Scientific Goals for Future Lander Missions to Europa and Titan

Pat Beauchamp

Jet Propulsion Laboratory
California Institute of Technology

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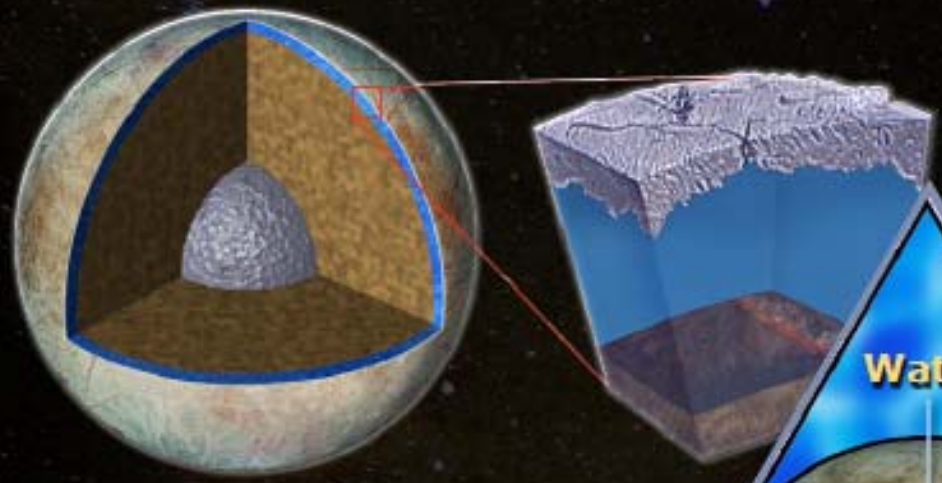
Host of Contributors and Collaborators

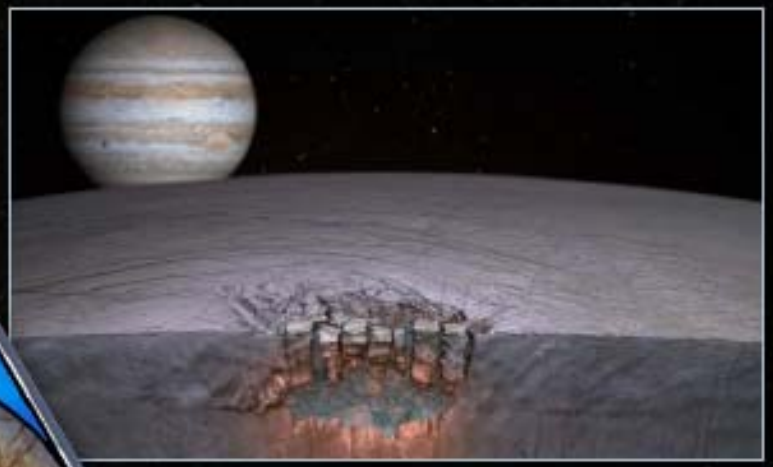
- Innumerable Cassini and Galileo scientists
- Europa Multiple Fly-by team
  - Bob Pappalardo
  - Kevin Hand
- TSSM team
  - Jonathan Lunine
  - Kim Reh
- NAI Team
  - Christophe Sotin
  - Rob Hodyss
  - Morgan Cable

……to name a few

Europa: Ingredients for Life?



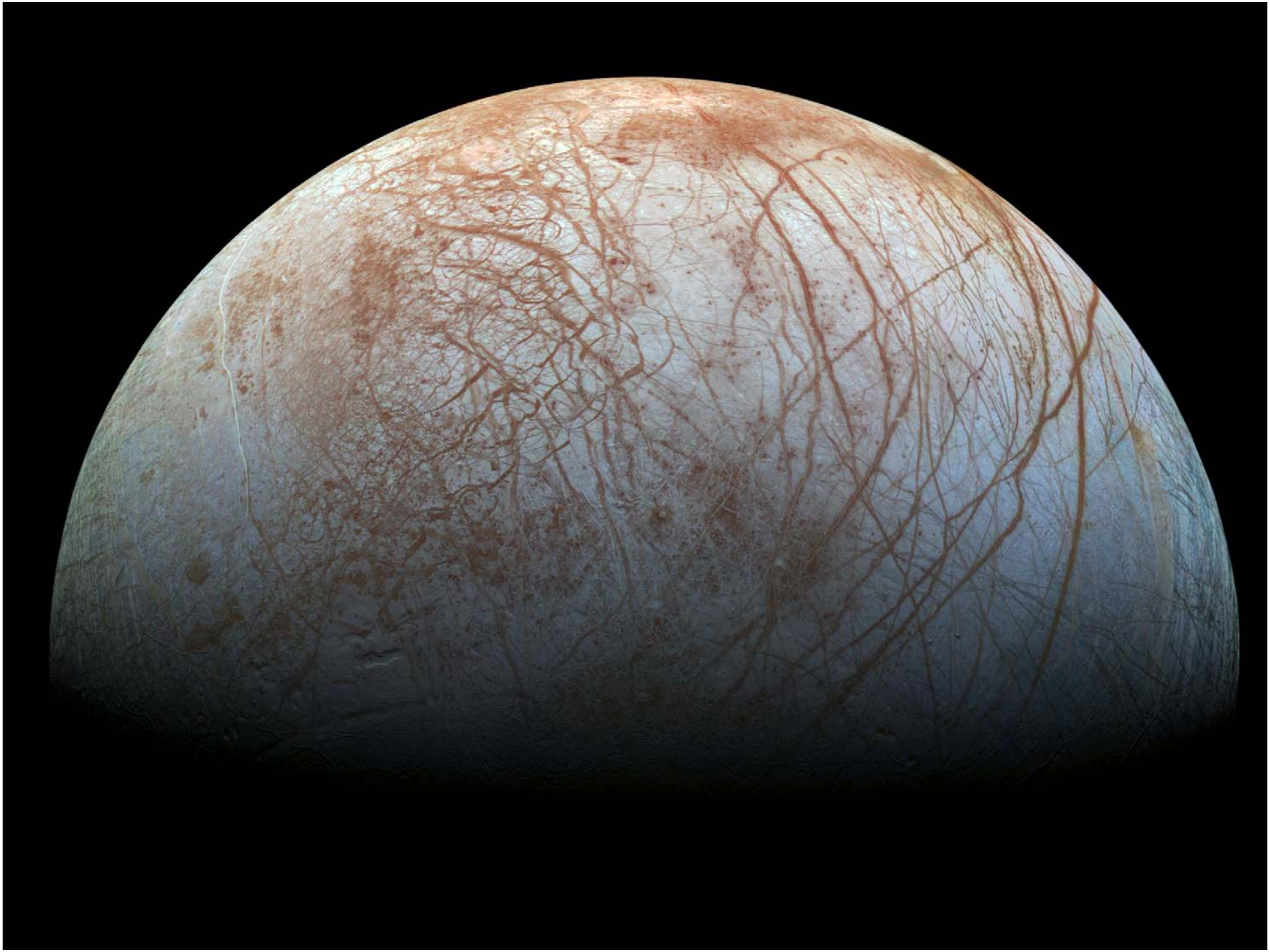
Water: Are a global ocean and lakes of water hidden below the ice?

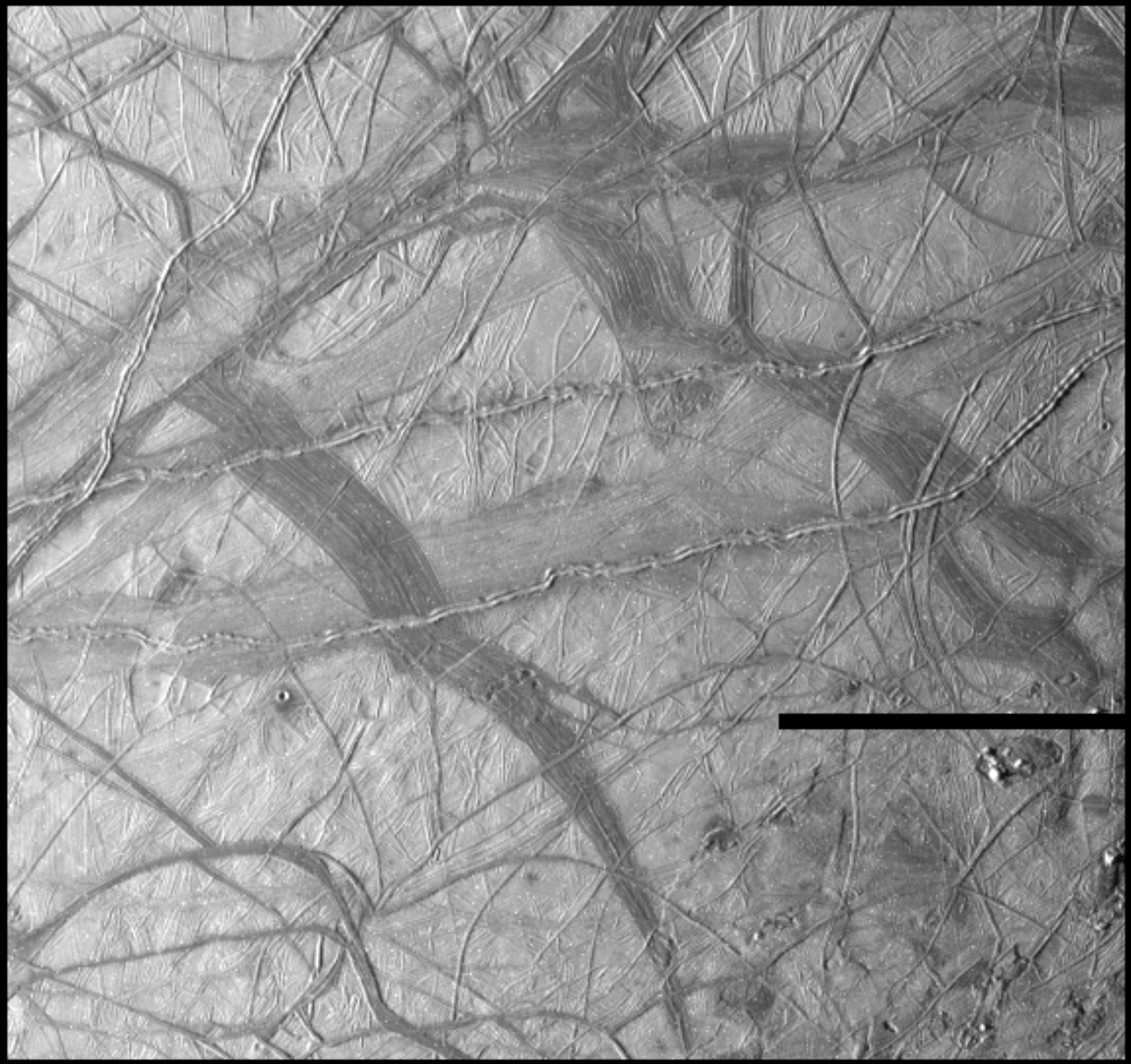


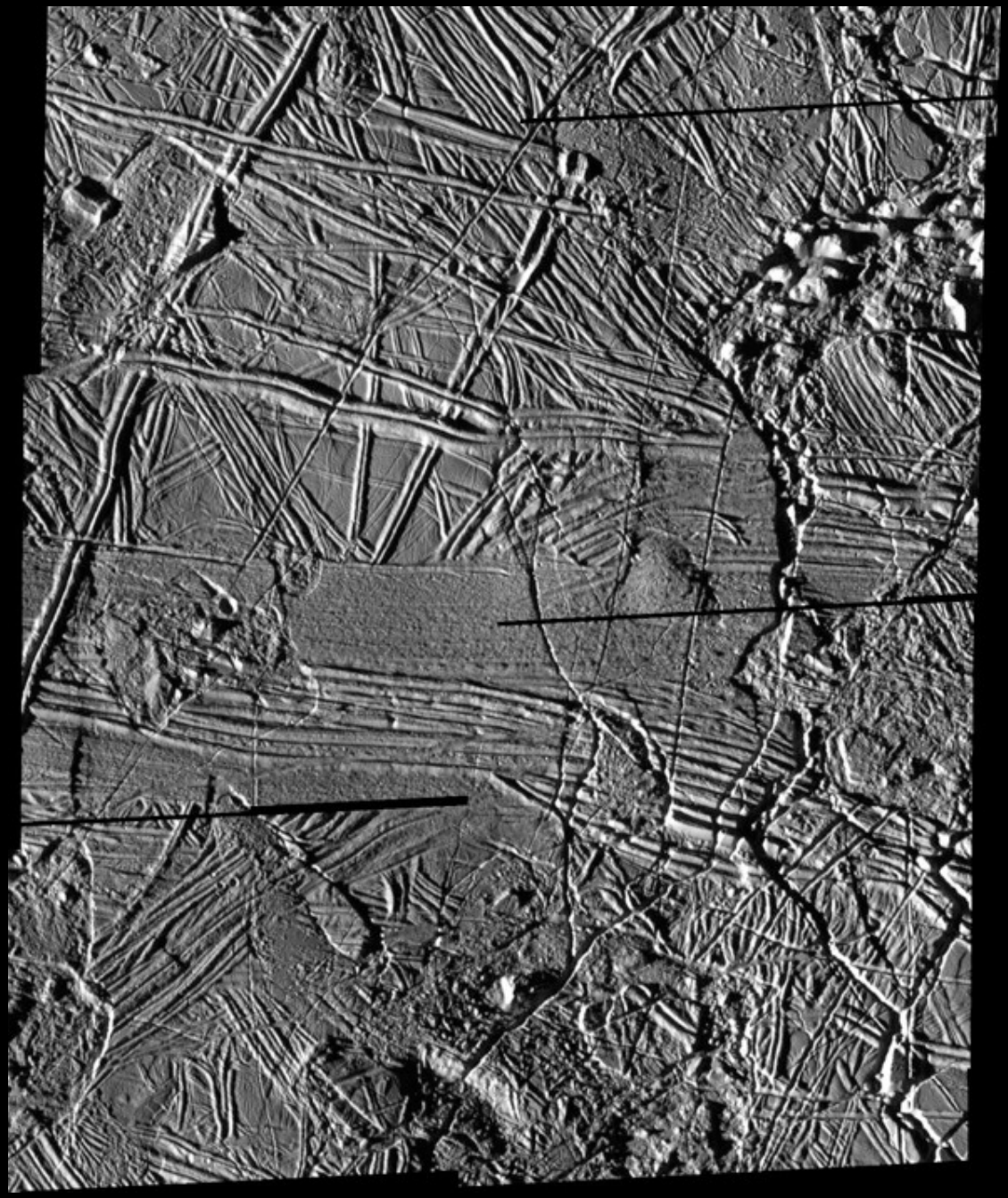
Chemistry: Do red surface deposits tell of habitability below?

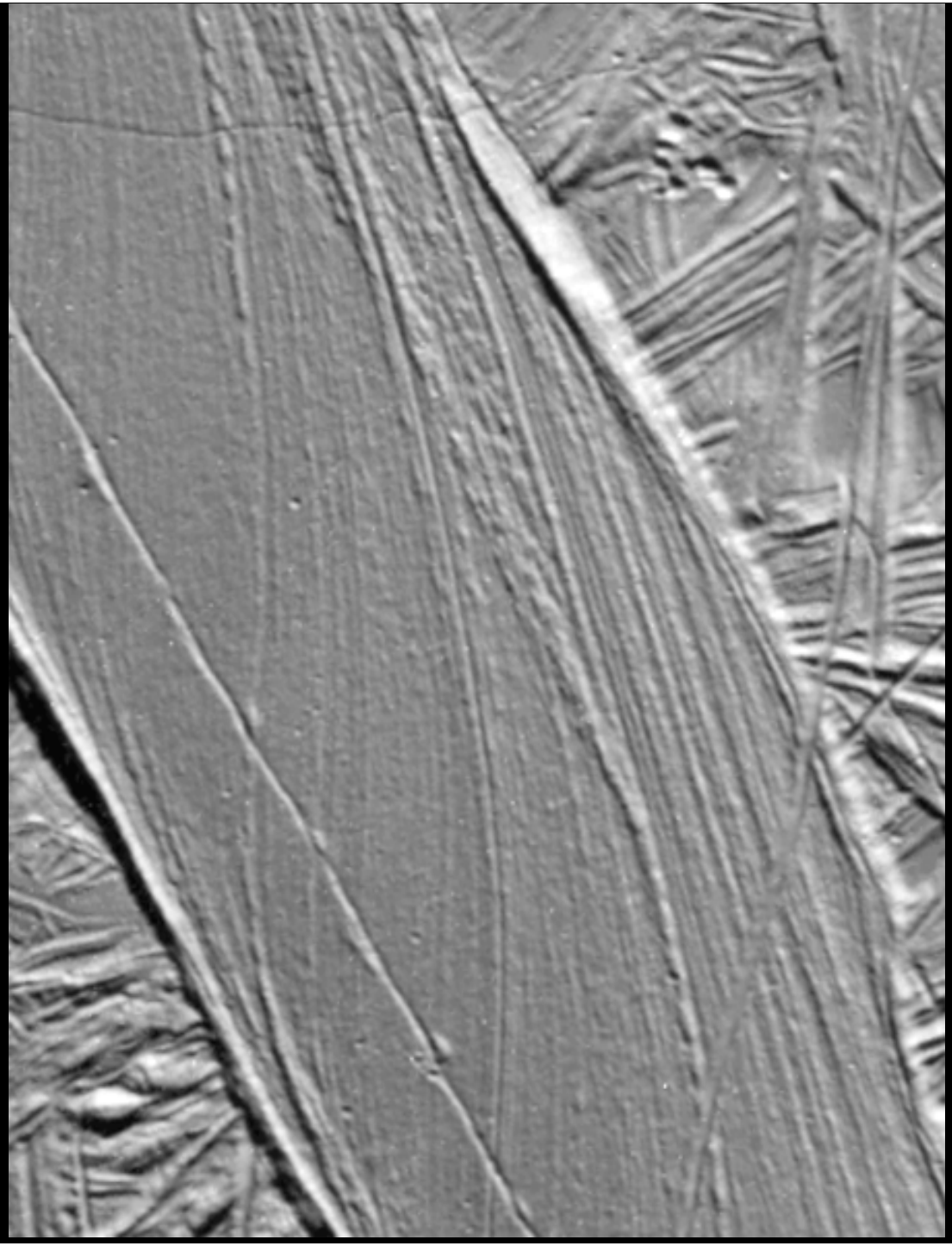
Energy: Can chemical disequilibrium provide energy for life?

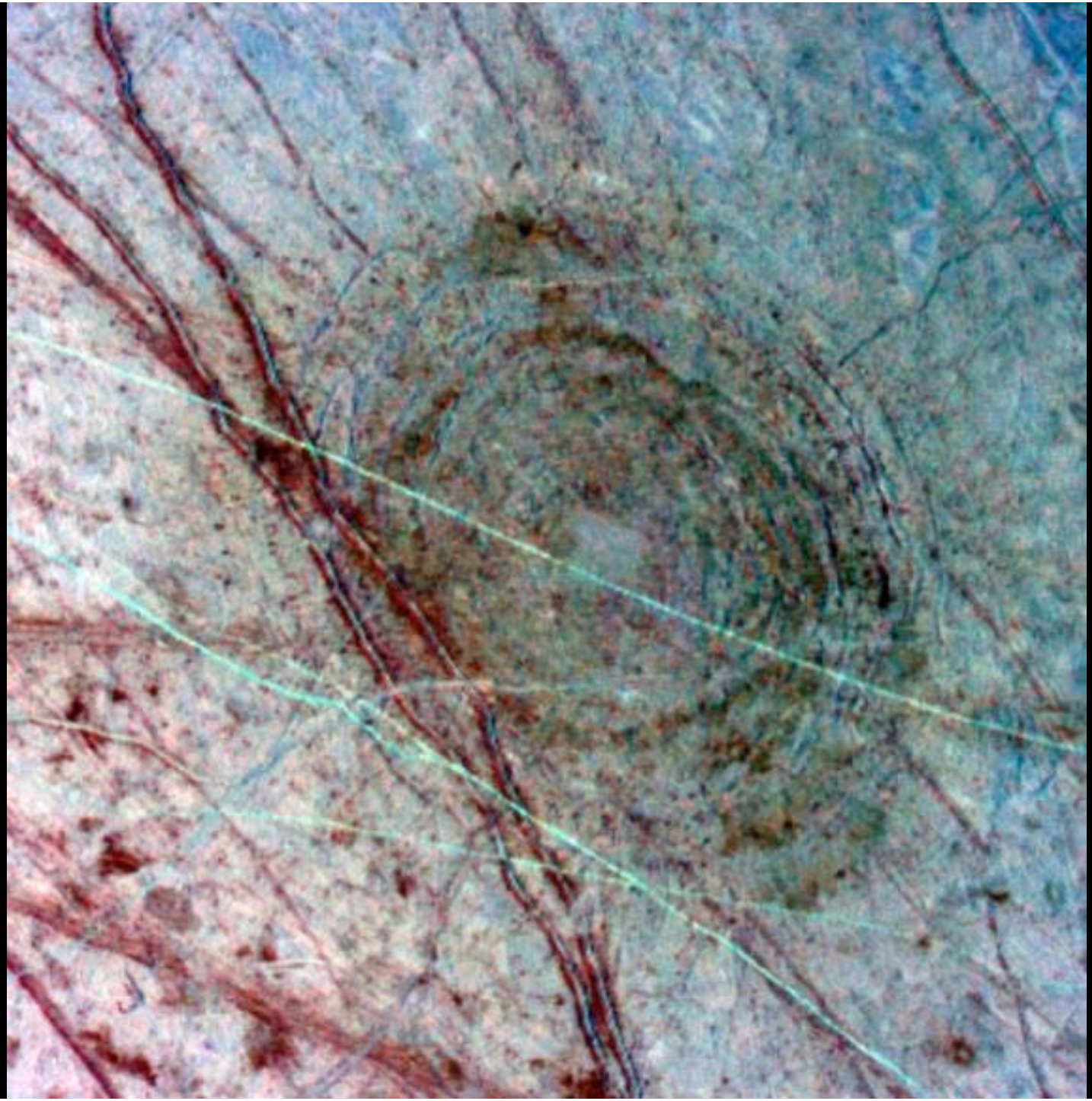
Pre-Decisional — For Planning and Discussion Purposes Only.

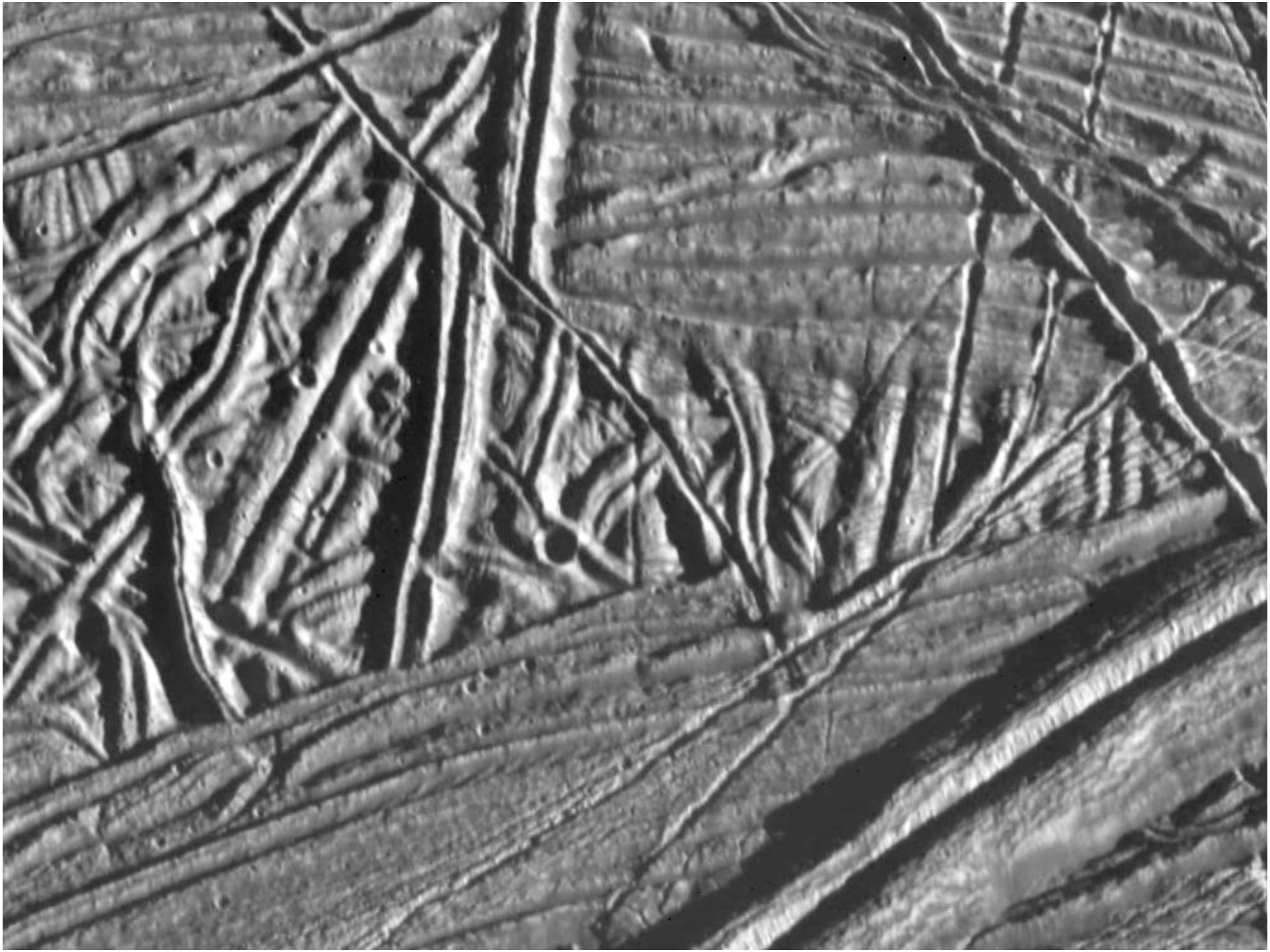


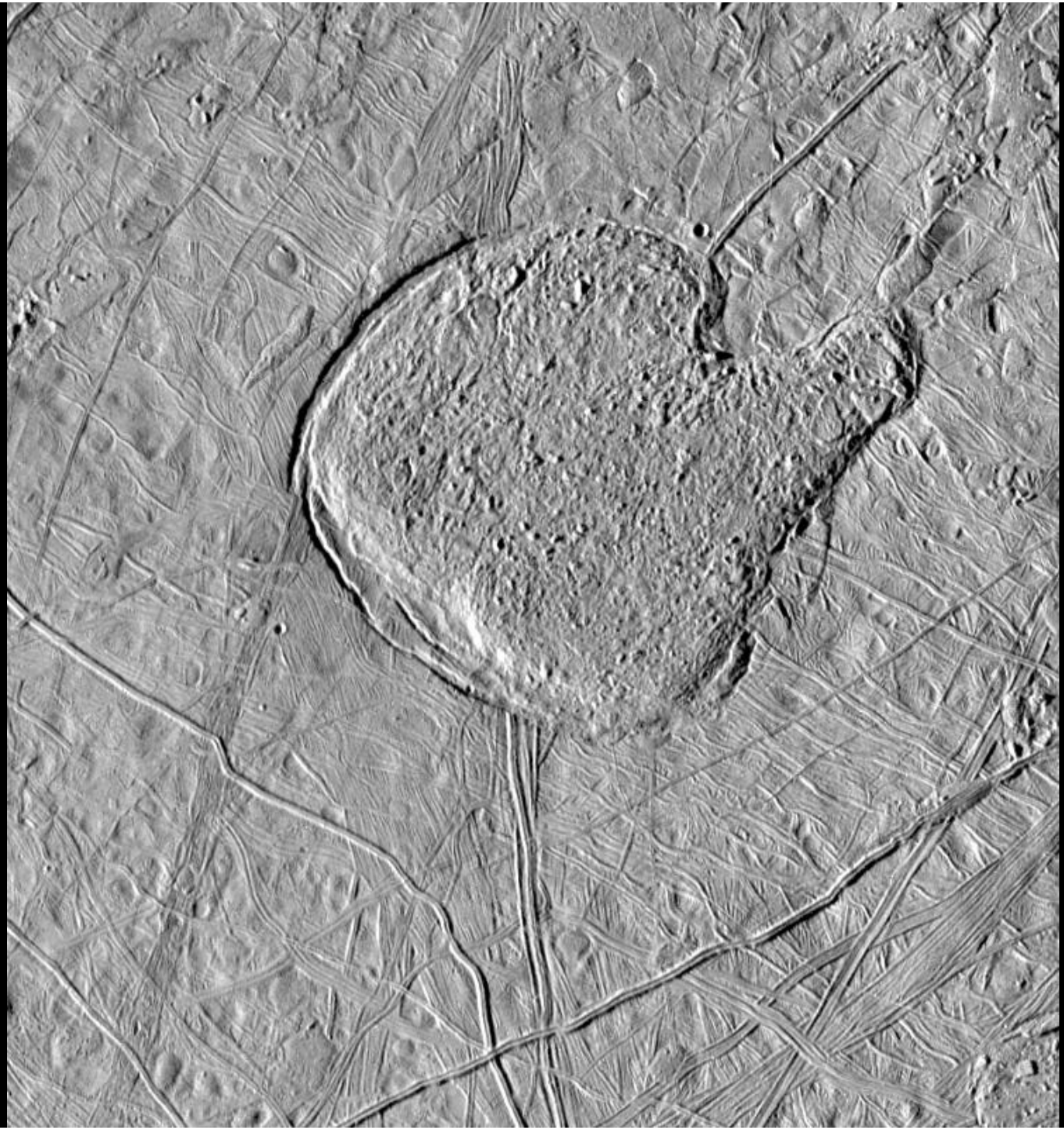


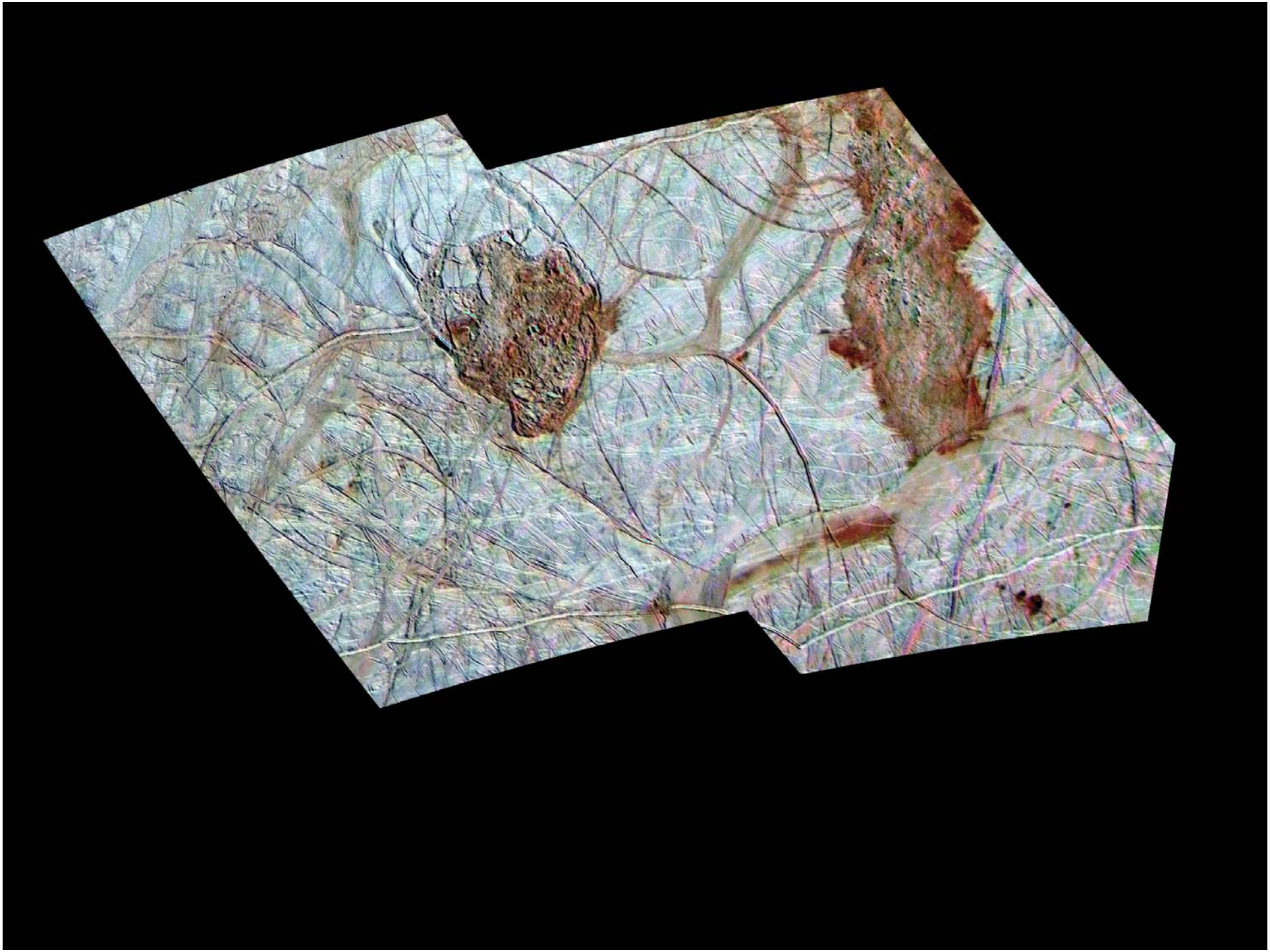


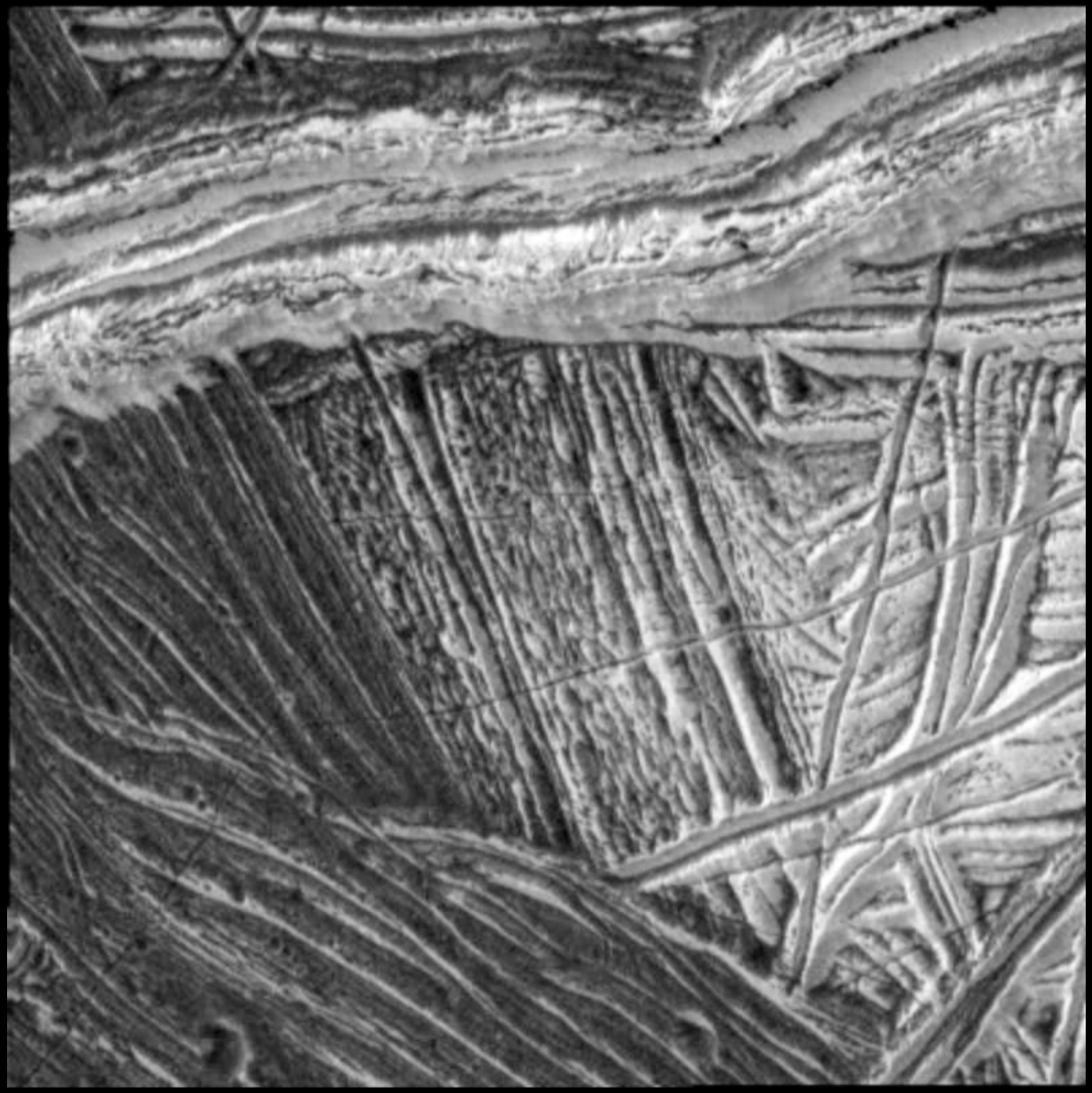


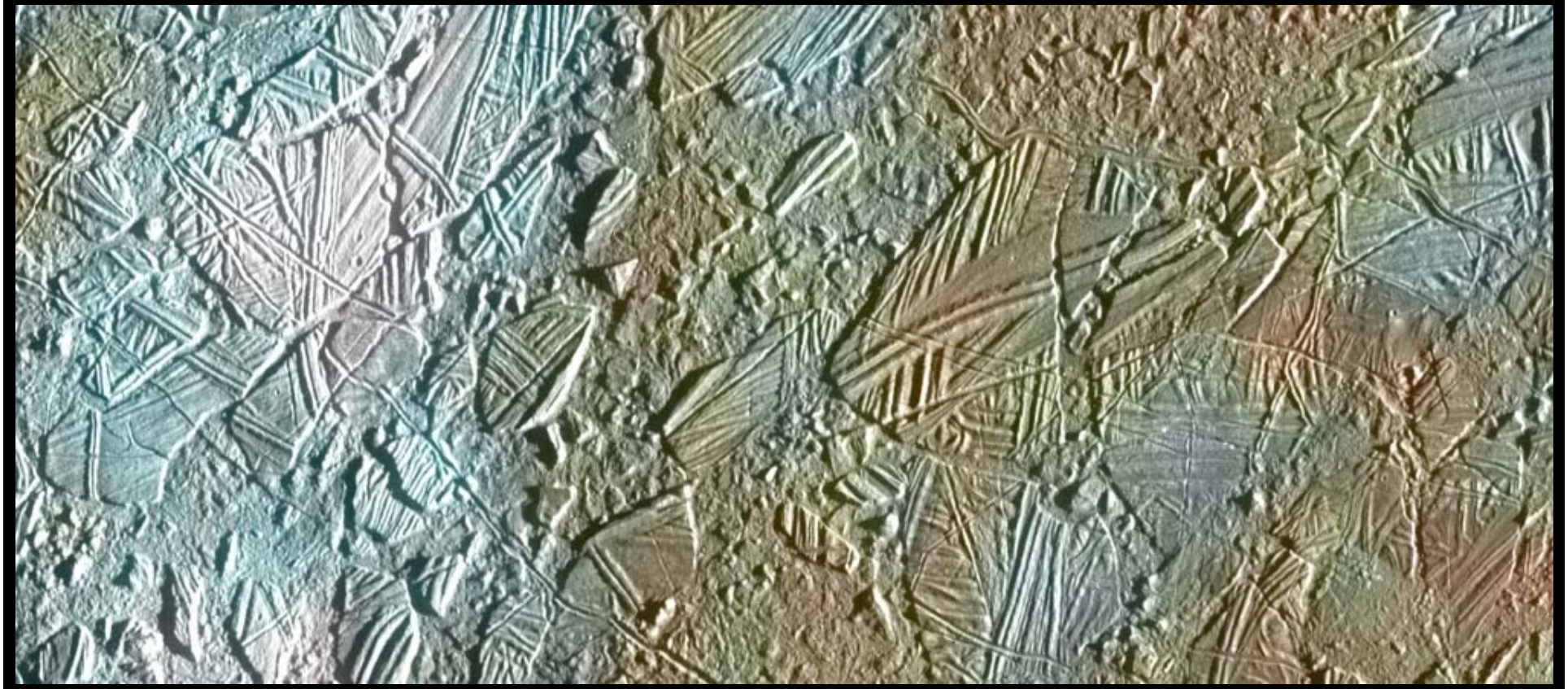




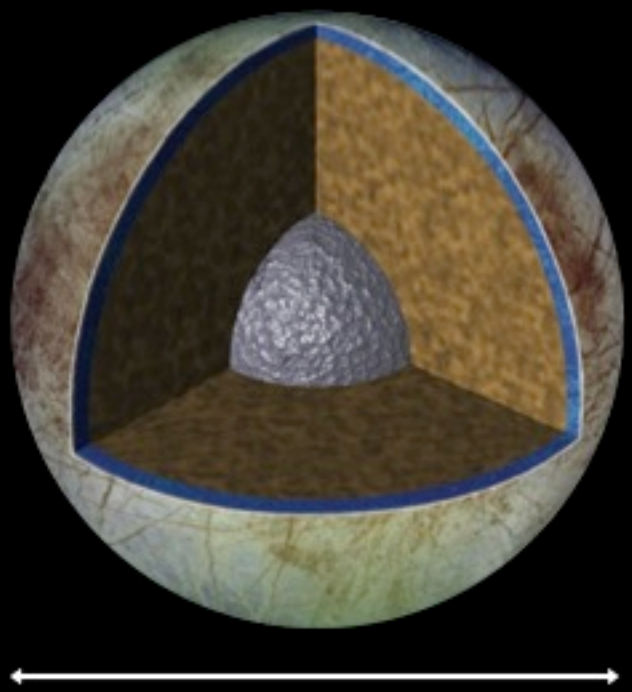








Europa



3120 km

~ a few km across

Hazards of Landing on Europa

Earth glacier surfaces

Europa at 12 m/pixel and 10 m/pixel

1 m/pixel

Devil's Golf Course – Death Valley

Current knowledge cannot exclude the possibility of ubiquitous landing hazards

Surface Temperatures: ~110 ± 25K at Equator to ~50K at the poles
Gravity = 0.13g. Exosphere – no atmosphere. P = 10^{-12} bar

Science Objectives of a Europa Lander

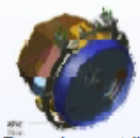
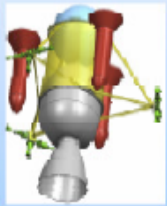
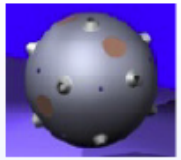
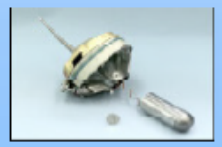
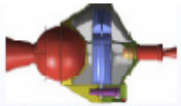
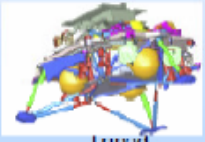
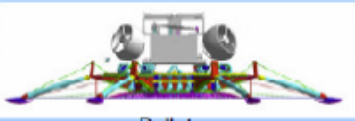
- Explore Europa to investigate its habitability
  - 1) Characterize the chemistry of the non-ice material on Europa's surface, especially as relates to habitability and biosignatures.
  - 2) Assess the regional and local geology to advance our understanding of the relationship of Europa's ocean with the overlying ice shell.
  - 3) Measure tectonic activity within the ice shell over a Europan day to determine if Europa is geologically active in the modern epoch.

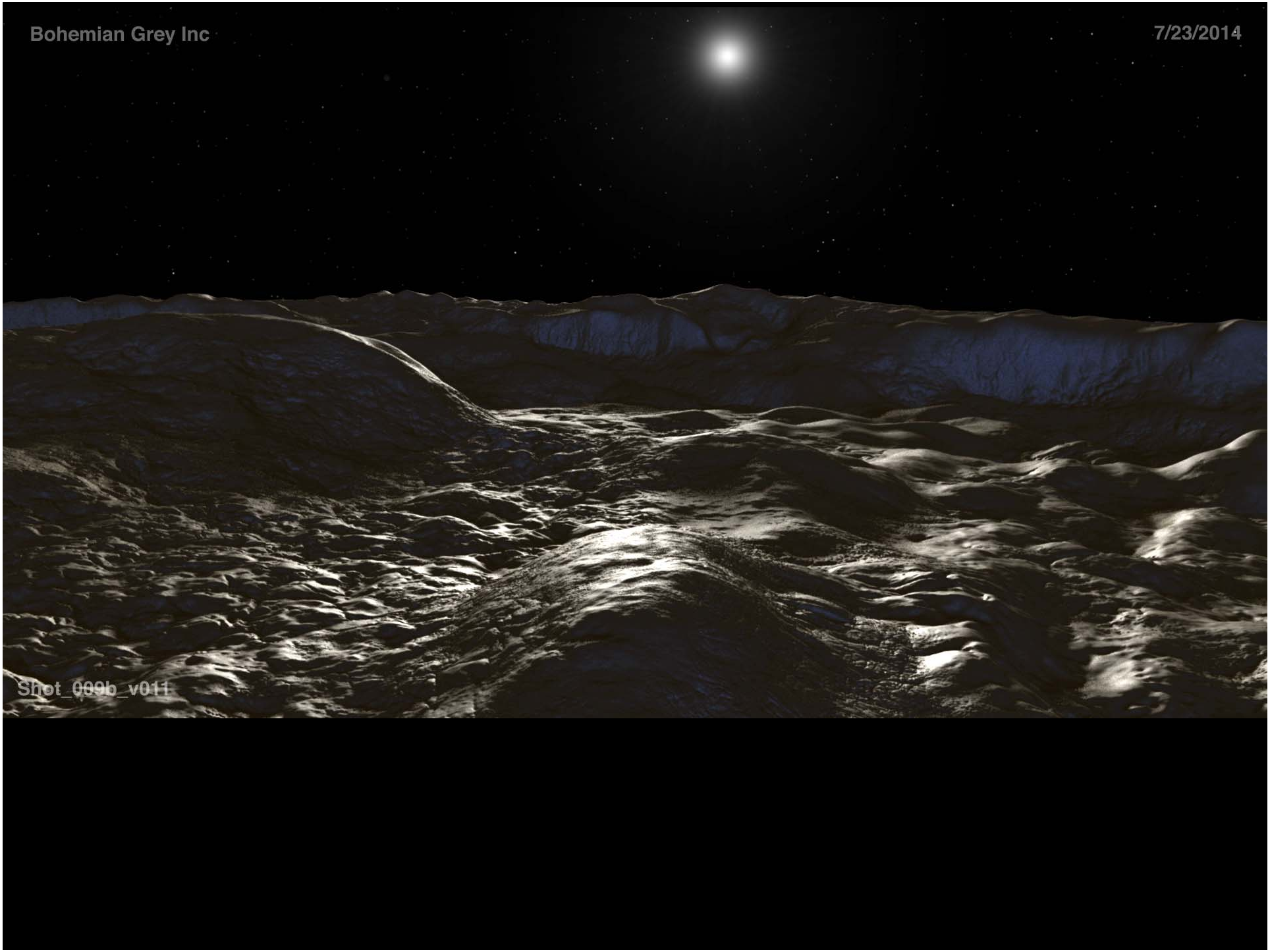
- These objectives map directly to critical questions identified for the exploration of Planetary Habitats by the *Vision and Voyages for Planetary Science (2013-2022)* report:
  - What were the primordial sources of organic matter and where does organic synthesis continue today?
  - Beyond Earth, are there today, elsewhere in the solar system habitats with necessary conditions, organic matter, water, energy, and nutrients to sustain life, **and do organisms live there now?**

Example of a Science Traceability Matrix

GOAL	Science Objective	Science Investigation	Notional Instrument(s)
Explore Europa to Investigate its habitability	Determine surface composition and chemistry, especially as related to habitability	Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis in indicators of habitability and potential biosignatures.	Mass spectrometer with m/z 1-550 [NMS, SAM, Huygens] Microscopic imager
	Determine if Europa is geologically active in the modern epoch.	Measure tectonic activity and surface motion within the ice shell over a europan day and characterize any changes in the ice shell surface.	Seismometer Cameras/OpNav
	Assess the regional and local geology to advance our understanding of the relationship of Europa's ocean with the overlying ice shell.	Constrain regional surface ages and investigate processes of erosion and deposition, and their effects on the physical properties of the surface.	Cameras/OpNav

Europa Lander Concepts Studied over Last Decade

	Kinetic Impactor	Very High G Probes	High G Probes	Rough Landing Probes	Soft Landers
	10,000's m/s	1000's m/s	100's m/s	10's m/s	~1 m/s
G's	N/A	10,000's to 1,000 's	10,000's to 1,000's	100's to 10's	10's
	 Deep Impact like impactor	Deep Impact like impactor  Very High G Penetrators	 High G Omni-Directional Lander Rough Lander High G Penetrators  DS-2 Style High G	 Airbags Rough Lander Symmetric Multi-Probe Rough Lander w Multi-Probes	Skycrane  Tripod  Pallet Soft Multi-Probe


Bohemian Grey Inc
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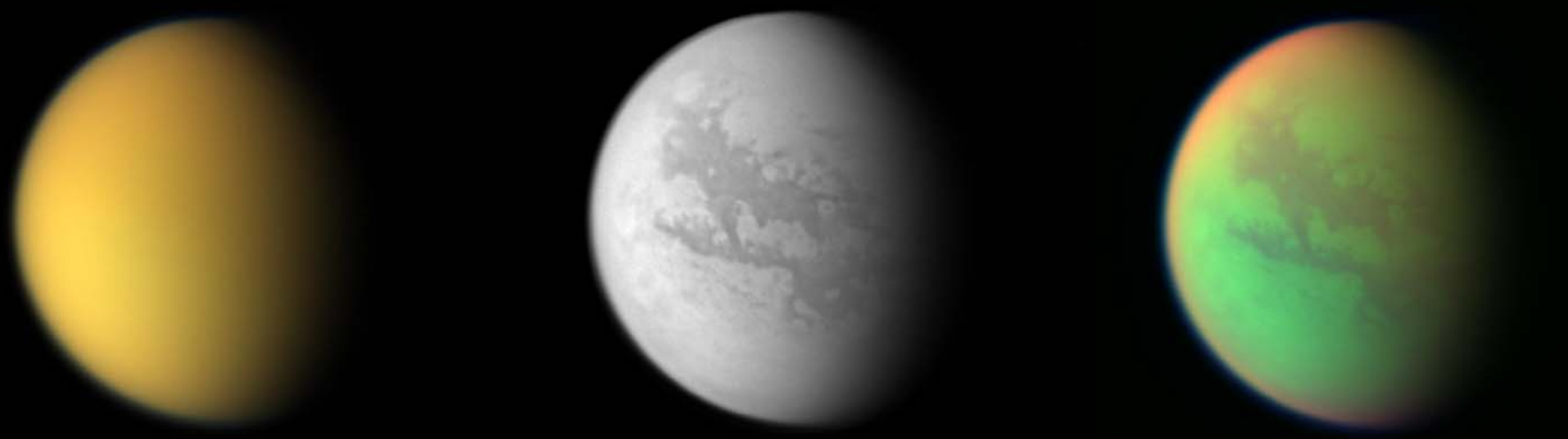
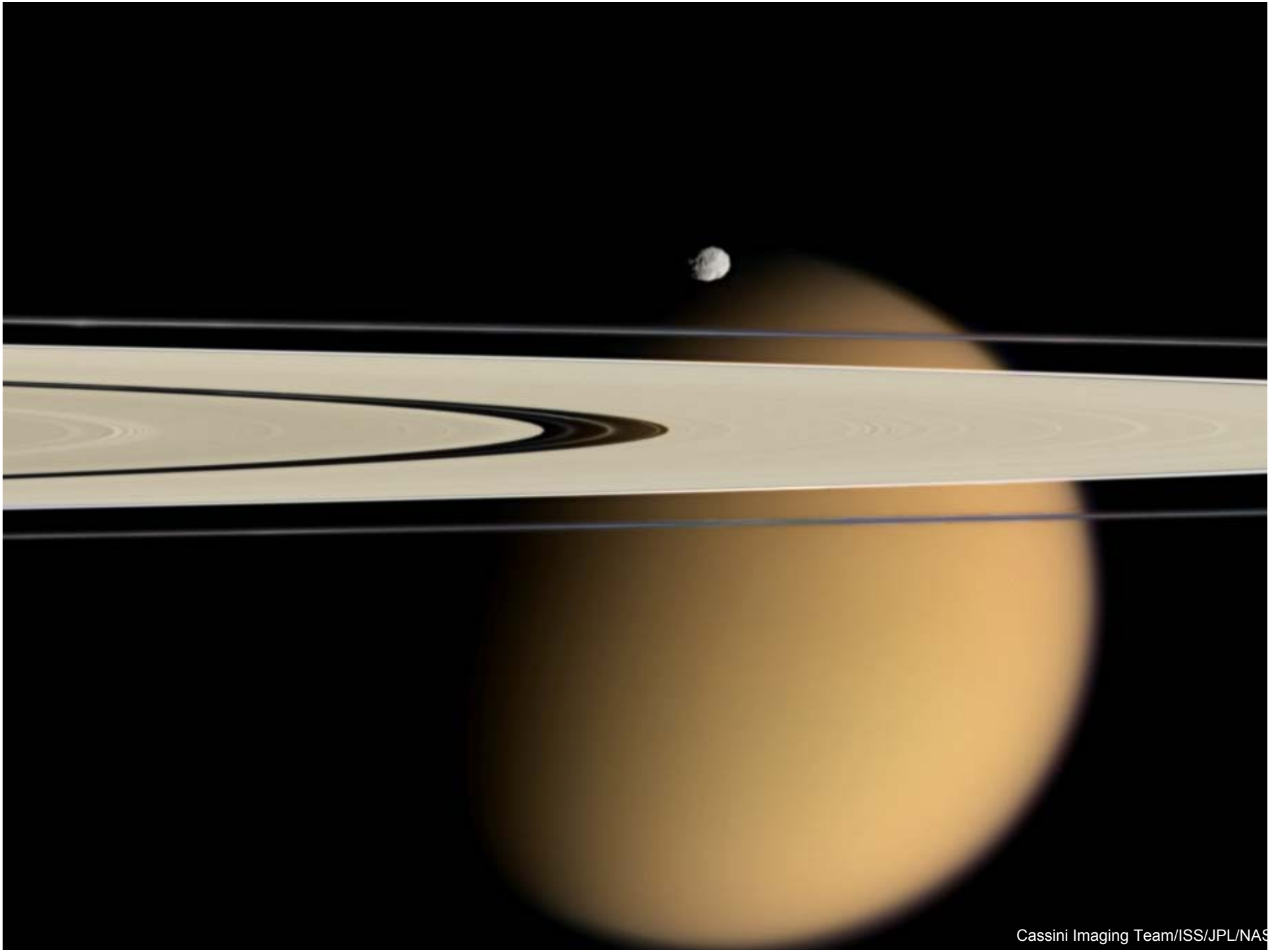
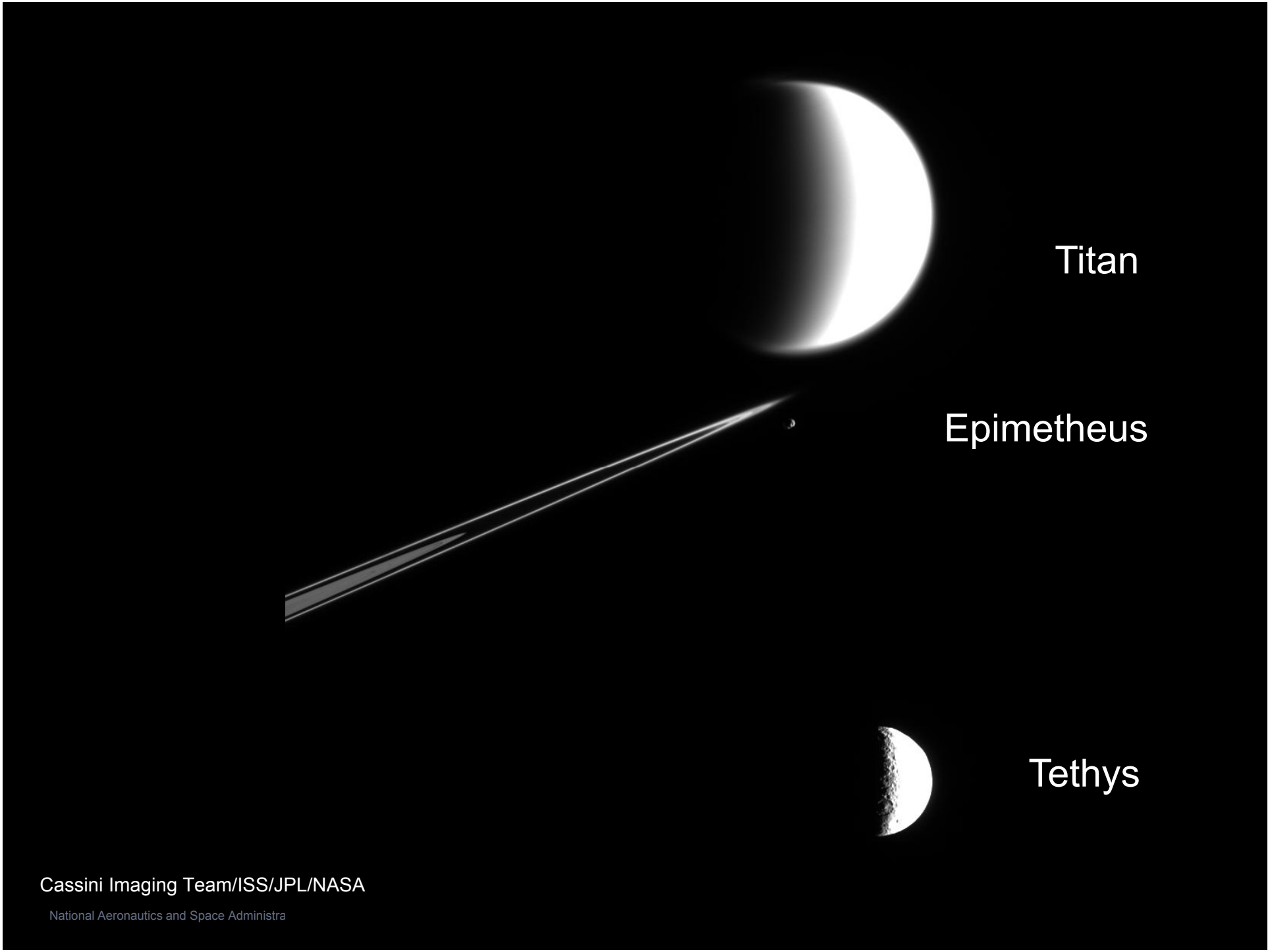
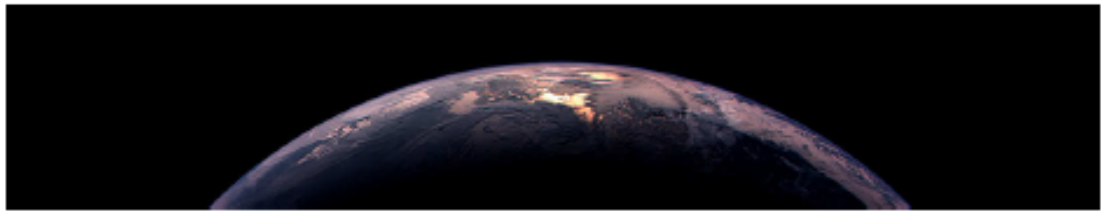
Titan, the enigmatic moon of Saturn



Cassini Imaging Team,/ISS/JPL/NASA


Cassini Imaging Team/ISS/JPL/NAS

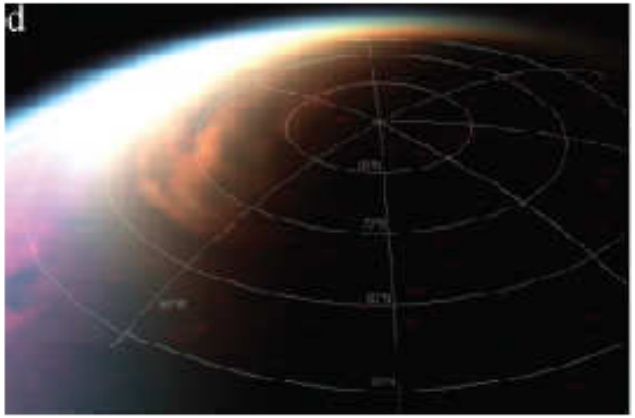

Titan
Epimetheus
Tethys
Cassini Imaging Team/ISS/JPL/NASA
National Aeronautics and Space Administra

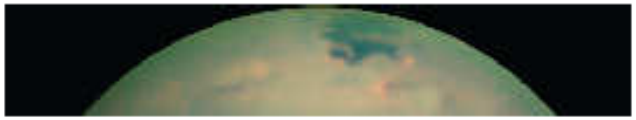


@ ESA 2010 MPS for OSIRIS Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

Specular reflection on Titan (left) and Earth (right)

Spring comes to Titan: Glimmer from a Distant Pool



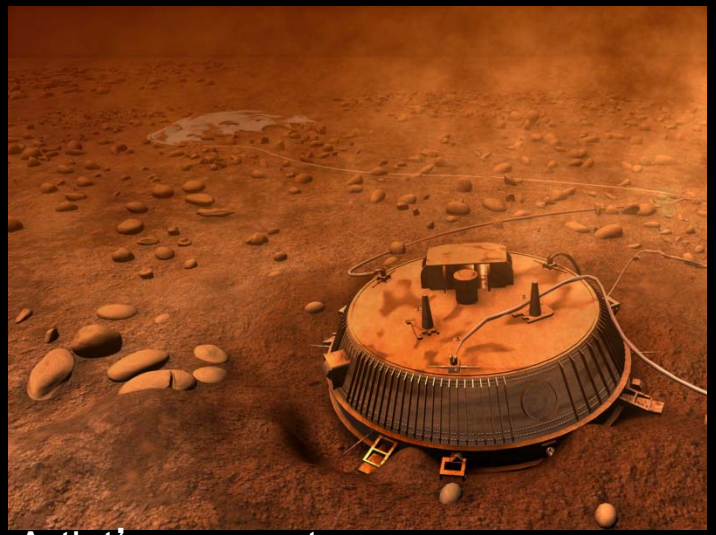


Top: Titan polar hood in winter vanishes during the spring revealing Kraken Mare and other lakes.

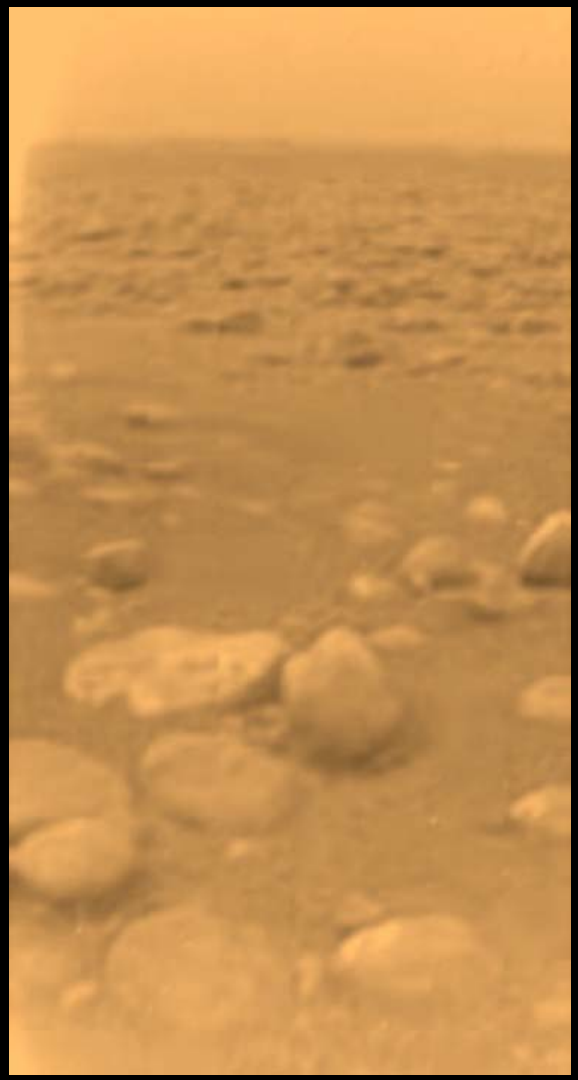
Left: A clear day on Titan: April 5, 2010. It is the beginning of spring and not a single cloud to mask the surface.

Huygens Probe

- Landed January 14, 2005
- On what appears to be a flood plain saturated in methane
- surface T= 93.6 K
- fluvial ice "rocks"



Artist's concept



Actual image from lander

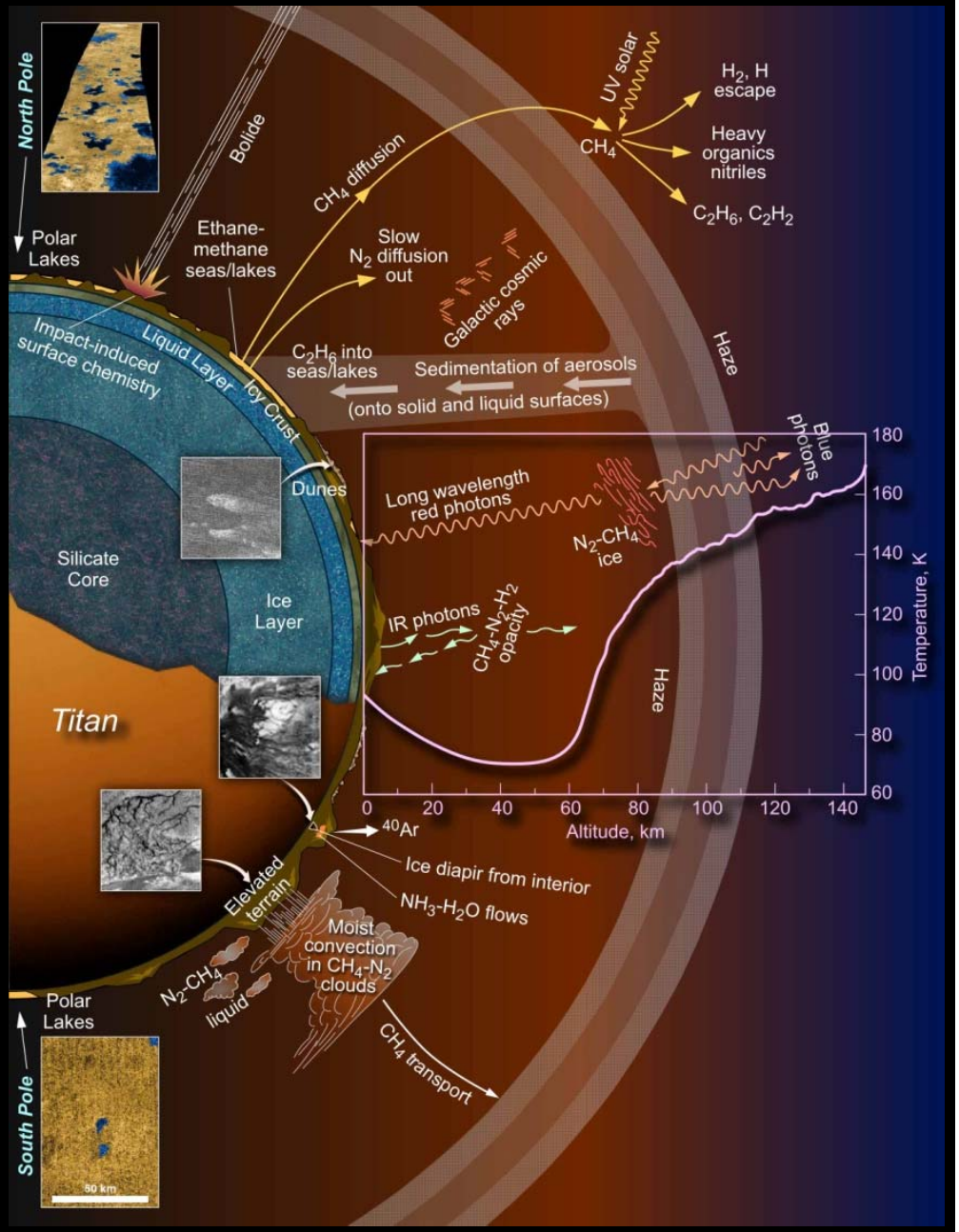
Titan's Properties

- A natural satellite of Saturn, discovered in 1655 by Dutch scientist Christian Huygens
- Atmosphere discovered by Gerard Kuiper in 1943.
- The second largest moon in the solar system
- One of 3 moons with bulk densities of 1.8 g/cm^3, and radii ~ 2500 km (Ganymede, Callisto, and Titan)

- One of 6 moons with roughly the same mass of silicates (Moon, Io, Europa, Ganymede, Callisto, Titan)

Titan looks a lot like Earth but…

- 10x farther from the Sun than the Earth
- N_2 dominates the atmosphere, CH_4 is the second most abundant gas
- 94 K surface temperature & ~70 K at 50 km, so that methane condenses out in the troposphere.
- No O_2. Only ~10 ppm CO
- Upper atmosphere bathed in UV and particle radiation; surface is very well shielded
- Methane in the stratosphere is broken apart by ultraviolet photons from the Sun; makes C2 & higher hydrocarbons
- Position in Saturnian system important
- Contributions from the rings to the upper atmosphere chemistry



Like Earth… only colder

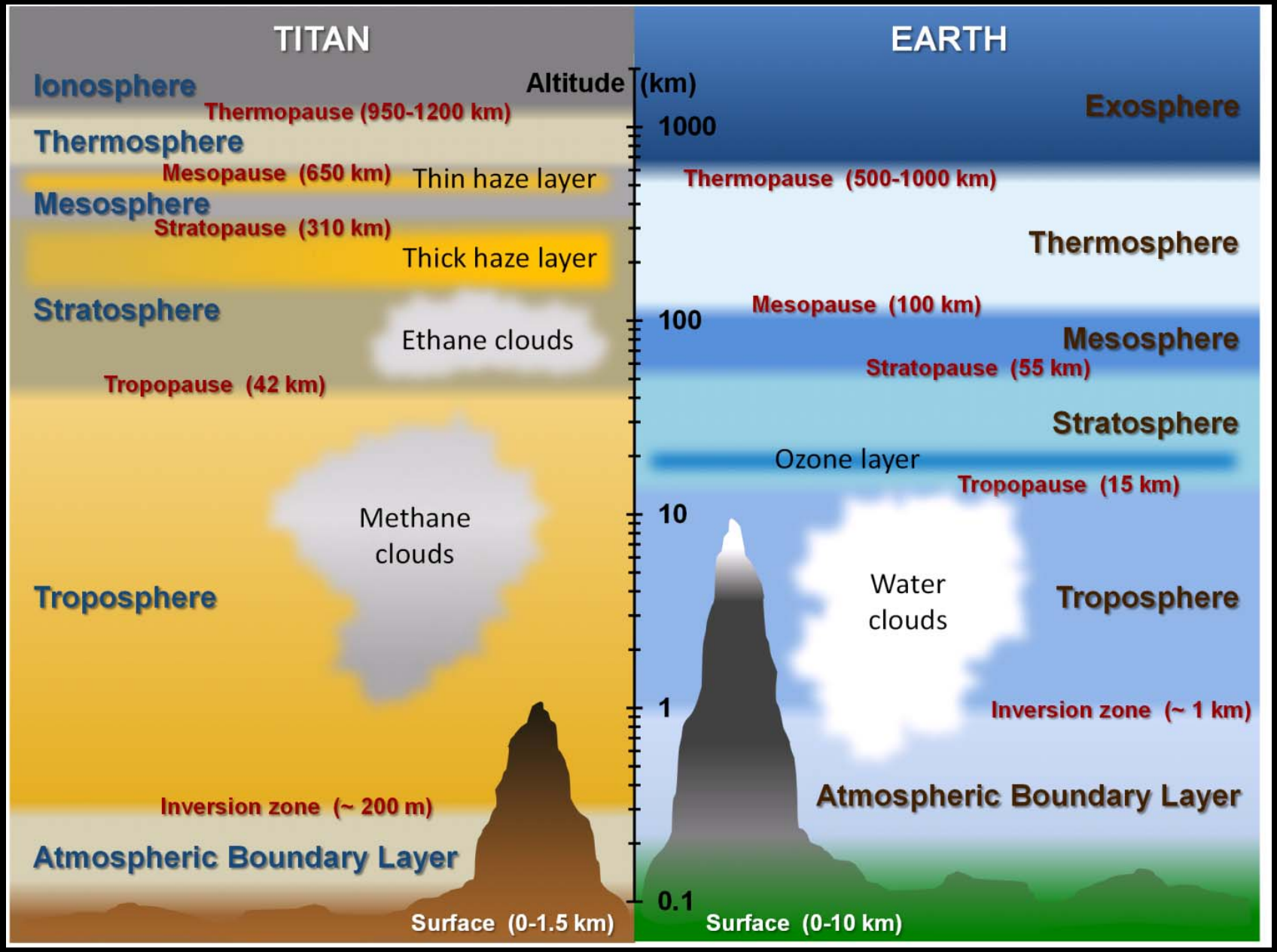
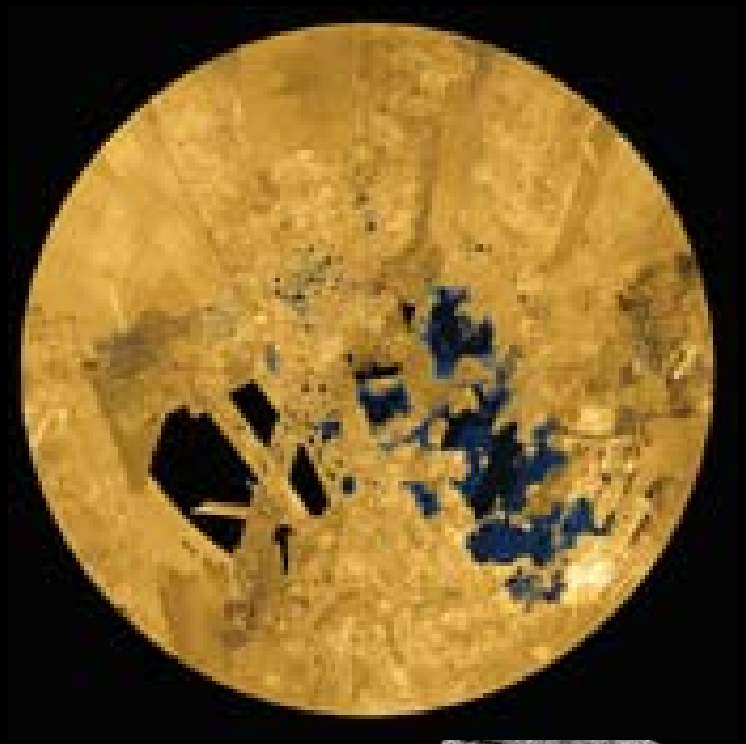
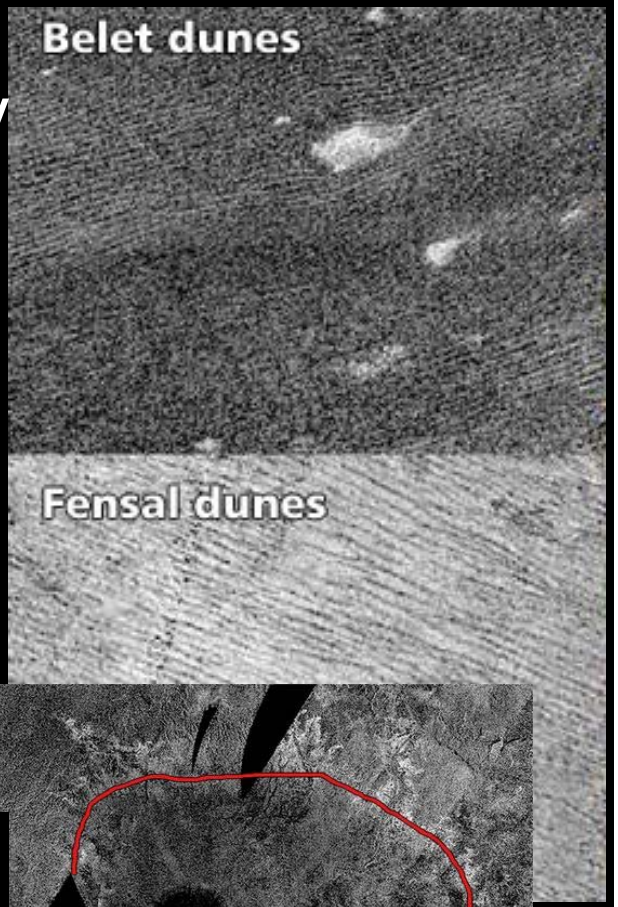
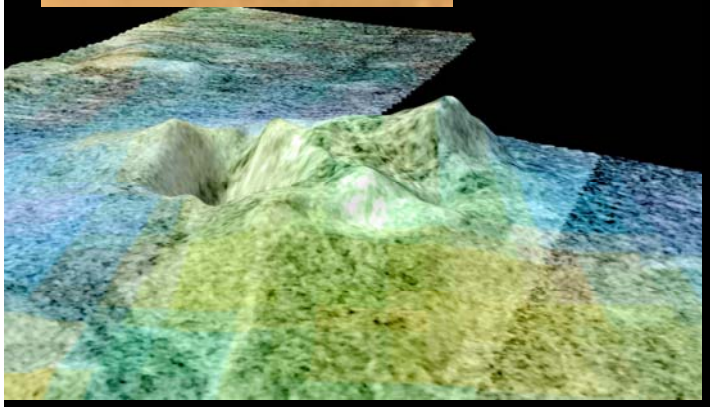


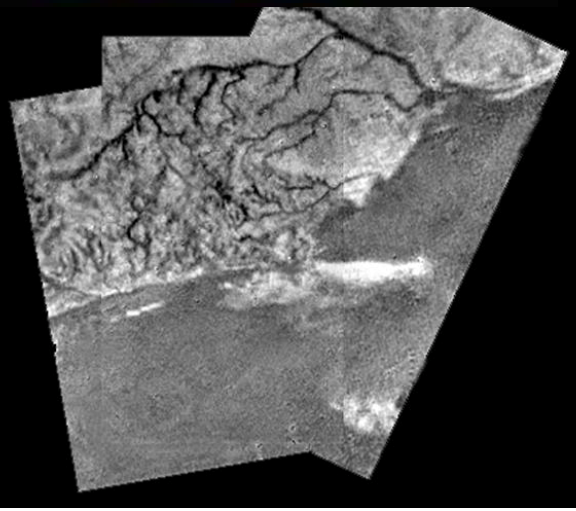
Figure adapted from R. Lorenz and C. Sotin, 2010, Scientific American, 302 (3), 36-43.

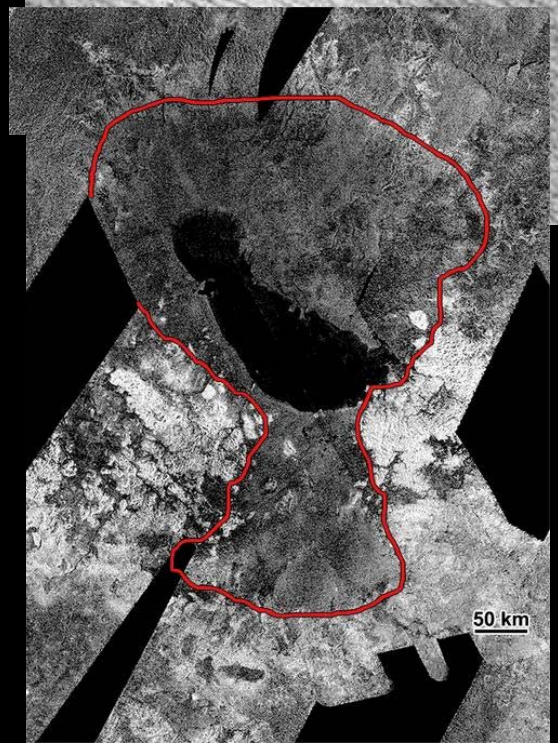
Titan's surface: Radar and Huygen's images show a widely diverse geology











Titan Lander Mission Studies

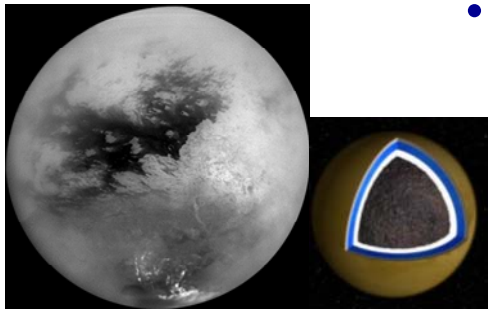
Many Titan studies over a the last 15 years *e.g.*

- 2007 Titan Explorer
- 2011 Titan Saturn System Mission
- 2013 TiME – Ellen Stofan, PI
- Ongoing research based on Cassini data
- Laboratory data from the NAI "Titan as a Prebiotic Chemical System"
- NIAC– Titan submersible– Ralph Lorenz, PI
- NIAC – Titan rotorcraft – Larry Mathies, PI

All concepts target either the lakes and/or circumnavigating with a balloon.

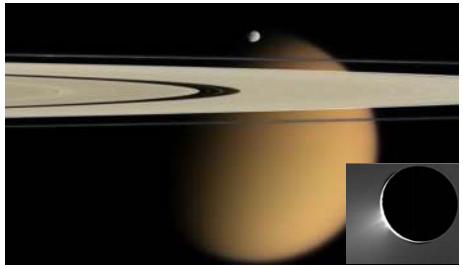
Recent work has looked at lake submersibles and rotorcraft (to aid exploration from either a lander or balloon)

A proposed flagship mission concept derives from science goals that address a wide range of planetary science



- **Goal A**: Explore Titan, an Earth-Like System
  - How does Titan function as a system? How are the similarities and differences with Earth, and other solar system bodies, a result of the interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?

- **Goal B**: Examine Titan's Organic Inventory—A Path to Pre-biological Molecules
  - What is the complexity of Titan's organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean and how does this inventory differ from known abiotic organic material in meteorites and therefore contribute to our understanding of the origin of life in the Solar System?



Cassini Imaging Team /ISS/ PL/NASA

Goal C: Explore Enceladus and Saturn's magnetosphere— clues to Titan's origin and evolution

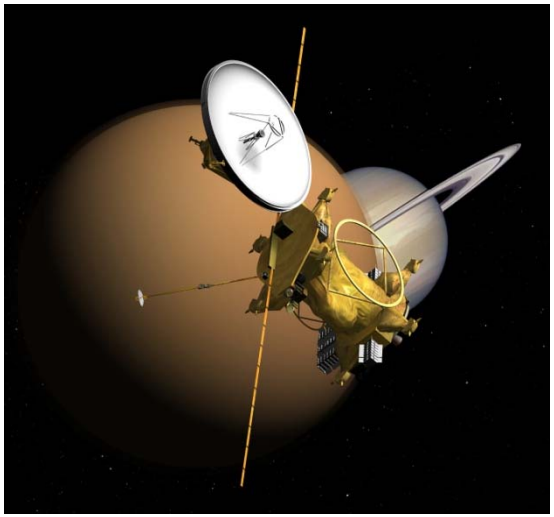
- What is the exchange of energy and material with the Saturn magnetosphere and solar wind? What is the source of geysers on Enceladus? Does complex chemistry occur in the geyser source?

Proposed baseline mission architecture may combine a remote sensing mission with in situ measurements

Combining

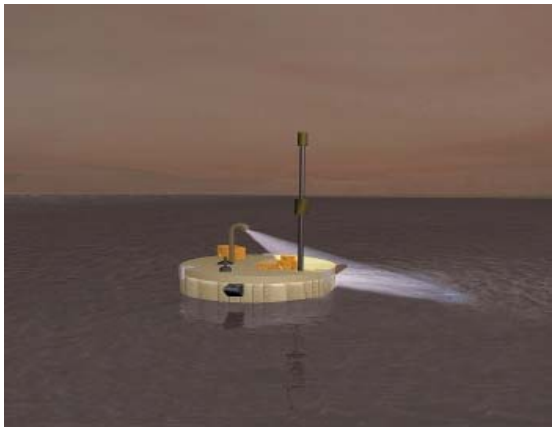
- **An orbiter (first of Saturn, with Enceladus flybys, then dedicated to Titan),**
- **A hot-air balloon**
- **A North-pole lake-landing probe**

Dedicated Titan Orbiter would also be used for relay



A balloon would float at 10 km above the surface around the equator with some altitude control

A short-lived probe/lander with chemical analysis package would land in a northern lake



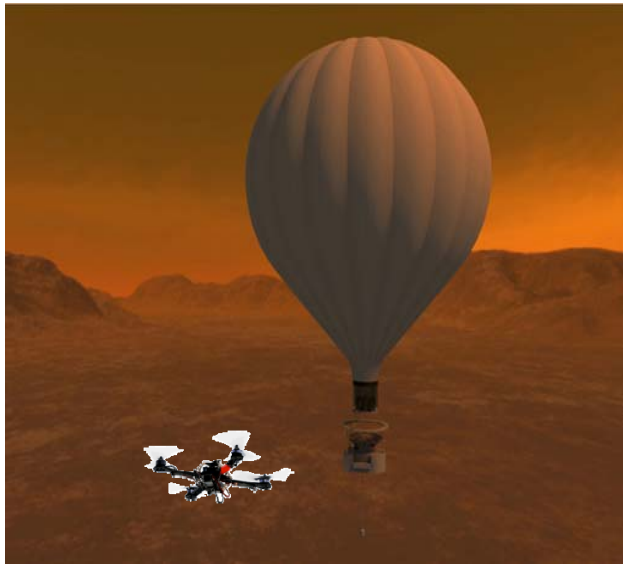
Conceptual designs
Artist's concepts NASA/JPL

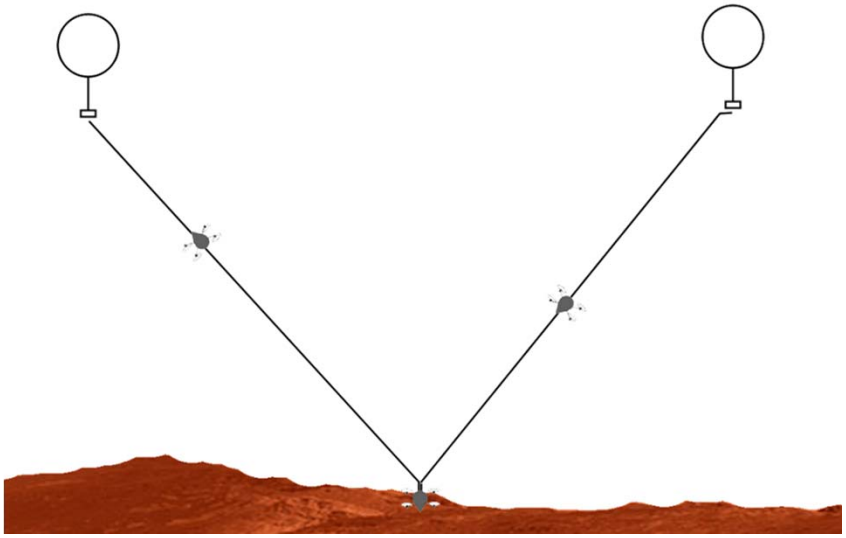
Primary In situ Science Objectives

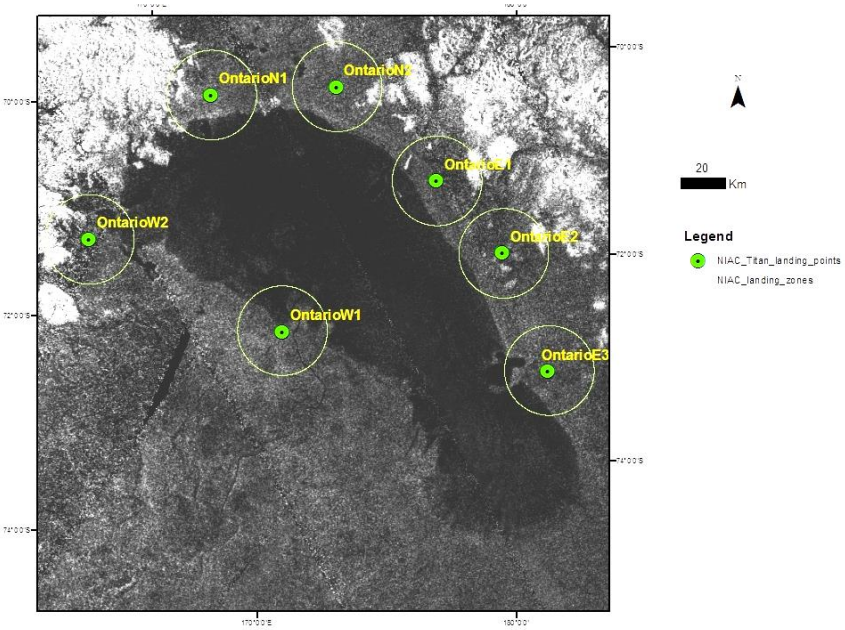
New astrobiological insights would be delivered through balloon and lander investigations.

- Perform chemical analysis, both in the atmosphere and in the liquid of the lake, the latter to determine the kinds of chemical species that accumulate on the surface, to describe how far such complex reactions have advanced and define the rich inventory of complex organic molecules that are known or suspected to be present at the surface.
- Analyze the composition of the surface, in particular the liquid material and in context, the ice/organics content in the surrounding areas.
- Study the forces that shape Titan's diverse landscape. This objective benefits from detailed investigation at a range of locations, a demanding requirement anywhere else, but that is uniquely straightforward at Titan with balloon high-resolution cameras and subsurface-probing radar.

A valuable addition to Exploring Titan: Miniature Titan Rotorcraft

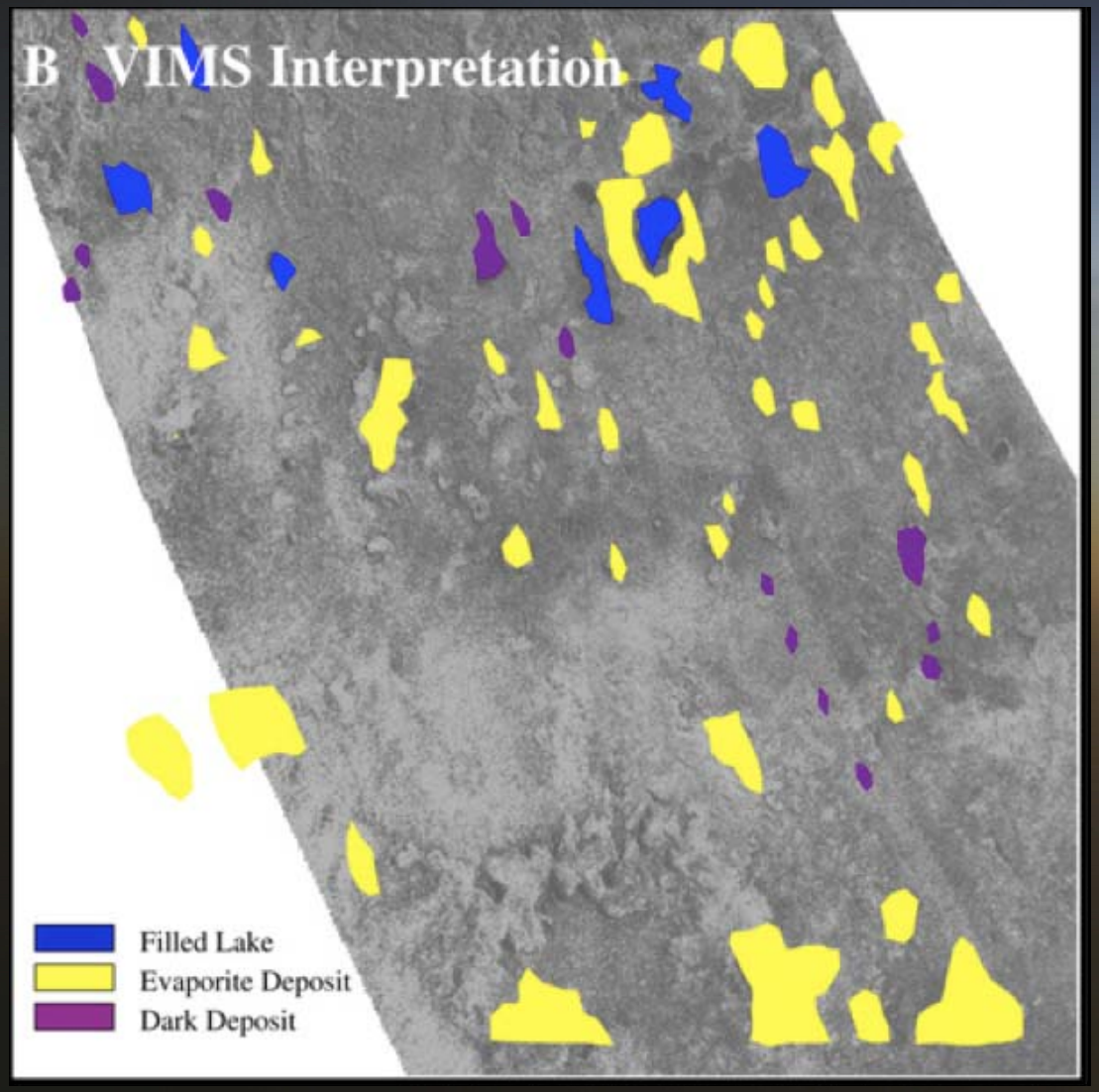






Some recent work on Titan Beaches

Titan lake evaporites should contain benzene.



North polar region, just south of Ligeia Mare (75°N, 135°E)

Barnes J.W. et al., **2011**, *Icarus,* 216, 136-140.

- Benzene solubility in ethane* = 18.5 mg/L
- Lakes saturate from benzene airfall in millions of years

*Malaska and Hodyss 2014, Icarus 242, 74-81.

The Liquid Phase of Titan

- Hydrocarbon Lakes
  - Methane
  - Ethane
  - Propane
- Dissolved organics
  - Hydrogen cyanide
  - Acetylene
  - Benzene
  - Others…

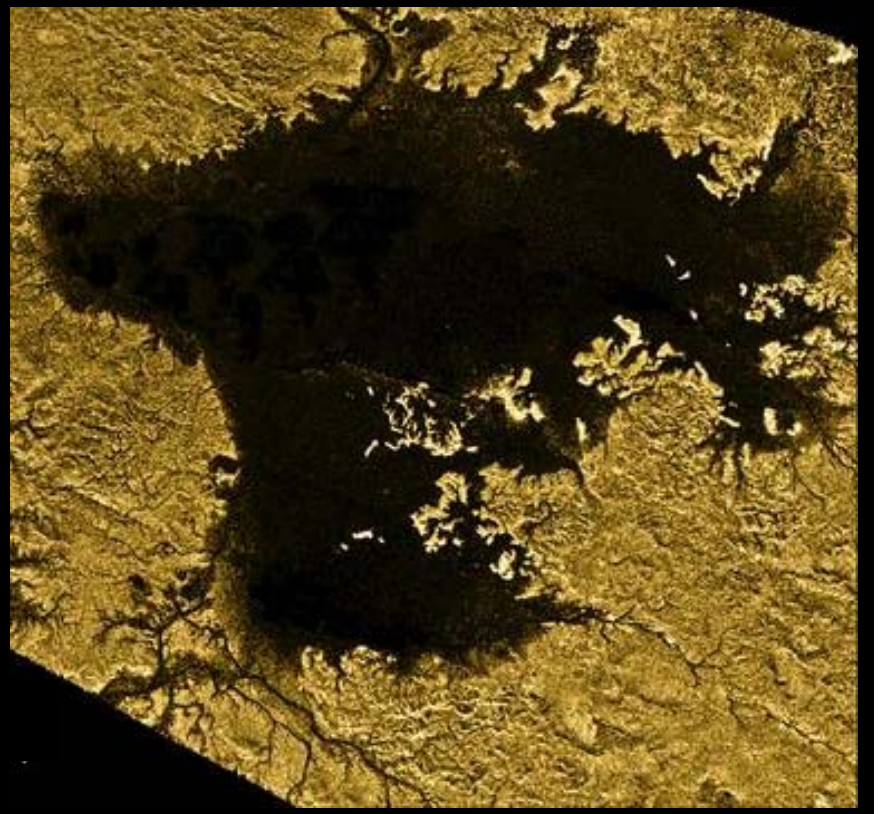


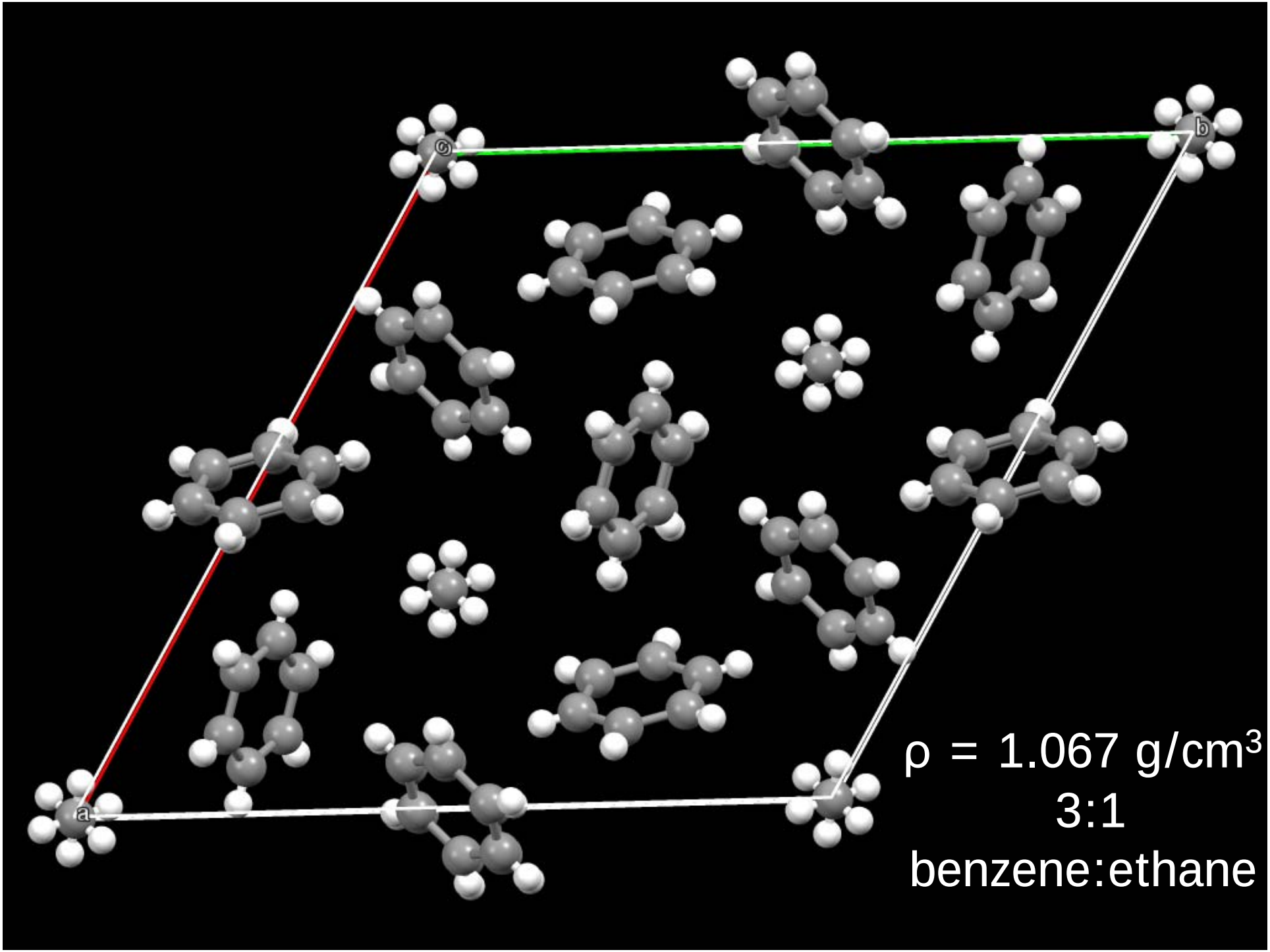
Photo: NASA/JPL/USGS

Modeling suggests that some organic species may be present at or near their saturation levels

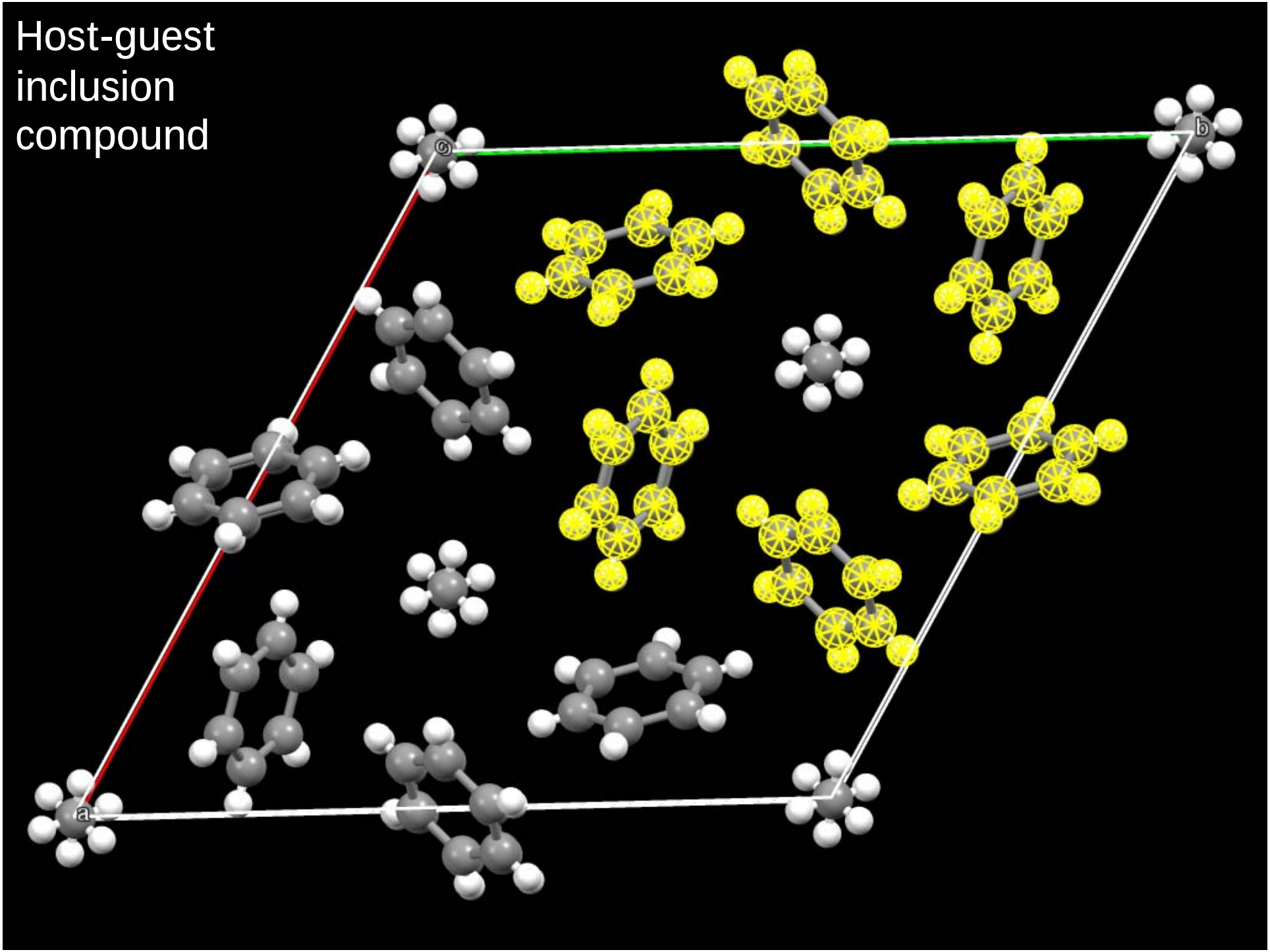
Cordier D. et al., **2009**, *Ap. J.*, 707, L128.

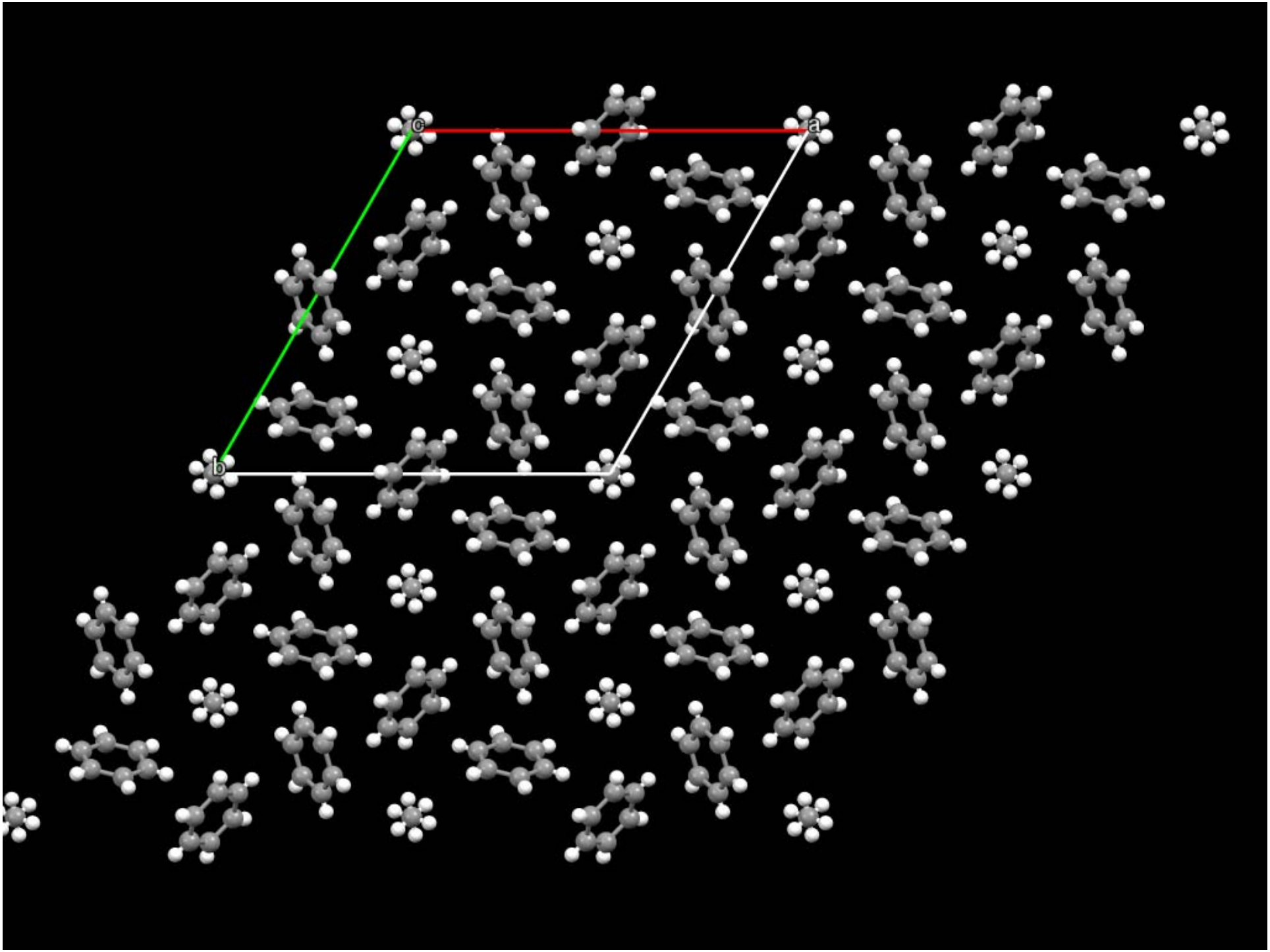
The Benzene-ethane Co-crystal will Form Readily at Titan Surface Conditions.

- Kinetics experiments show rapid formation of the co-crystal at 94 K.
- The co-crystal forms when saturated solutions of benzene in ethane are evaporated.
- The benzene-ethane co-crystal forms when mixtures of methane and ethane are placed in contact with solid benzene. Methane and propane do not form a co-crystal with benzene.

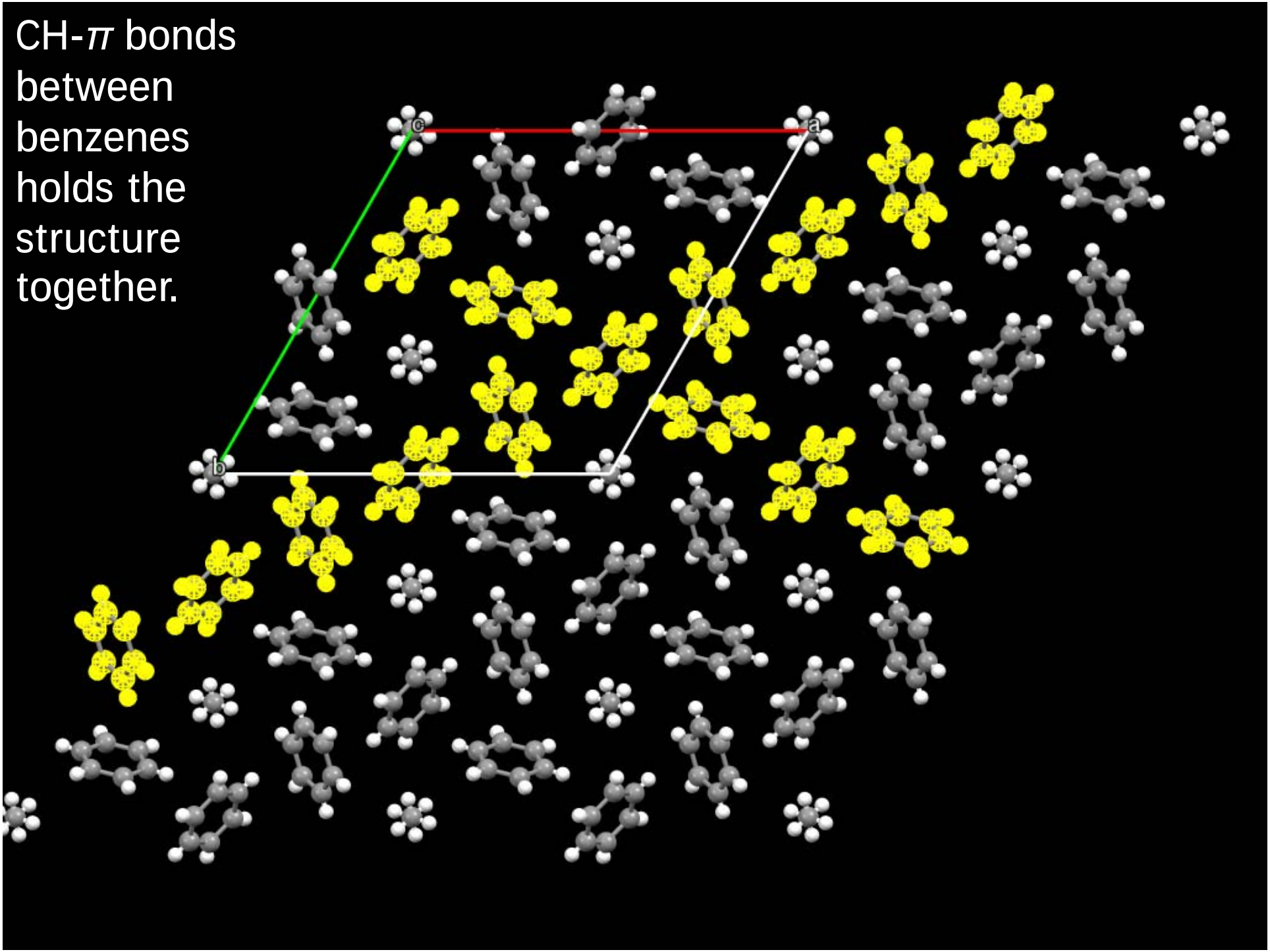

c
b
a
ρ = 1.067 g/cm³
3:1
benzene:ethane

Host-guest inclusion compound



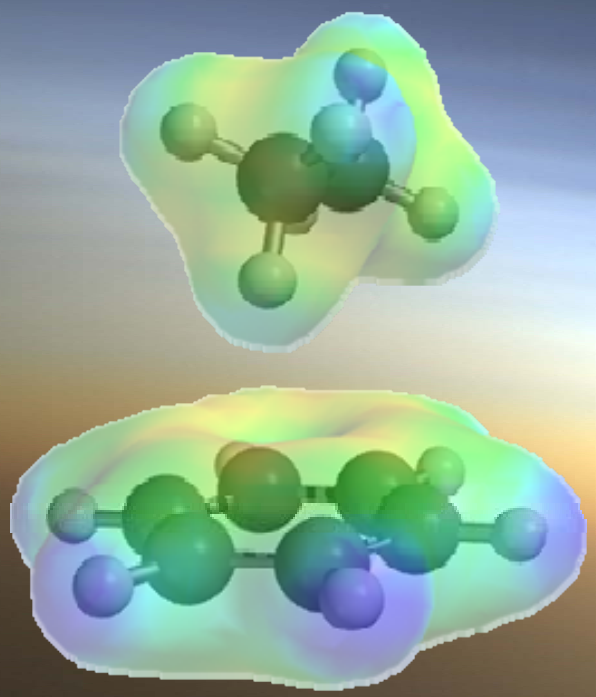

c
a
b

CH-π bonds between benzenes holds the structure together.



So, on the beaches or dry lakes...

- Benzene and ethane readily form a co-crystal at Titan surface temperatures, analogous to hydrated minerals on Earth.
- The co-crystal may be an important form of benzene where benzene and ethane have coexisted, as in evaporate deposits.
- Other important Titan surface (HCN, C_2H_2) materials have the potential to be co-crystal formers.



Summary

- The general *in situ* science objectives of looking for habitable niches are similar for Europa and Titan but the conditions are vastly different.
  - Europa has no atmosphere while Titan has a thick atmosphere with aerosols and complex organic molecules
  - Radiation plays a significant role on Europa's surface while Titan's surface is benign.
  - Chemical analysis of the surface material is a key measurement especially investigating where sub-surface ocean material might have reached the surface
  - Europa measurements would focus on analyzing the 'red stuff' and determine if life could exist in Europa's sub-surface oceans.
  - Titan measurements are likely to reveal the potential for novel and complex chemistry indicative, perhaps, of a prebiotic world.
    - although some NAS scientists feel there is a potential for 'weird' life