

**Fertile Ground in Our Cosmic Backyard?
How to Find Life Elsewhere in Our Solar System
and What It Would Mean to Succeed**

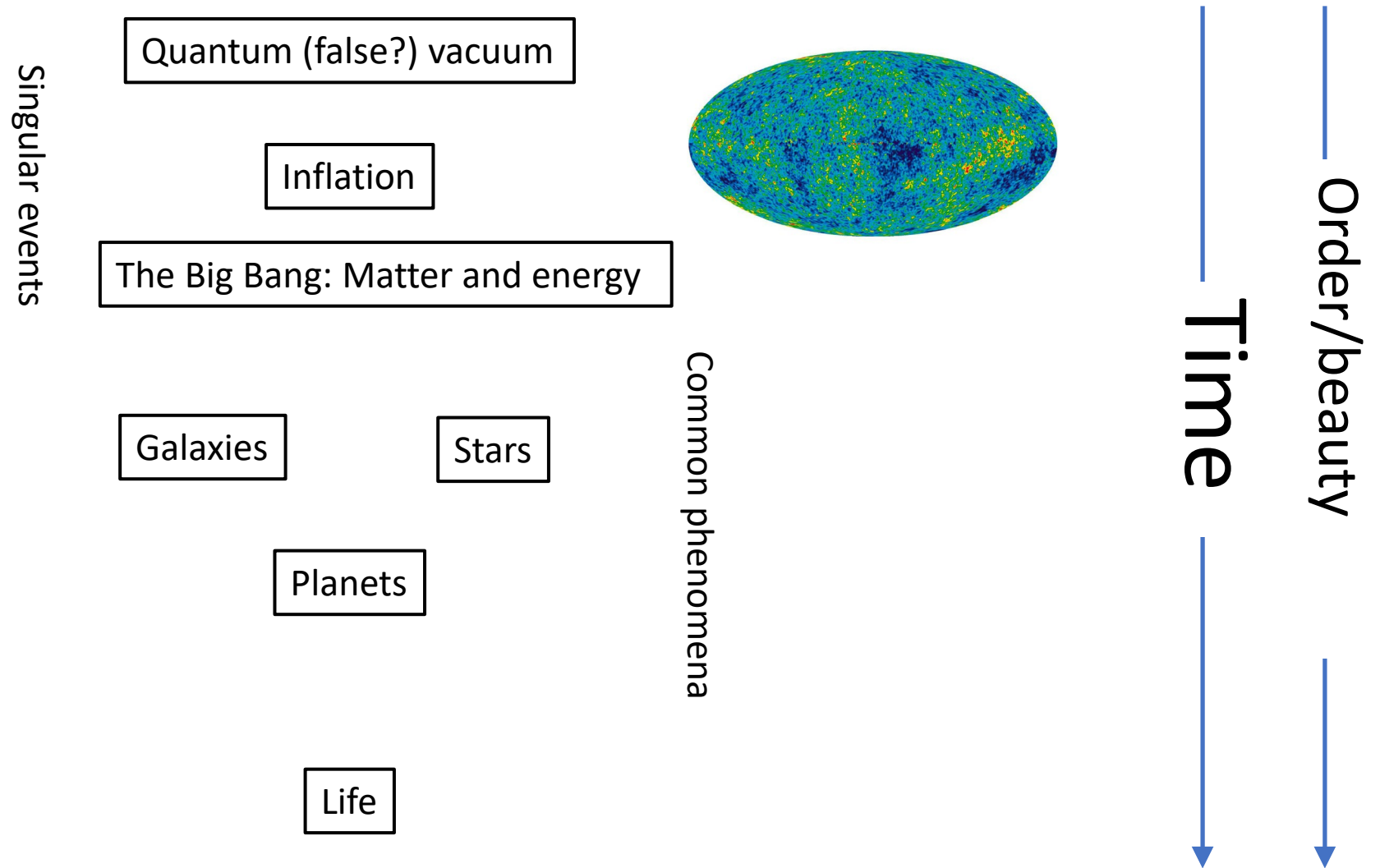
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Cornell University

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Pontifical Faculty of the Dominican House of Studies
(Spring 2023)

Q1: Is the origin and prevalence of life baked into the nature of the cosmos?



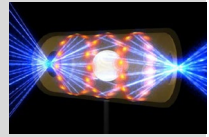
Is life a singular event (Earth) or a common cosmic phenomenon?

The Cosmic Calendar



Big Bang

First stars



Enough heavy elements for planets



Earth forms



First cells



First animals



Humans

January

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

February

S	M	T	W	T	F	S
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4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28			

March

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4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

April

S	M	T	W	T	F	S
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8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May

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6	7	8	9	10	11	12
13	14	15	16	17	18	19
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27	28	29	30	31		

June

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					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

July

S	M	T	W	T	F	S
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15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

August

S	M	T	W	T	F	S
			1	2	3	4
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12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

September

S	M	T	W	T	F	S
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16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

October

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14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

November

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

December

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

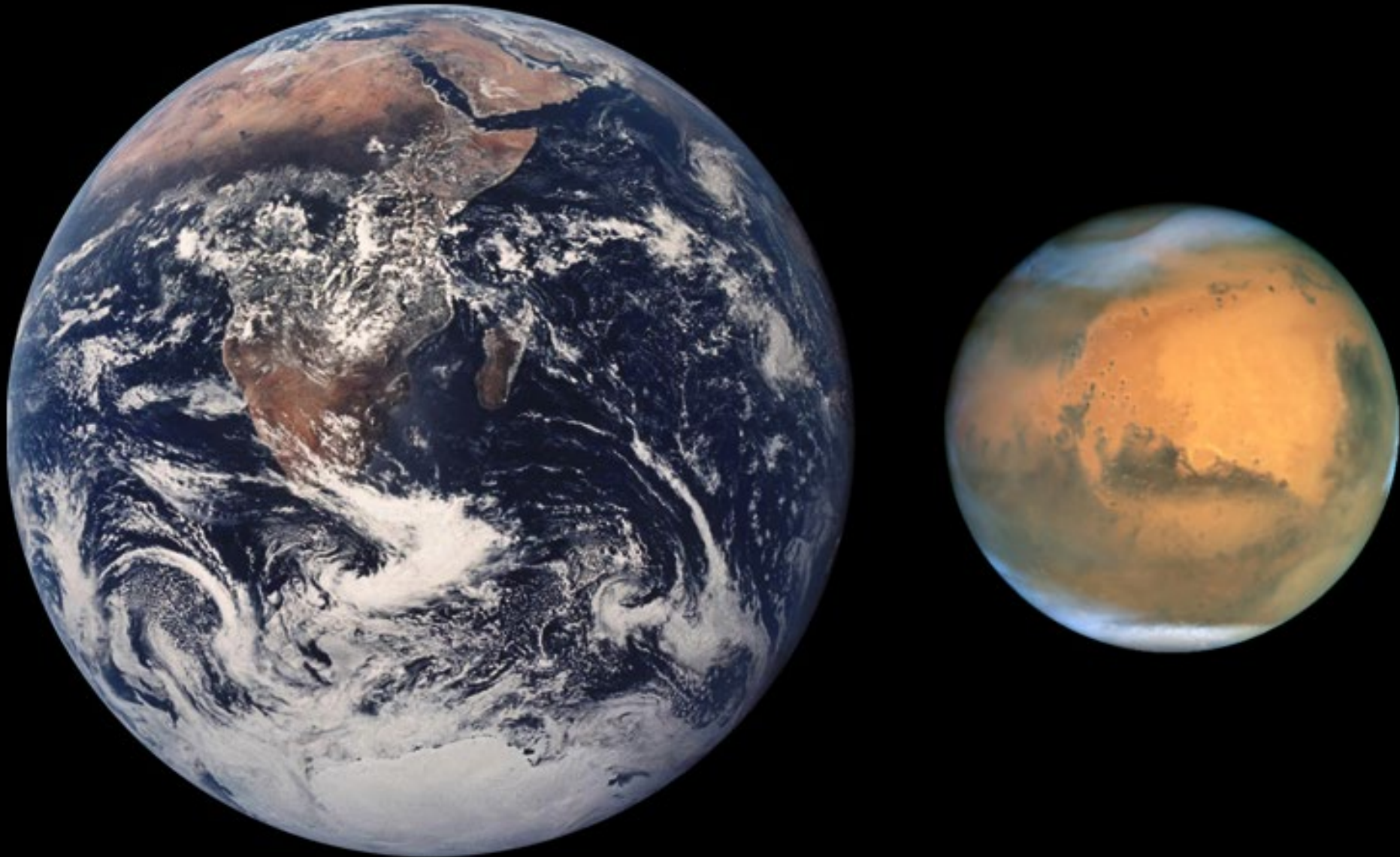
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Q2: In searching for life, where and what do we search for?

Microbes in our solar system are the best bet

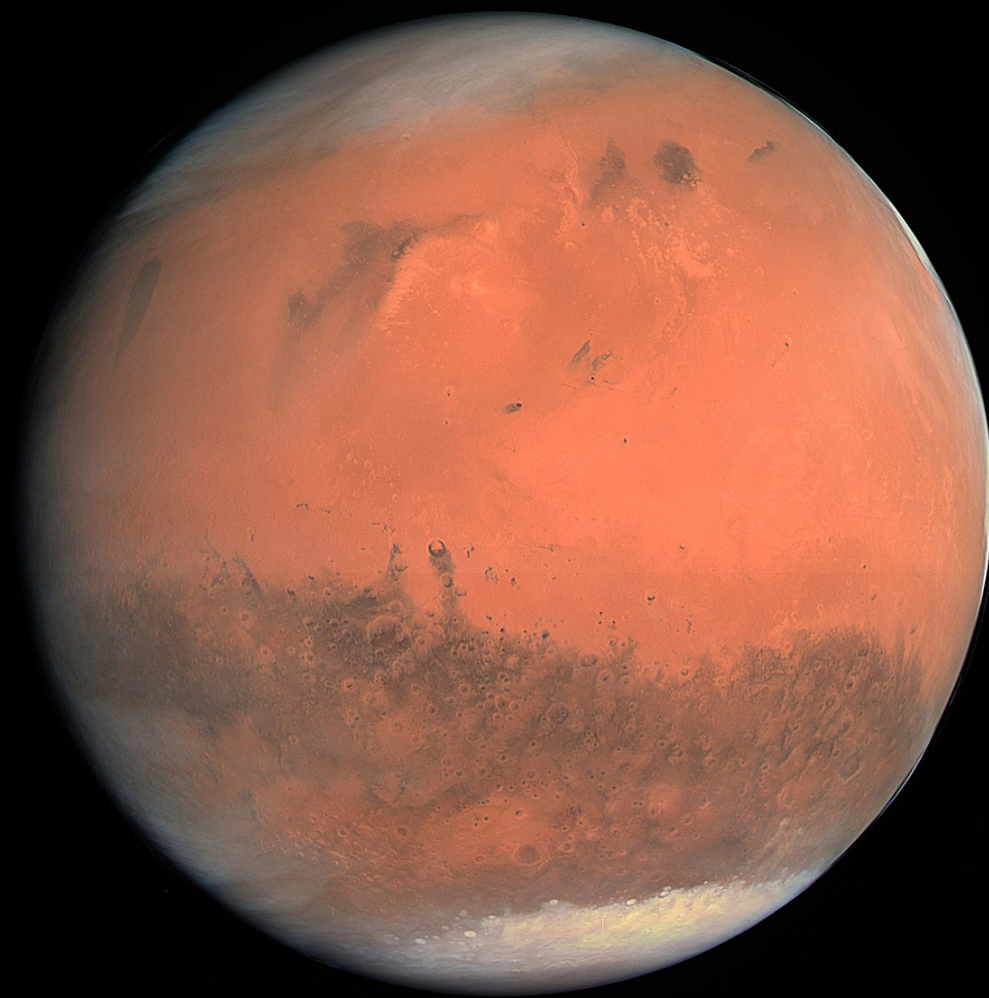
- SETI: A roll of the dice. But what if self-aware intelligent beings
 - aren't there?
 - aren't talking?
 - aren't enough like us to be recognizable (self-aware but not intelligent, intelligent but not self-aware, or something else)?
- Search for life in the planets of our Galaxy by telescopes?
 - We are just now at the point of being able to observe atmospheres
 - It will be difficult to find clear evidence of biology on an exoplanet
- Search for microbial life in our solar system?
 - Microbial life began very early on our own planet
 - One can do direct chemical tests without having to drill into the crust or ocean
 - One can potentially bring microbes back to Earth for study

Mars is $\frac{1}{2}$ the diameter and 10% the mass of Earth. A rocky planet.



Atmospheric conditions today on Mars

- Air predominantly carbon dioxide
- Air pressure at surface averages 6 millibars (0.6% air pressure on Earth at sea level). Varies by a factor of two seasonally.
- Water is only 10 parts per million. Air very dry!
- Solar UV radiation pounds the surface: destroys essentially all organic compounds exposed at the surface.



Mars Today

Mars 3.5 Gyr ago?

Water on Mars **past** and **present**: Evidence from Orbiters and Landers

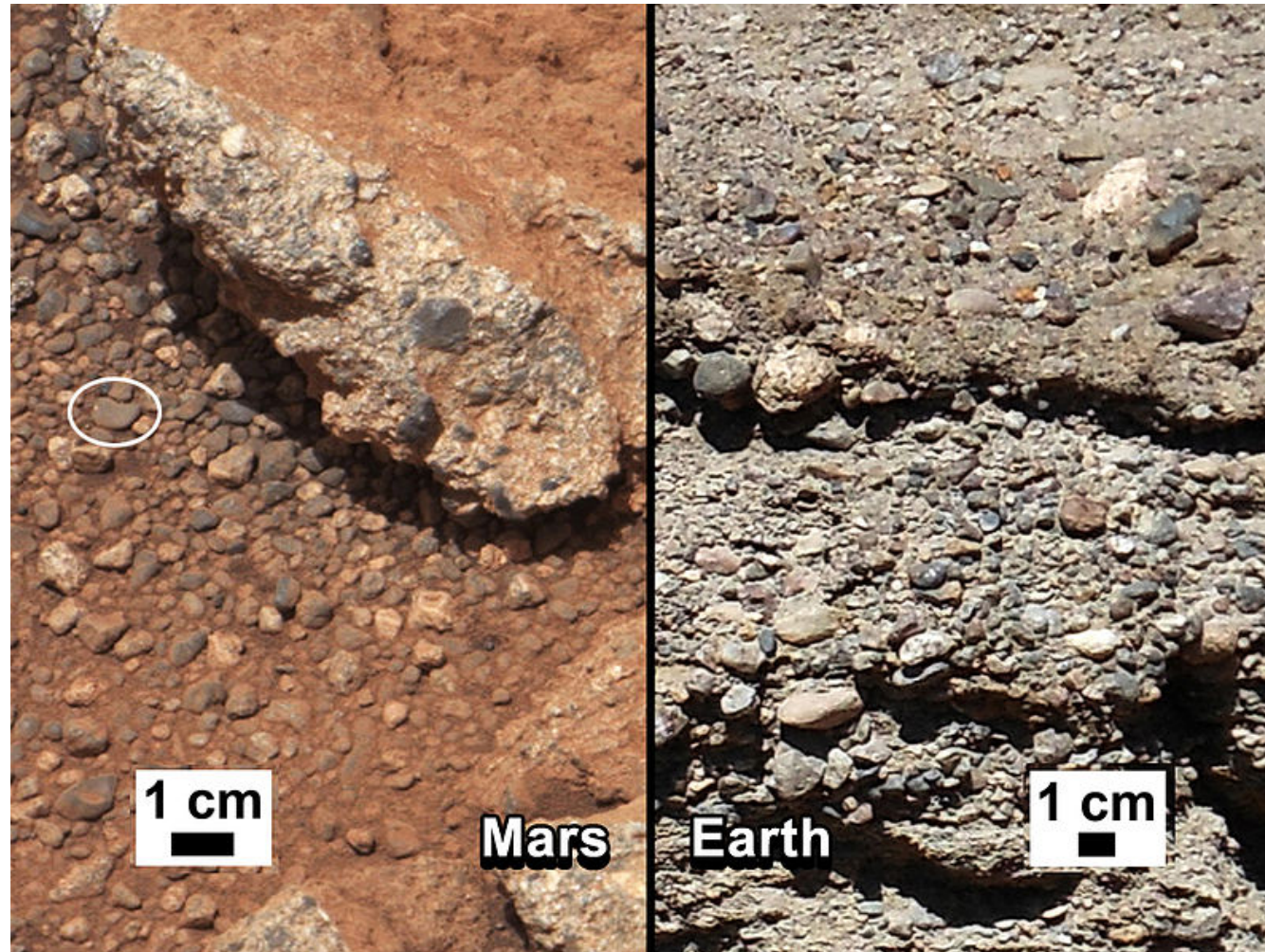
1. Hydrogen in the soil
2. Layers in the crust detected by orbiting radar
3. Polar ice caps
4. Valley networks and outflow channels
5. Sulfates and carbonates exposed on the surface
6. Minerals and “cross-bedding” indicative of water at various rover sites
7. Mudstones at Curiosity and Perseverance sites.

Curiosity near its landing site in Gale Crater finds an outcrop....



NASA/JPL-Caltech/MSSS

...with pebbles cemented into the rock suggest that there was once a stream here



VIKING 2 TEST FINDS NO ORGANIC MATTER

Results Termed Preliminary, but
Scientists Are More Doubtful
About Mars Life Search

By **JOHN NOBLE WILFORD**
Special to The New York Times

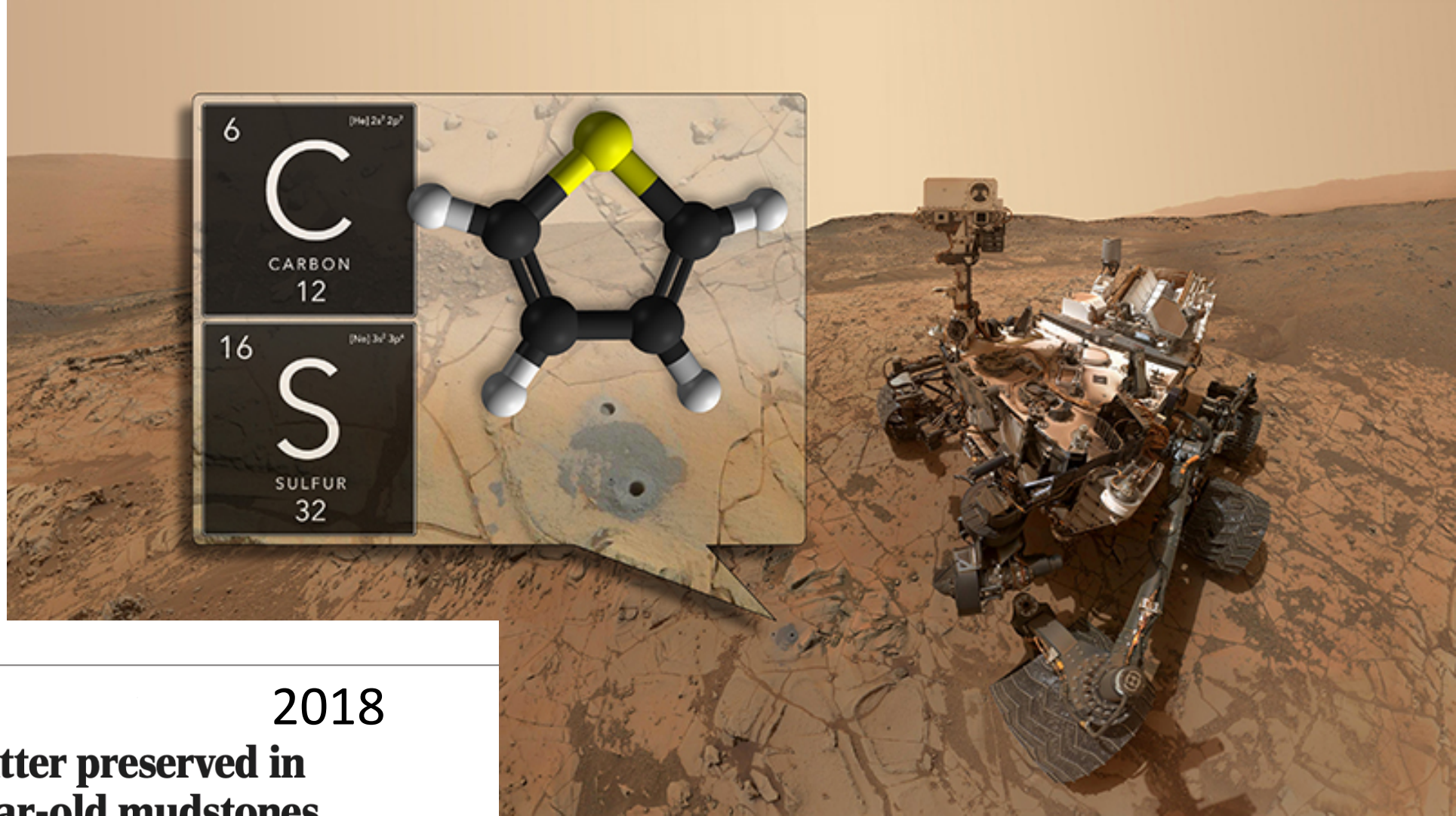
PASADENA, Calif., Sept 30—The first organic chemistry test by the Viking 2 lander has failed to turn up any evidence of organic material in the soil of Mars, project scientists reported today.

1976: Viking
Landers on Mars:
no organic matter. I
had just graduated
high school.



The search for organics has over 40
years...

Curiosity discovers ancient organic molecules on Mars



RESEARCH

PLANETARY SCIENCE

2018

Organic matter preserved in 3-billion-year-old mudstones at Gale crater, Mars

Jennifer L. Eigenbrode^{1*}, Roger E. Summons², Andrew Steele³, Caroline Freissinet^{1†}, Maëva Millan^{4,†}, Rafael Navarro-González⁵, Brad Sutter^{6,7}, Amy C. McAdam¹,

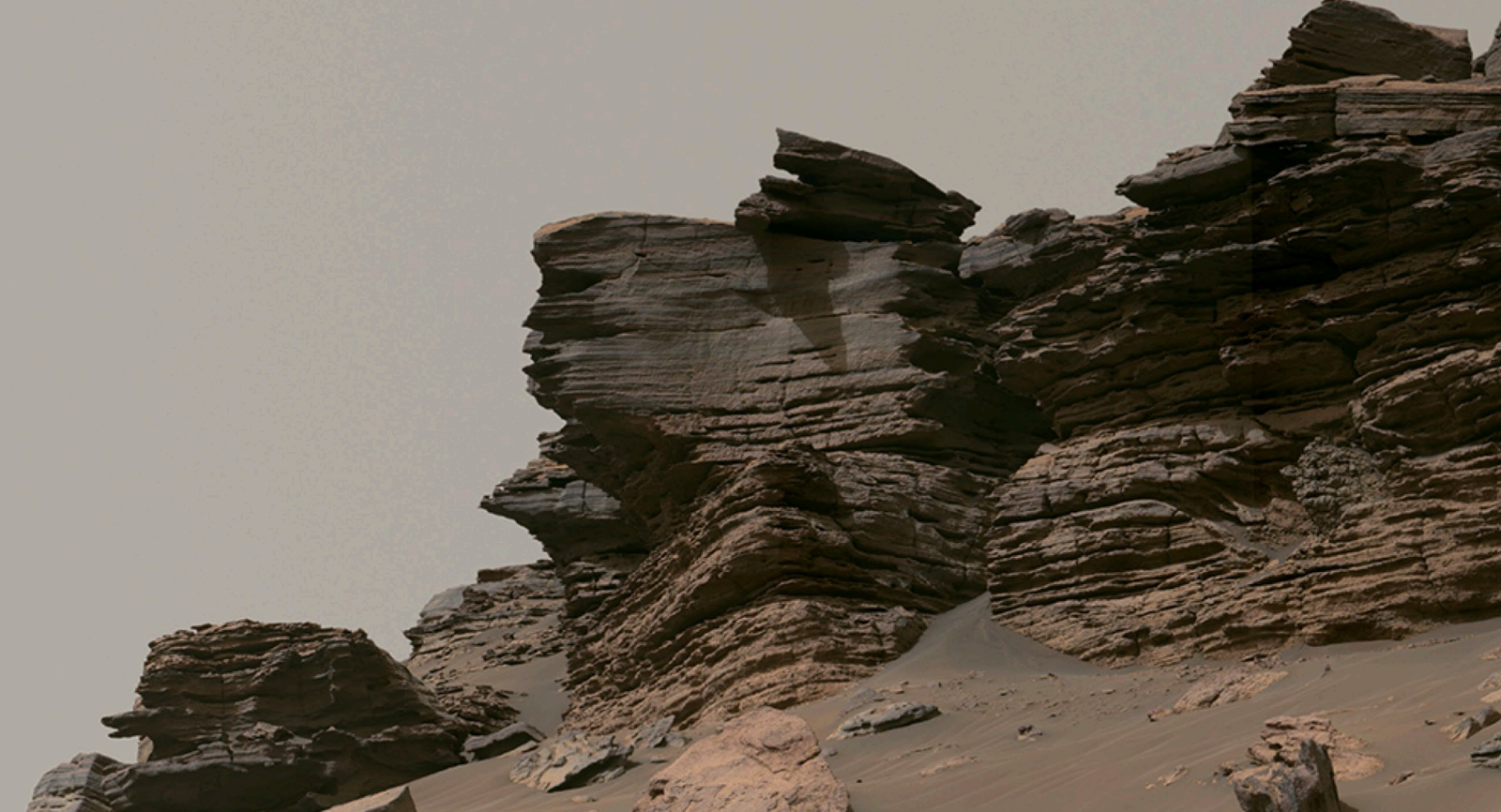
Bolstering the case for finding life on Mars...

- Areas where stable liquid water was once-upon-a-time present (Many places)
- Evidence of organic molecules (Gale Crater and Jezero Crater)
- Hints of current biology (CH_4 at Gale Crater)
- Process to return samples for analysis on Earth is underway (Jezero crater)



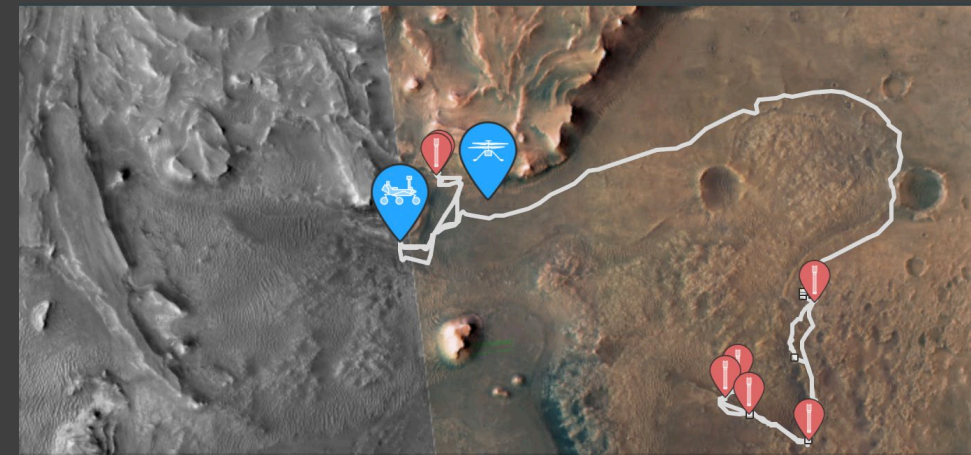
Jezero Crater

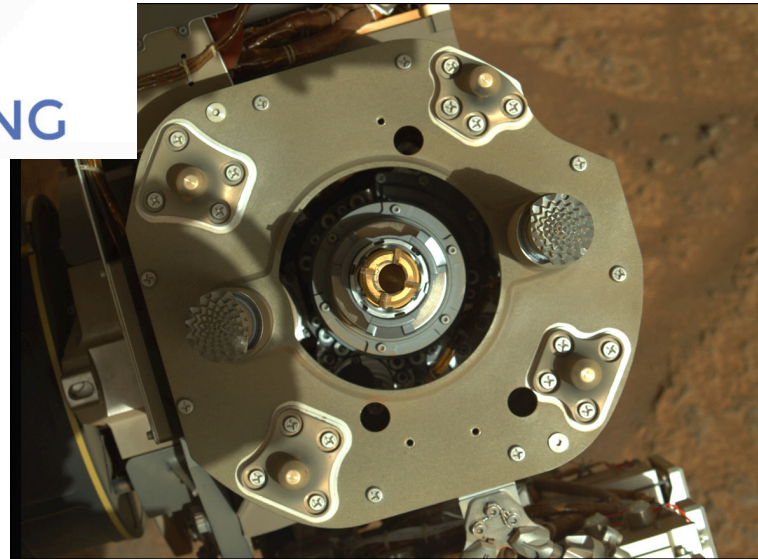
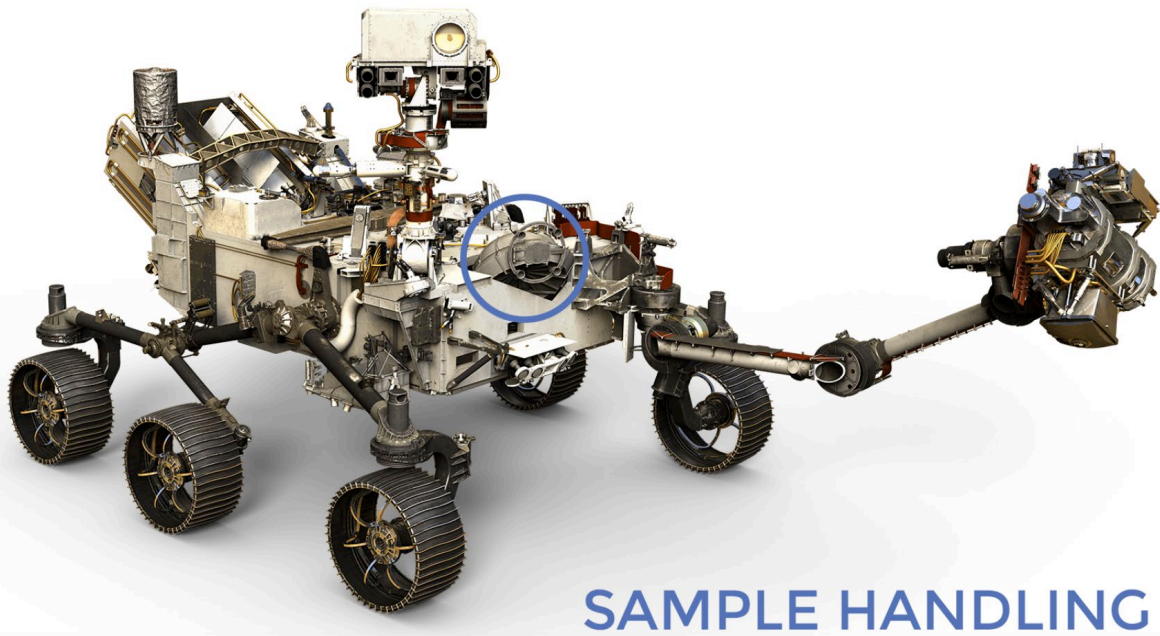
Western end



Perseverance at the
delta. Summer/fall 2022
(NASA/JPL-Caltech/ASU/MSSS)

[https://mars.nasa.gov/mars2020/mission/
where-is-the-rover/](https://mars.nasa.gov/mars2020/mission/where-is-the-rover/)





Perseverance does not carry a complex organics analyzer in its belly. Instead, it carries a sample caching system for storing tubes that will come back to Earth.







Perseverance rover seen from Ingenuity helicopter in flight (NASA/JPL-Caltech)

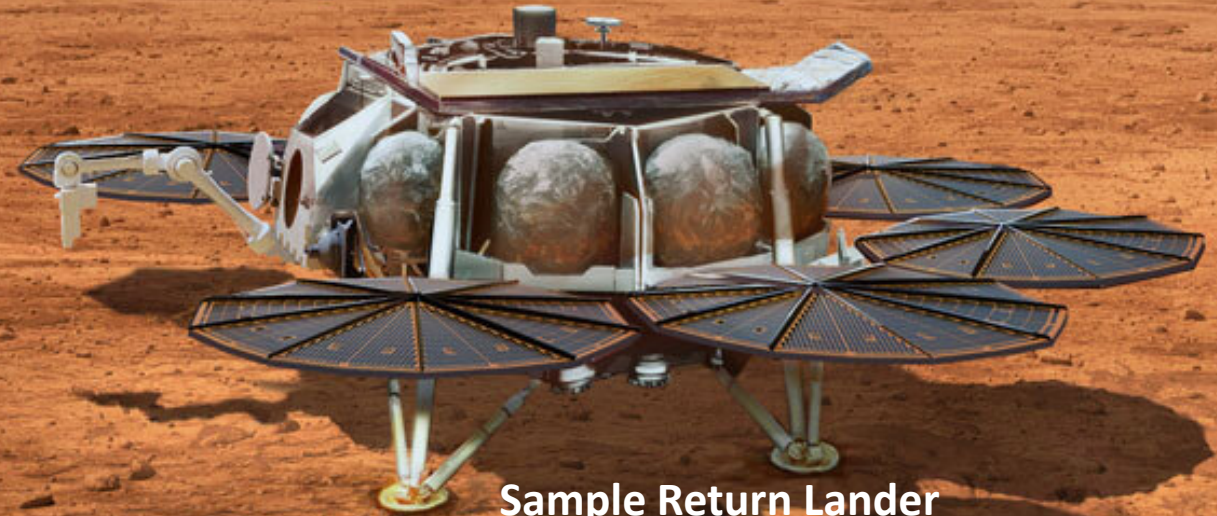
Samples will come back in
a decade.



Sample
Recovery
Helicopter

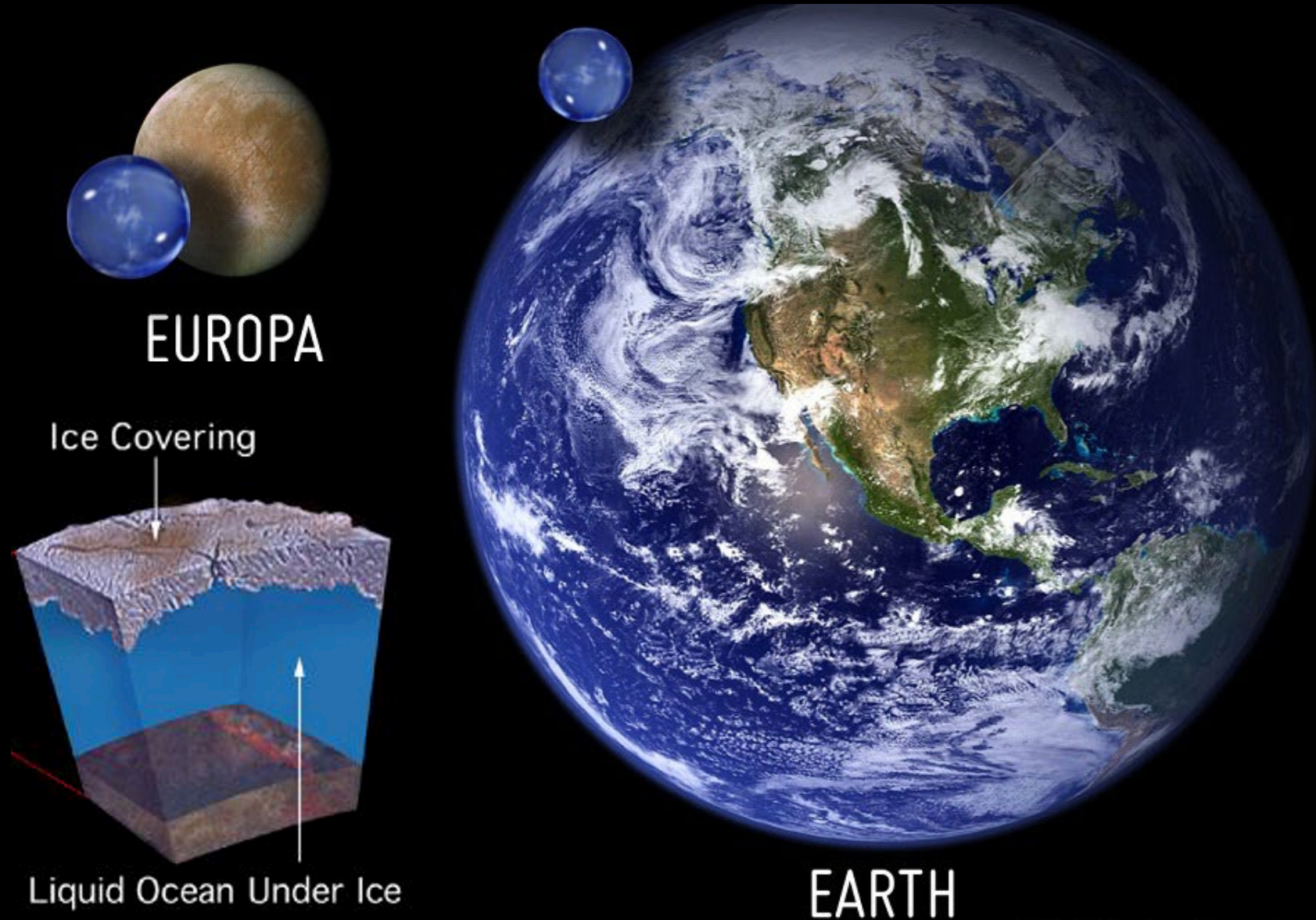


Perseverance



Sample Return Lander

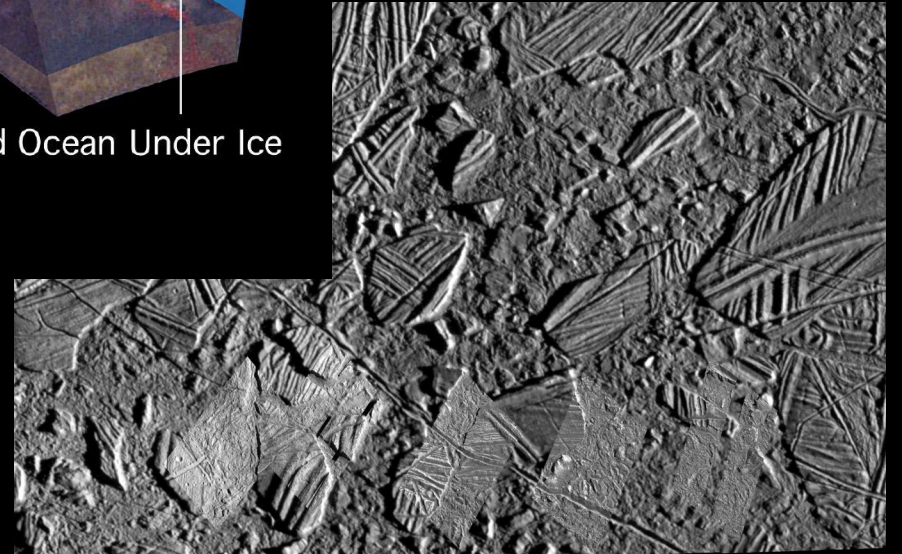
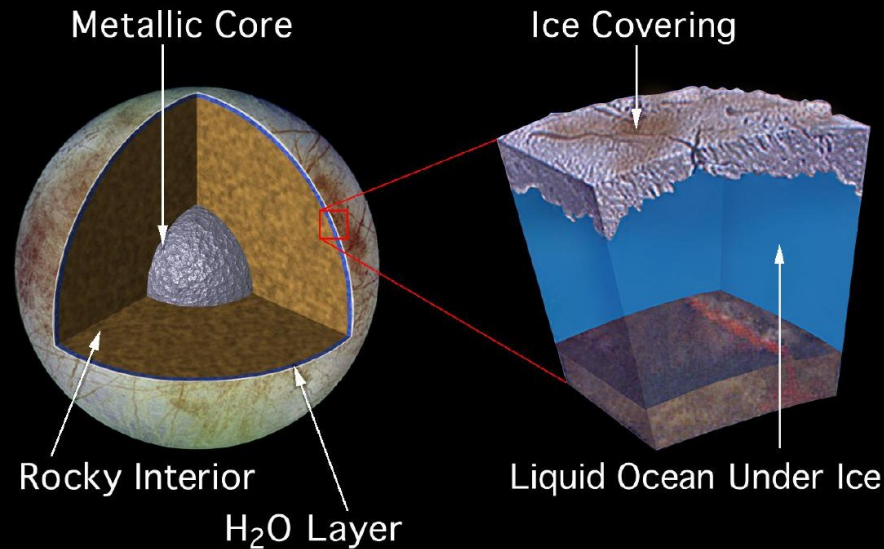
Europa—twice the volume of ocean water compared to Earth



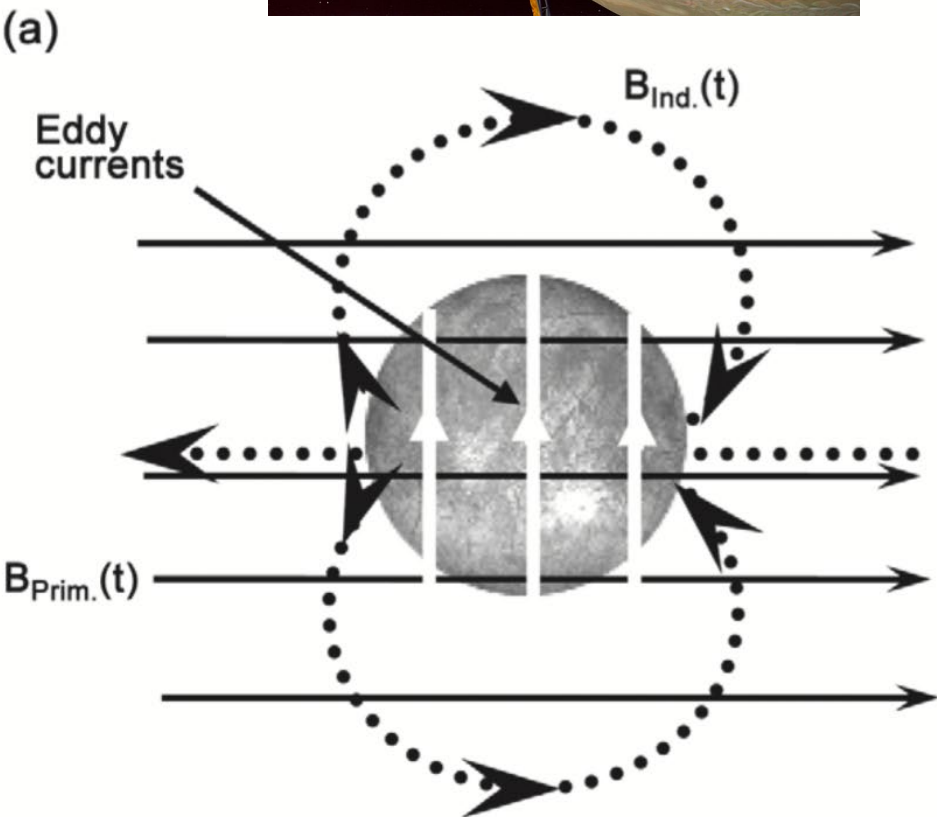
CREDIT: PHL @ UPR Arecibo, NASA

Europa: best place for conventional life?

- Almost as large as Earth's Moon
- Ocean twice the volume of Earth's in contact with silicate rock
- Possible mechanism to sustain redox disequilibrium via radiolysis of surface ice
- A lot not known (pH, organics, hydrothermal activity...)



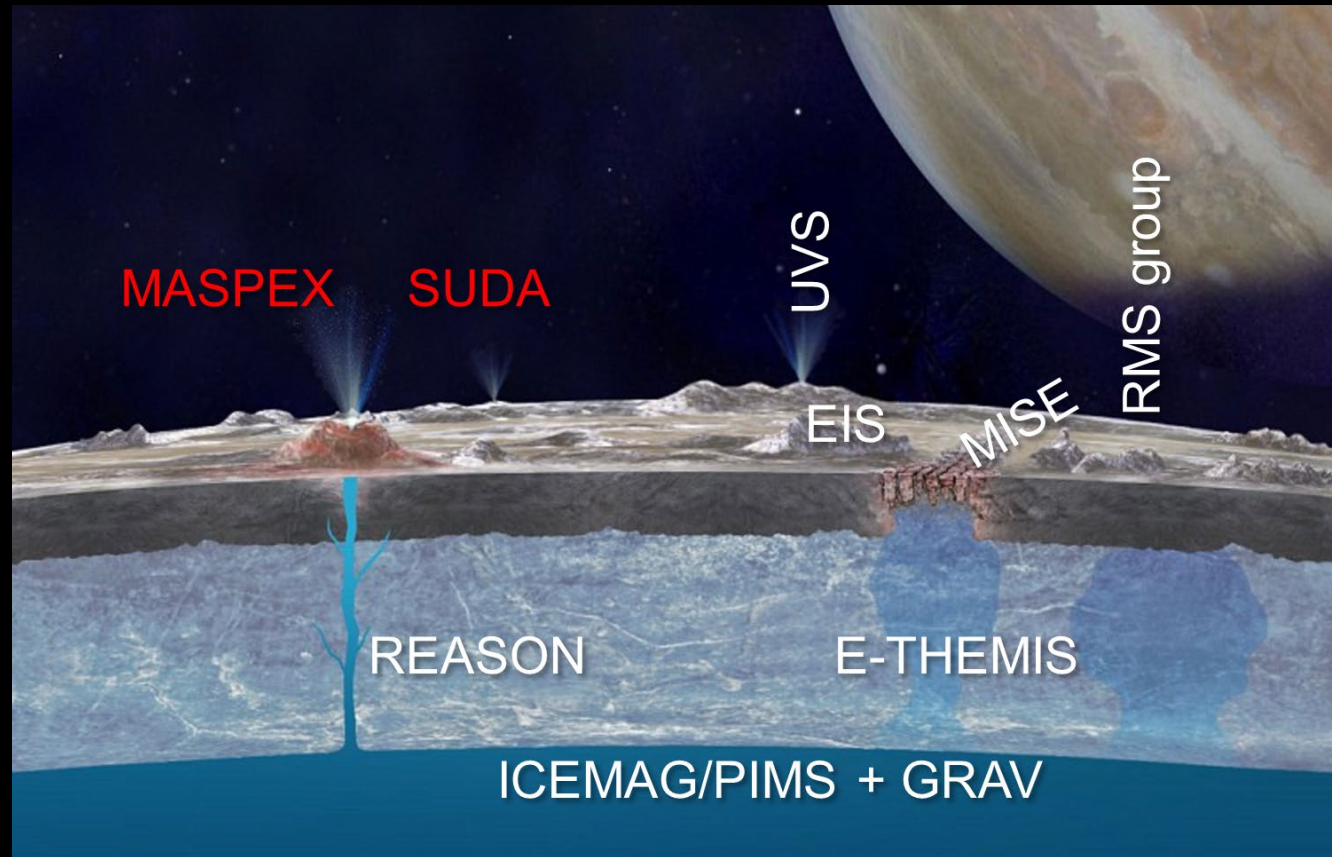
The magnetometer on Galileo discovered the subsurface ocean in Europa



Jupiter’s magnetic field.

Local situation at Europa

Europa Clipper instruments: determine if
ocean habitable/expressed onto surface

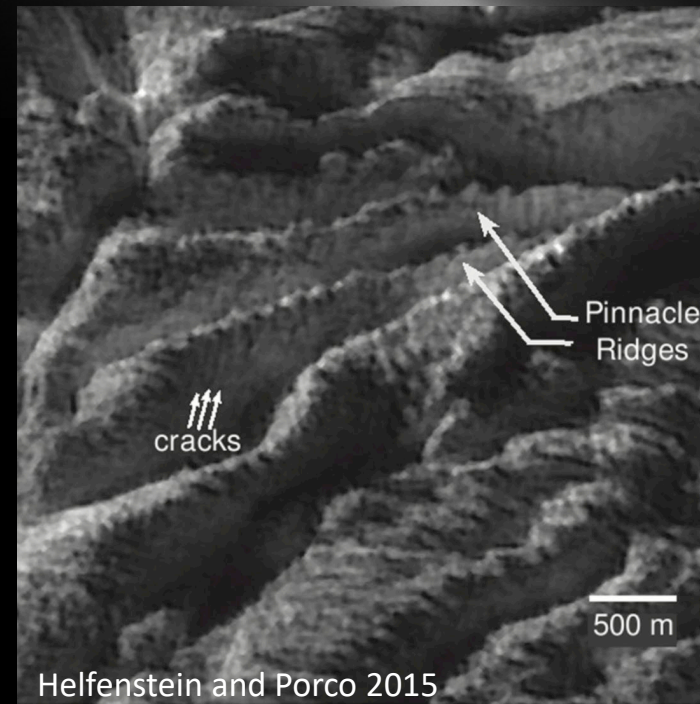
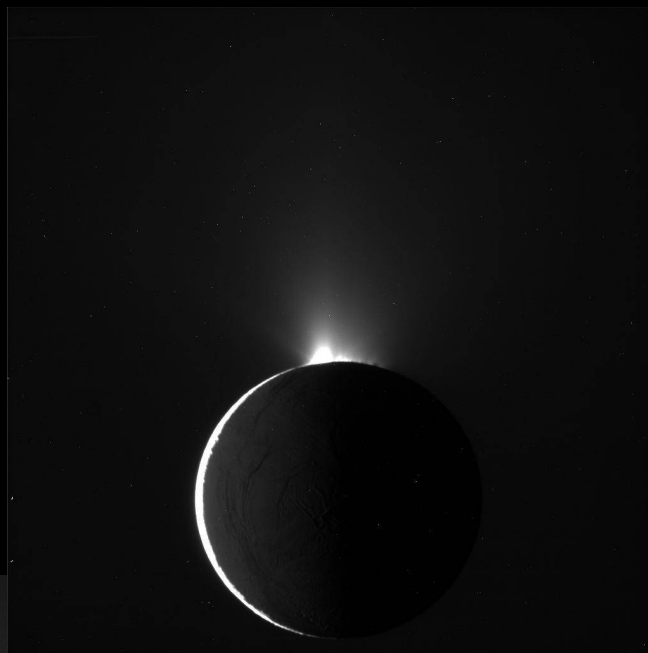
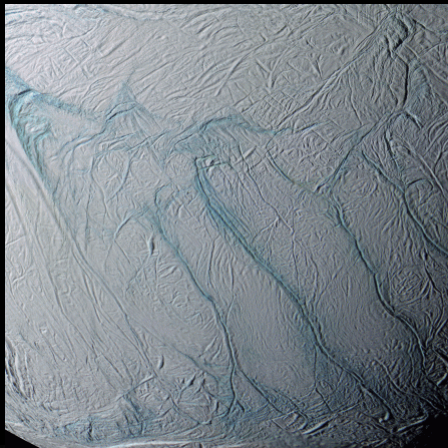


Saturn's moon Enceladus: easiest to explore; most known about the ocean

- Salt-water ocean with established hydrothermal activity
- Ocean reliably expressed into space by a big plume, ability to sample demonstrated by Cassini
- By today's standard, the most habitable place known off Earth

Enceladus → ●

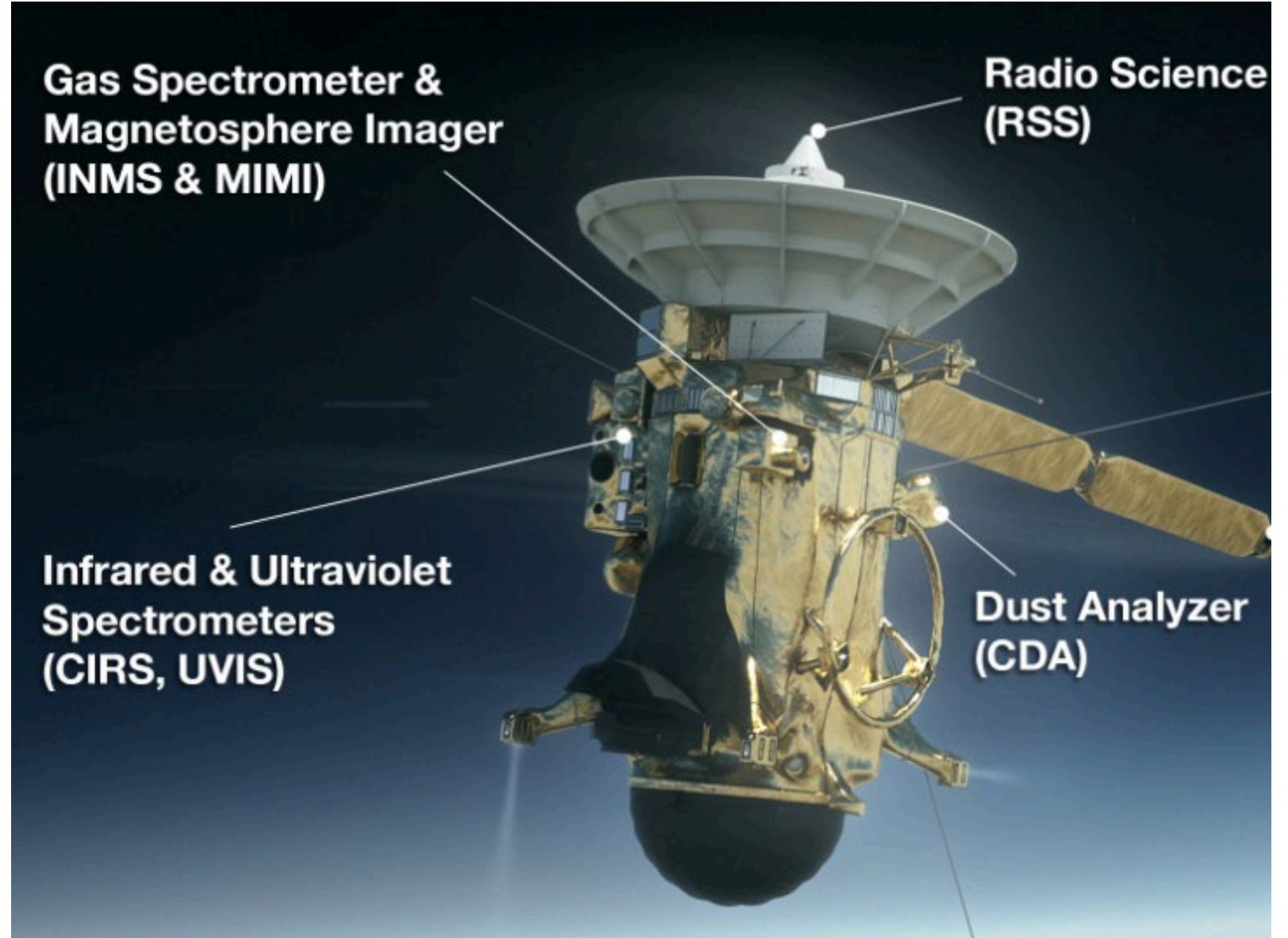




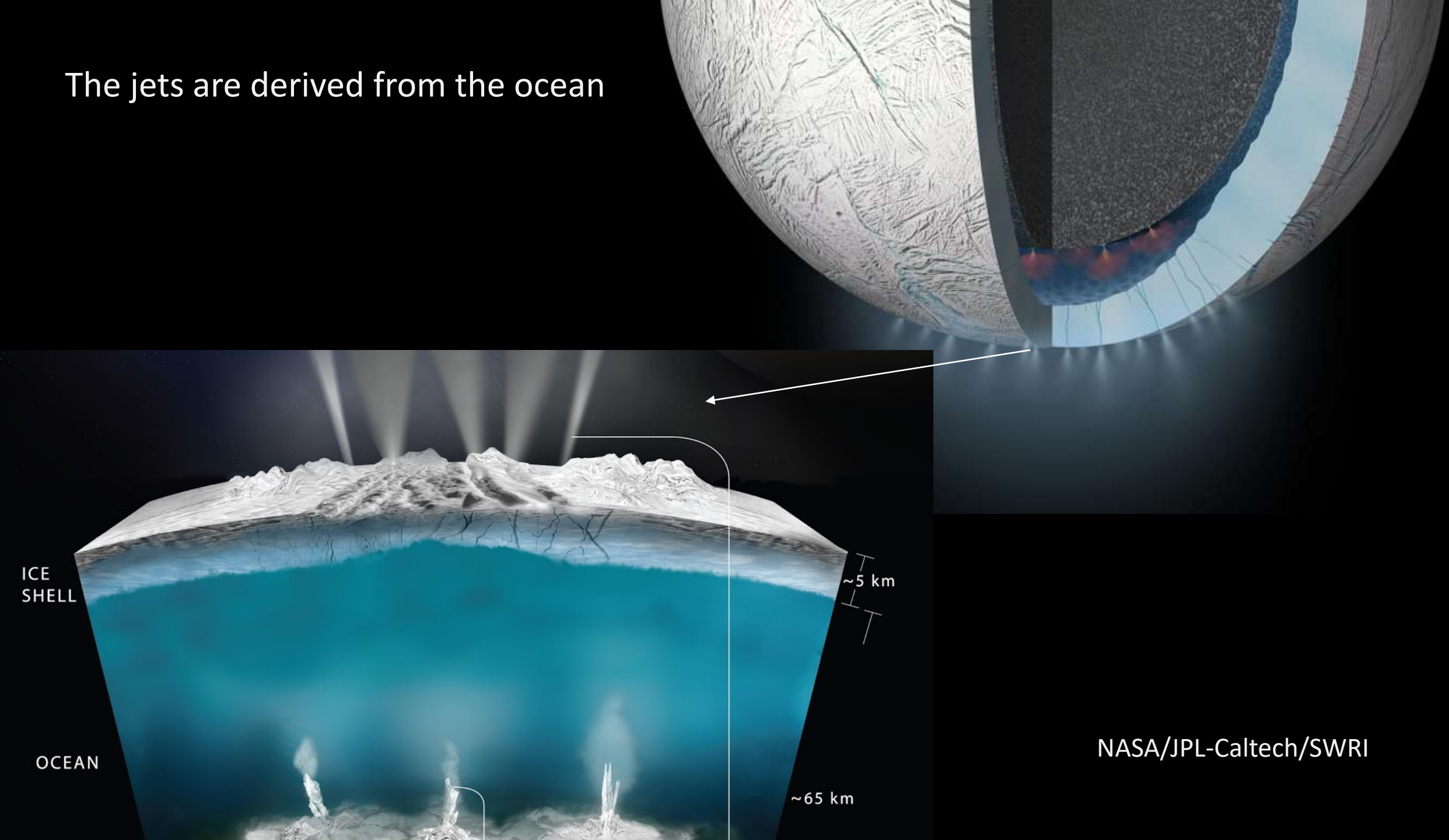
All images NASA/JPL-Caltech/SSI

Evidence for an ocean beneath the ice crust

- Gravity mapping
- Libration (rocking) of Enceladus
- Large salty ice grains
- Fractures are very warm

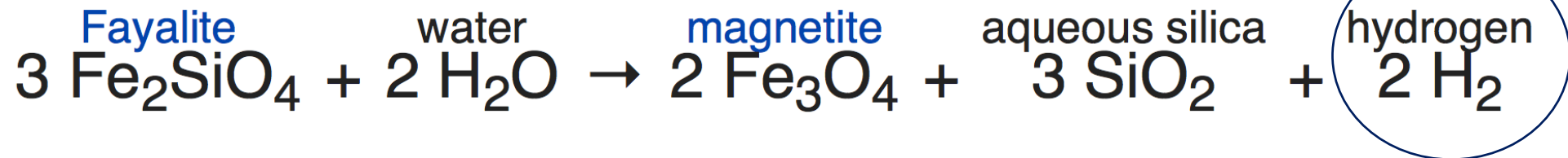
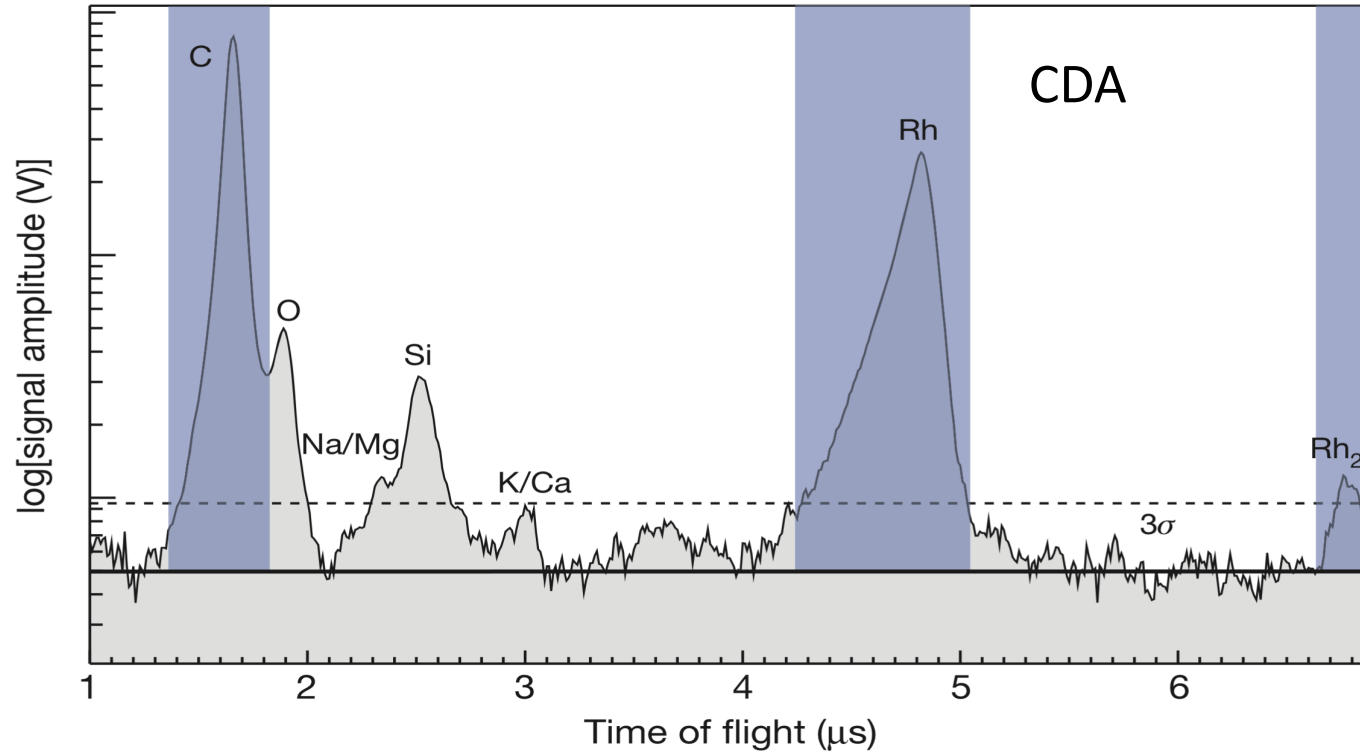


The jets are derived from the ocean



NASA/JPL-Caltech/SWRI

Nanometer-sized silica (SiO_2) grains (Hsu et al 2015) and molecular hydrogen Waite et al. (2017) found by Cassini argue for active water-rock chemistry at ocean base.

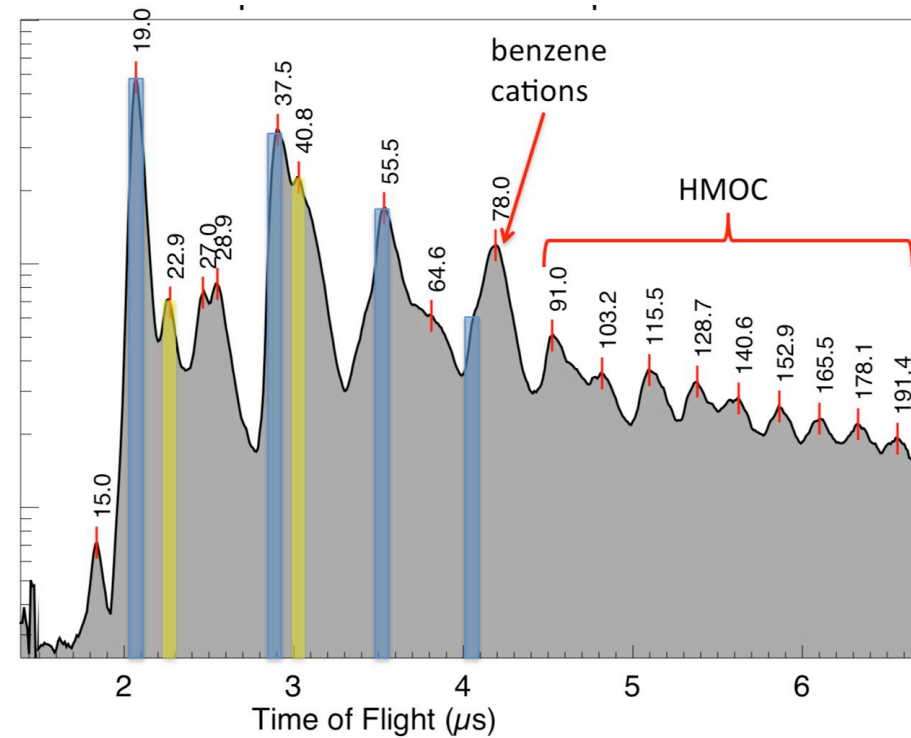


There are organics in the Enceladus ocean

Table 1. The major species composition of Enceladus' plume gas. Volume mixing ratios are derived from Cassini INMS measurements [(20), sections 2.4 and 3.2].

Constituent	Mixing ratio (%)
H ₂ O	96 to 99
CO ₂	0.3 to 0.8
CH ₄	0.1 to 0.3
NH ₃	0.4 to 1.3
H ₂	0.4 to 1.4

Waite et al 2017, Science



Postberg et al 2018, Nature

What about life?

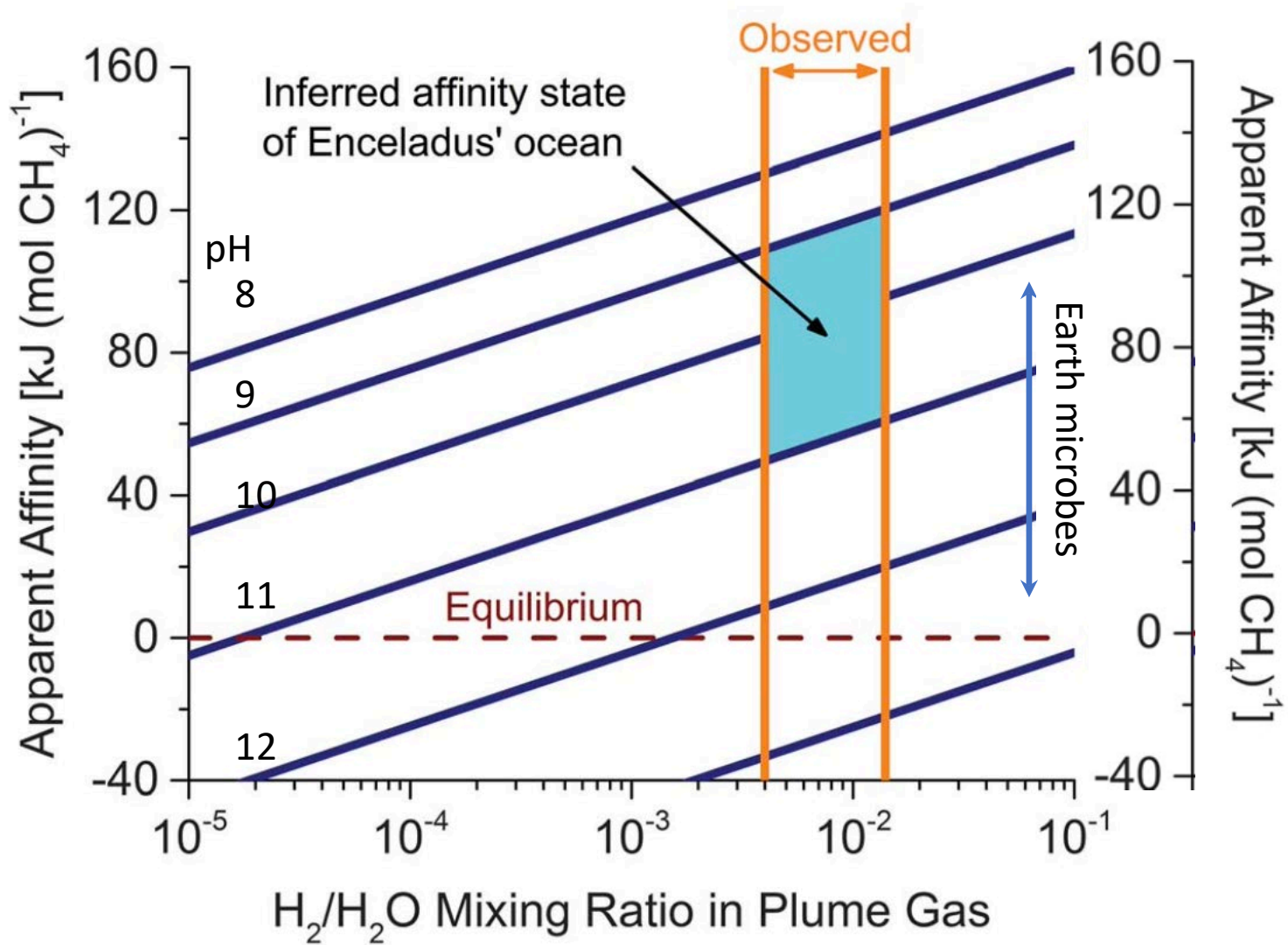
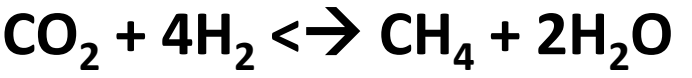
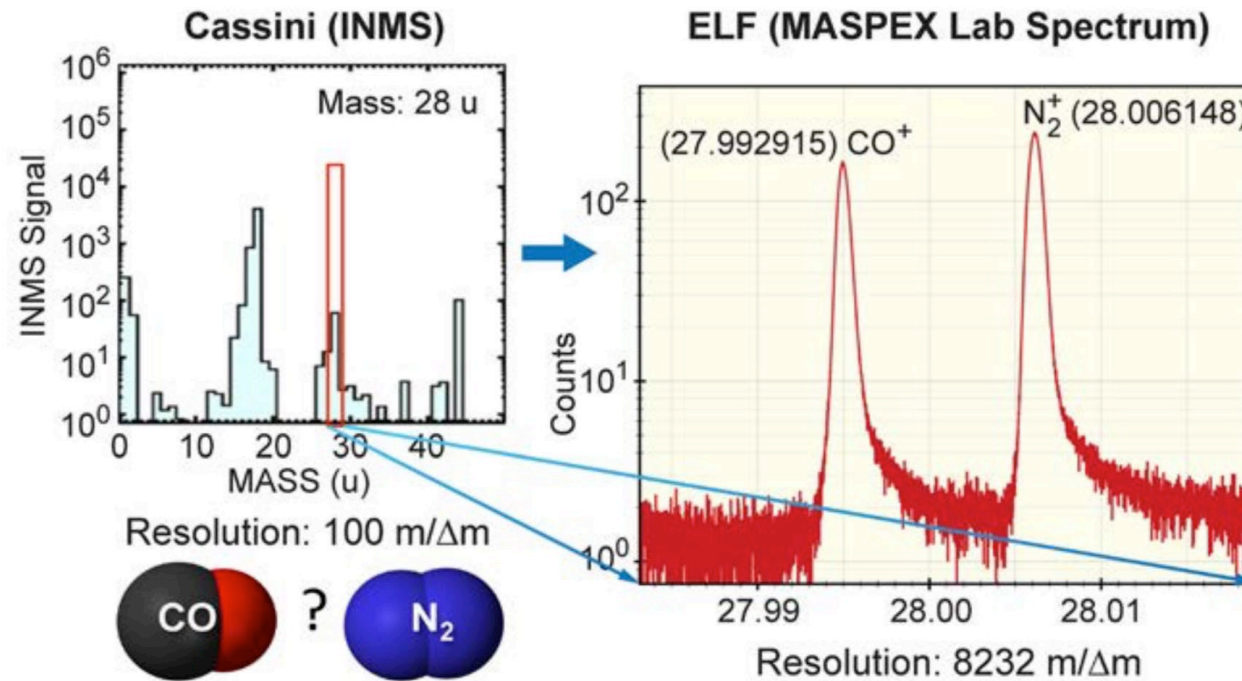


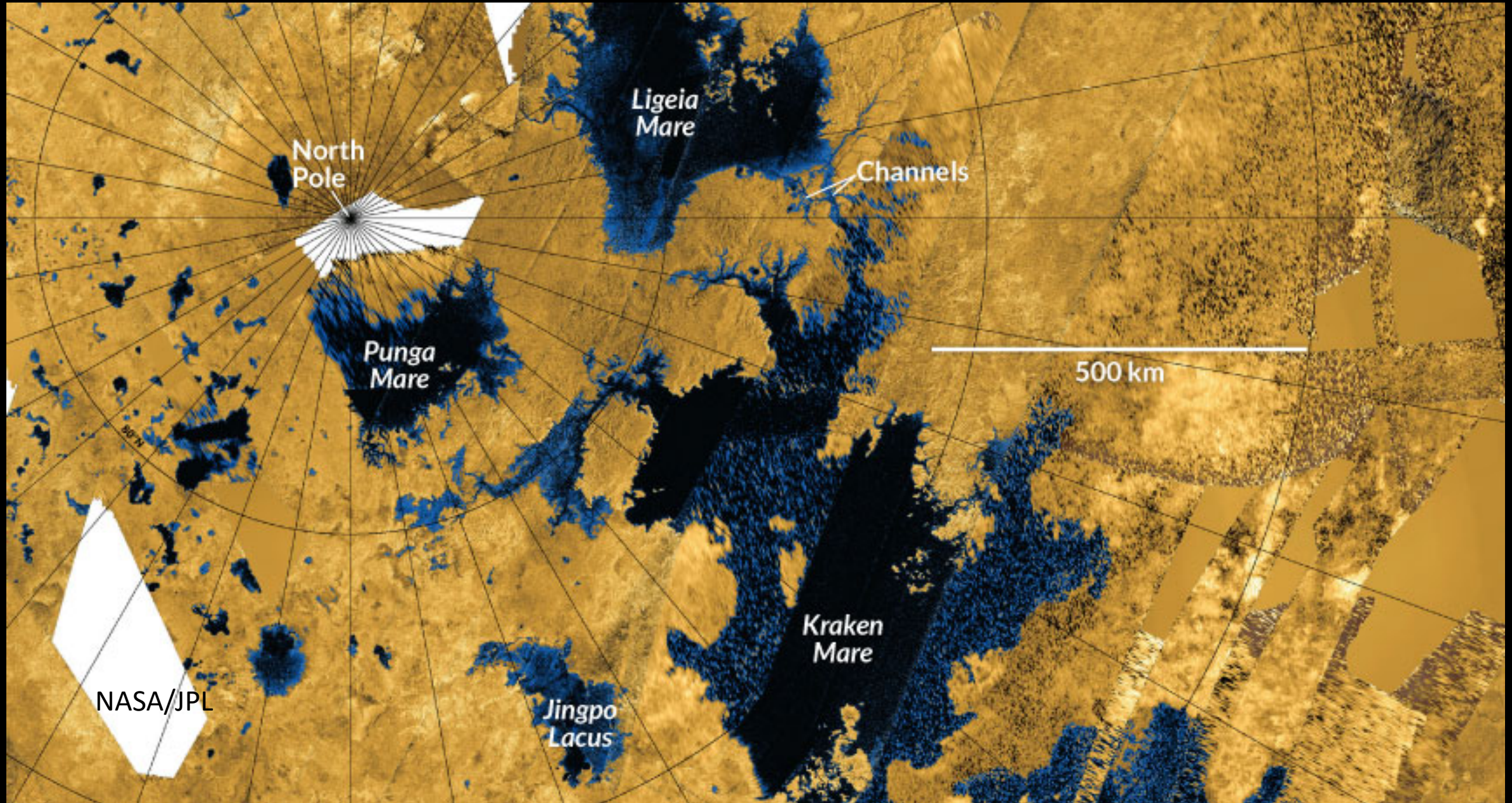
Figure from Waite et al 2017; Earth microbes from T.M. Hoehler, 2022 Nature

What is the next step? Go back to the plume
with better instruments



Current generation mass spectrometers
have much higher resolution than did
Cassini

Saturn's giant moon Titan: Dense N_2 atmosphere, CH_4 weather, rivers, seas



Q3: What does our faith say about the implications of finding microbial life?

Are we entitled to treat alien life any way we like?

Let them have dominion over the fish of the sea, the birds of the air, the tame animals, all the wild animals, and all the creatures that crawl on the earth. Gen. 1.

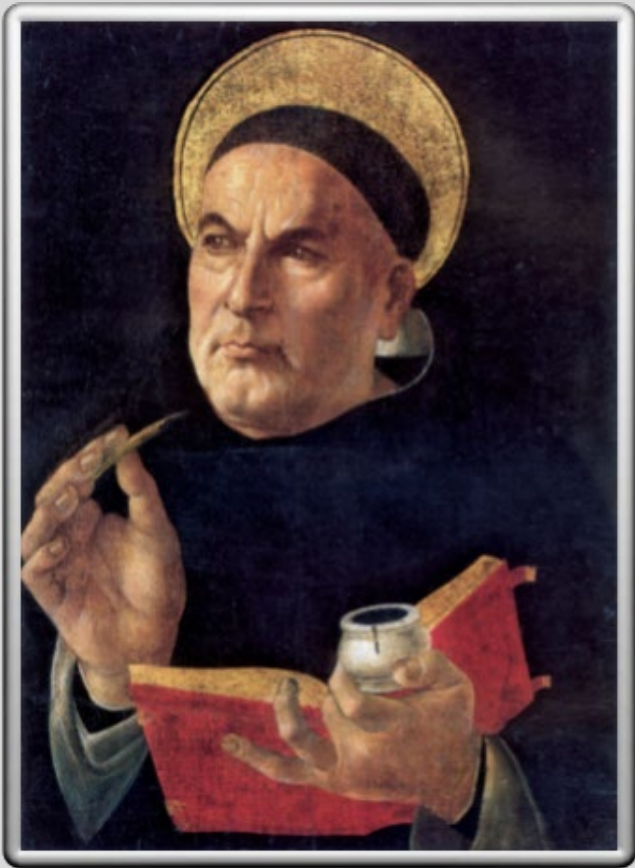
- What are the ethics of invasive exploration of an alien biosphere?
- ...the ethics of bringing microbes back to Earth?
- ...the ethics of exploiting alien microbes by culturing them for medicinal or commercial purposes?

What are the theological implications of life originating elsewhere?

- What are the implications of discovering a life form that demonstrably had an independent origin from life on Earth? *Life arose n times in the cosmos, $n > 1$.*
- What are the implications of finding extinct ancient life on Mars, identical in nature to Earth life? *Did Earth life begin on Mars and then was contingently delivered to Earth by impact?*

Order and beauty

“The multiplicity and distinction existing among things were devised by the divine intellect and established in things so that the divine goodness might be represented by created things in various ways, and that different things might participate in the divine goodness in varying degree....



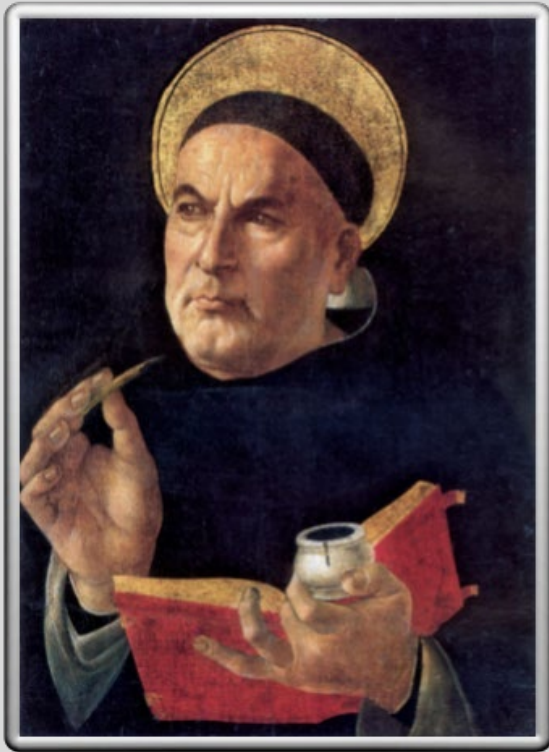
“All this was so that a certain beauty might shine forth from the very order existing among diverse things, a beauty which would direct the mind to the divine wisdom.”

St. Thomas Aquinas, *Compendium Theologiae*, 1273, Bk. 1 Chp. 102.

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Contingency is part of divine providence

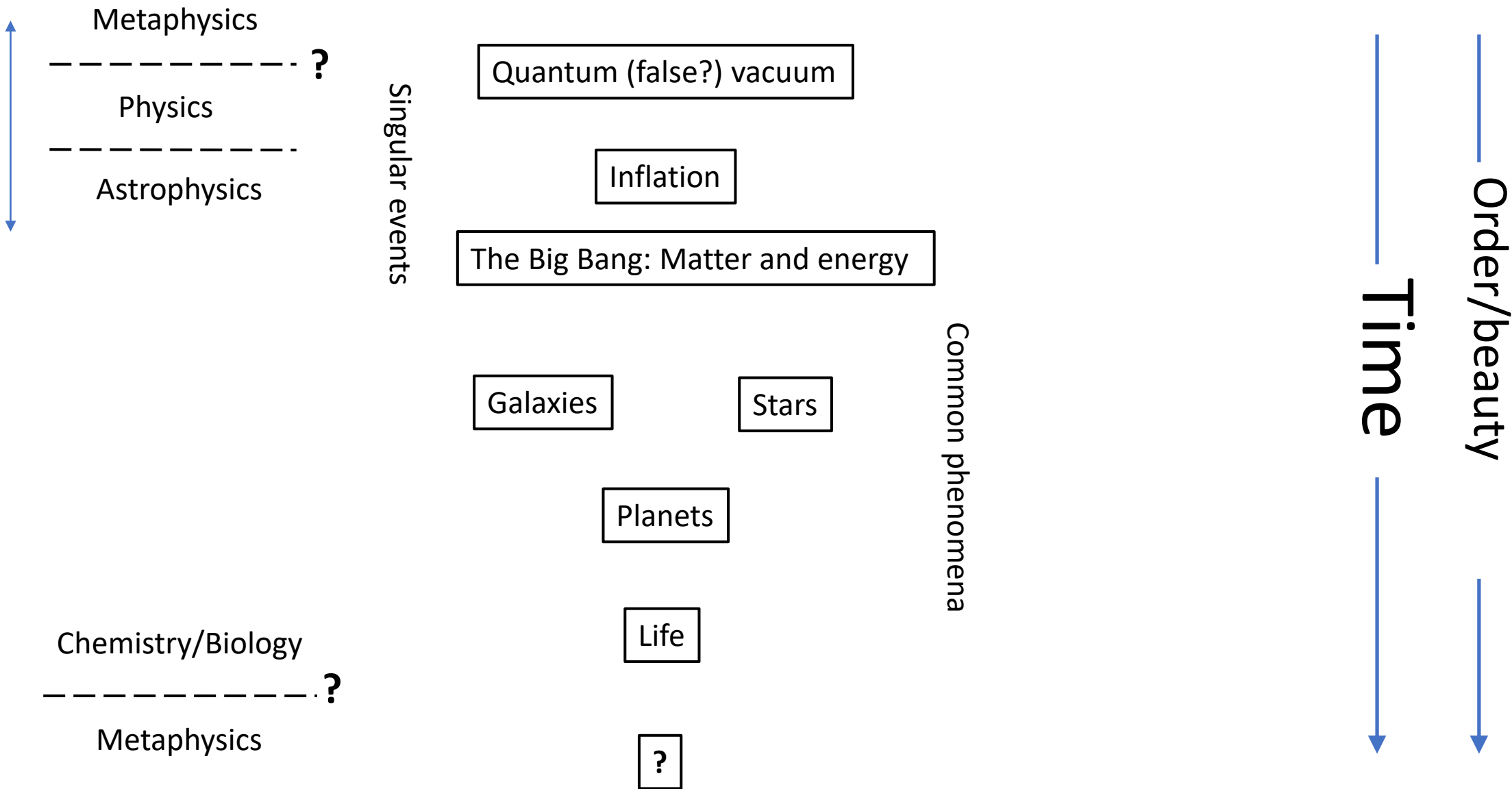


ST I., q. 22, a. 4.

I ANSWER THAT, Divine providence imposes necessity upon some things; not upon all, as some formerly believed. For to providence it belongs to order things towards an end. Now after the divine goodness, which is an extrinsic end to all things, the principal good in things themselves is the perfection of the universe; which would not be, were not all grades of being found in things. Whence it pertains to divine providence to produce every grade of being. And thus it has prepared for some things necessary causes, so that they happen of necessity; for others contingent causes, that they may happen by contingency, according to the nature of their proximate causes.

REPLY OBJ. 1: The effect of divine providence is not only that things should happen somehow; but that they should happen either by necessity or by contingency.

Q4: Is biology the pinnacle of creation?



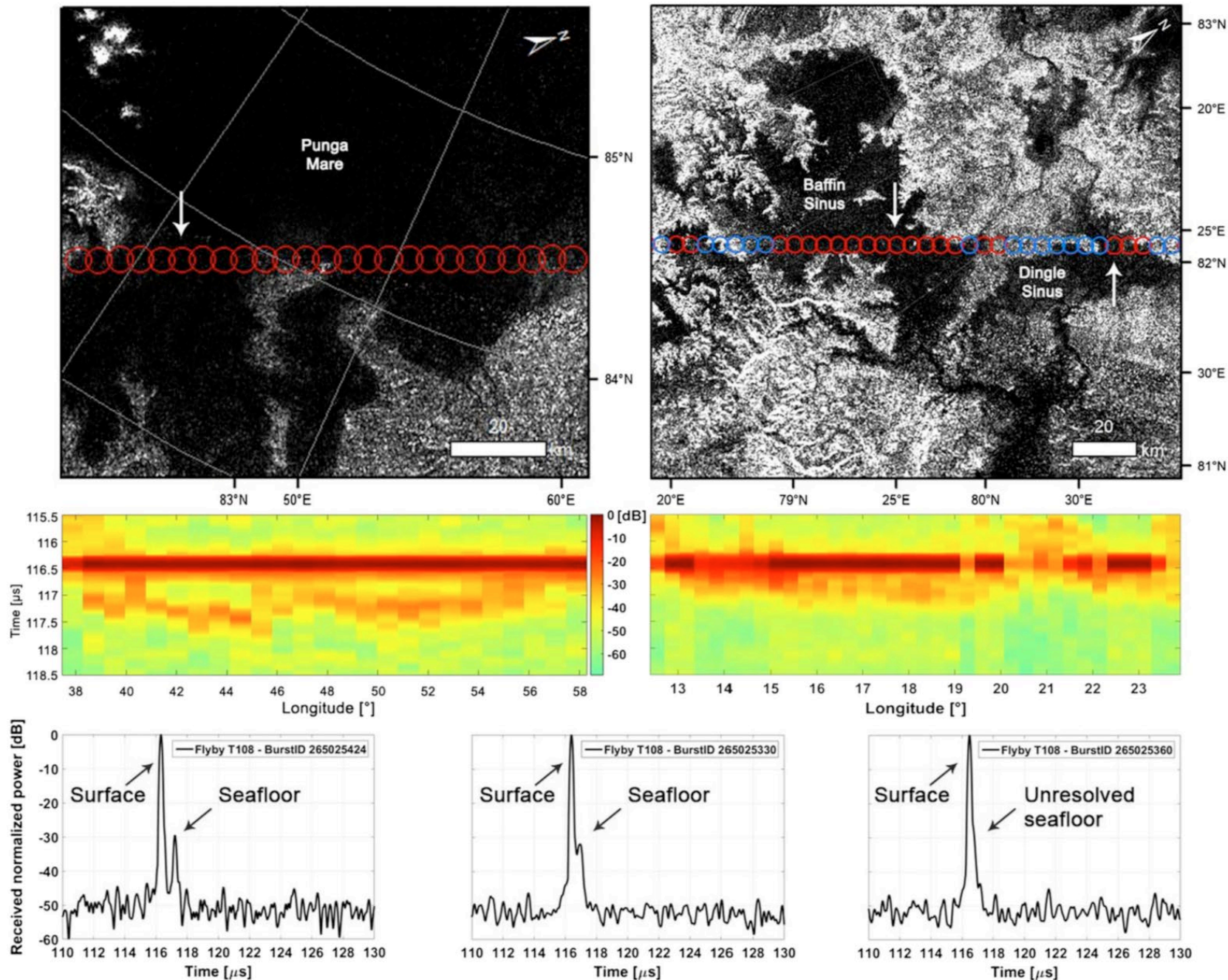
For creation was made subject to futility, not of its own accord but because of the one who subjected it, in hope that creation itself would be set free from slavery to corruption and share in the glorious freedom of the children of God.

Romans 8:20-21

Beloved, we are God's children now; what we shall be has not yet been revealed. We do know that when it is revealed we shall be like Him, for we shall see Him as He is.

1 John 3:2

Backup



Saturn's giant
moon Titan:
Home of
methane-rich
lakes and seas

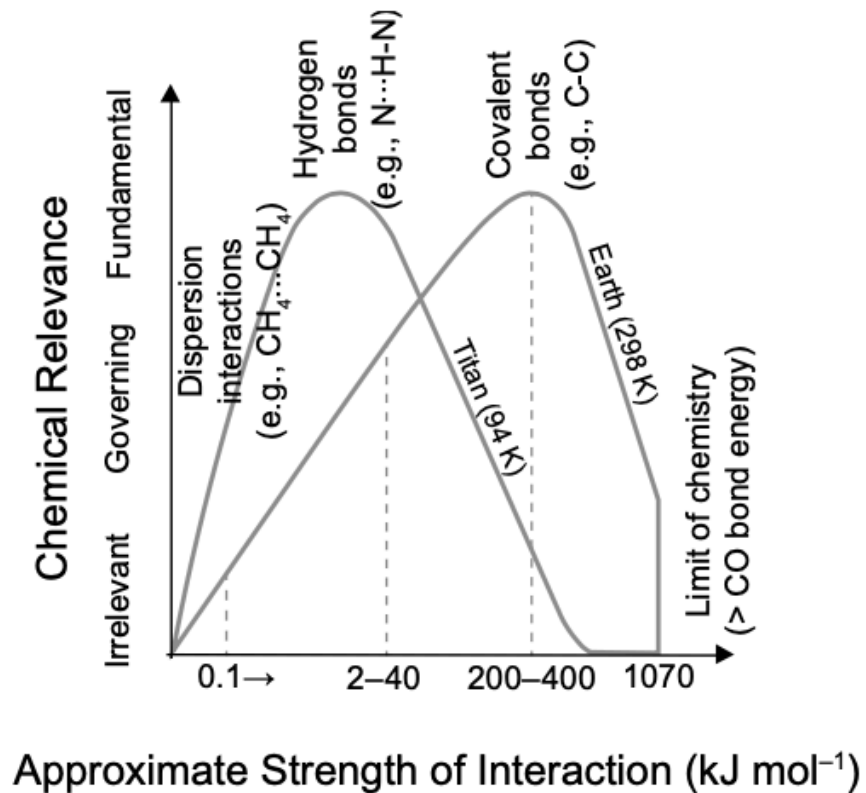
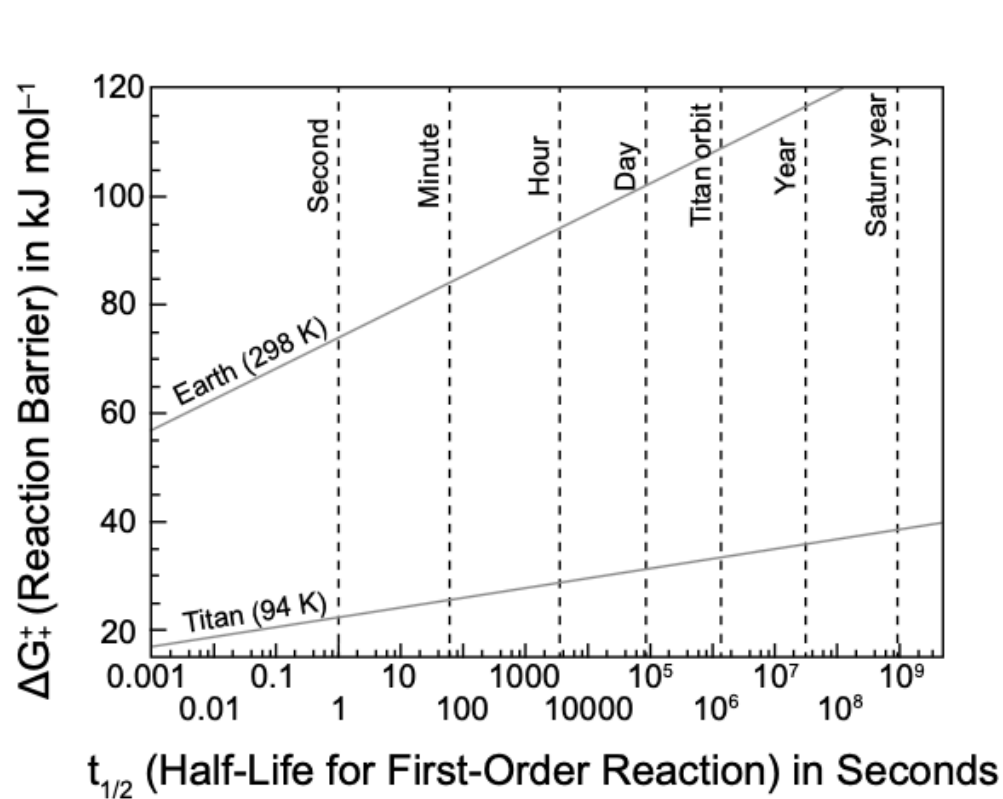
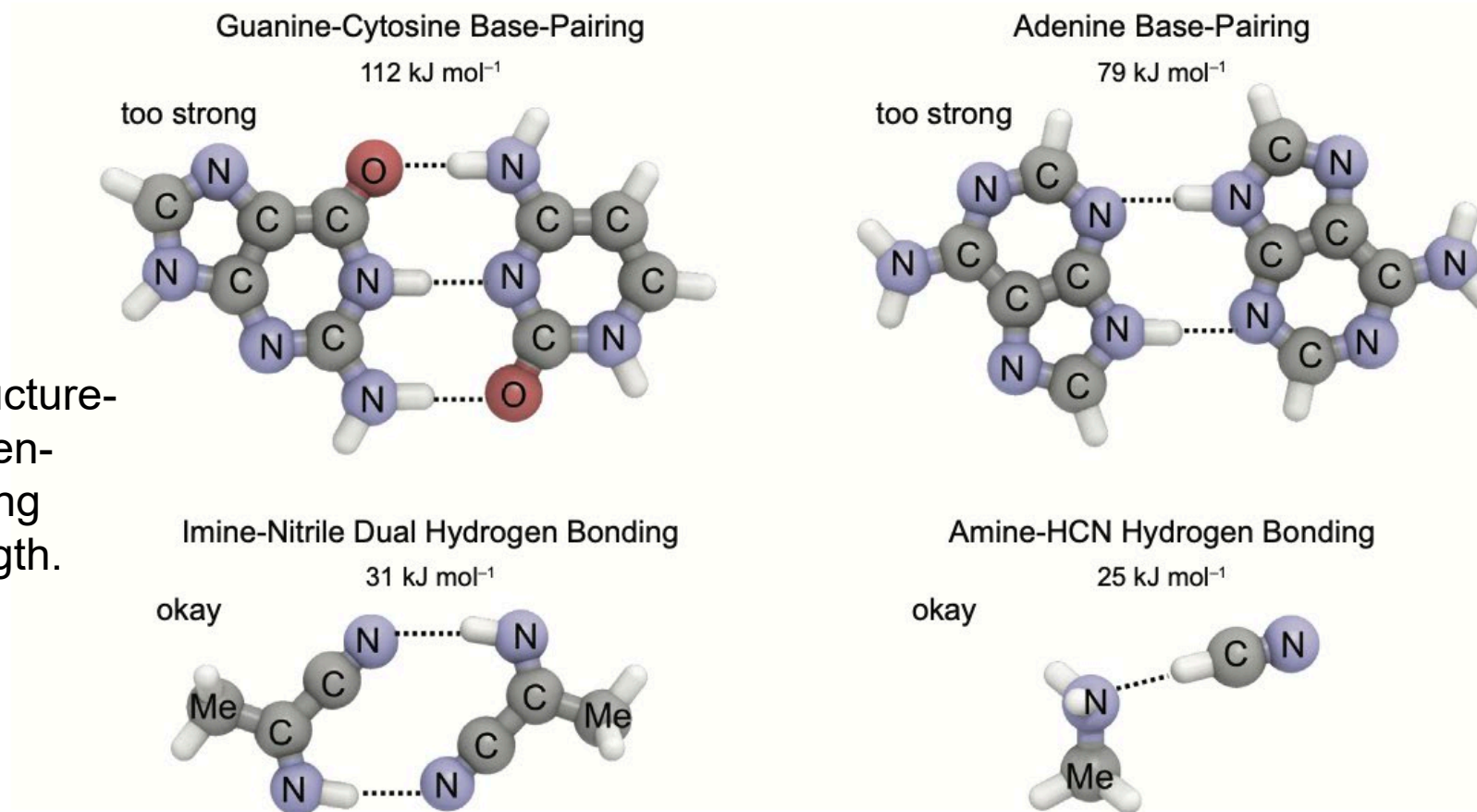


Fig. 1. (a) Reaction energy barriers required for chemical processes to occur over reasonable timescales (milliseconds to years) on Titan (17–35 kJ mol^{-1}) and on Earth (55–110 kJ mol^{-1}). **(b)** Approximate schematic showing differences in the types of chemical interactions that might allow for thermally driven dynamical processes.

Examples of structure-directing hydrogen-bonds with varying interaction strength.



- Stacked guanine-cytosine base pairs are sufficiently strong to maintain the DNA double helix on Earth, but much too strong to allow for dynamic chemistry on Titan.
- On Titan, weaker C/N-H—N hydrogen bonds could be the primary linkages holding together biostructures