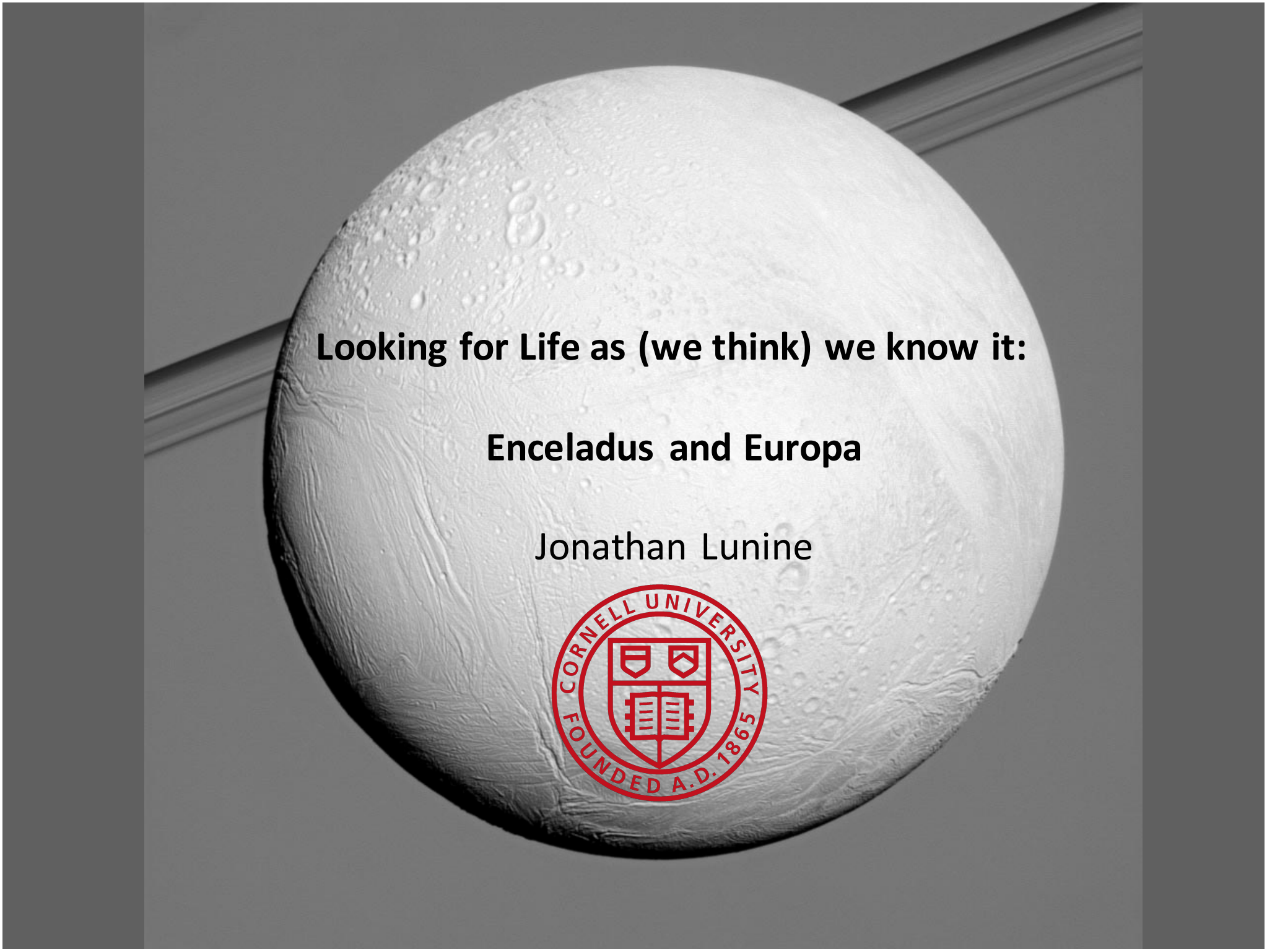
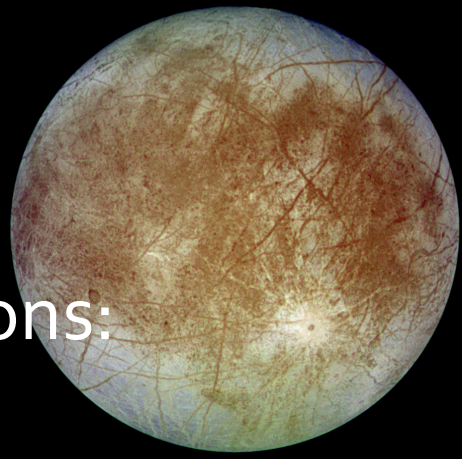


Looking for Life as (we think) we know it:

Enceladus and Europa

Jonathan Lunine

Conclusions



- We have strong indicators of habitable environments in two outer solar system moons: Europa and Enceladus
- Europa: search for organics, confirm identity of salts, and determine how to access seawater. Get Europa Flyby mission ASAP to Europa!

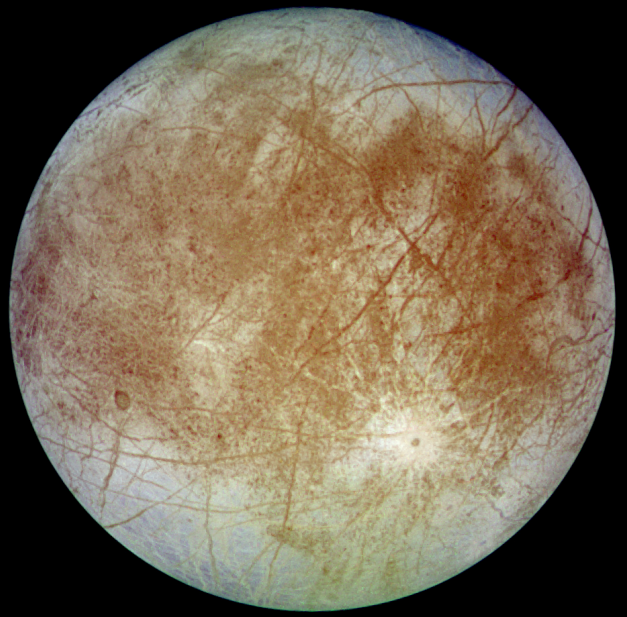
- Enceladus: there is definitive evidence of a subsurface ocean with organics, salts, free energy.
- The plume of Enceladus includes ocean material and is readily analyzed for evidence of life—a goal of Enceladus Life Finder.

There are a small number of good targets to explore for life:

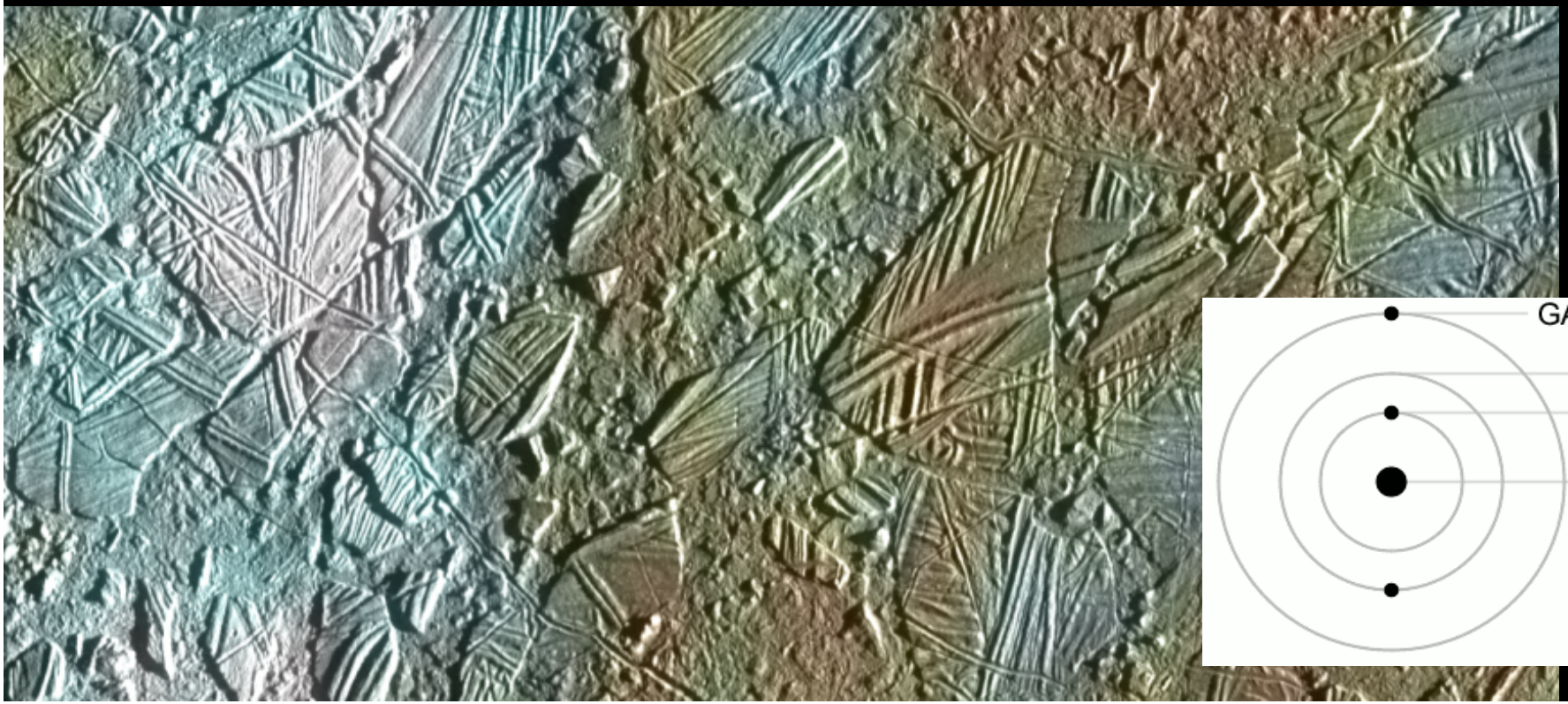
- Mars-- test of outer edge of “habitability zone”; access to extant life difficult; frequent exchange of material with Earth makes likely common origin for terrestrial and martian life.
- Titan—moon of Saturn with hydrocarbon seas; search for non-aqueous life to test the notion that chemical evolution proceeds to the level of minimal life in any liquid medium.
- Europa and Enceladus—distant (hence quasi-isolated) moons with liquid water “oceans” that might harbor terrestrial-type life.

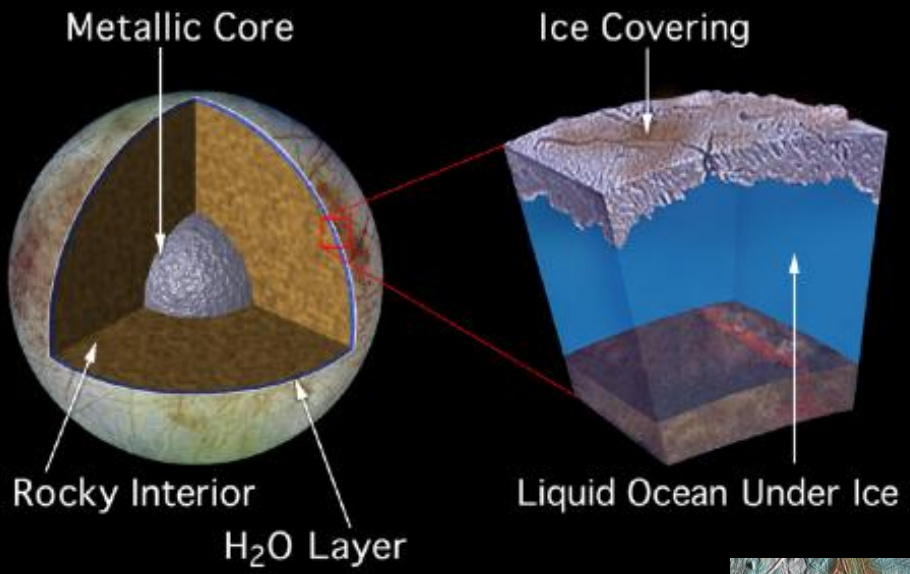
Jupiter's Moon Europa:

- size of our moon; a rock-ice world
- tenuous atmosphere
- lethal radiation from Jupiter
- subsurface water ocean under an ice crust

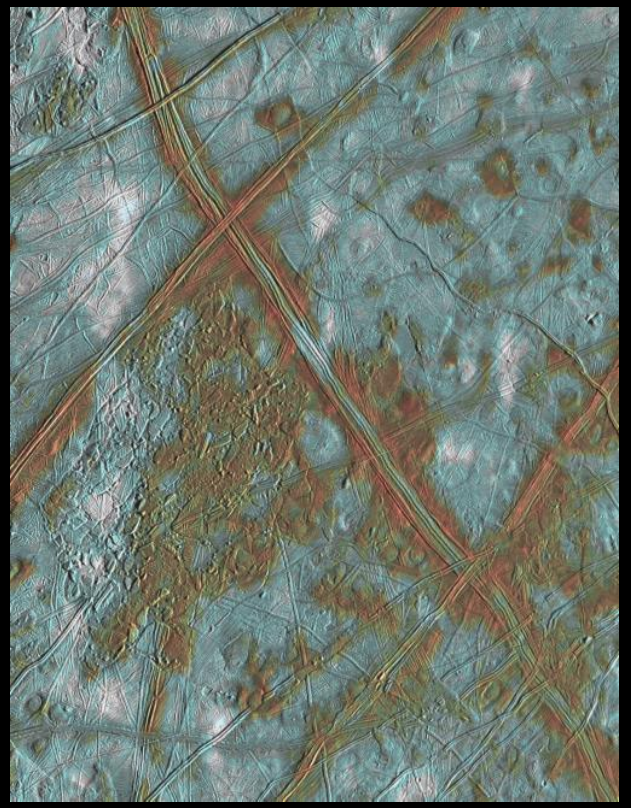


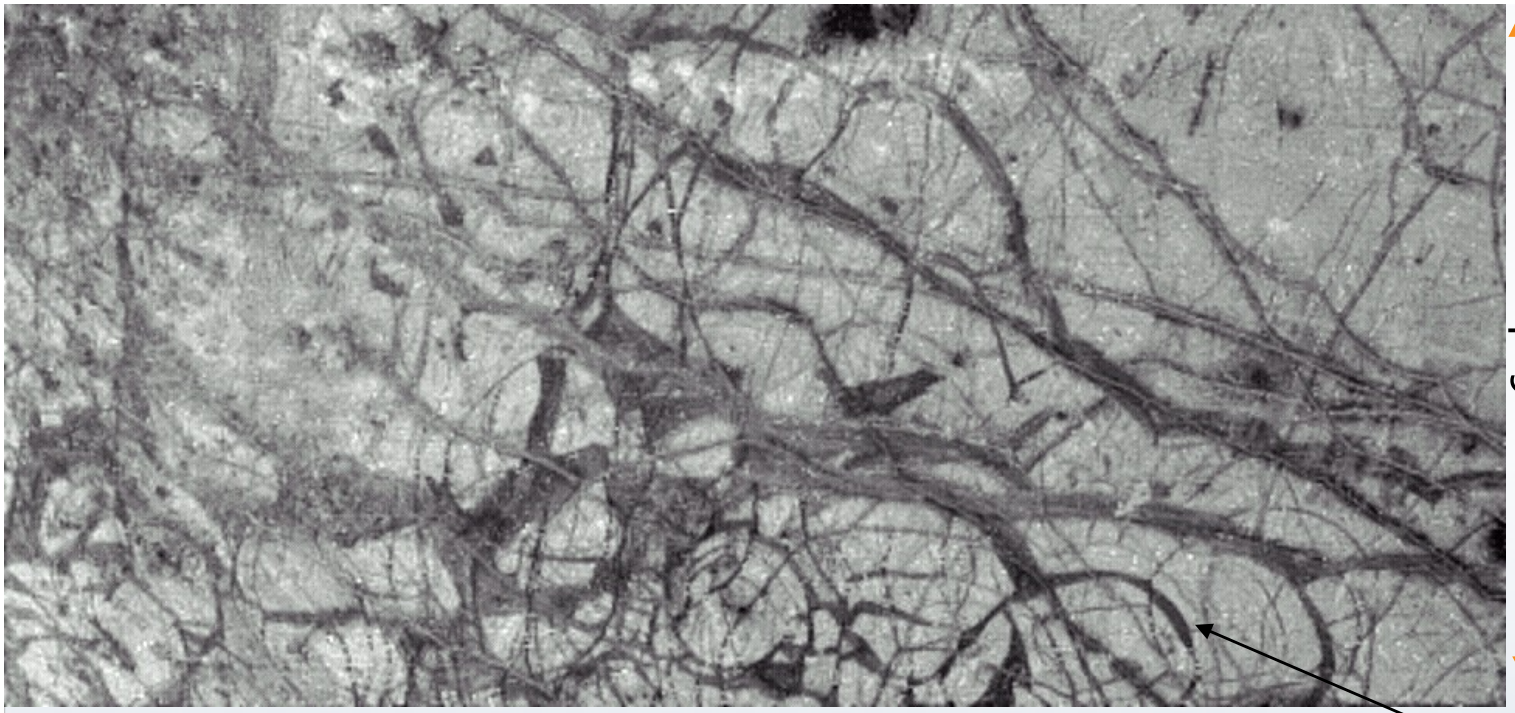
70 km





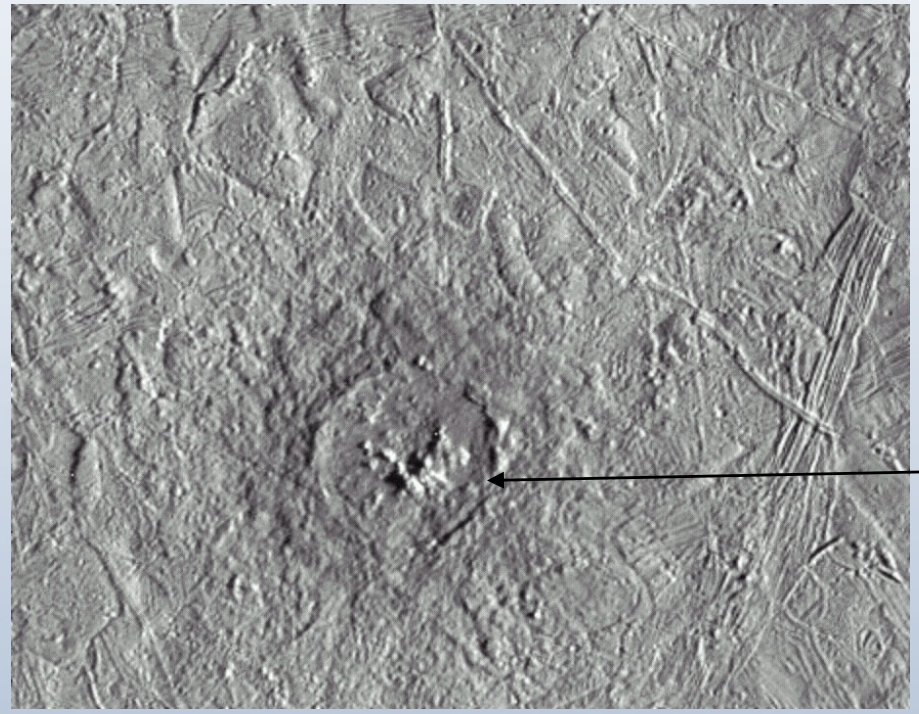
There are: liquid water, salts and possible sources of chemical energy. But are there organics in Europa? *We don't know.*





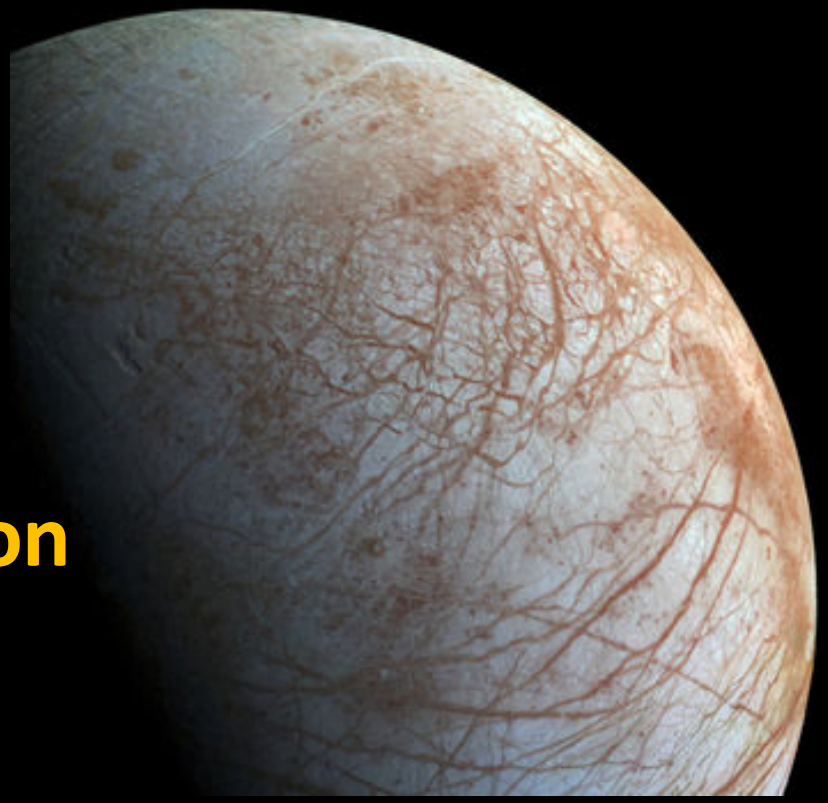
Nor do we know the thickness of the ice crust.

These say thin…100 meters?.



…this says thick -- tens of kms, perhaps upwards of 100 km

(Pwyll crater, 26 km in diameter)

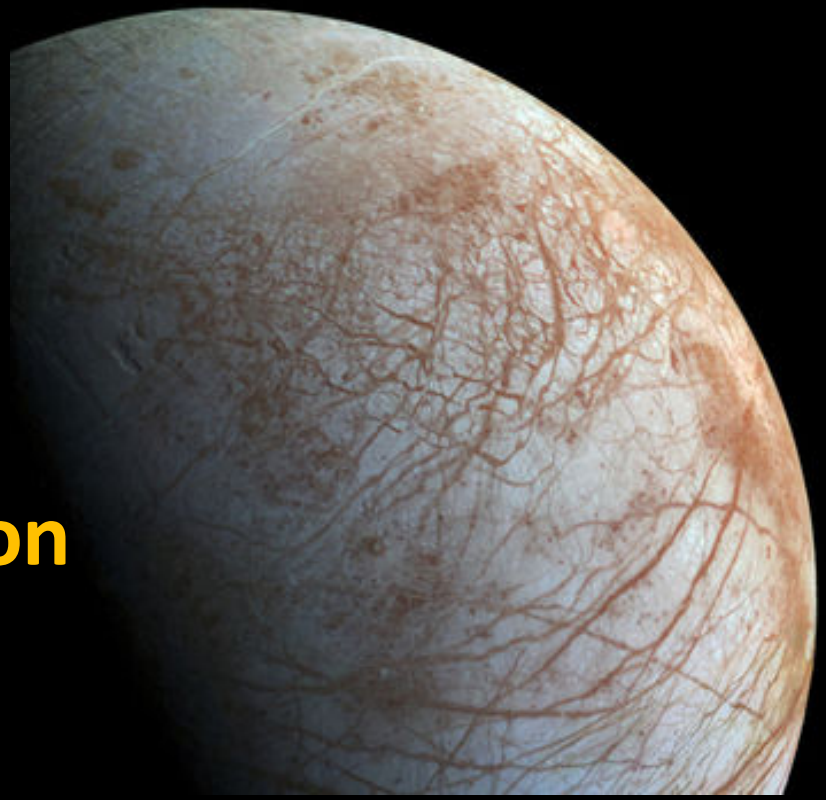


Europa Mission

Scientific Instrument(s)

- Plasma Instrument for Magnetic Sounding (PIMS)
- Interior Characterization of Europa using MAGnetometry (ICEMAG)
- Mapping Imaging Spectrometer for Europa (MISE)
- Europa Imaging System (EIS)
- Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)
- Europa THermal Emission Imaging System (E-THEMIS)
- MAss SPectrometer for Planetary EXploration/Europa (MASPEX)
- Ultraviolet Spectrograph/Europa (UVS)
- SUrface Dust Mass Analyzer (SUDA)

Europa Mission



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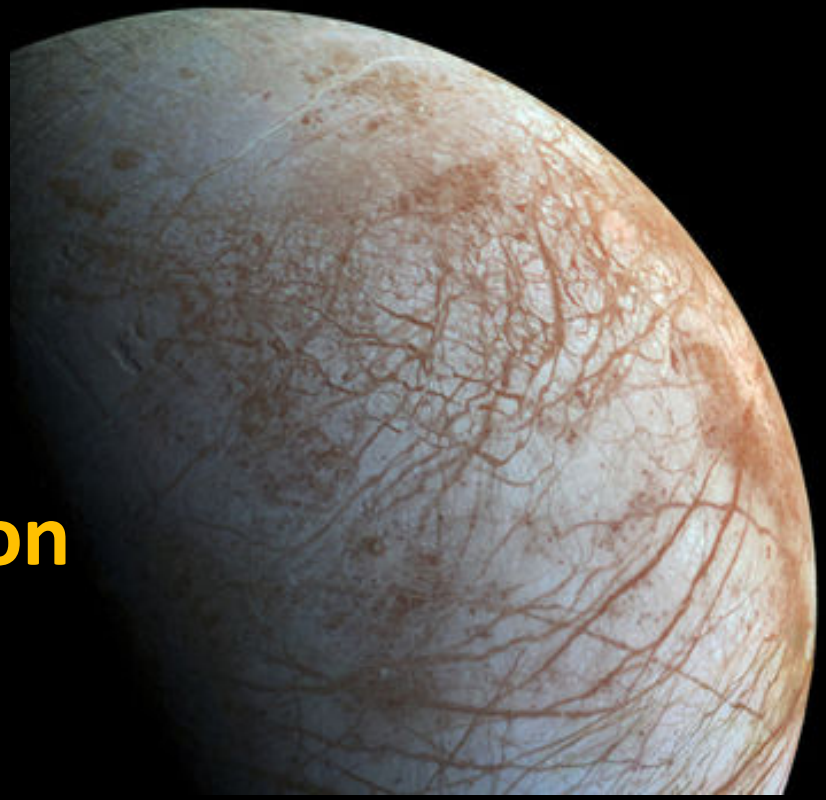

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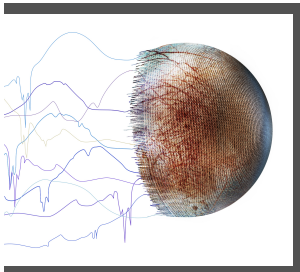
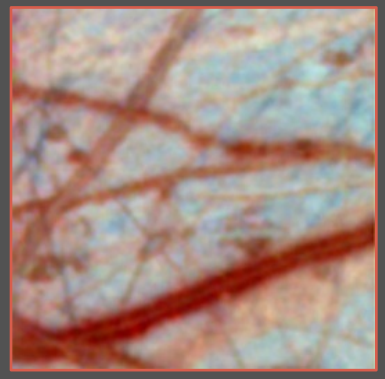


MISE Science Goals

Goal 1: Assess the habitability of Europa's ocean by understanding the inventory and distribution of surface compounds.

Goal 2: Investigate the geologic history of Europa's surface and search for areas that are currently active.

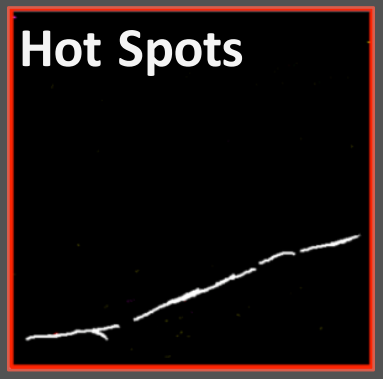
MISE will produce maps of key compounds to answer questions about Europa's ocean and it's habitability



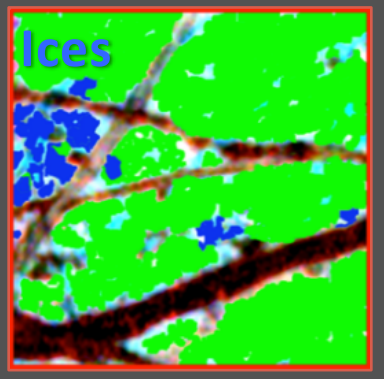
Links surface geology and composition.

Does Europa's ocean have organics?

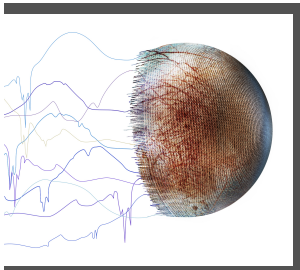
What does surface chemistry tell us about habitability?



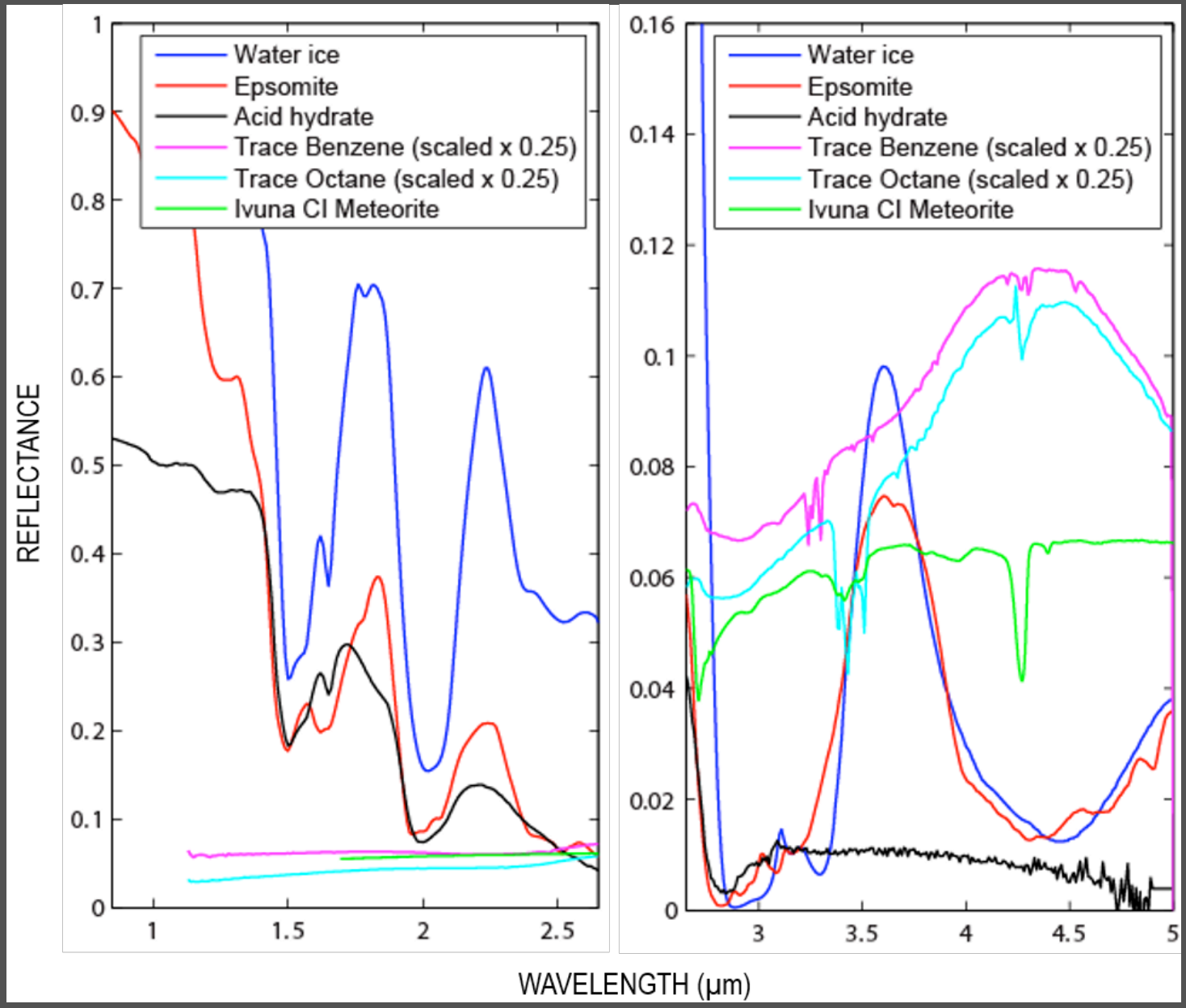
Is Europa currently active?

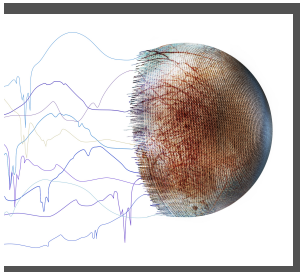


How do changes in ice crystal structure relate to the age of Europa's surface?



Near-IR spectra determine surface composition



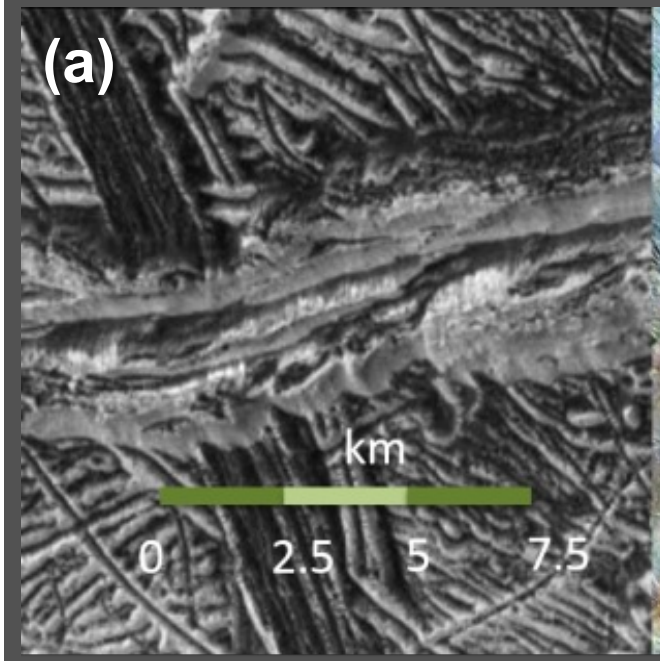


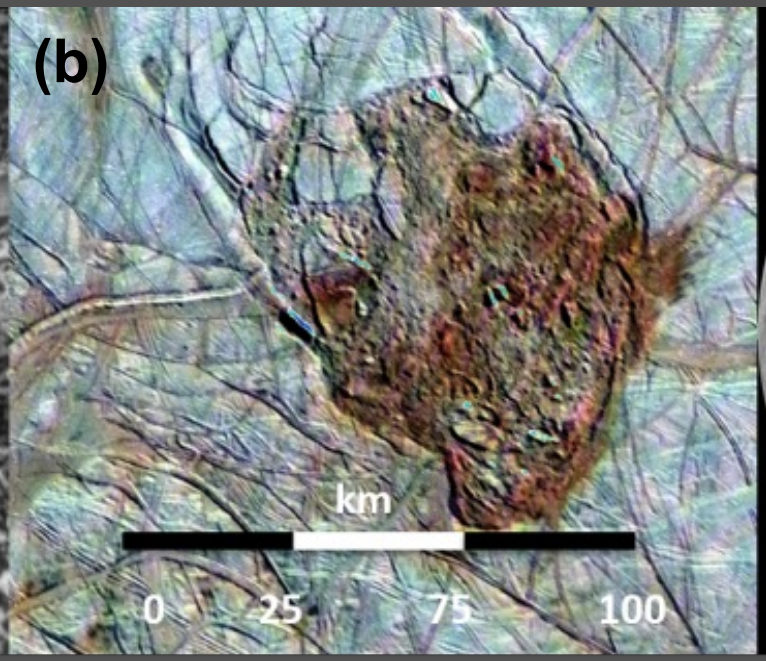
…on meaningful spatial scales

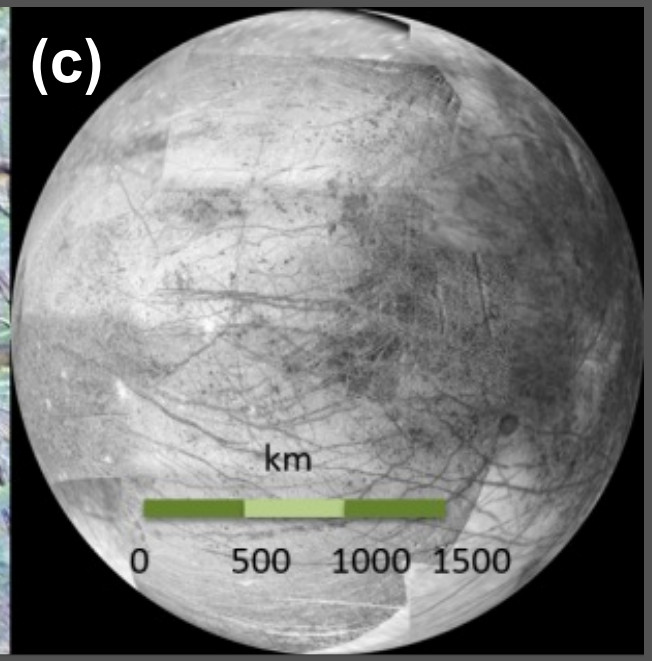
Local

Regional

Global





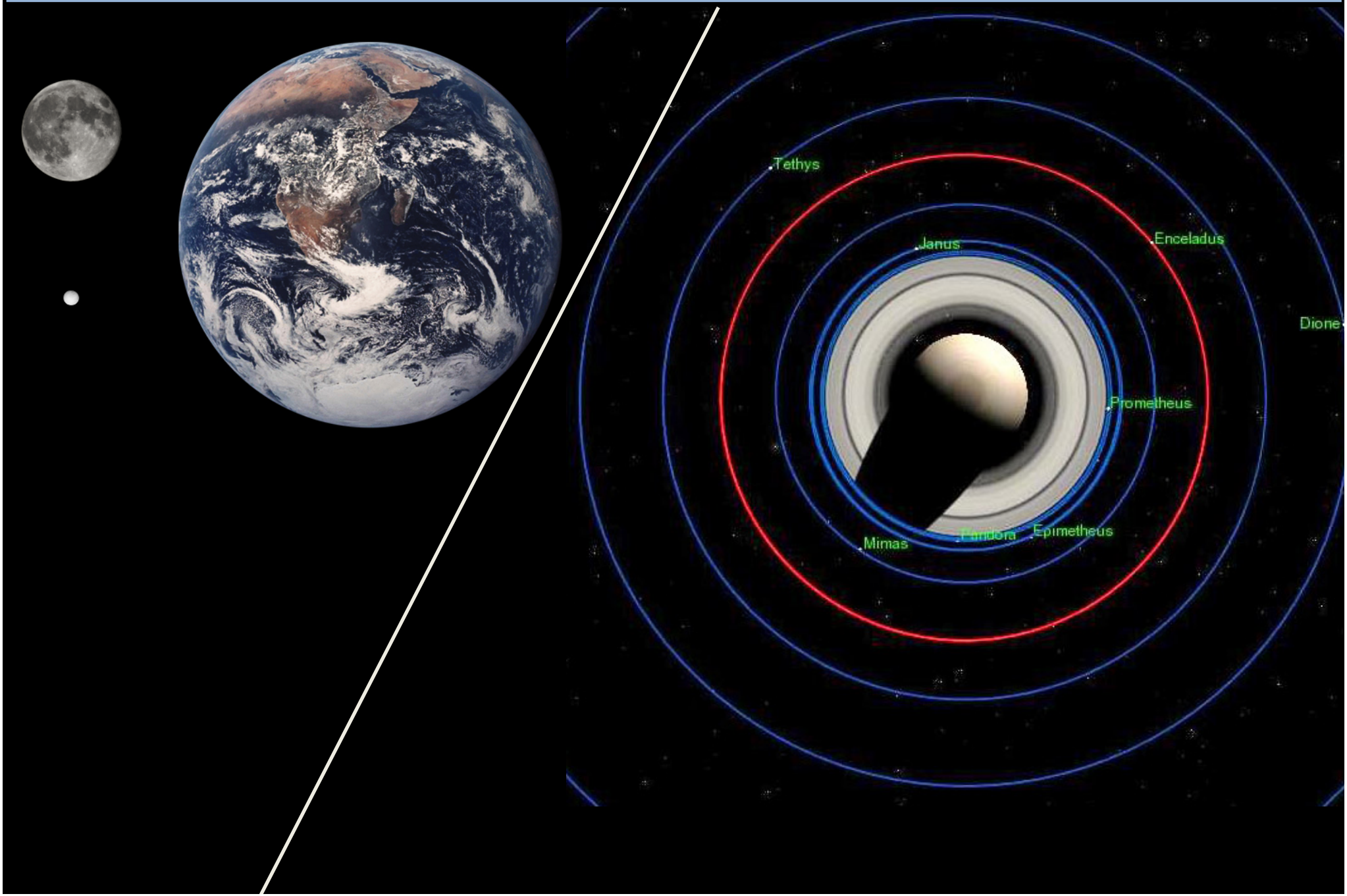


< 25 m / pixel

< 300 m / pixel

< 10 km / pixel

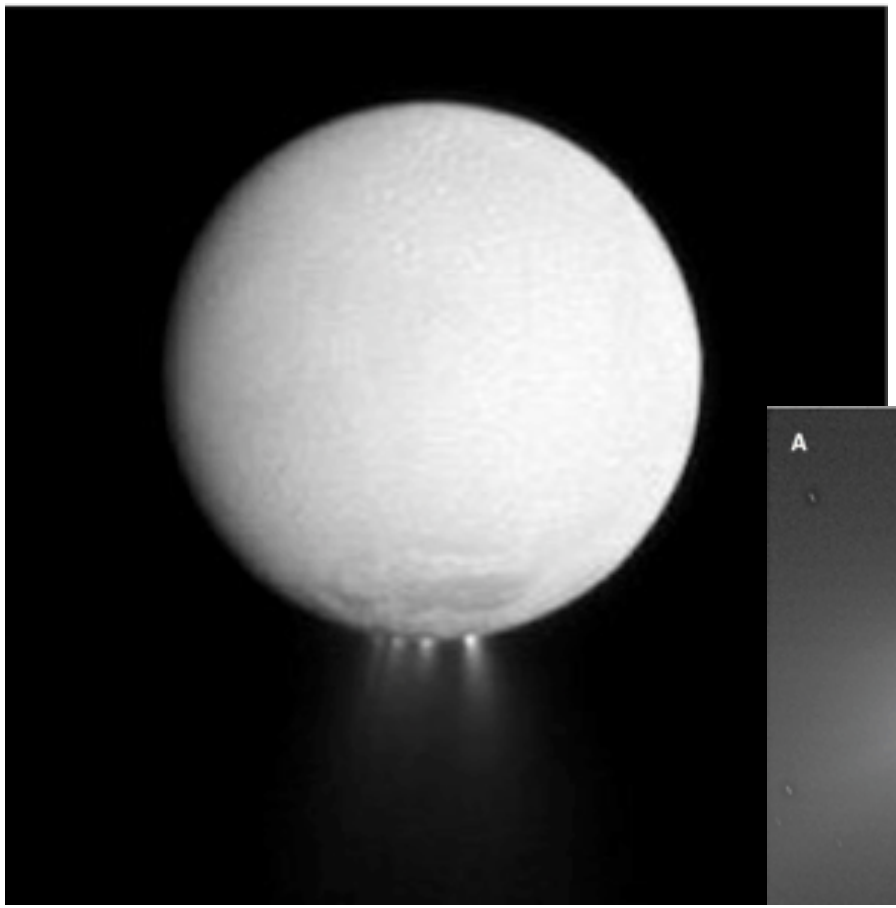
Enceladus: A small moon quite close to Saturn

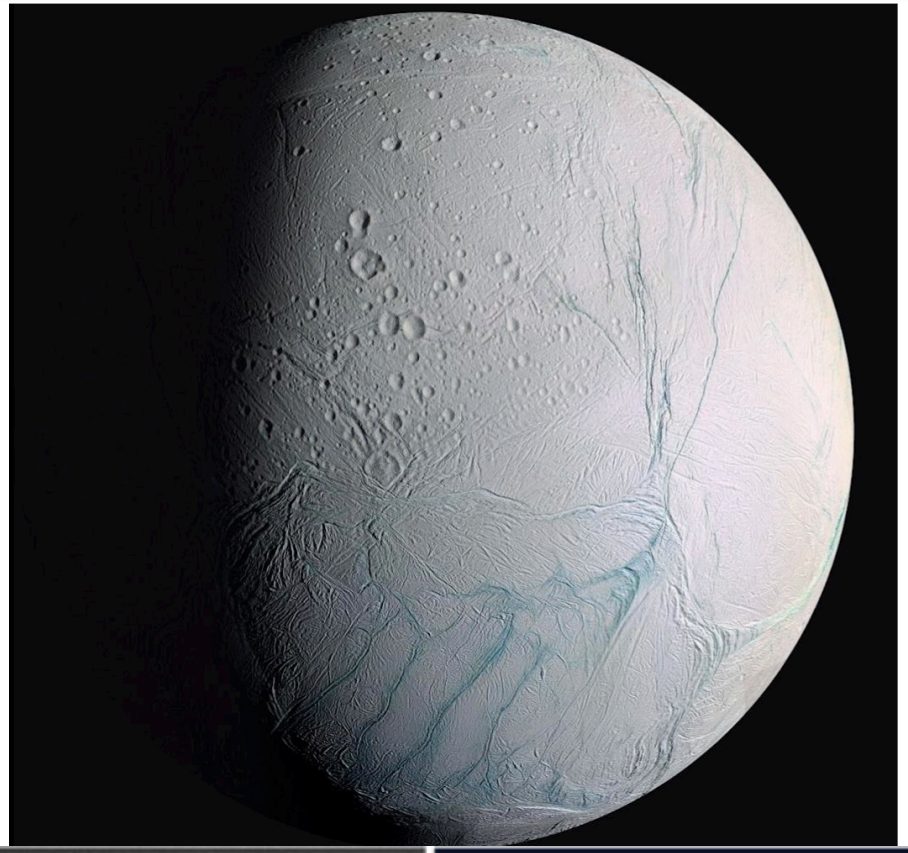


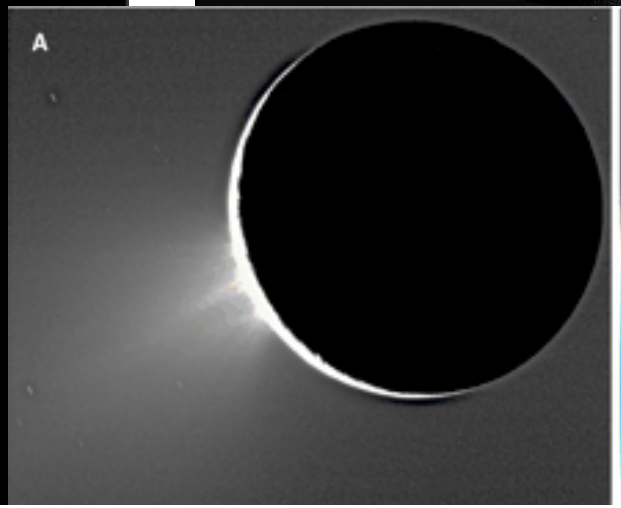
Cassini (2500 kg dry mass) discovered a plume coming from Enceladus…

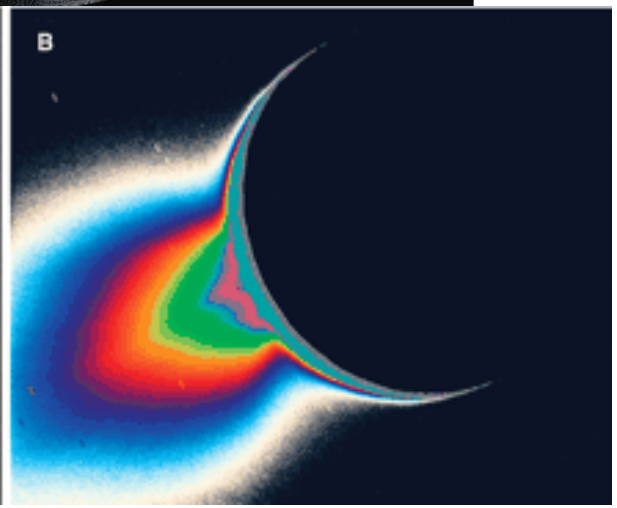
Enceladus Plumes

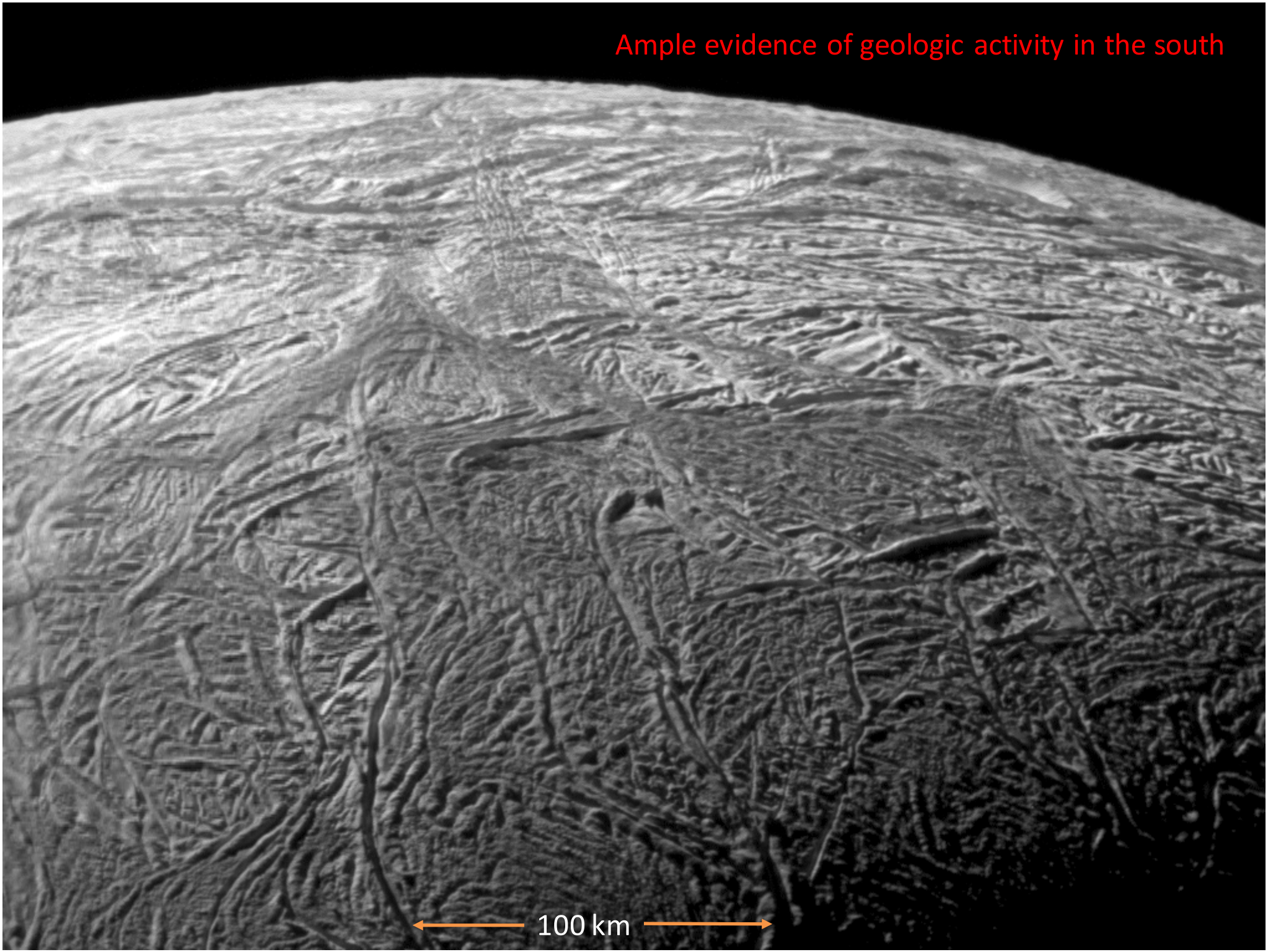
2005: Cassini discovers plumes and a south polar fracture system (Porco et al., 2006; Dougherty et al 2006)





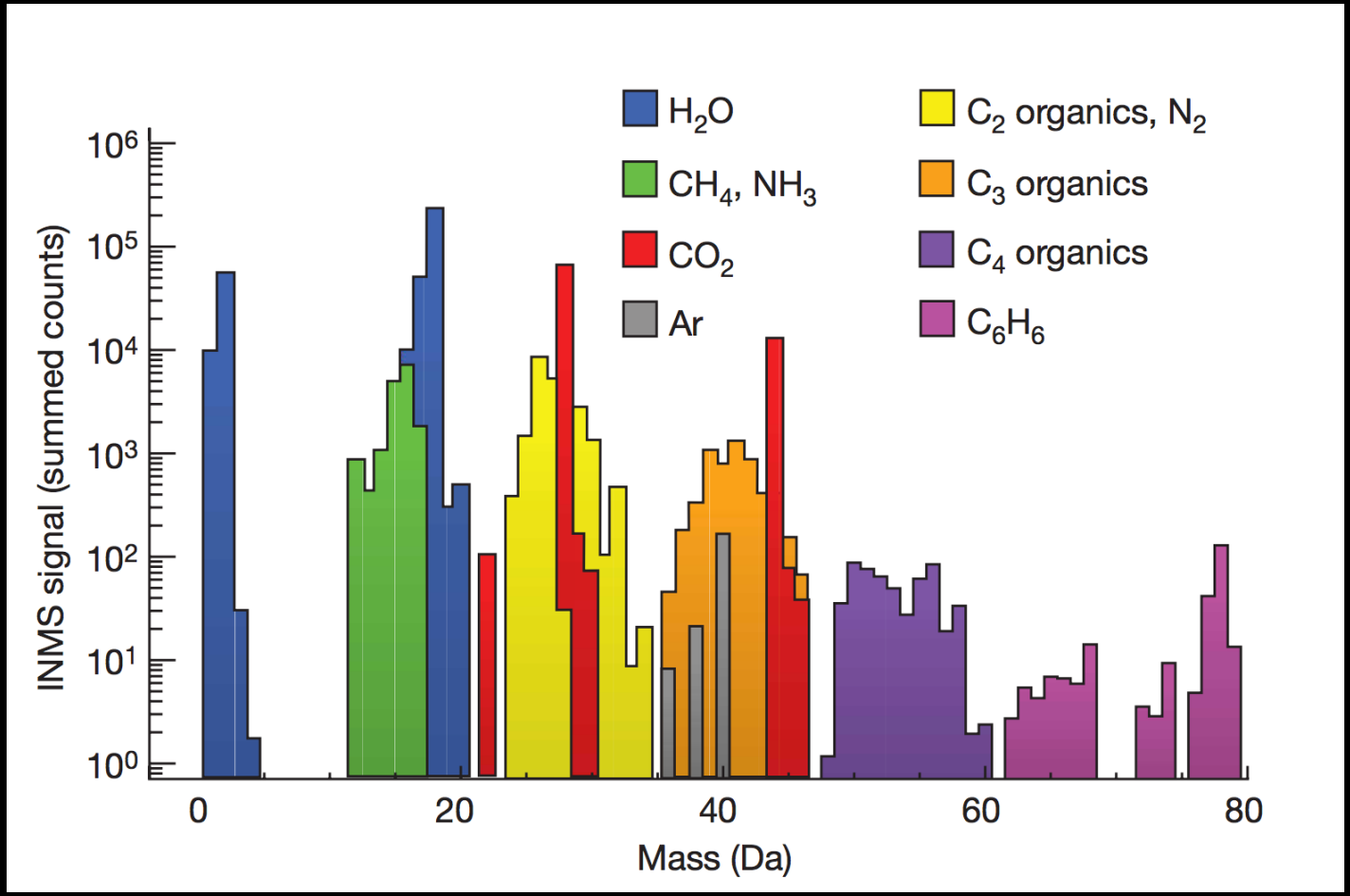




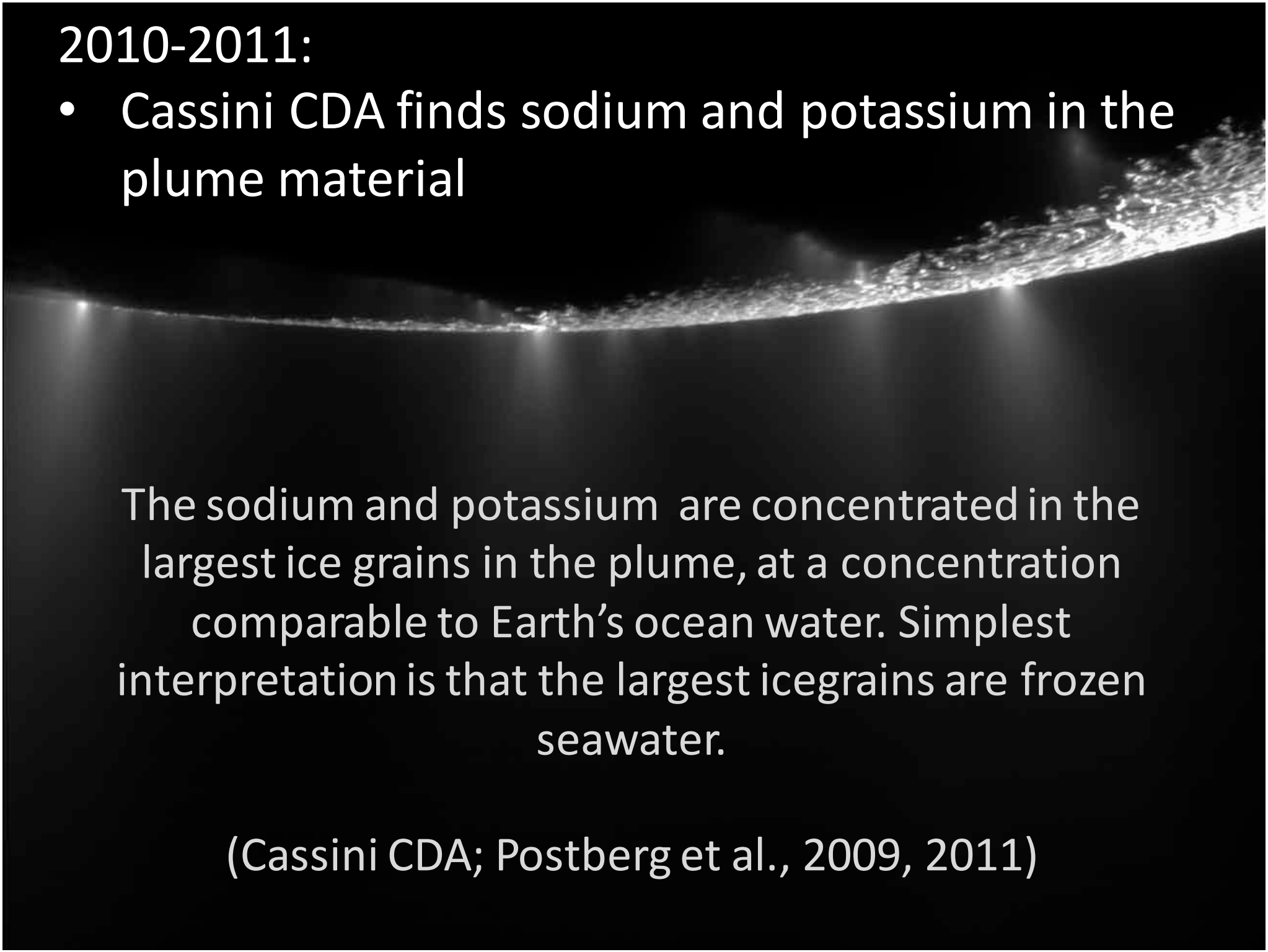

Ample evidence of geologic activity in the south
100 km

2008: Organics in the Plume

Cassini INMS discovers organics, ammonia in the plume by flying through plume and analyzing the material with its neutral mass spectrometer. (Waite et al. 2009)



Waite et al, *Nature*, 2009.



2010-2011:

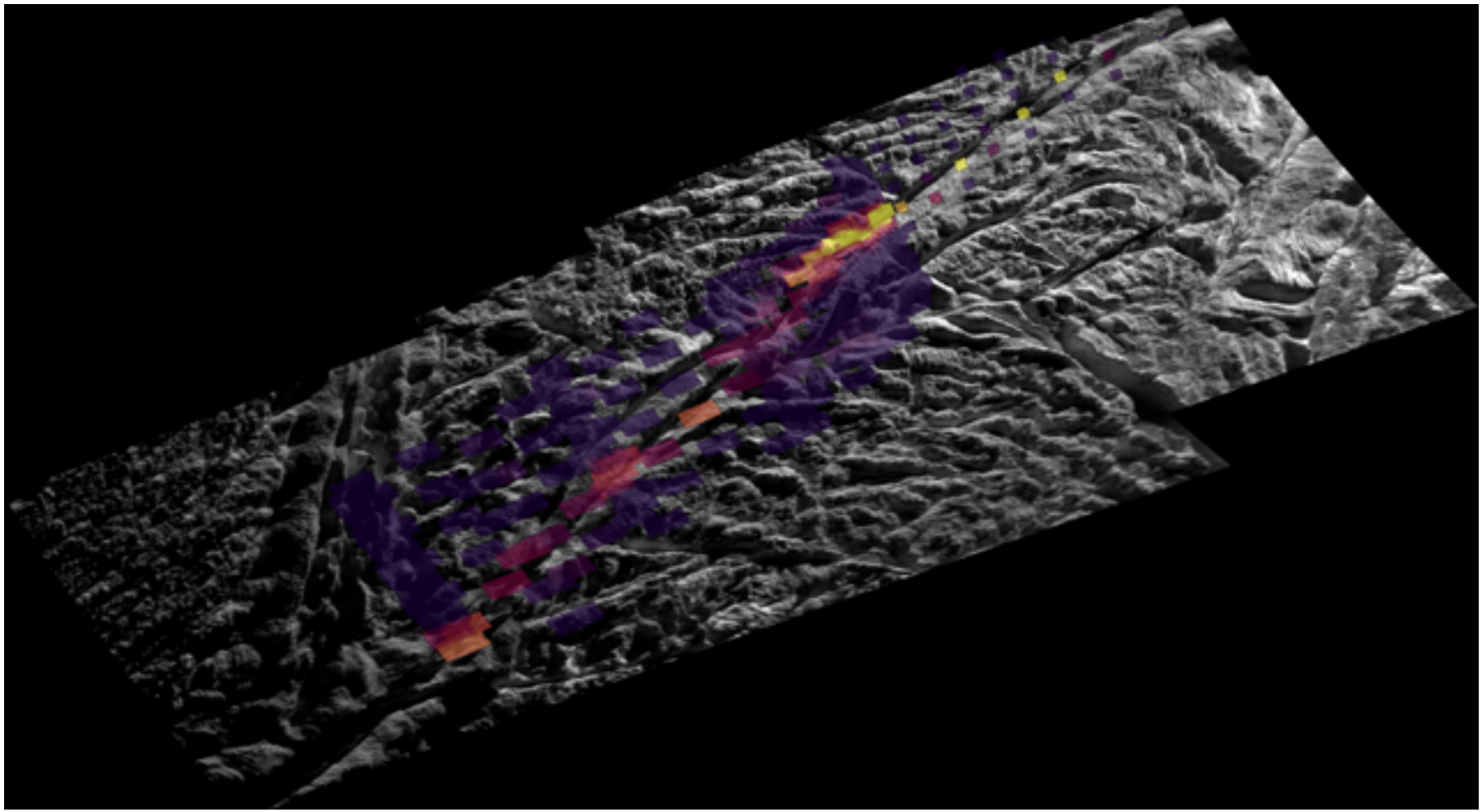
- Cassini CDA finds sodium and potassium in the plume material

The sodium and potassium are concentrated in the largest ice grains in the plume, at a concentration comparable to Earth's ocean water. Simplest interpretation is that the largest icegrains are frozen seawater.

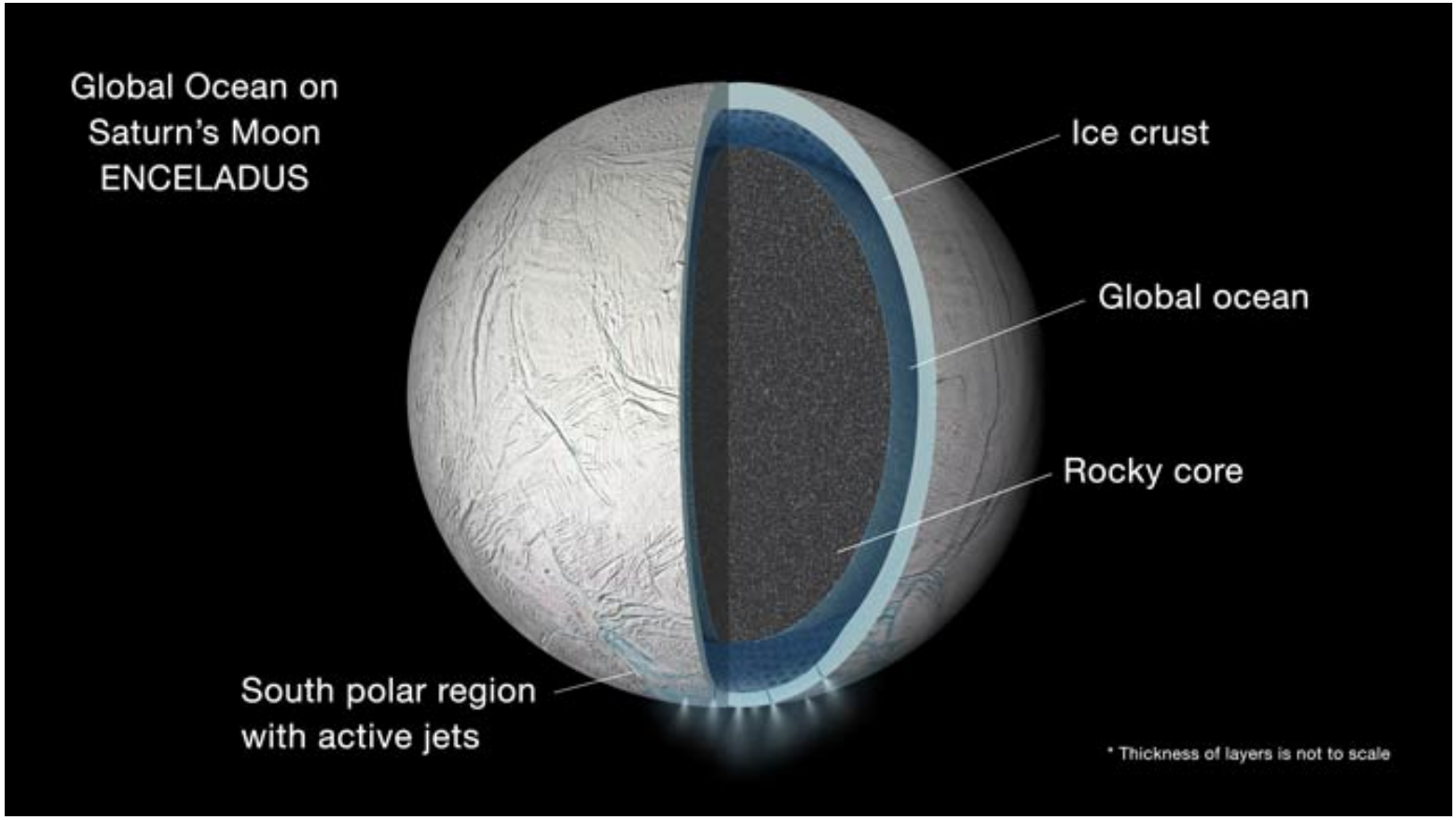
(Cassini CDA; Postberg et al., 2009, 2011)

2008-2012: Excess heat at the south pole.

- Several gigawatts from the south polar region, indicative of a warm interior (CIRS; Howett et al)



2014-5: Regional Sea under the Ice



Cassini radio science combined with topography and rotational data discovers a global ocean, perhaps thicker at the south pole: the smoking gun that beneath the jets is a region of liquid water, stable for very long time periods.

Iess et al., 2014. Science; McKinnon 2015; Thomas et al. 2015, Icarus

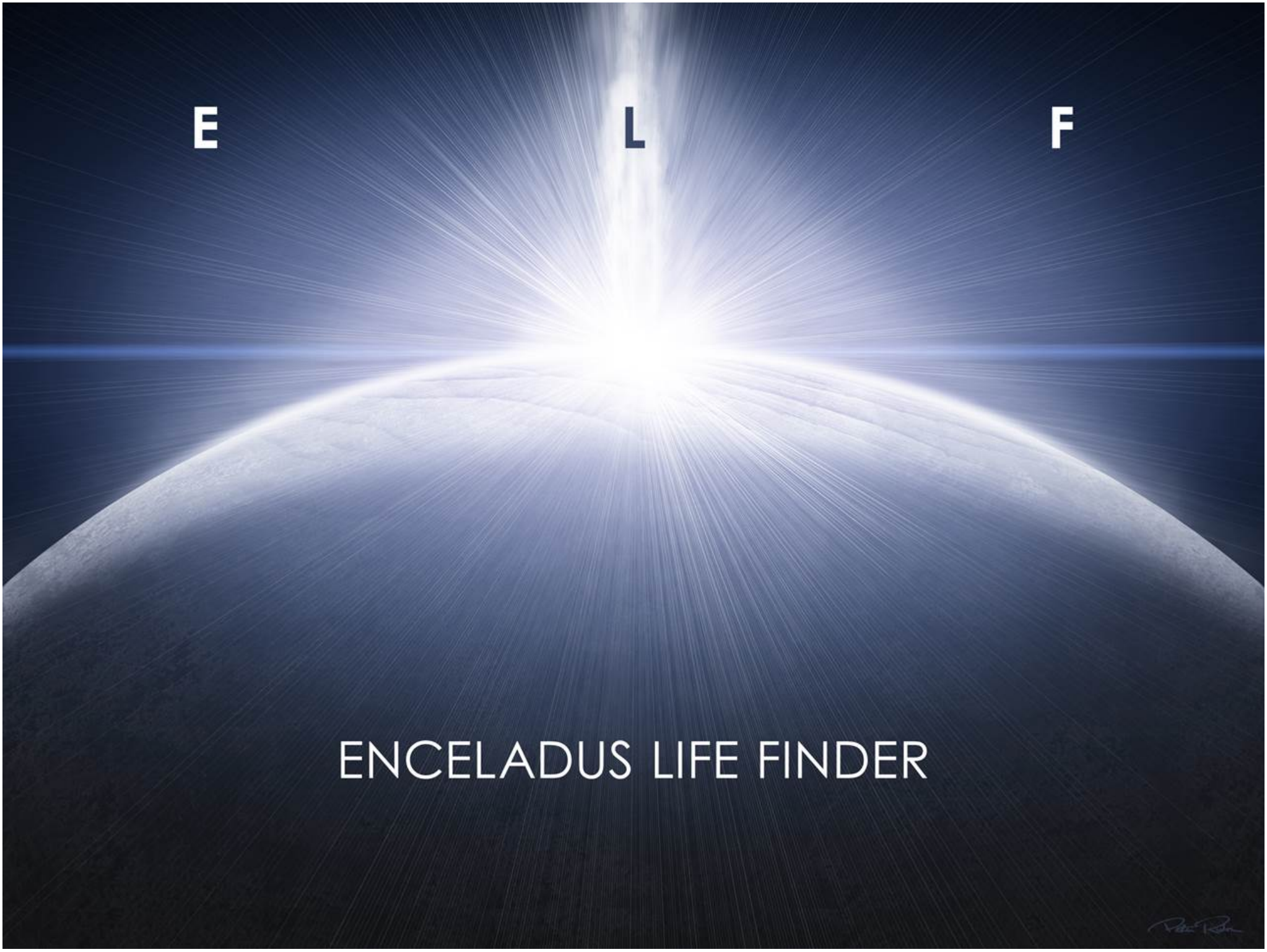
Life *in* Enceladus?

Multiple factors *make plausible the idea that life exists there:*

- An accessible, salty (CDA) ocean (RSS+ISS)
- Organics (INMS)
- Energy (CIRS)
- Hydrothermal system at ocean base (CDA)

Last Cassini Flyby through Enceladus' Jets

- Flyby date: October 28, 2015
- 50-km closest approach
- Looks for H_2 with INMS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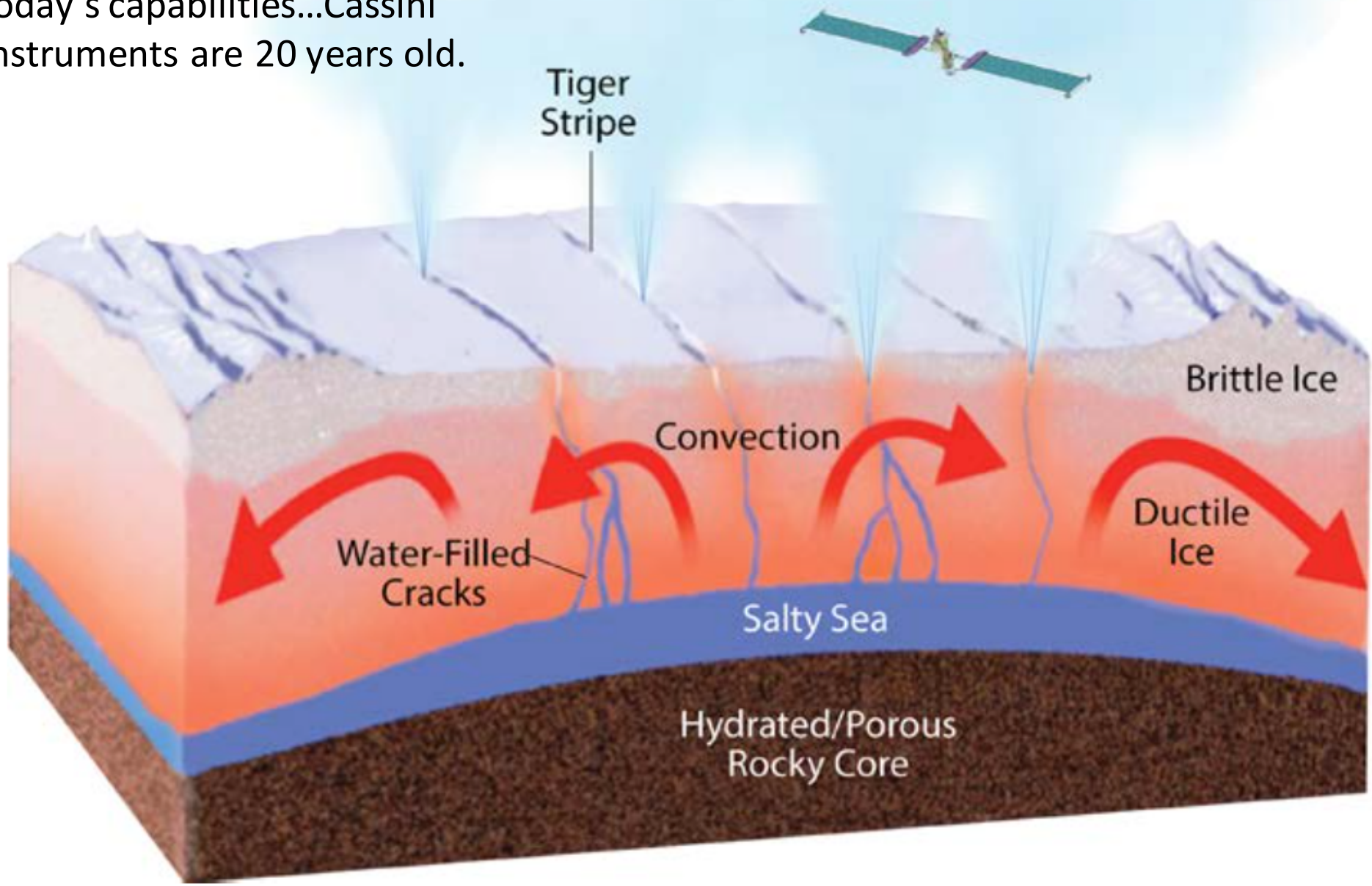
ENCELADUS LIFE FINDER

- Fly through the Enceladus plume just like Cassini did….
- But do it with instruments of today's capabilities…Cassini instruments are 20 years old.



Three objectives addressing two science goals

What were the primordial sources of organic matter and where does organic synthesis continue today? (Planetary Habitats Question 4)

1. Determine if Enceladus' volatiles, including organics, have evolved over time.

Evolution

Beyond Earth, are there modern habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now? (Planetary Habitats Question 6)

2. Determine if the ocean of Enceladus satisfies the basic requirements of habitability

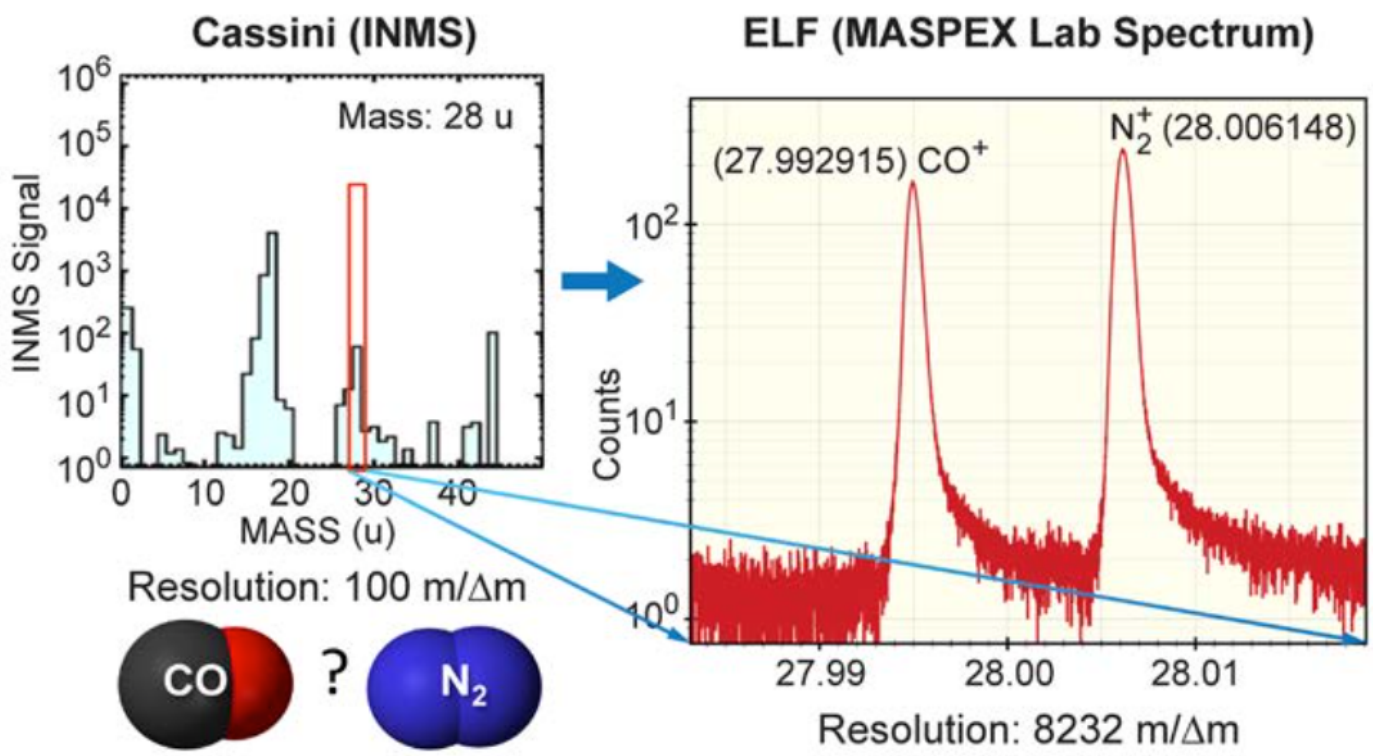
Habitability

3. Determine if the plume of Enceladus contains chemical signatures of biology.

Life

10 measurement objectives satisfied by two mass spectrometers, one optimized for gas, one for dust.

1997 2020

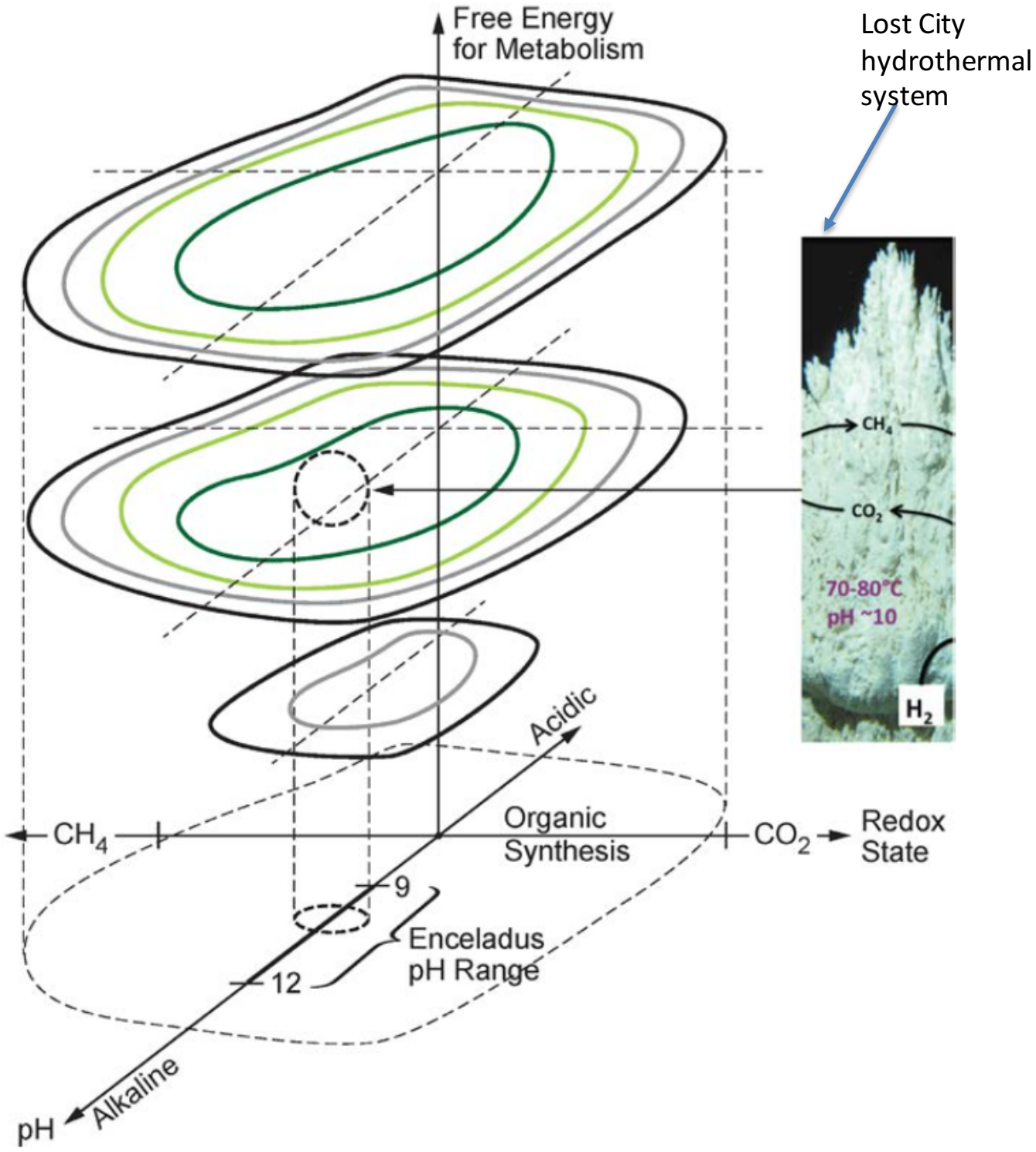


ELF uses mass spectrometers of much higher resolution, range, sensitivity.

ELF measures a large number of species to obtain ocean properties

- Temperature: Standard temperature indicators in geochemistry including the oxygen isotopic geothermometer for H_2O and CO_2, D/H ratios in H_2O and H_2, the ratio of Na/K, the ratios of CO_2/CH4 and N_2/NH_3. Preliminary number from Hsu et al (2015) from Cassini data
- Redox (free energy):Abundances relative to H_2O of reduced and oxidized species that may be out of equilibrium: H_2, CH_4, NH_3, H_2S, O_2, CO, CO_2, N_2, NO_3^- and SO_4^{-2}.
- Oxidation state (or redox potential) of the ocean and underlying hydrothermal systems: H_2/H_2O ratio; relative abundances of HCO_3^-/CO_3^{-2} and HCO_2^-; SO_4^{-2} relative to water, CO_2/CH_4 and N_2/NH_3 ratios. $Na(Na_2CO_3)_n$ in clusters up to n = 3.
- pH of ocean: Abundances relative to H_2O of CO_2, HCO_3^-, CO_3^{-2}; Ca^{+2}, Na^+, Cl^-, $Na(Na_2CO_3)_n$ in clusters up to n = 3; $Na(NaOH)_{)n}$ and $Na(NaCl)_n$ clusters up to n=4. (Preliminary estimate from Glein et al 2015 with Cassini data)

Conceptual diagram of the parameters defining habitability in a water ocean (temperature axis not shown)



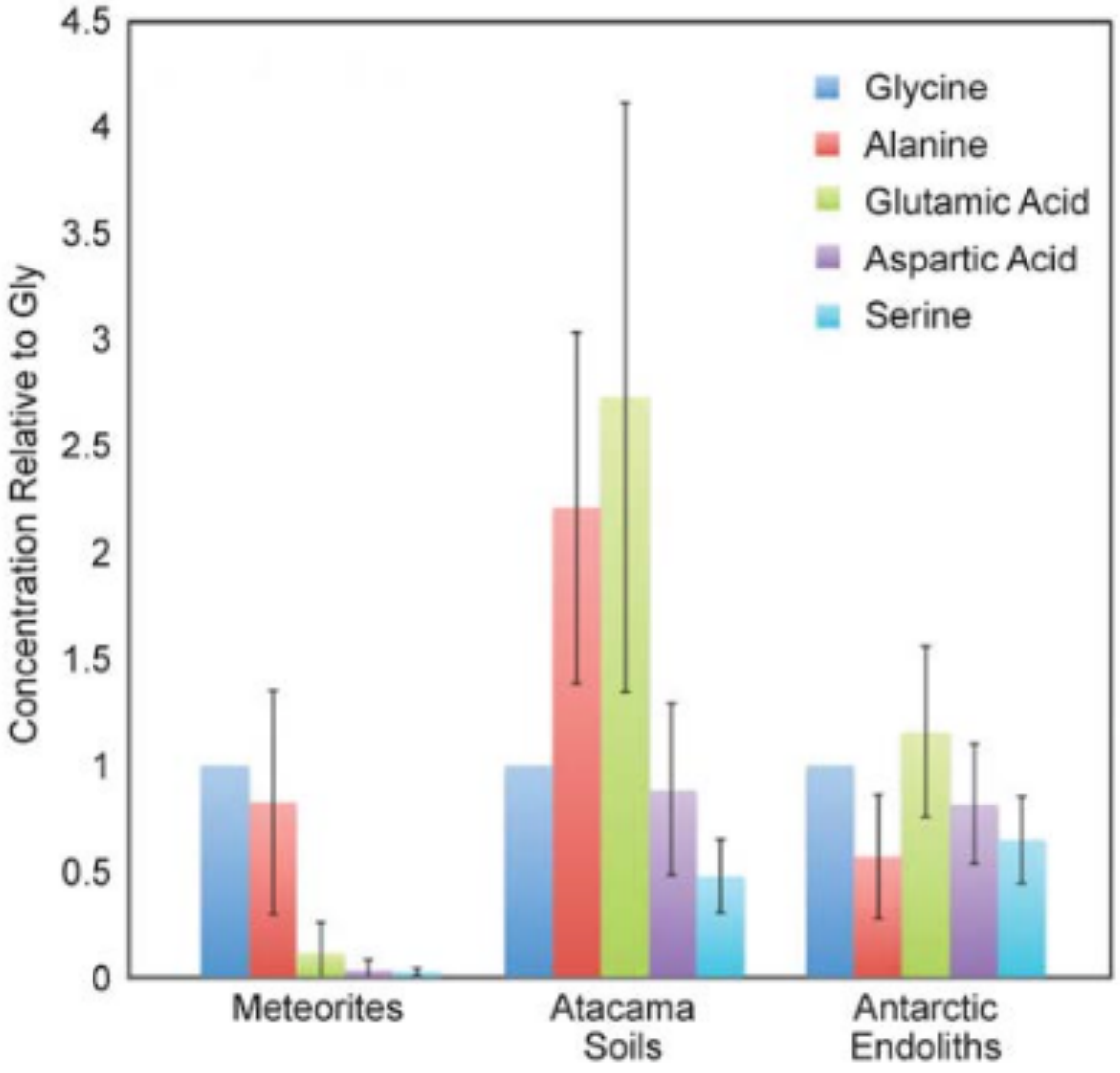
Evidence of biological processes

- ELF's objective 3 is to search for evidence of biological processes, *not* to capture and study an organism.
- The tests in objective 3 are designed to minimize the ambiguity involved in life detection by adhering to the following principles:
  - The three tests are distinct from each other – two are pattern related, one is isotopic. The two pattern tests involve completely different classes of organic compounds.
  - The tests seek properties of life that are inherent in its essential nature: (a) relative concentrations of related chemical monomers that are not dictated by reaction kinetics or thermodynamics, but rather by adaptive utility; (b) uneven distribution patterns of structurally related compounds, for example in carbon number; (c) isotopic signatures of the specificity and efficiency of enzymatic organic reactions.
  - The tests are as universal as possible.

ELF's three tests for biological processes:

1. Amino acid pattern deviating from abiotic

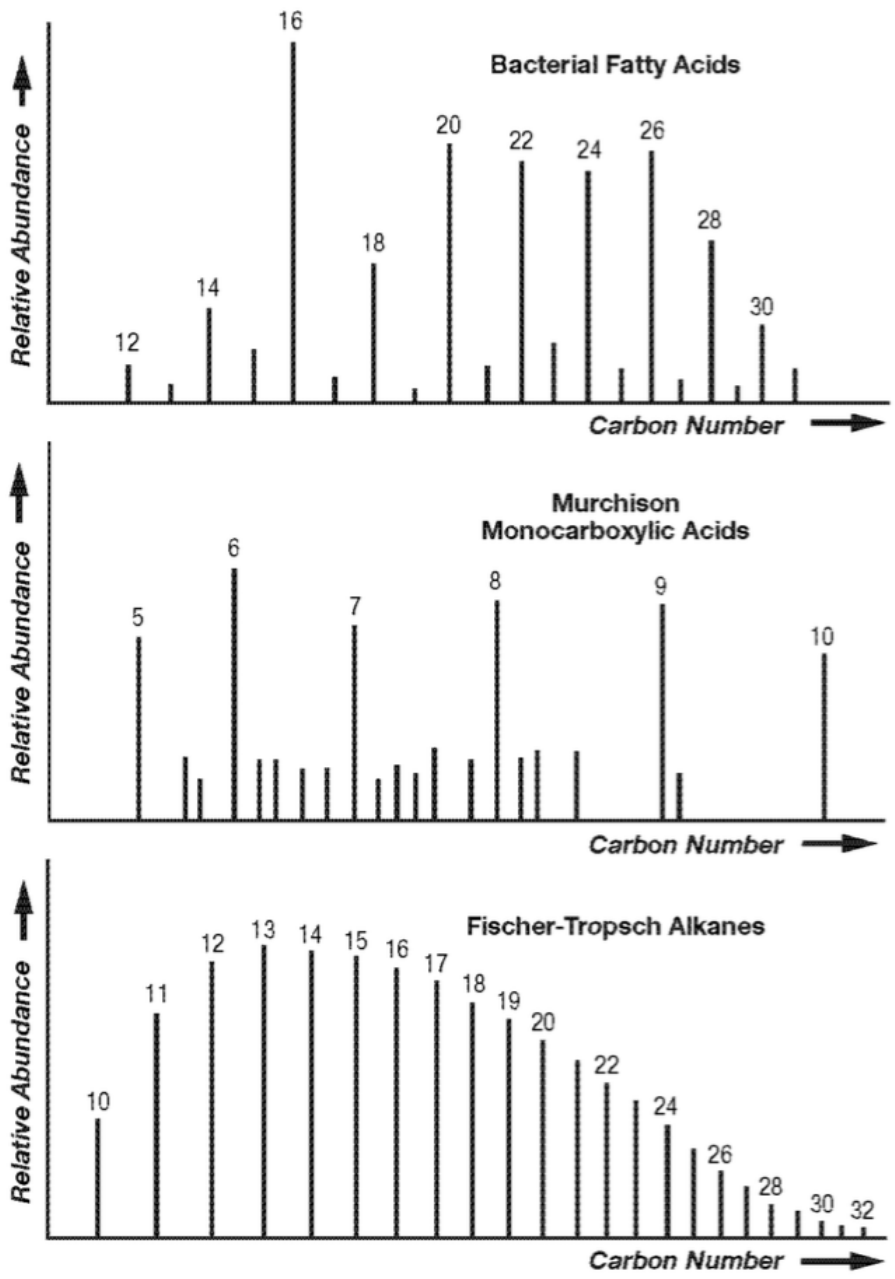
Put simply: Glycine and Alanine dominate in abiotic systems, but not in biotic systems.



ELF's three tests for biological processes:

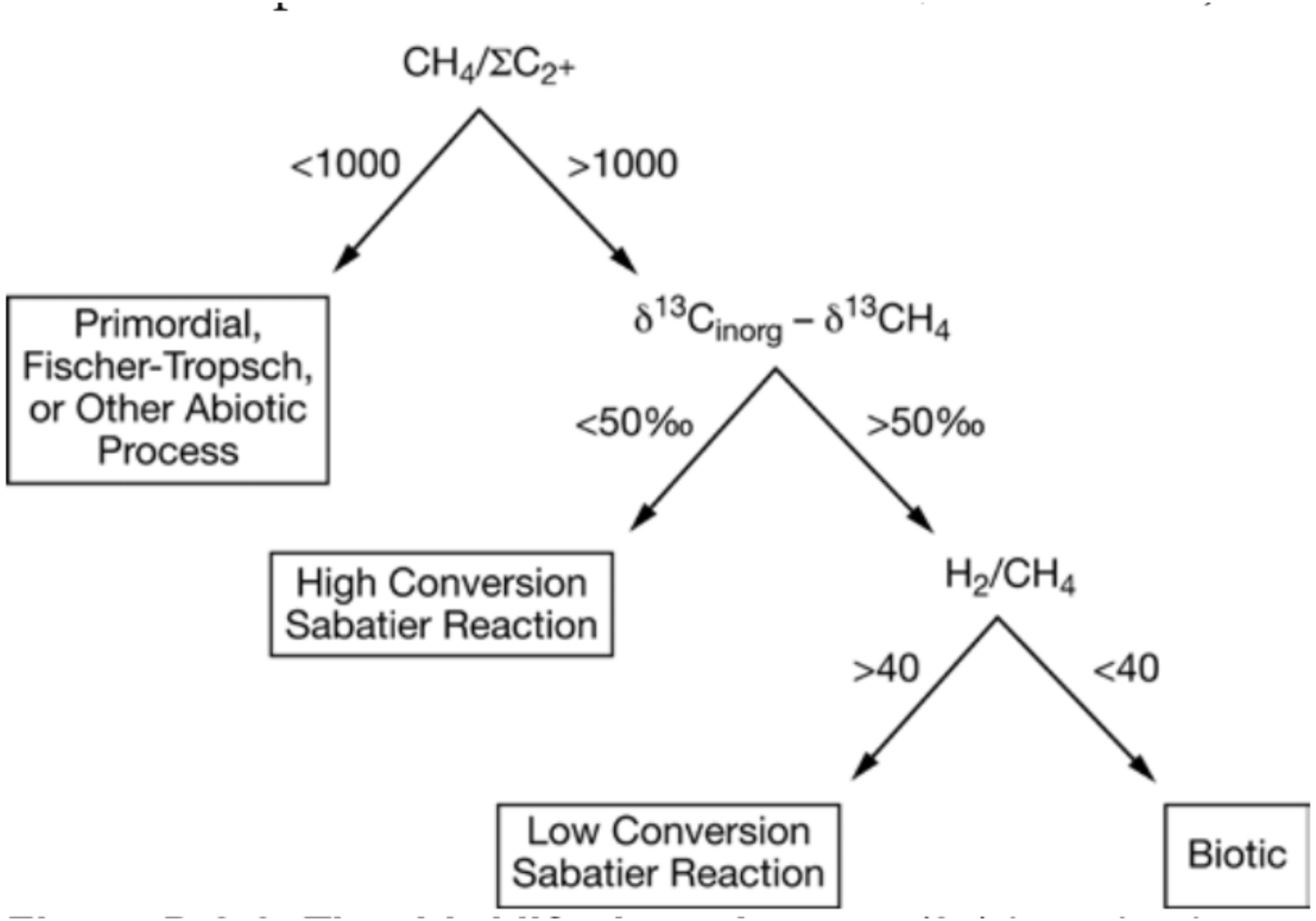
1. Amino acid pattern deviating from abiotic
2. Repeating subunits and clustering in membrane-building molecules

Put simply: biotic membranes exhibit repeating carbon subunits; abiotic do not.

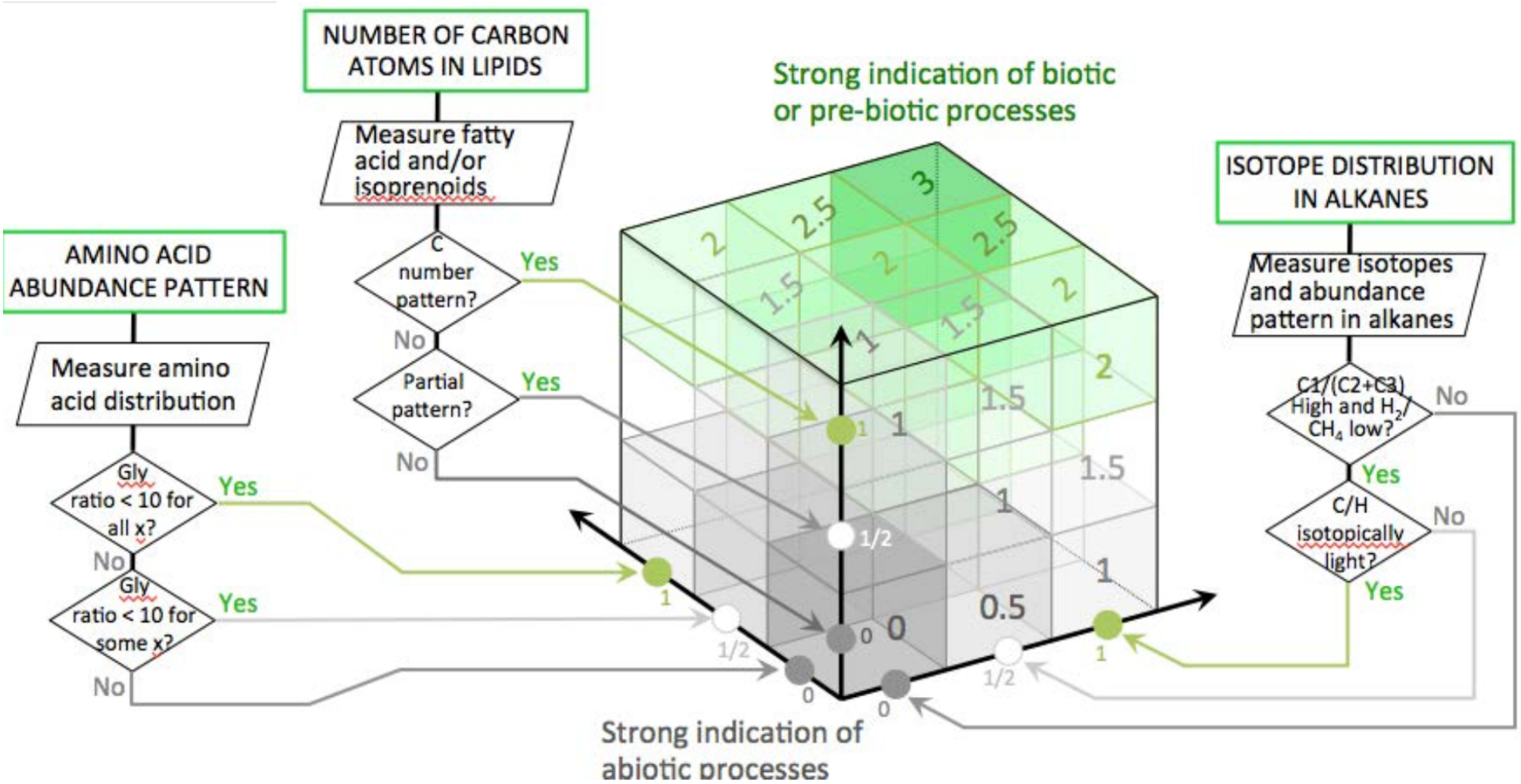


ELF's three tests for biological processes:

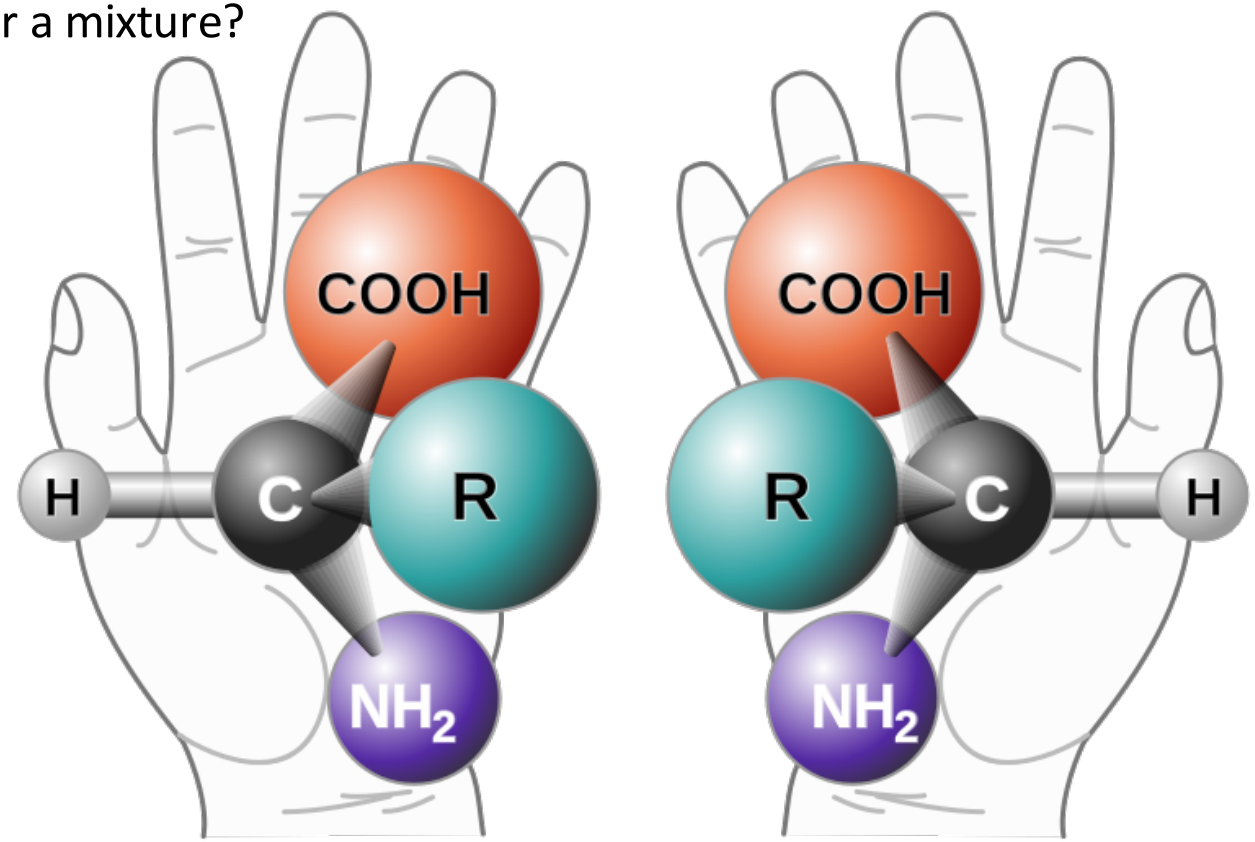
1. Amino acid pattern deviating from abiotic
2. Repeating subunits and clustering in membrane-building molecules
3. Combined isotopic and compositional trends



Search for biological processes involves all three tests in combination



A fourth independent test, carried as a “technology demonstrator”, measures the entantiomeric ratios of chiral amino acids—are they overwhelmingly left- or right-handed, or a mixture?



This .... or that... or both?

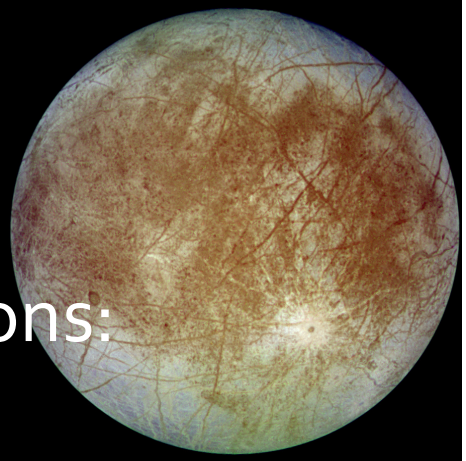
Enceladus Organics Analyzer (EOA)--*microchip capillary electrophoresis:*
Provided by Dr. Richard Mathies at *UC Berkeley*

Why Discovery for an Enceladus mission?

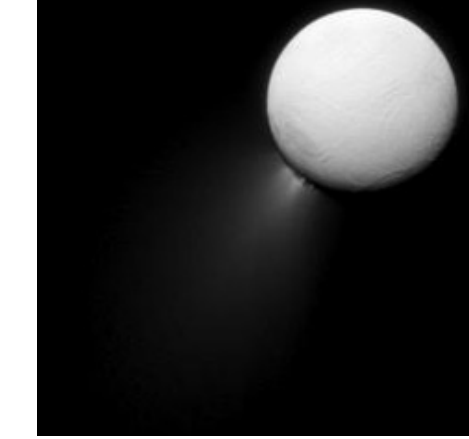
- Classic Discovery mission—follows on from Flagship with a well-proven analysis technique (Cassini did it, at a range of flyby speeds and altitudes that allow us to fine-tune our fly-throughs).
- We will not do costlier, high-risk missions at Enceladus without knowing something more about its biological potential
- There is “too much” to do in the outer solar system…do with Discovery what you can do with Discovery.


ELF
ENCELADUS LIFE FINDER

Conclusions



- We have strong indicators of habitable environments in two outer solar system moons: Europa and Enceladus
- Europa: search for organics, confirm identity of salts, and determine how to access seawater. Get Europa Flyby mission ASAP to Europa!



- Enceladus: there is definitive evidence of a subsurface ocean with organics, salts, free energy.
- The plume of Enceladus includes ocean material and is readily analyzed for evidence of life—a goal of Enceladus Life Finder.

Thank you's…

- The ELF science and instrument team
- Diana Blaney and the MISE team
- Jet Propulsion Laboratory management and engineers
- The Cassini-Huygens Project