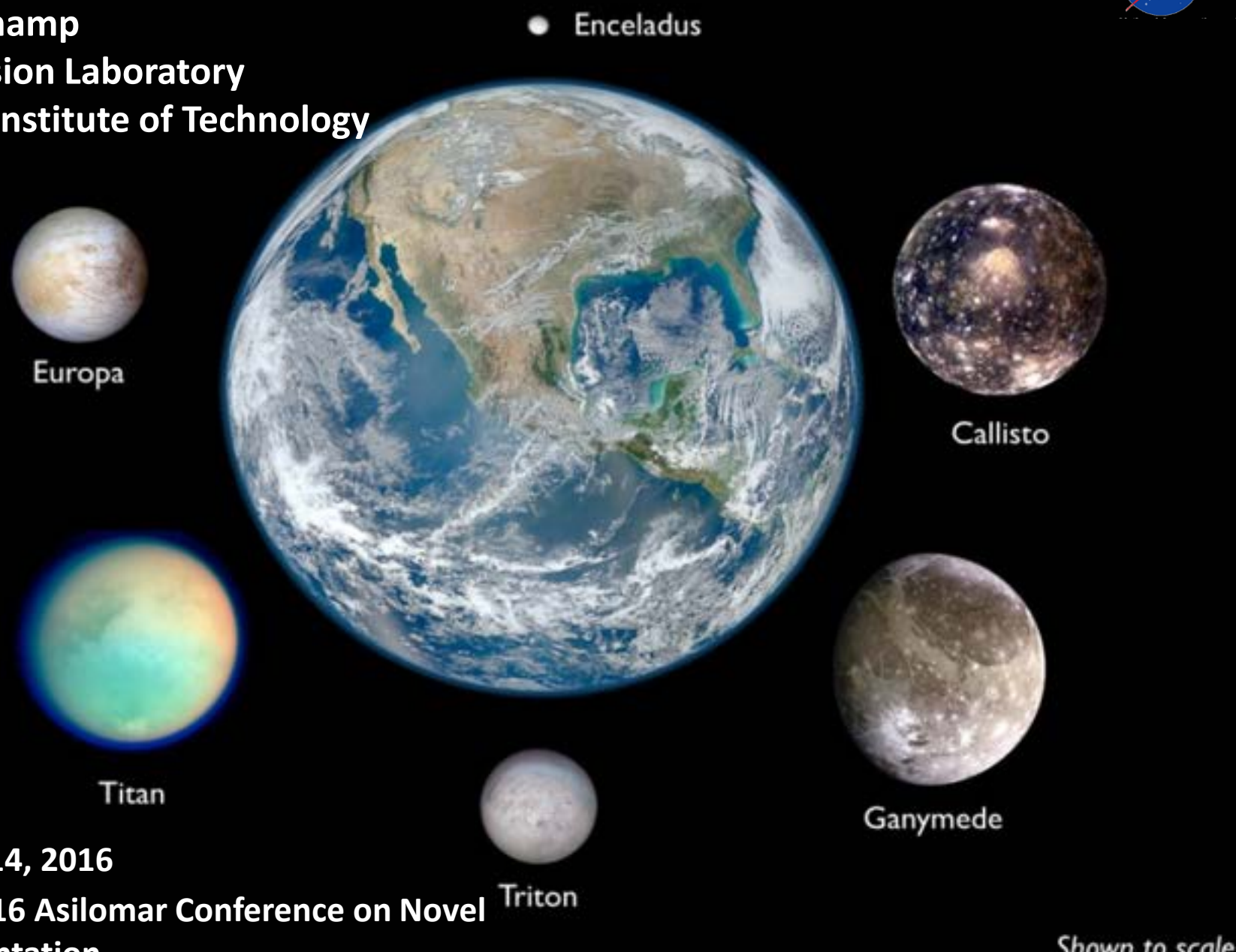
Mass Spectrometers for Ocean Worlds

Pat Beauchamp
Jet Propulsion Laboratory
California Institute of Technology



October 14, 2016

ASMS 2016 Asilomar Conference on Novel Instrumentation

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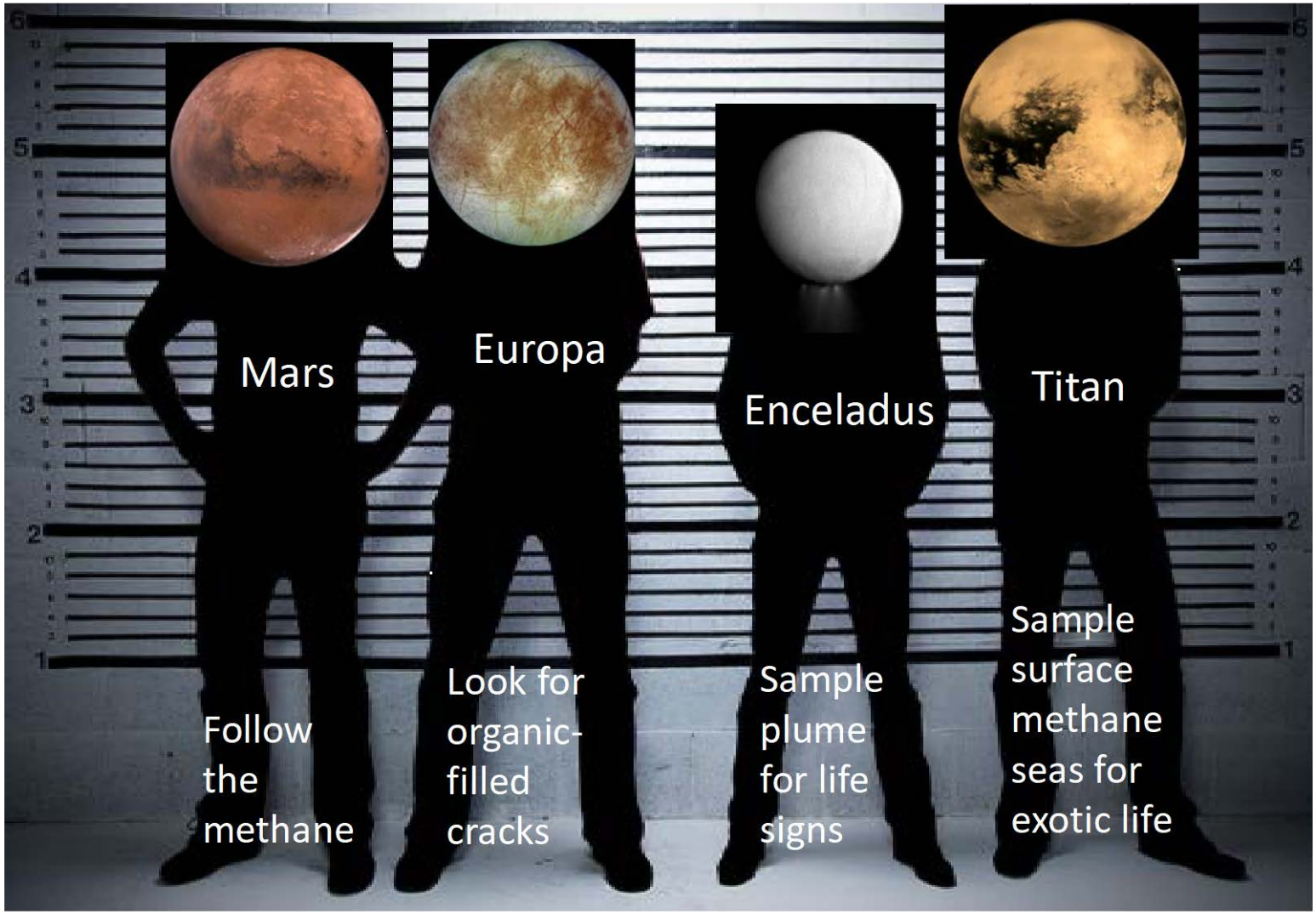
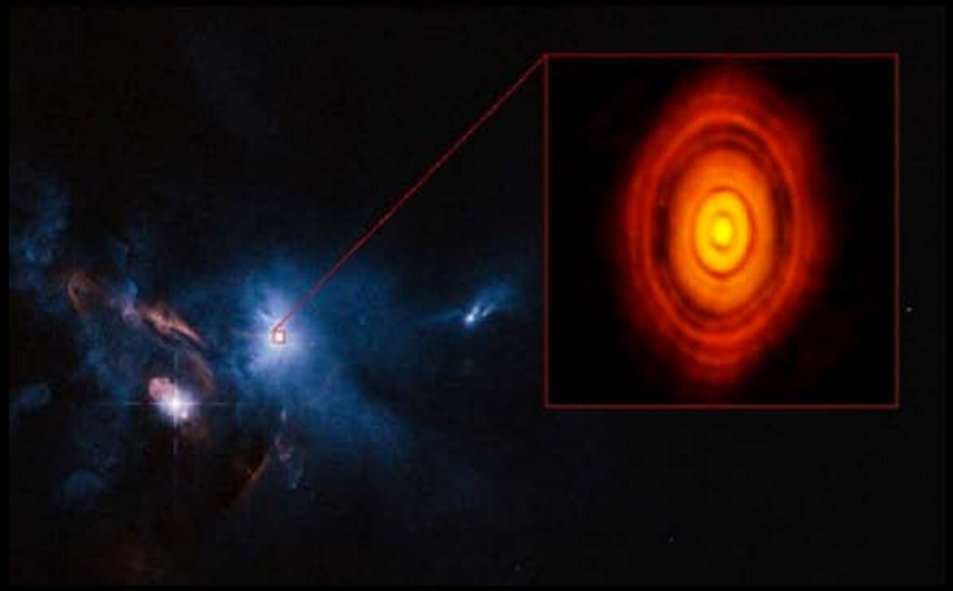
The lineup of solar system suspects in the search for life

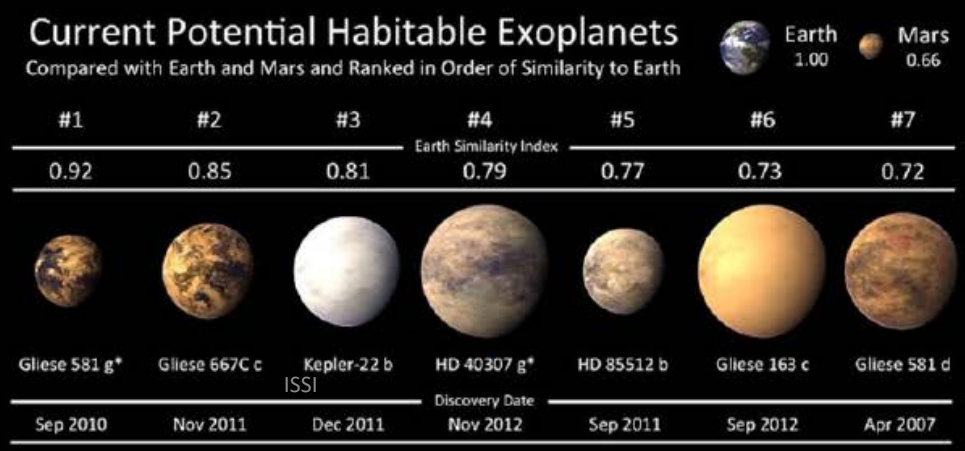


J. Lunine 2015

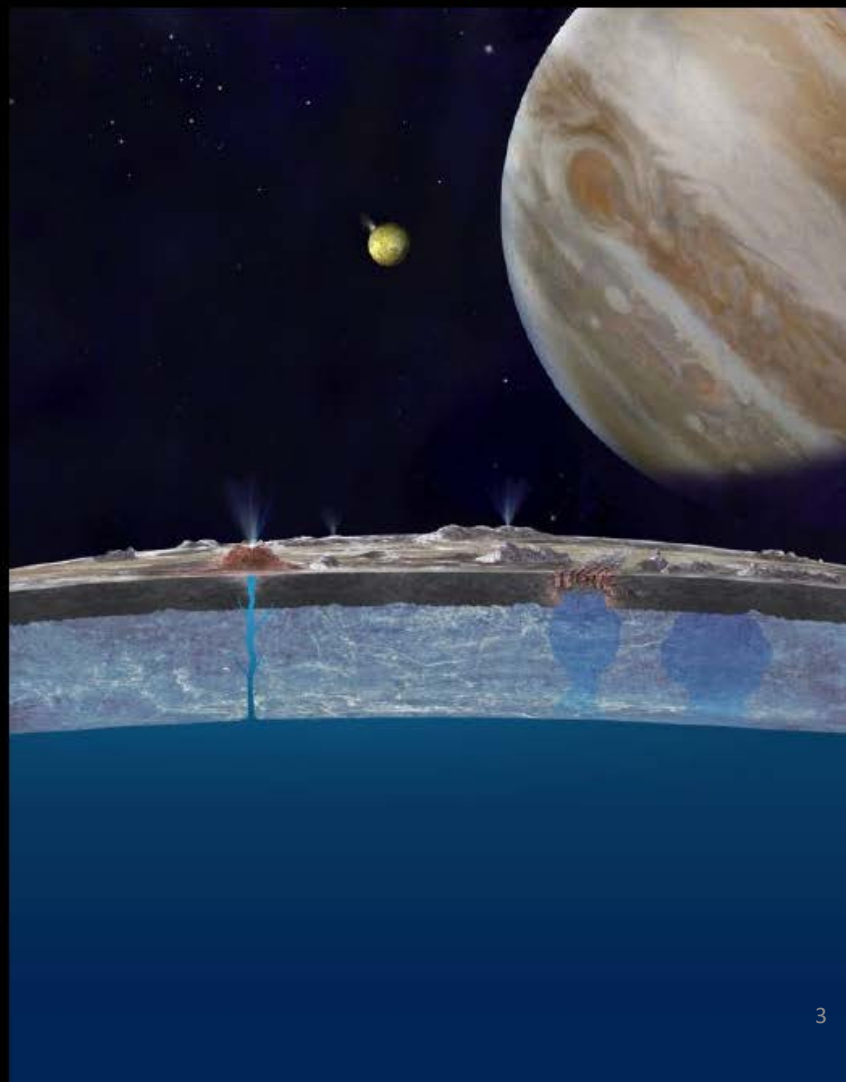
Is there life somewhere else in the Universe ?

Extra-solar habitable planets





Life in icy moons

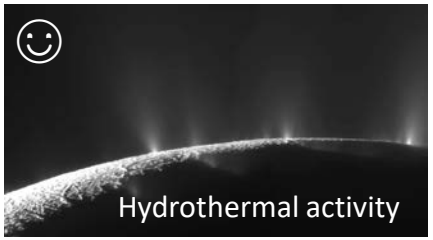


WATER

HABITABILITY

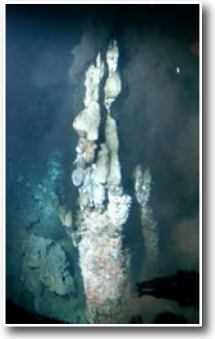
LIFE

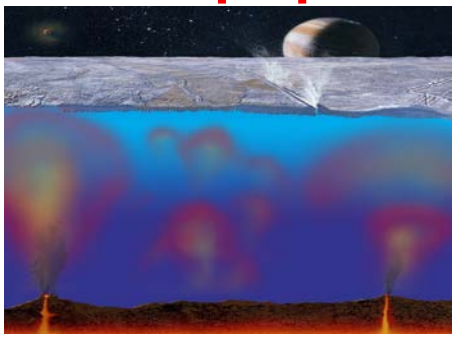
Galileo Mission

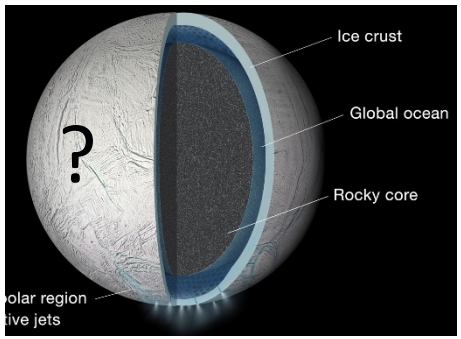


Cassini Mission

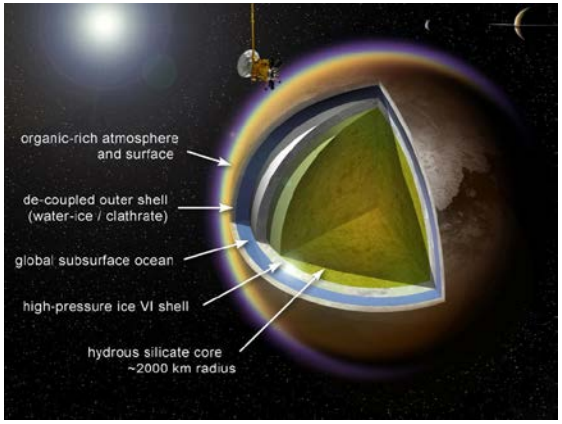
Sea-floor – Life as we know it





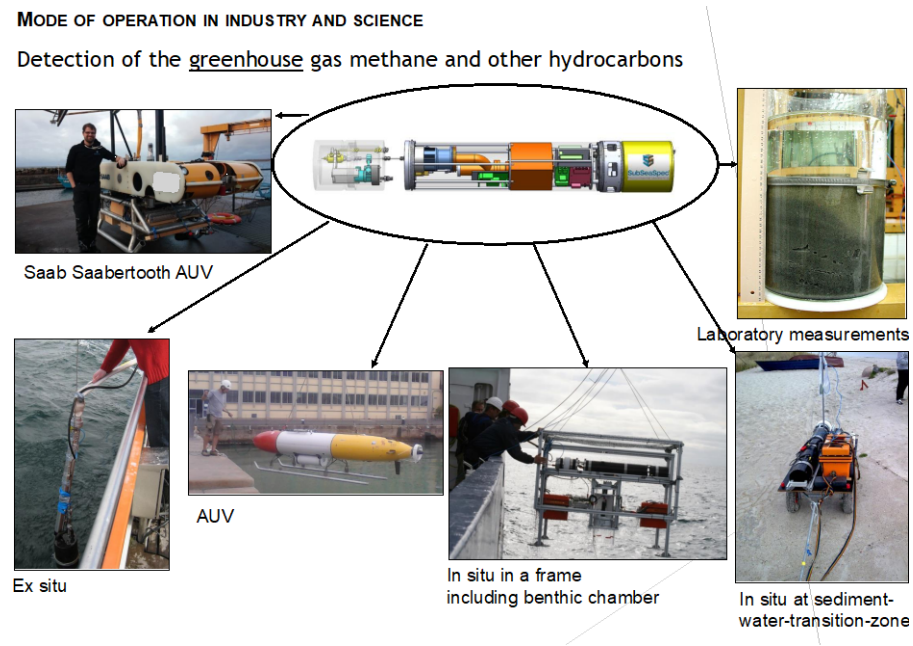


Other type of life ?



Improvements in Under Water Mass Spectrometry

Mass Spectrometry in our Oceans is more routine now



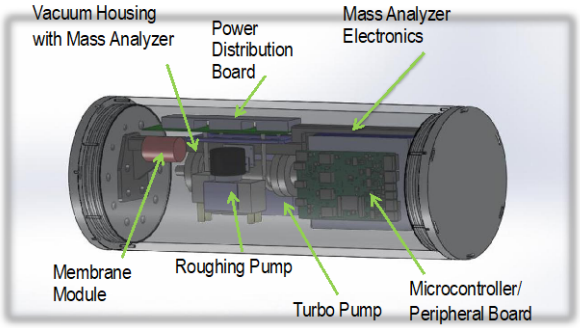
In-Water Mass Spectrometry for Characterization of Light Hydrocarbon Seeps and Leaks

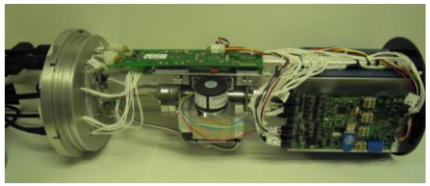
R. T. Short, S. K. Toler, A. M. Cardenas-Valencia, S. Untiedt, C. Cullins, M. Ryder, and J. Kloske

SRI's MIMS Instrument is AUV Deployable

Specifications

- Power: 60-80 Watts
- Voltage: 24 VDC
- Dimensions:
  - Length: 64 cm
  - Diameter: 24 cm
- Weight:
  - In air: 35 kg
  - In water: 5 kg neg.
- Depth rating: 2000 m

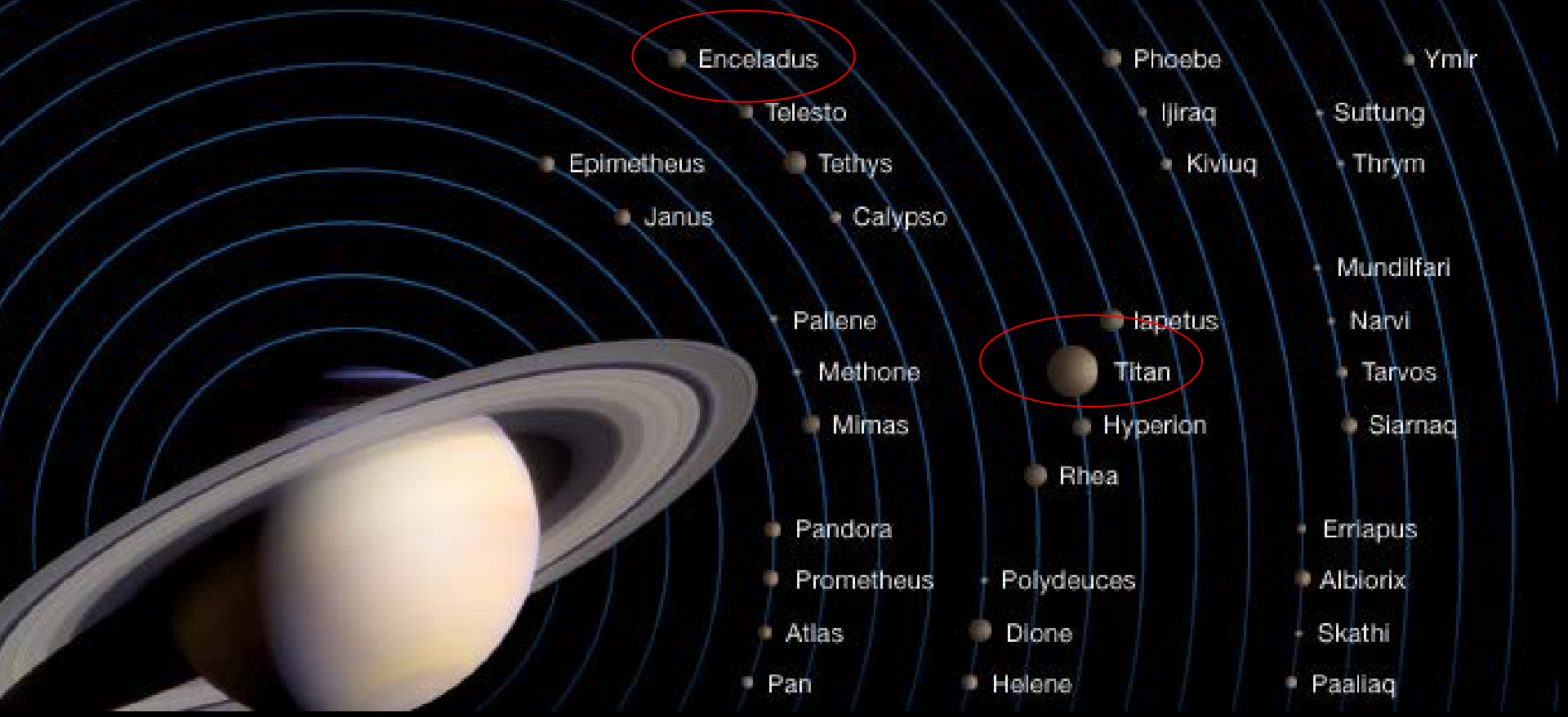




But what do we do a billion miles or more away….?

EARTH

Saturn's Moons

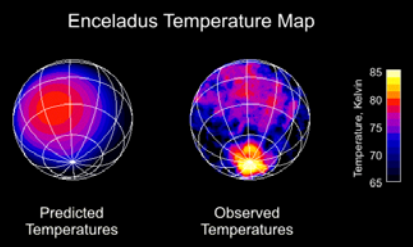


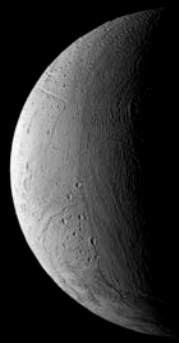
NASA/JPL

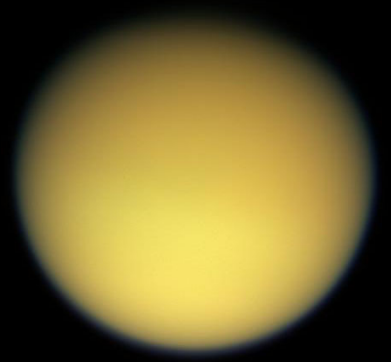
Cassini Imaging Team,/ISS/JPL/NASA

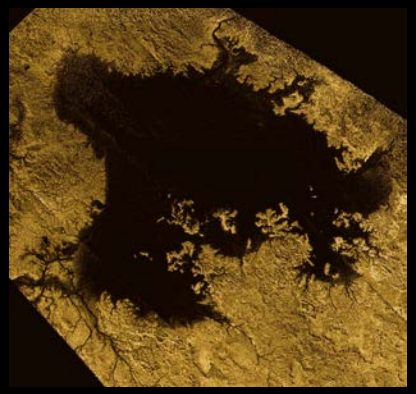
Saturnian System: Enceladus and Titan

	Enceladus	**Titan**
Radius	250 km	2575 km
Atmosphere	None	N_2, Ar, CH_4, H_2
Density	1.24 g/cm^3	1.88 g/cm^3
Surface Composition	Water ice; dark rocky material	Water ice, surface methane/ethane liquids, organic compounds
Drivers for investigation	Subsurface ocean; Plumes of water ice and organics; active geologic activity	Abundant organics, active hydrological cycle; active organic chemistry; subsurface ocean

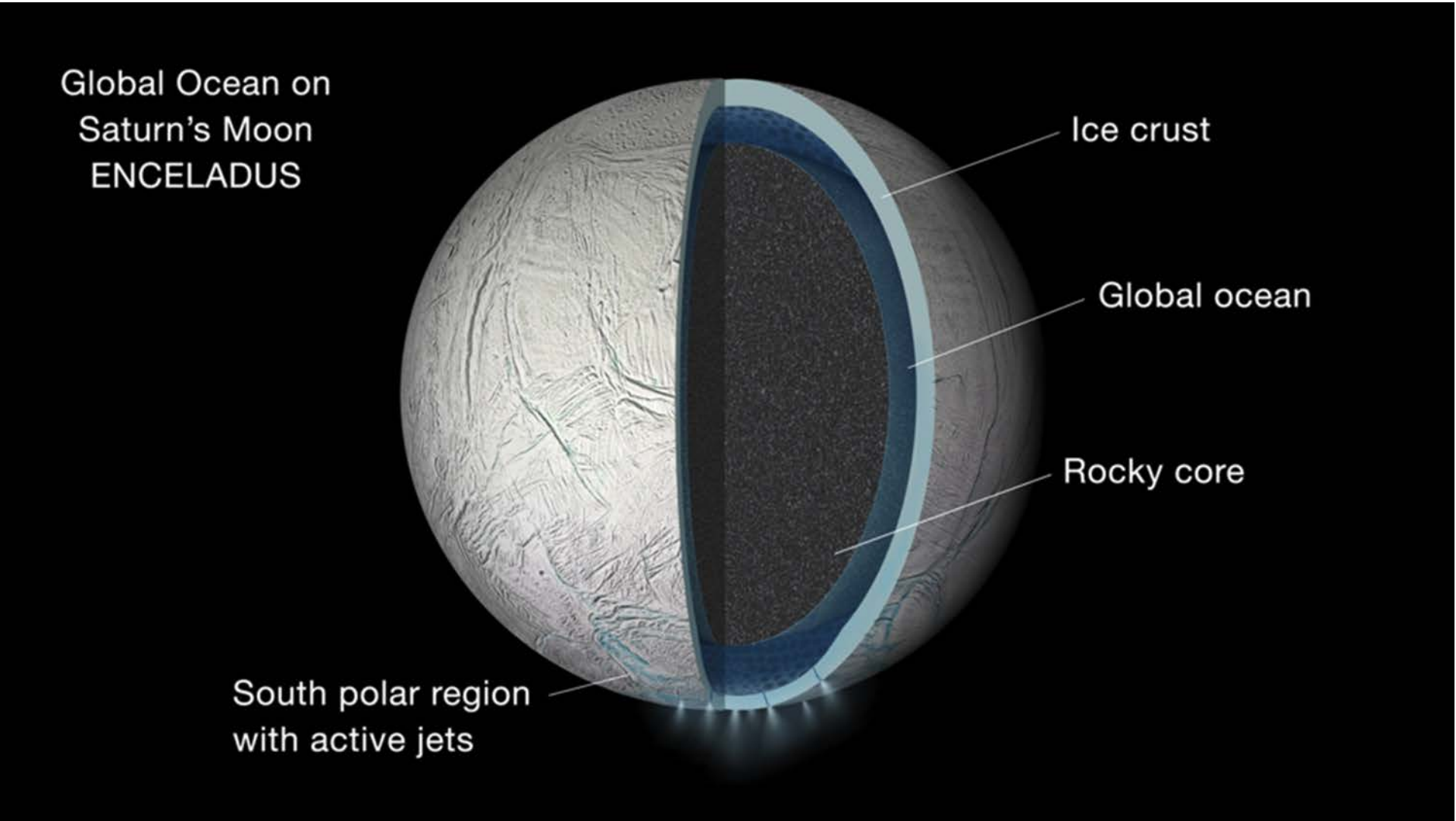






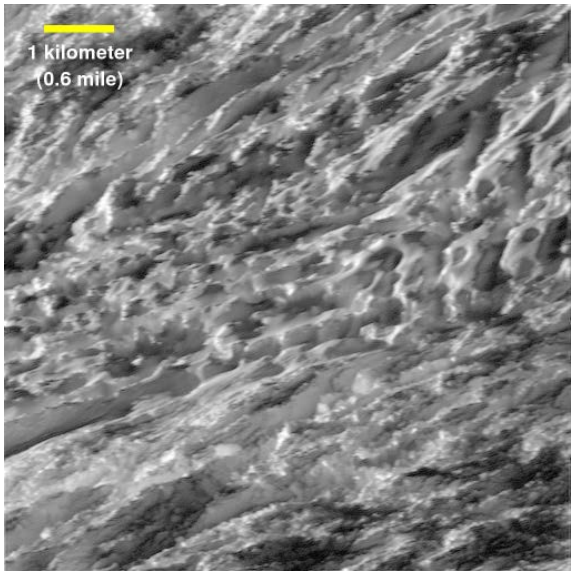


Enceladus's Ocean

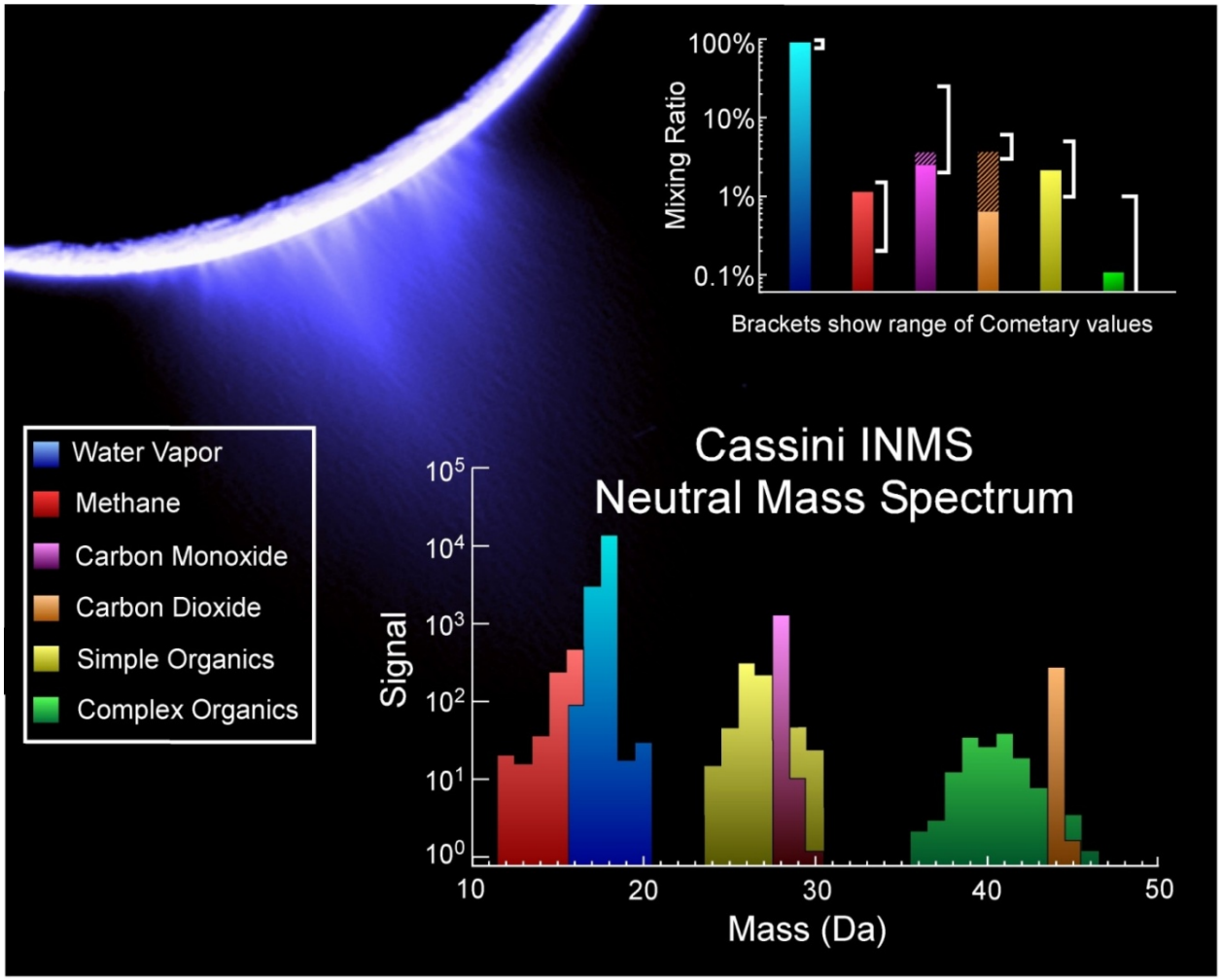


Enceladus

The little moon with active geysers



Cassini Imaging Team/ISS/JPL/NASA

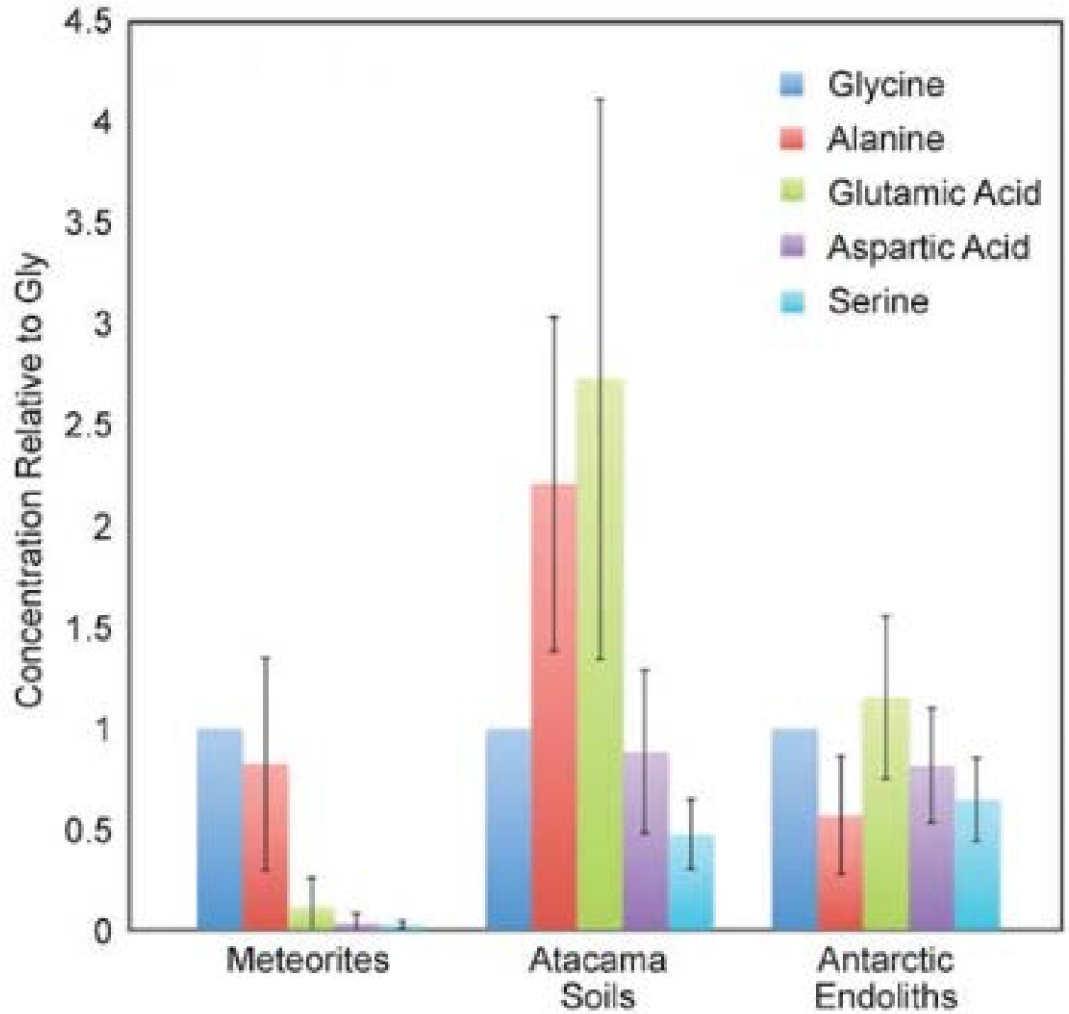


Looking like a comet, Enceladus shows its plume in scattered sunlight as this moon casts a shadow some 500 km across on the

LEGO principle: life chooses a small number of building blocks out of the wide spectrum of available organic molecules.

Free energy corollary: Relative abundances of biomolecules are not determined by the thermodynamic gradients (free energies of formation) or kinetics of the system.

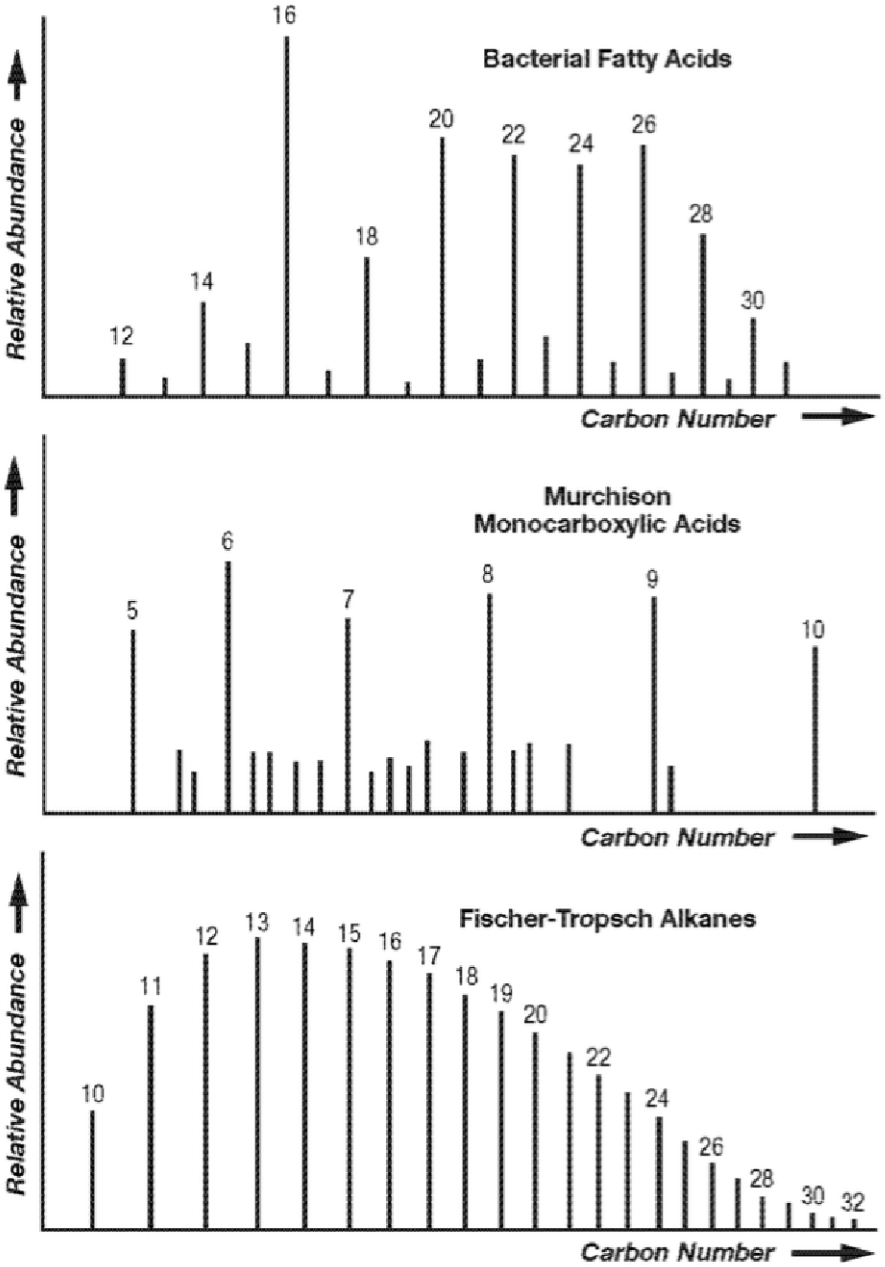
ELF's three tests for biological processes:



1. Amino acid pattern deviating from abiotic

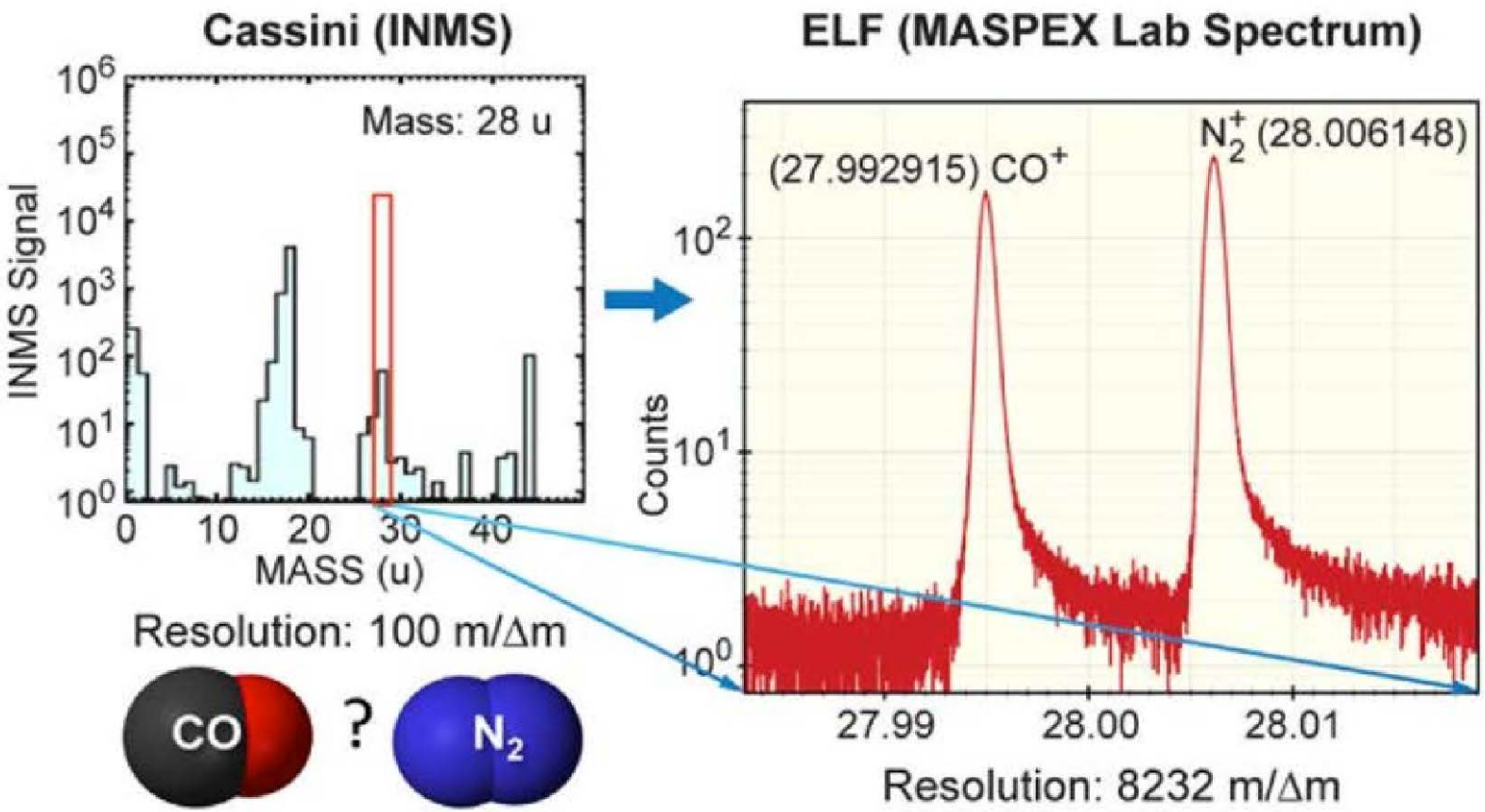
ELF's three tests for biological processes:

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

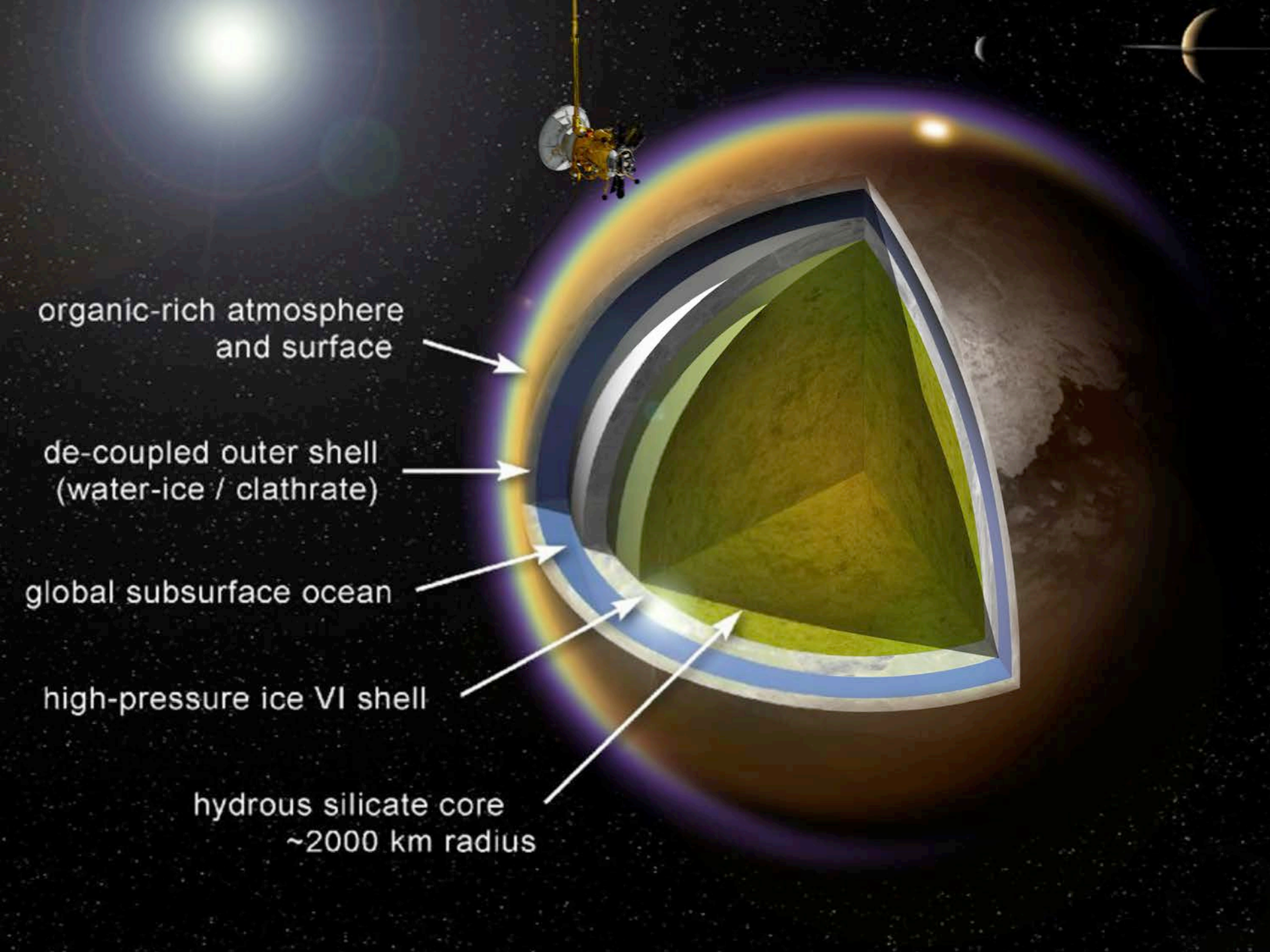


3. Combined isotopic and compositional trends

1997 2020

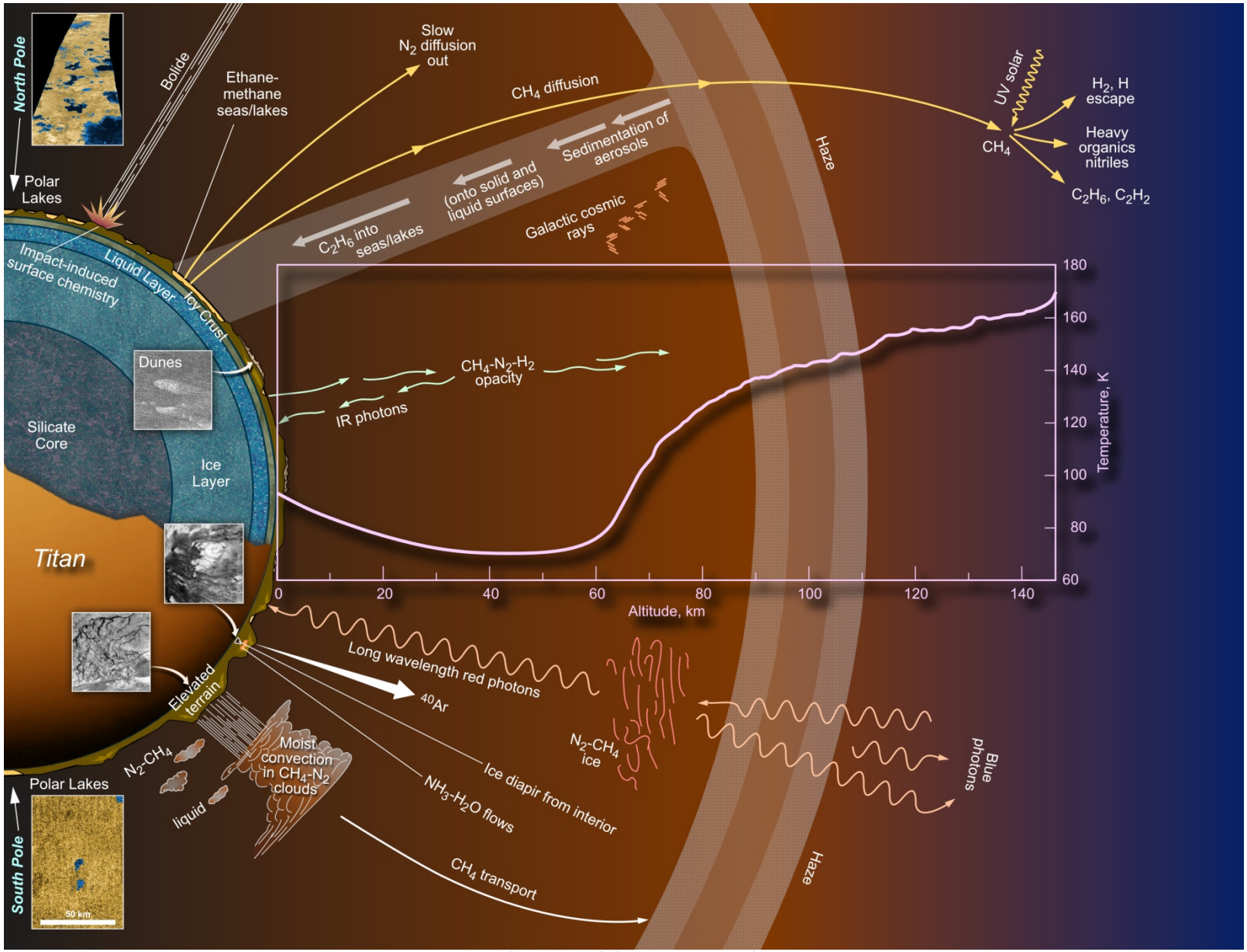


ELF uses mass spectrometers of much higher resolution, range, sensitivity.

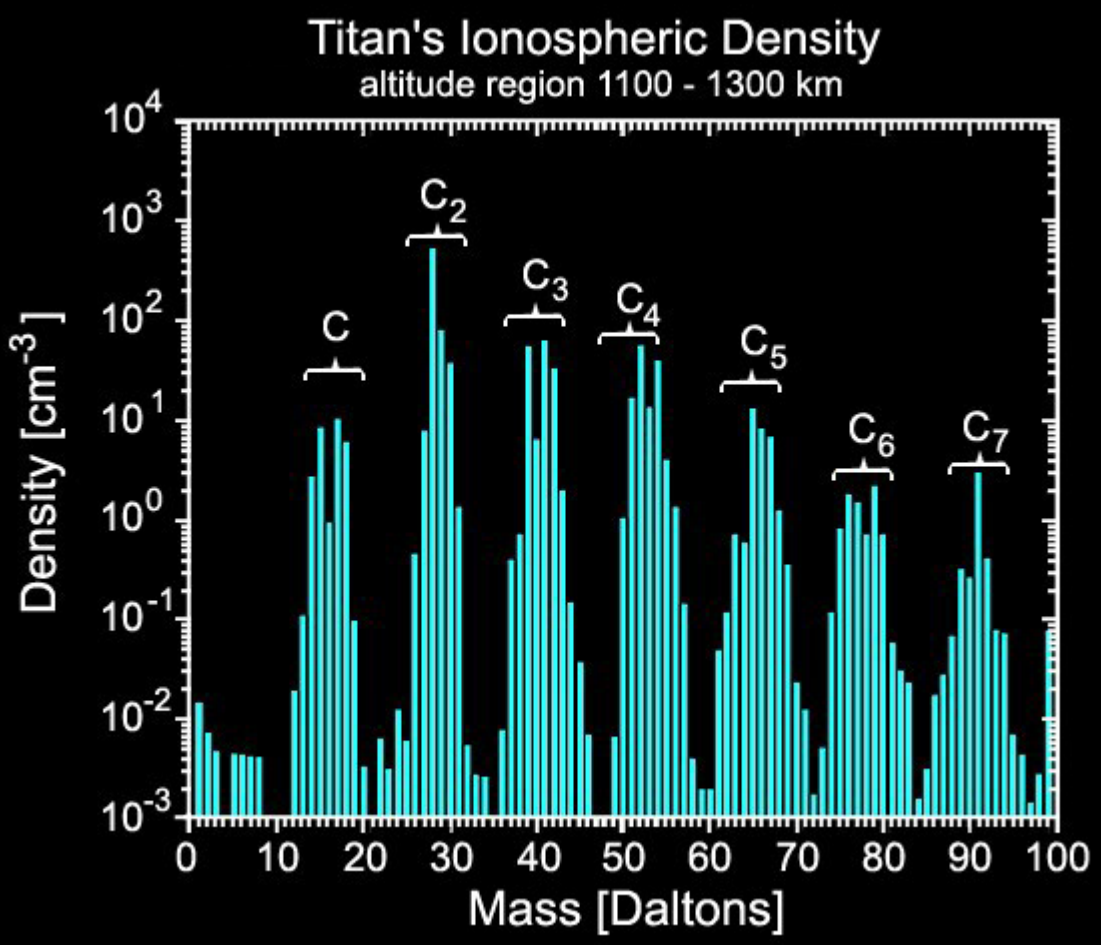

organic-rich atmosphere
and surface
de-coupled outer shell
(water-ice / clathrate)
global subsurface ocean
high-pressure ice VI shell
hydrous silicate core
~2000 km radius

Ligeia Mare: hydrocarbon sea

Titan has a complex organic factory in the atmosphere which deposits the products on the surface



Mass Spectrum Recorded in Close Approach (½ radius) of Cassini to Titan (INMS)



CH_3^+

CH_5^+

NH_4^+

$HCNH^+$

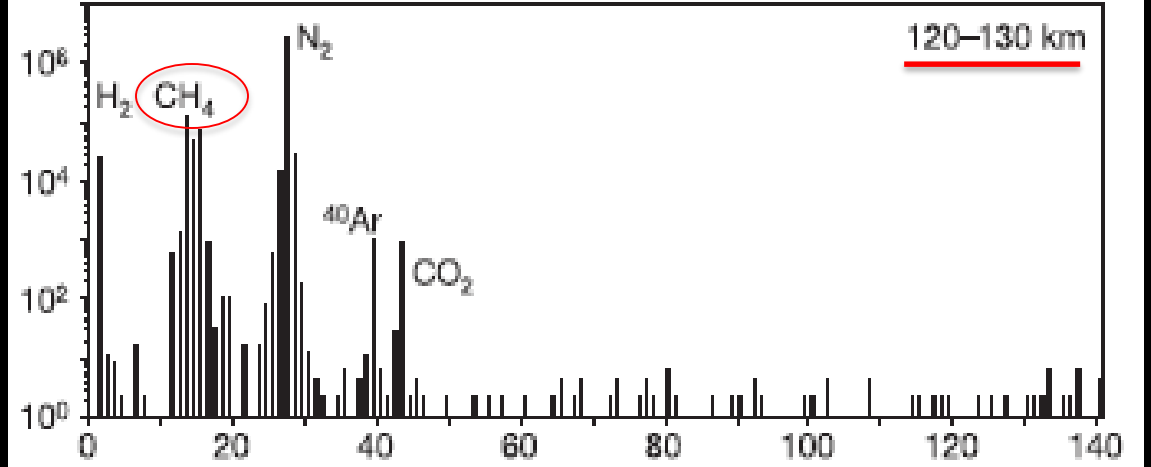
CH_3CNH^+

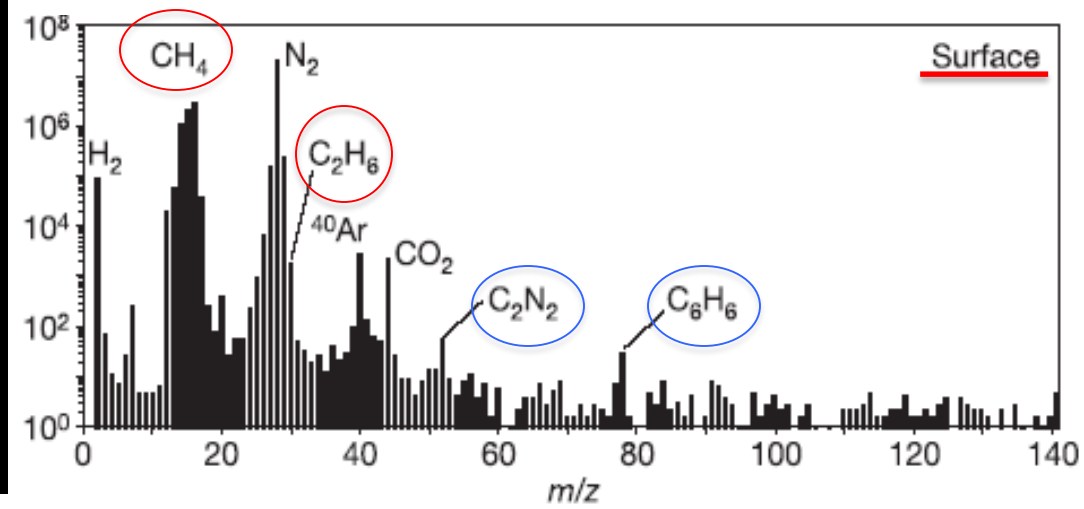
$C_6H_7^+$

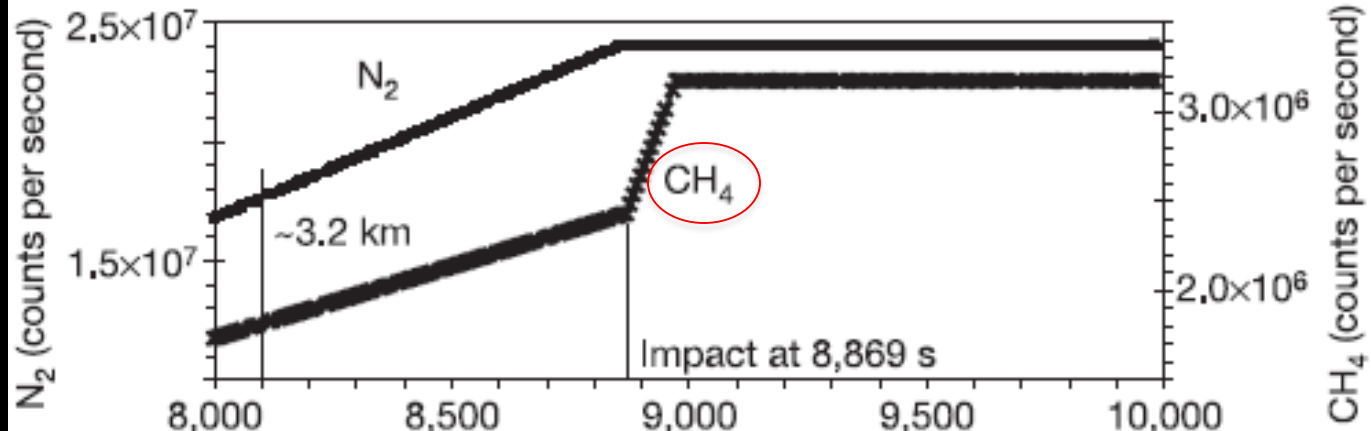
$C_6H_5CH_2^+$

Mass spectrometer: surface is charged with methane, ethane

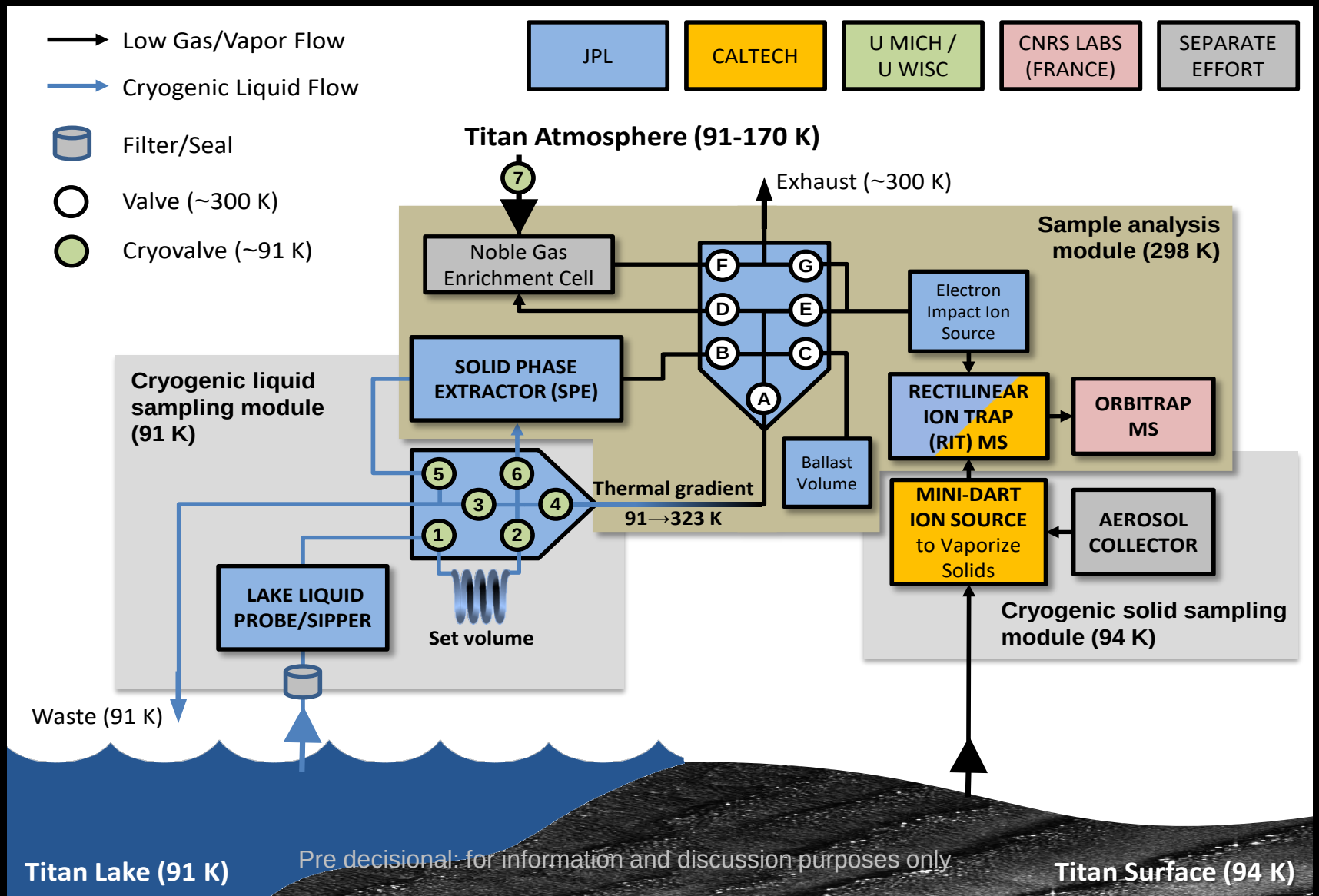
(Niemann et al., 2005





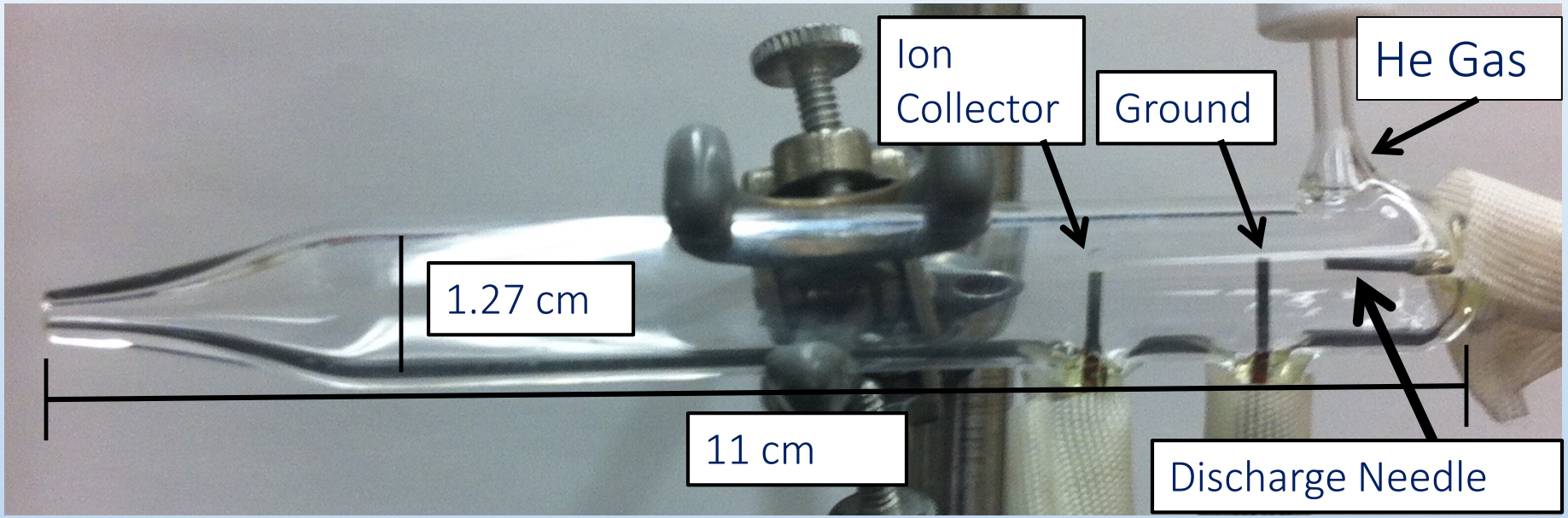


Planetary Organic Detector (POD) has subsystems organized into three modules depending on operation temperature and sample type



Pre decisional: for information and discussion purposes only

Caltech Mini-DART with Multistep MS/MS Capability for Structure Determination

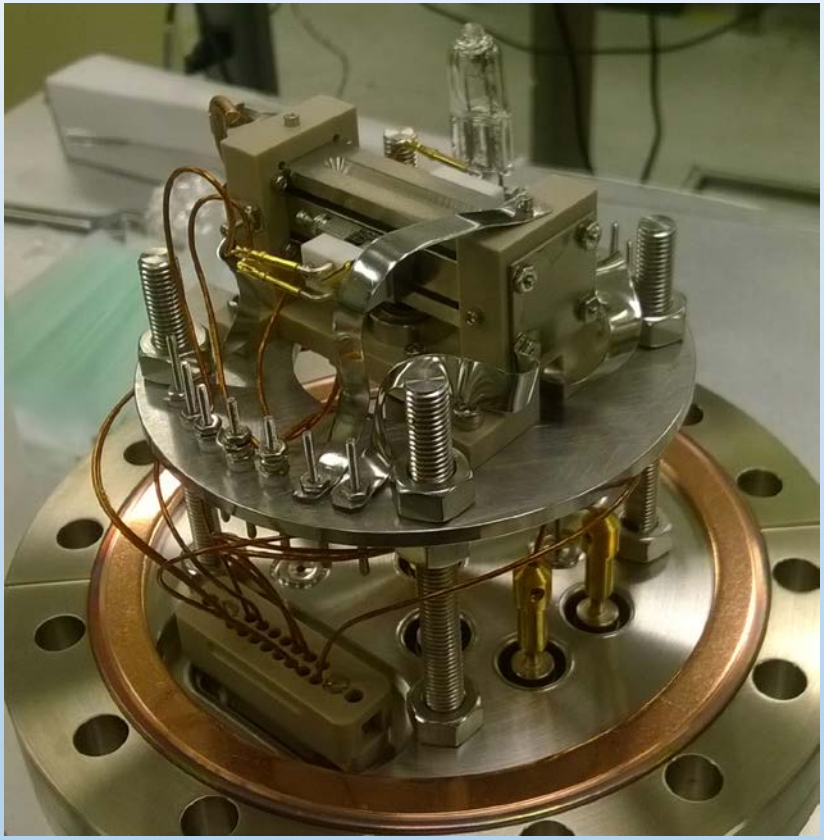


- Inexpensive: $100
- Lightweight
- Variable Temperature
  Wrapping in heater can increase temperature
- 1kV Operating Voltage
- Mobile
- Minimal sample ablation

Kate Upton - Caltech

Pre decisional: for information and discussion purposes only

Rectilinear Ion Trap



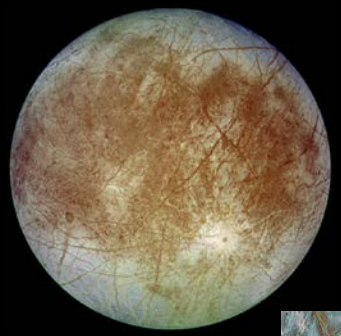
- Rectilinear Ion Trap (RIT) mass spectrometer flange mounted and complete for testing. Initial testing uses electron impact to ionize gaseous samples in the RIT. Ions are ejected from the slot in the top electrode into the Orbitrap.

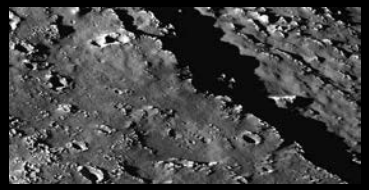
Josh Wiley - JPL, J. L. Beauchamp - Caltech

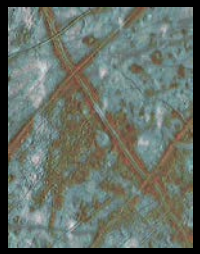
Pre decisional: for information and discussion purposes only

The Jovian System: Europa, Ganymede, and Callisto

	Callisto	**Ganymede**	**Europa**
Radius	2400 km	2634 km	1560 km
Atmosphere	None	None	Tenuous oxygen & hydrogen
Density	1.85 g/cm^3	1.94 g/cm3	3.02 g/cm^3
Surface Composition	Water Ice; dark rocky material	Water Ice; dark rocky material	Rocky silicates; water ice
Drivers for investigation	Ancient surface that retains the history and materials of the early solar system; subsurface ocean	Ancient and younger surfaces; internal dynamo; subsurface ocean	Young surface; rocky mantle; subsurface ocean; significant potential for habitability







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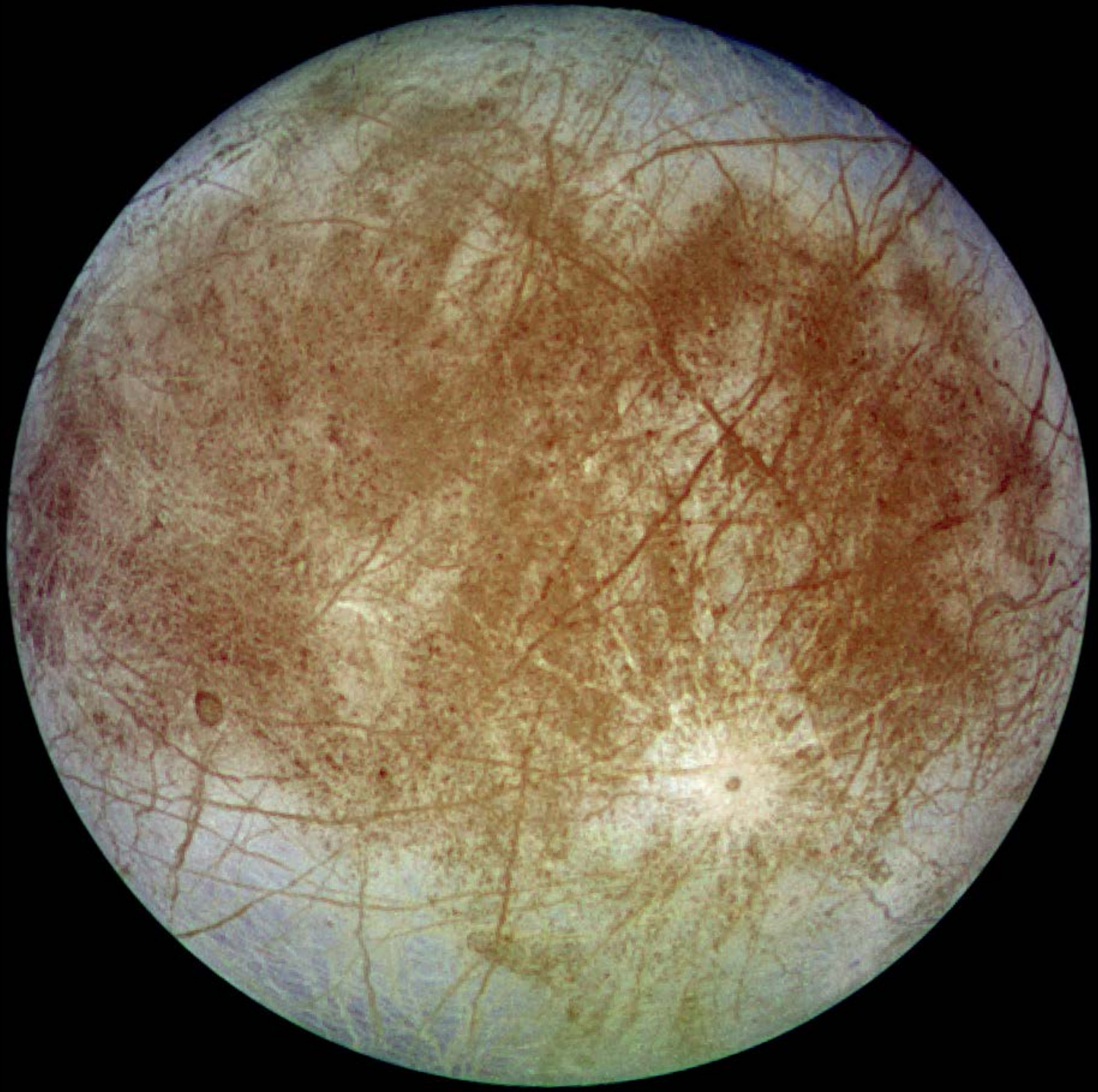
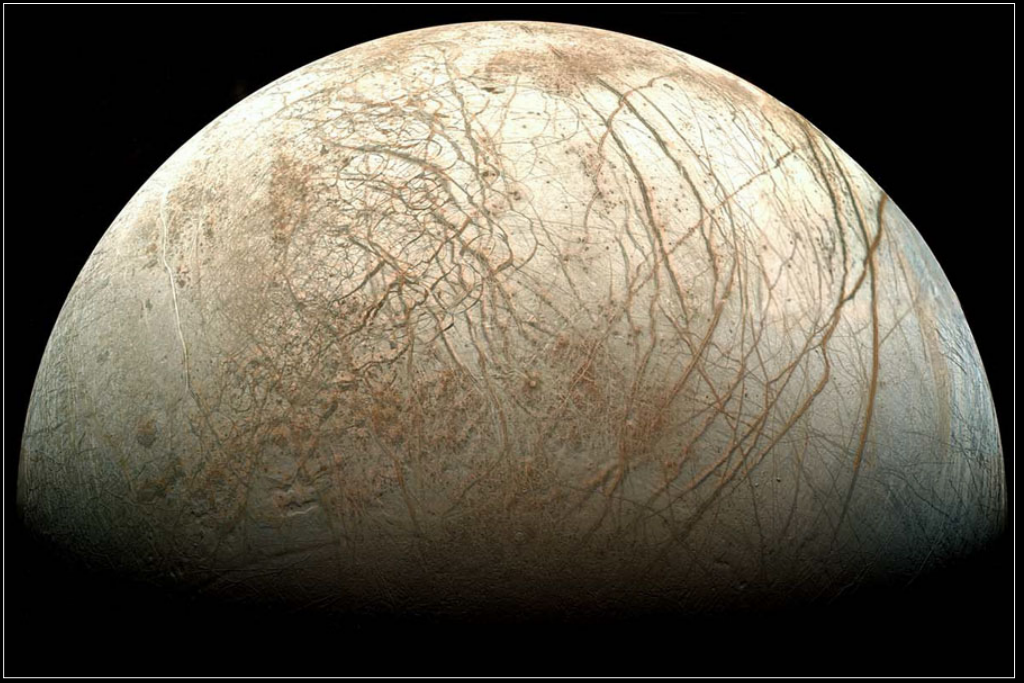


Europa's youthful surface

- A world of rock, ice, and water approximately the size of Earth's moon
- Very few impact craters suggest that Europa has one of the youngest surfaces in the solar system (~60 Ma)



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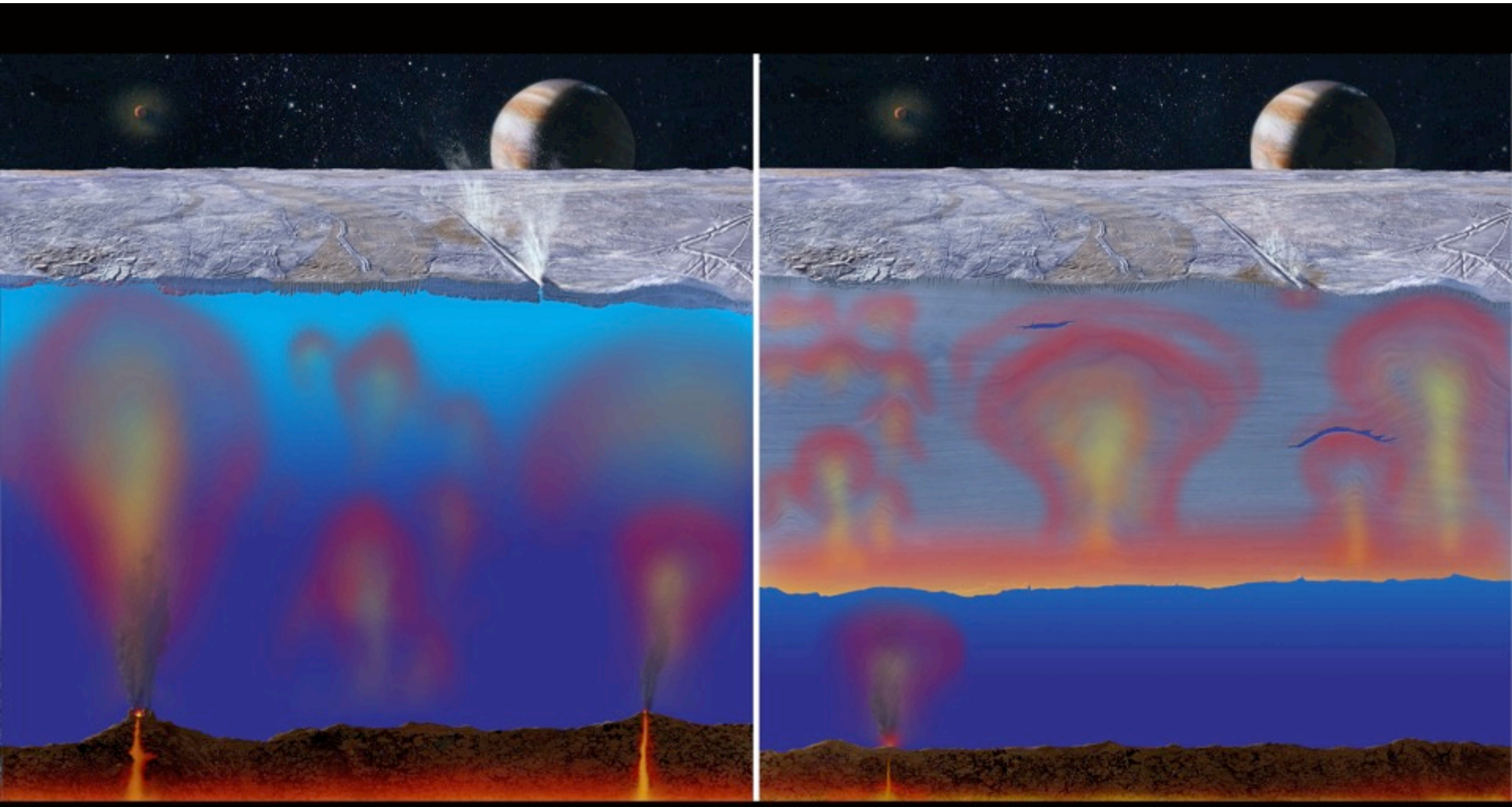
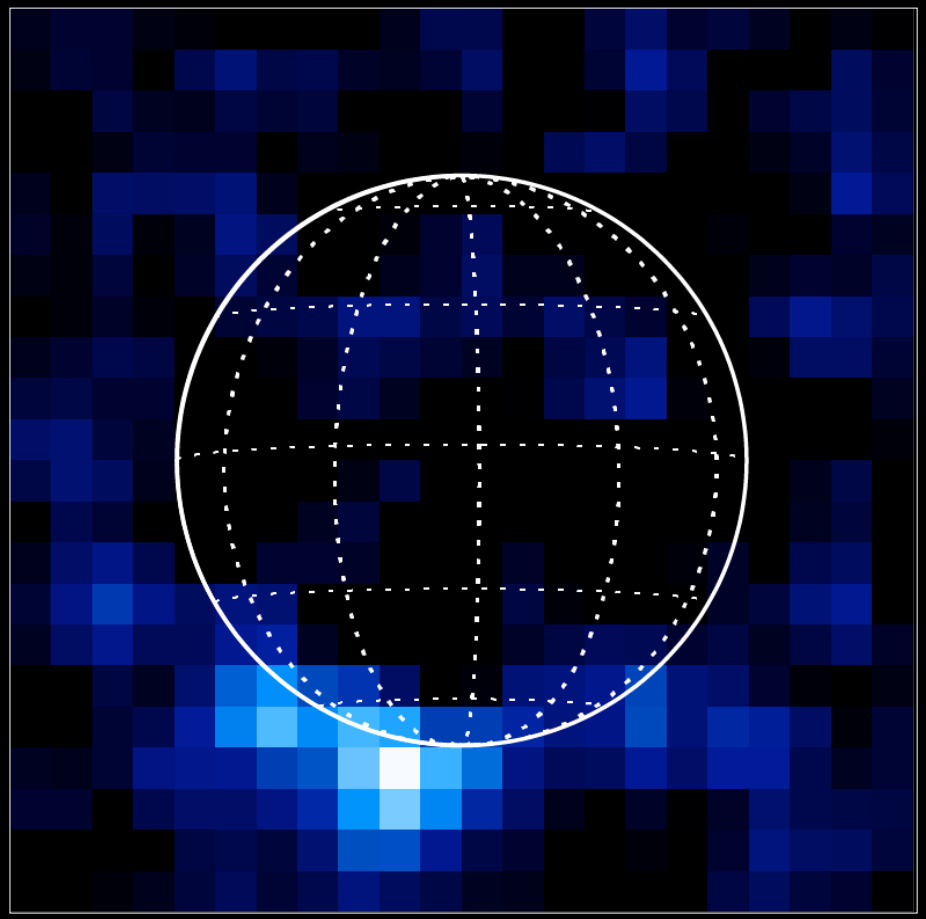
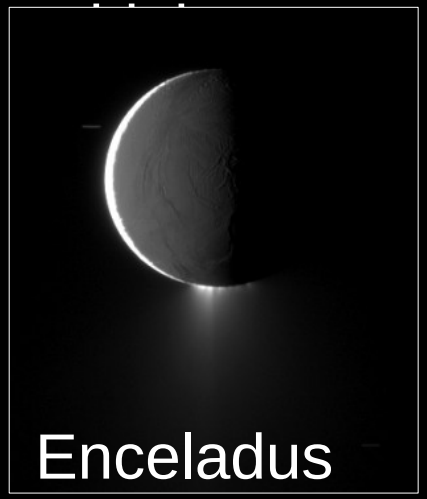
Europa's Ocean

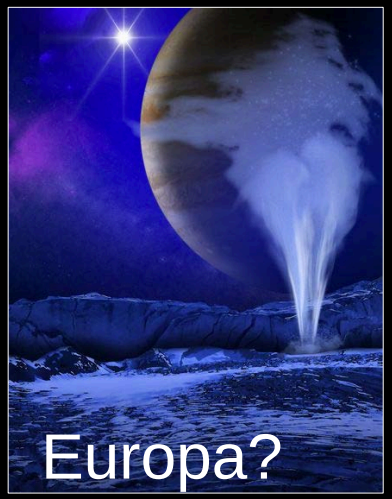


Possible plumes of water



- Recent Hubble observations of hydrogen and oxygen ions concentrated at high southern latitude
- Interpreted as plumes of water vapor ~200 km





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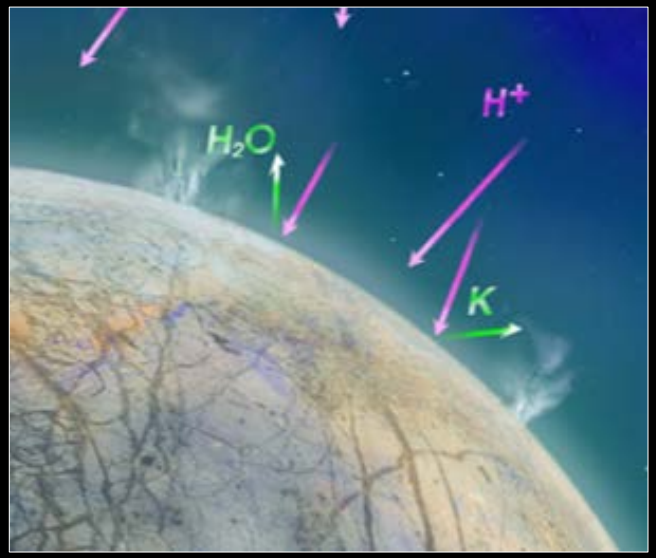
Surface chemistry of salts and acid

- Surface is bombarded by charged particles from Jupiter's magnetosphere
- Interaction of these particles with the surface leads to intriguing chemistry



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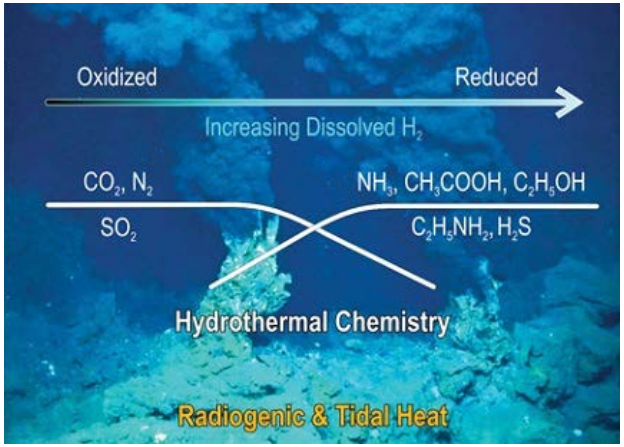
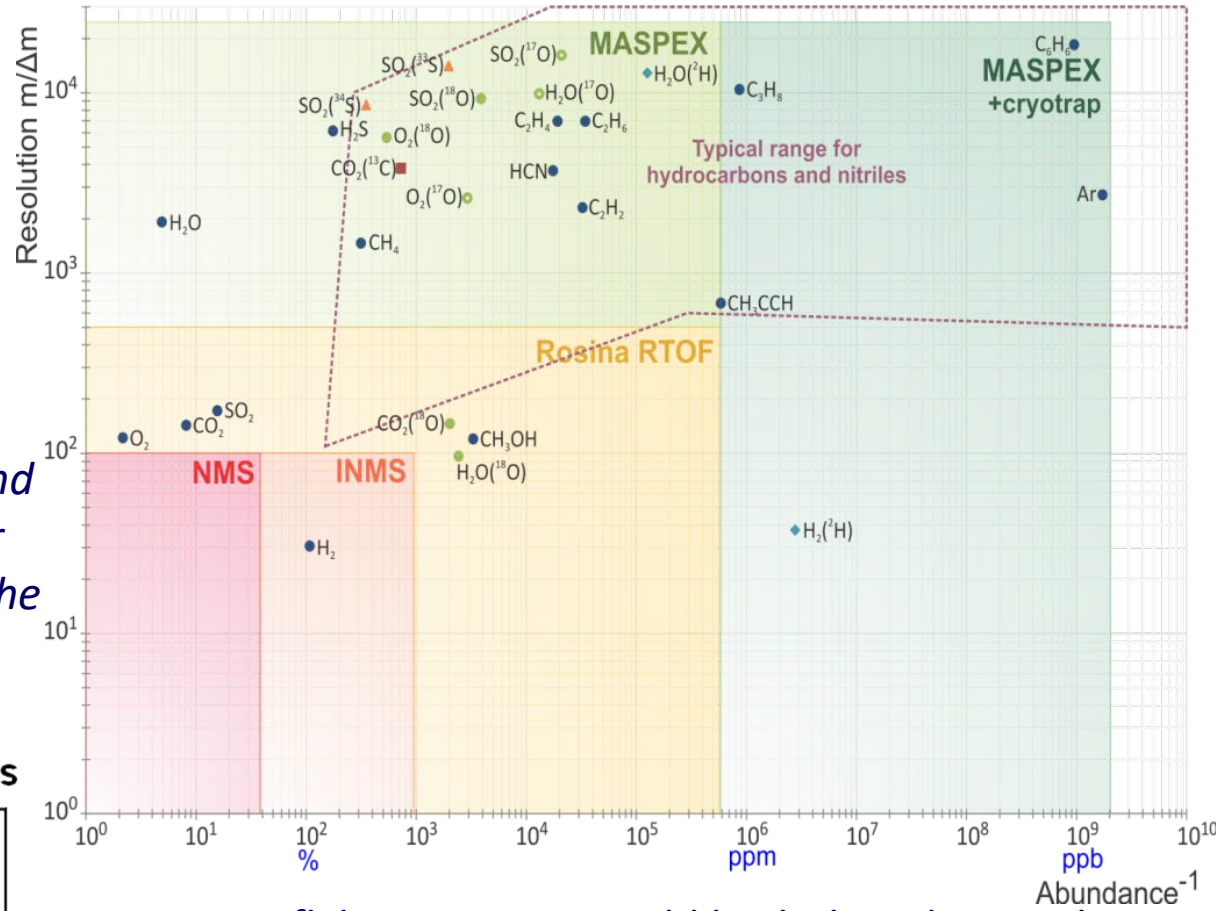
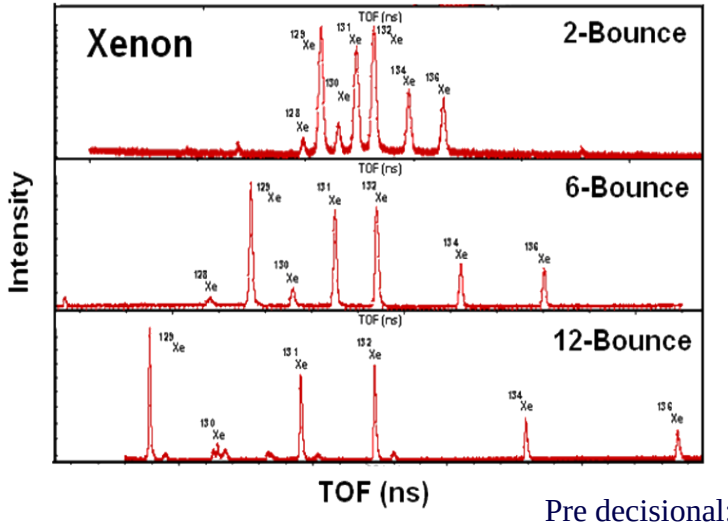
MASPEX - Europa PI: Hunter Waite, SWRI





The proposed MASPEX molecular and isotopic composition study will offer insights into the oxidation state of the subsurface ocean and potential metabolic energy sources.

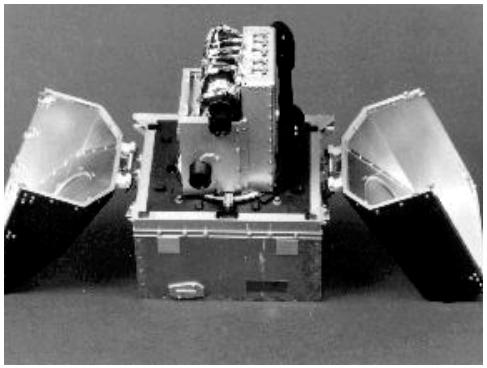
Mass Resolution = 10,800 in 12 bounces



On every flyby, MASPEX would both directly sample the atmosphere and concentrate a sample of the atmosphere, using the cold surface to trap the gas. After the flyby, this cryotrap releases the sample into MASPEX's detectors, providing a concentrated sample of Europa's atmosphere and effectively increasing the instrument's sensitivity.

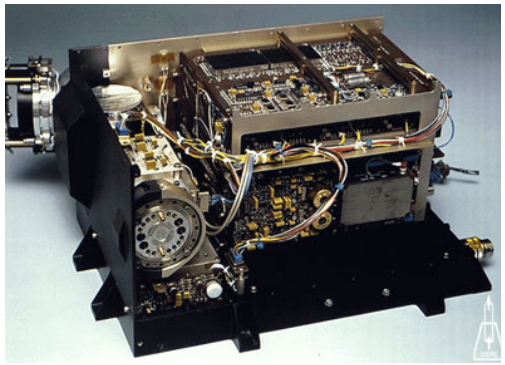
Pre decisional: for information and discussion purposes only

Examples of Mass Spectrometers Flown over the Years



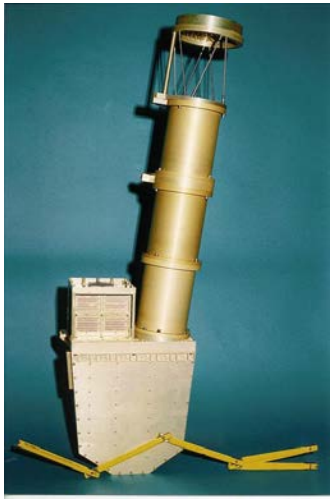
Galileo Orbiter
Energetic Particles Detector (EPD)

Mass	10.5 kg
Power	10.1 W
Dimensions	19.5 × 27 × 36.1 cm



Cassini
Ion and Neutral Mass Spectrometer (INMS)

Mass	9.25 kg
Power	27.70 W
Dimensions	20.3 × 42.2 × 36.5 cm



STARDUST
Cometary and Ion Dust Analyzer (CIDA)

Mass	125 kg
Power	14.5 W
Tubular	L = 1,050 mm
	H = 235 mm
	W = 370 mm

Galileo Orbiter
Dust Detector Subsystem (DDS)

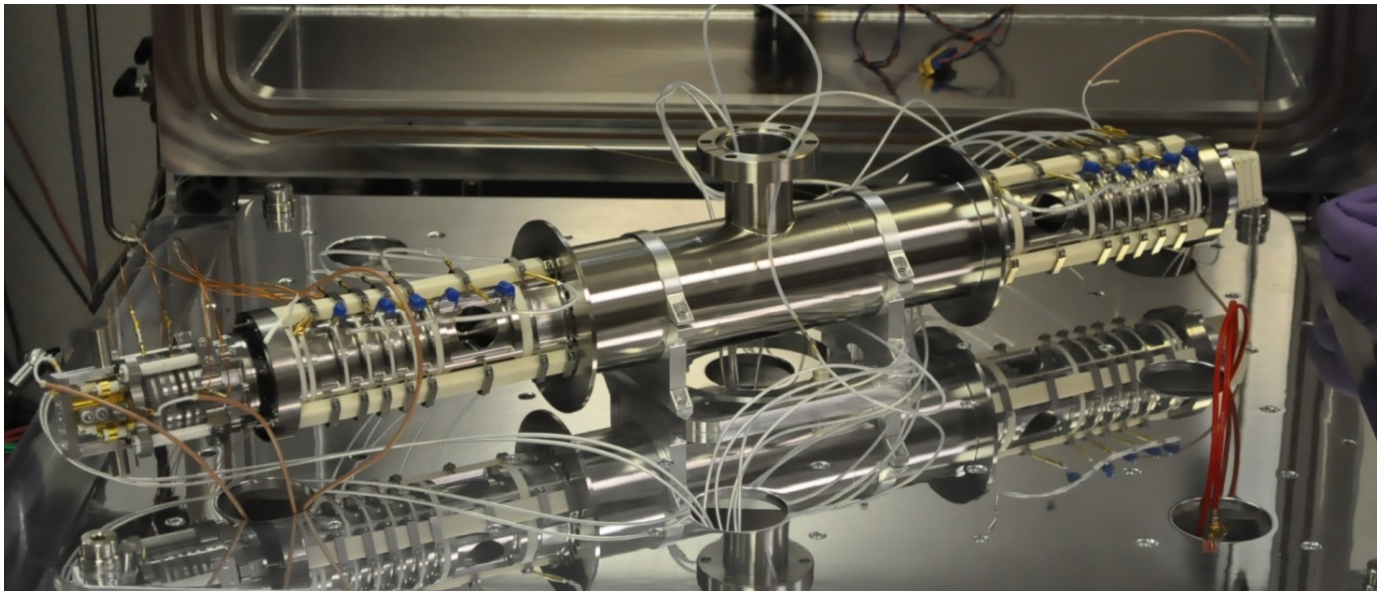
Mass	4.2 kg
Power	5.4 W
Dimensions	28.3 × 10.0 × 10.0 cm

Cassini/Huygens Probe
Gas Chromatograph
Mass Spectrometer (GCMS)

Mass	17.3 kg
Power	41 W
Cylindrical	198 mm diameter,
	470 mm high

MASPEX-Europa

A variable resolution time-of-flight mass spectrometer



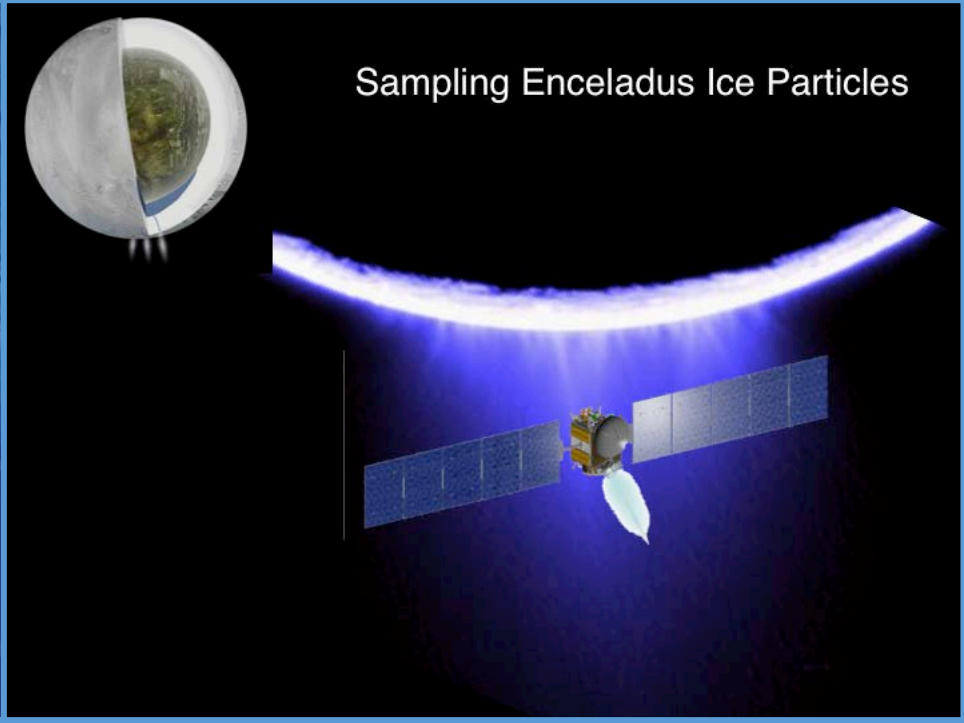
System Characteristics		
Subsystem	**Type**	**Specification**
GIS - thermalizer	Spherical antechamber, single use cover	2π steradians, ram boresighted
GIS - cryotrap	Cryotrapping/direct inlet, neutral gas	Sensitivity boost: up to 200 counts s^{-1} per mol cm^{-3}
MS - closed source	Storage, electron ionization, redundant emitters	Ambient sensitivity: 0.02 counts s^{-1} per mol cm^{-3}
MS - ion optics	Multibounce time-of-flight	Resolution: 24,540 m/Δm 10% valley definition
MS - detector	Electron multiplier	MCP, 3 plate z-stack, 2μm pore
Resources		
Mass & Volume	**Power (W)**	**Average Data Rate**
24.3 kg, instrument, 5.3 kg harness	42.6 (Peak), 4.5 (Survival)	57 kbps (peak), 14 kbps (average)

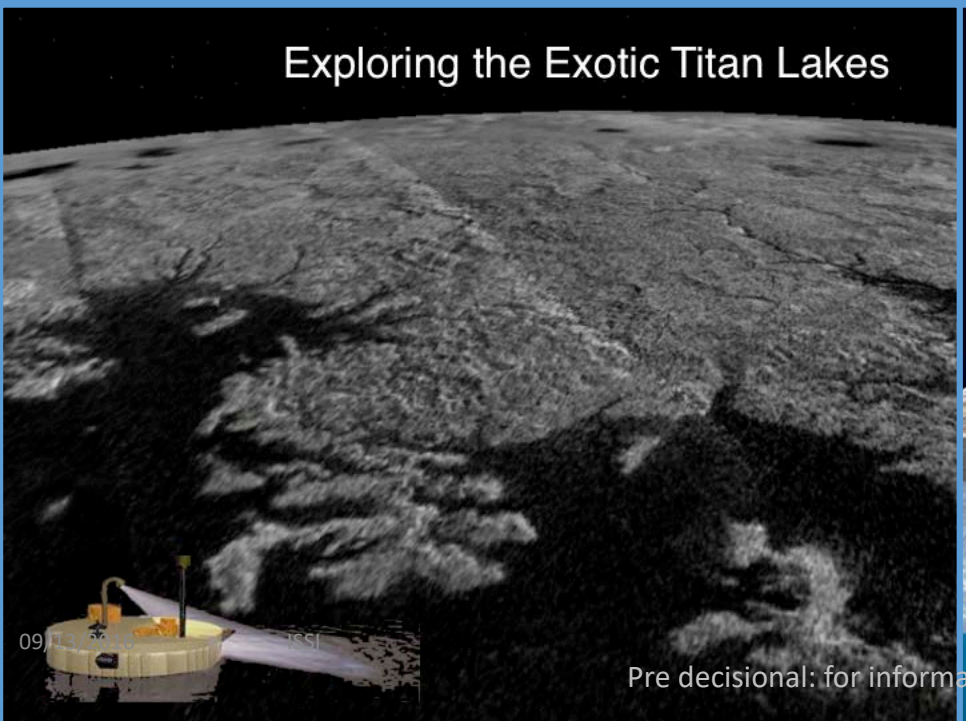
It's not just the Mass Spectrometer—It's the system!
And developing the technologies needed to make the system work a billion miles (or more) away

- Sample introduction methods
- Ionization
- Pumping
- Calibration
- Protection from environment
- Thermal management
- Anti-fouling technologies
- Autonomous operations
- Data management
- Archiving data
- Reliability
- Able to withstand launch loads
- Long-term operations in harsh environments

Some Important Considerations for *Mass Spectrometers* used for Ocean Worlds

- Low power
- Low mass
  - Cryogenic mechanisms
  - Electronics that can survive surface ambient ($\leq$94K)
- High resolution
- High sensitivity
- Able to maintain cleanliness
- Low volume
- High reliability
- Long lifetime (sometimes as long as a 15 years +)
- Manageable data rate
- Easily calibrated
- Must have compatible sample handling mechanisms that are cold-operable
- Able to withstand extremely low temperature environments
- Accommodates Planetary Protection and Contamination Control requirements





Pre decisional: for information and discussion purposes only

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