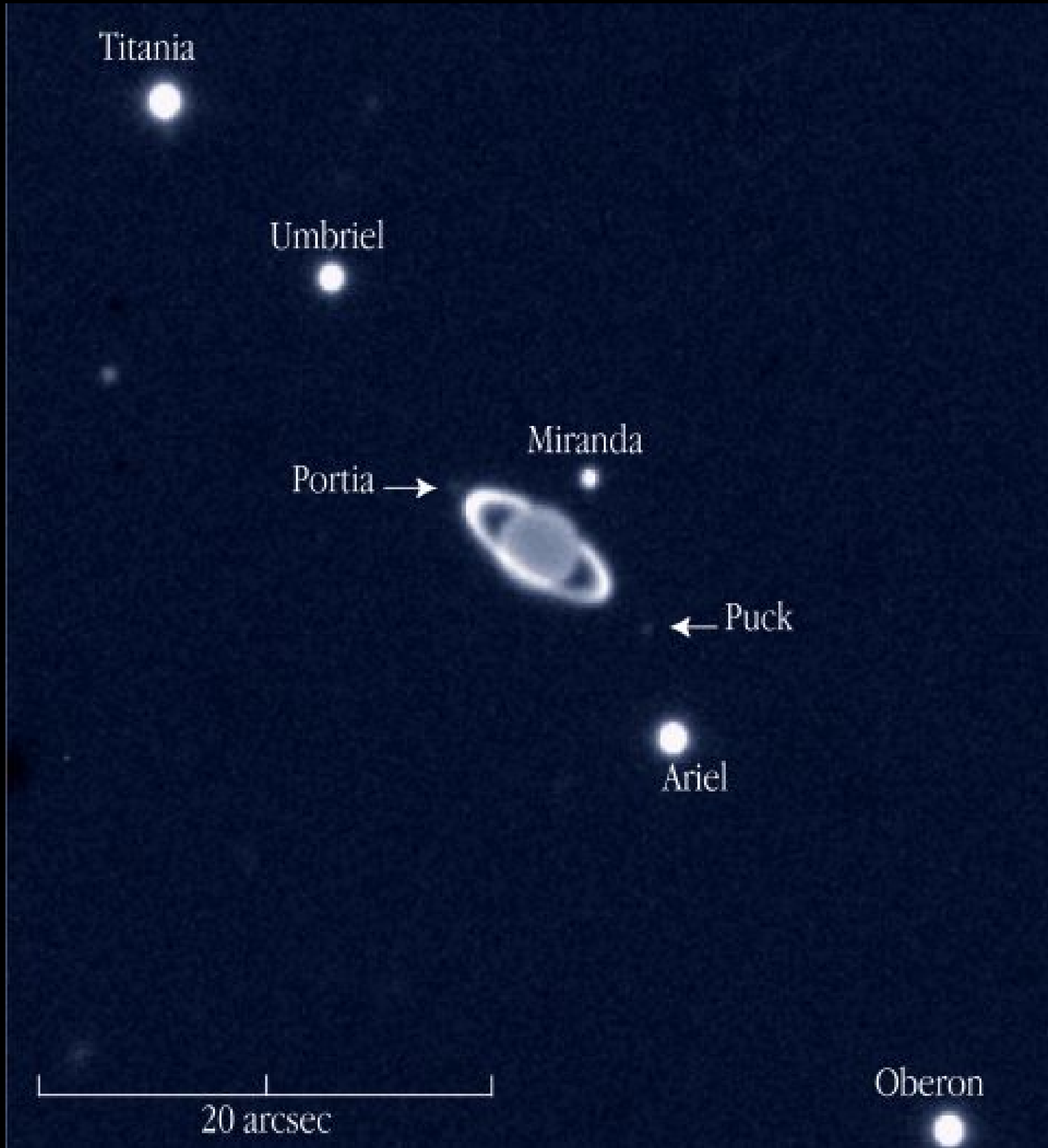
- About 5 times the diameter of Earth.
- Mass of 14 Earth’s
- Too little mass to create a liquid hydrogen core. Hydrogen, Helium interior down to rocky core.
- Colored Bluish by methane (CH_4), which absorbs red sunlight.

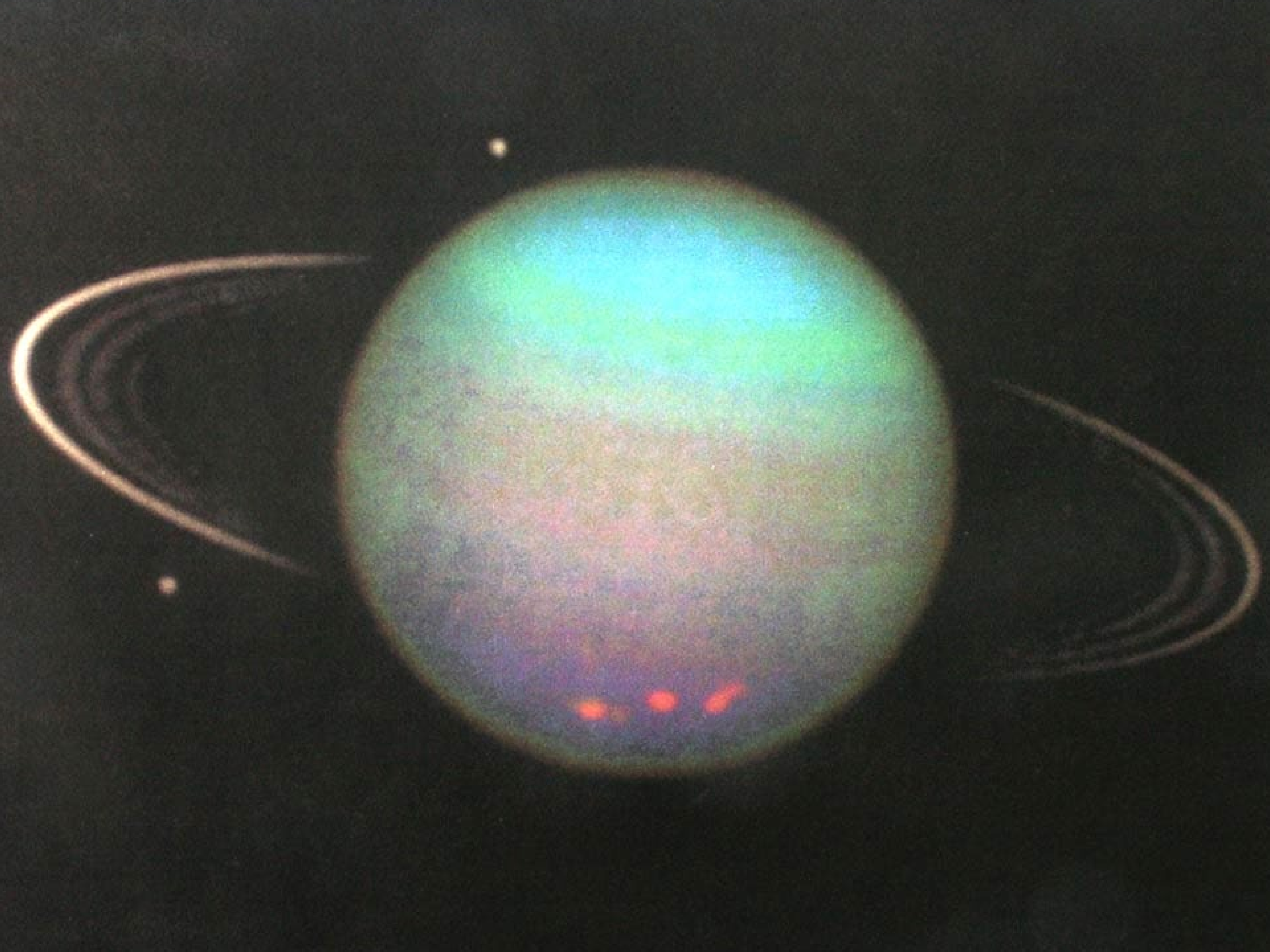
Internal Structures of Uranus and Neptune



Both Uranus and Neptune have

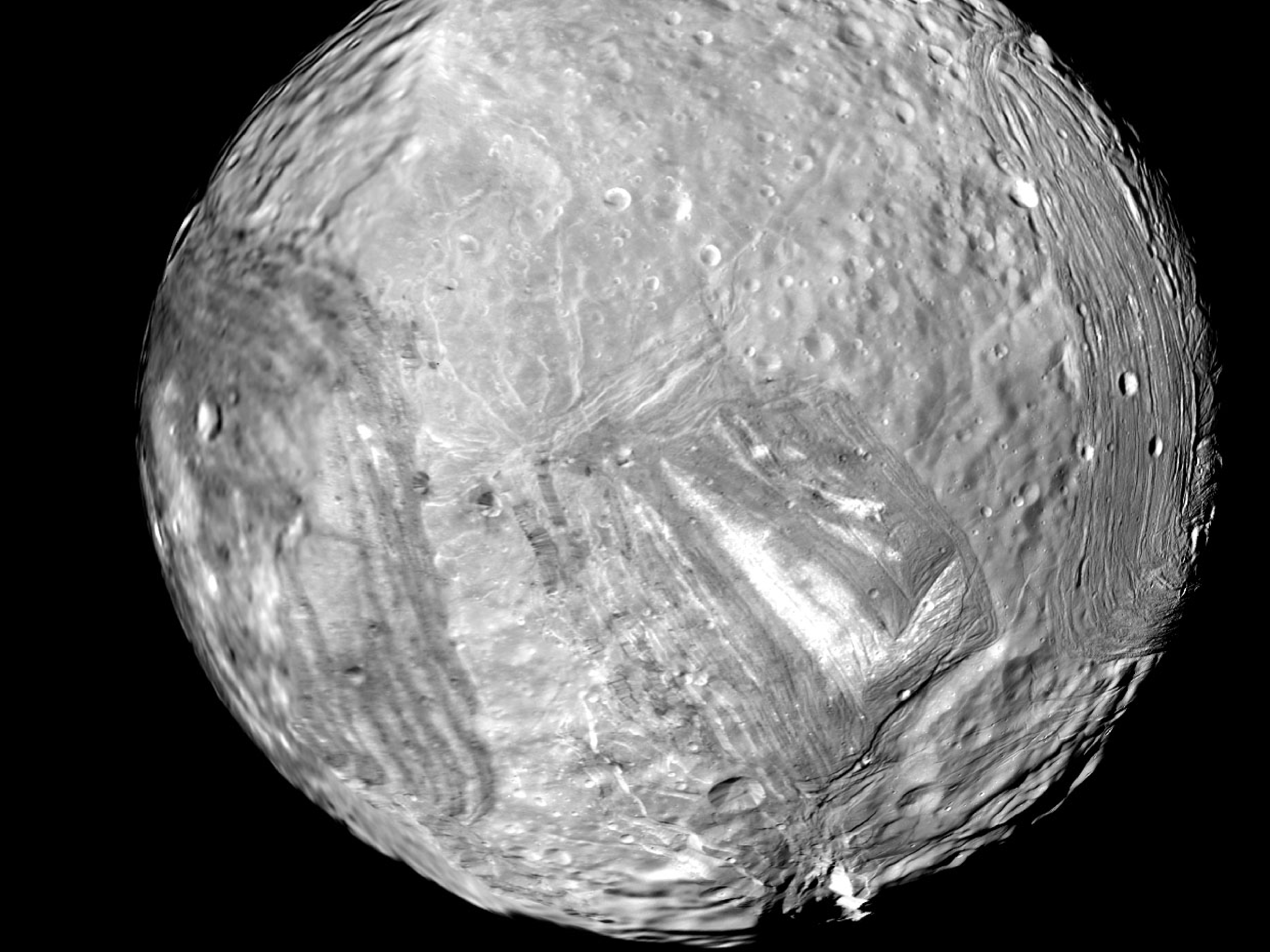
- a rocky core, resembling a terrestrial planet
- a mantle of liquid water with ammonia dissolved in it
- an outer layer of liquid molecular hydrogen and liquid helium


Titania
Umbriel
Miranda
Portia
Puck
Ariel
Oberon
20 arcsec

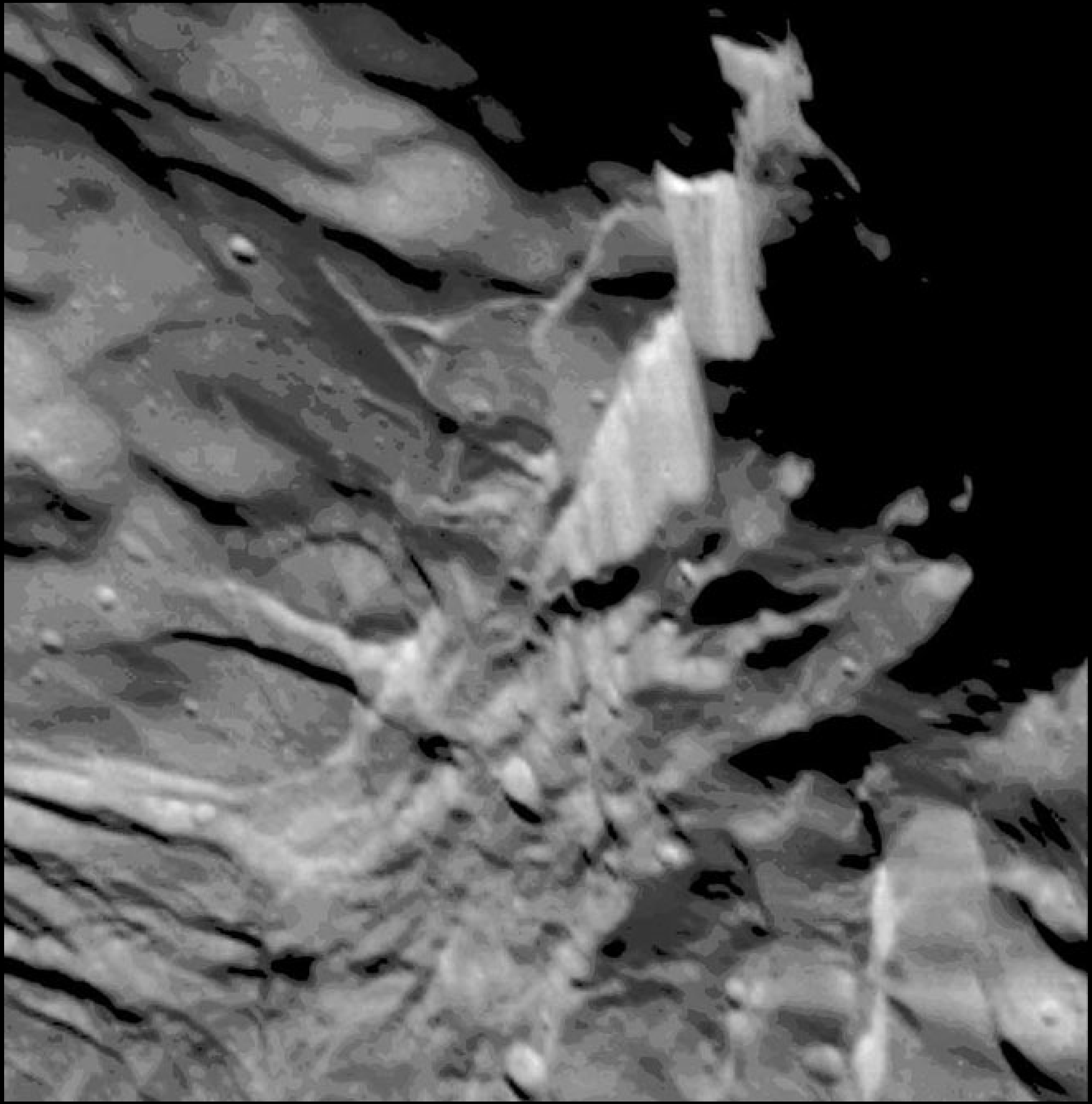


Oberon

Miranda



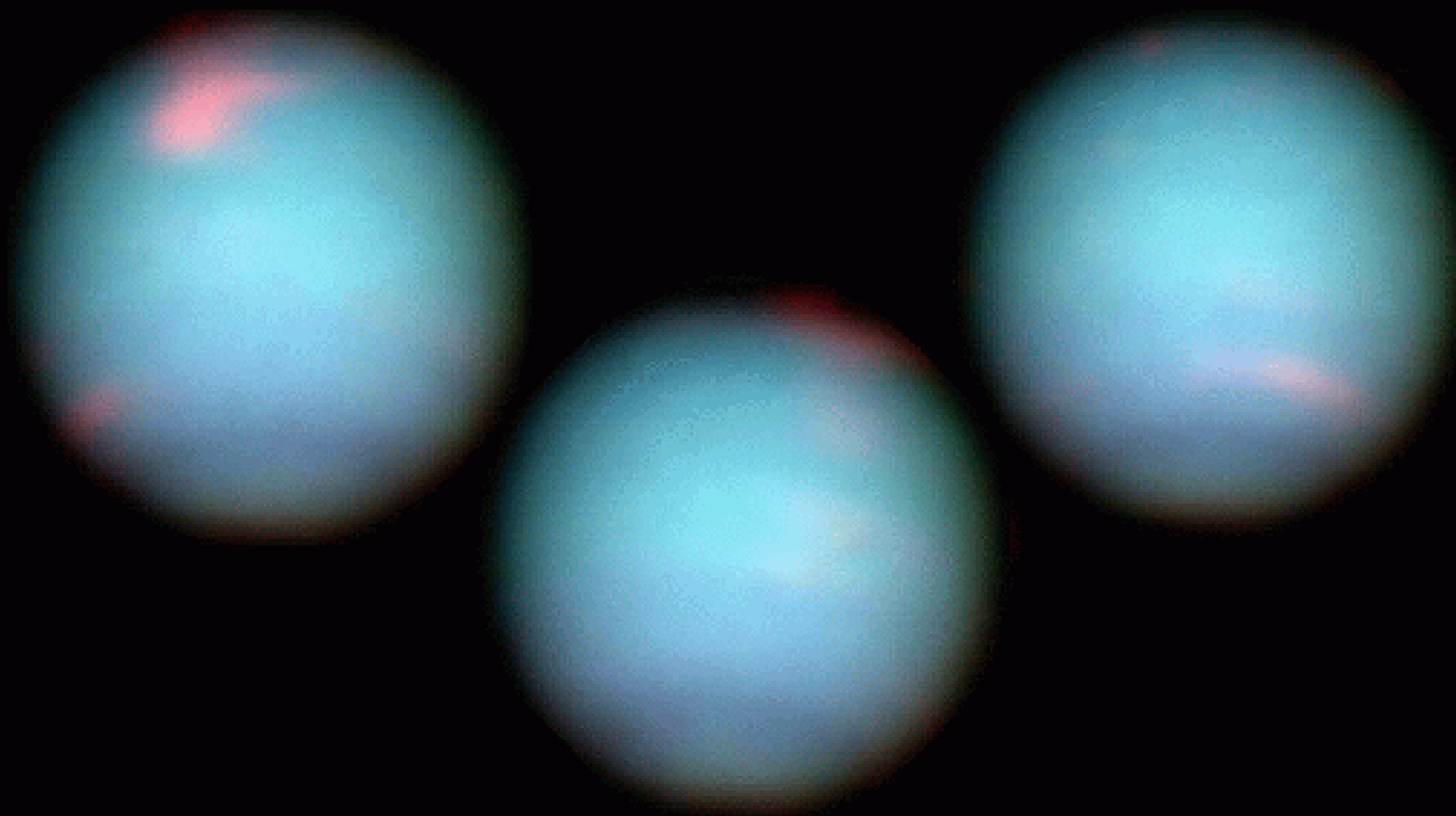
Miranda - Bizarre Landscape;



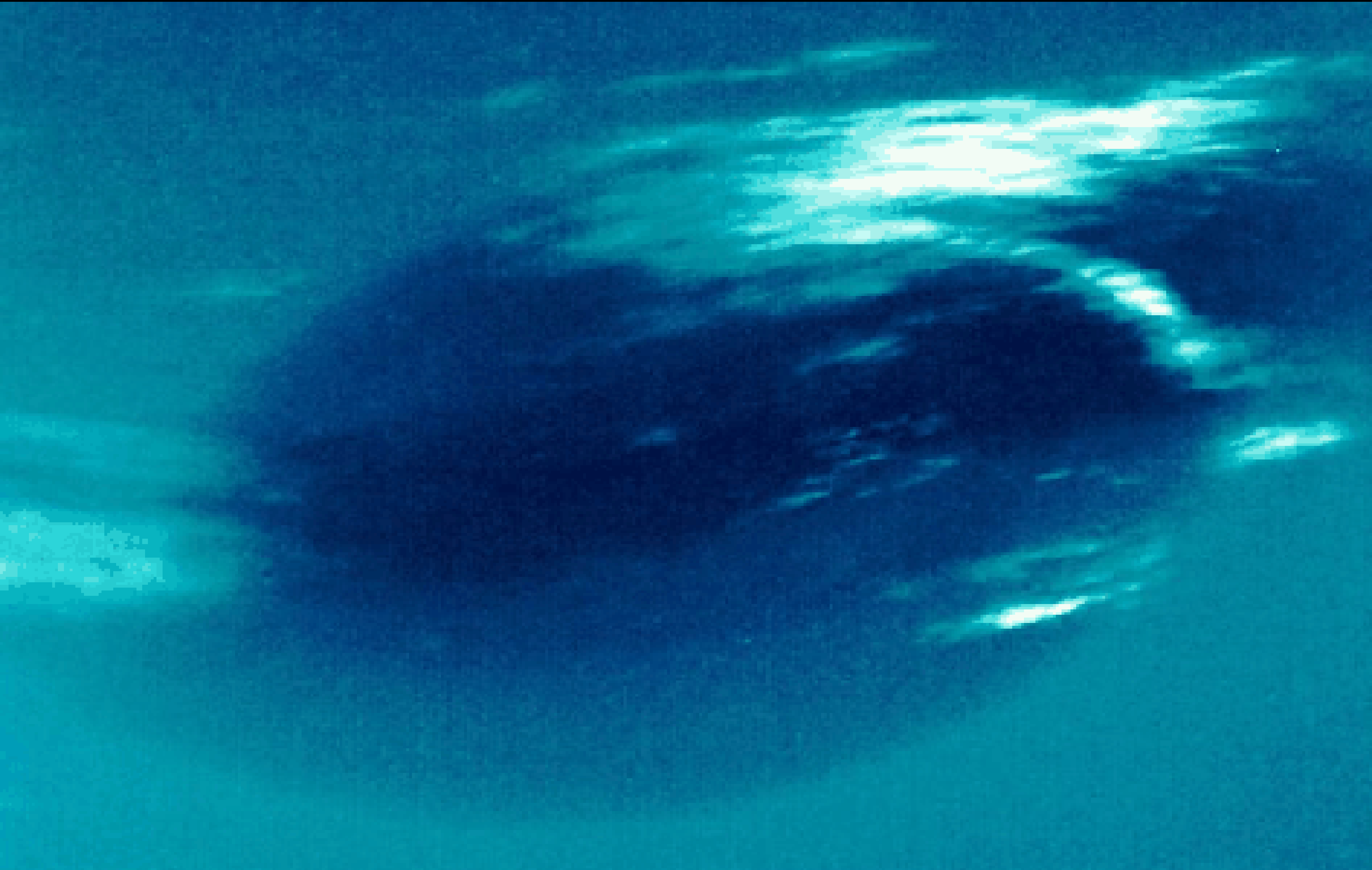
- A cliff 50,000 ft high!
- All water ice
- Large forces applied to this little moon

Neptune

- Mass of 17 Earth's
- Structure very similar to Uranus'
- Hydrogen, helium, and methane in the upper atmosphere



Neptune’s Great Dark Spot (1989 picture. It was gone by 1992)

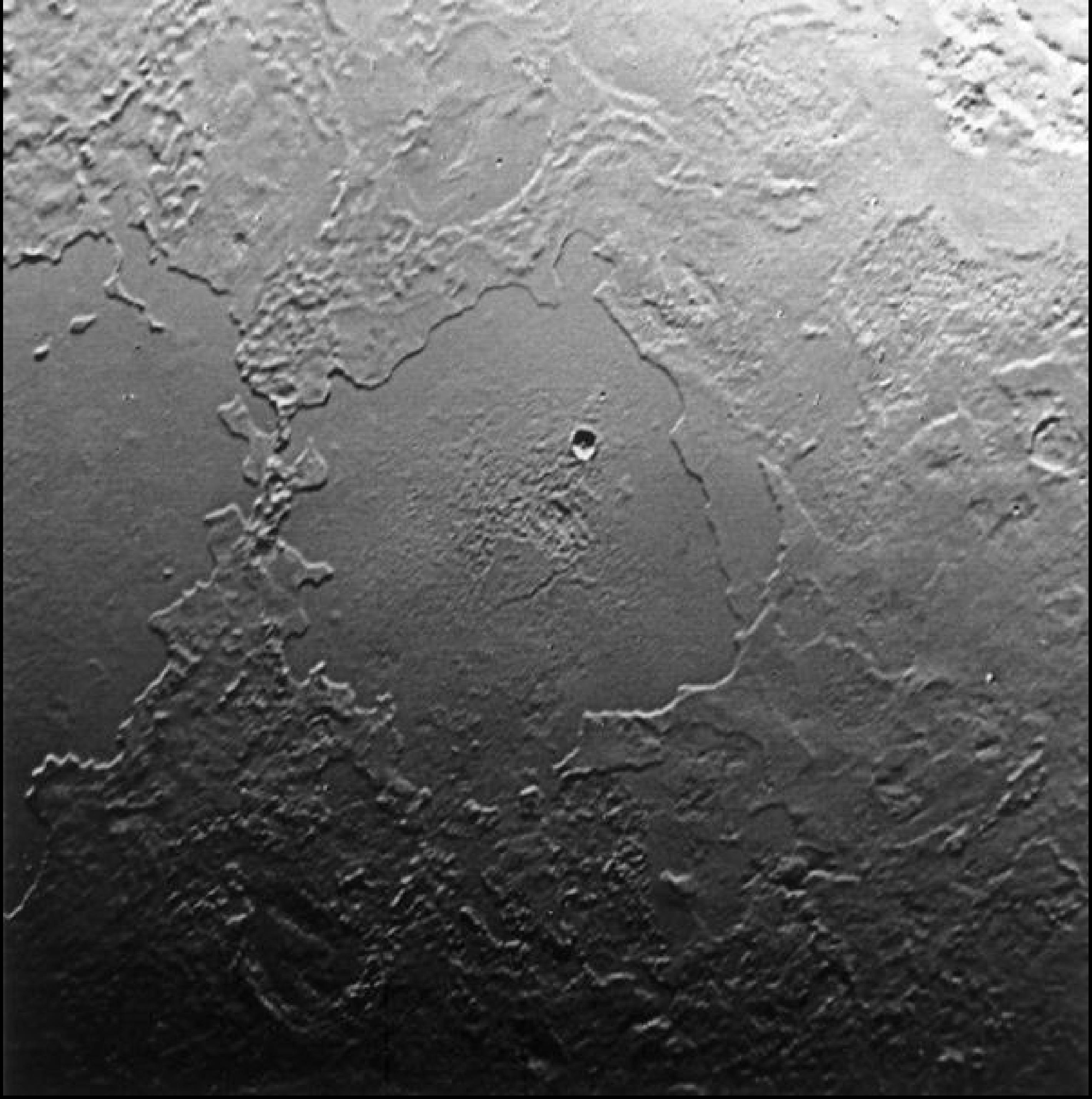


One Big Moon - Triton

- Triton orbits Neptune in a near perfect circular orbit
- But, orbits backwards from Neptune’s spin
- Impossible if formed from the same protoplanetary condensation as Neptune, so must be a captured former **Kuiper Belt Object**.

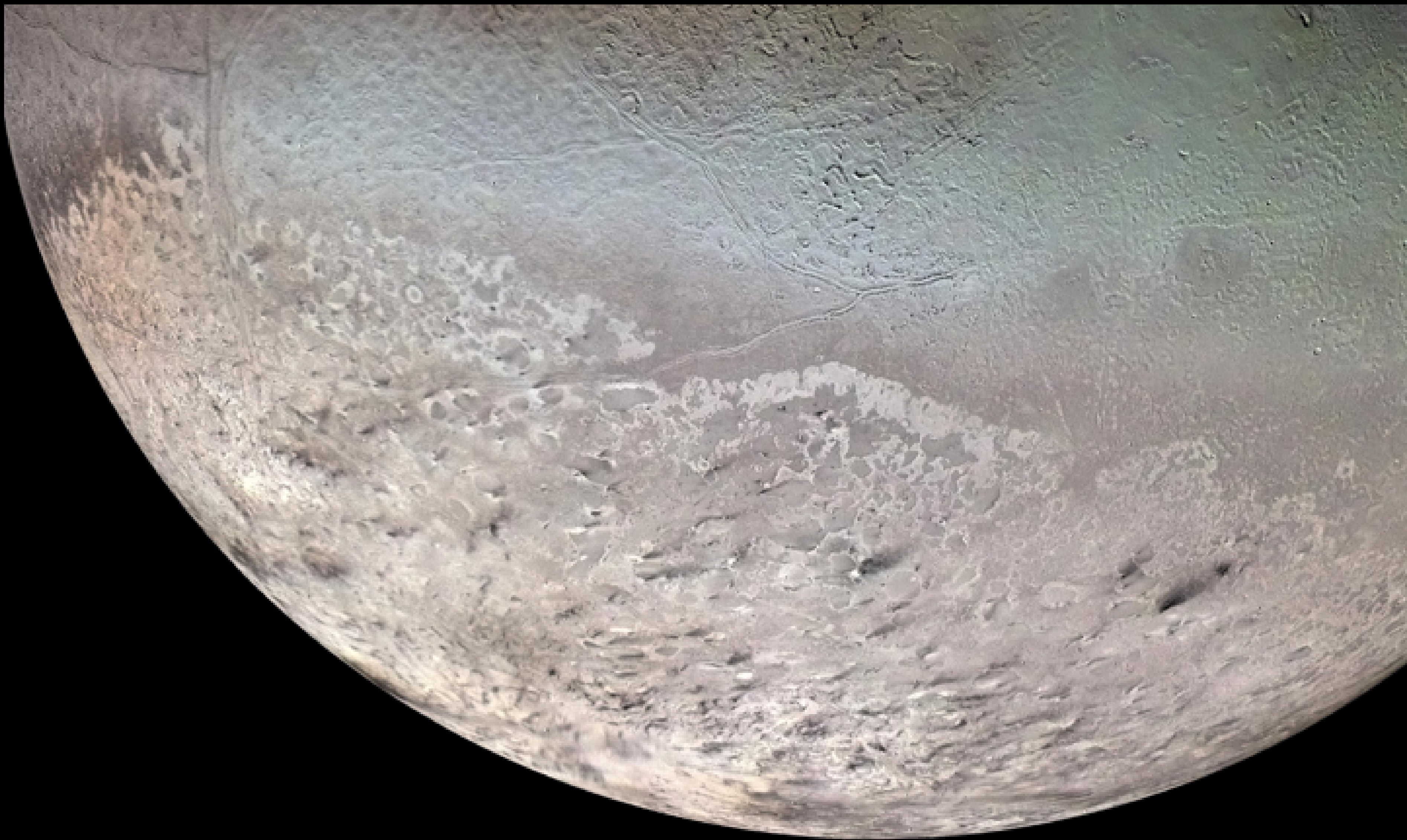
“Climate” on Triton

- Triton has an extremely thin atmosphere of molecular nitrogen N2 about 1/70,000 the pressure of sea level Earth
- At about -400F, this N2 is near the freezing point. It is a thin gas in mid/low latitudes, but freezes onto the ground in polar regions
- Black surface plumes of carbon from geysers of organics melting/vaporizing beneath frozen nitrogen crust in polar areas
- Solar heating is microscopic way out here more than 2 billion miles from the sun. Not much energy to drive a vigorous climate, and not much atmosphere to work with either.

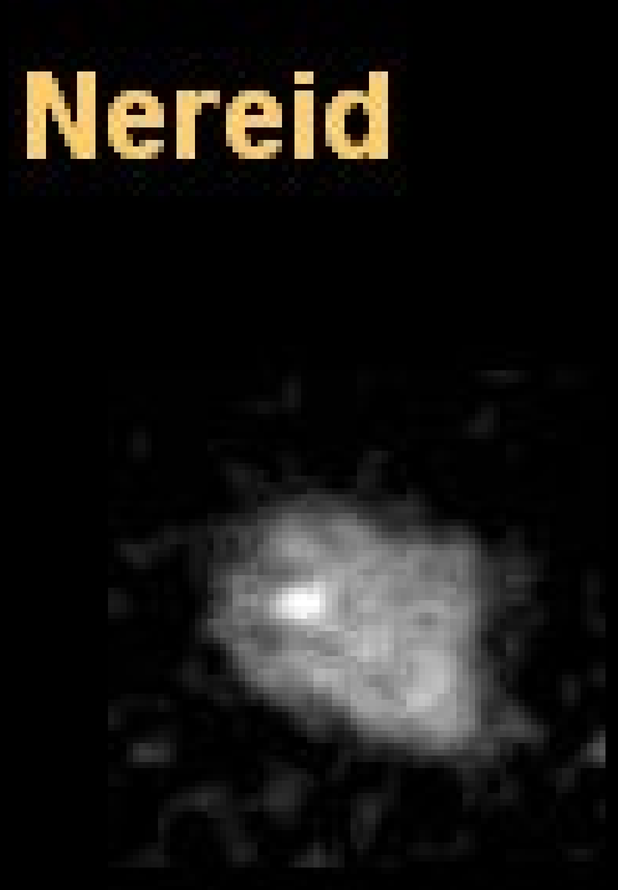


Geologically young (a billion years or so?) surface, with faults, few craters, mostly water ice “cantelope” surface with puzzling dimples, in low latitudes Cryo-volcanos of water/ammonia or water/organics which melt at very low temperatures to form a cryo-”lava”, which have flooded these basins. Impact ejects at center. Surface ices are water and/or nitrogen

Triton: “Cantelope” tropics, icy nitrogen poles with black carbon plumes from geysers



Tiny Nereid. Probably icy, Just photo'd up close once, and not that close, by Voyager



Key Points – Chap 11: Jovian Planets and Moons

- Jupiter & Saturn both emit more heat than they receive from sun, know why
- Virtually all moons of all planets are tidally locked; same face towards planet at all times
- All outer planets have rings, which decay over ~few hundred million years, inside tidal Roche Limit
- Young rings=water ice, older rings=dust
- Cloud tops; condensations of ammonia on Jupiter and Saturn, and of methane in Uranus and Neptune.
- Tidal friction heats Io, Europa, Titan, Enceladus, and to a smaller extent, the other moons.
- Rapid rotation and conducting interior -> magnetic field
- Rapid rotation, strong Coreolis force and more banded atmosphere, especially seen on Jupiter
- Outermost moons of some Jovians; some orbit backwards: must be captured asteroids or KBO's.
- Titan – remarkable hydrologic cycle involving methane, not water like on Earth
- Neptune has the highest winds in the solar system: over 1000 mph