Astrobiology of Icy Ocean Worlds: Habitability and Habitancy

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Washington Univ in St. Louis

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OCEAN WORLDS

Earth isn't the only ocean world in our solar system. Oceans could exist in diverse forms on moons and dwarf planets, offering clues in the quest to discover life beyond our home planet.

SIZE COMPARISON

1 AU

DISTANCE FROM SUN

ACTIVE

Dynamic ocean, known to support life

OCEAN WORLD STATUS

TERRESTRIAL PLANET

EARTH

Our home planet, Earth, is the only body known to have life. Called the "ocean planet," Earth's surface-land-to-water ratio is 29% land to 71% water.


SIZE COMPARISON
5.2 AU
DISTANCE FROM SUN
ACTIVE?
Possibly a dynamic ocean, could support life
OCEAN WORLD STATUS
MOON OF JUPITER
EUROPA
Scientists strongly suspect that a subsurface salty ocean lies beneath Europa's icy crust. Tidal heating from its parent planet, Jupiter, maintains this ocean's liquid state and could also create partially melted pockets, or lakes, throughout the moon's outer shell.
MOON OF JUPITER
GANYMEDE
Ganymede is the largest moon in our solar system, and the only moon with its own magnetic field. Recent studies indicate a large, underground saltwater ocean is present at the Jovian moon. Ganymede could in fact have several layers of ice and water sandwiched between its crust and core.
SIZE COMPARISON
5.2 AU
DISTANCE FROM SUN
LOCKED
Trapped ocean, unlikely to support life
OCEAN WORLD STATUS
SIZE COMPARISON
5.2 AU
DISTANCE FROM SUN
LOCKED
Trapped ocean, unlikely to support life
OCEAN WORLD STATUS
MOON OF JUPITER
CALLISTO
Callisto's cratered surface lies at the top of an ice layer, which is estimated to be about 60 miles (100 km) thick. An ocean, which is thought to be at least 6 miles (10 km) deep, could be directly beneath the ice.

MOON OF SATURN

ENCELADUS

Scientists predict that a regional reservoir about 6 miles (10 km) deep lies under a shell of ice 20 to 25 miles (30 to 40 km) thick at Enceladus' south pole. This underground ocean is thought to feed the moon's impressive jets, which spray from deep fissures (called "tiger stripes") in the moon's surface.

SIZE COMPARISON

9.5 AU

DISTANCE FROM SUN

ACTIVE

Dynamic ocean, could support life

OCEAN WORLD STATUS

SIZE COMPARISON

9.5 AU

DISTANCE FROM SUN

LOCKED?

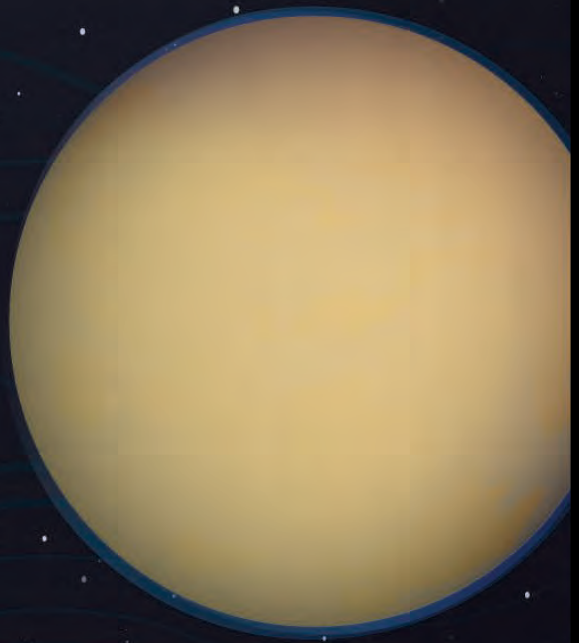
May have a trapped ocean, unlikely to support life if ocean is trapped

OCEAN WORLD STATUS

MOON OF SATURN

TITAN

Titan is believed to have a salty subsurface ocean -- as salty as the Dead Sea on Earth -- beginning about 30 miles (50 km) below its ice shell. It is also possible that Titan's ocean is thin and sandwiched between layers of ice, or is thick and extends all the way down to the moon's rocky interior.



SIZE COMPARISON

30.1 AU

DISTANCE FROM SUN

POSSIBLE

Evidence of an ocean, biological potential unknown

OCEAN WORLD STATUS

MOON OF NEPTUNE

TRITON

Active geysers on Triton spew nitrogen gas, making this moon one of the known active worlds in the outer solar system. Volcanic features and fractures mark its cold, icy surface, likely results of past tidal heating. A subsurface ocean at Triton is considered possible, but is unconfirmed.

DWARF PLANET

PLUTO

A world of many unknowns, Pluto could have rings and perhaps a subsurface ocean. Data from NASA's New Horizons mission will provide new insights about this unexplored world.

SIZE COMPARISON

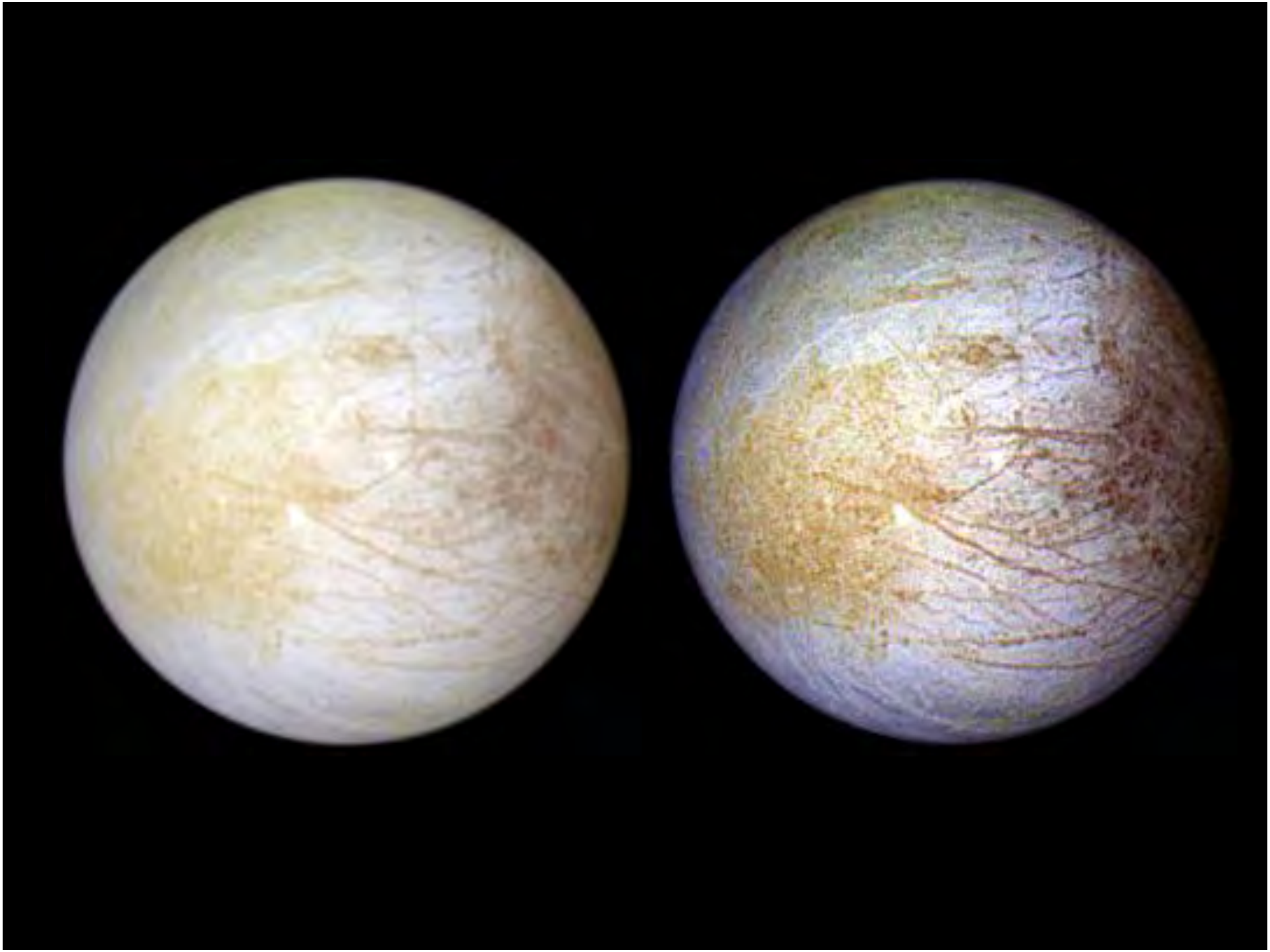
39.5 AU

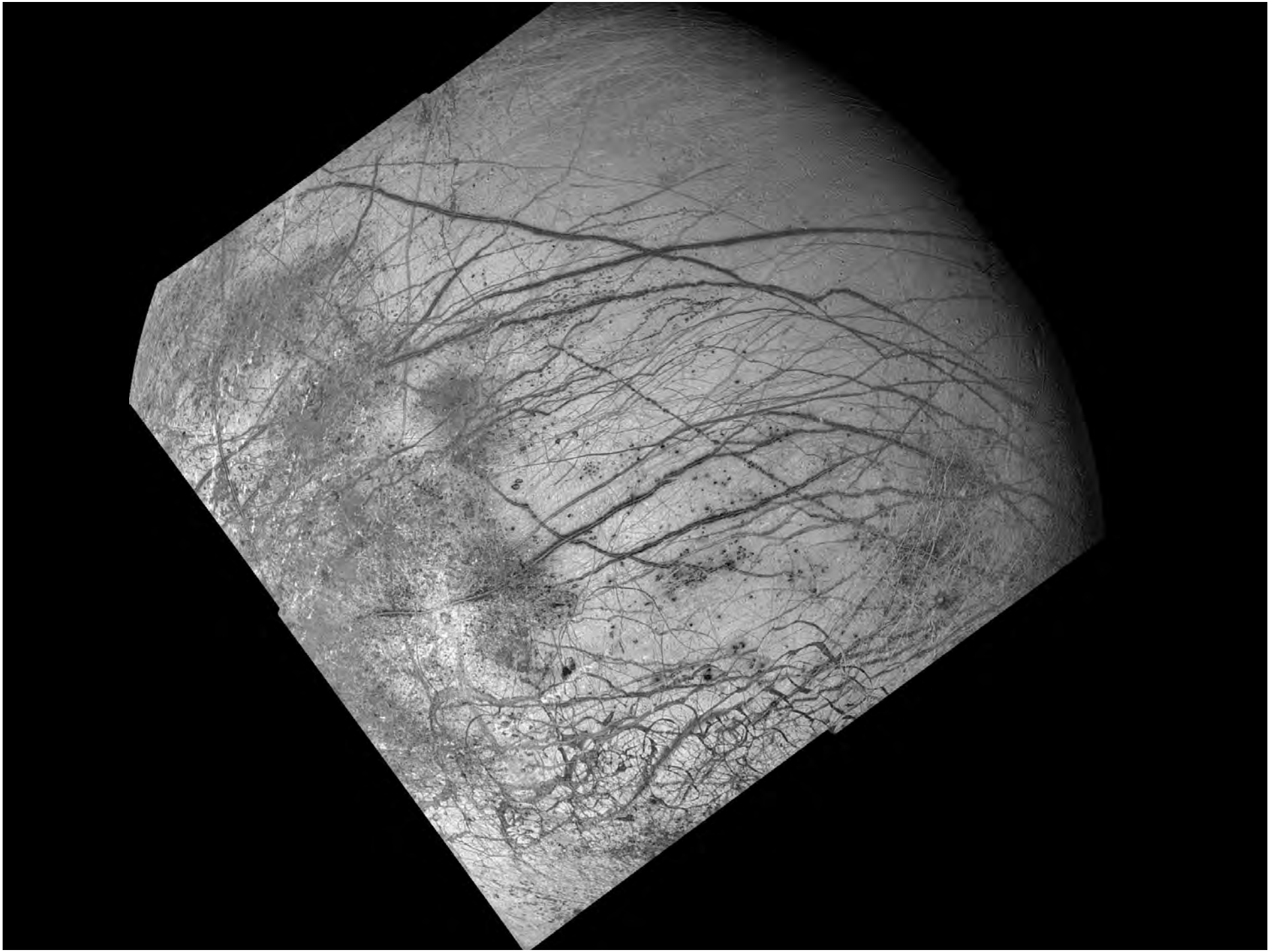
DISTANCE FROM SUN

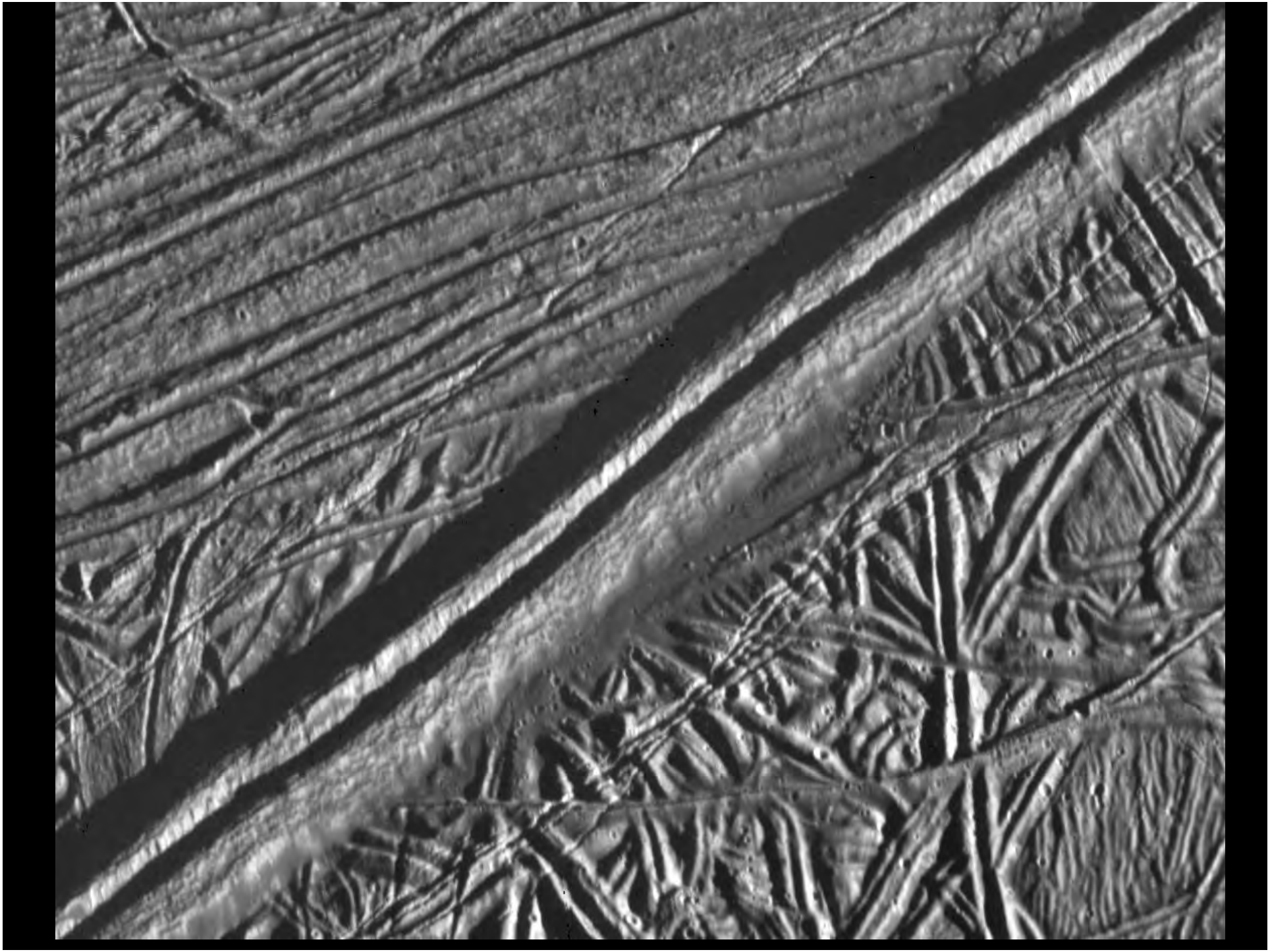
POSSIBLE

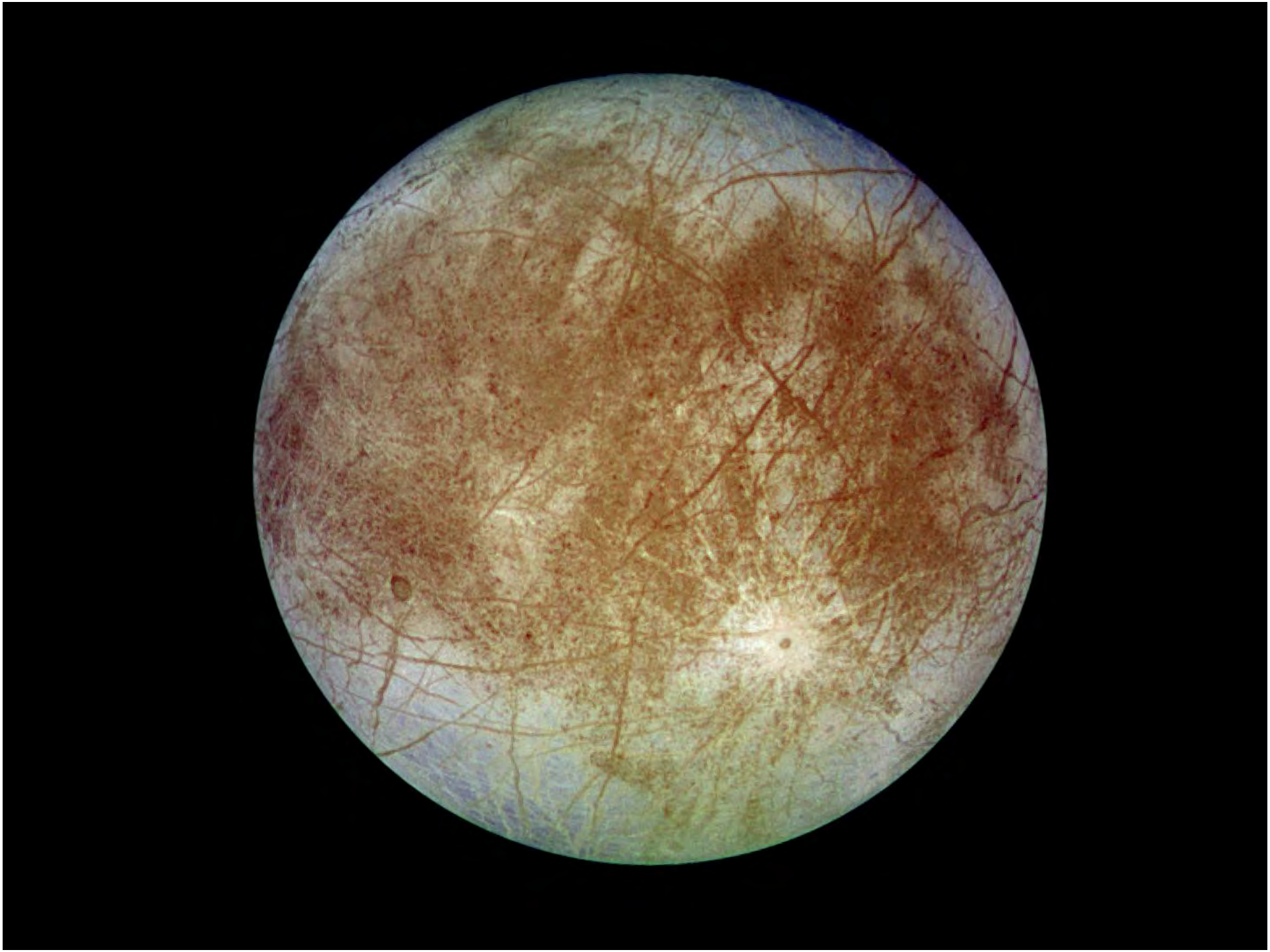
Evidence of an ocean, biological potential unknown

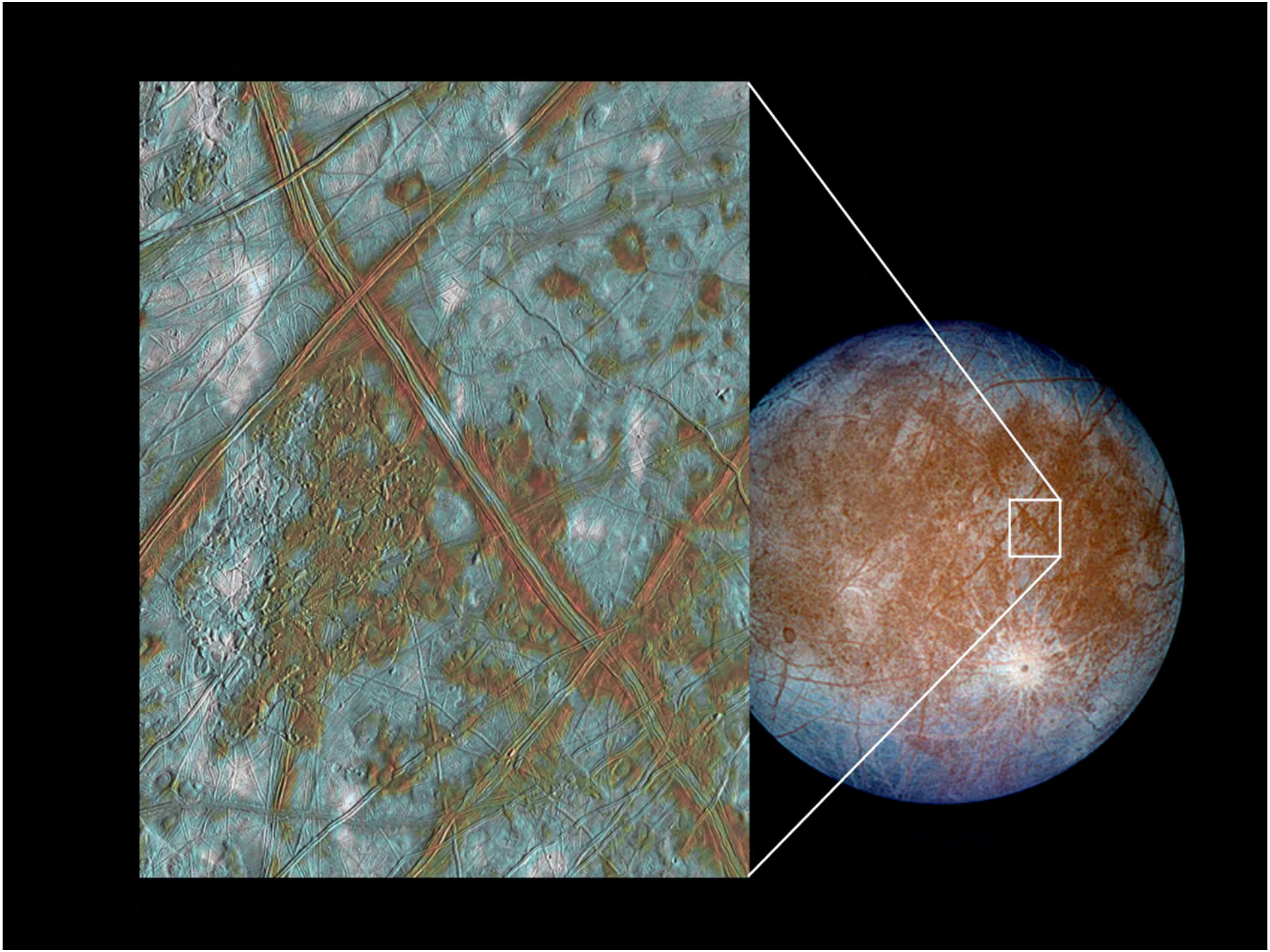
OCEAN WORLD STATUS

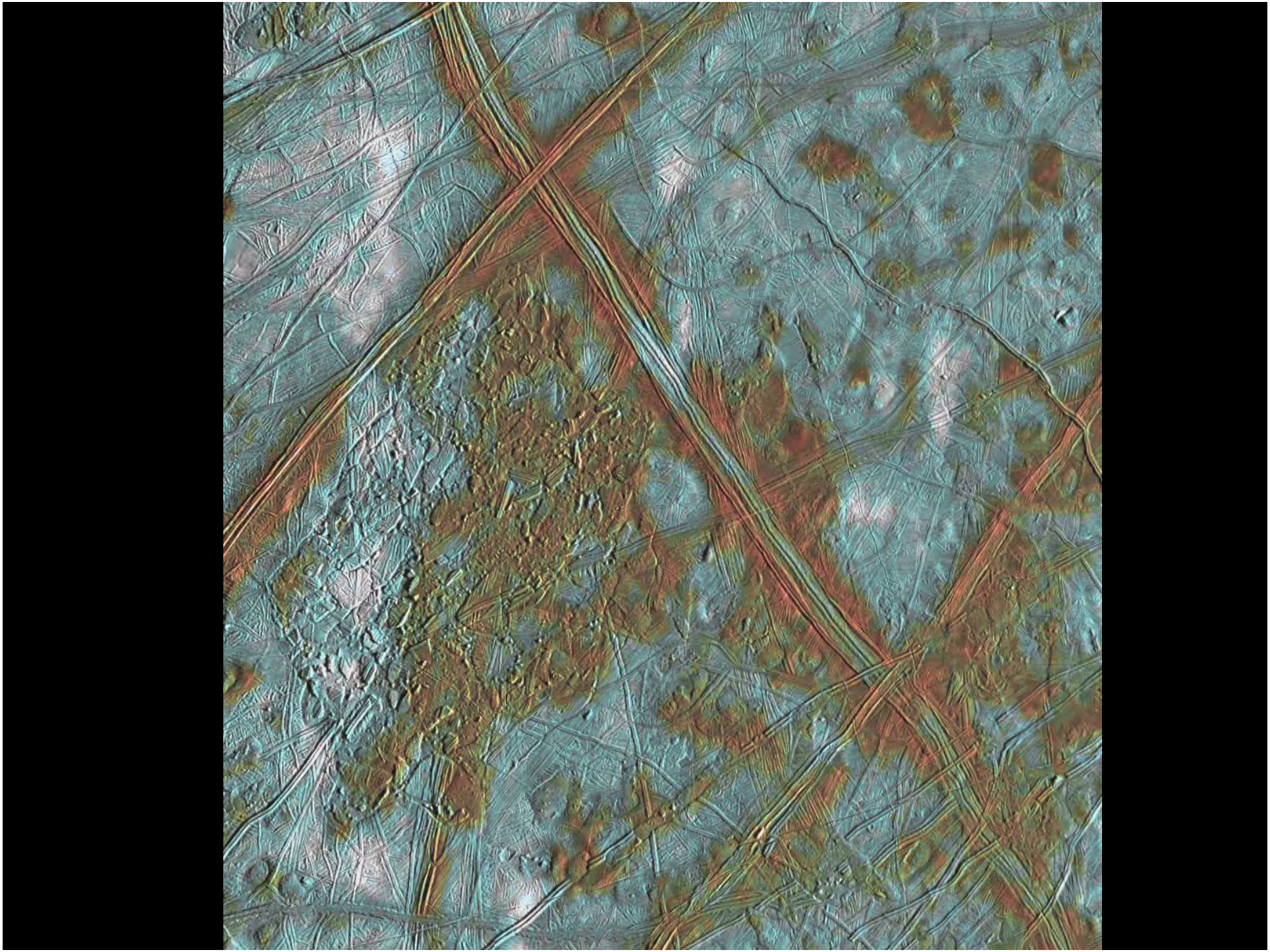


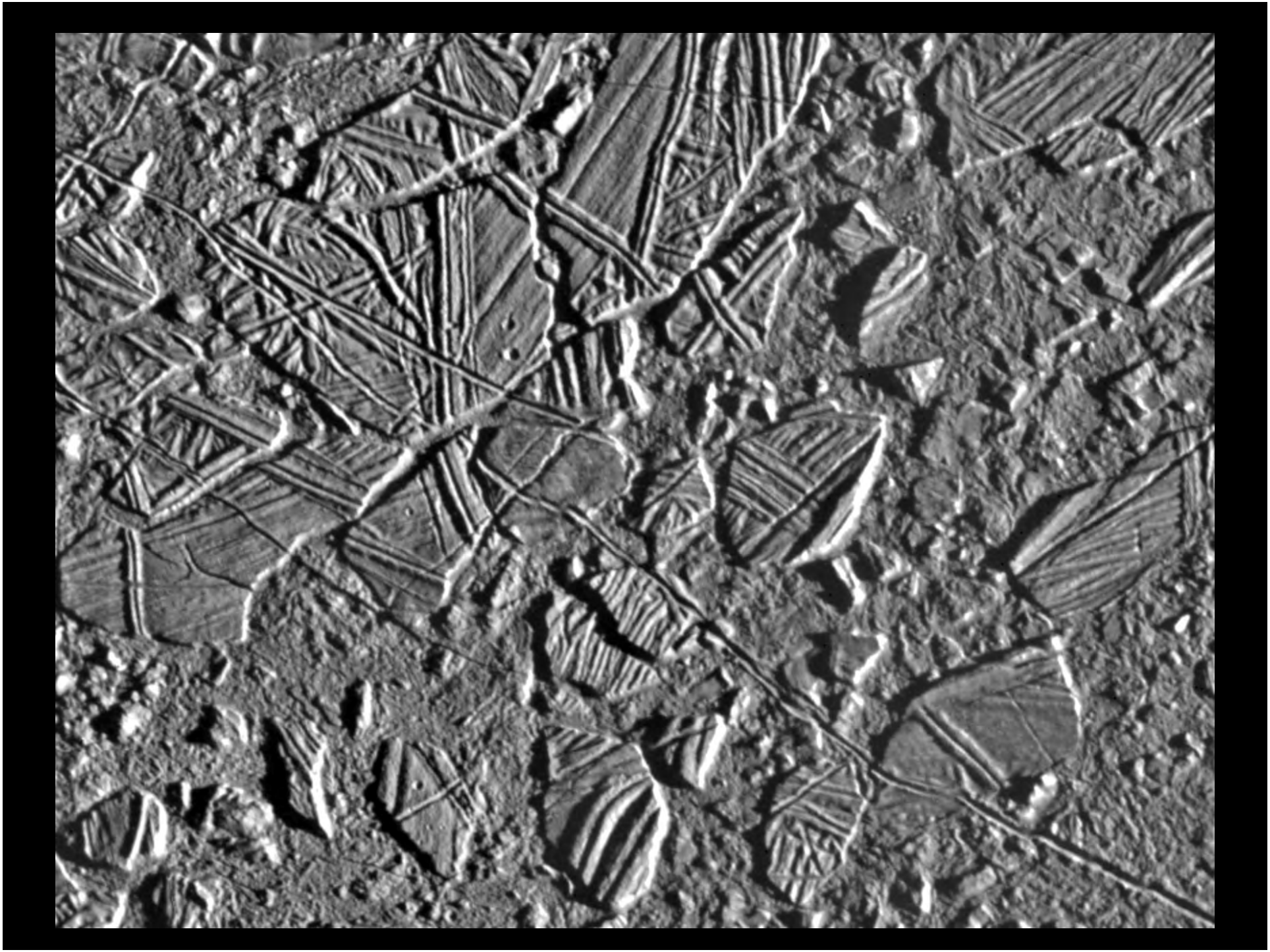


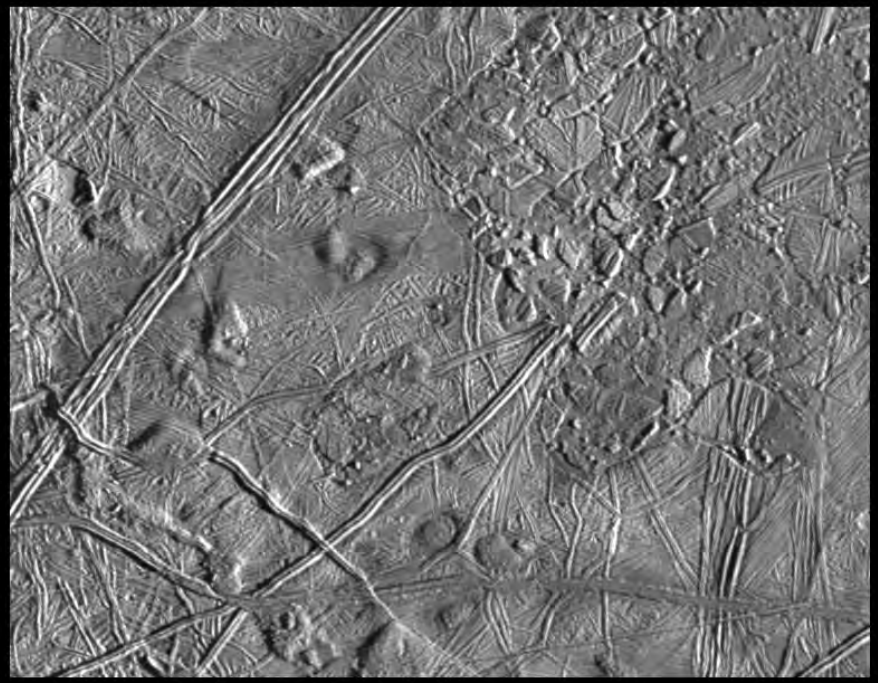




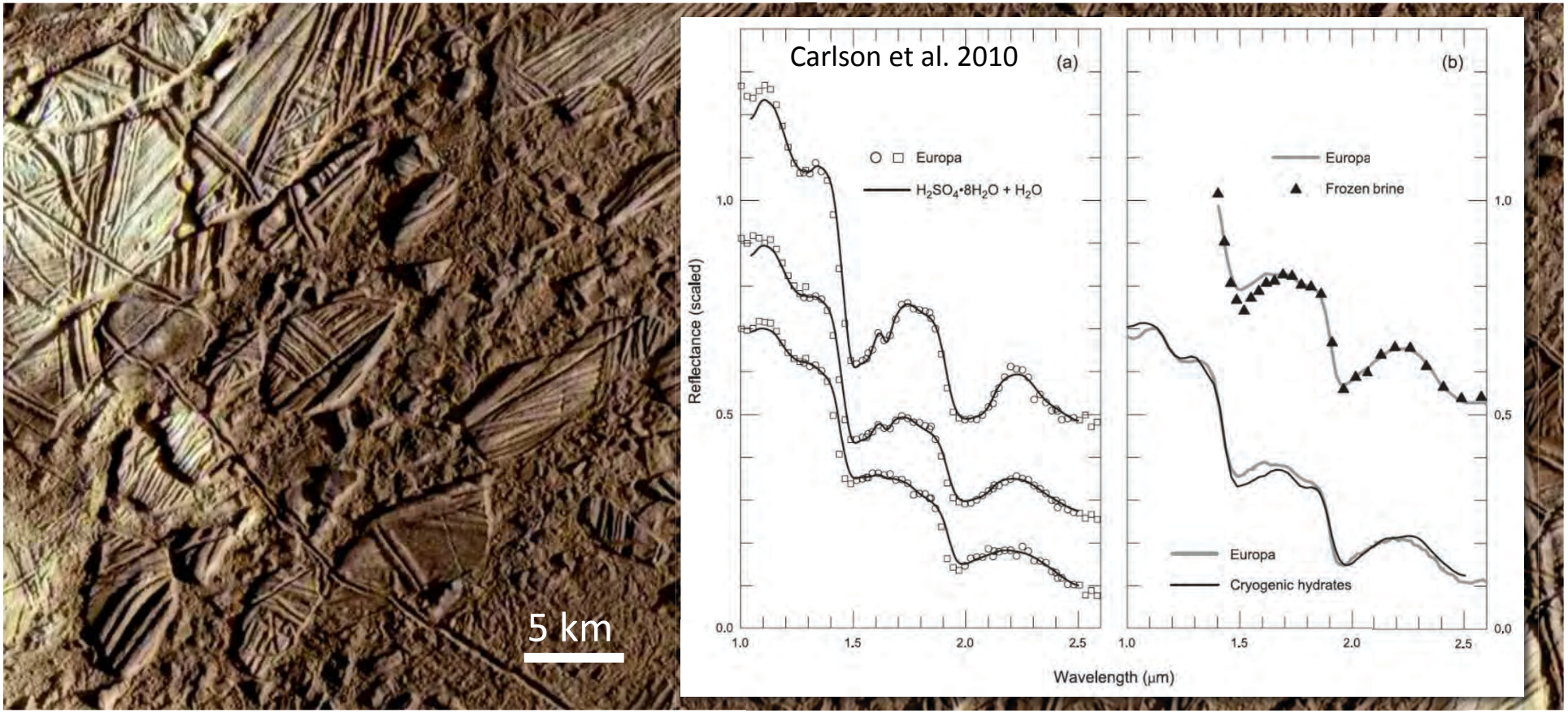




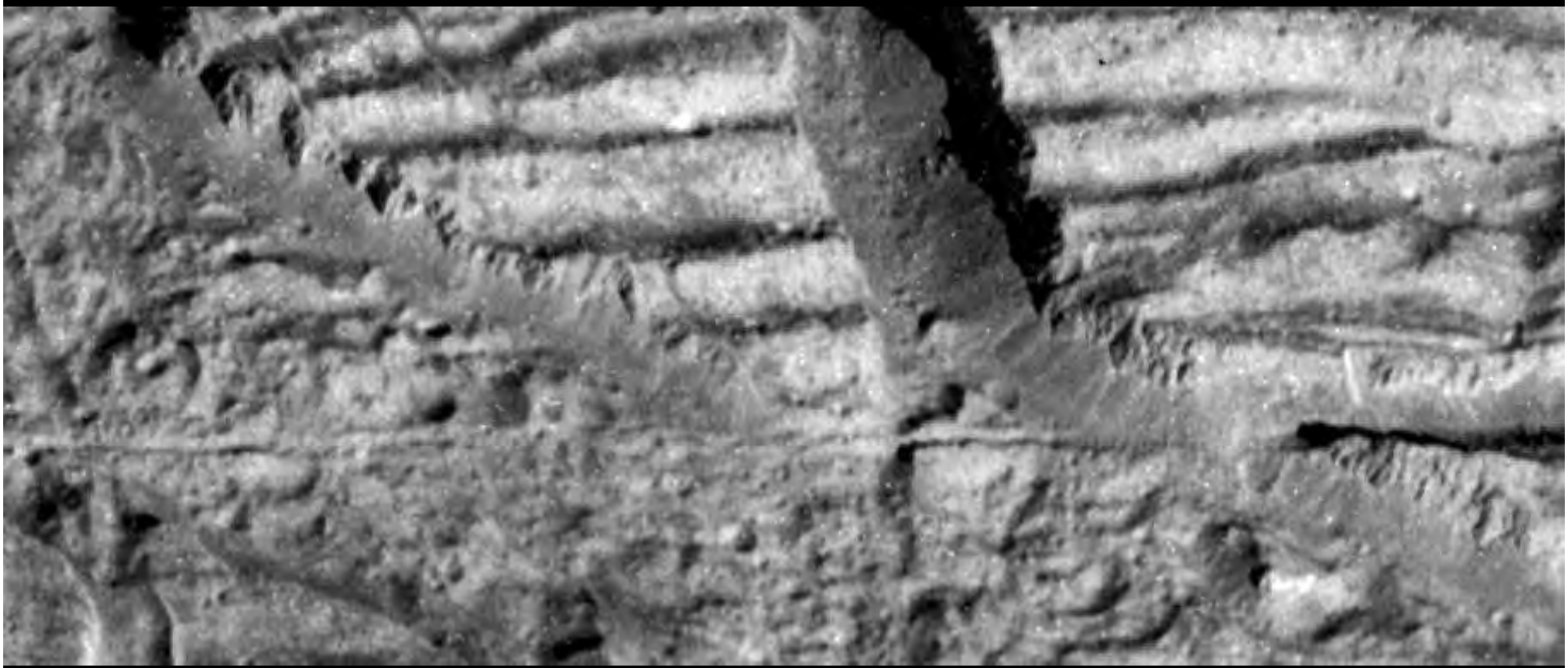


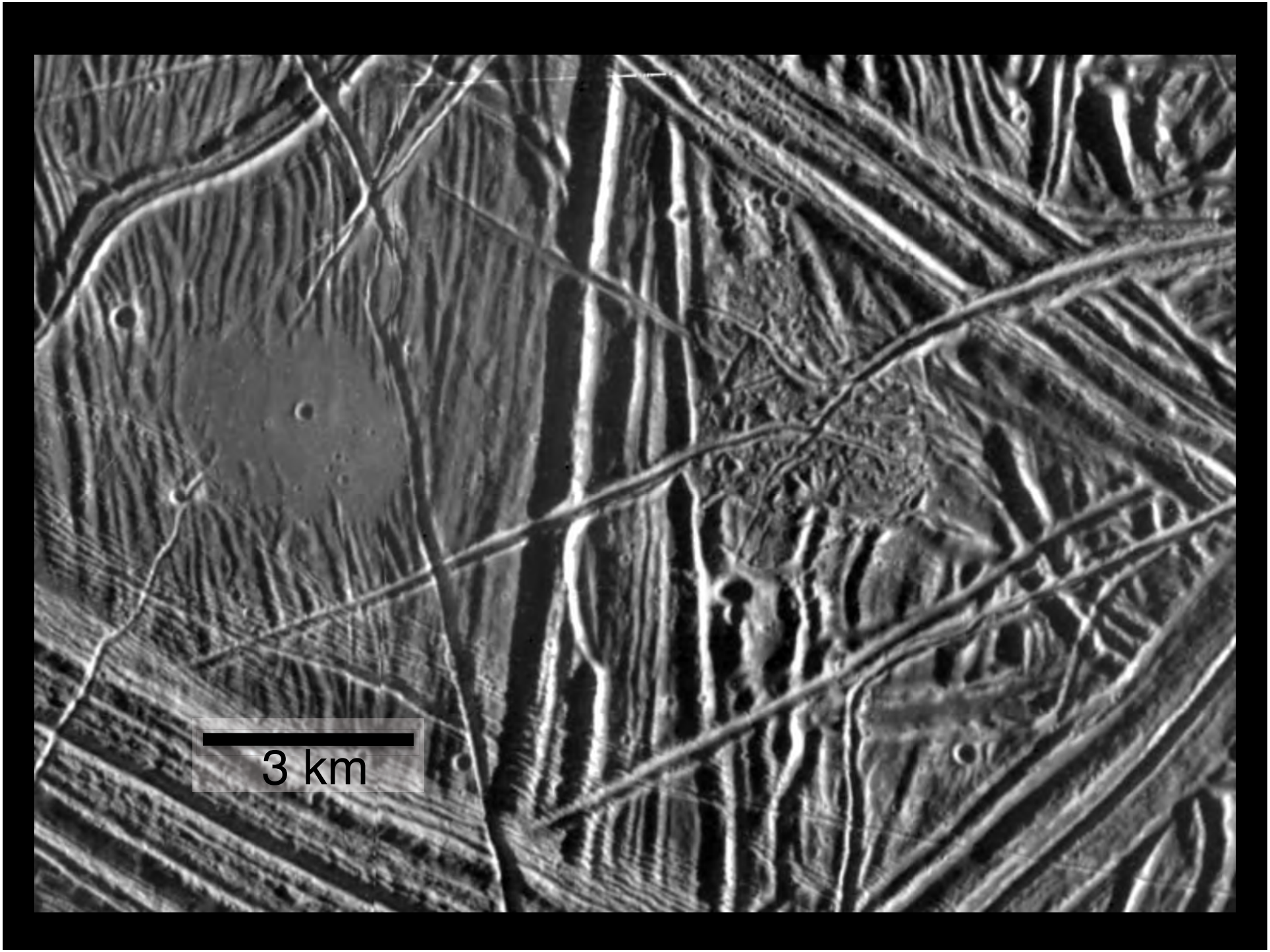


Composition of **Europa**'s non-ice

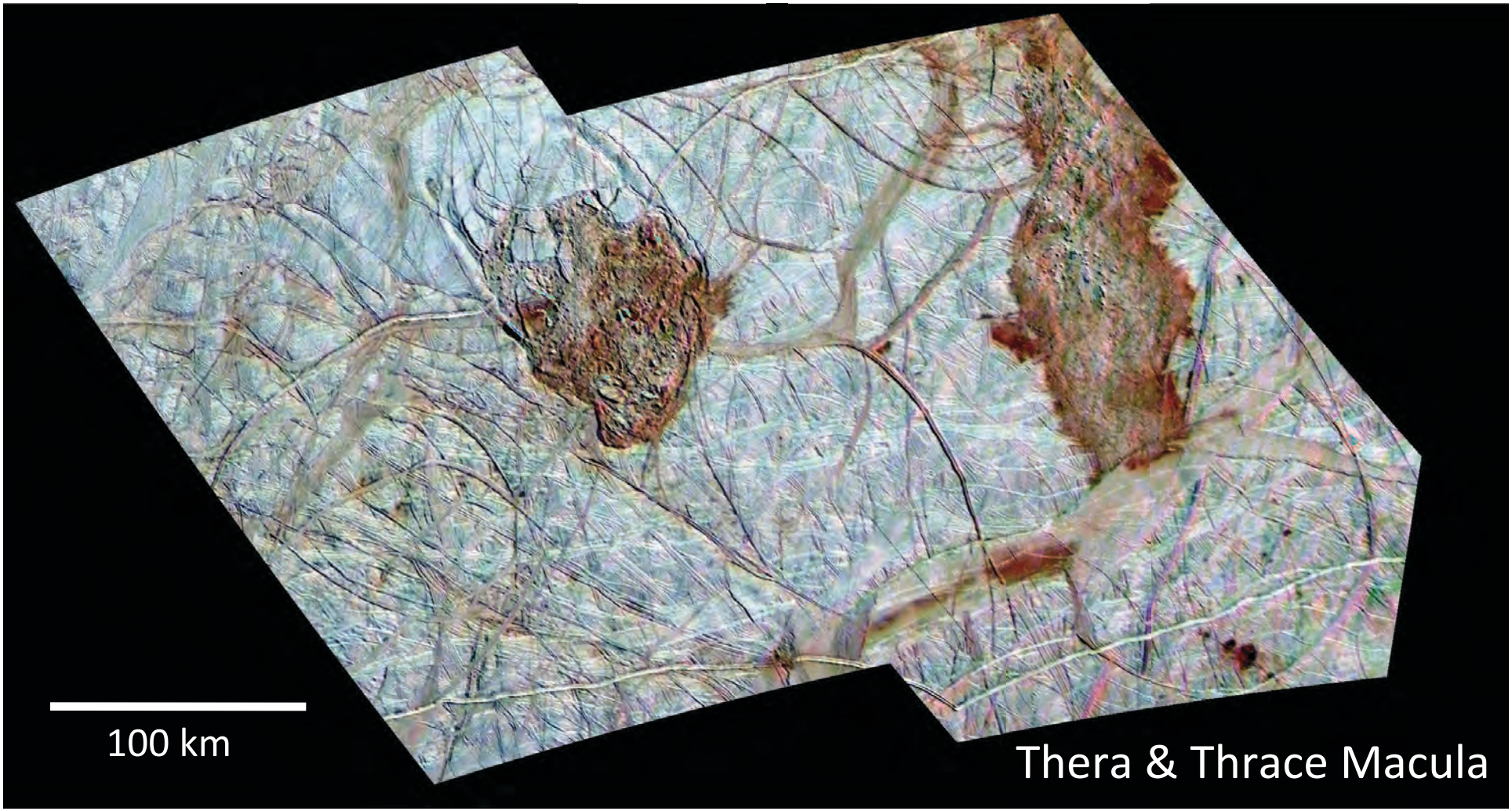


- Leading candidates are hydrated sulfates
- Sulfuric acid hydrate almost surely present, Mg-sulfate hydrate?
- Na, K seen in sputtered atmosphere

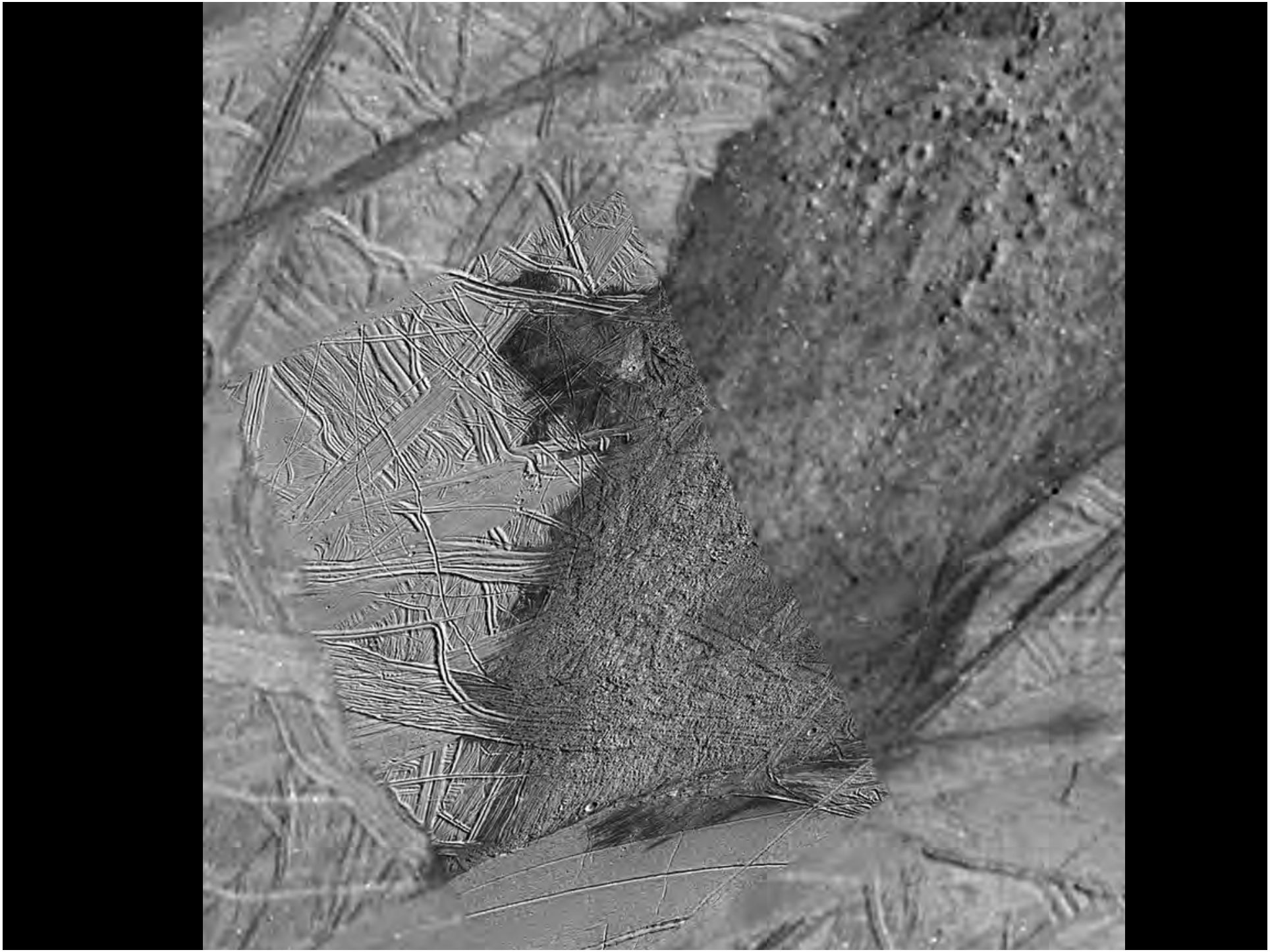



3 km

Is **Europa** geologically active?

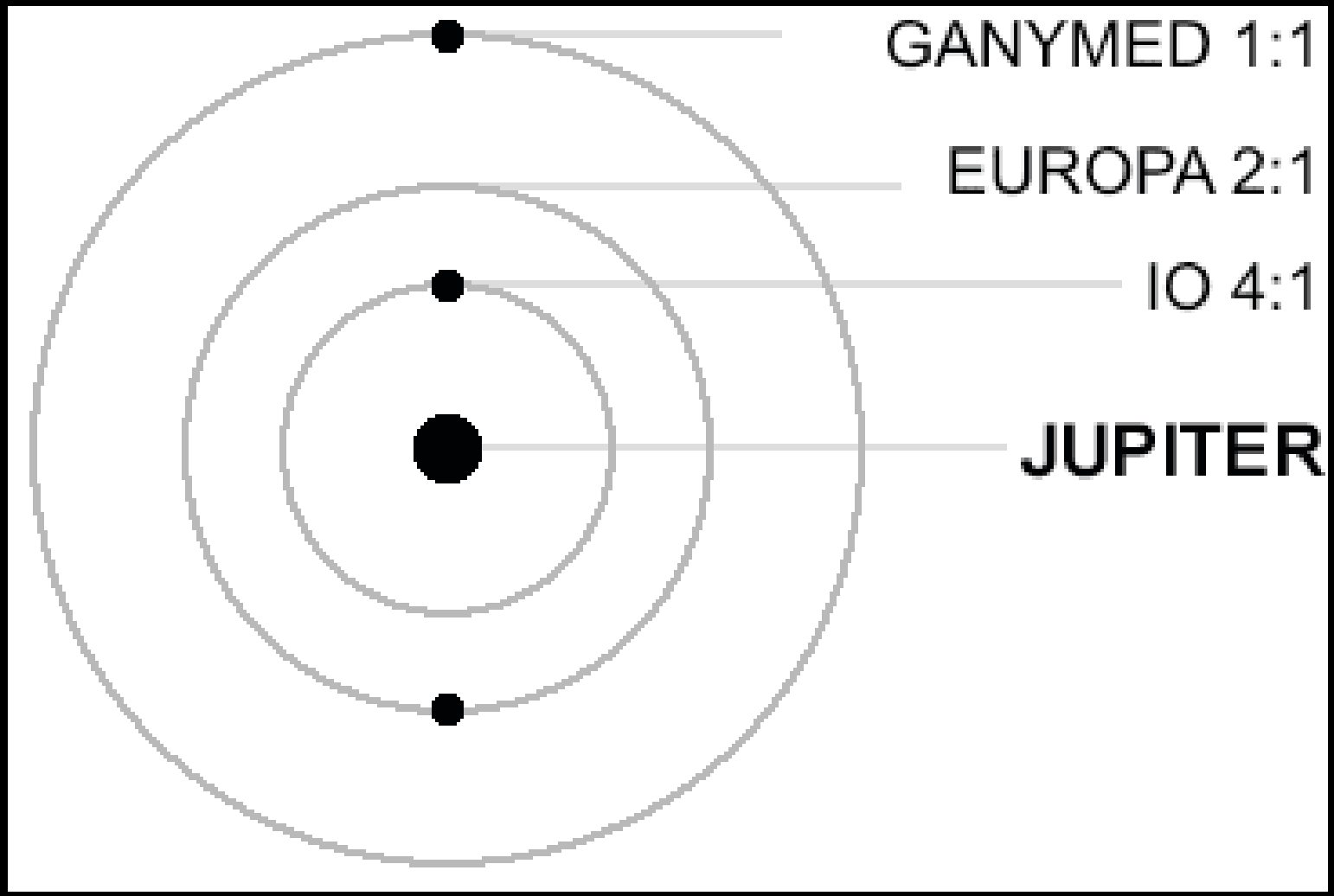


- Average surface age from impact crater density 65 ± 25 Ma
- Thera Macula has been proposed as presently active (Schmidt et al., 2011)

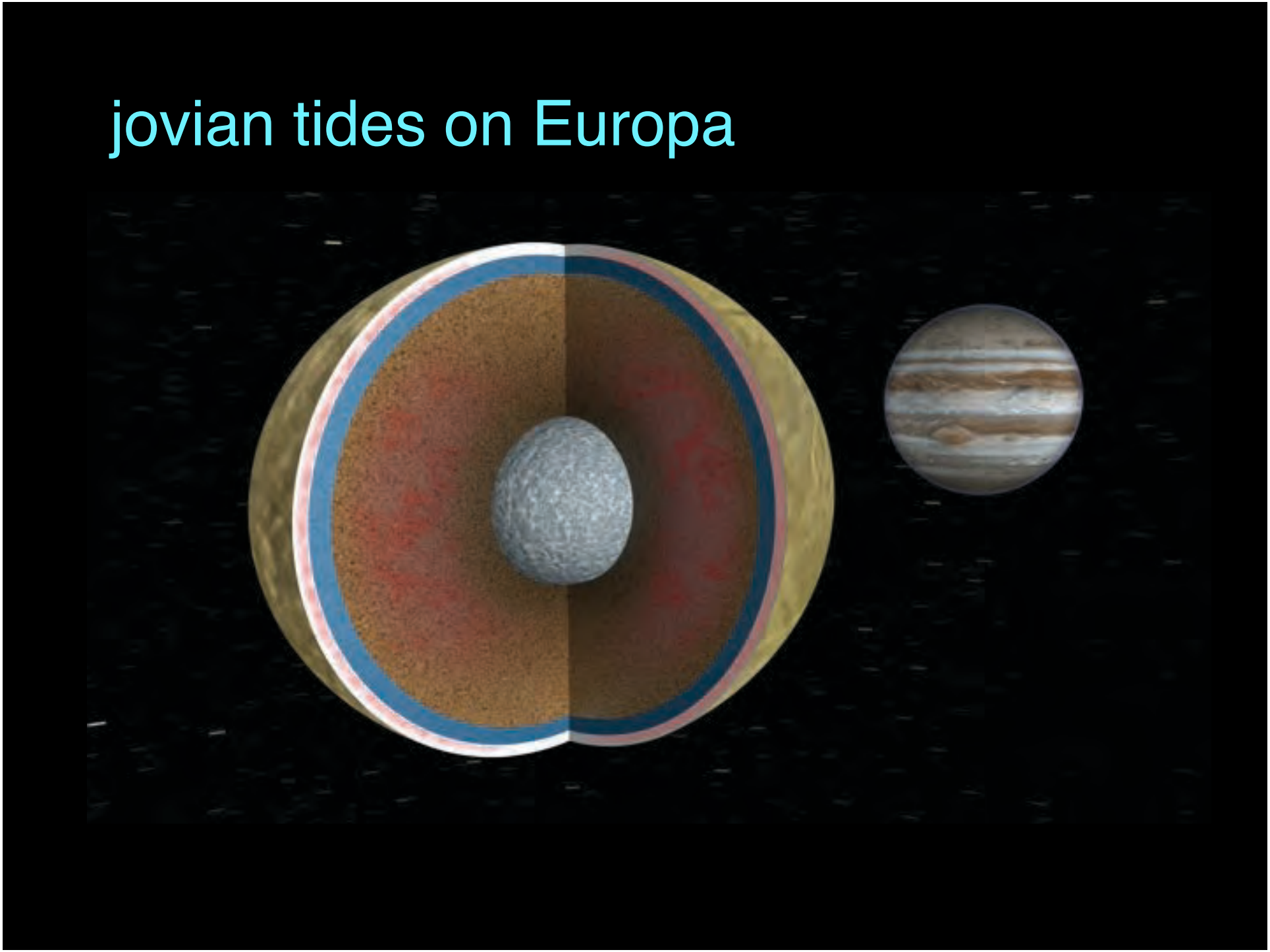


highest resolution Europa

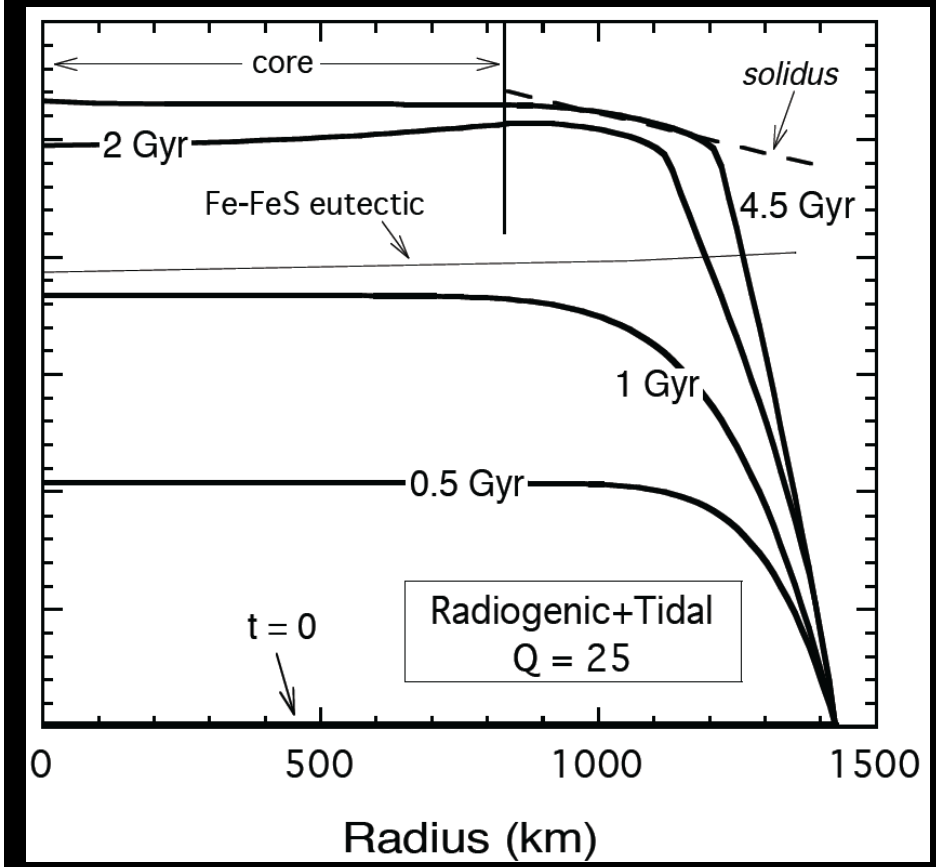
the *Laplace* Resonance



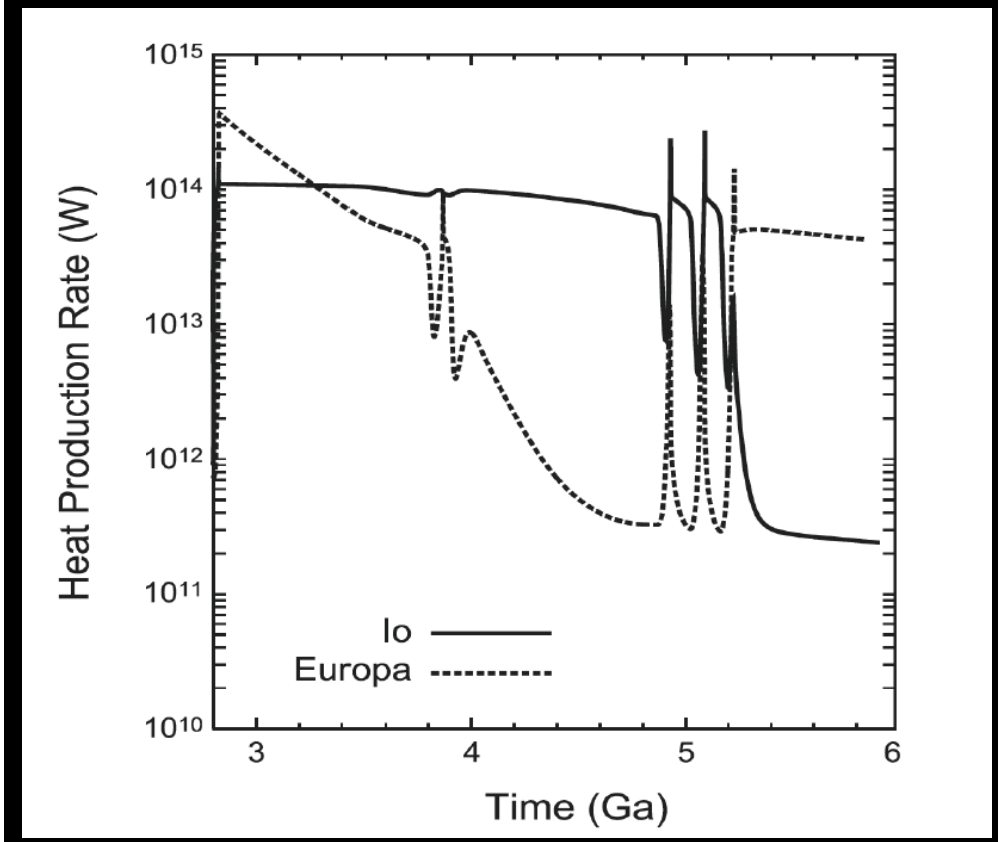
jovian tides on Europa



ENERGY: RADIOGENIC & TIDAL



Greeley et al. 2004



Moore & Hussmann 2009

Protoplanetary Disks
Orion Nebula

HST • WFPC2

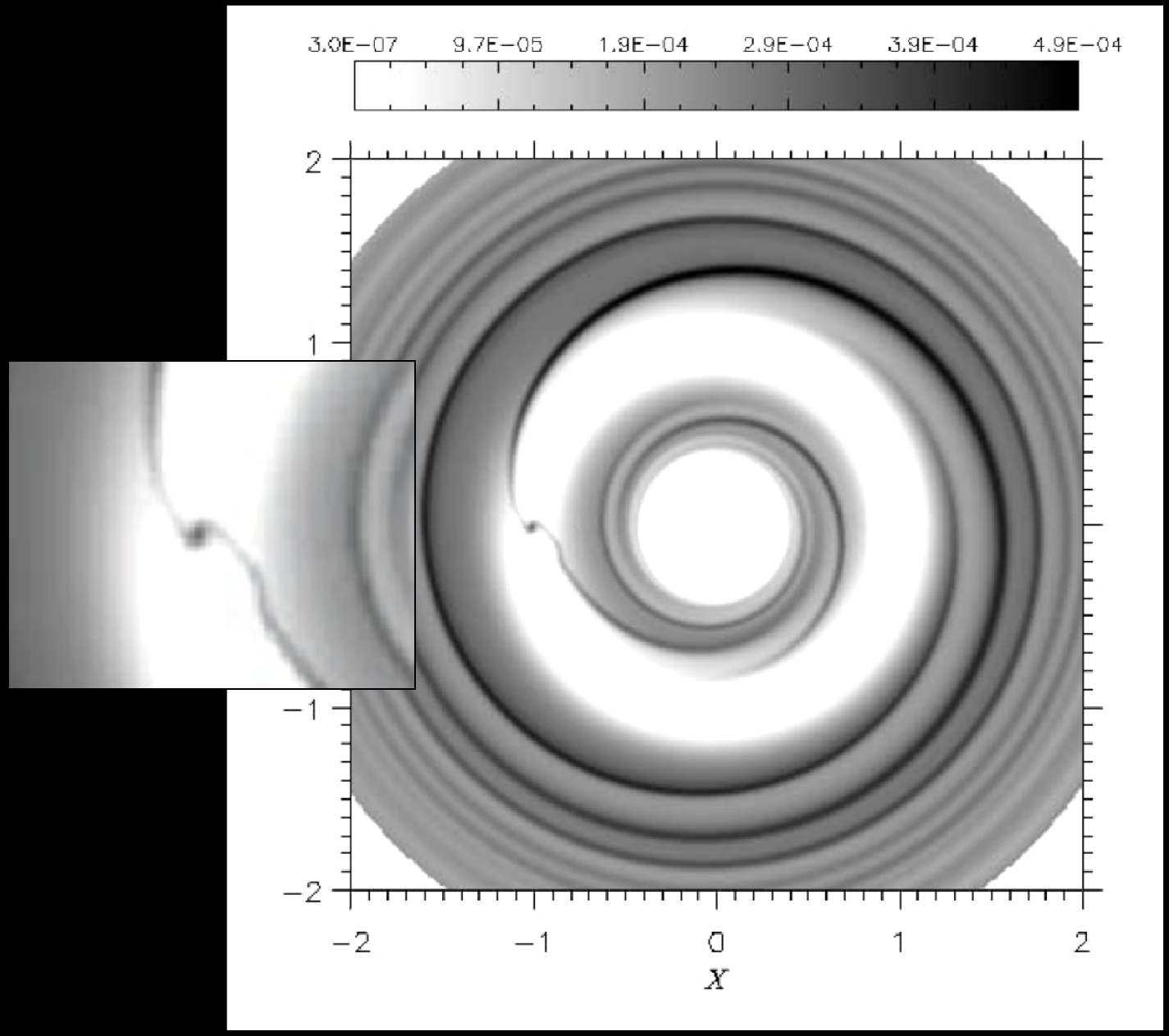
PRC95-45b · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

distance = 500 pc
panels 3000 AU across

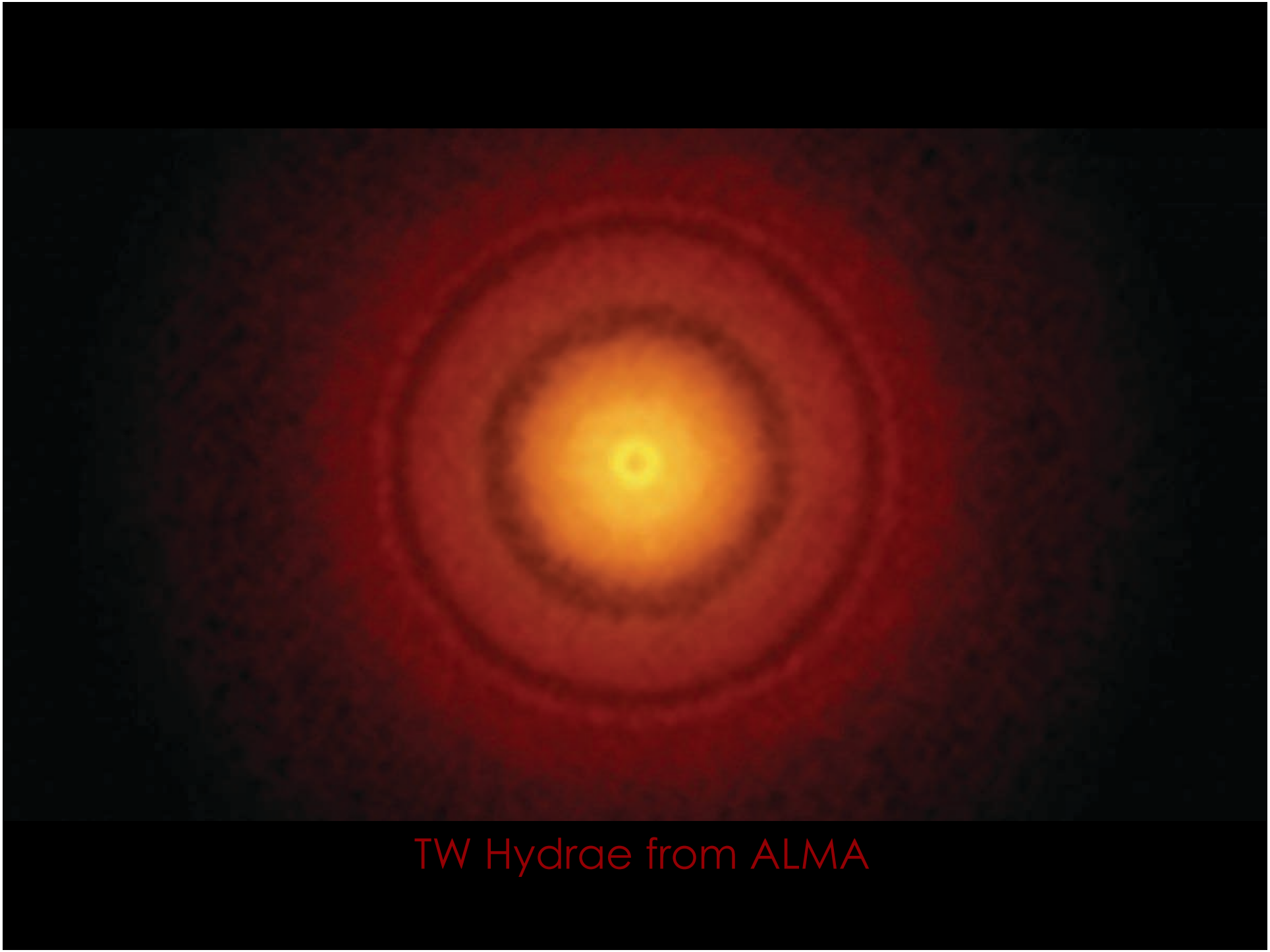
Edge-On Protoplanetary Disk
Orion Nebula

HST • WFPC2

PRC95-45c · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

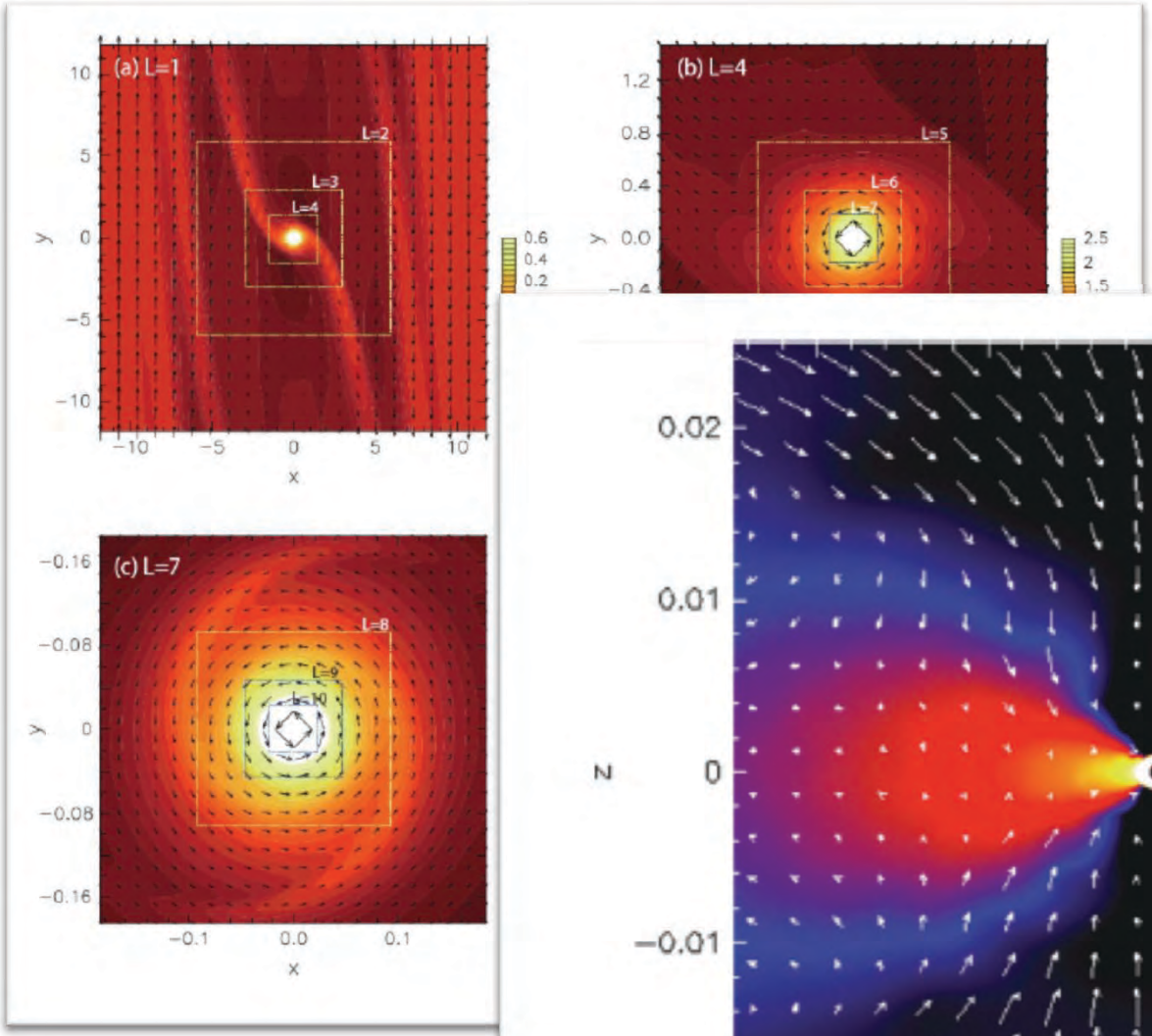


D' Angelo et al. (2003) Astrophys. J. 599, 548-576.

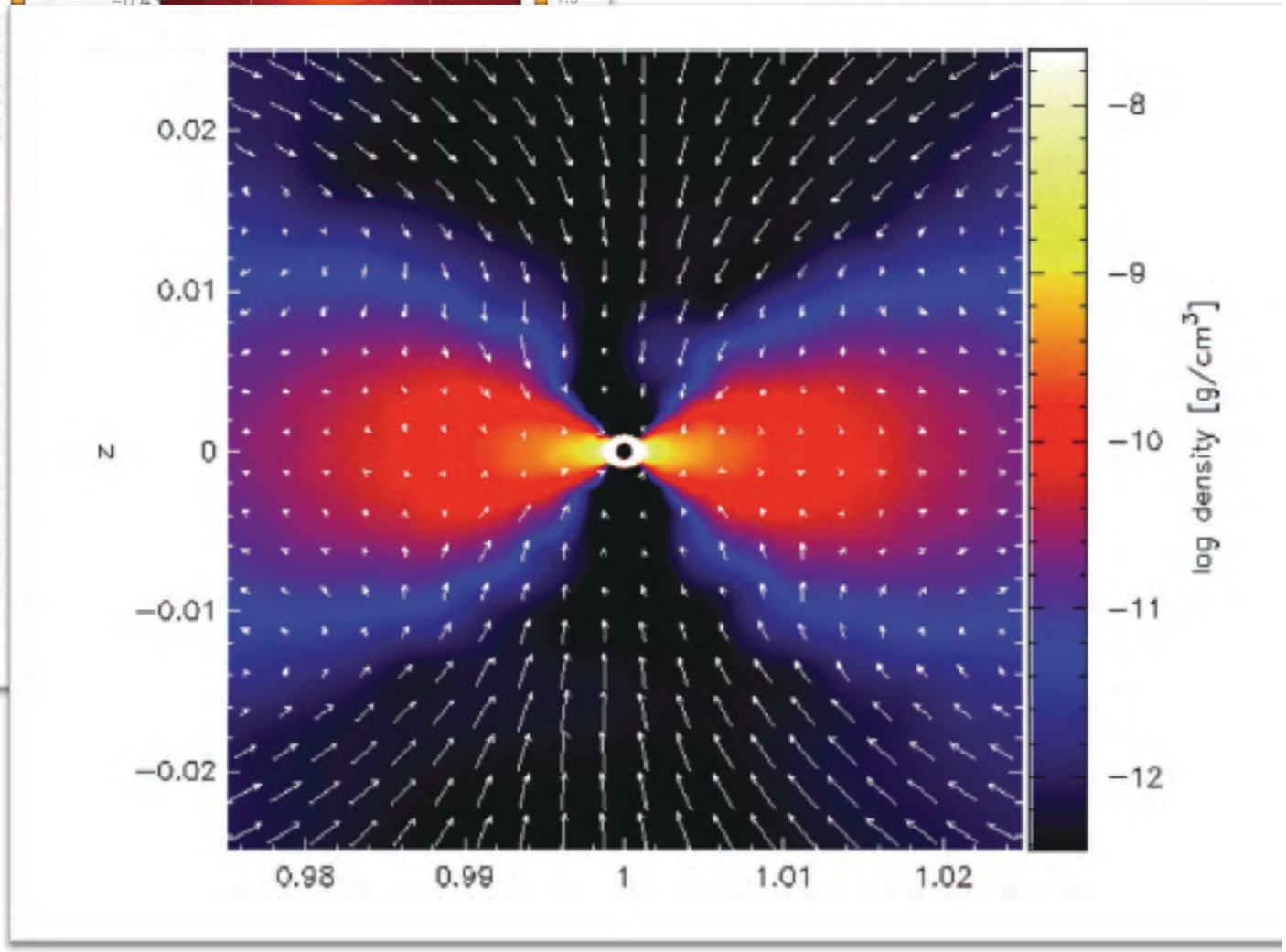


TW Hydrae from ALMA

Numerical Models



Tanagawa et al. 2014



Ayliffe & Bate 2009

RECENT CARCONACEOUS METEORITE FALLS: CANDIDATE PRIMITIVE EUROPA ROCK

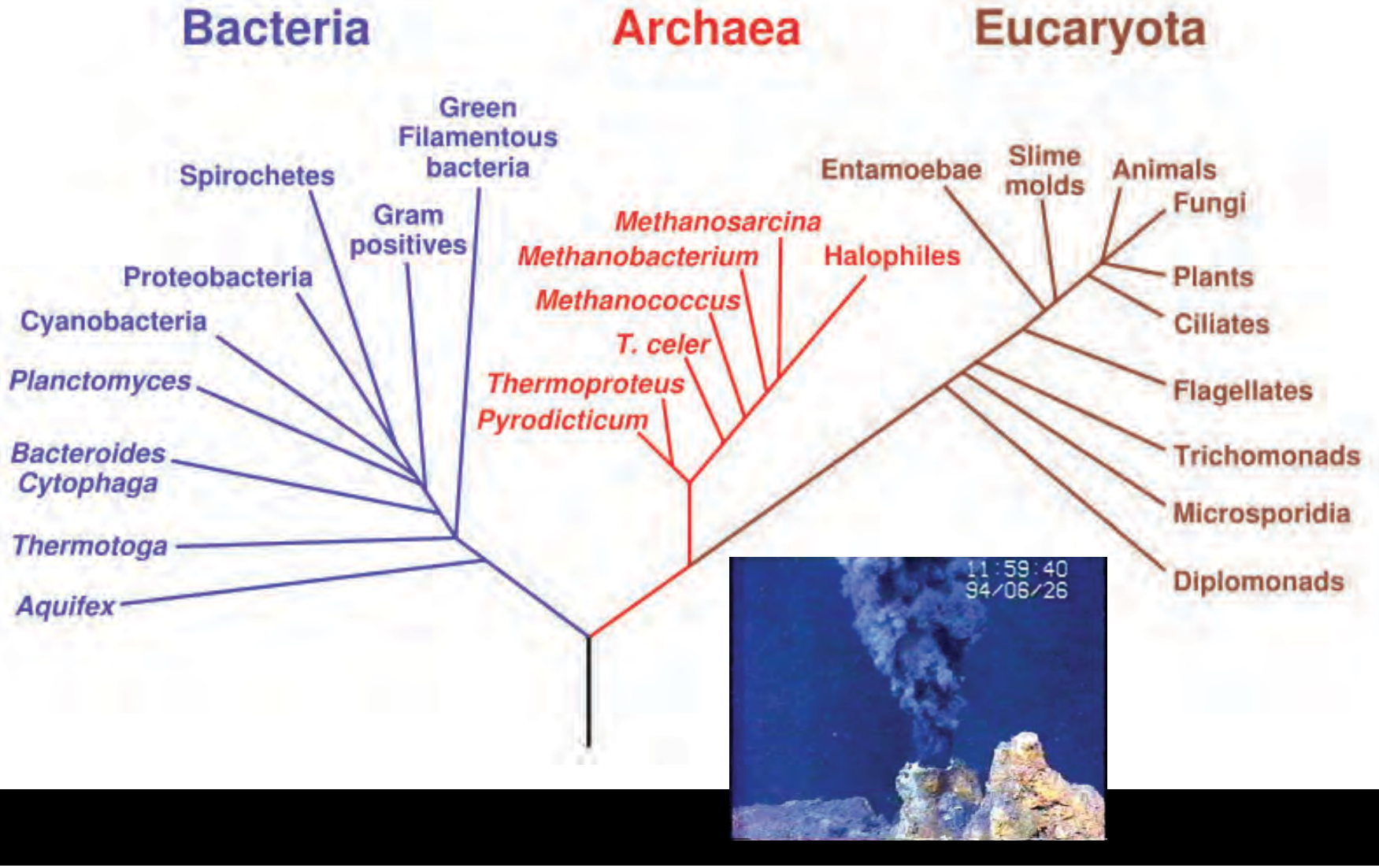
Initial Europa "Rock" Composition

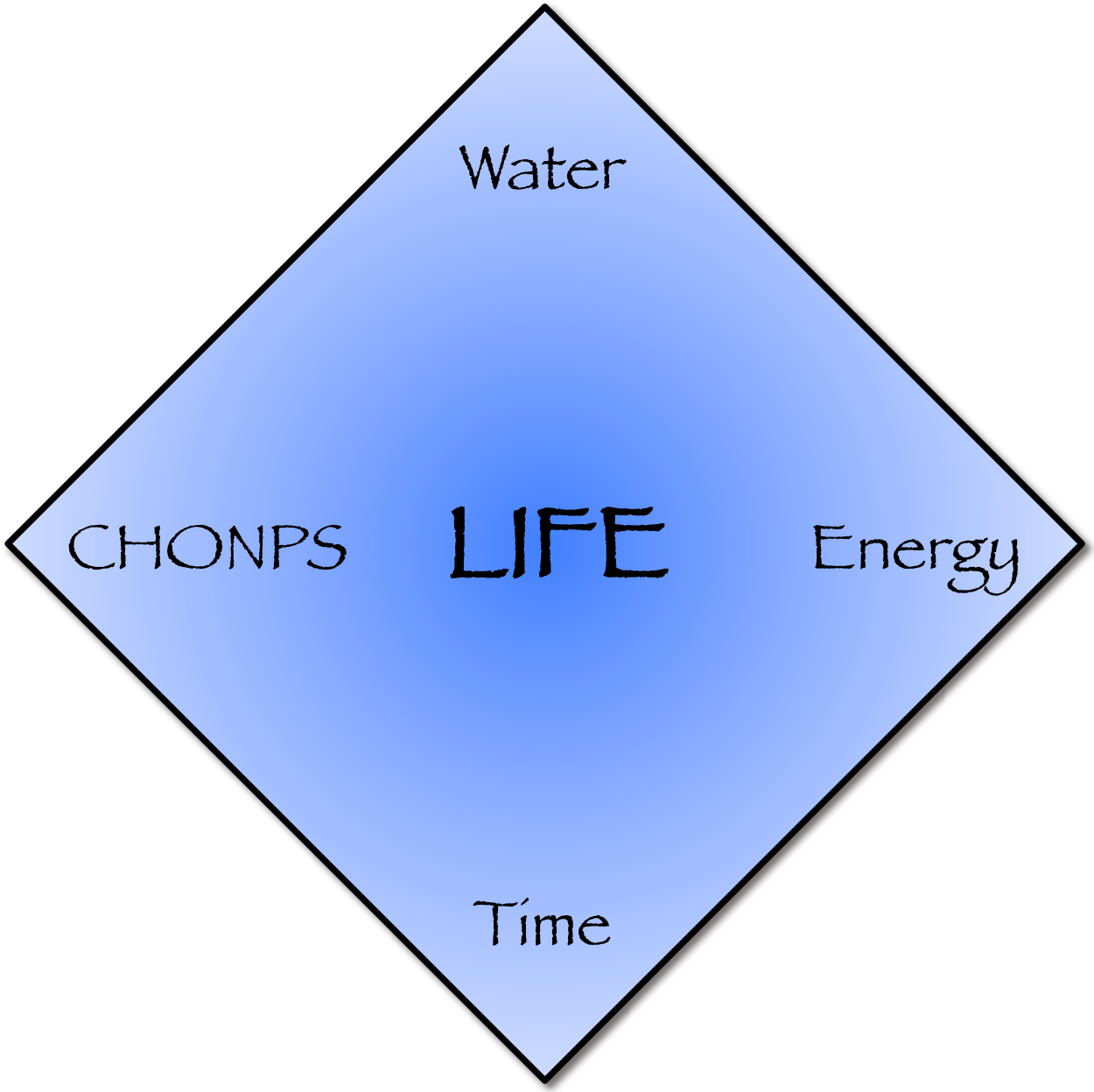
Hydrated & anhydrous silicates, sulfides, sulfates, oxides, carbonates, phosphides, phosphates, chondrules, CAIs, CHONPS — unequilibrated but ~ solar!

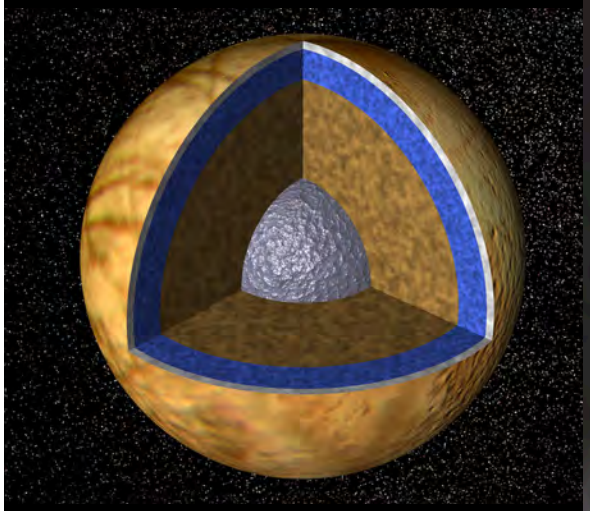
Tagish Lake chondrite fall, Jan 2000

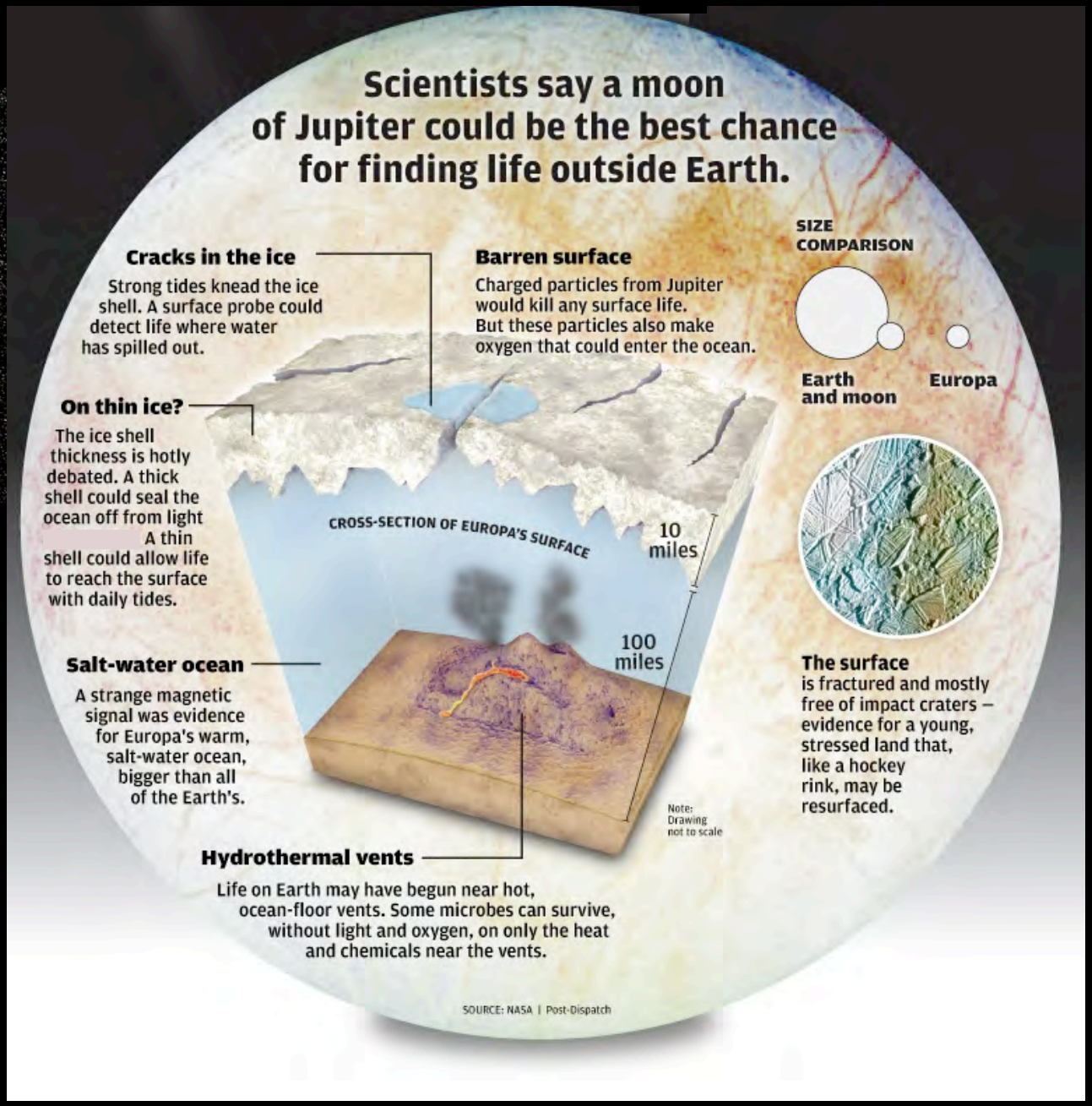
Sutter's Mill chondrite fall, Apr 2012

Phylogenetic Tree of Life



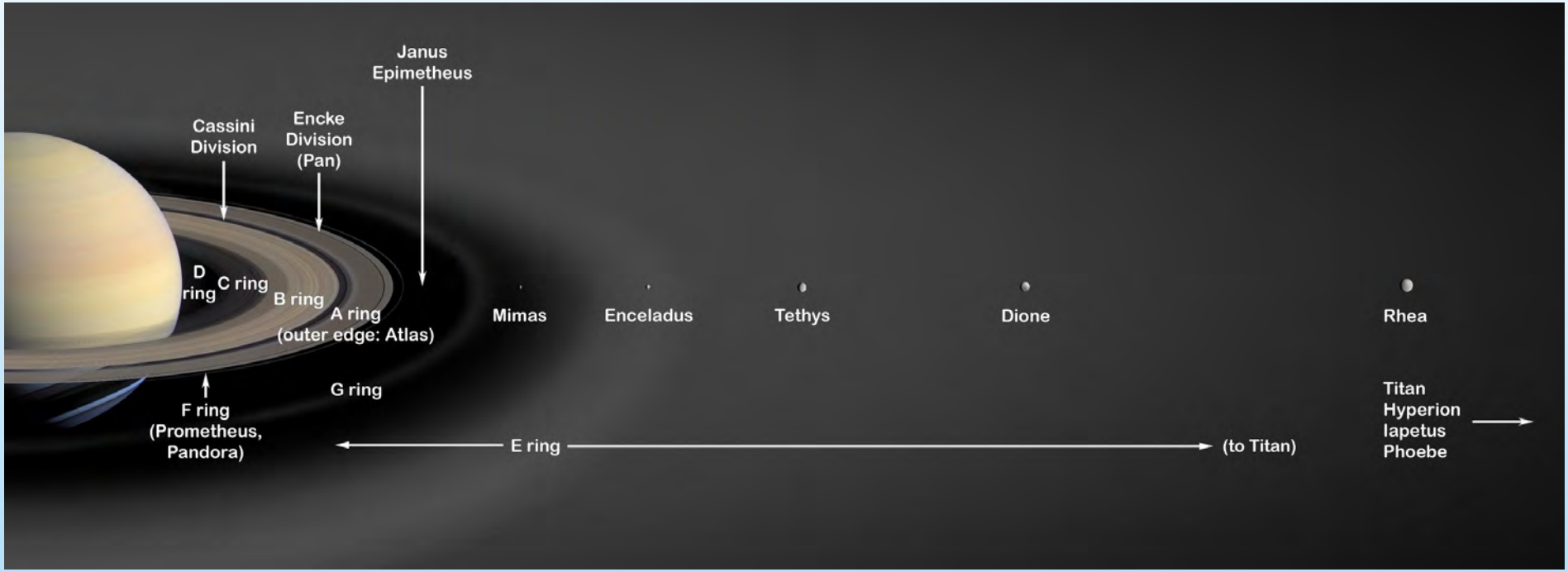

Water
CHONPS
LIFE
Energy
Time

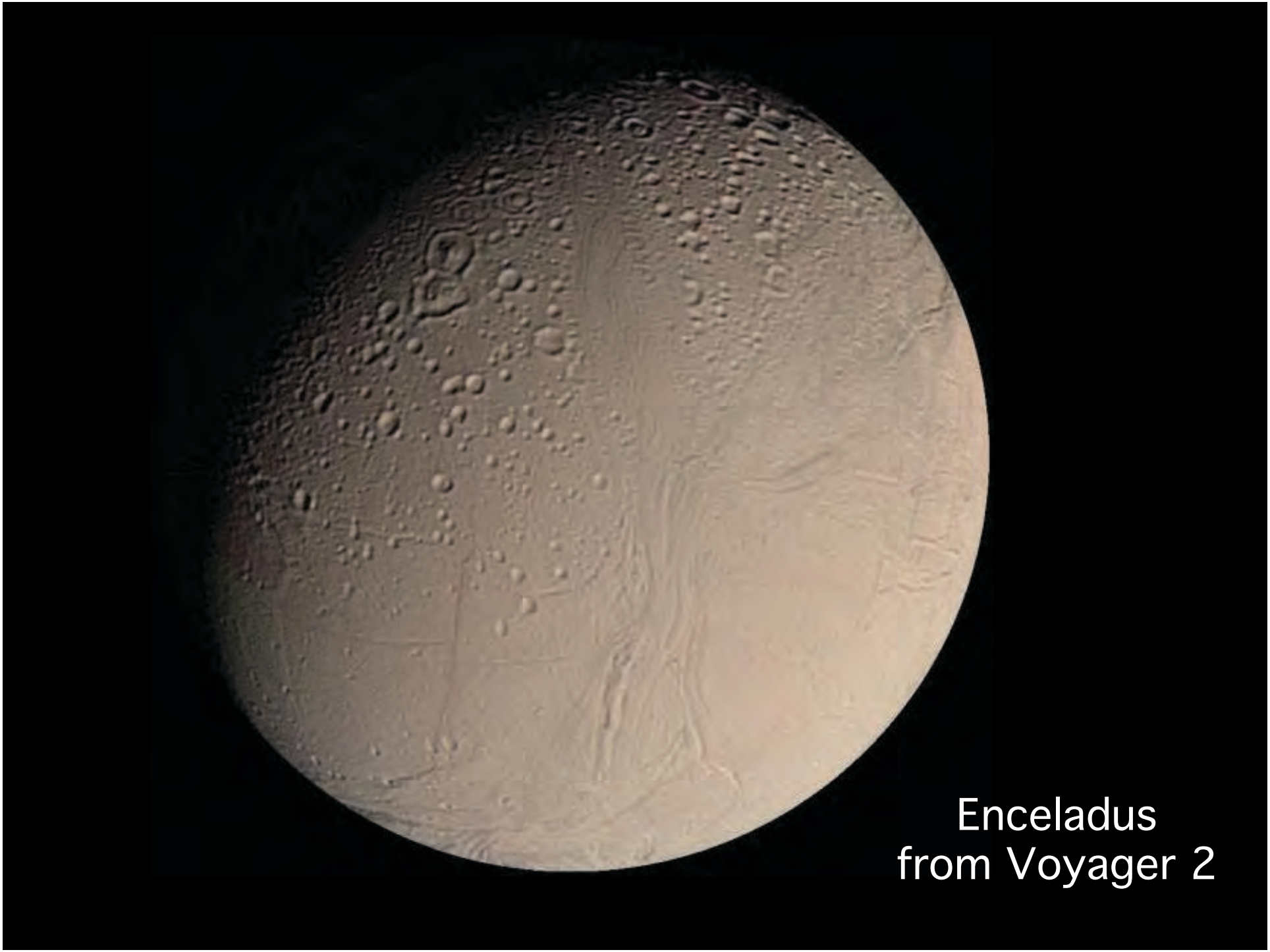


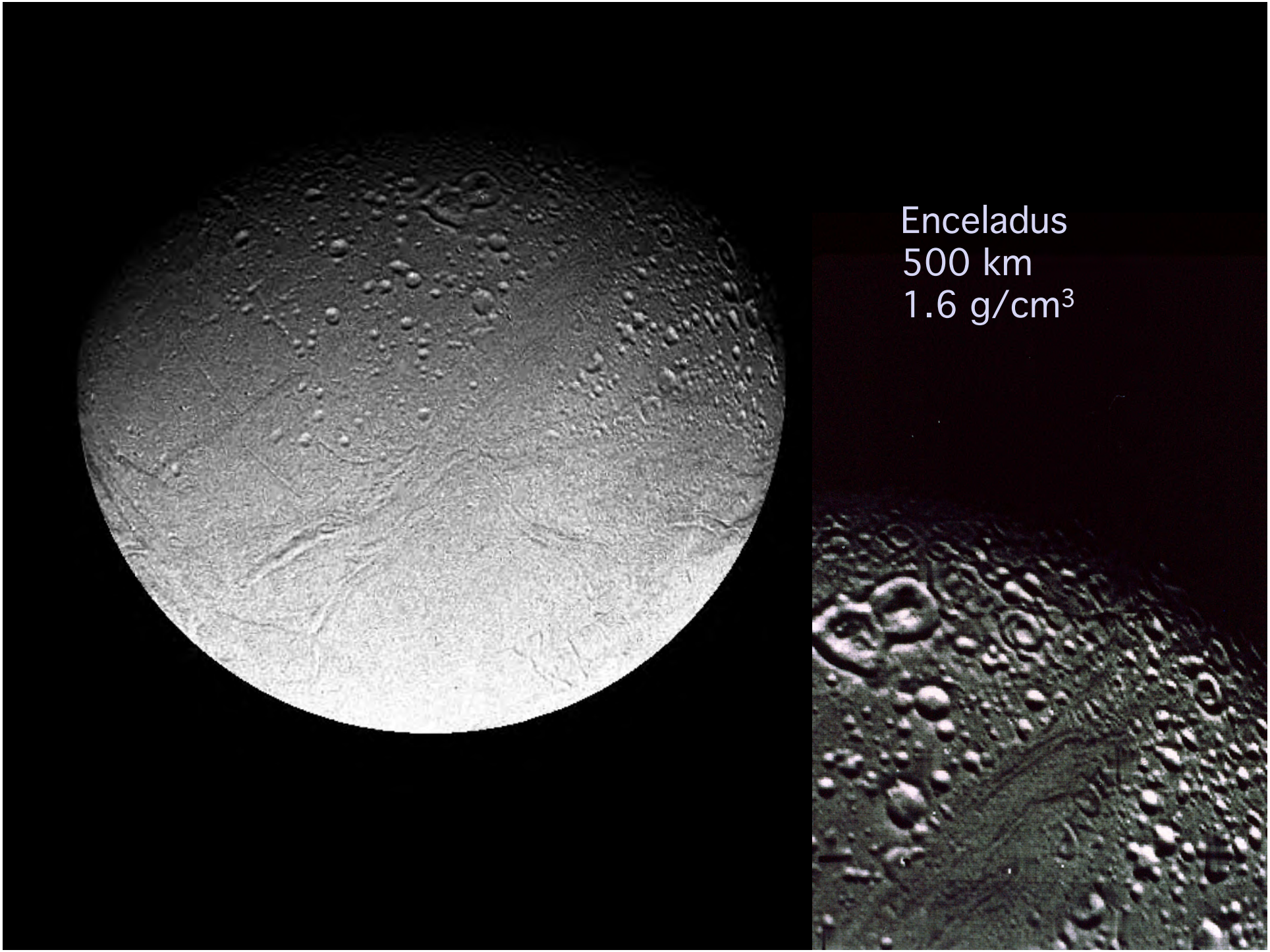


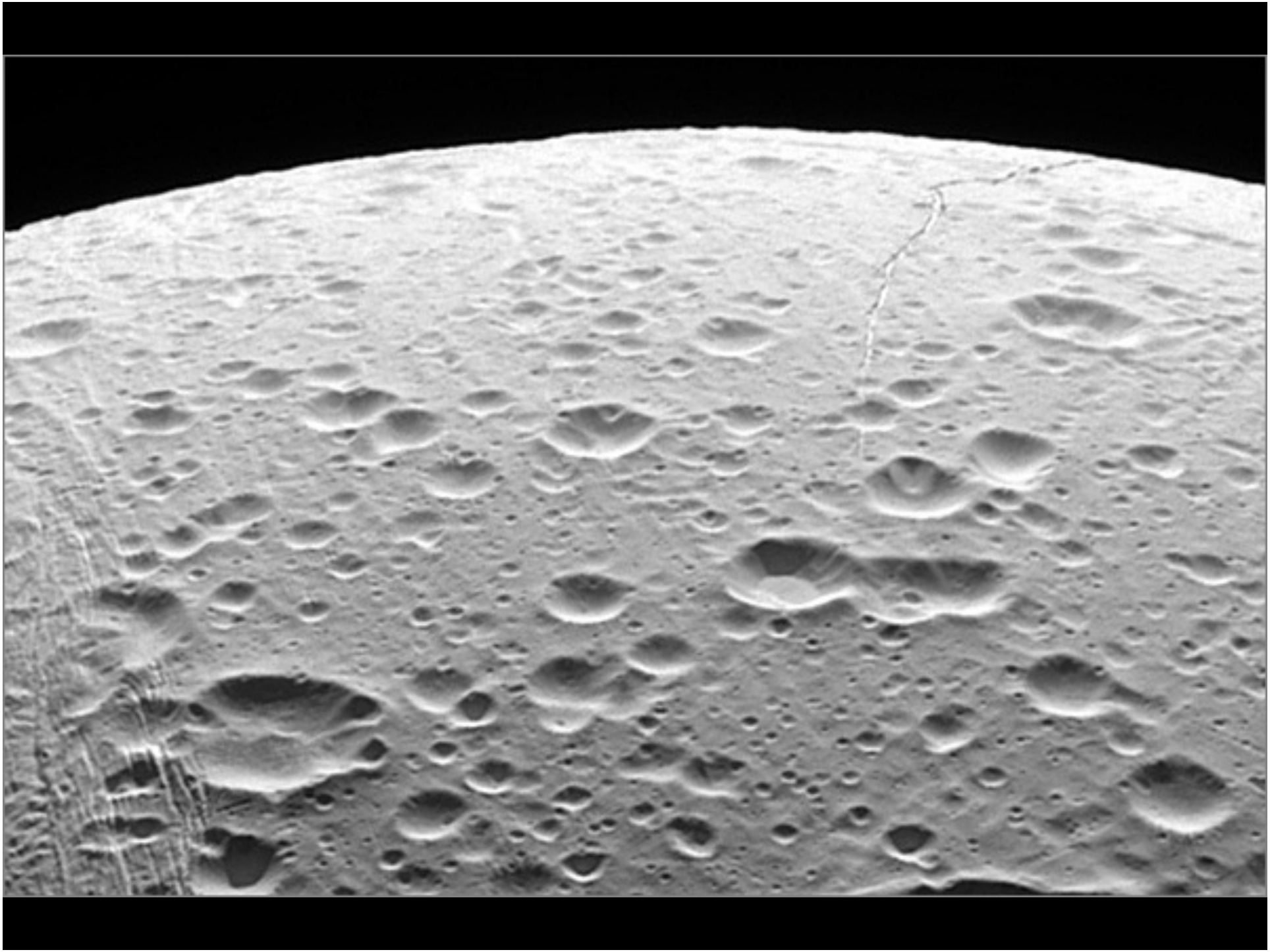
Eric Hand (2007)
St. Louis Post-Dispatch

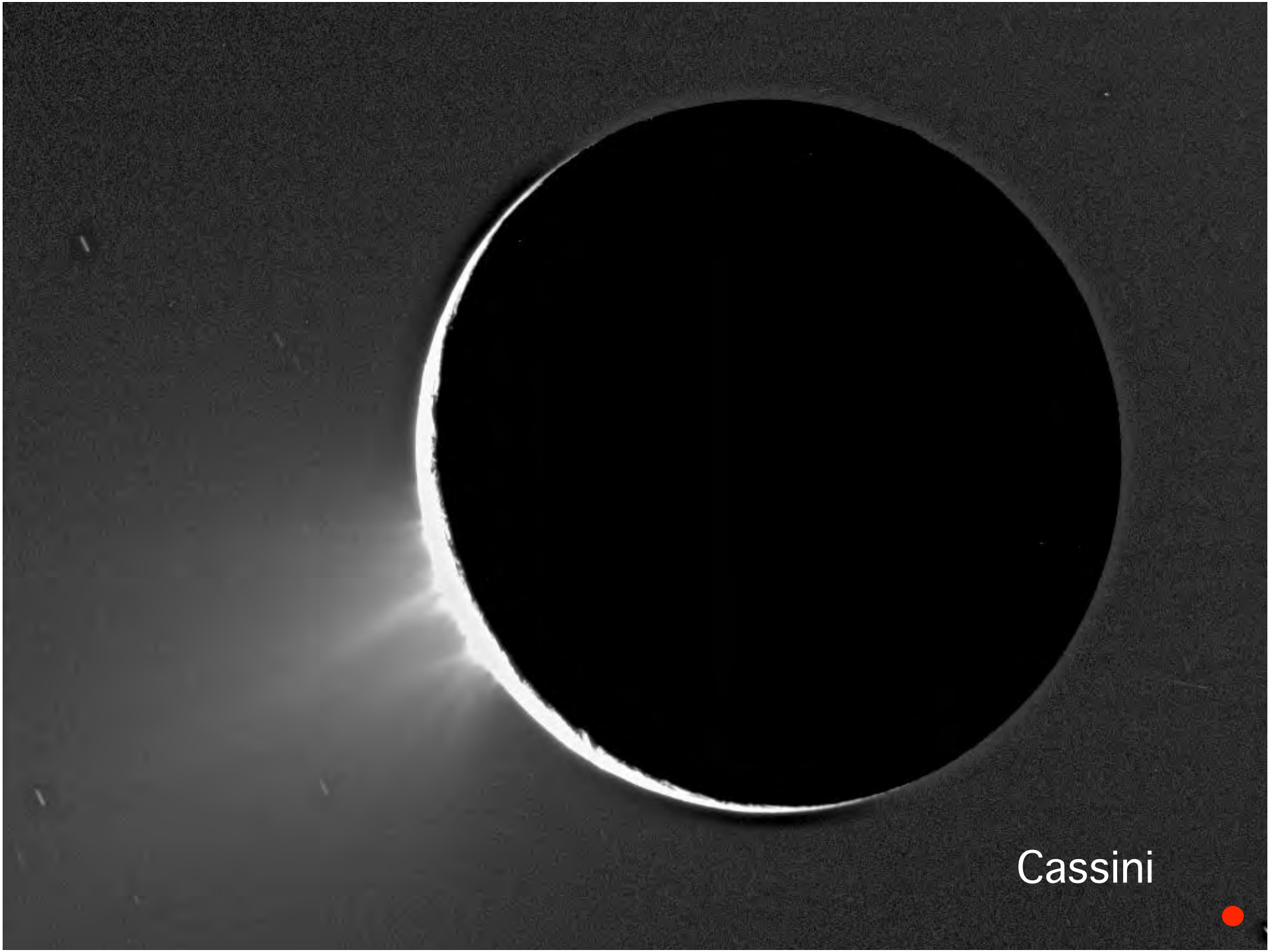
On to Enceladus

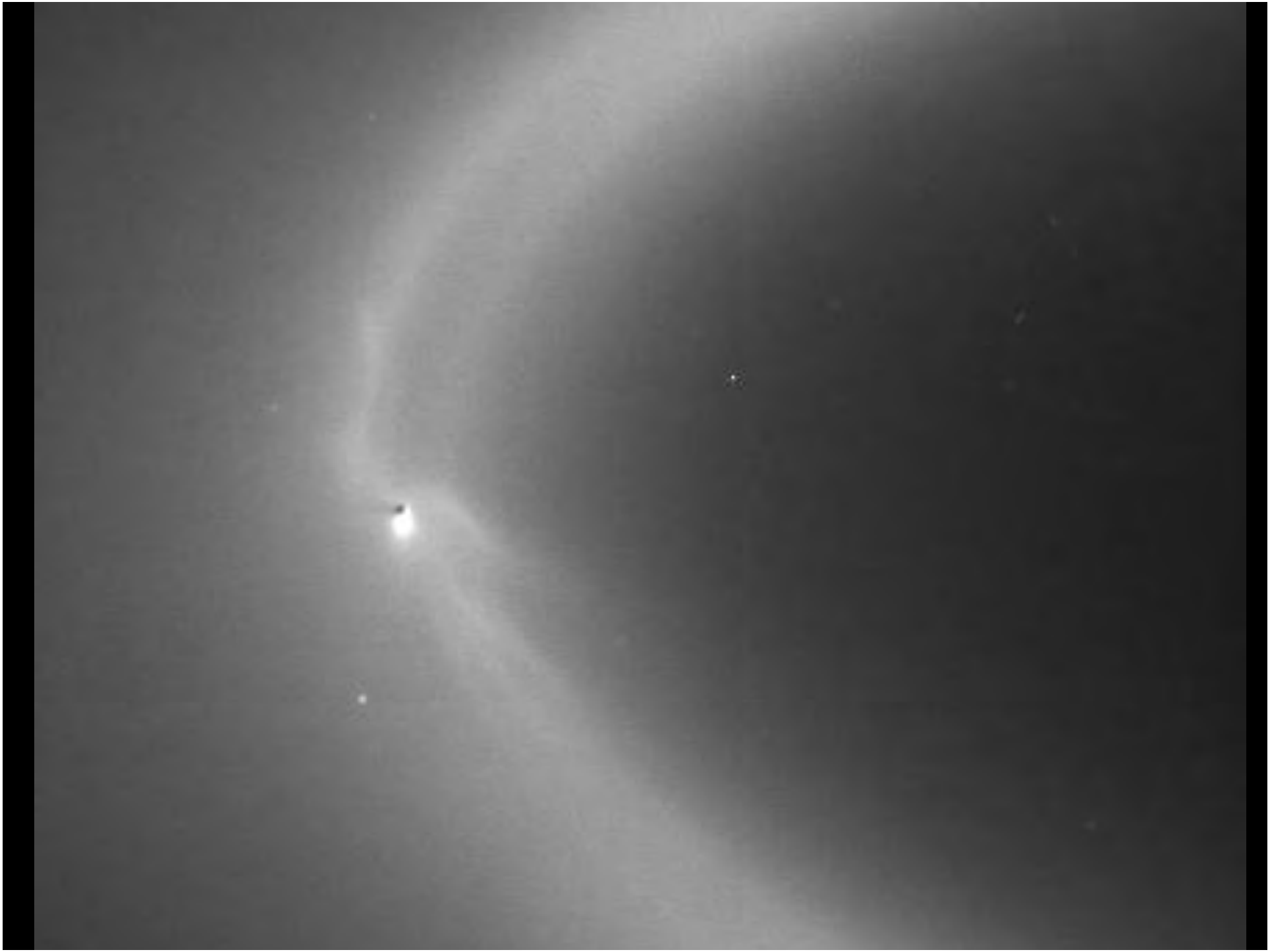


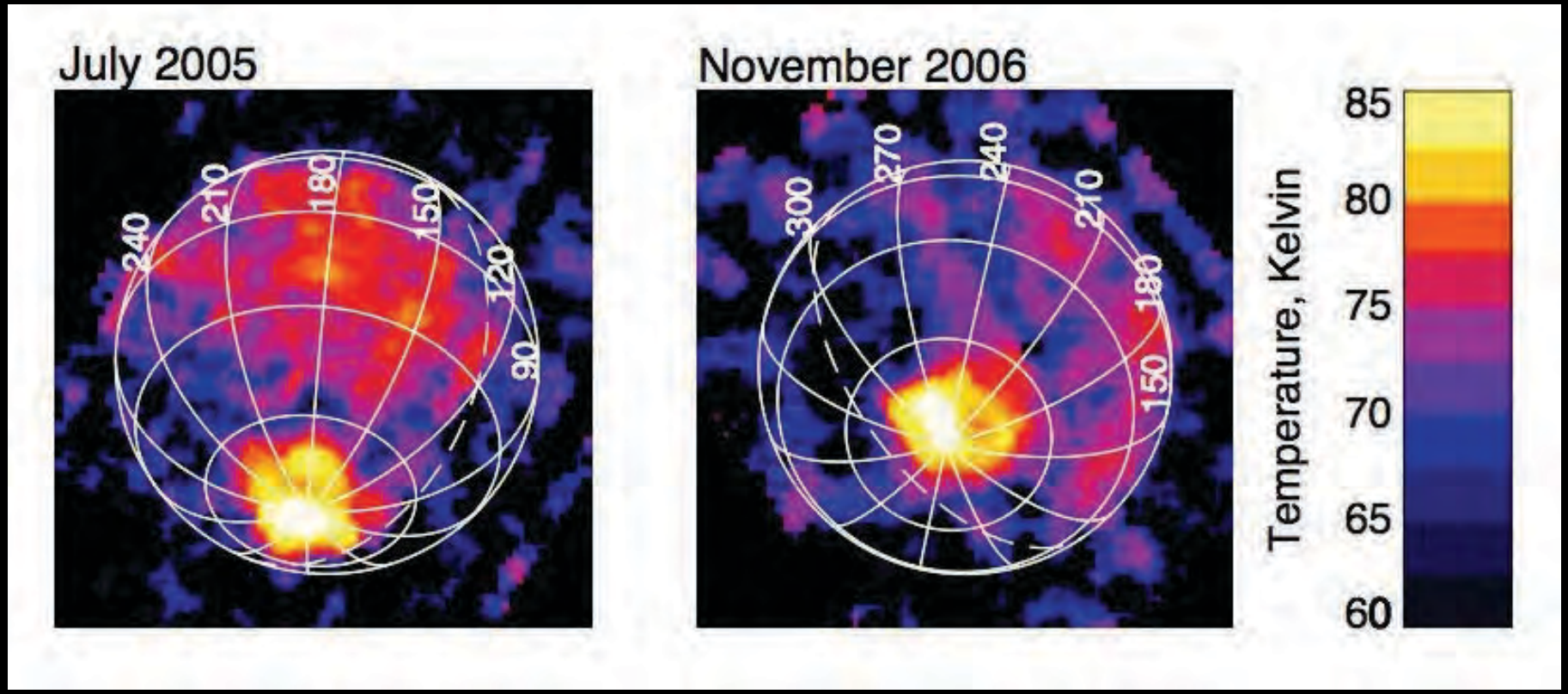

Enceladus
from Voyager 2


Enceladus
500 km
1.6 g/cm3

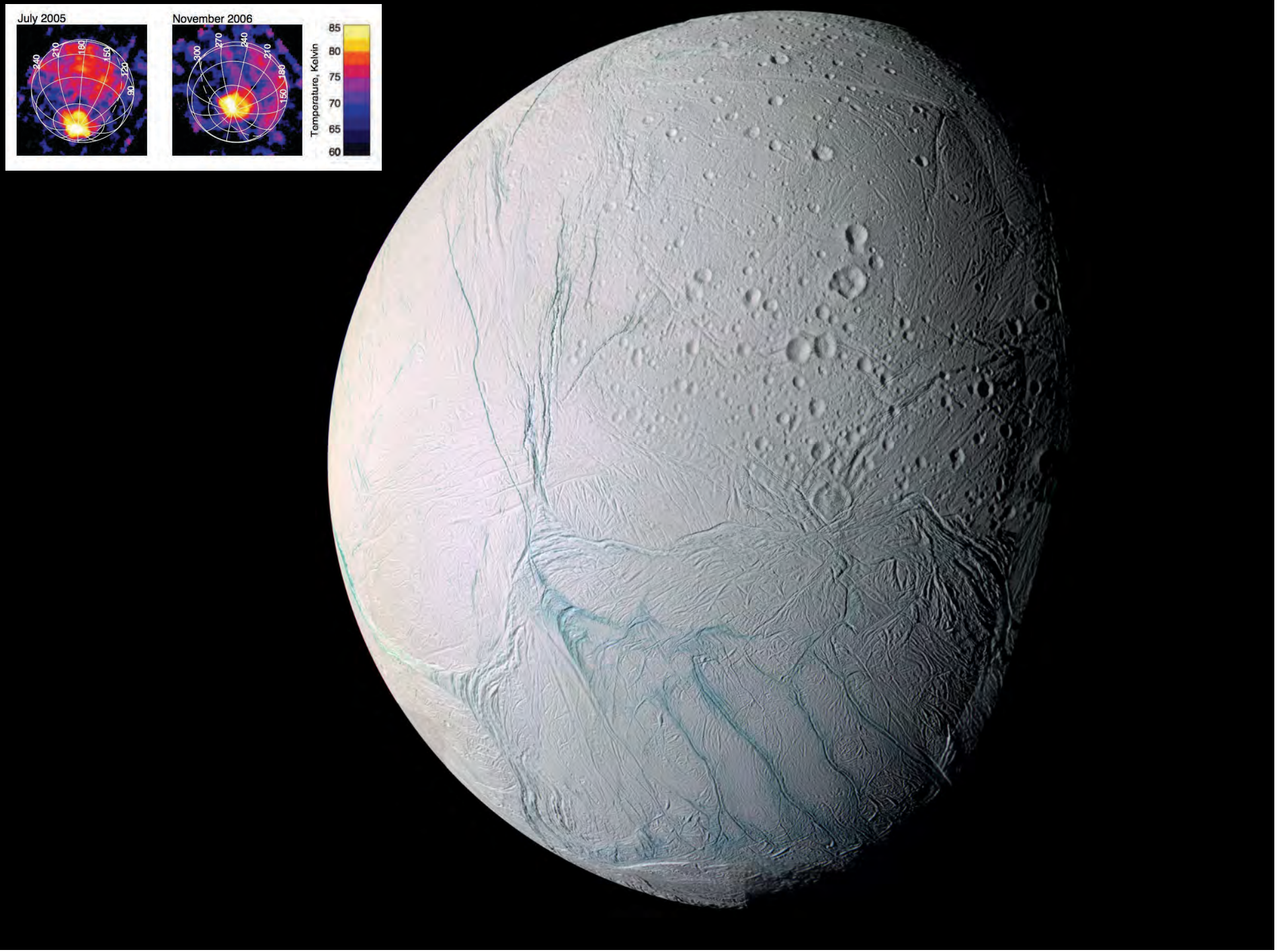


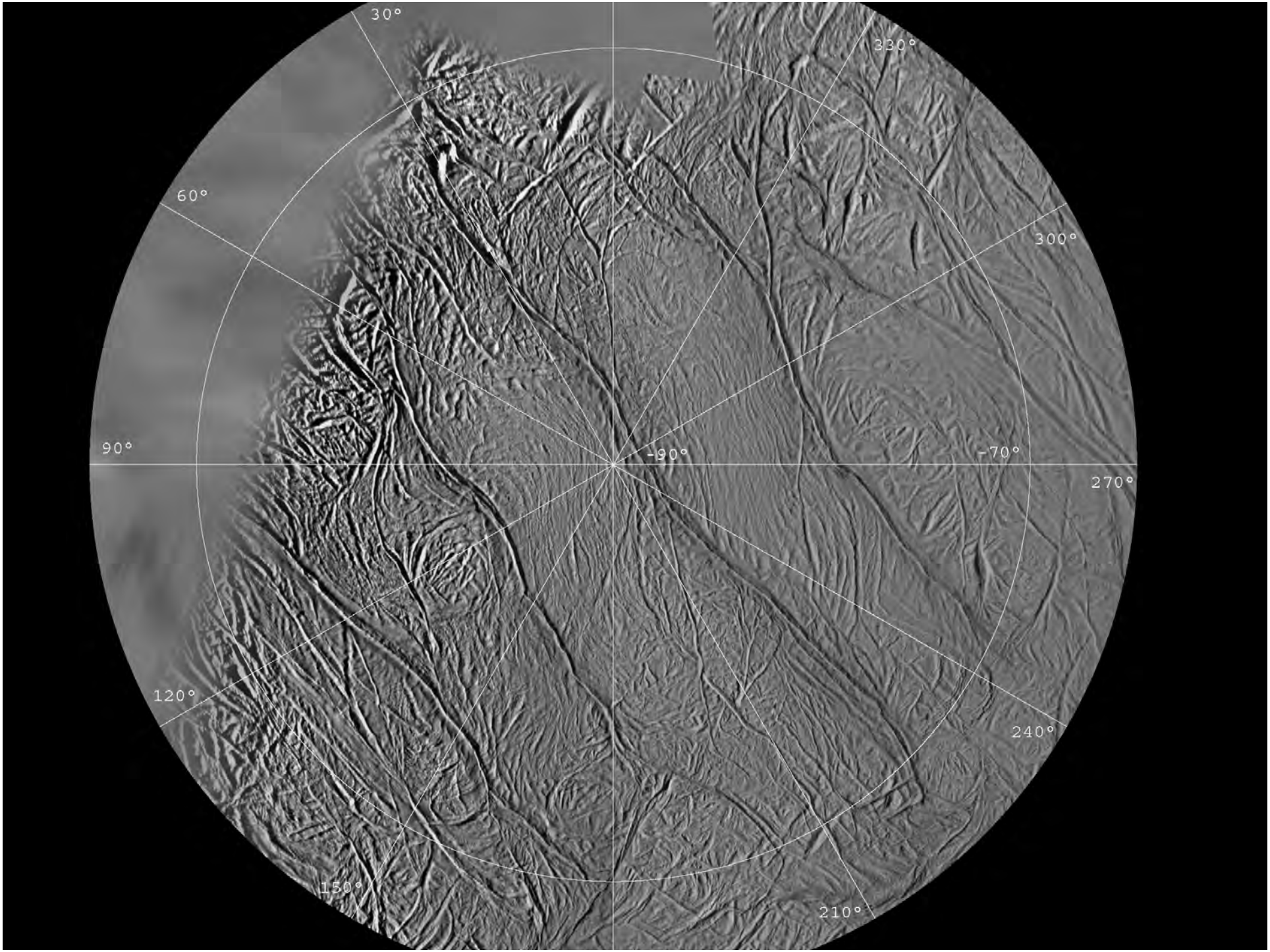

Cassini

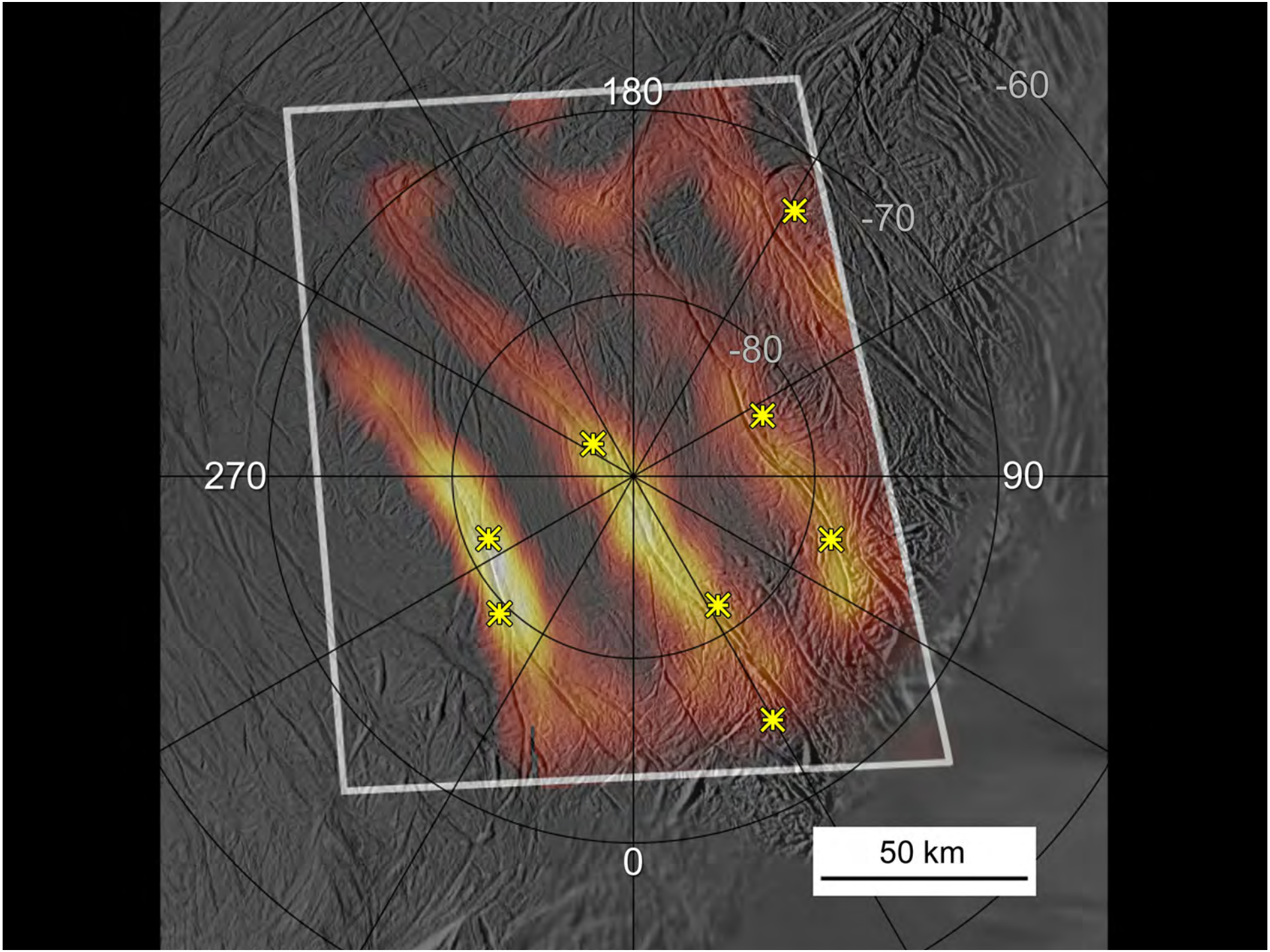


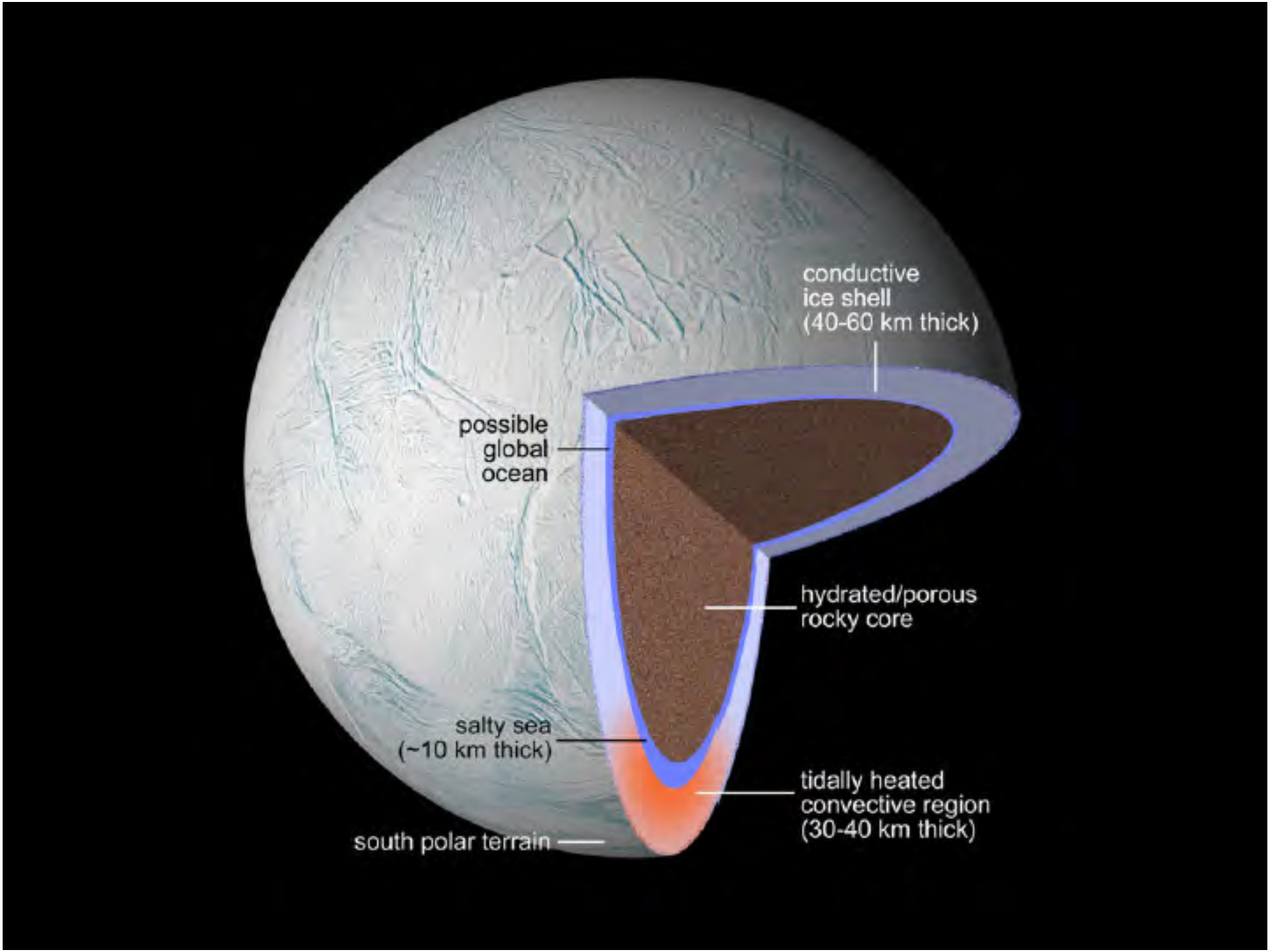


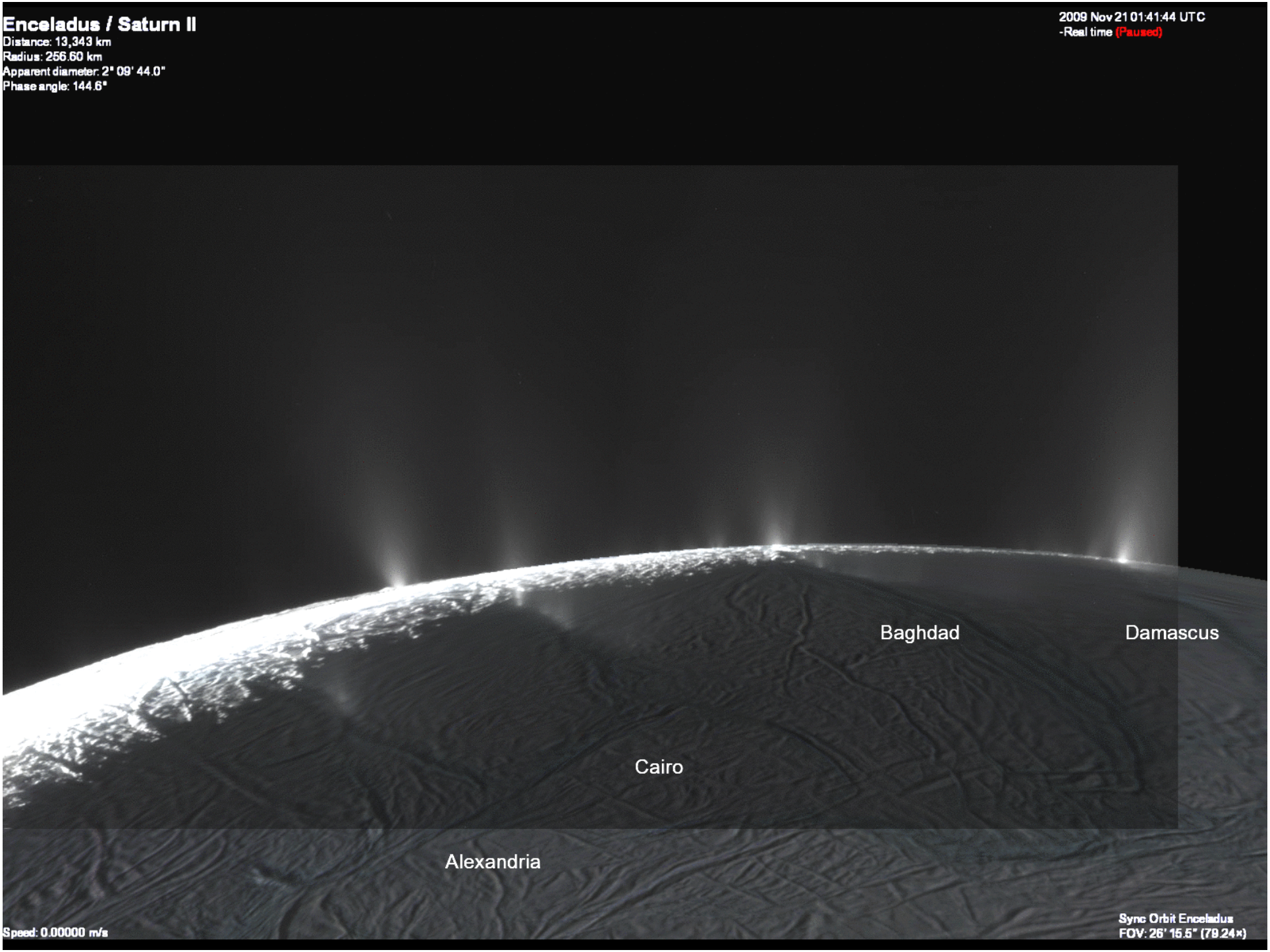
Cassini CIRS

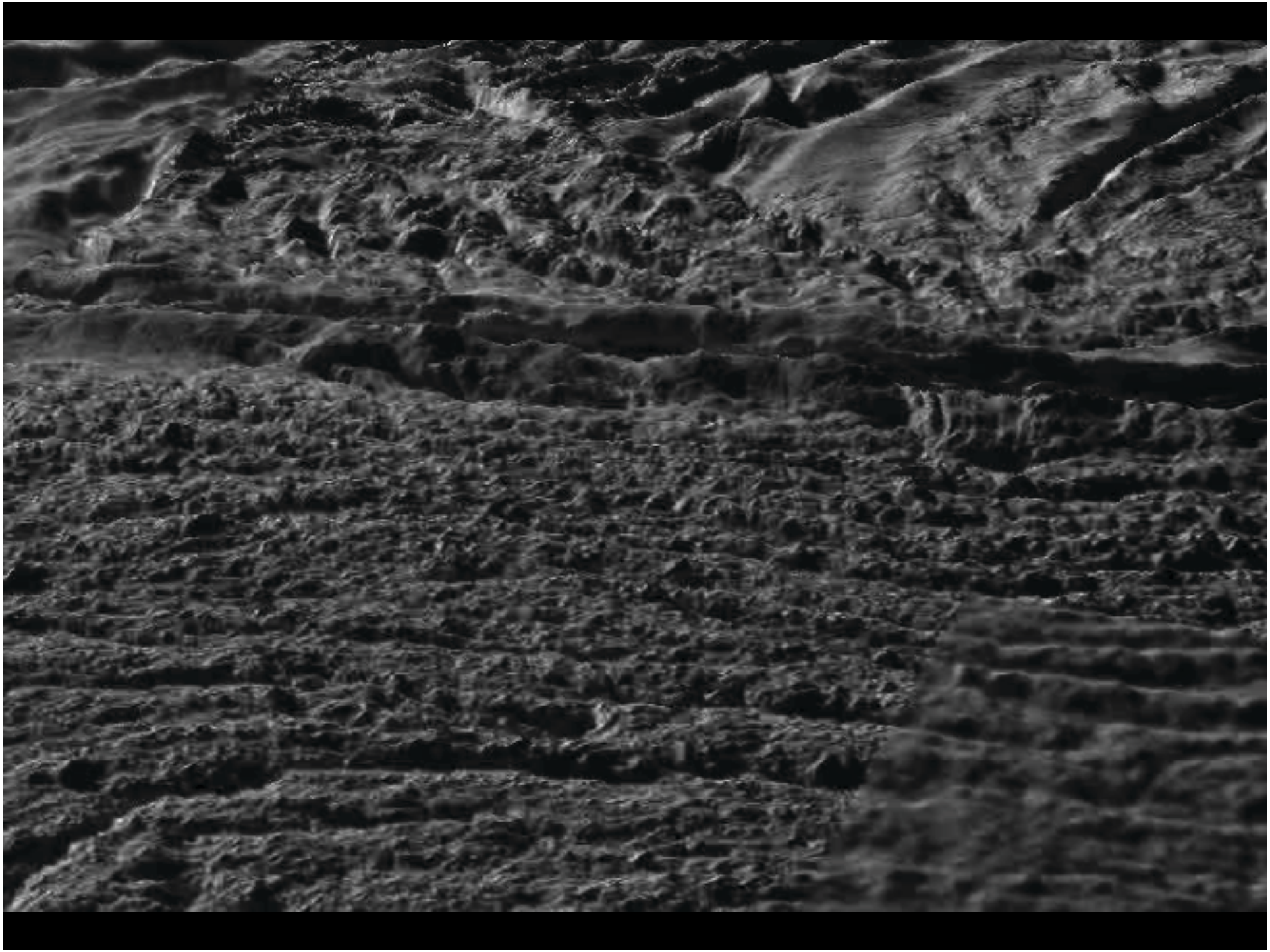

July 2005
November 2006
240
210
180
150
120
90
300
270
240
210
180
150
Temperature, Kelvin
85
80
75
70
65
60

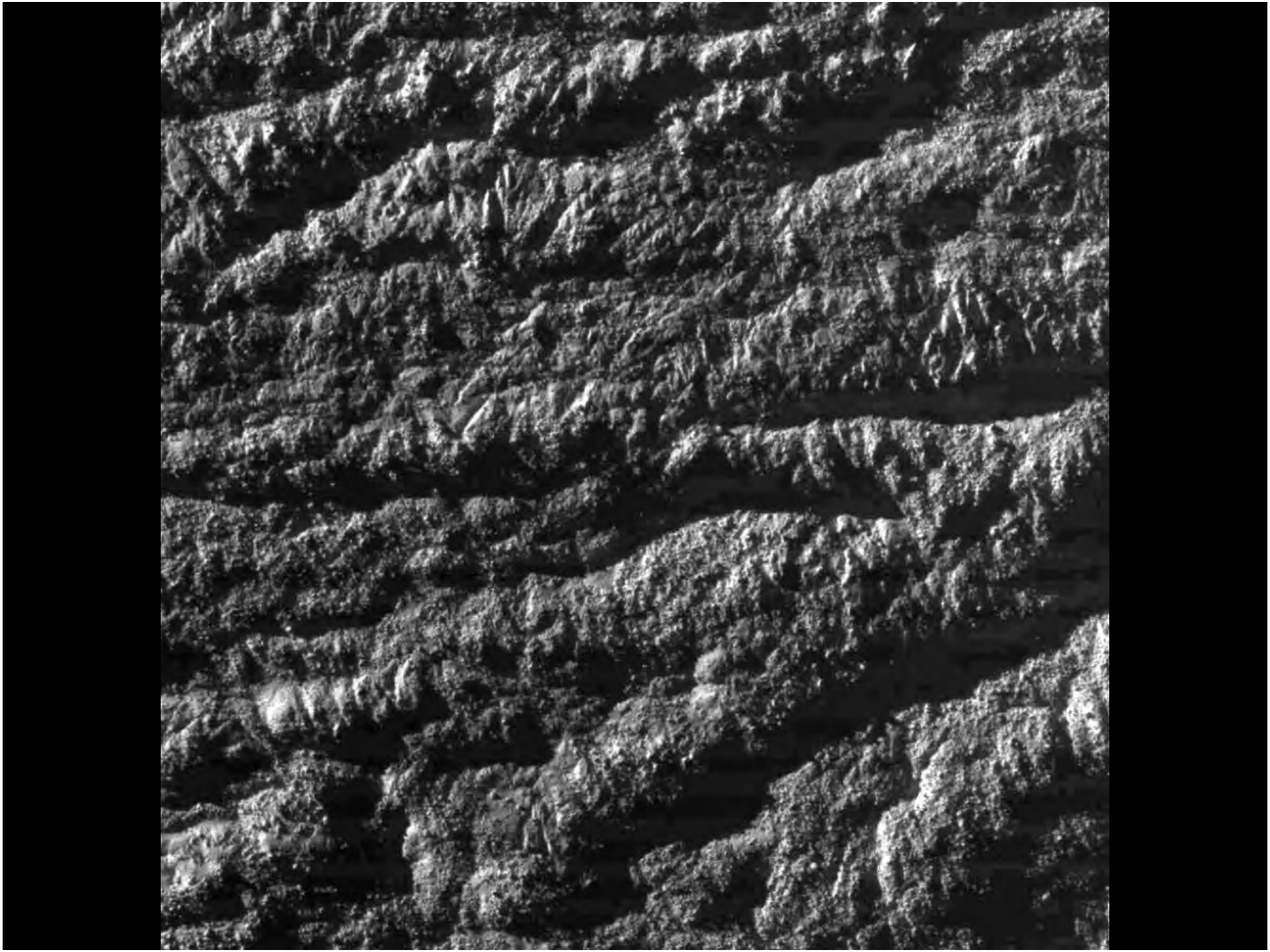

30°
330°
60°
300°
90°
-90°
-70°
270°
120°
240°
150°
210°

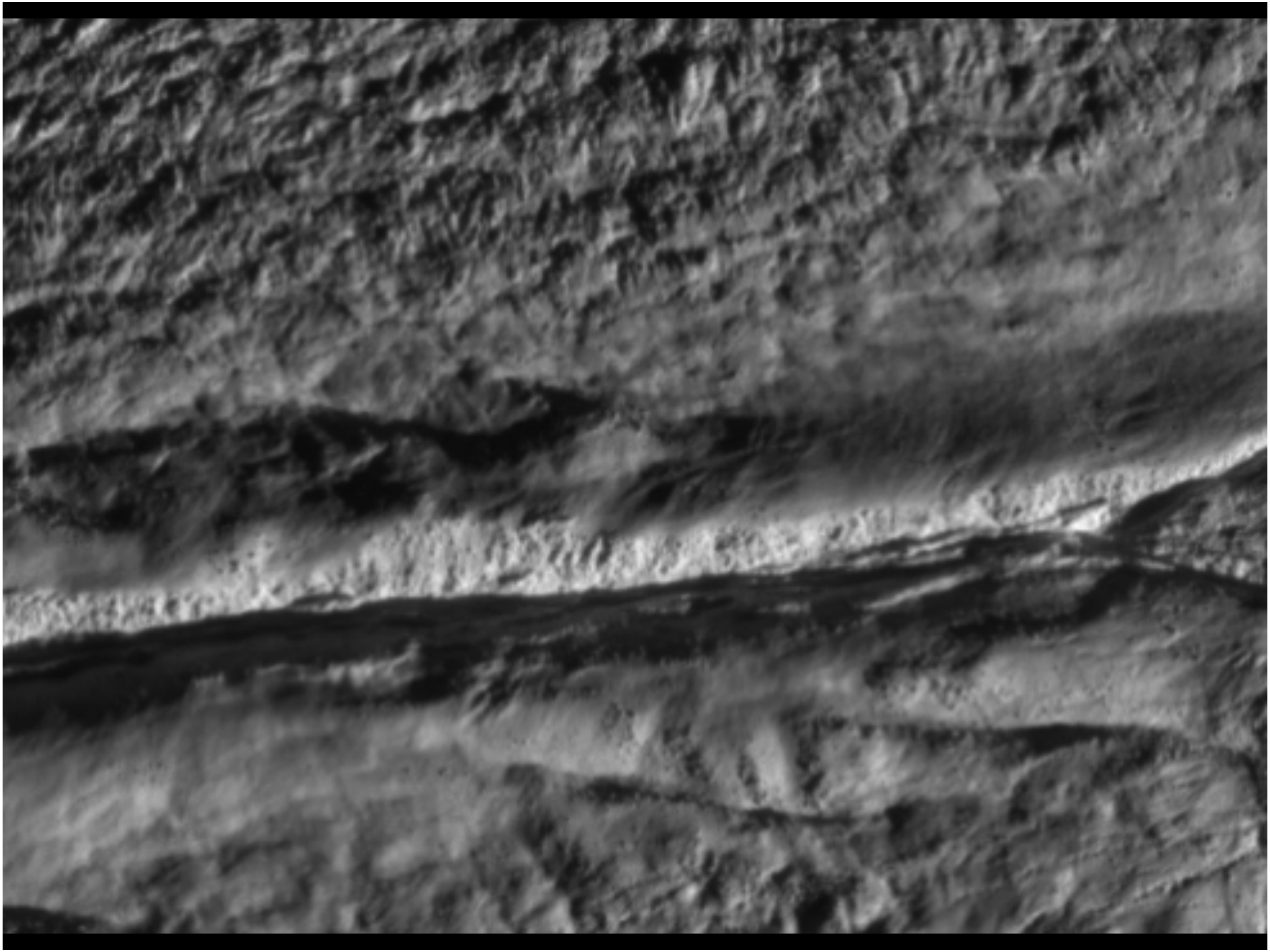

180
-60
-70
-80
270
90
0
50 km

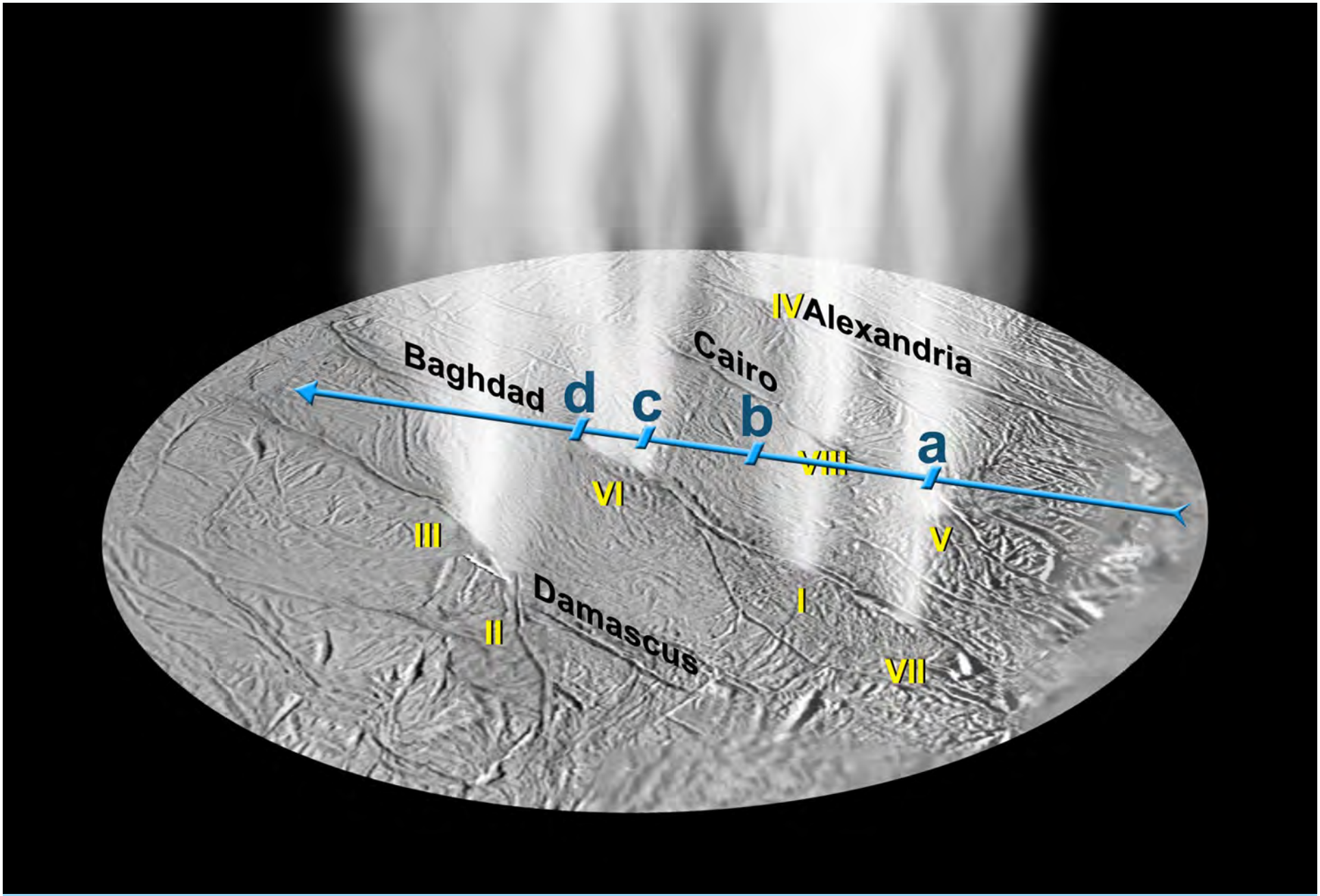

conductive
ice shell
(40-60 km thick)
possible
global
ocean
hydrated/porous
rocky core
salty sea
(~10 km thick)
tidally heated
convective region
(30-40 km thick)
south polar terrain

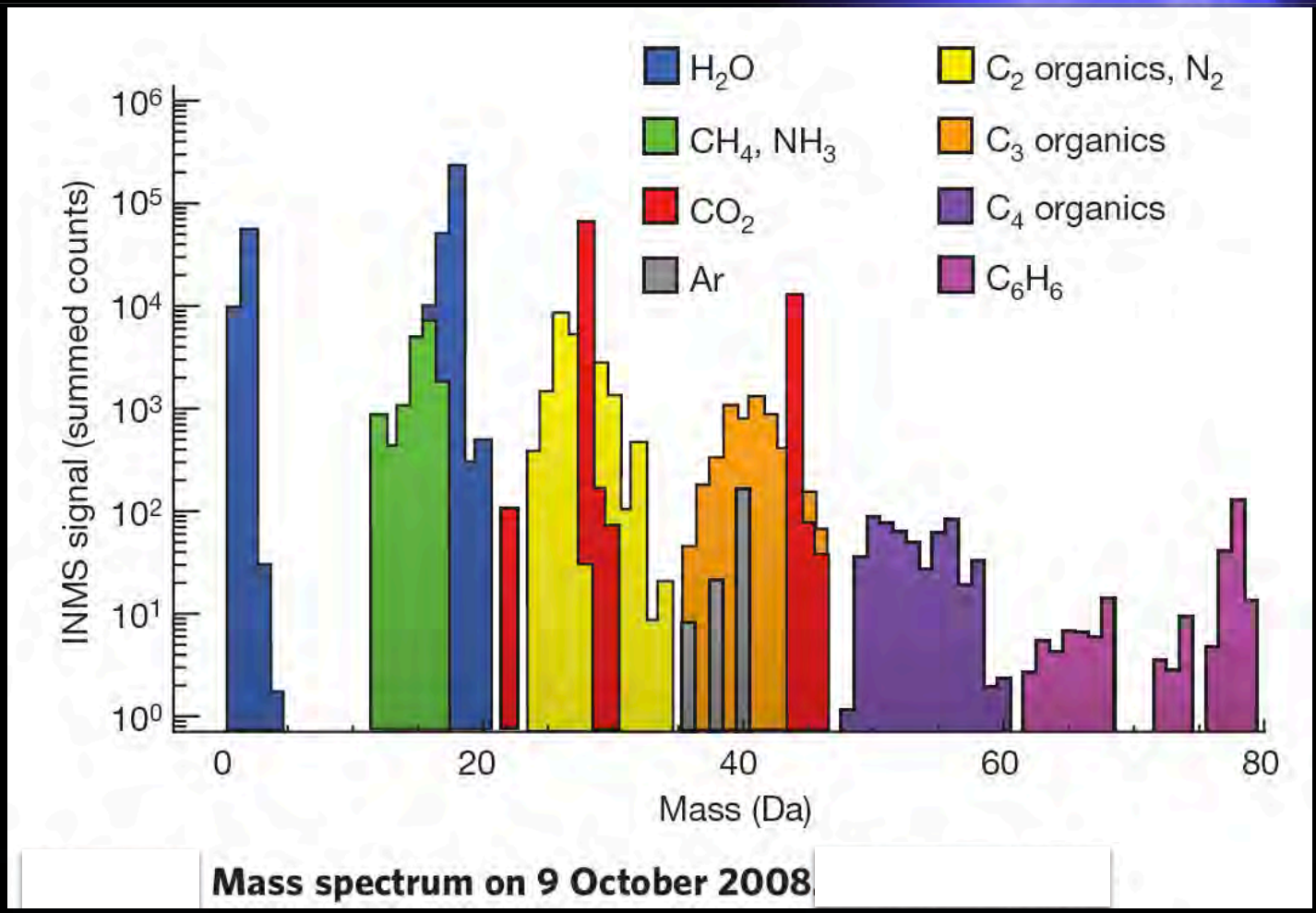

Enceladus / Saturn II
Distance: 13,343 km
Radius: 256.60 km
Apparent diameter: 2° 09' 44.0"
Phase angle: 144.6°
2009 Nov 21 01:41:44 UTC
-Real time (Paused)
Baghdad
Damascus
Cairo
Alexandria
Speed: 0.00000 m/s
Sync Orbit Enceladus
FOV: 26' 15.5" (79.24×)





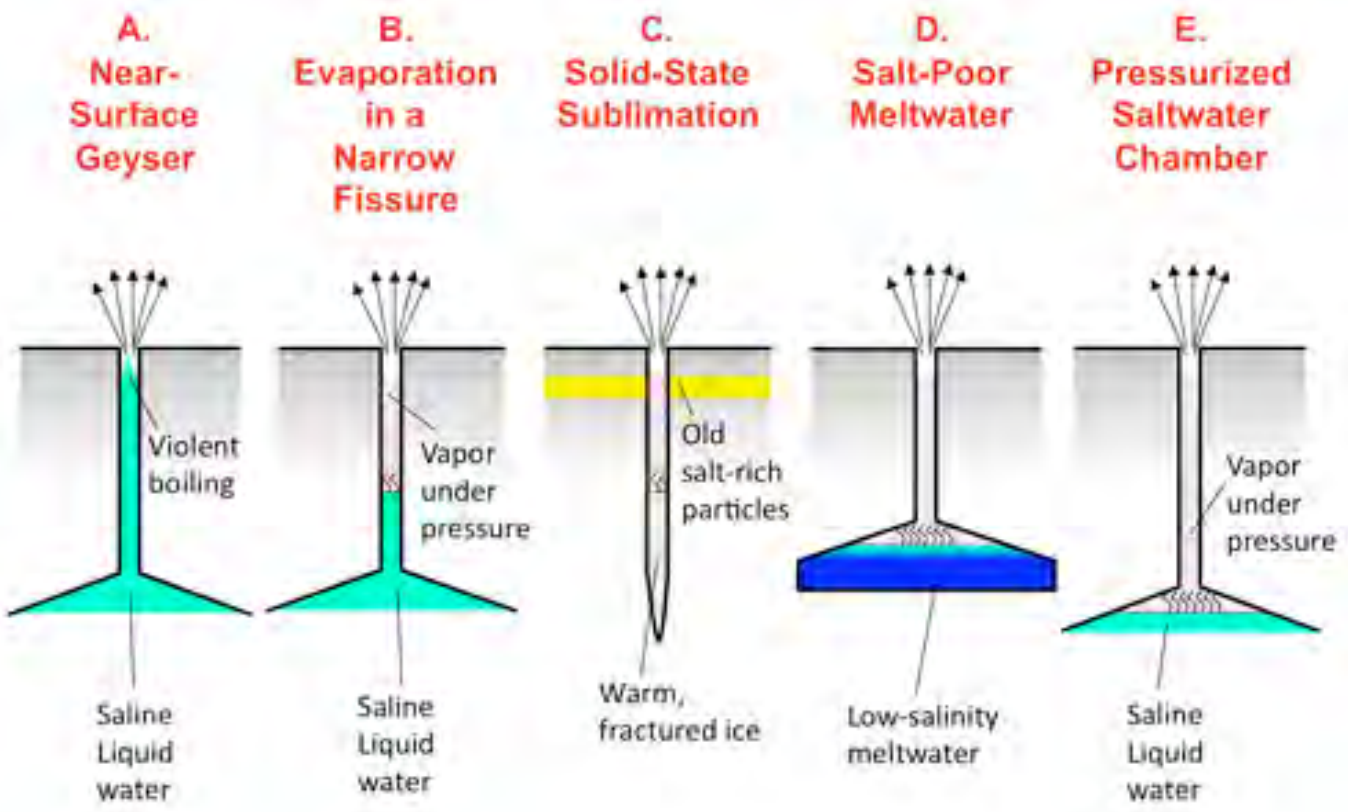



Baghdad
d
c
Cairo
b
IV Alexandria
a
VIII
VI
III
V
Damascus
I
II
VII



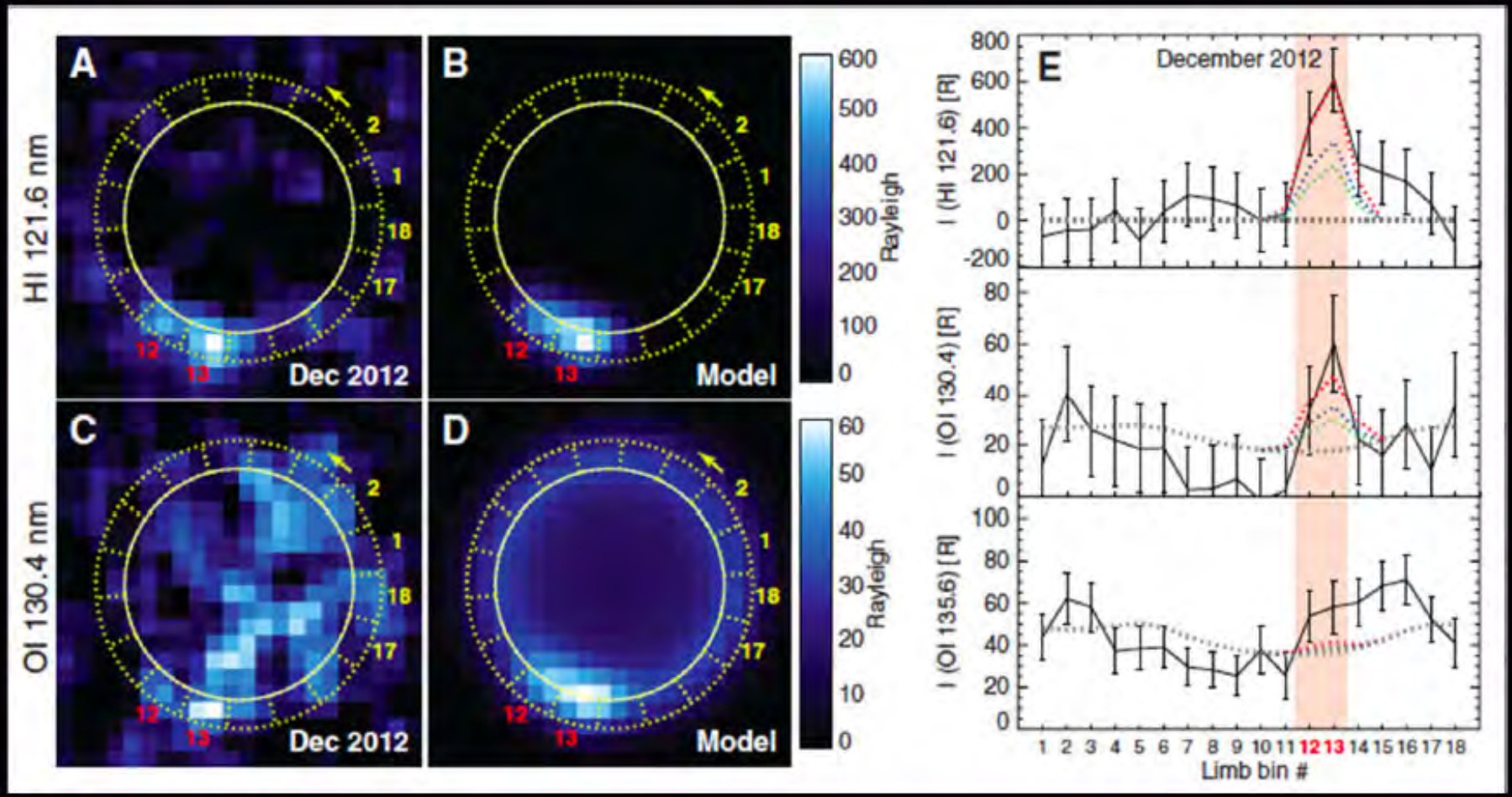
Mass spectrum on 9 October 2008

Plume Vent Models

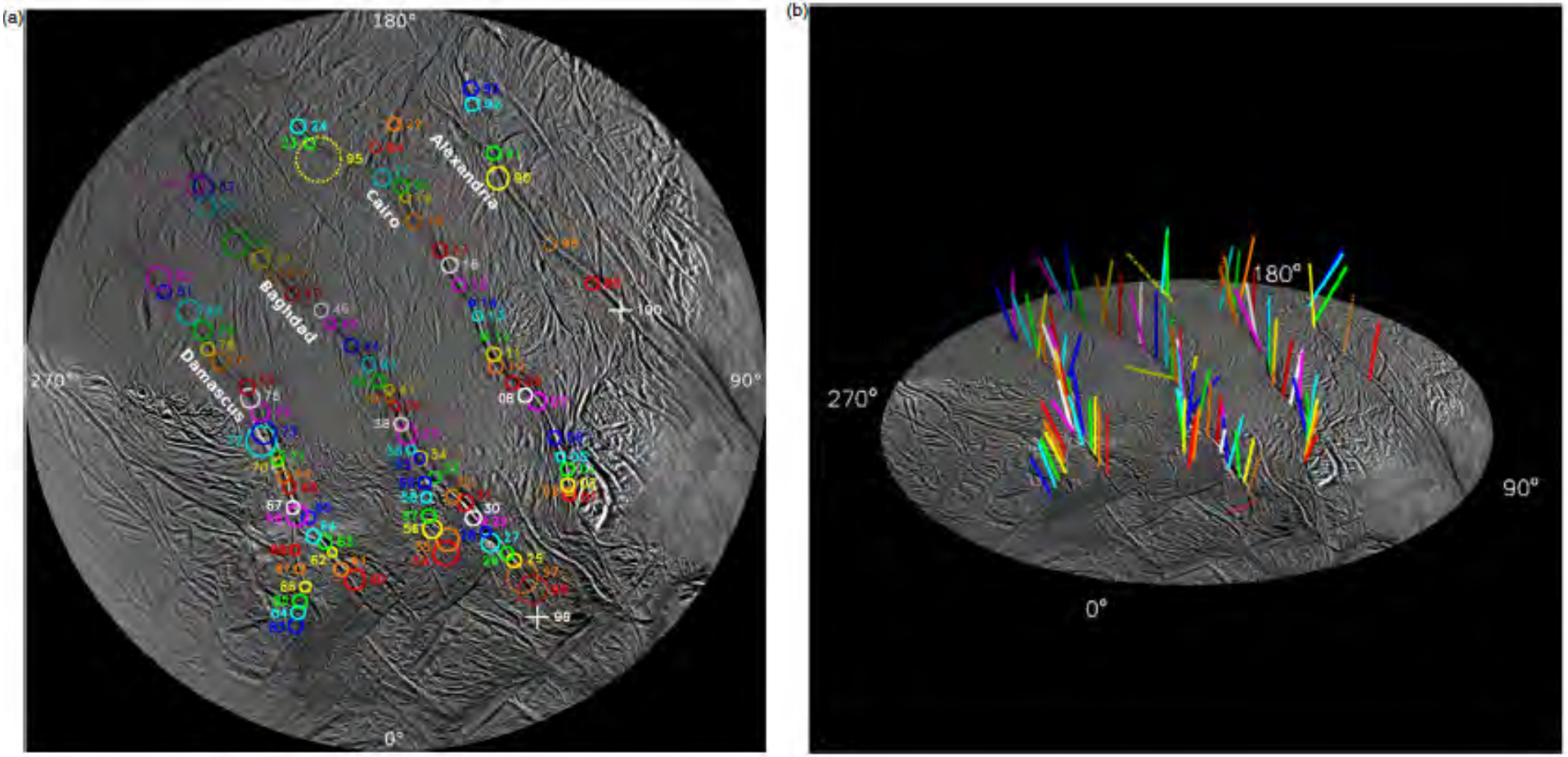


NaCl and bicarbonate in some E ring particles
There must be, or have been, water-rock interaction

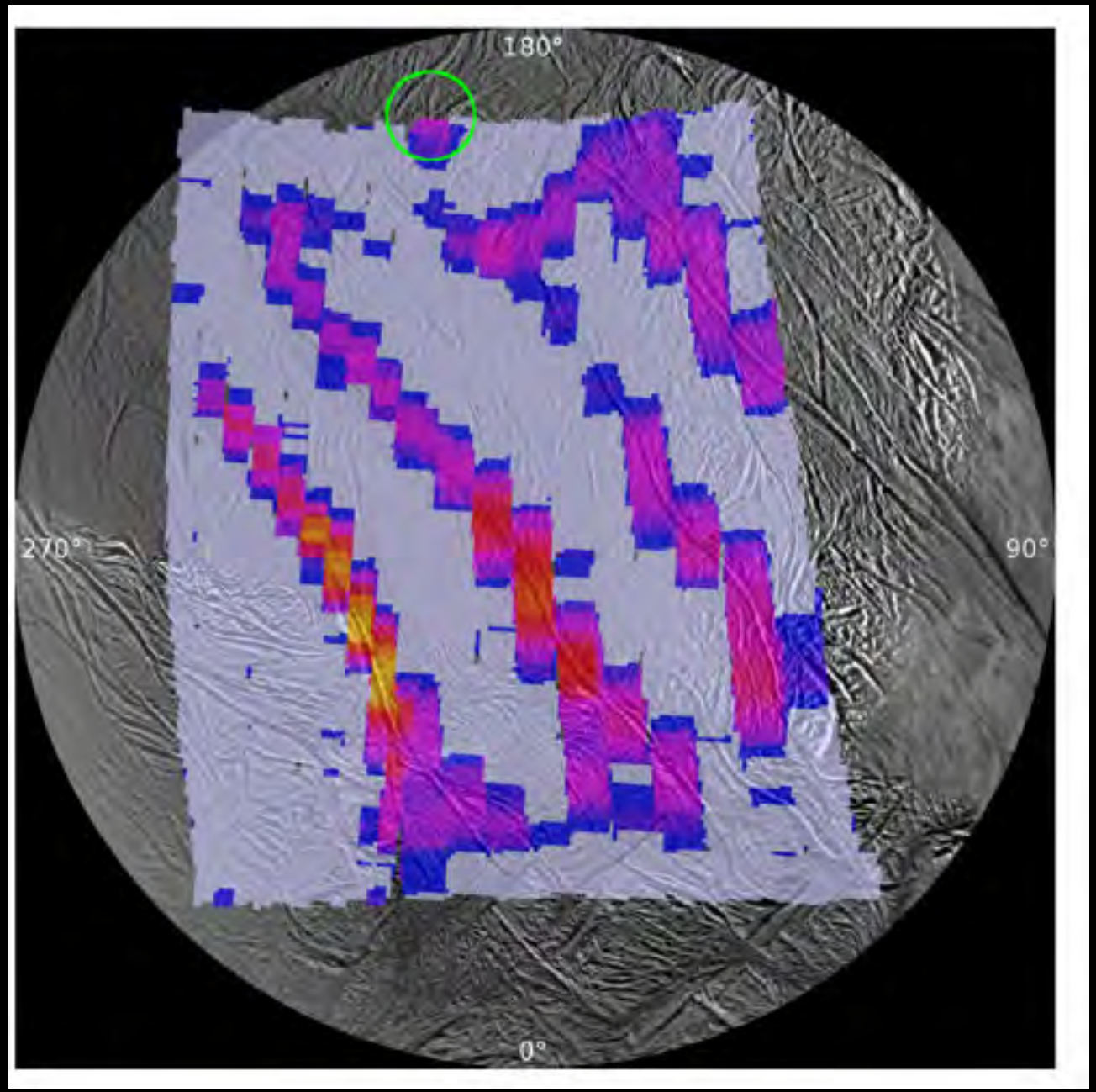
EUROPA PLUME?



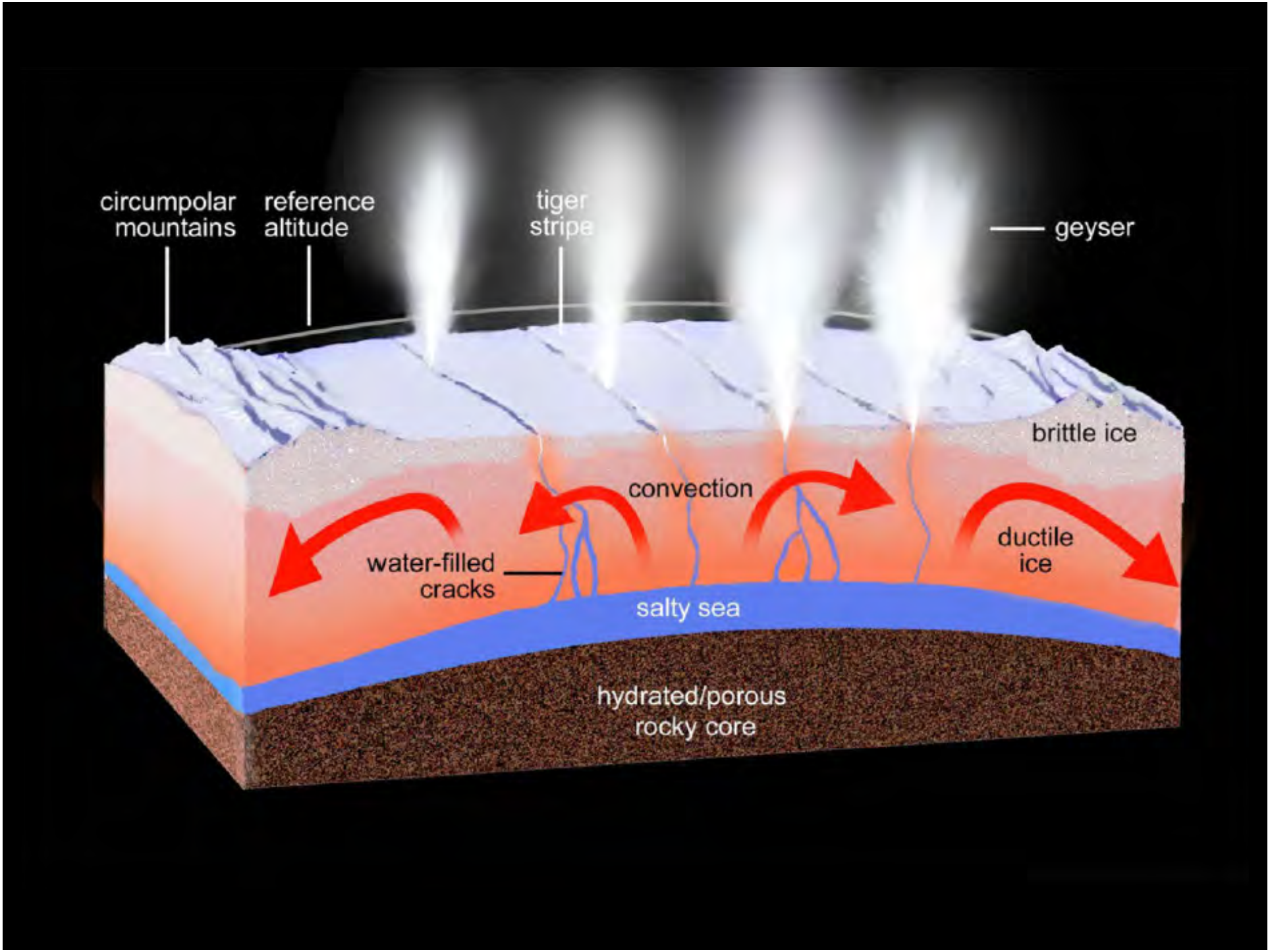
Roth et al 2014, *Science*



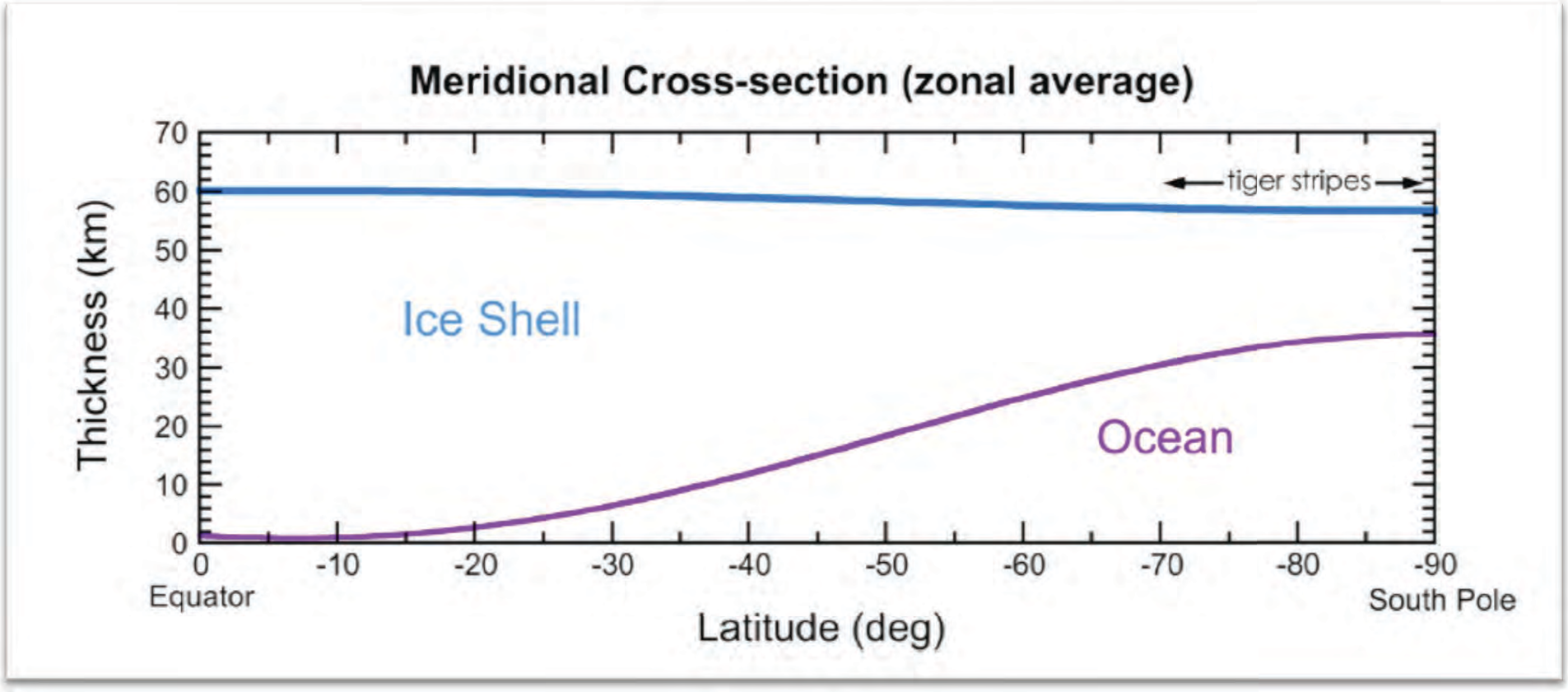
Porco et al. 2014



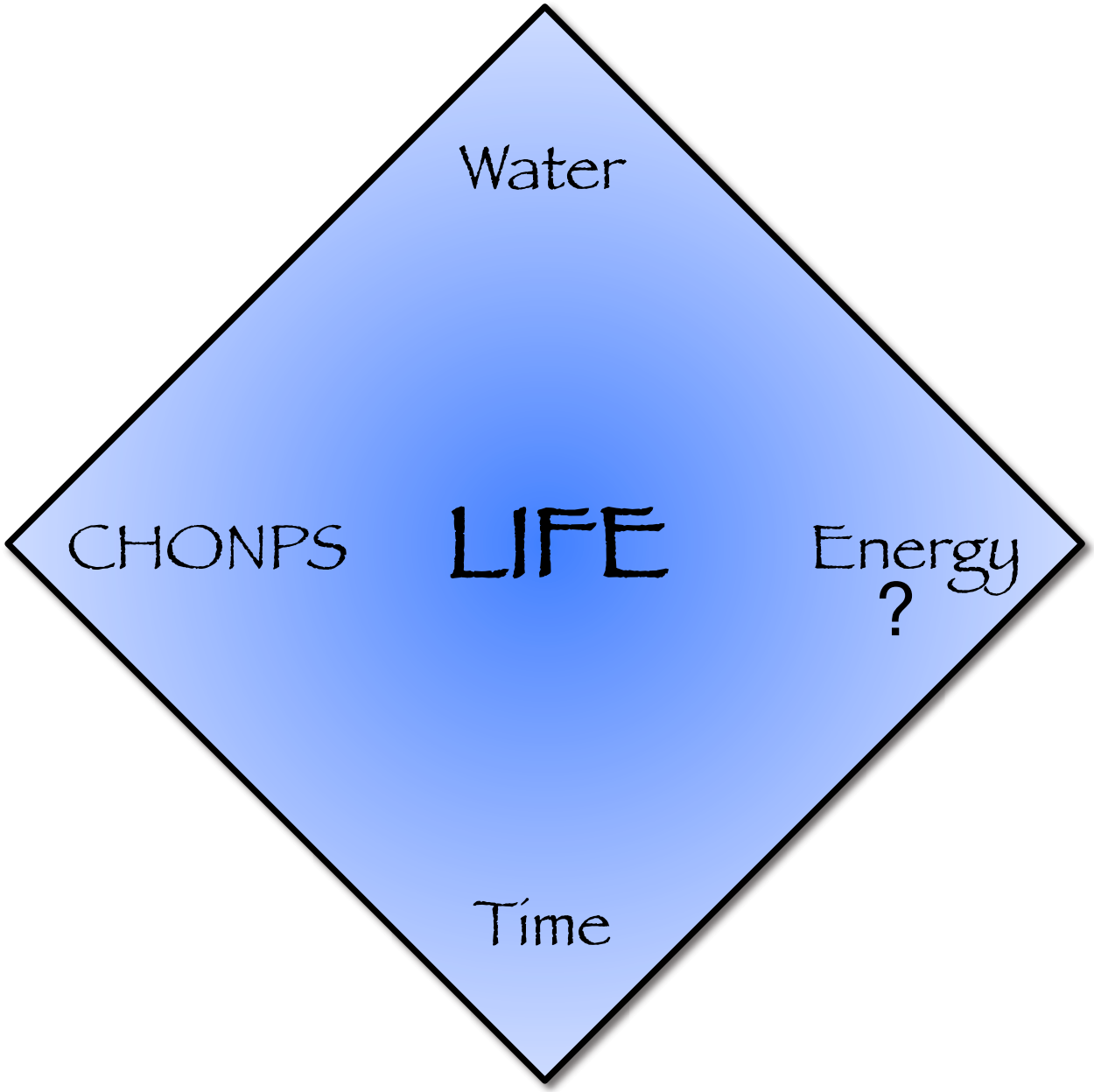
Howett et al. 2011

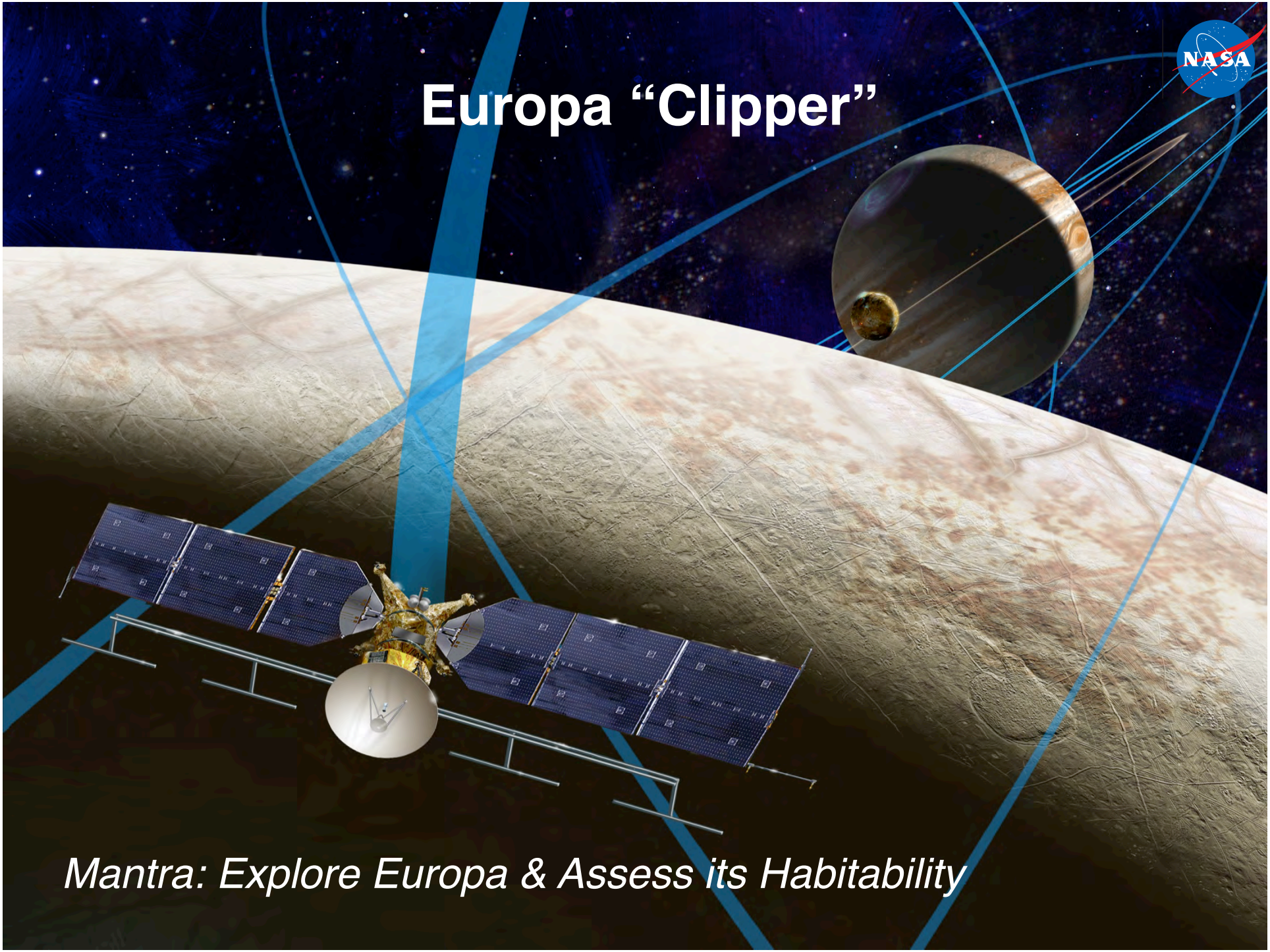

circumpolar mountains
reference altitude
tiger stripe
geyser
brittle ice
convection
ductile ice
water-filled cracks
salty sea
hydrated/porous rocky core

Enceladus Gravity and Topography Model (McKinnon 2014)



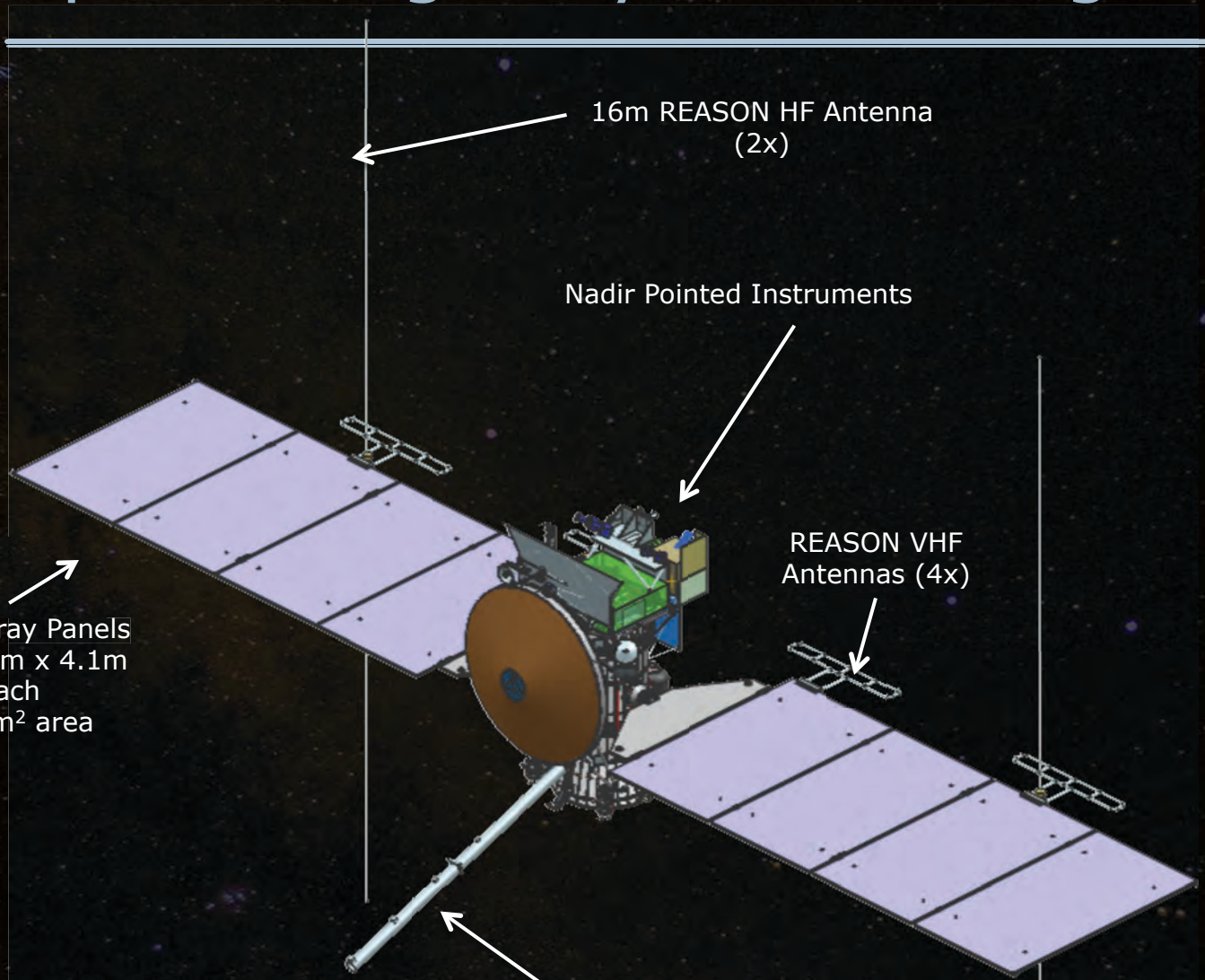
A global ocean….now confirmed by libration measurements (Thomas et al. 2015)


Water
CHONPS
LIFE
Energy
?
Time

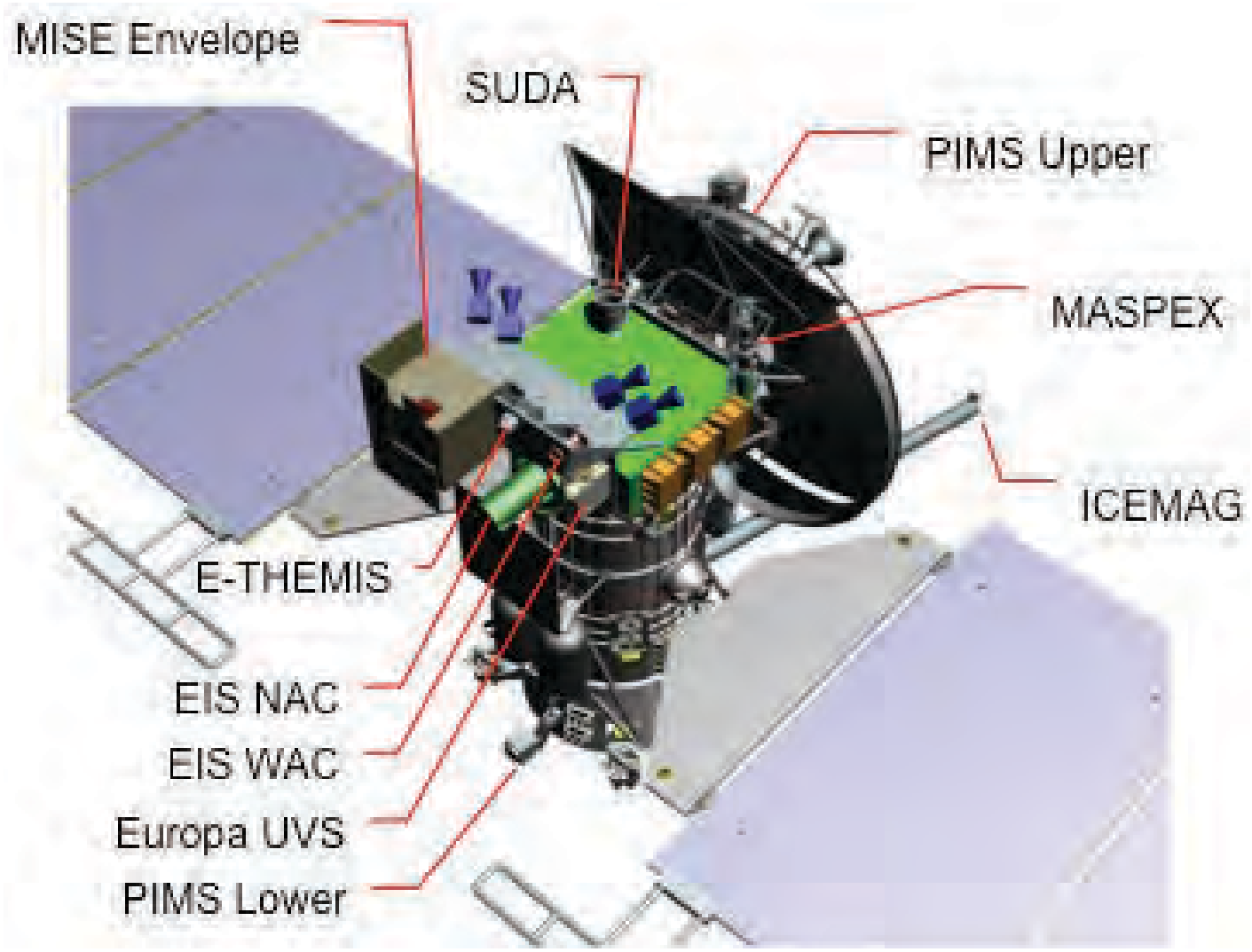

Europa “Clipper”
NASA
Mantra: Explore Europa & Assess its Habitability

NASA-Selected Europa Instruments

Proposed Flight System Configuration



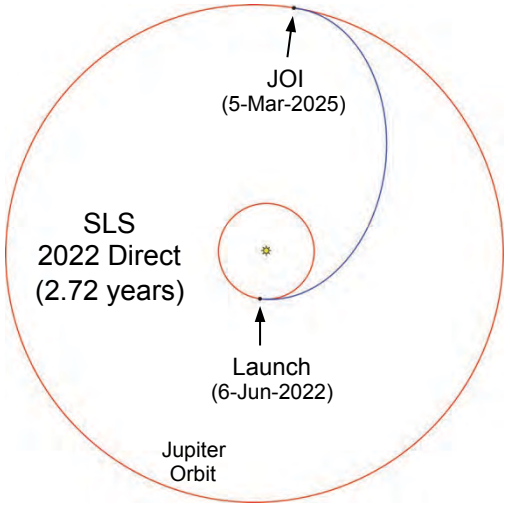
Payload Accommodation



Current Jupiter Delivery Strategy

Baseline

Launch Vehicle: SLS Block-1
Transfer: Earth-Jupiter Direct
Time-of-flight: 2.5-2.7 yrs.

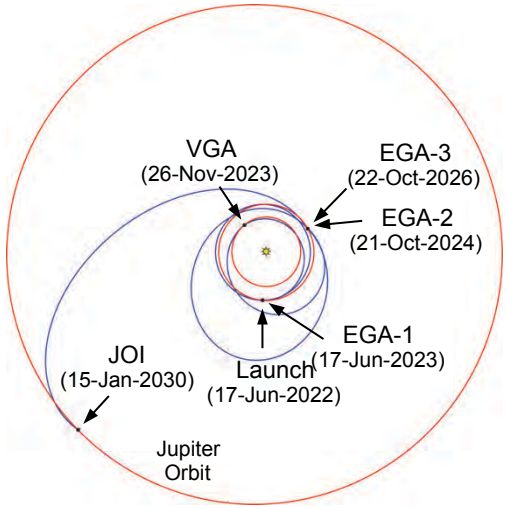


Mass Margin

35% - 2022 Launch
33% - 2023 Launch

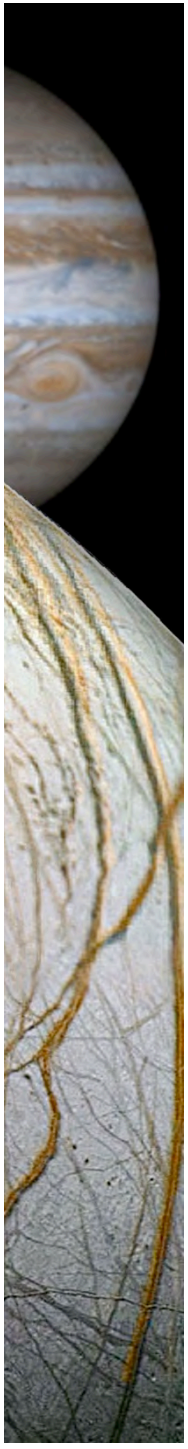
Backup

Launch Vehicle: Atlas V 551 or Delta IV Heavy
Transfer: EVEEGA
Time-of-flight: 7.4 yrs.

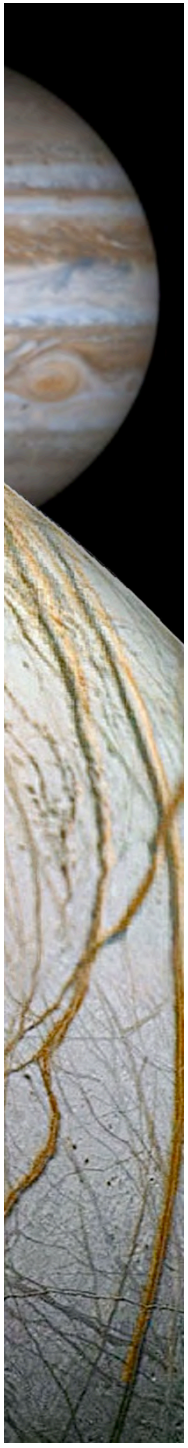


Atlas V 551	Mass Margin	Delta IV Heavy**
29%	2022 Launch	65%
30%	2023 Launch	66%

** **IF fully** utilize L.V. capability



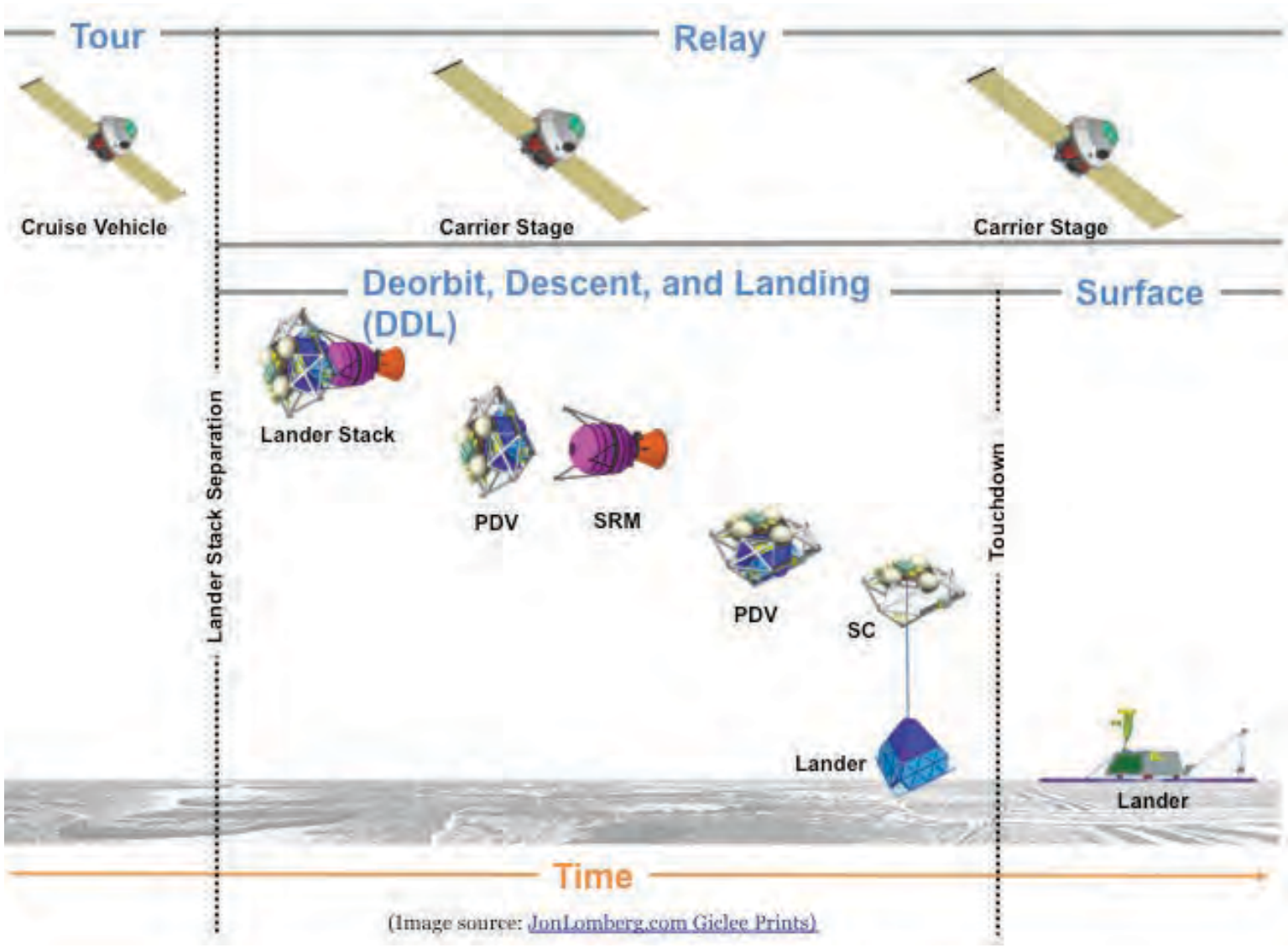
Lander Concept



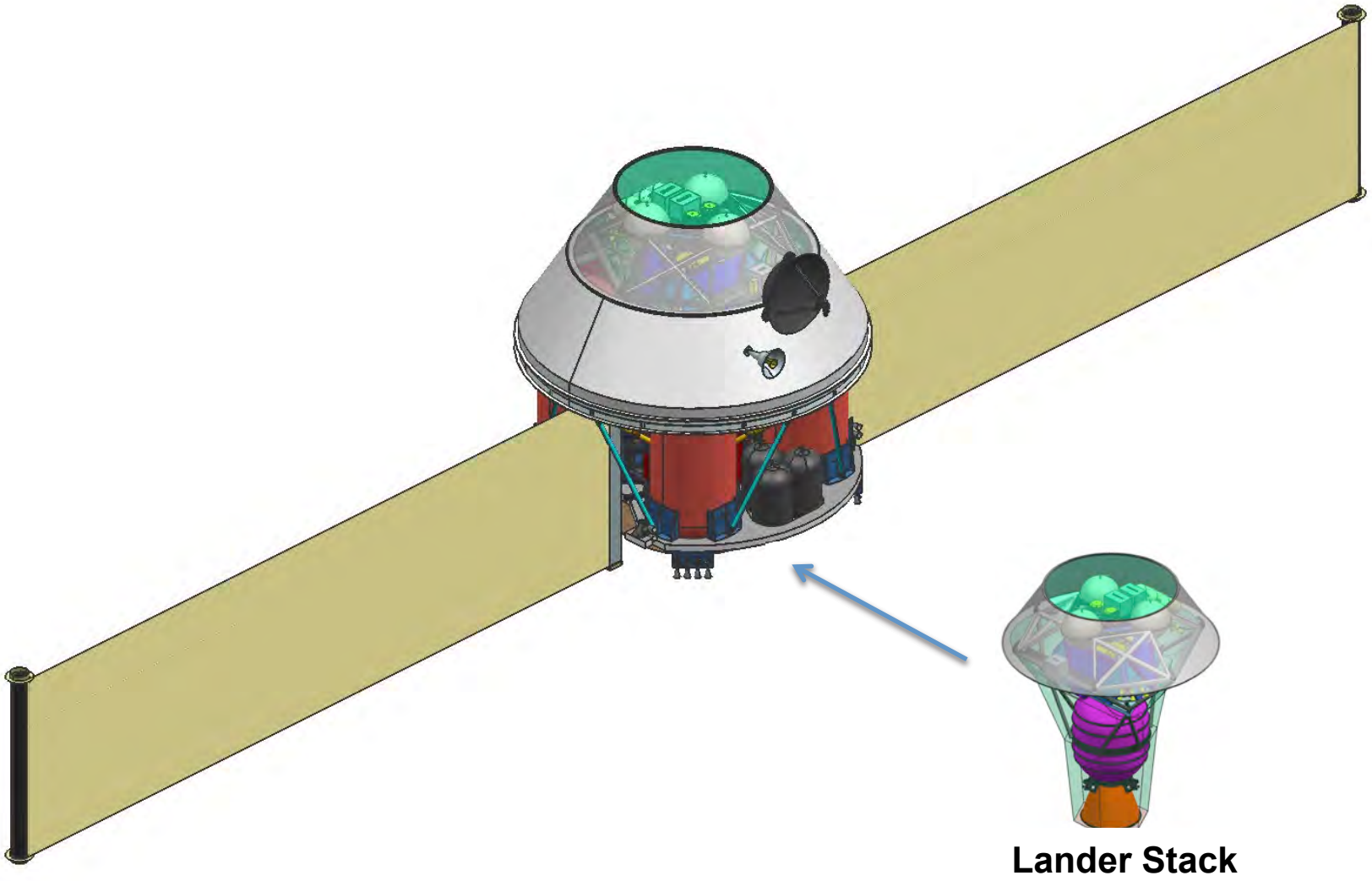
Concept Highlights

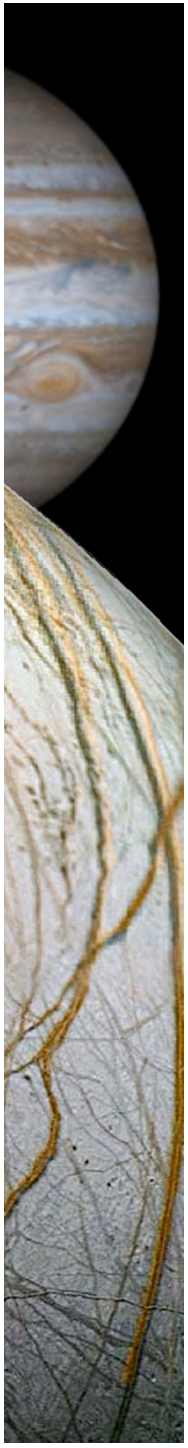
- Spacecraft physically decoupled from Clipper
- Enter Jovian system and '*park*' in a radiation safe orbit awaiting reconnaissance from Clipper to decide where to target landing
- Spacecraft components:
  - **Carrier/Orbit Stage**
    - Delivers system to Jovian system and eventually targets lander stack (everything bellow)
    - Provides relay capability (Clipper can be backup) to earth
  - **De-orbit Module**
    - Decelerates lander to capture a Europa descent trajectory
  - **Descent Module**
    - Slows down lander, terminal descent to Europa
  - **Lander**
    - Science!!!

Top-Level Mission Event Sequence

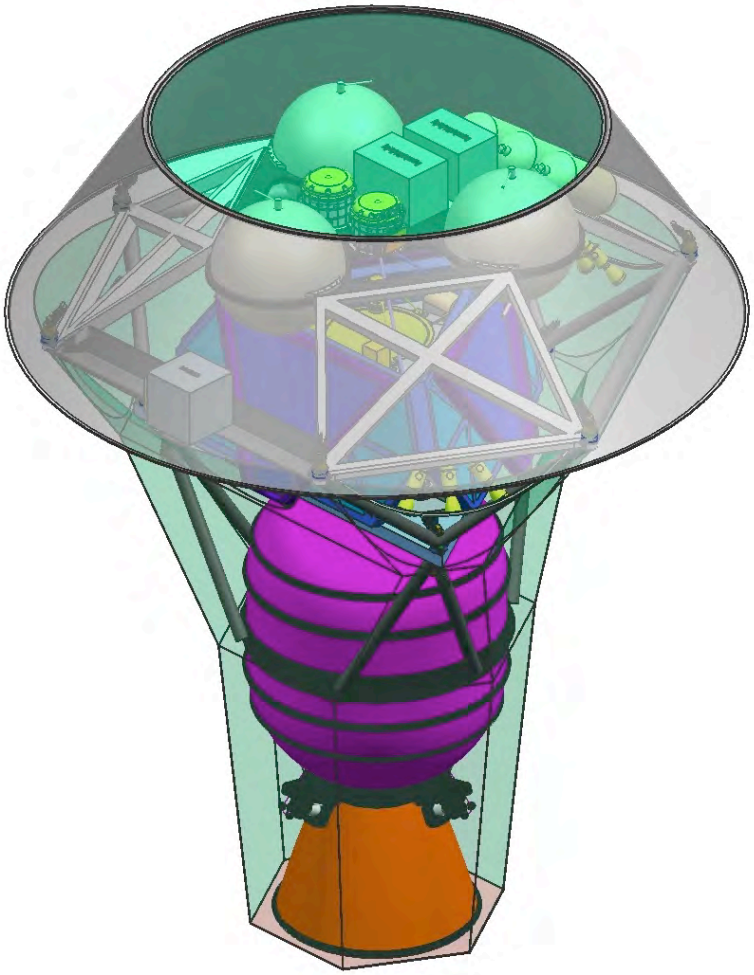


Carrier / Orbit Stage Concept

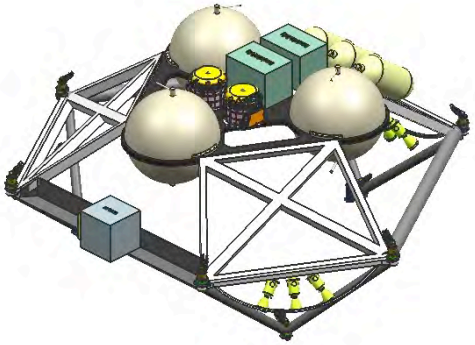




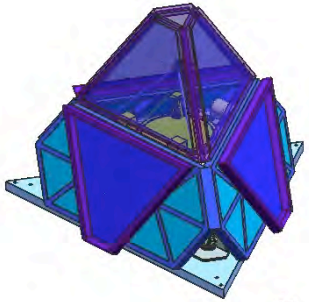
Lander Full System Concept



Lander Stack at Integration



Descent Stage

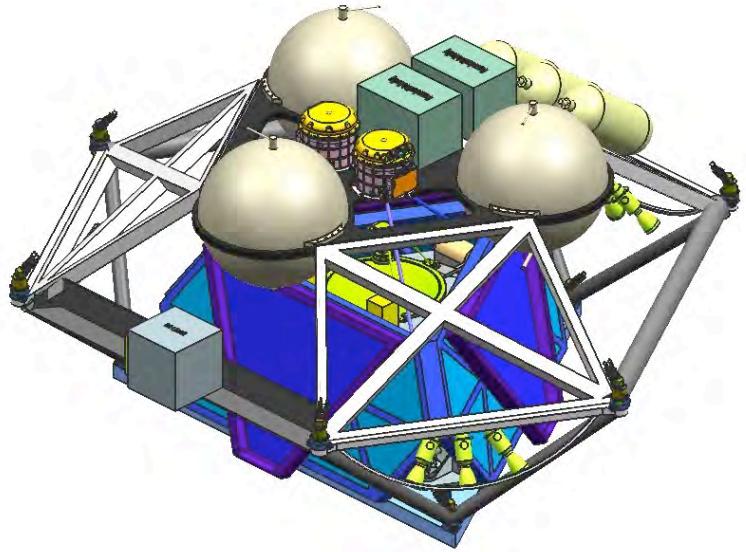


Lander

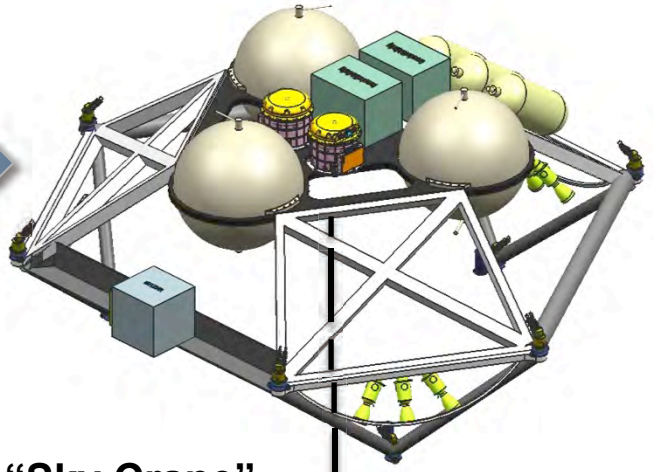
De-orbit Stage

Lander Stack Exploded View

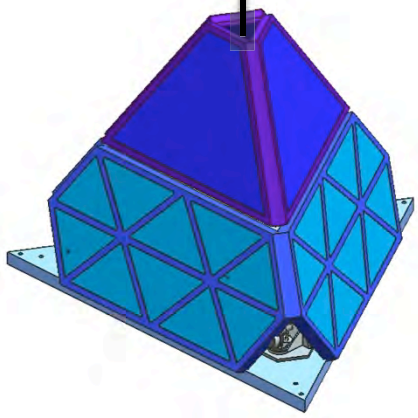
Lander Descent and Surface Concepts

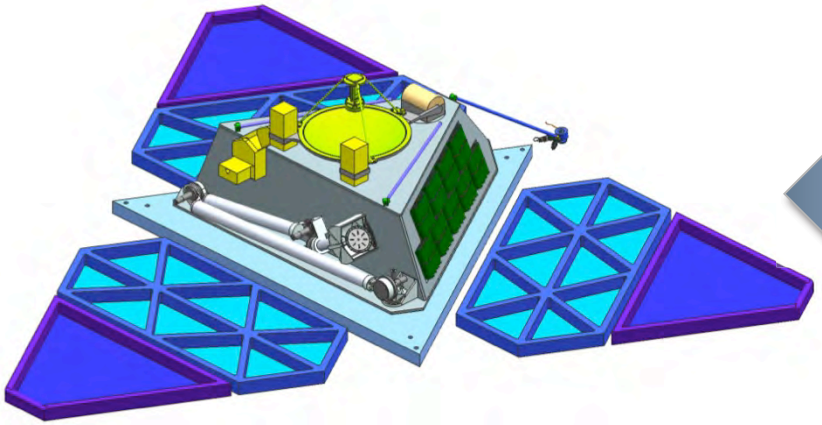


1 - Descent Configuration



2 – "Sky Crane" Configuration

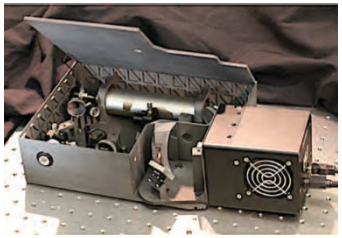


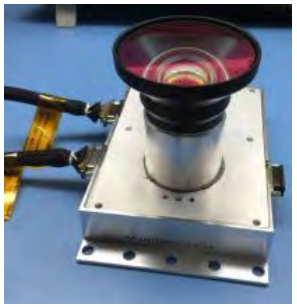


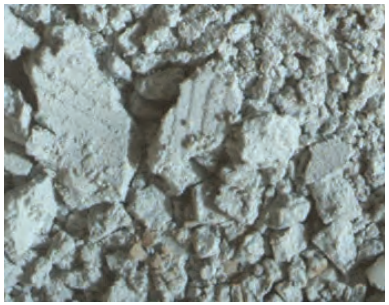
3 - Landed Deployed

Model Payload (Total Mass: 25 kg)

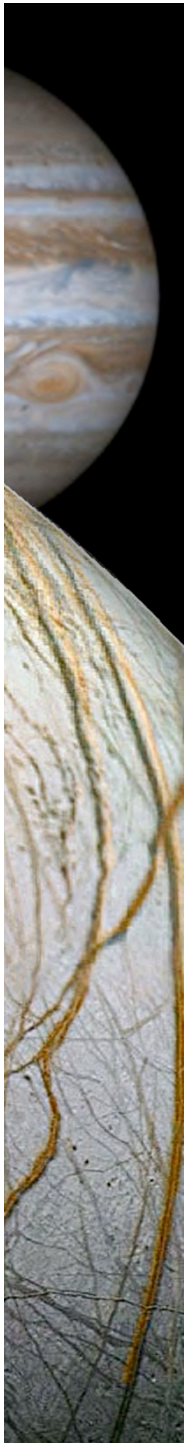
- Centerpiece Instruments for Astrobiology
  - **GCMS**: VCAM GC + Ion Trap MS, 8.3 kg CBE
  - **Raman**: SHERLOC 5.4 kg CBE
- Auxiliary Instruments
  - **Context LanderCams (x2)**, 0.5 kg each CBE
  - **Microscopic SampleCam**, 0.5 kg CBE
- Baseline Instrument (not included in Threshold)
  - **3-axis Geophone**, 0.8 kg

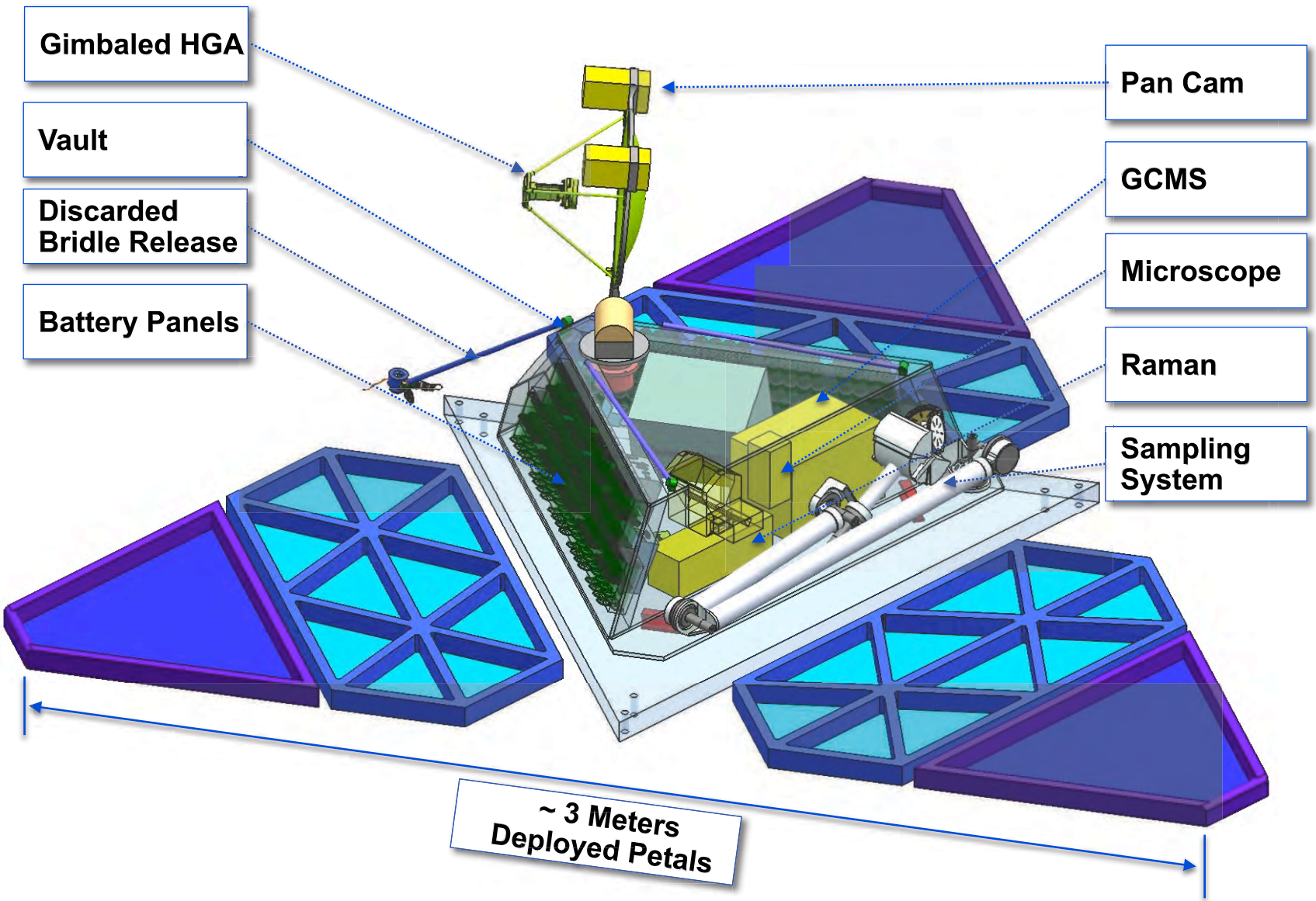






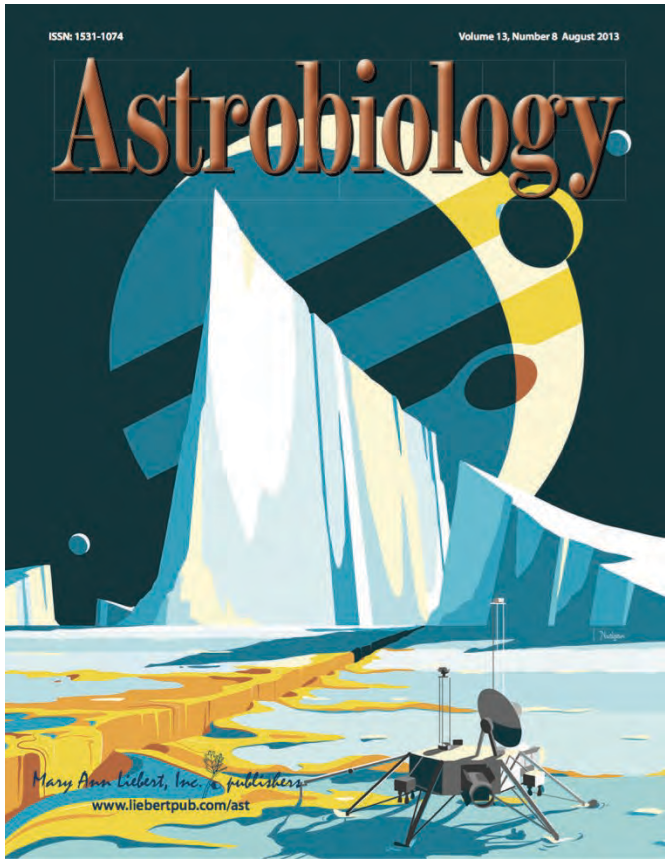
Lander Surface Concept





Want to Know More?

- 2012 Science Definition Team consensus on key questions best answered by a lander:



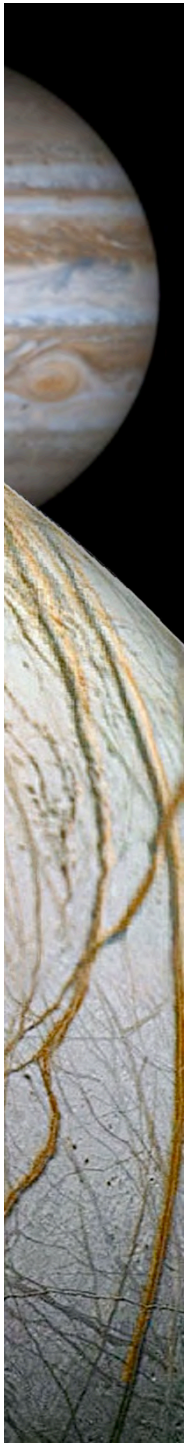
Pappalardo et al. 2013

NASA Ocean Worlds Program

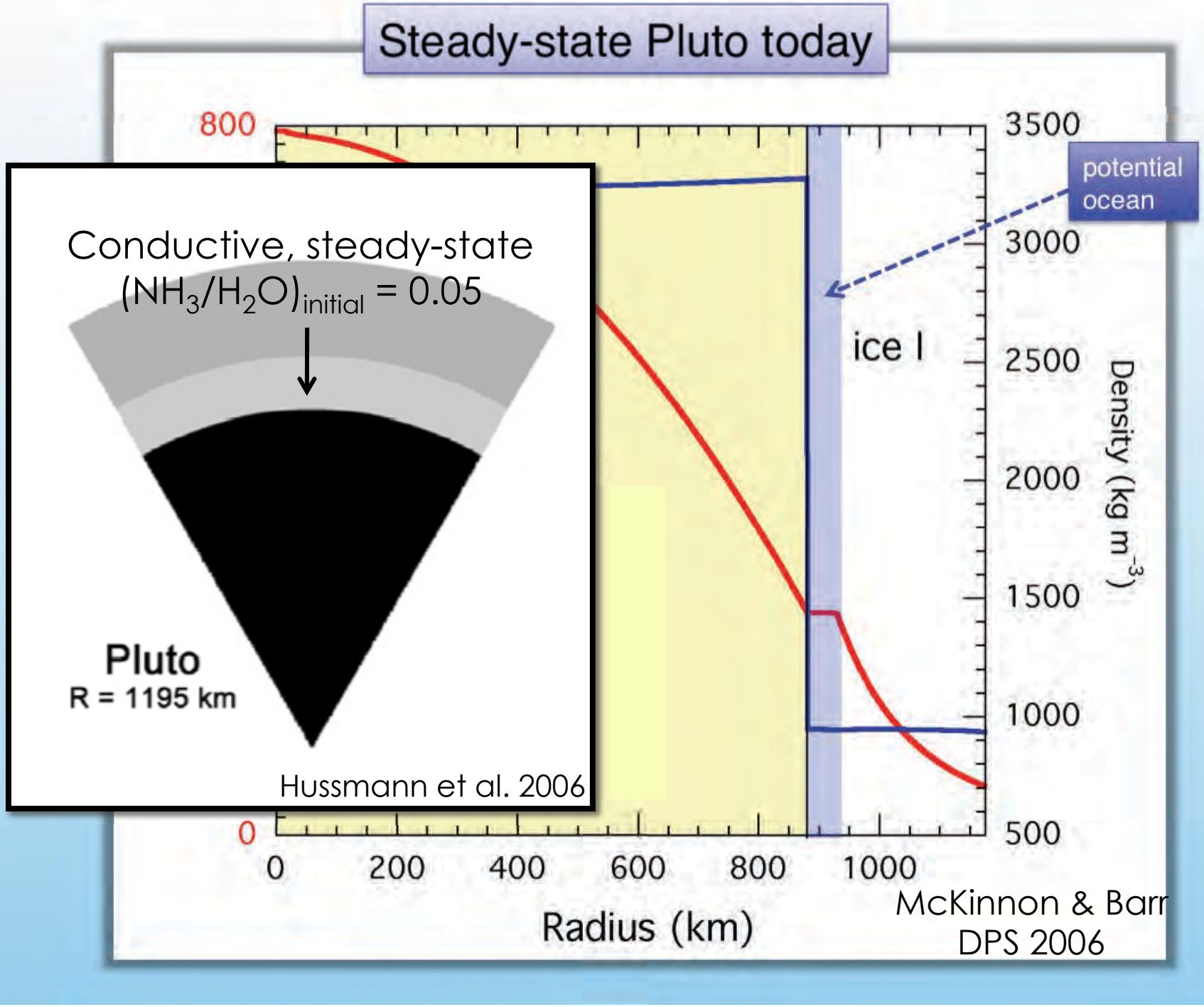
NASA is supporting the House recommendation (Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2016) to create an Ocean Worlds program:

"*Ocean Worlds Exploration Program.*—The recommendation provides $226,000,000 for Outer Planets, of which not less than $140,000,000 is for the Jupiter Europa Clipper, or comparable mission, to support the process of finalizing the mission design concept that meets the scientific objectives described in the most recent Planetary Science decadal survey. To support sustained momentum in this program, NASA shall ensure that future funding requests are consistent with achieving a launch no later than 2022, with the goal of launching on a Space Launch System platform as discussed elsewhere in this report.

Many of NASA's most exciting discoveries in recent years have been made during the robotic exploration of the outer planets. The Cassini mission has discovered vast oceans of liquid hydrocarbons on Saturn's moon Titan and a submerged salt water sea on Saturn's moon Enceladus. **The Committee directs NASA to create an Ocean World Exploration Program whose primary goal is to discover extant life on another world using a mix of Discovery, New Frontiers and flagship class missions consistent with the recommendations of current and future Planetary Decadal surveys.** "



Backup


Steady-state Pluto today
800
0
3500
3000
2500
2000
1500
1000
500
potential ocean
ice I
Density (kg m^{-3})
0
200
400
600
800
1000
Radius (km)
Conductive, steady-state
$(NH_3/H_2O)_{initial}$ = 0.05
Pluto
R = 1195 km
Hussmann et al. 2006
McKinnon & Barr
DPS 2006