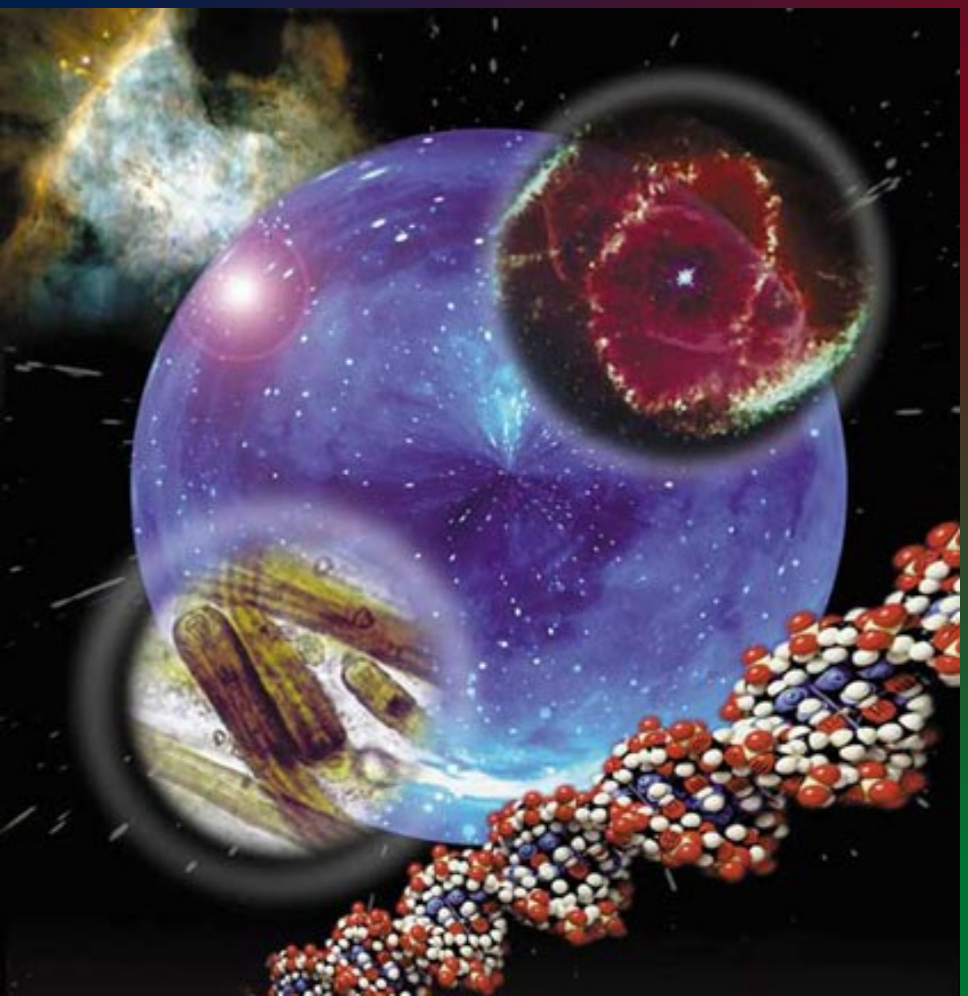
# Astrobiology

## Life in the Universe




***William Welsh***

San Diego State University

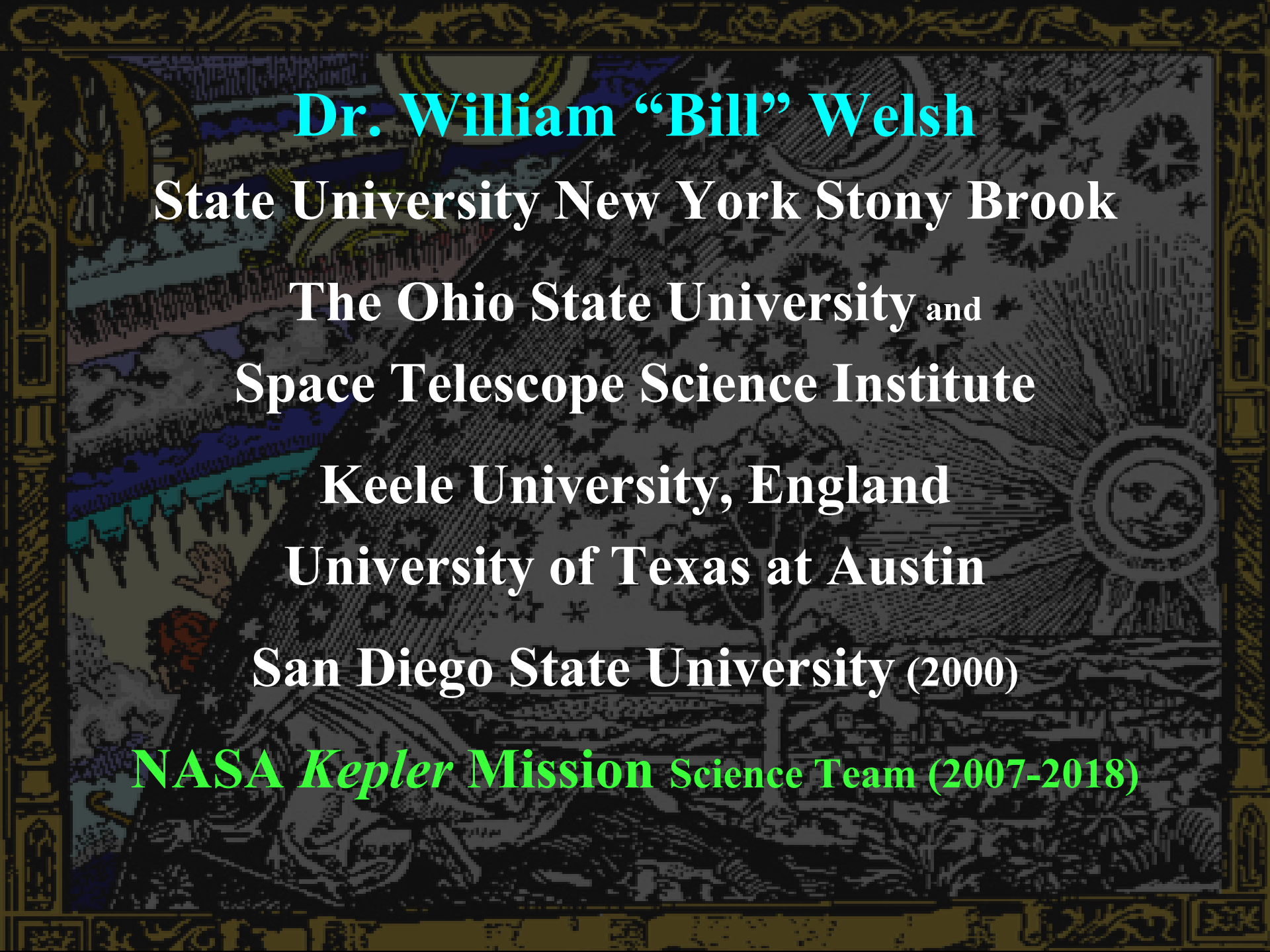

2024 July 25

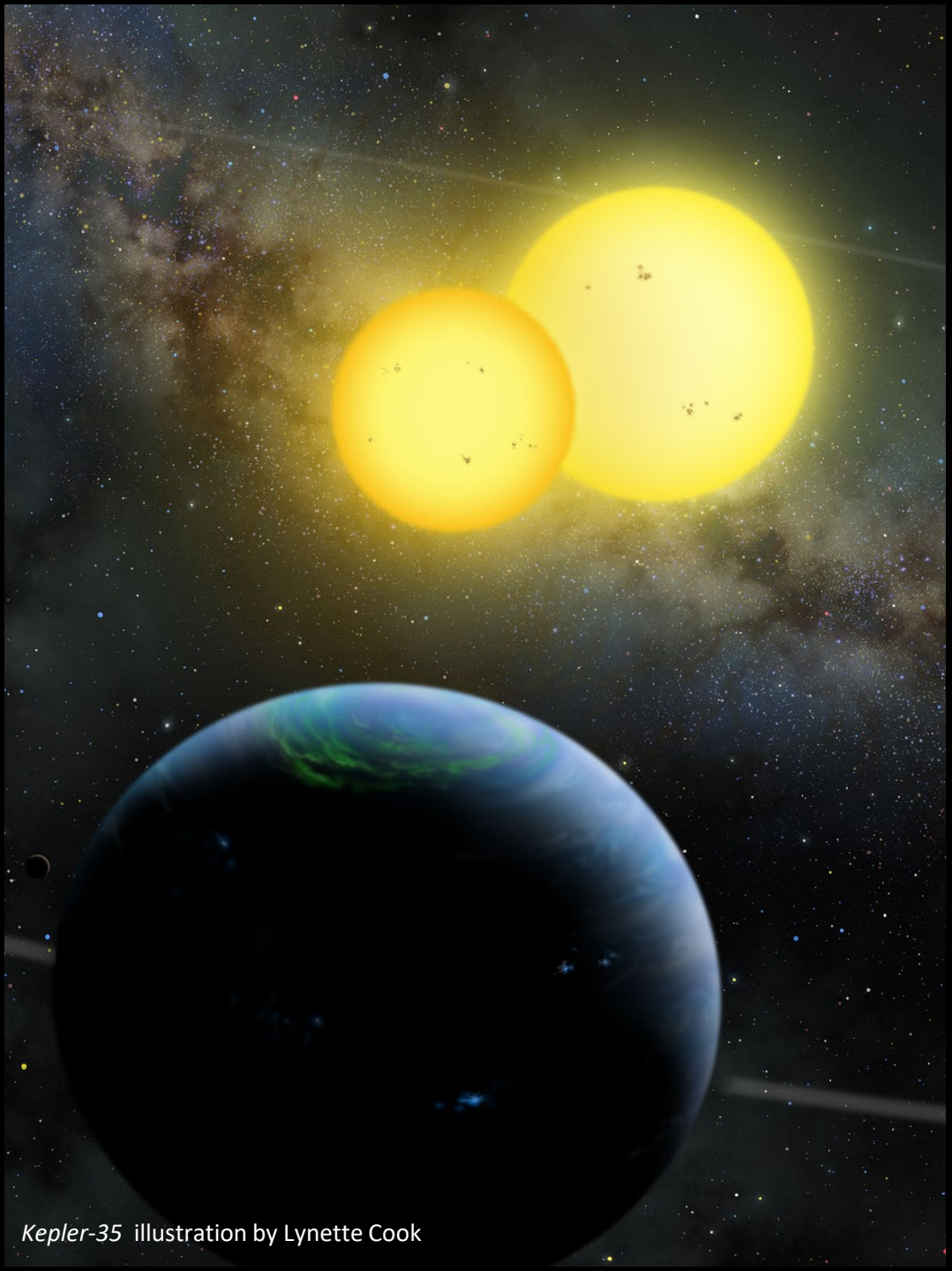
for the

Namibia Scientific Society

Wissenschaftliche Gesellschaft

*Science for Society*


Dr. William "Bill" Welsh
State University New York Stony Brook
The Ohio State University and
Space Telescope Science Institute
Keele University, England
University of Texas at Austin
San Diego State University (2000)
NASA *Kepler* Mission Science Team (2007-2018)



*Kepler-35* illustration by Lynette Cook

# *Kepler Mission*

discovery of "circumbinary planets" :

planets that orbit around two stars.

They have 2 suns!

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September 2011 > Doyle et al., 333 (6049): 1602-1606

*Science* 16 September 2011:
Vol. 333 no. 6049 pp. 1602-1606
DOI: 10.1126/science.1210923

RESEARCH ARTICLE

# Kepler-16: A Transiting Circumbinary Planet

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Joshua N. Winn[5], Jerome A. Orosz[6], Andrej Pr˘sa[7], William F. Welsh[6], Samuel
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REPORT

# Kepler-47: A Transiting Circumbinary Multiplanet System

Jerome A. Orosz[1,*], William F. Welsh[1], Joshua A. Carter[2,†], Daniel C. Fabrycky[3,†], William D. Cochran[4], Michael Endl[4], Eric B. Ford[5], Nader Haghighipour[6], Phillip J. MacQueen[4], Tsevi Mazeh[7], Roberto Sanchis-Ojeda[8], Donald R. Short[1], Guillermo Torres[2], Eric Agol[9], Lars A. Buchhave[10,11], Laurance R. Doyle[12], Howard Isaacson[13], Jack J. Lissauer[14], Geoffrey W. Marcy[13], Avi Shporer[15,16,17], Gur Windmiller[1], Thomas Barclay[14,18], Alan P. Boss[19], Bruce D. Clarke[12,14], Jonathan Fortney[3], John C. Geary[2], Matthew J. Holman[2], Daniel Huber[14], Jon M. Jenkins[12,14], Karen Kinemuchi[14,18], Ethan Kruse[2], Darin Ragozzine[2], Dimitar Sasselov[2], Martin Still[14,18], Peter Tenenbaum[12,14], Kamal Uddin[14,20], Joshua N. Winn[8], David G. Koch[14], William J. Borucki[14]

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*NATURE* | LETTER

日本語要約

# Transiting circumbinary planets Kepler-34 b and Kepler-35 b

William F. Welsh, Jerome A. Orosz, Joshua A. Carter, Daniel C. Fabrycky, Eric B. Ford, Jack J. Lissauer, Andrej Prša, Samuel N. Quinn, Darin Ragozzine, Donald R. Short, Guillermo Torres, Joshua N. Winn, Laurance R. Doyle, Thomas Barclay, Natalie Batalha, Steven Bloemen, Erik Brugamyer, Lars A. Buchhave, Caroline Caldwell, Douglas A. Caldwell, Jessie L. Christiansen, David R. Ciardi, William D. Cochran, Michael Endl, Jonathan J. Fortney + *et al.*

Affiliations | Contributions | Corresponding authors

*Nature* **481**, 475–479 (26 January 2012) | doi:10.1038/nature10768

U-T San Diego

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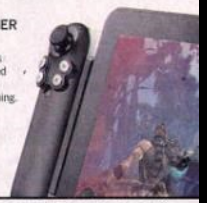

RY 12, 2012 • THE WORLD'S GREATEST COUNTRY & AMERICA'S FINEST CITY

# MAYOR SEES END TO FISCAL

In his final State of the City speech, Sanders seeks progress on a range of civic projects

CRAIG GUSTAFSON • U-T

Mayor Jerry Sanders pledged the financial problems that have plagued San Diego for the past decade — a chaotic era of escalating pension costs and devastating budget cuts for America's Finest City — will end before he leaves office in December and make way for a new period of growth and prosperity.

In his seventh and final State of the City address, Sanders said Wednesday he also plans to shepherd several major civic projects to reality, from a new Chargers stadium to a convention center expansion to a makeover of San Diego's crown jewel: Balboa Park.

To emphasize his point of closing his tenure strong, Sanders took the stage to the sound of AC/DC's "Hells Bells," which was the favored entrance music for former Padres closer Trevor Hoffman.

"I promise we won't give an inch to those who doubt this city or would hold it back out of self-interest. Not now, not ever," Sanders said at the downtown Balboa Theatre. "We will be fearless, and we'll finish what we started, closing the deal on civic projects

SEE CITY • A3

Mayor Jerry Sanders de
City address Wednesday

# DOUBLE VISION

SDSU astronomer leads study on planets that orbit two suns

GARY ROBBINS • U-T

The dreamy notion that there are planets that orbit two suns is no longer merely an idea found in the pages of science-fiction novels. Months after scientists announced they had found one, researchers at San Diego State University said Wednesday that they have discovered two more — and that these eerie worlds probably dot the Milky Way.

"We estimate that there are at least

SEE SUNS • A9

**"We estimate that there are at least millions in our galaxy, but there could be many more than that."**

William Welsh
SDSU astronomer

COURTESY ILLUSTRATION • SAN DIEGO STATE UNIVERSITY

Detecting distant orbiting

Top view Star A Star B

THE WALL STREET JOURNAL.
WSJ.com

U.S. NEWS | January 12, 2012

# An Otherworldly Discovery: Billions of Other Planets

By ROBERT LEE HOTZ

Astronomers said Wednesday that ea
one companion planet. Lee Hotz has

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The New York Times

**Science**

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OBSERVATORY

# Kepler Finds More Planets Orbiting Two Stars

By SINDYA N. BHANOO
Published: January 11, 2012

In the "Star Wars" movies, Luke Skywalker's home planet, Tatooine, orbits two suns, giving it two sunsets and two sunrises every day. In September, scientists discovered the first planet in our galaxy that orbits two stars; now they have discovered two more and suggest that there are probably millions of these so-called circumbinary planets in the Milky Way.

**Related**

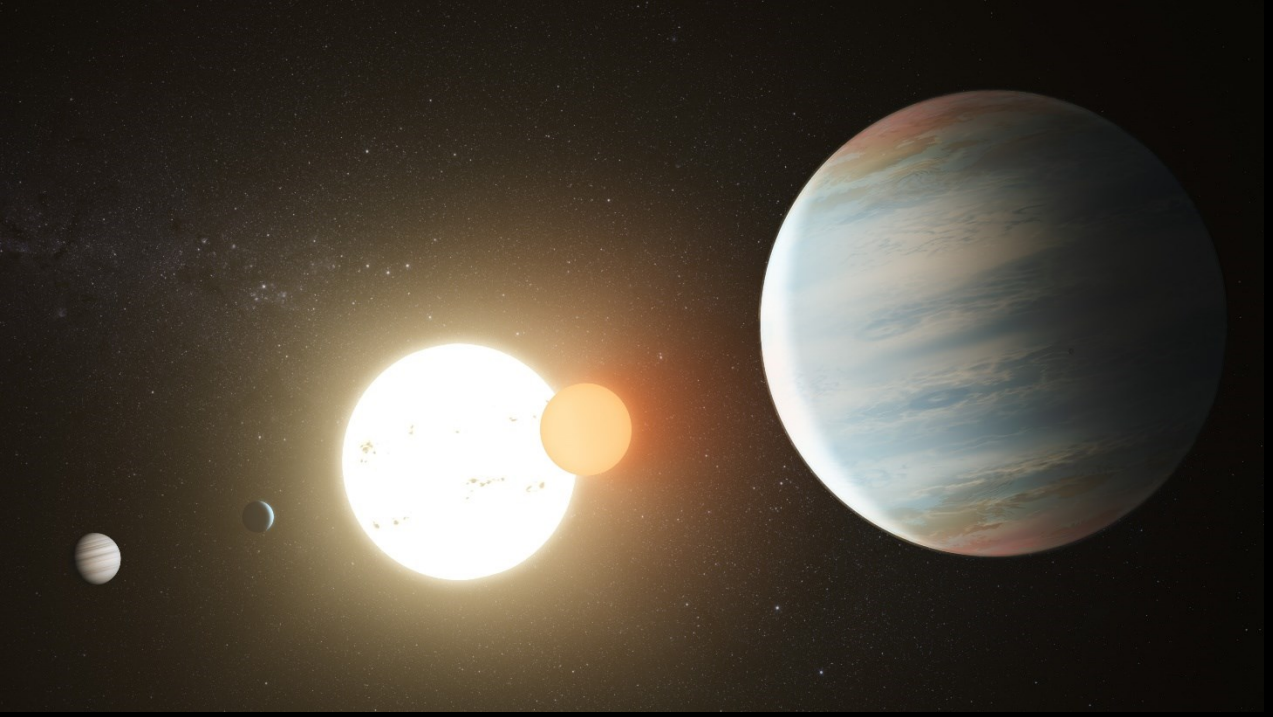
More Observatory Columns

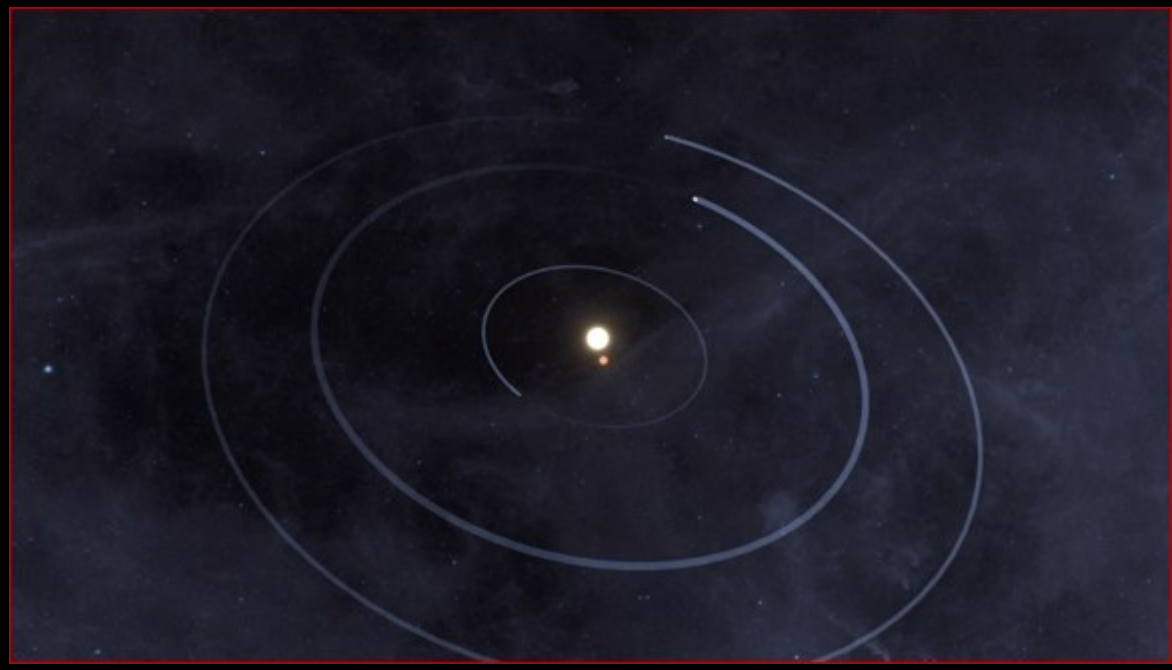
"We found two more, and that immediately tells us, wow, this wasn't a fluke," said William Welsh, an astronomer at San Diego State

As of today, a total of 17 circumbinary planets have been detected.

Two are multi-planet systems, e.g. Kepler-47 has 3 planets orbiting its binary star.

Kepler-45 copyright Mark Garlick

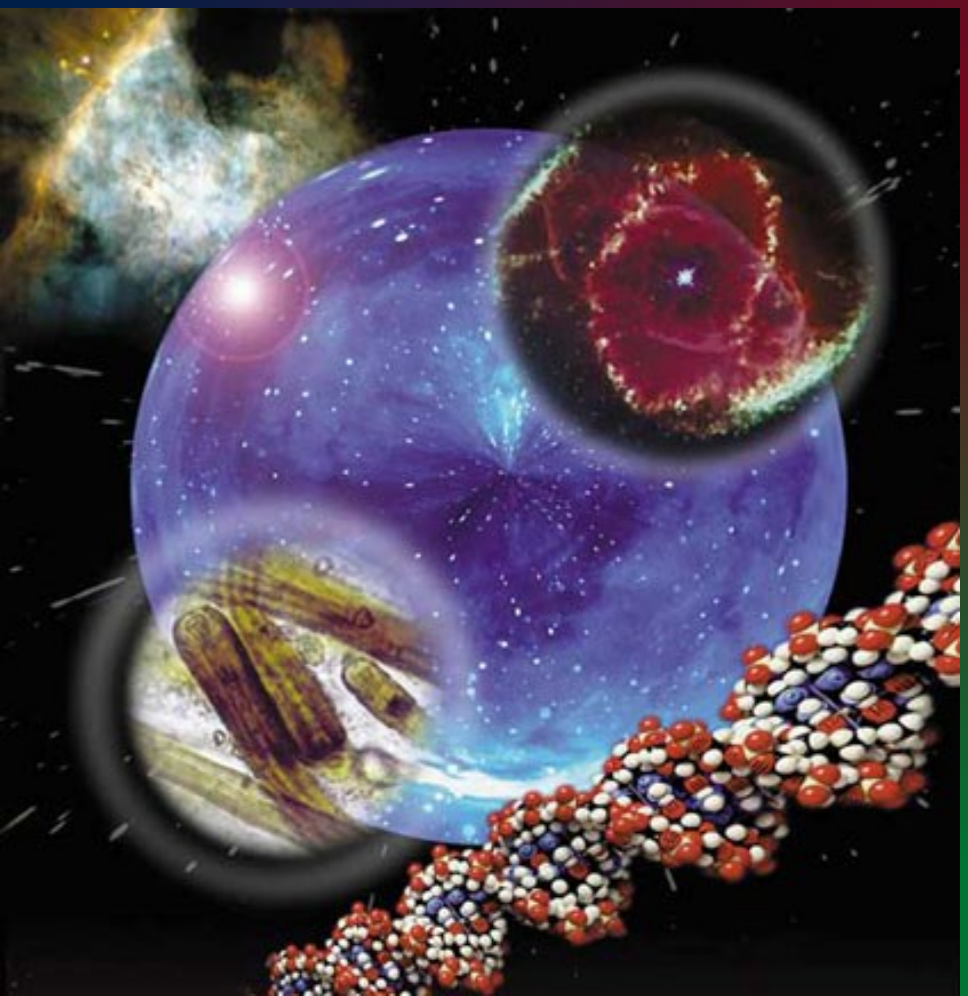




Kepler-47 illustration and animation credit: Tim Pyle / NASA / Caltech JPL

# Astrobiology

## Life in the Universe




***William Welsh***

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# Motivation

## Four "Recent" Major Discoveries:

1) Exoplanets
2) Extremophiles
3) Rapid Origin of Life on Earth
4) Icy Moons of the outer Solar System

# The History of Planets

- For most of human history, we knew of 5 planets: M, V, M, J, S
- By 1610 there were 6: the Earth!
- By 1930 there were 9 (...if you count Pluto…)

- By 1995 there were 10 – first "exoplanet" discovered (Michel Mayor & Didier Queloz)

- As of 2024 July 25, there are 5690 confirmed exoplanets!


Kepler

NASA's *Kepler Mission* (2009-2013) is responsible for discovering 2773 exoplanets

+ 1982 additional *candidate* planets

(probably planets, but we don't have enough evidence to be sure)


*Kepler* has found

+ 361 candidate planets in the *habitable zone (HZ)*

+ 23 have R < 1.25 $R_\oplus$ ← these are potentially Earth-like

Habitable Zone: the region around a star such that a rocky planet could have liquid water on its surface.

Liquid water is a requirement for life as we know it.

Current estimates put the occurrence rate of Earth-size planets (0.5-1.4 $R_e$) in the HZ at

~ 22% for G & K-stars and

~ 50% for M stars!

And in general, there are probably more planets than stars in the galaxy!

over ~100 billion planets in the Milky Way

# Important discovery in 2016: a HZ planet orbiting Proxima Centauri - the nearest star system to the Sun!

# *Part 2: Extremophiles*

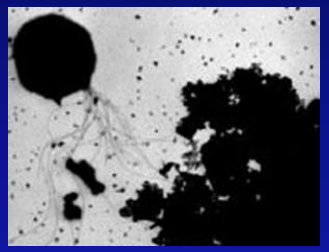
"Lovers of extreme conditions"

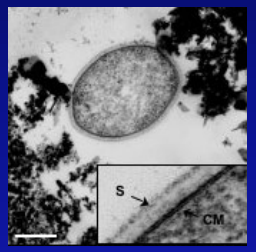
- Terrestrial life can survive in places we did not think possible.
- In particular, the archaea microbes can thrive in "hostile environments"; some *require* it. Their proteins, etc., function *only* in these extreme conditions.

Some extreme environments:

- Heat: *pyrolobus fumarii* thrives at 90-113$^{o}$ C;

  record holder: **"*Strain 121*": 85-121$^{o}$ C, survives 130$^{o}$ C (266$^{o}$ F)**






- Pressure: *barophilic* organisms can survive at the bottom of the ocean (~11,000 m) at ~1000 bar (987 atm or 100 M Pa)

- Salt: *halophiles* thrive at 8 x the salinity of ocean water (e.g. the Dead Sea)

Acid: *picrophilus oshimae* thrive at pH ~0.5 and survive at 0.0; disintegrate if the pH reaches 5! (*Helicobacter pylori* live in stomach acid; ulcers)

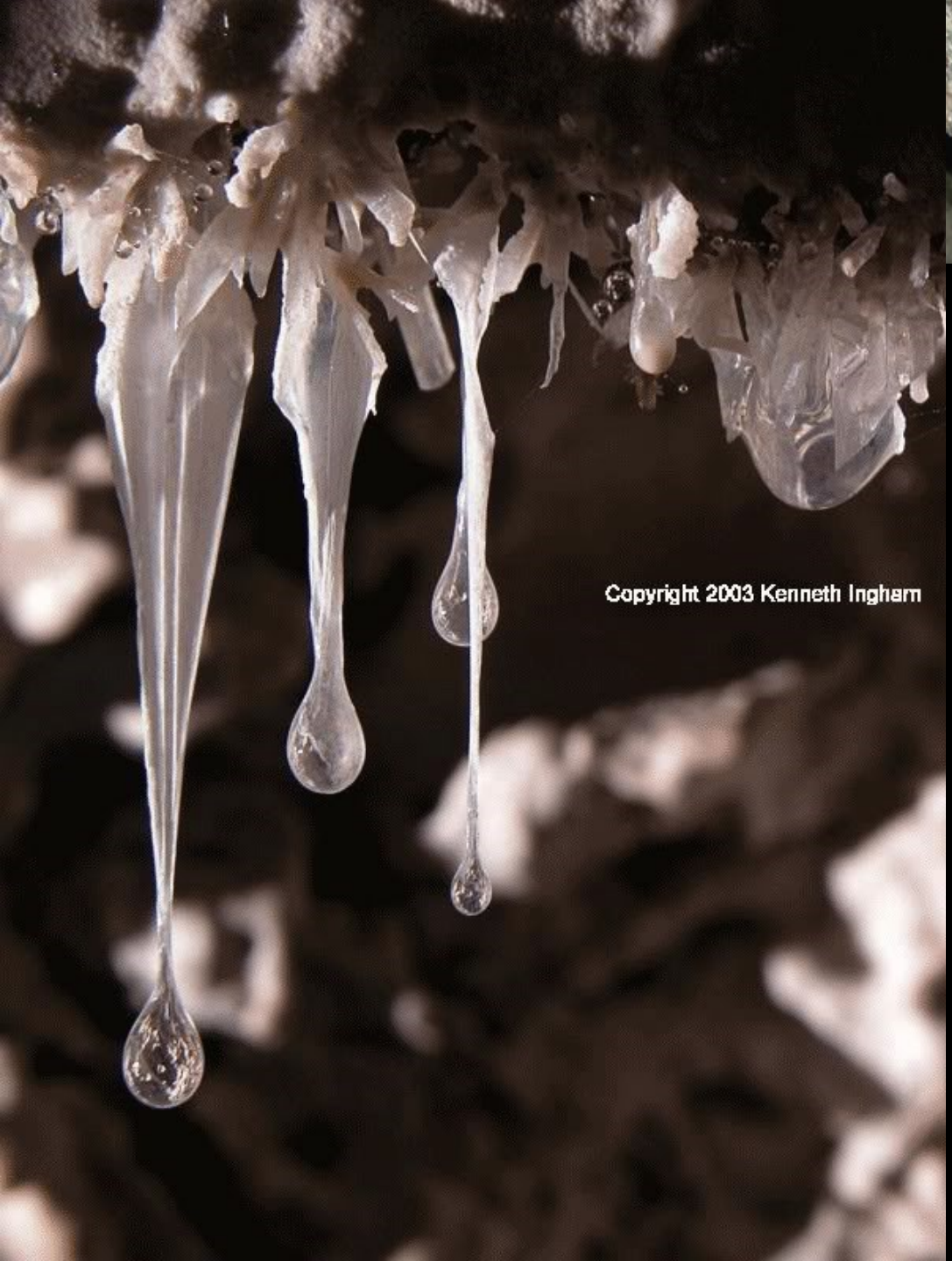
Alkali: *bacillus alcalophilus* thrives at pH > ~10

Dryness (drought): *deinococcus radiodurans* can survive being vacuum-dried for over 6 weeks

Some archaea and bacteria can derive energy from inorganic molecules (e.g. by reducing iron or sulfur) completely independent of sunlight in closed, isolated caves.

"Rock-eaters" (*lithoautotrophes*) can live on water and pure rock (basalt) 2.8 km underground

→ the vast "deep biosphere".




*"snottites"*

# Hydrothermal vent ecosystem

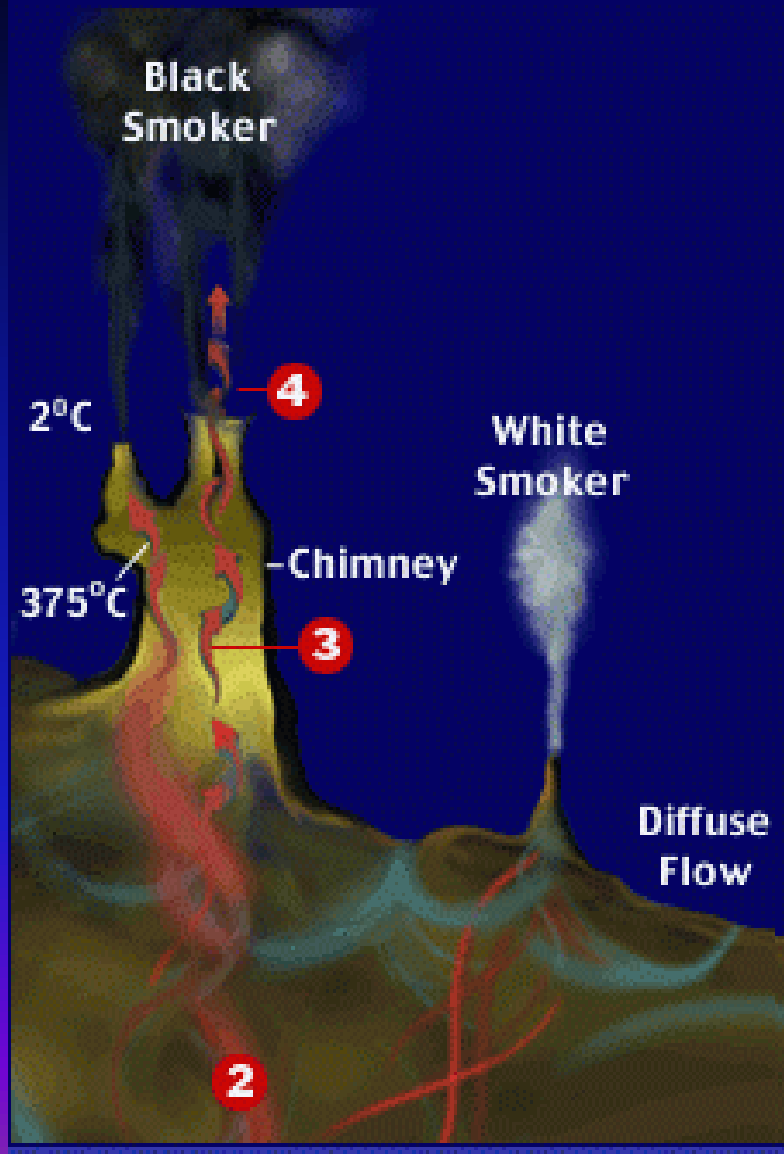
Certain *thermophilic bacteria* and *archaea* can derive energy from inorganic molecules (e.g. iron, sulfate), *completely independent of sunlight* [no photosynthesis needed].

These microbes form the basis of the hydrothermal vent food chain.

Note: Larger organisms (like *Pompeii worms*, shrimp, clams, etc.) do require oxygen, derived from photosynthesis.

# Hydrothermal Vents

## DIVE & DISCOVER




**2.** The seawater continues to seep far below this point in the ocean crust. Energy radiating up from molten rock deep beneath the ocean floor raises the water's temperature to around 350–400°C. As the water heats up, it reacts with the rocks in the ocean crust. These chemical reactions change the water in the following way:

All oxygen is removed.

It becomes acidic.

It picks up dissolved metals, including iron, copper and zinc.

It picks up hydrogen sulfide.

Click on the words and numbers for more info

# Extreme Adaptations

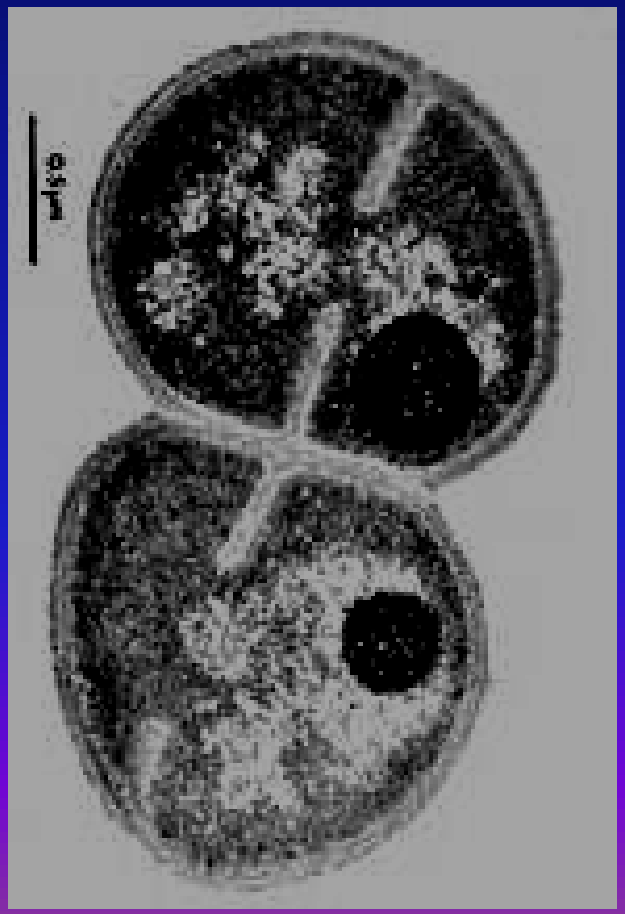
Tardigrades can survive temperatures
as low as -200 C (-328 F);
as high as 150 C (~300 F).


- can be repeatedly frozen & thawed
- tolerate extreme changes in salinity

- resistant to X-ray radiation
(hundreds of times more than what is lethal to humans & most other organisms)

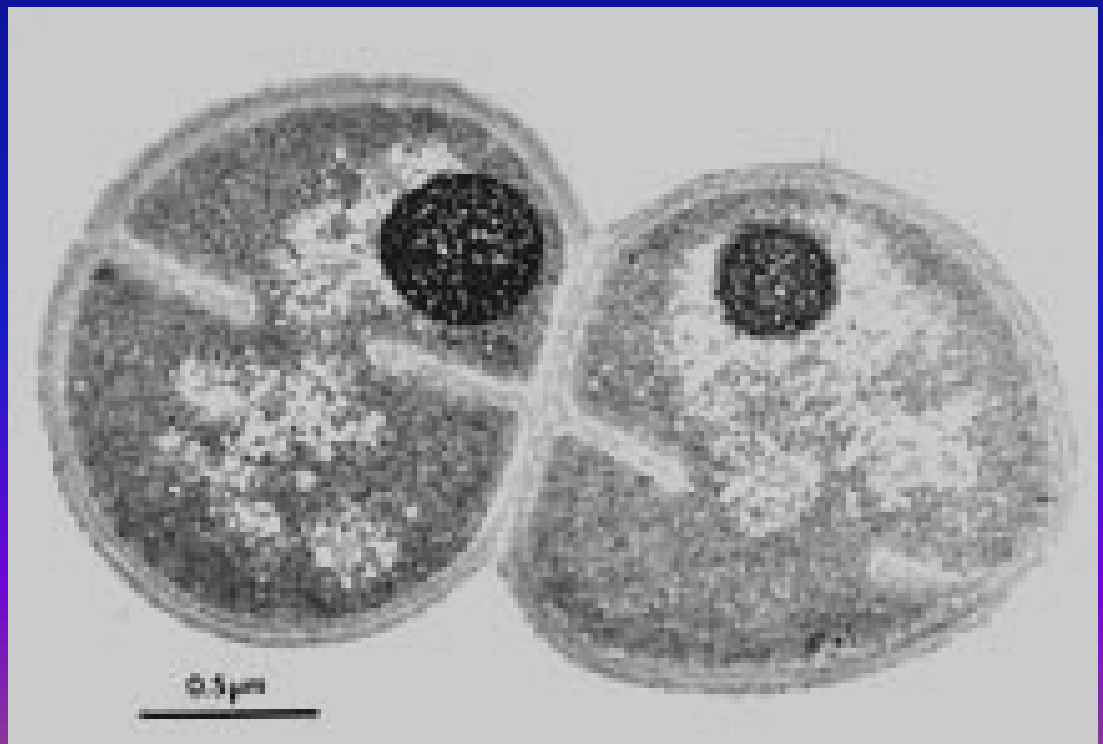
- extreme vacuum conditions,
like the vacuum of space!

*Deinococcus radiodurans* can withstand extremely high doses of radiation: 3000 x more than a lethal dose to a human!!!




- *Deinococcus radiodurans* can repair hundreds of double-strand breaks in its DNA!
- How it can tolerate so much radiation is not fully understood; nowhere on Earth has this much radiation. It is probably a by-product of drought-resistance.

*D. radiodurans* could withstand the harsh radiation on Mars and Europa.



- In the "spore" state, bacteria can withstand incredible conditions.

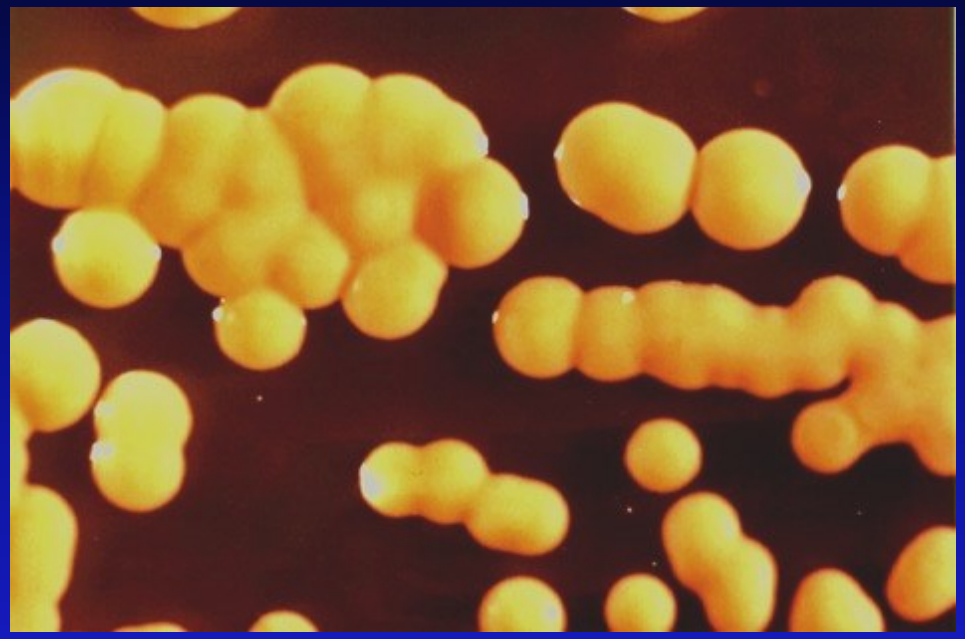
For example, *Bacillus subtilis* can survive:

freeze-drying (over and over...)

20 min hydrogen peroxide bath (enough to bleach your hair or peel off your skin!)

30 min of heat sterilization at 85° C [185 F]

- Bacterial spores found inside a bee's stomach trapped in amber….



*were revived after being dormant for ~ 40 million years!*

Five “Surveyor” spacecraft were sent to the Moon prior to the Apollo missions.

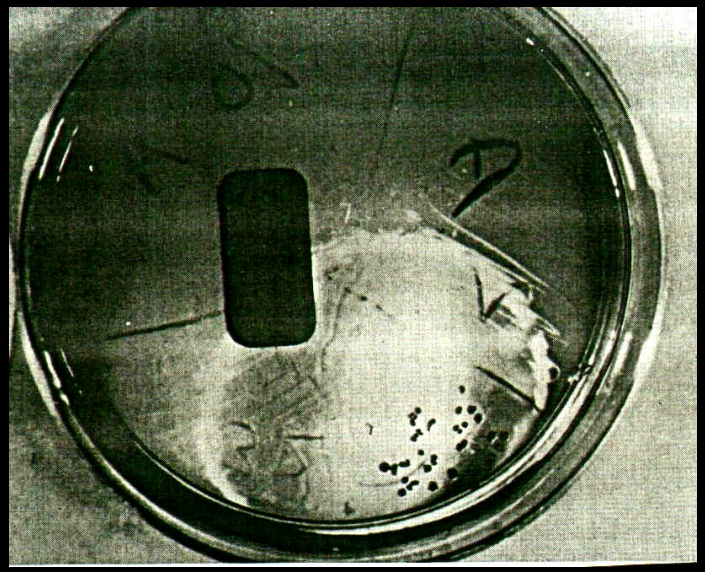
The camera from one of these was retrieved by the Apollo 12 astronauts.

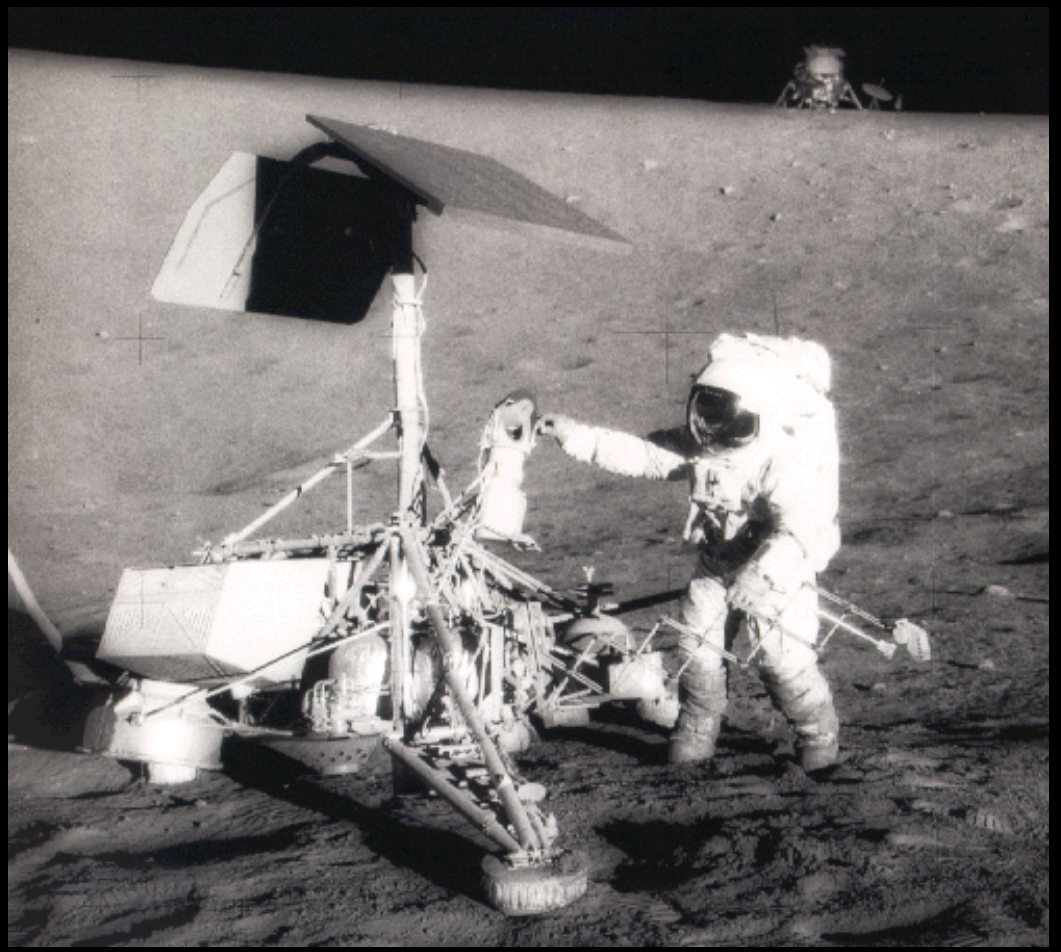
Bacteria endured the hostile space environment

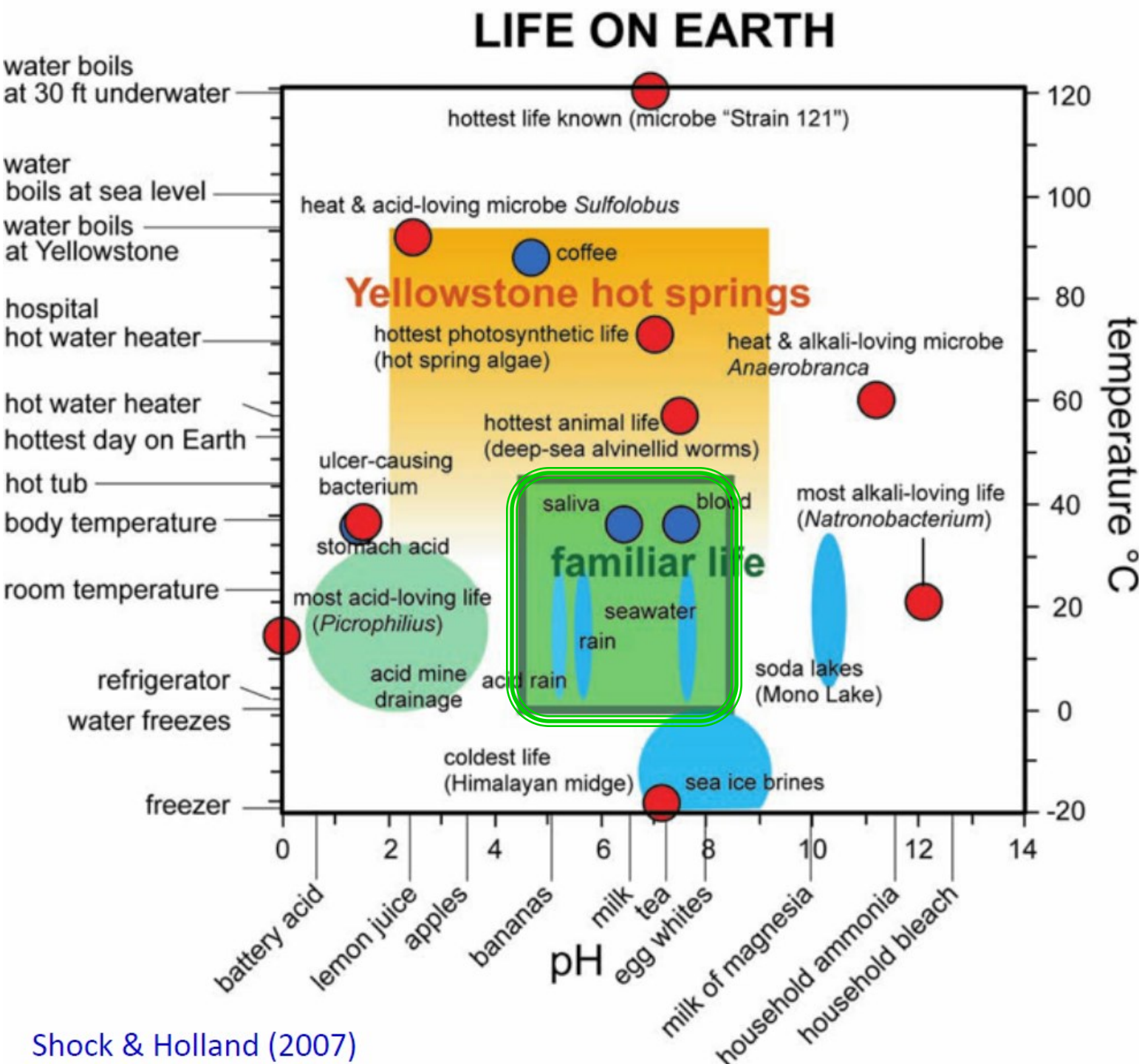
[vacuum, extreme cold (20 K), & intense radiation]

with no nutrients, no water, and no energy source

for 2.5 years!








Shock & Holland (2007)

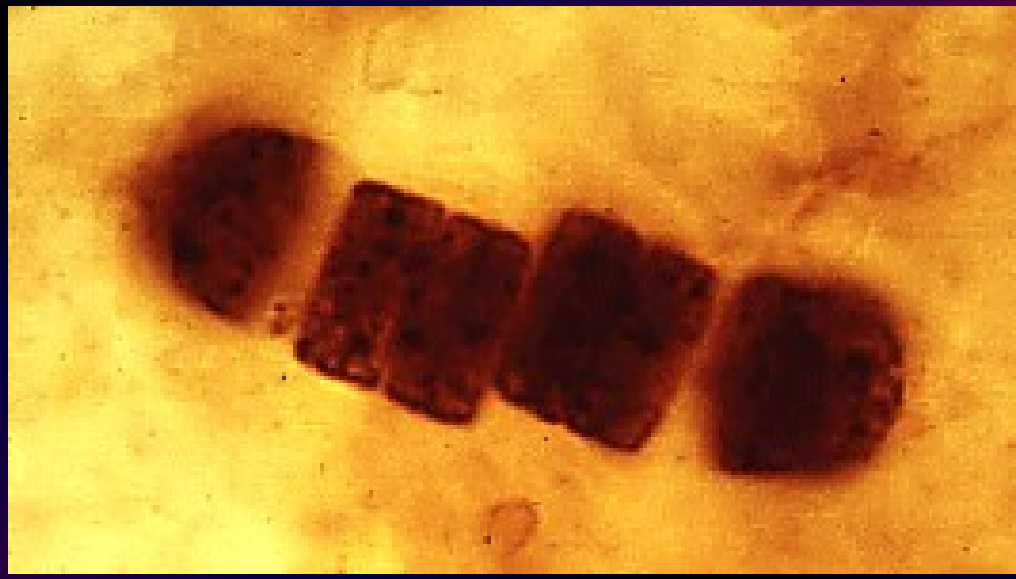
# Part 3. The Rapid Origin of Life on Earth

Illustration credit: Mark Garlick

Rare fossils of cyanobacteria *may* have been found, dating to 3.5 billion years ago.

This is controversial… we aren't sure.

Note: Because of plate tectonics and erosion, *very* few sedimentary rocks exist older than this.



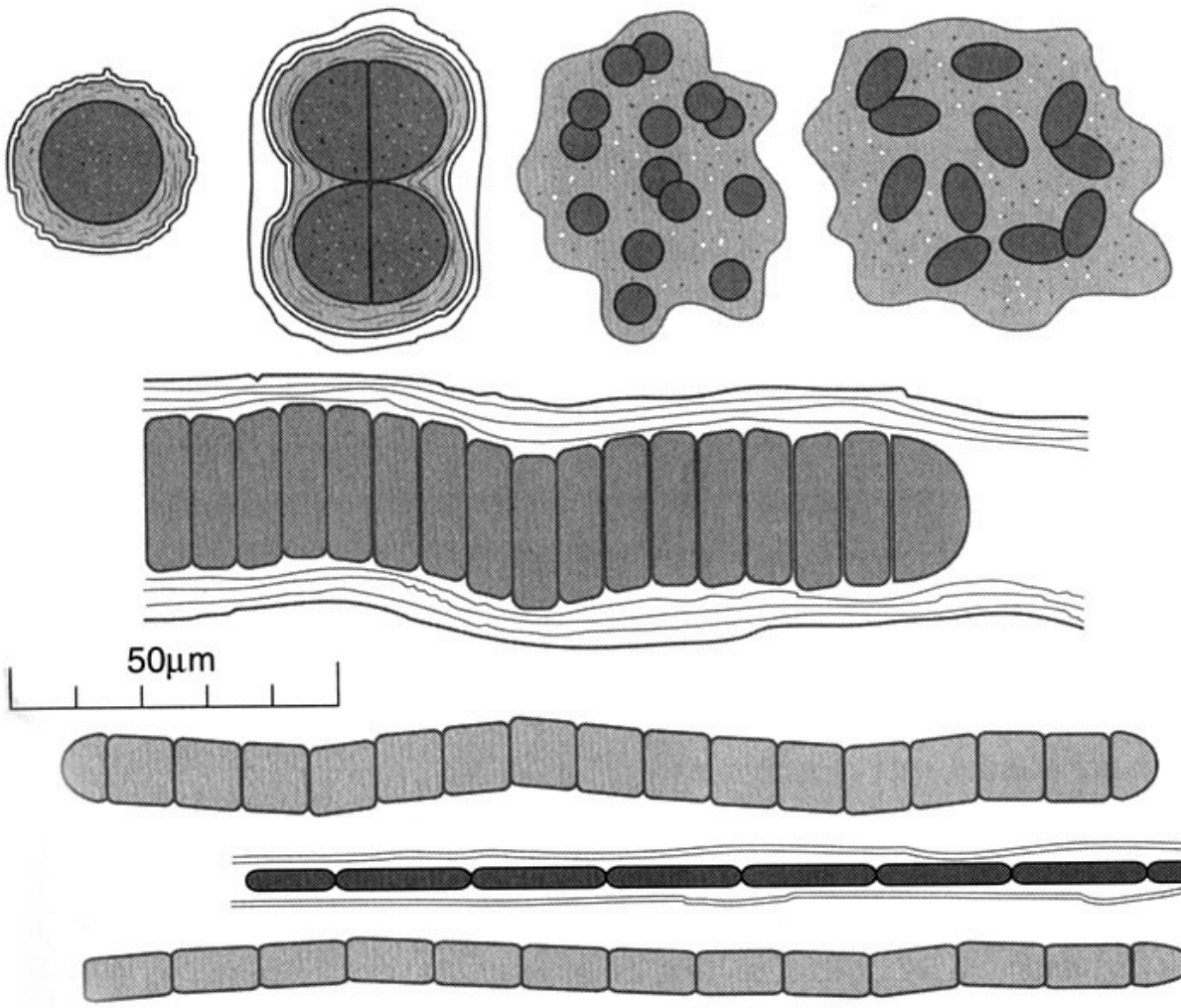

30
20
µm
10
0

Solid evidence for life on Earth 3.5 Gyr ago comes from fossilized “stromatolites”.

Stromatolites are bacterial mounds built up layer upon layer. Living stromatolites still exist today (though rare).

# Living stromatolites at Shark Bay, Australia

# Living stromatolites at Shark Bay, Australia




**CYANOBACTERIA**

*COCCOIDAL, ELLIPSOIDAL, AND FILAMENTOUS*

**Figure 7.1** Cyanobacteria come in a variety of shapes and sizes and are often surrounded by or embedded in secreted layers of sticky mucilage.

from J. William Schopf's *Cradle of Life (1999)*

# The Carbon Isotope Signature Of Life

Along with the usual $^{12}C$ and radioactive $^{14}C$, there is a stable isotope $^{13}C$.

In biological systems, there is a slight preference for $^{12}C$ over $^{13}C$ (because $^{12}C$ is lighter).

This results in a $^{13}C$ / $^{12}C$ ratio in biological chemistry that differs from non-biological chemistry (by about 25 parts per thousand).

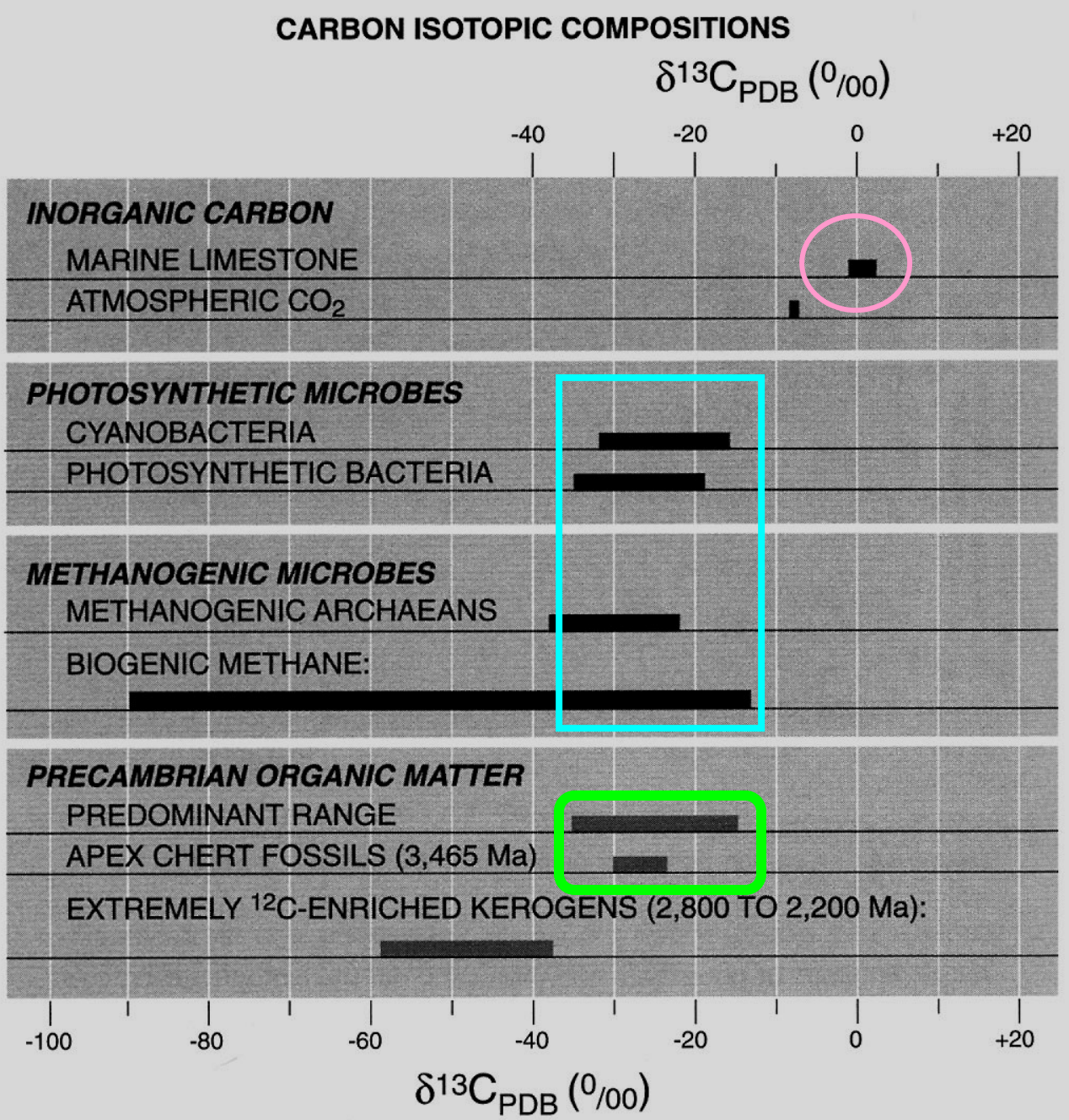


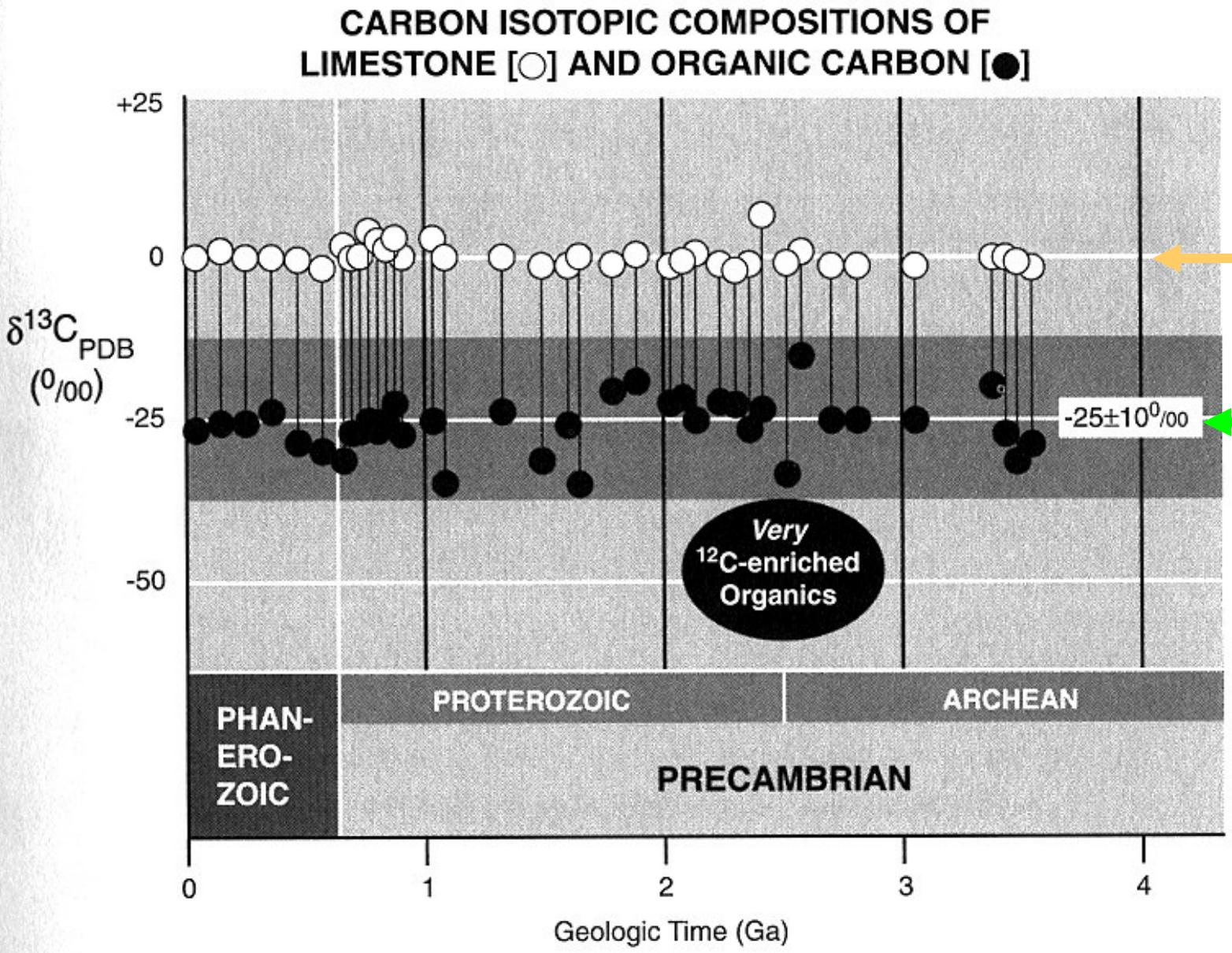

**Figure 6.5** Inorganic carbon, living microbes, and Precambrian organic matter have telltale carbon isotopic compositions.

from J. William Schopf

# The Carbon Isotope Signature Of Life

A sample of material that was created by a living organism will have a $^{13}C/^{12}C$ ratio "signature" that is different from non-biologically created material. [about ~25 ‰ deficit of $C^{13}$]

This is known as biological *"isotopic factionation"*.




inorganic

organic

**Figure 6.4** The carbon isotopic fingerprint of photosynthesis extends to 3.5 Ga

# Carbon Isotope Signature Of Life

Earth rocks 3.85 Gyr old show this carbon-13 isotope signature, which implies:

There is evidence that life existed on Earth at least 3.85 billion yrs ago!

# *Significance of the Rapid Origin of Life on Earth*

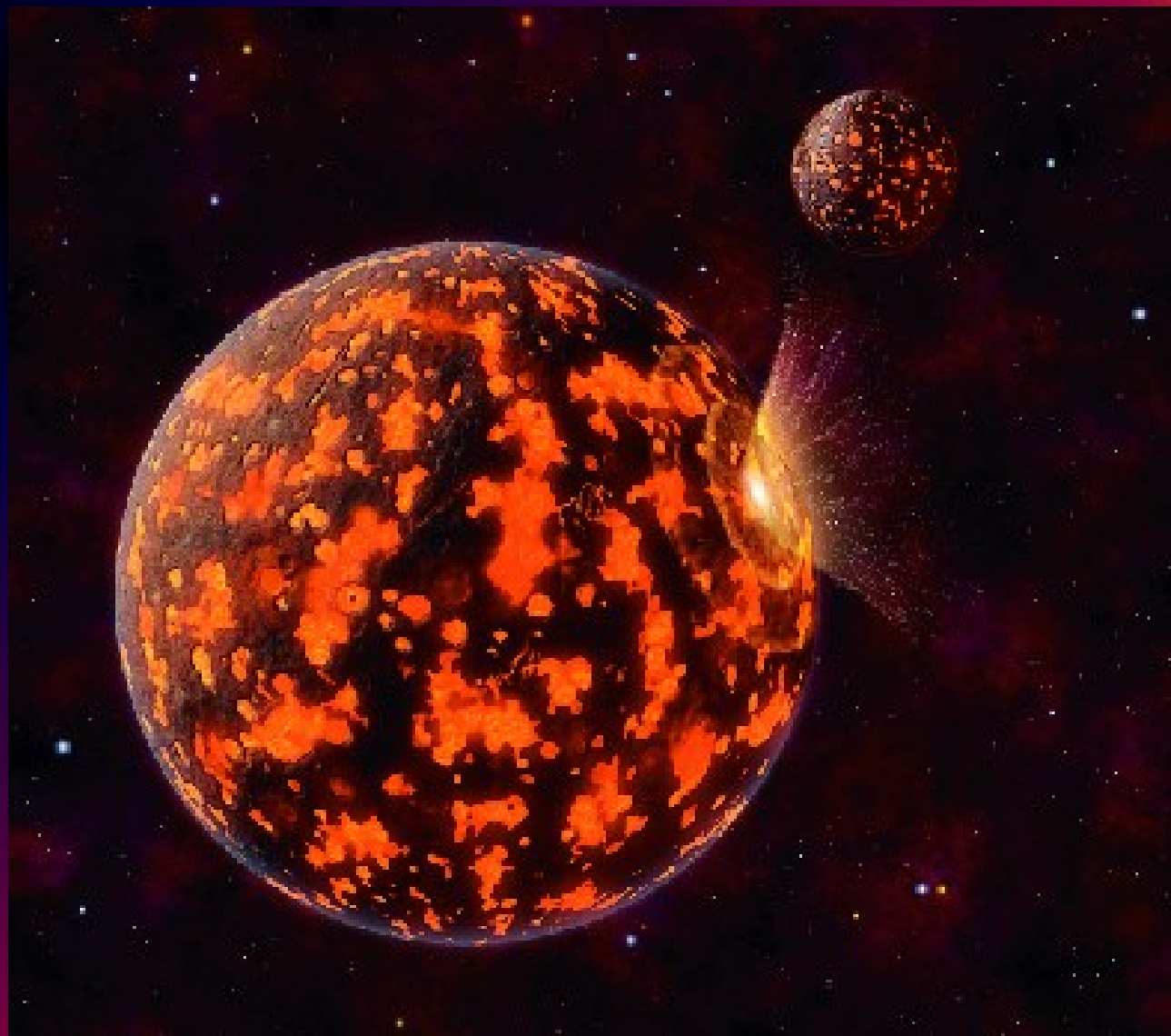
The data tell us:

- "Sophisticated" life (photosynthetic) existed 3.5 Gyr ago (direct fossils and stromatolites)

- Good evidence that life existed 3.85 Gyr ago ($C^{13}/C^{12}$ ratio)

Yet the Earth was heavily bombarded by meteors from the time of its origin 4.5 Gya until about ~3.8-4.0 Gya.

A "*late heavy bombardment period*" occured ~ 3.9 Gyr ago based on Apollo samples and lunar meteorites



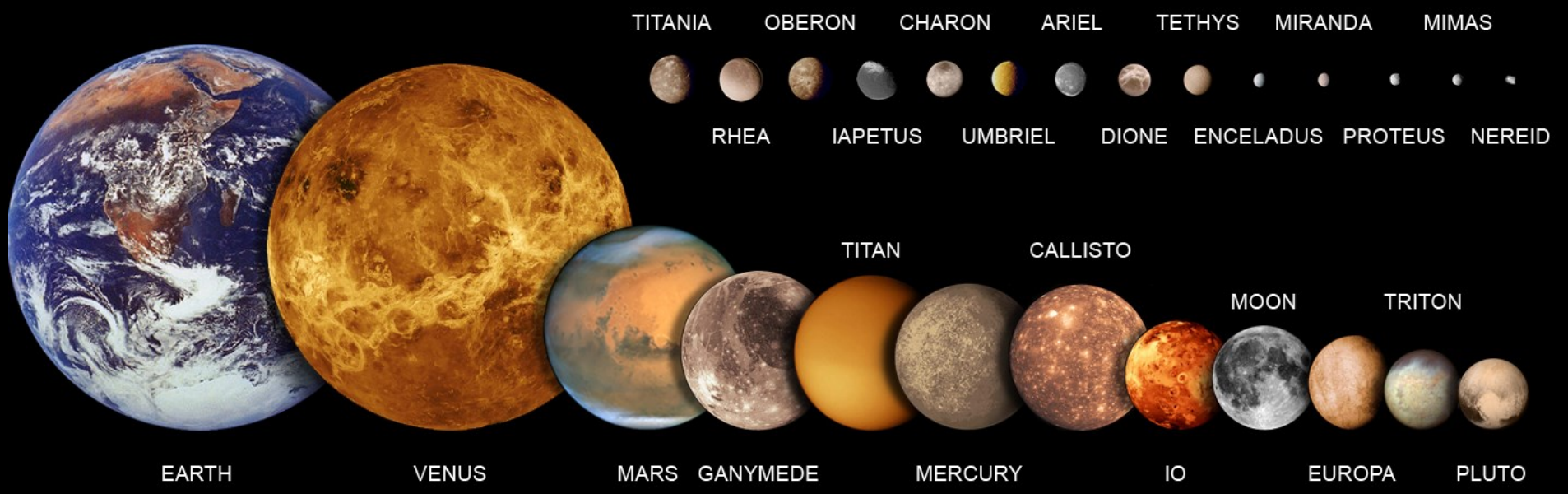

The Earth, circa 4,000,000,000 BC

It appears that life arose *as soon as it was possible* (as soon as huge extinction-causing impacts ceased and oceans became permanent). It did not take billions of years for life to emerge.

Life may have started many times and been obliterated many times.

This implies that if the conditions are right, life will arise; it is not a one-time miraculous event.

# Part 4. The Icy Moons



Ganymede

5262 km

Titan

5150 km

Mercury

4880 km

Callisto

4806 km

Io

3642 km

Moon

3476 km

Europa

3138 km

Triton

2706 km

Pluto

2300 km

Titania

1580 km

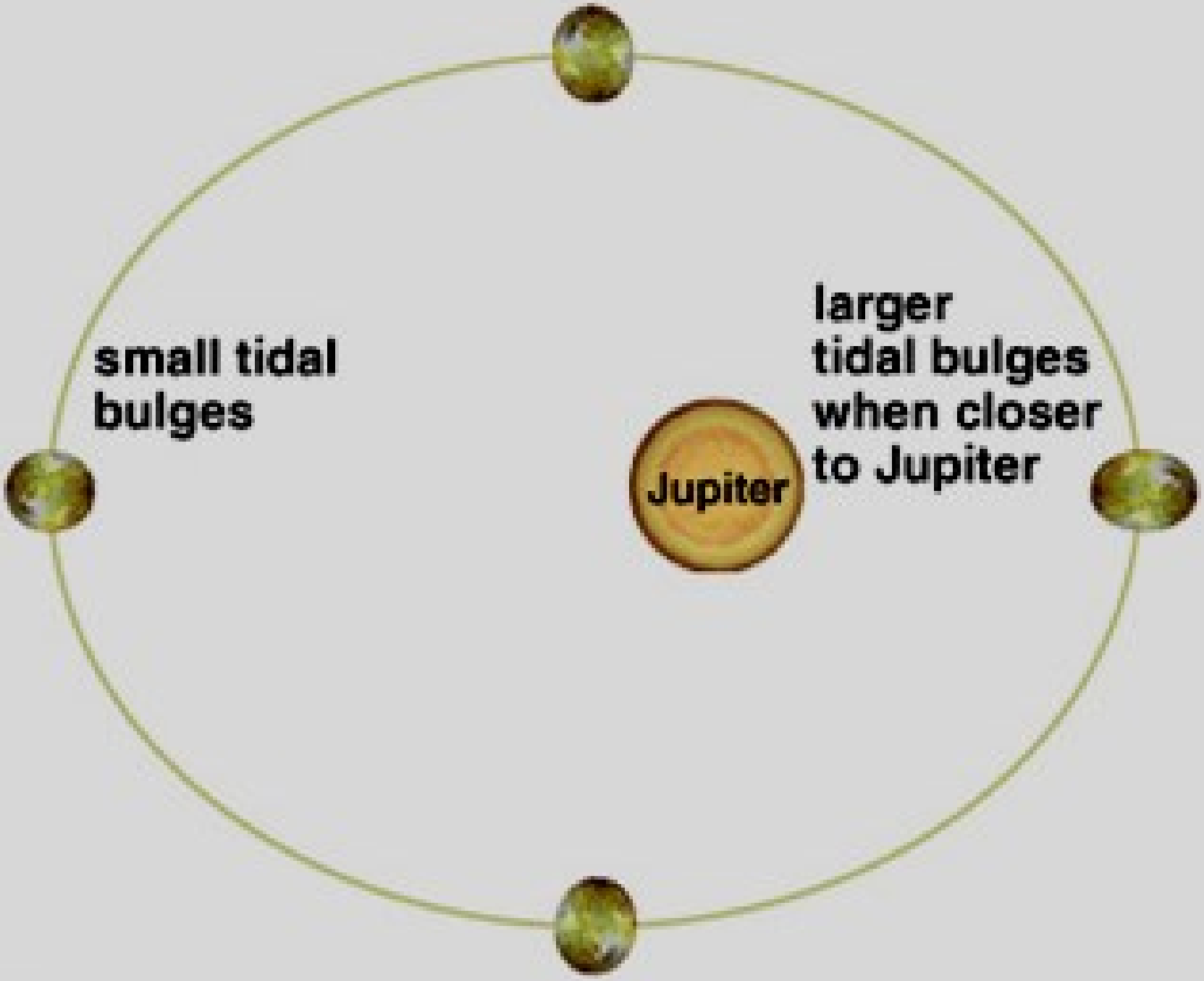
The Largest Moons and Smallest Planets

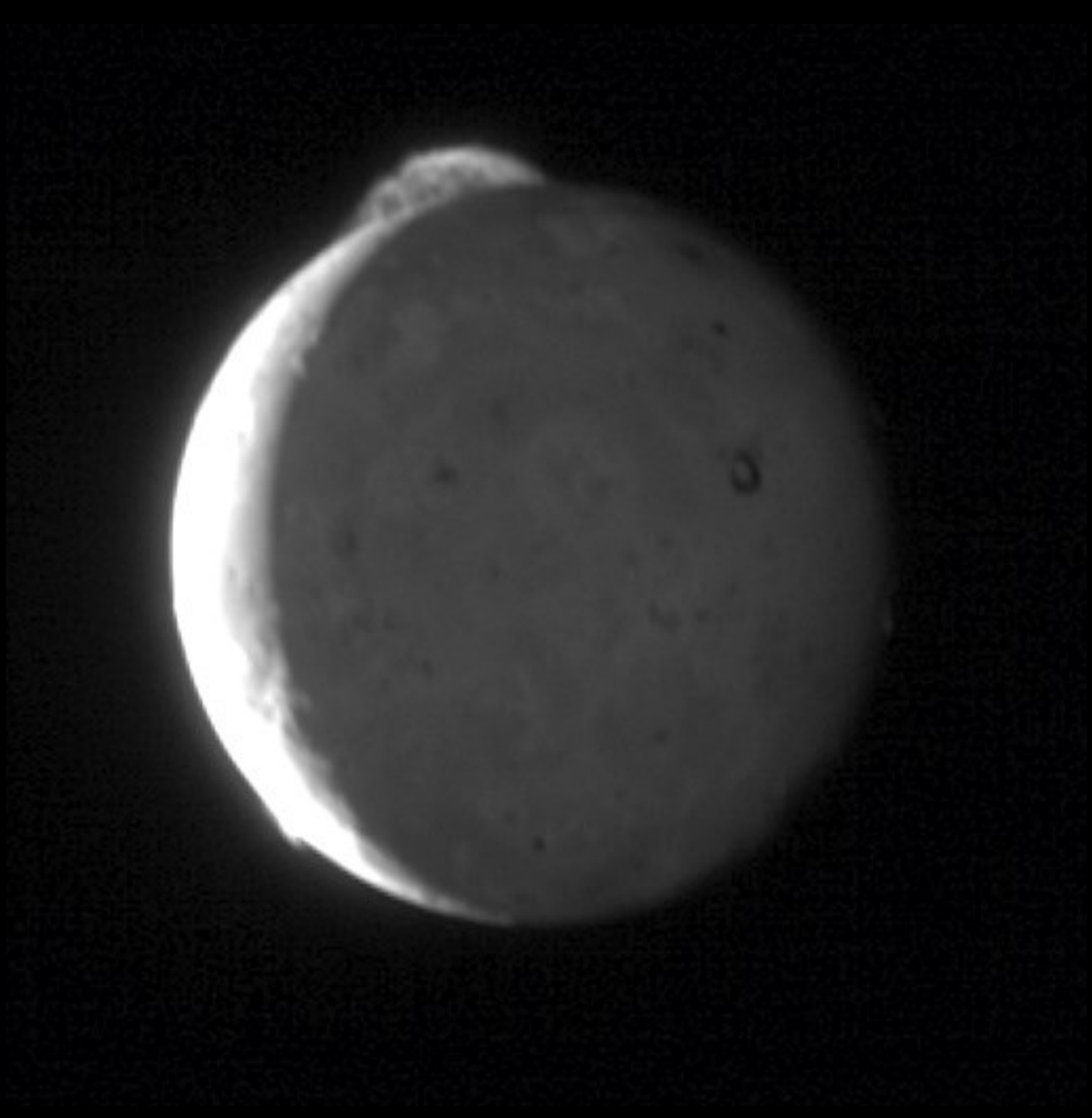
# Jupiter's Moons

Jupiter has four *large* moons (the Galilean satellites):

Io, Europa, Ganymede and Callisto.

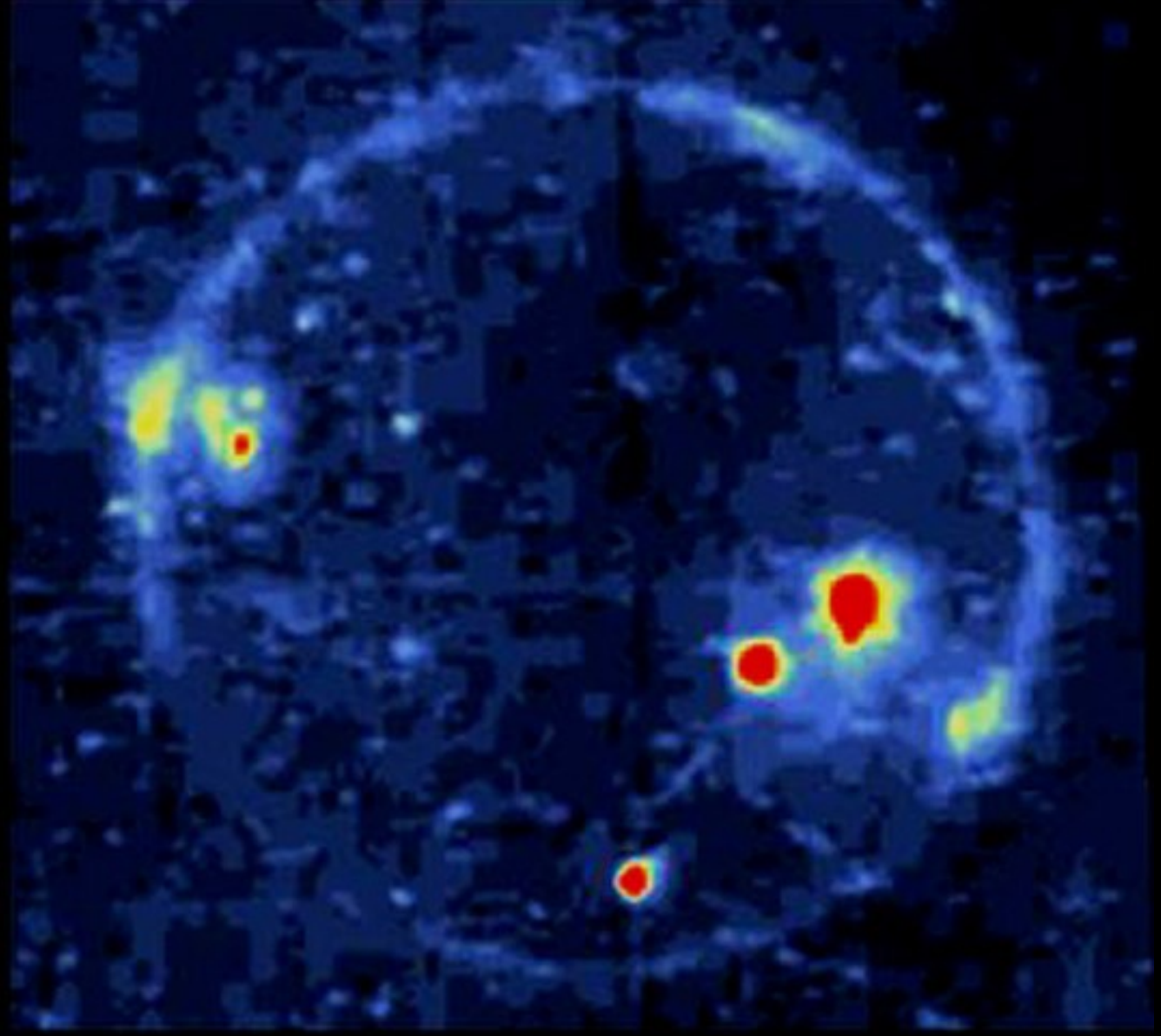
plus dozens of small moons


small tidal
bulges
Jupiter
larger
tidal bulges
when closer
to Jupiter

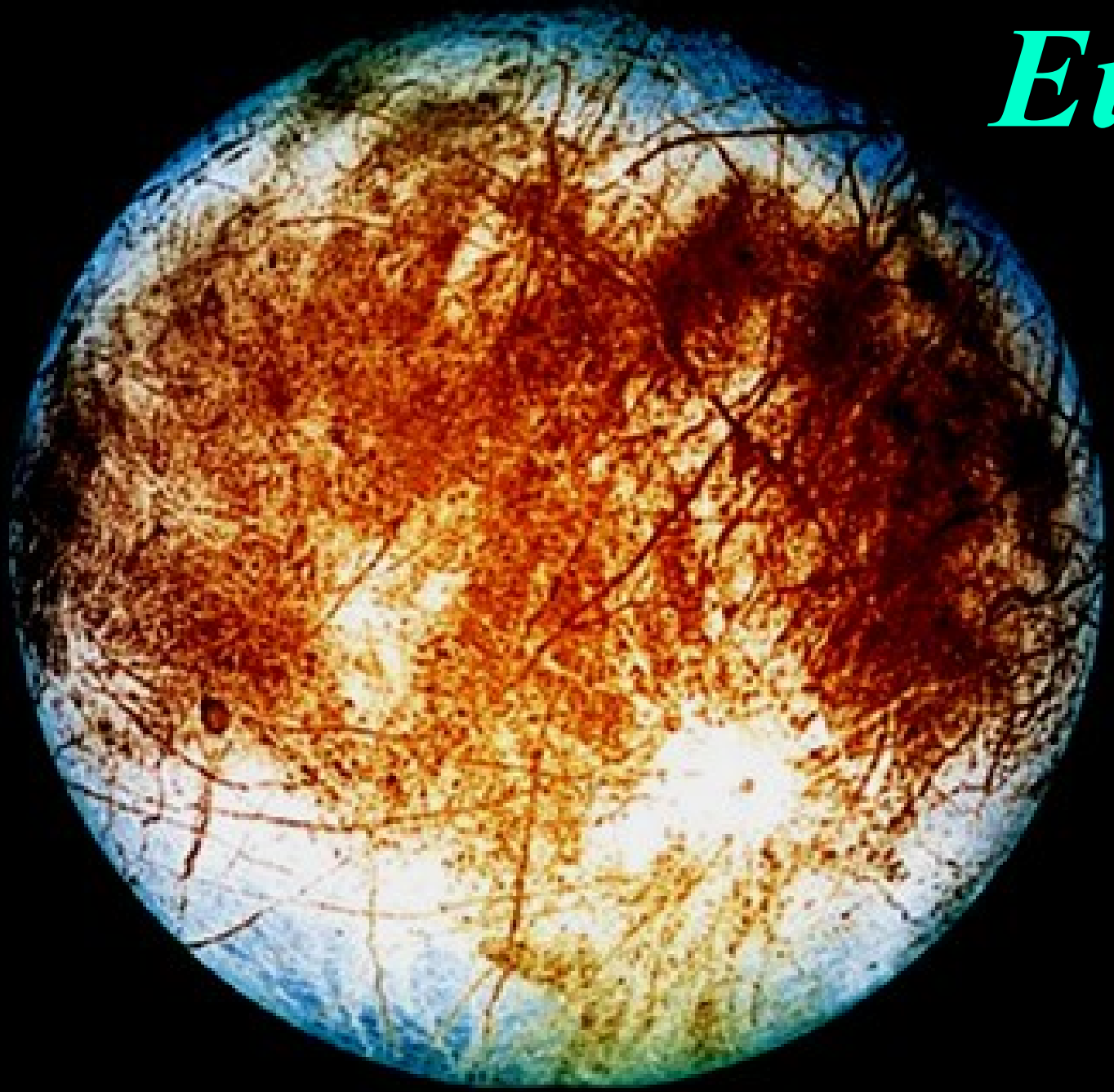


Volcanic Eruption on Io

(New Horizons Mission image)



Volcanic eruptions on Io as seen from the night side



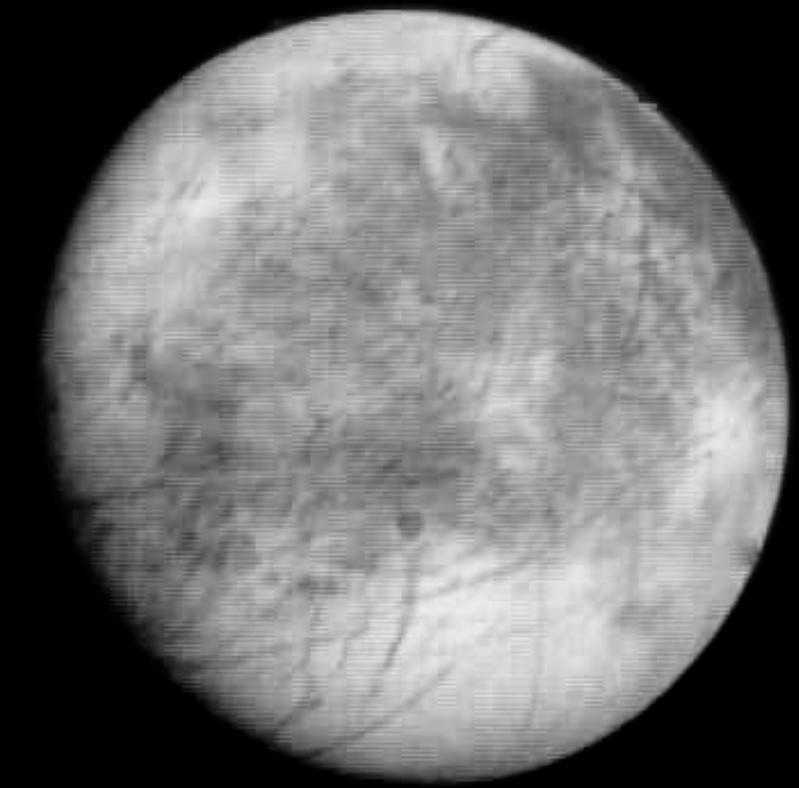
# *Europa*

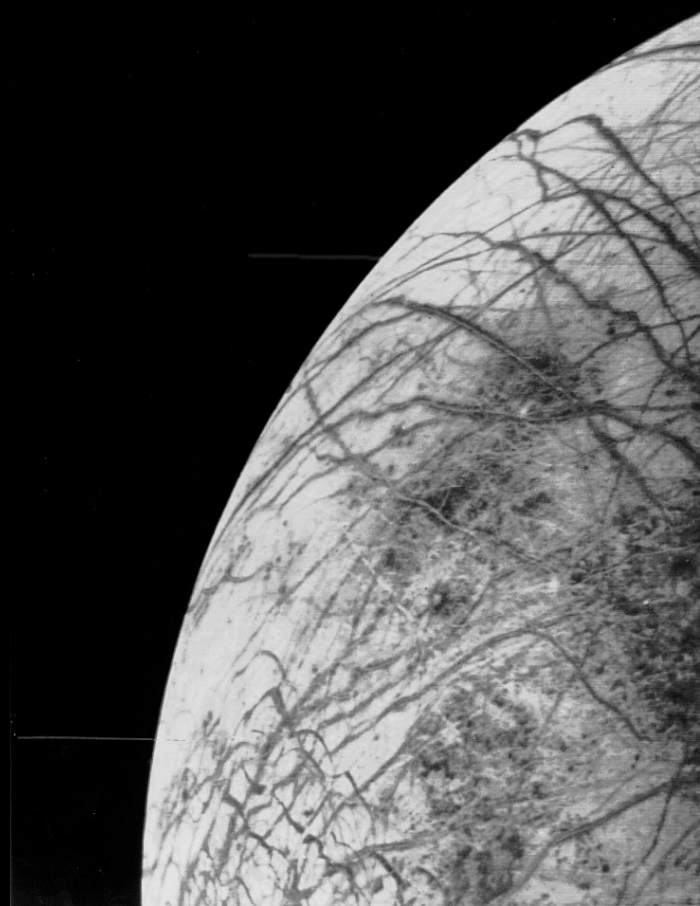
A little smaller than the Earth's Moon.

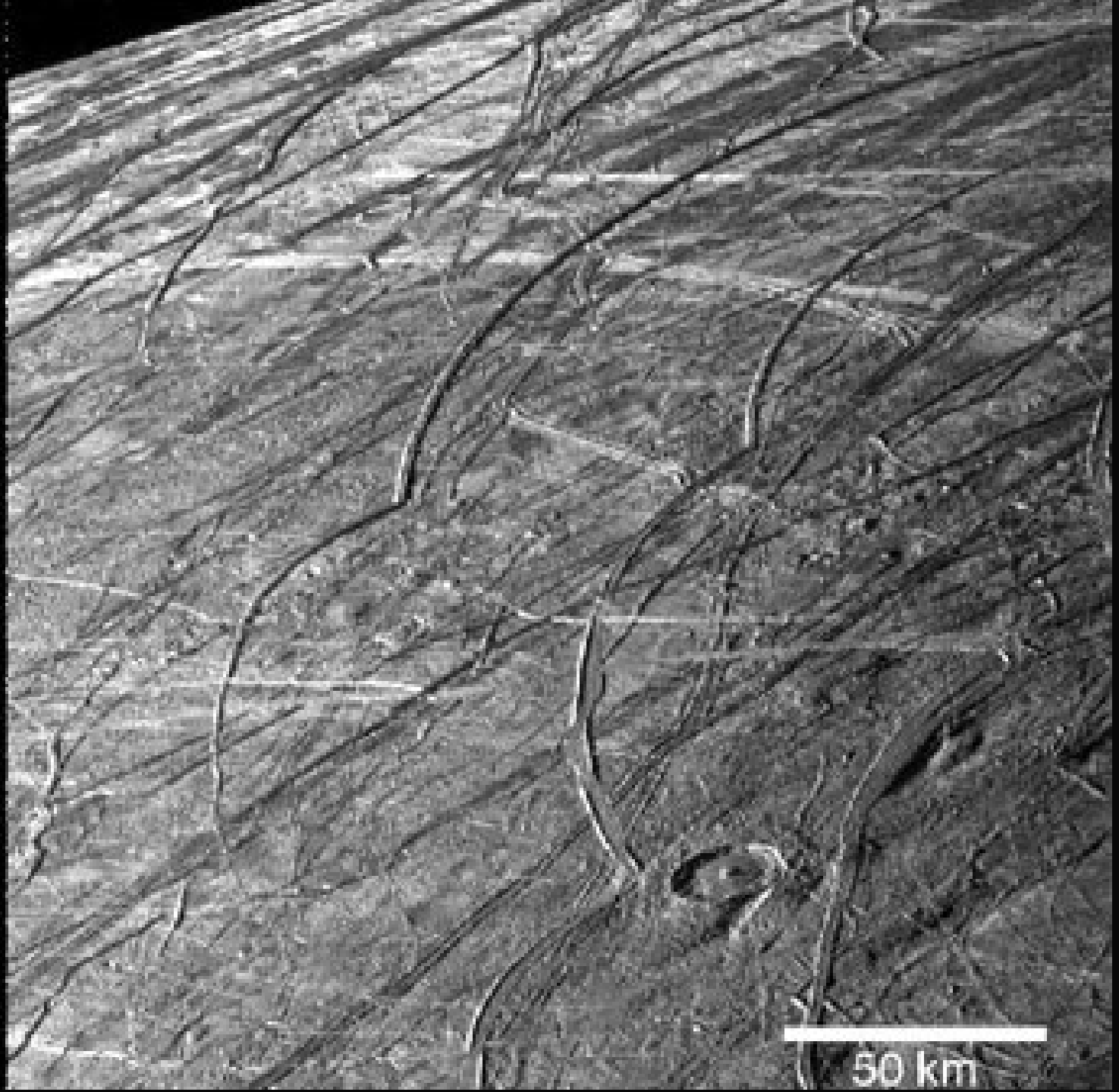
Surface is covered in ice (water ice!) and crisscrossed with long ridges ("cracks").

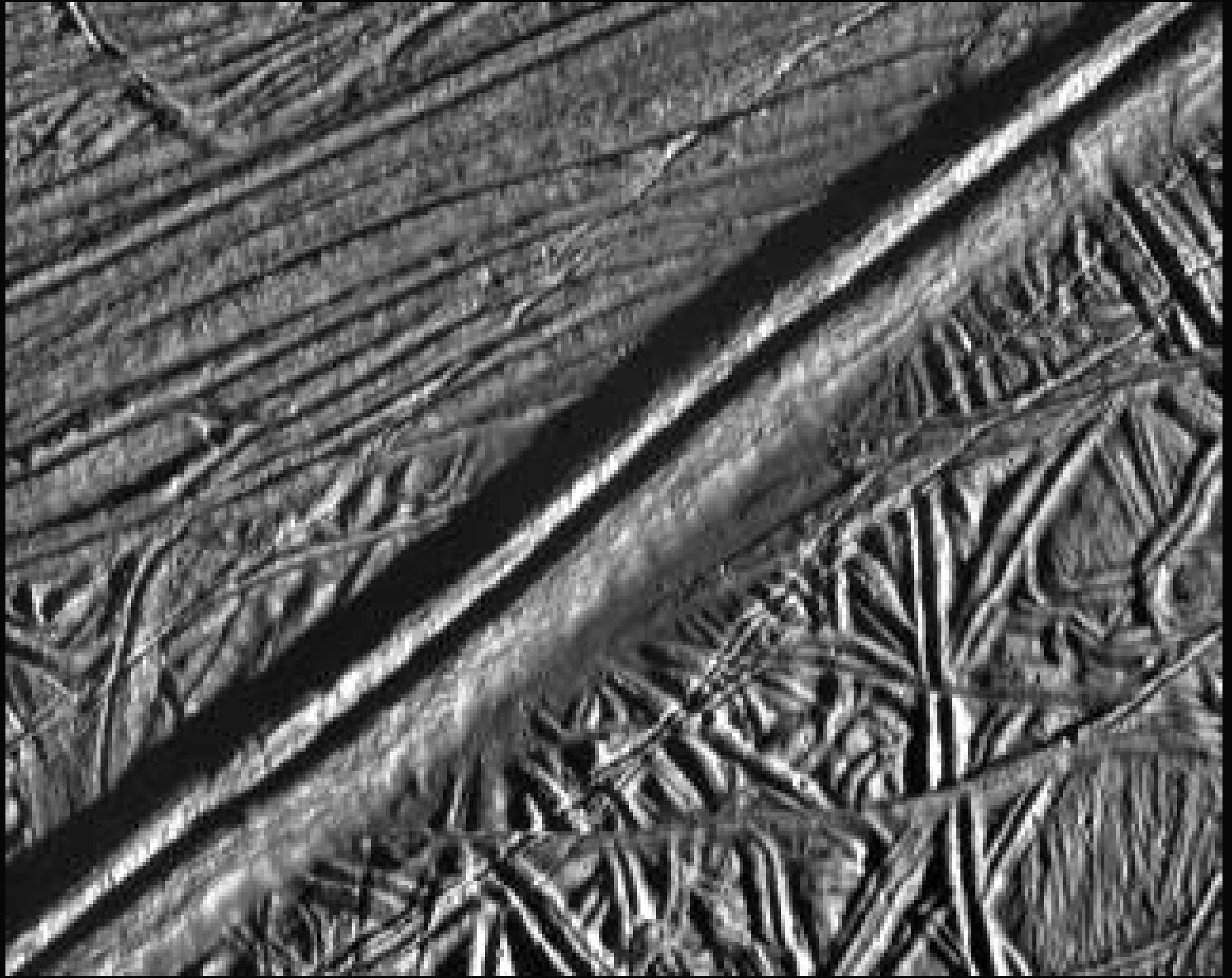
Very few craters → young surface.

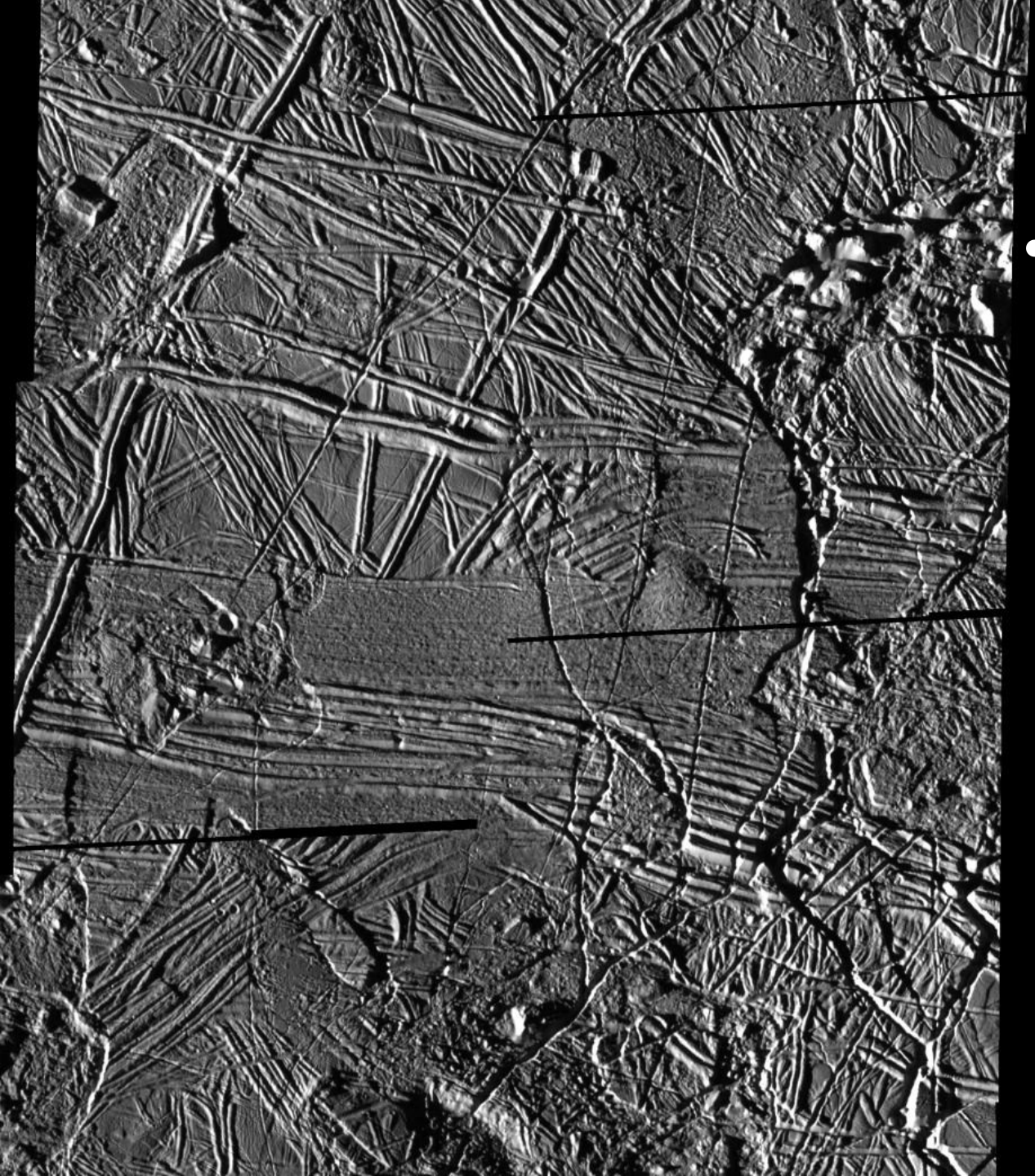
Some organic material is embedded in the ice.






50 km





# Europa

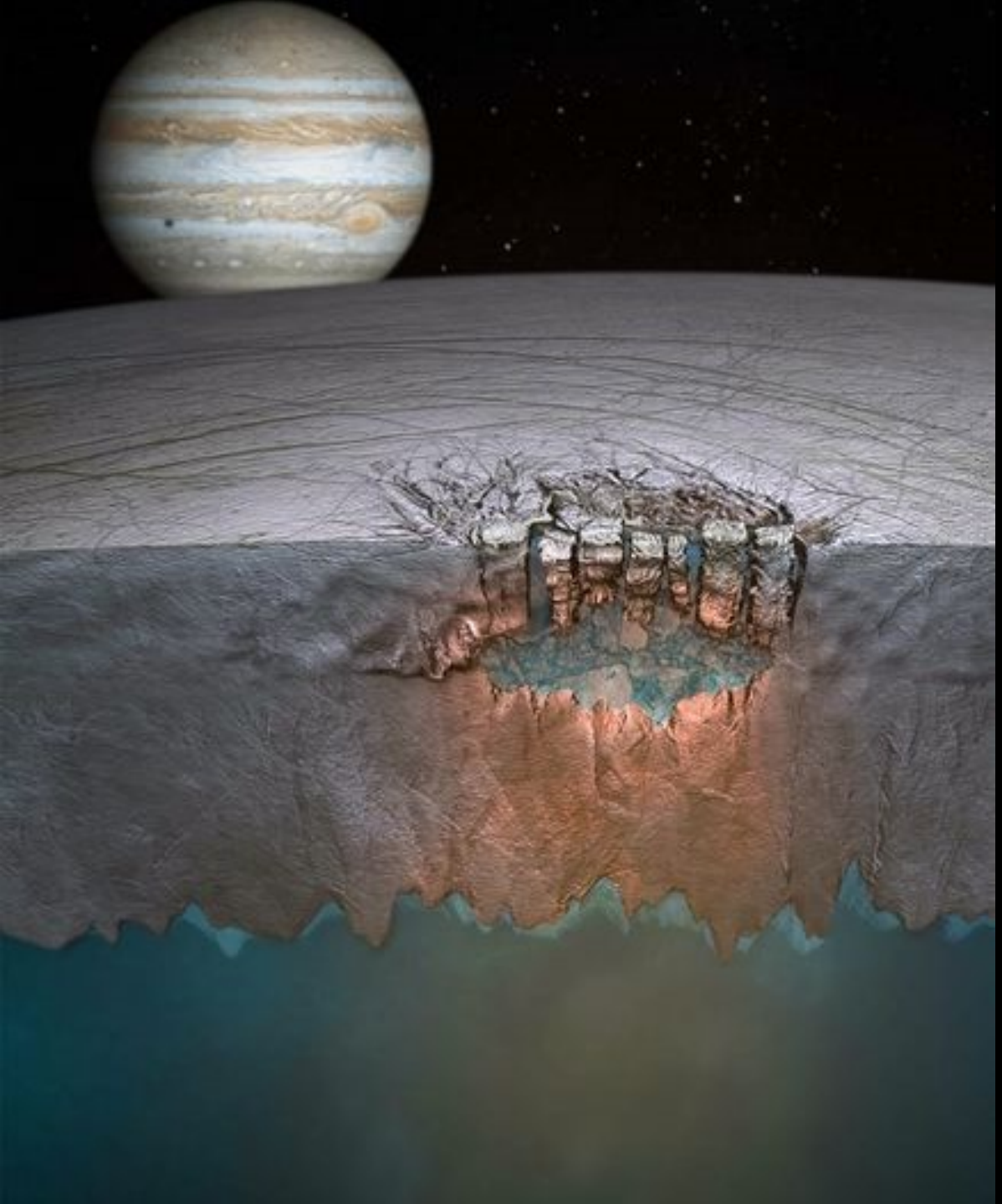
- Likely to be *liquid water* under its frozen surface - right now!

# Arguments for a possible Europan ocean:

- tidal heating *must* be present
- lack of craters
- cracked, arched, chaotic, and flooded surface features
- reaction of magnetic field to Jupiter's magnetic field
  (requires a good conductor, like salt water; probably acidic)

We are not certain how thick the ice crust is:
few hundred *meters* or few *kilometers.*

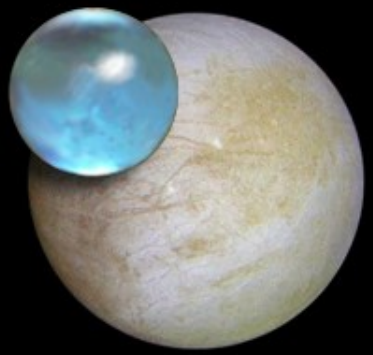
*Some* liquid water is present but how much, and how deep, is not well known.



- *Liquid water,*
- *a source of energy,*
- *organic material*

Europa contains the 3 key ingredients necessary for life.

# Europa



Europa is thought to
have more water than Earth!

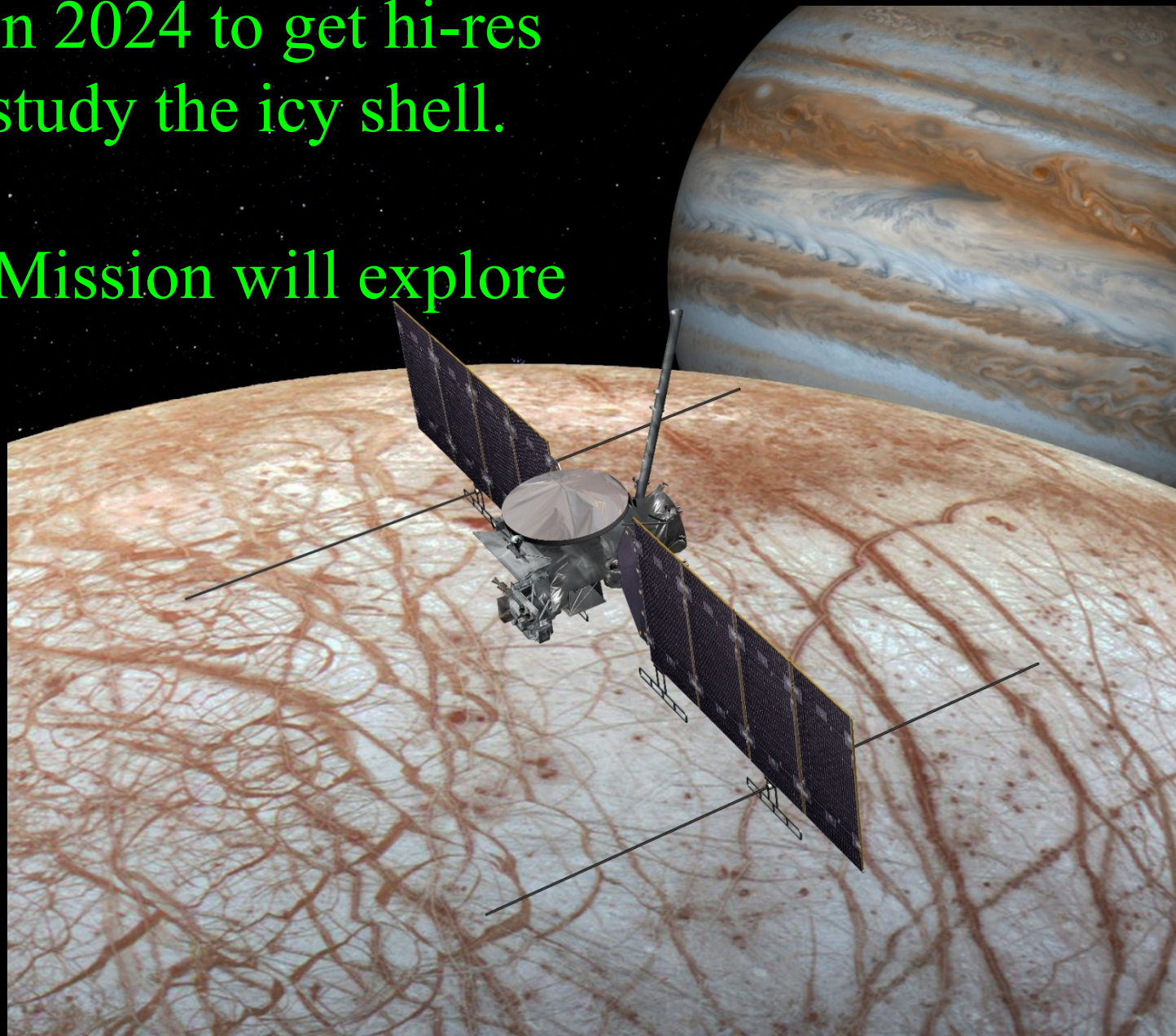
Ganymede seem to have enough internal energy to melt the ice and have liquid water under the icy crust. Therefore also of interest to astrobiology.

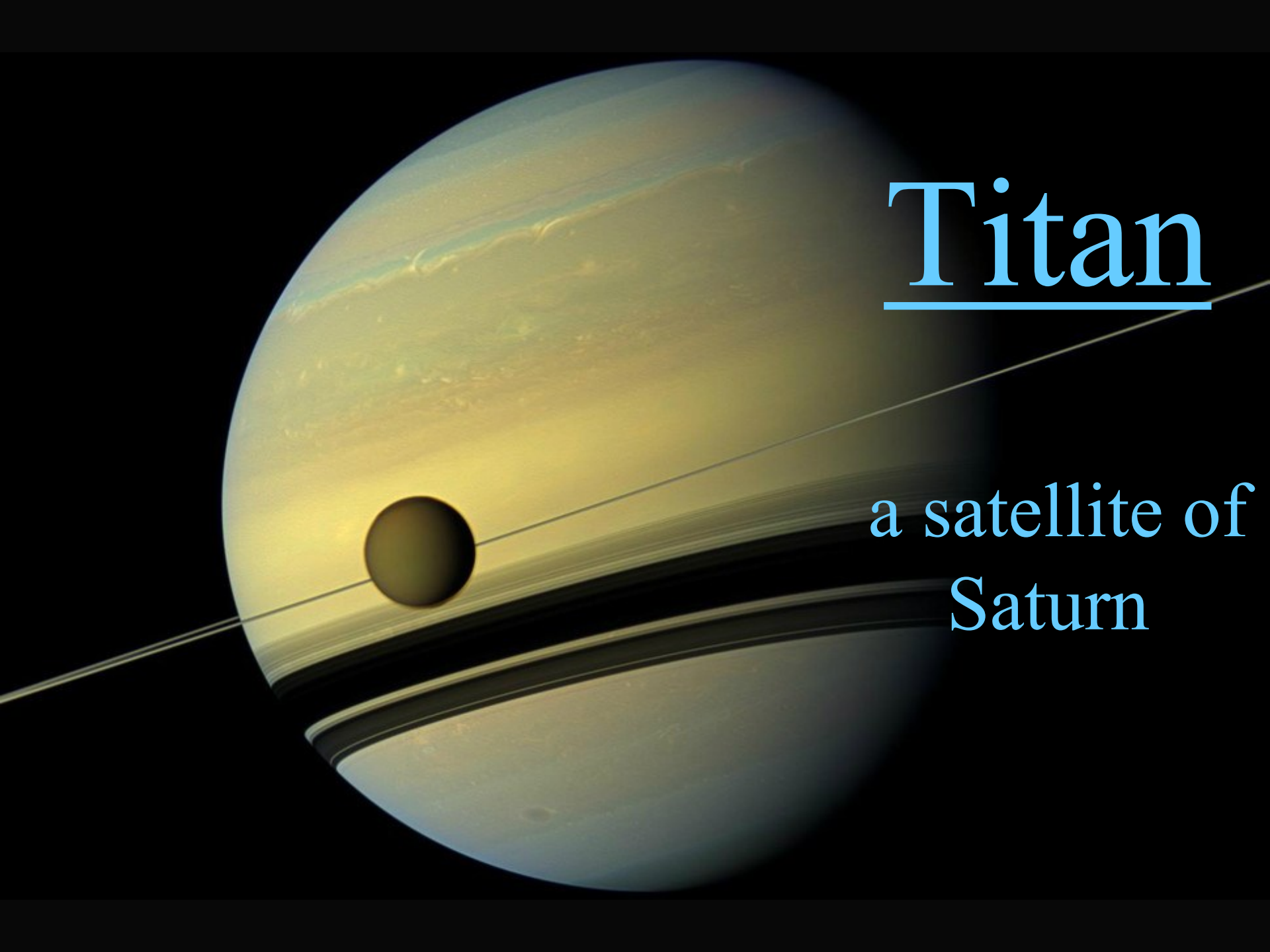
Ganymede

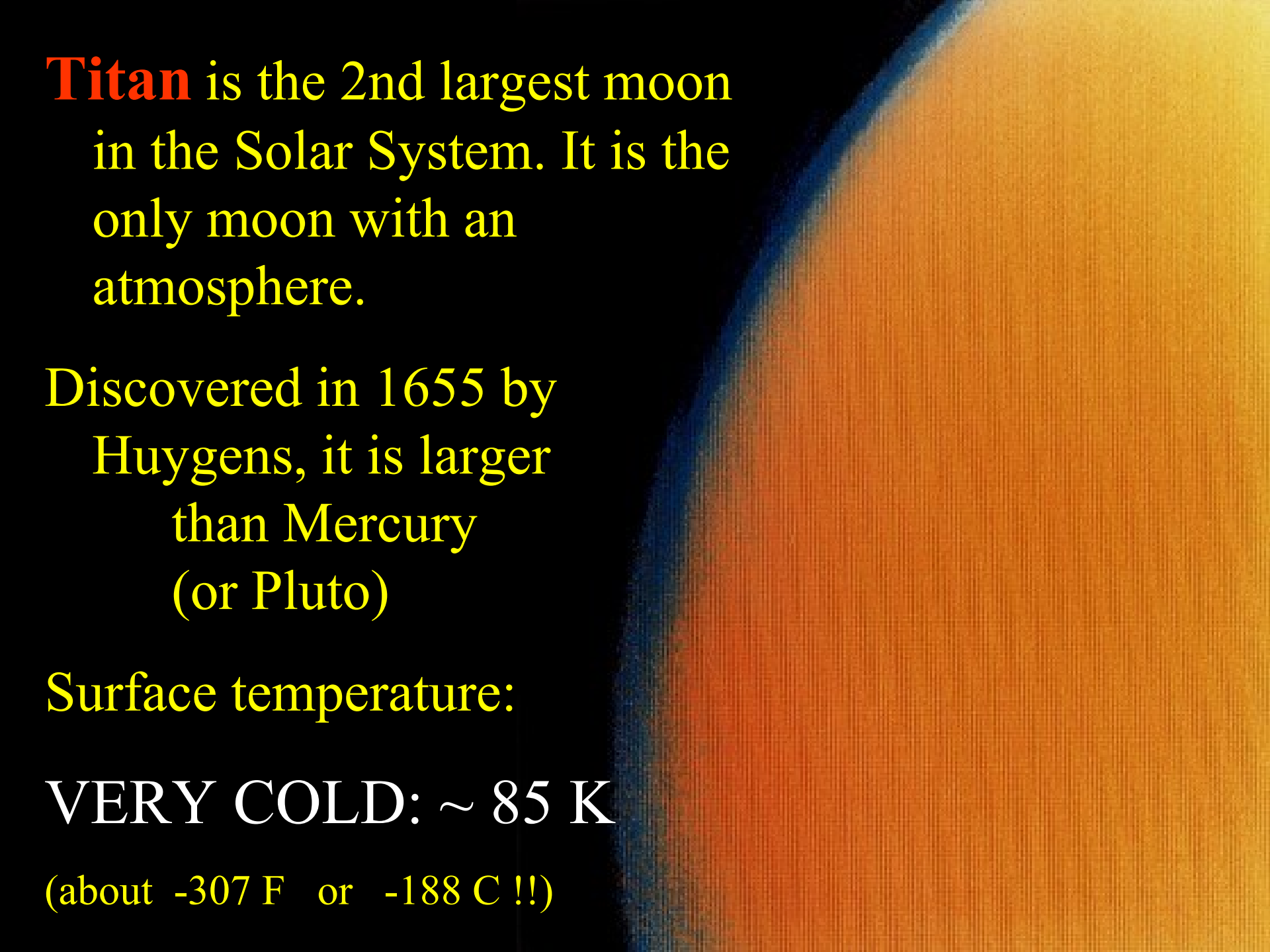
Callisto

NASA's ***Europa Clipper*** Mission will launch in 2024 to get hi-res images and study the icy shell.

ESAs Juice Mission will explore Ganymede; launched 2023 April 14




Titan
a satellite of
Saturn



**Titan** is the 2nd largest moon in the Solar System. It is the only moon with an atmosphere.

Discovered in 1655 by Huygens, it is larger than Mercury (or Pluto)

Surface temperature:

VERY COLD: ~ 85 K

(about -307 F or -188 C !!)

# Titan has a **thick** atmosphere: 1.5x thicker than Earth's!

Made mostly (90%) of nitrogen ($N_2$).

But the atmosphere is also rich in ***organic*** material. In particular, ethane $C_2H_6$ is very abundant. (Also contains methane, propane, acetylene, HCN, $CO_2$, etc...)

Almost impossible see surface features because the atmosphere is so full of organic "smog"!

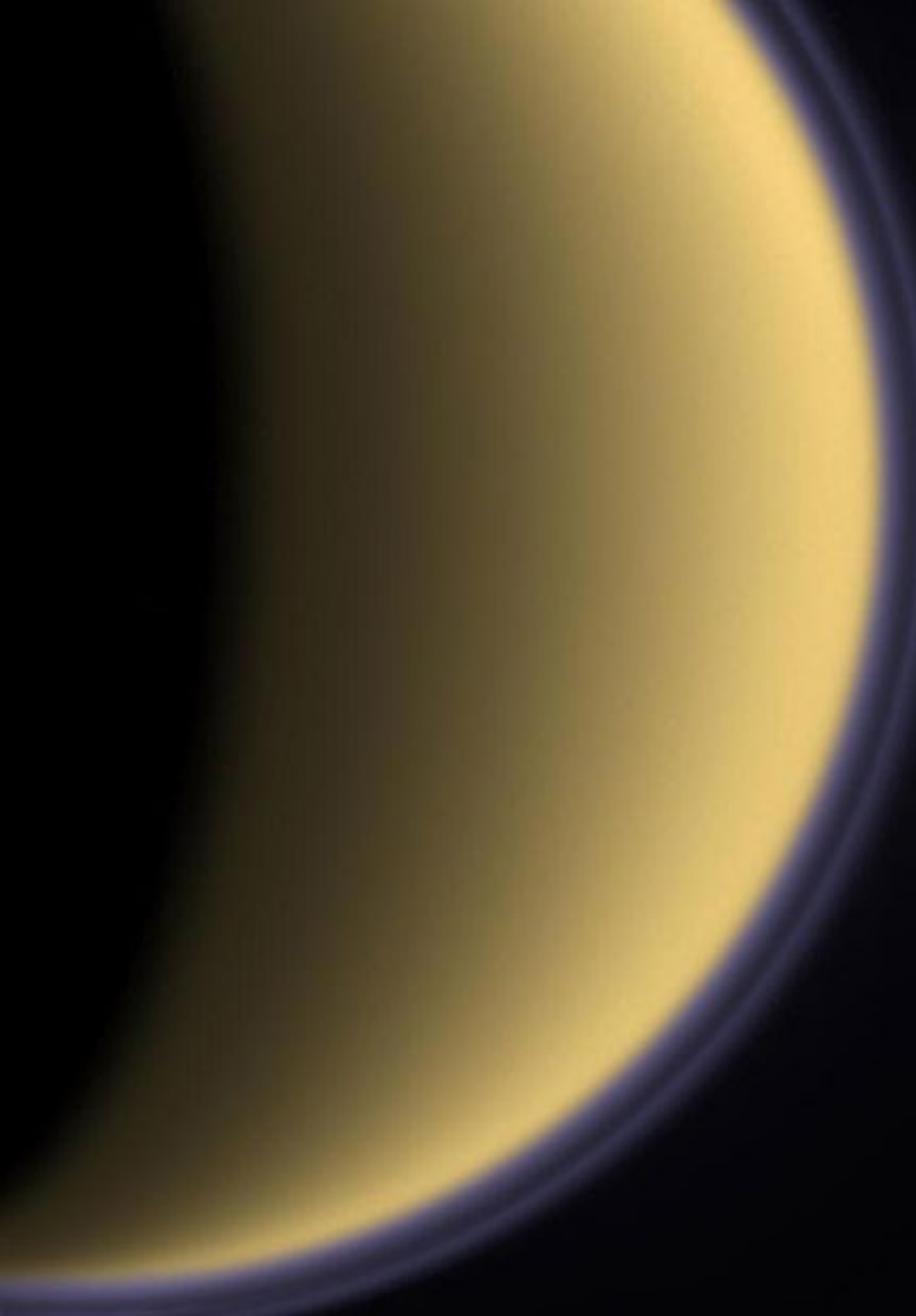
# Titan, a Satellite of Saturn

The atmospheric temperature and pressure are such that there are

- clouds of nitrogen and methane,
- liquid nitrogen rain,
- and lakes or seas of ethane!

And perhaps continents made of rock-hard water ice.

a fun braai!



# Titan

Given the very rich concentration of organic material, and lakes of liquid ethane,

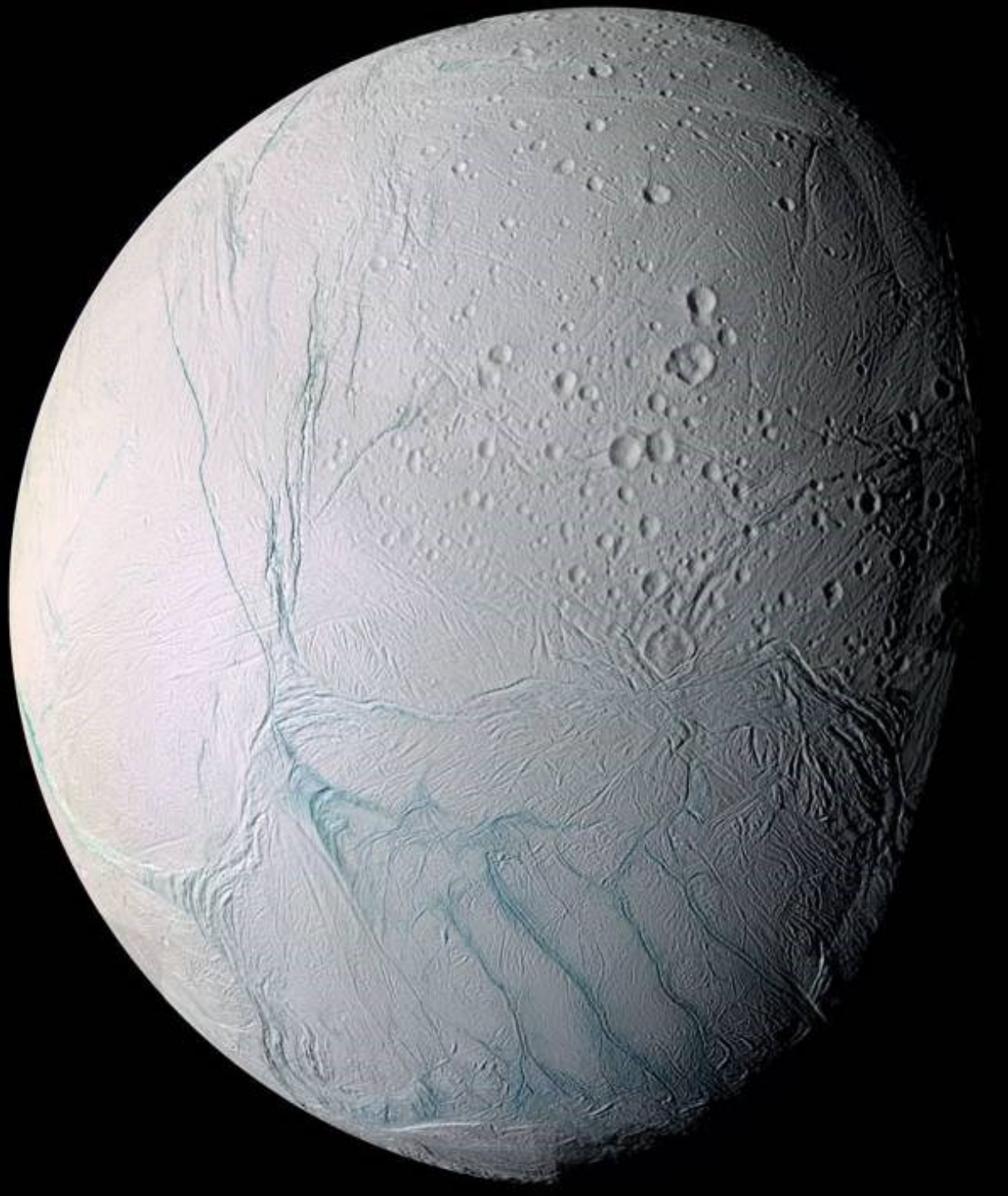
***Titan has the potential for extraterrestrial life.***

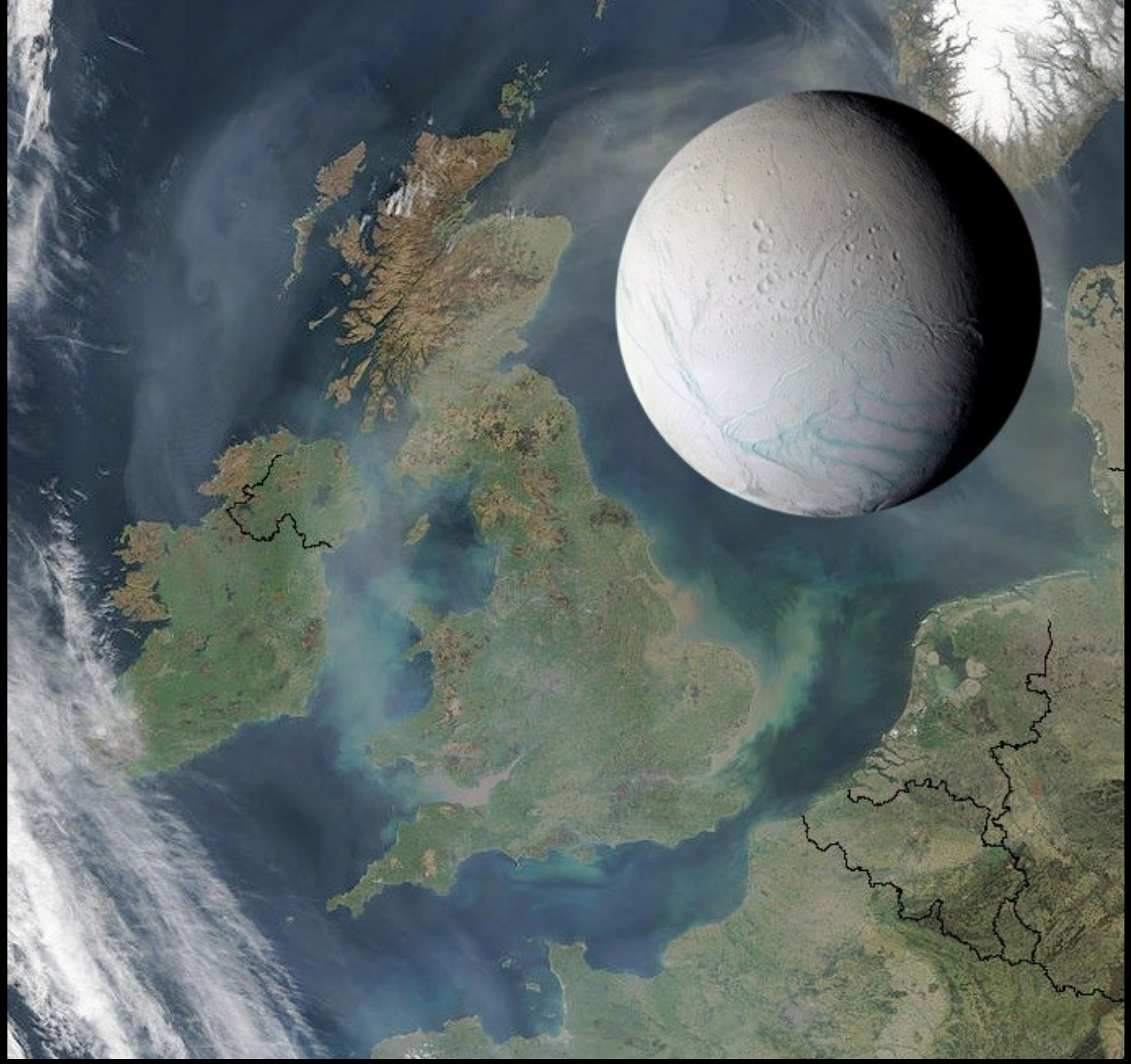
# Titan

But life on Titan would be more interesting than life on Mars or Europa since it would NOT be water-based life.

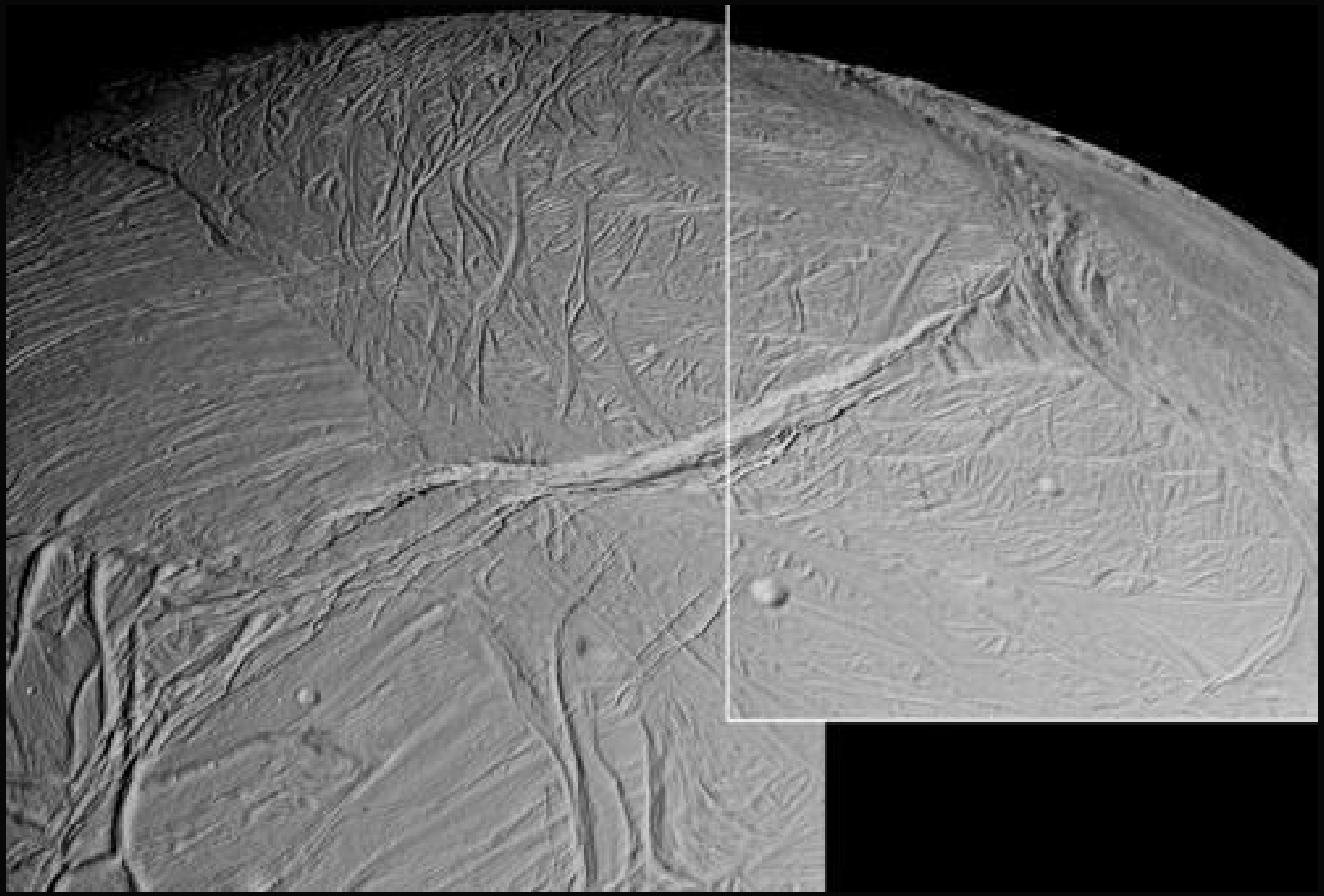
Though deep under the ice, there could be liquid water.

# Enceladus –
a moon of Saturn similar to Europa

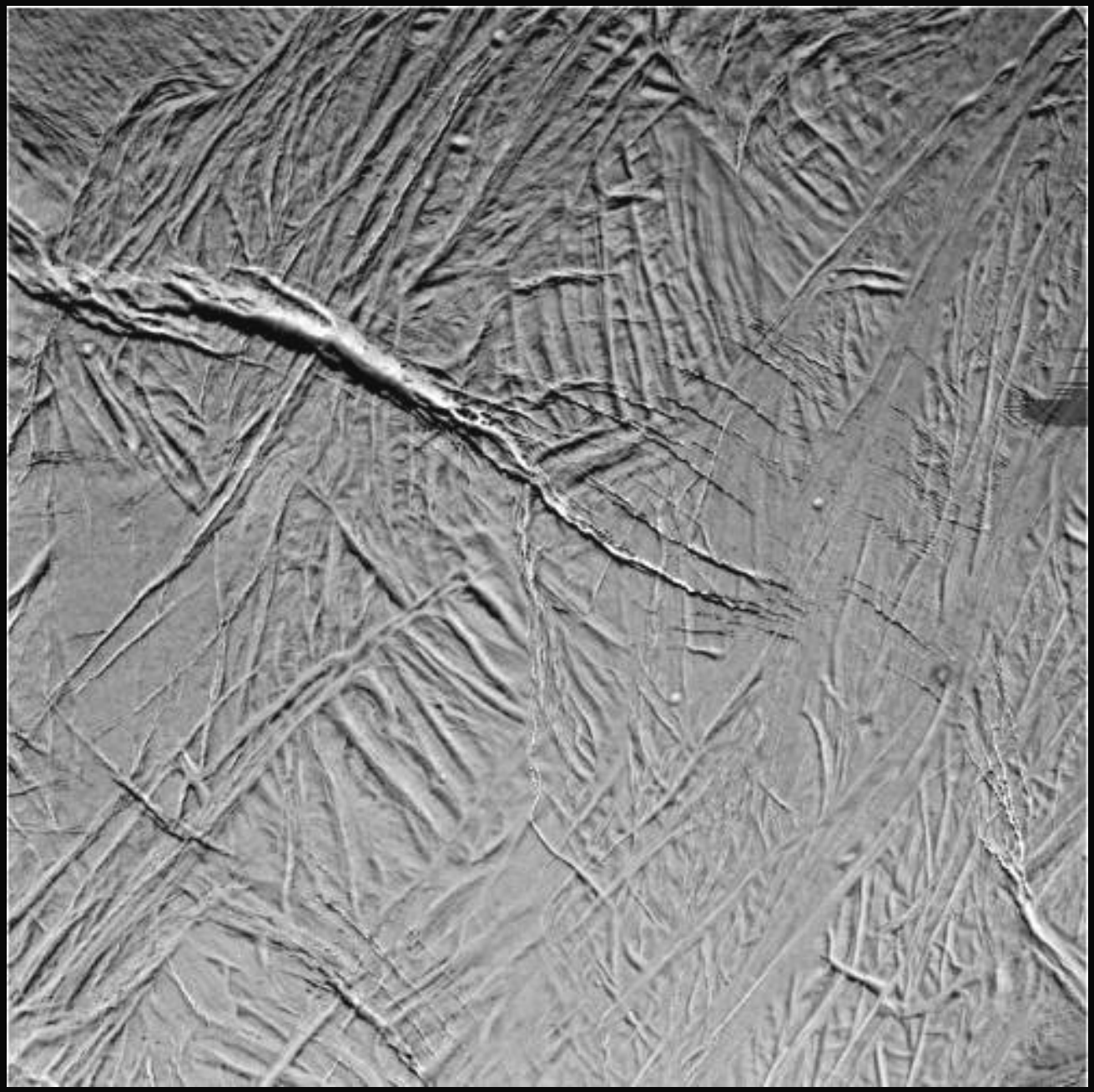




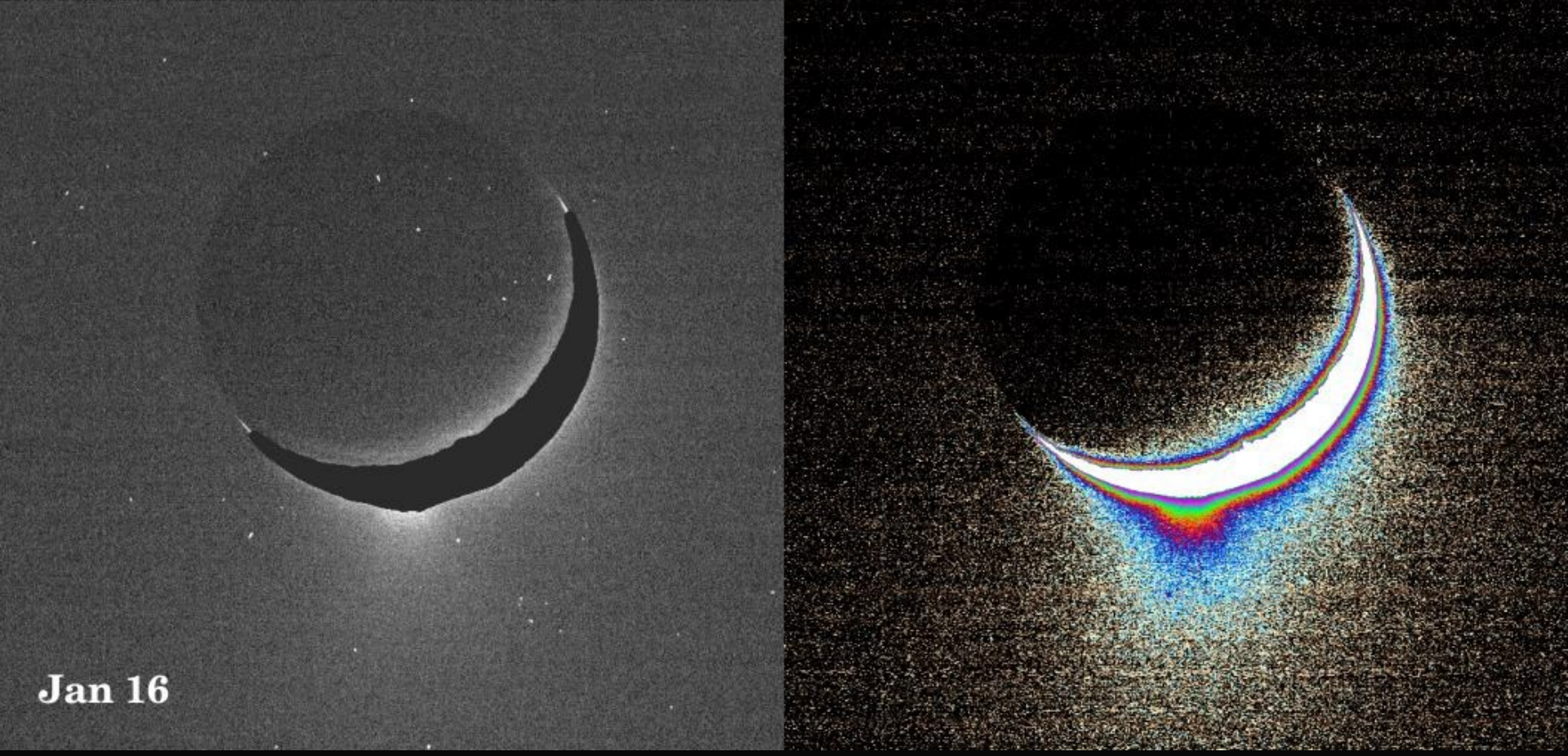
Comparison of Enceladus and the UK



Enceladus close-up: Saturn's version of Europa?

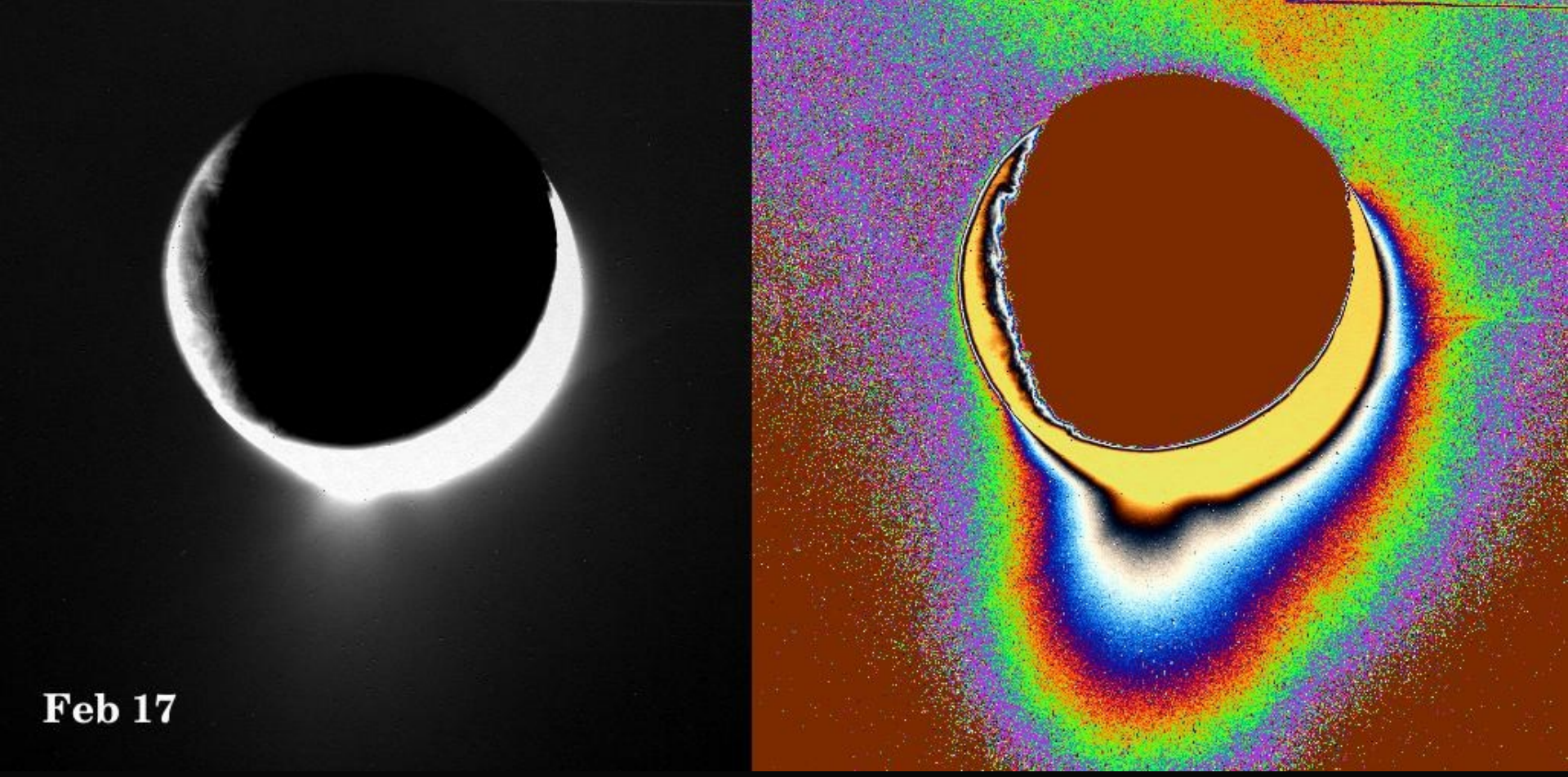


Enceladus close-up: Saturn's version of Europa?



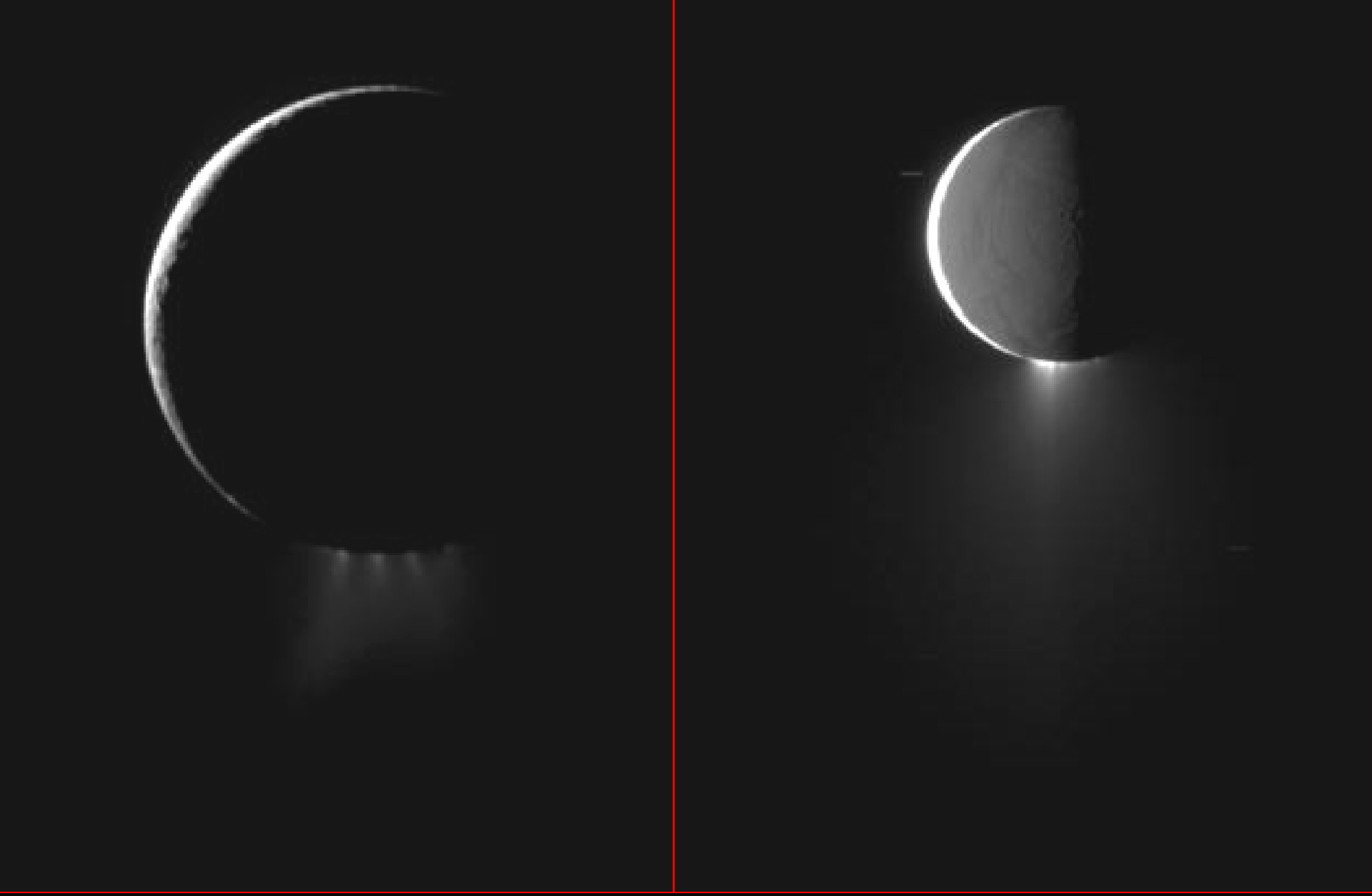

Cassini images of erupting geysers on Enceladus

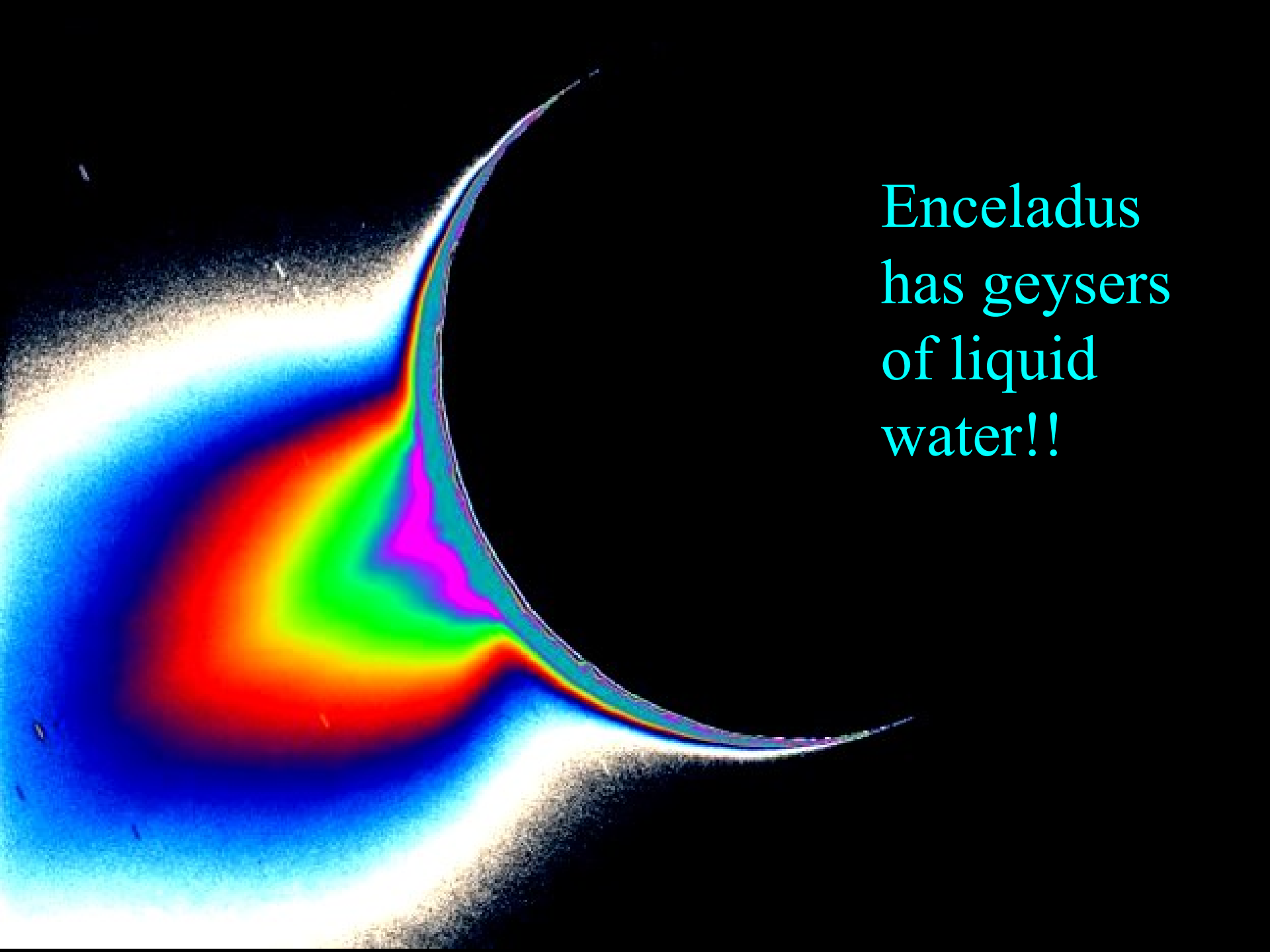
cryo-volcanism: water+ammonia volcanic eruption




Cassini images of erupting geysers on Enceladus

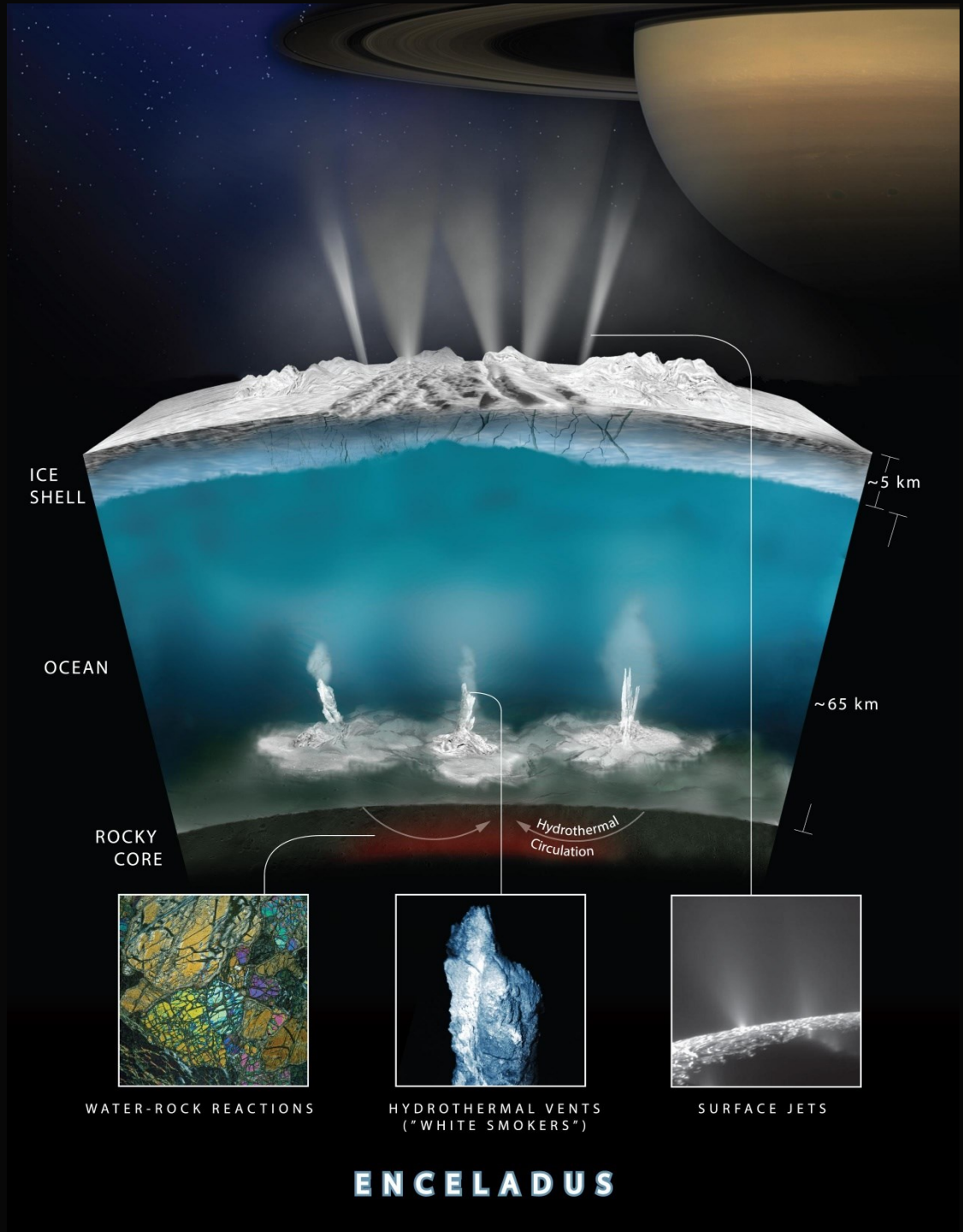
multiple water+ammonia volcanic eruptions on Enceladus: implies the presence of a lot of liquid water




Enceladus
has geysers
of liquid
water!!

Recent *Cassini* results indicate the presence of water, $CO_2$, $CH_4$, $NH_4$ and hydrogen gas $H_2$ in the geyser plumes.

$H_2$ is important because it suggests there could be (1) hydrothermal vents (2) an energy source for life (chemically reducing environment).



With eruptions of liquid water, little Enceladus could be more likely to host life than Europa.


Titan and Enceladus

# Four Recent Major Discoveries:

1) Exoplanets

→ billions of worlds

2) Extremophiles

→ extending the limits of life

3) Rapid Origin of Life

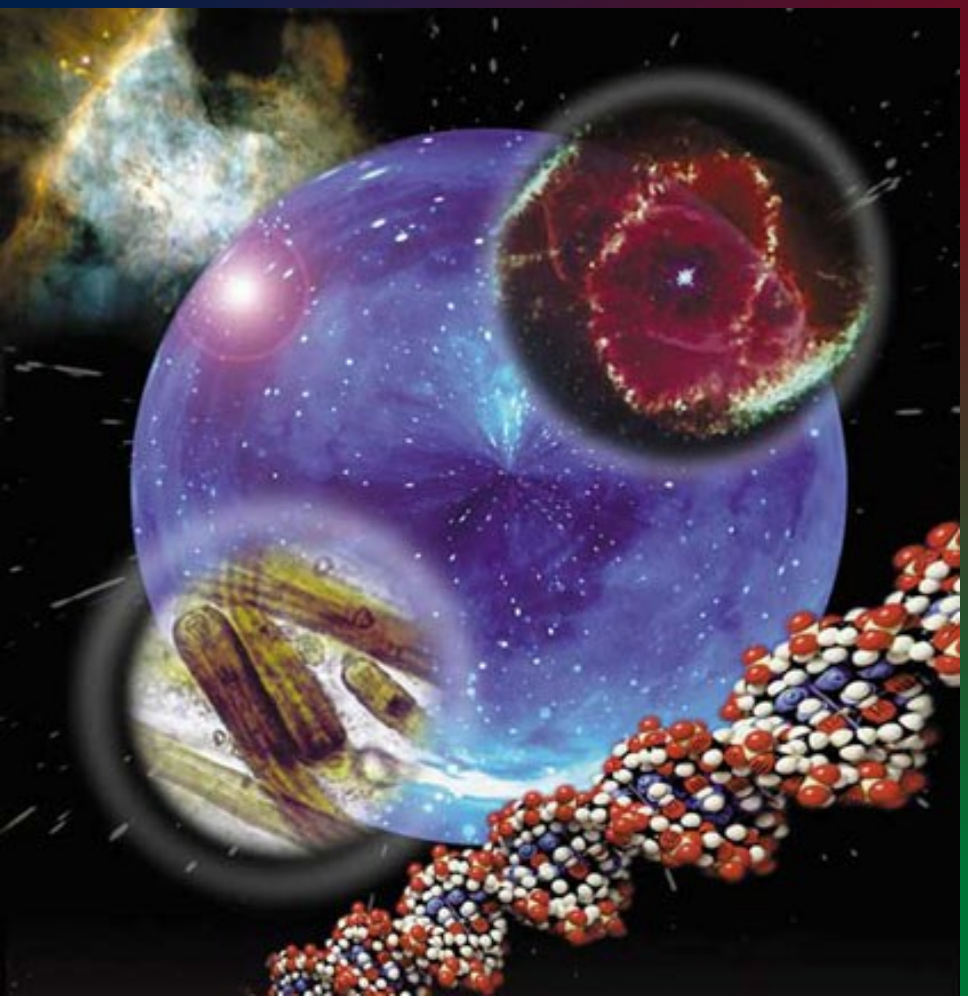
→ not a miraculous event

4) Icy Moons

→ life not limited to the habitable zone

# Astrobiology

## Life in the Universe




***William Welsh***

San Diego State University


2024 July 25

for the

Namibia Scientific Society

Wissenschaftliche Gesellschaft

*Science for Society*

# NBC Learn: *Science Behind the News*: "Extrasolar Planets"