Plume Fly-Through Missions

Detecting life in situ at several kilometers per second

Morgan L. Cable

December 6, 2016

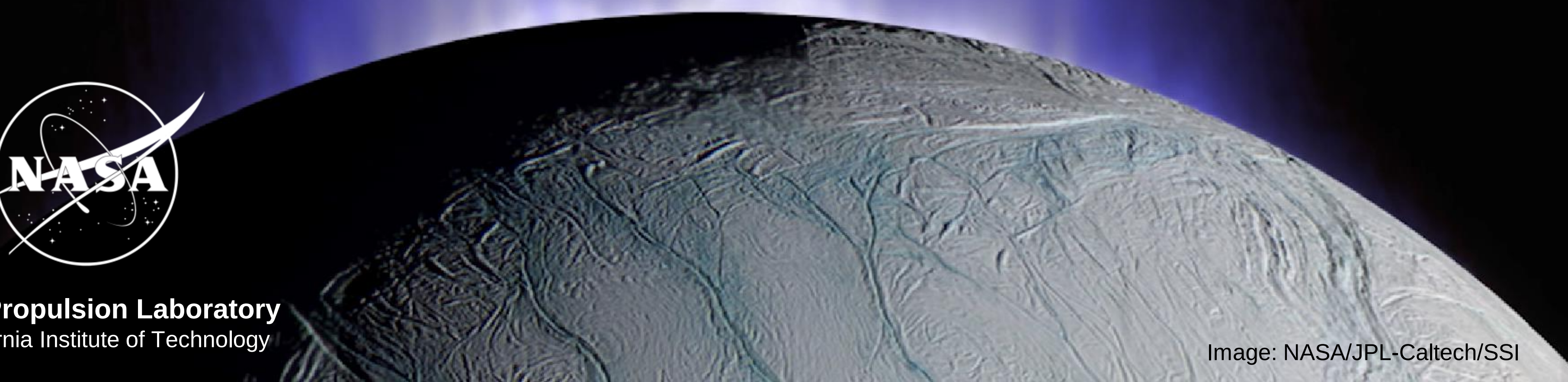
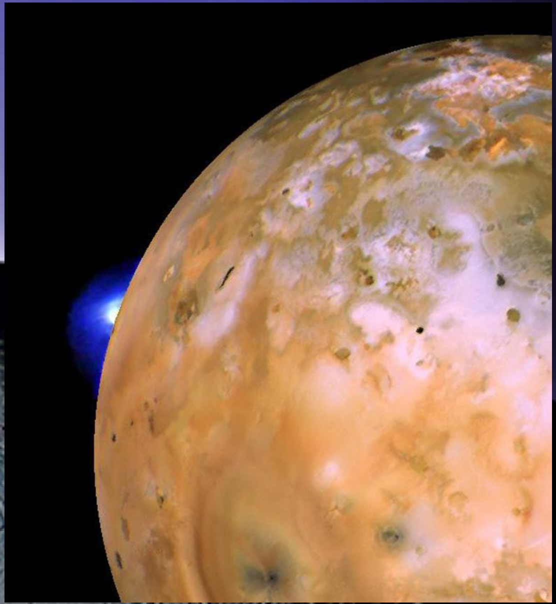
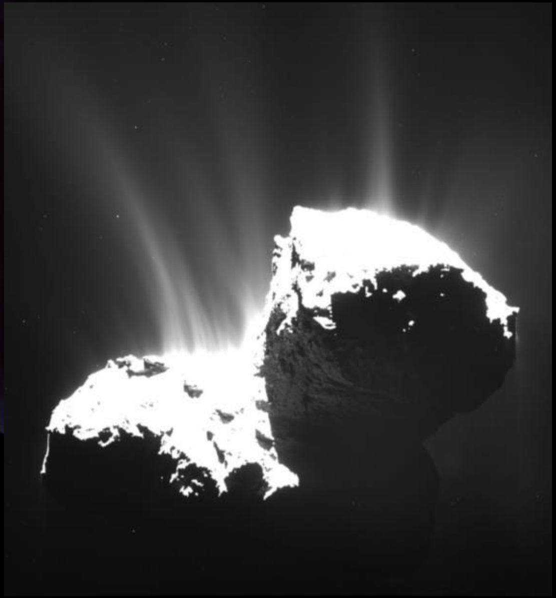
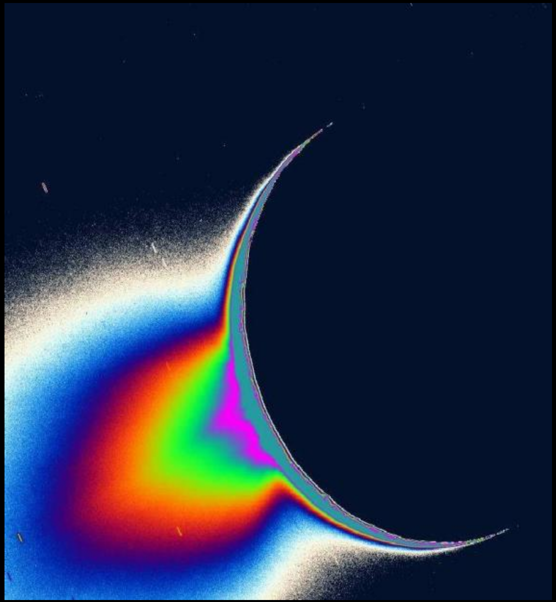


Image: NASA/JPL-Caltech/SSI

Jet Propulsion Laboratory
California Institute of Technology

Plumes in the Solar System

Fantastic plumes and where to find them

Volcanic	Cometary	Ocean Worlds
		

Images: NASA/JPL/USGS; ESA/Rosetta/MPS; NASA/JPL/Space Science Institute

Plumes from Ocean Worlds

Free sample, no need to dig or drill

- Best example is Enceladus

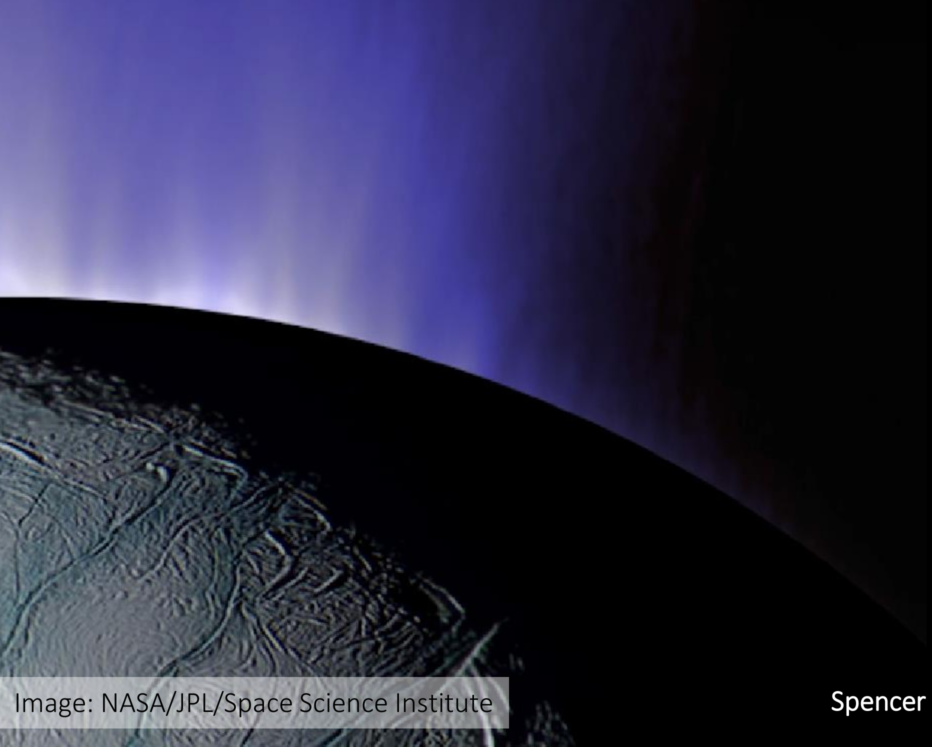
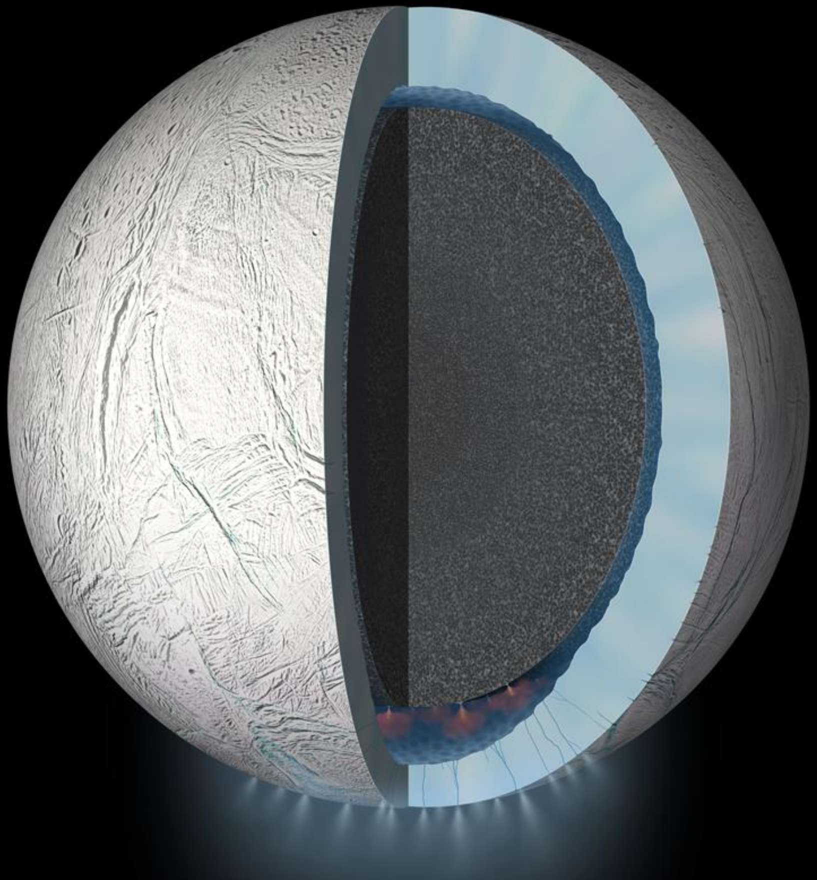


Image: NASA/JPL/Space Science Institute



Spencer and Nimmo, 2013, Annu. Rev. Earth Planet. Sci. 41, 693-717.

Plumes from Ocean Worlds

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- ~100 distinct, collimated jets emanating from 4 Tiger Stripes that form a single plume
  - Modulated by diurnal tidal flexing

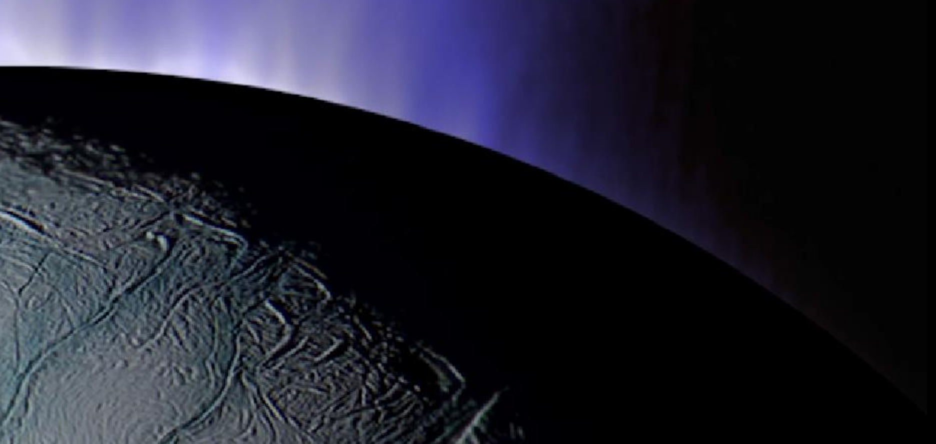
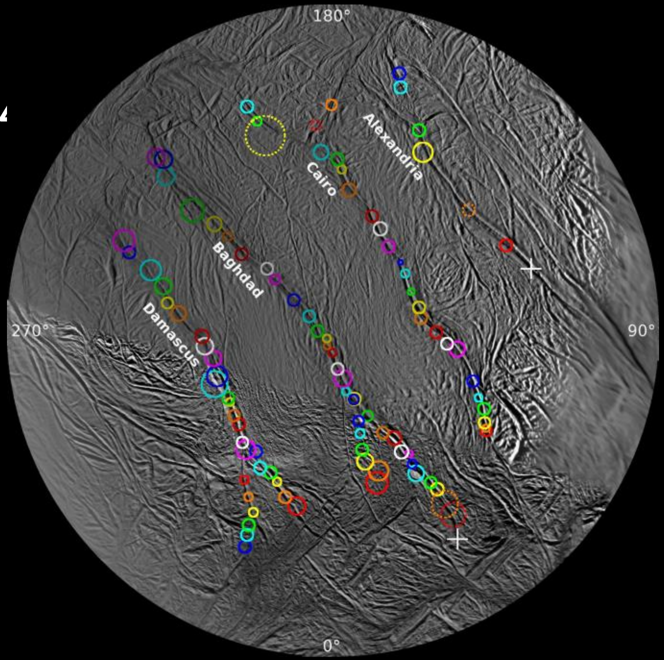


Image: NASA/JPL/Space Science Institute



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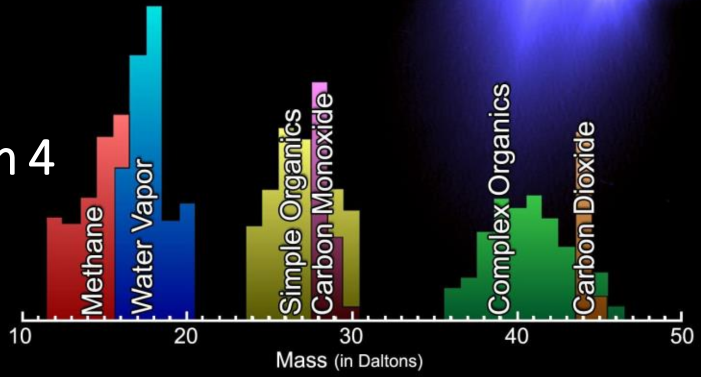

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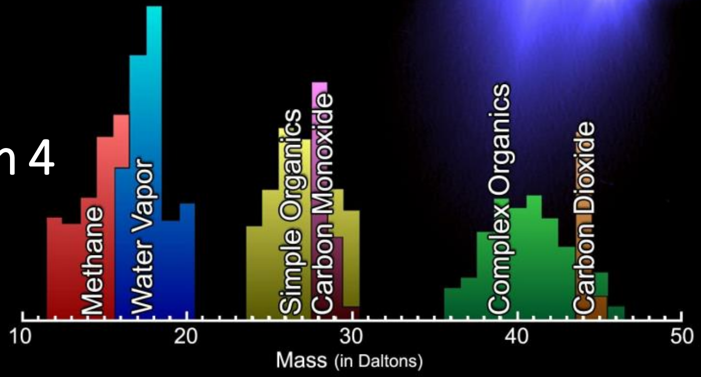
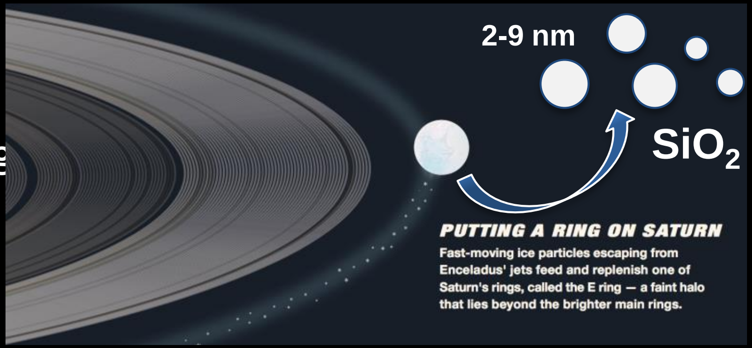
  - Particles: Water-ice, salts (mostly NaCl), SiO_2, org





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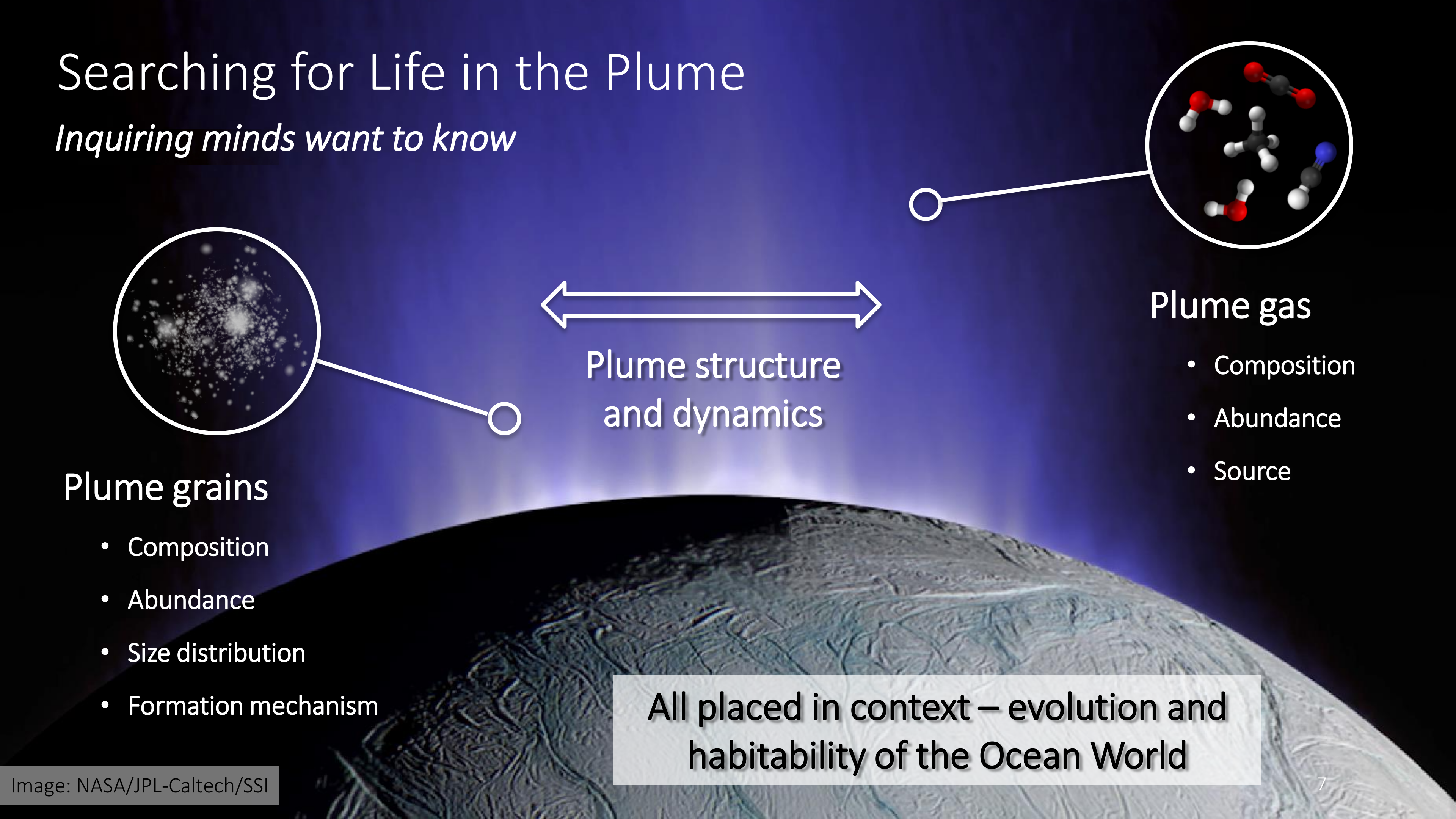
JPL


Searching for Life in the Plume
Inquiring minds want to know
Plume gas
• Composition
• Abundance
• Source
Plume structure and dynamics
Plume grains
• Composition
• Abundance
• Size distribution
• Formation mechanism
All placed in context – evolution and habitability of the Ocean World
Image: NASA/JPL-Caltech/SSI
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Instruments (Past and Present)

Life detection on the fly

Type	Target(s)	Recent Examples
Mass spectrometer	• Volatile organics in plume gas • Ions from plume grains post-impact	• Cassini INMS • Europa MASPEX 

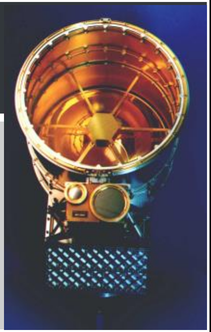
Pros	Cons
• Extensive flight heritage, including plume investigations • Significant recent advancements, in particular in **mass resolution** and **sensitivity**	• Deconvolution of complex mixtures requires supporting laboratory experiments

Image: NASA GSFC

Instruments (Past and Present)

Life detection on the fly

Type	Target(s)	Recent Examples
Dust detector	• Organics trapped in plume grains • Salts, ions in plume grains	• Cassini CDA • Stardust CIDA • Europa SUDA



Pros	Cons
• Extensive flight heritage, specific to plume investigations • Rapid measurement cadence gives plume structure	• Ionization is velocity- and mass-dependent

Image: NASA/JPL/U. of Kent

Instruments (Past and Present)

Life detection on the fly

Type	Target(s)	Recent Examples
NIR spectrometer	• Primary plume constituents (gas and grains) • Salts, CO_2, SO_2, hydrocarbons	• Cassini VIMS • Europa MISE 

Pros	Cons
• Imaging spectrometers provide identification and plume structure • Grain size at high phase angle	• Limited sensitivity for trace species • Can identify functional groups, but not complex organic structures specifically

Image: NASA/JPL-Caltech/U. of Arizona

Instruments (Past and Present)

Life detection on the fly

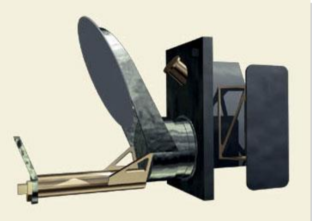
Type	Target(s)	Recent Examples
UV spectrometer/ spectrograph	• Hydrogen, oxygen auroras • Simple organics (CO_2, acetylene)	• Cassini UVIS • Juno UVS • Europa UVS 

Pros	Cons
• Plume structure and variability • Indirect evidence through surface albedo • Small angular scans at distance	• Limited sensitivity for trace species

Image: NASA/JPL-Caltech/LASP

Instruments (Past and Present)

Life detection on the fly

Type	Target(s)	Recent Examples
Microwave (sub-mm) radiometer	• Plume water vapor distribution, temperature • Volatile organics in plume gas (NH_3, CO, HCN, acetonitrile, formaldehyde)	Rosetta MIRO 

Pros	Cons
• 3D plume structure and dynamics • Water temperature	• Only polar molecules in gas phase (no methane, CO_2, H_2, N_2) • Gas phase constituents only • Limited sensitivity for trace species

Image: NASA/JPL-Caltech/GSFC

Instruments (Future)

Life detection on the fly

Type	Life-Specific Target(s)
Gas chromatograph or liquid chromatograph mass spectrometer (GC-MS/LC-MS)	• Chiral amino acids • Proteins • Lipids 

Pros	Cons
• High fidelity identification of simple and complex organic molecules • Discrimination of chiral species	• GC and LC columns must be tailored for the target species and possible confounding species • Limit of detection can be affected by separation front-end • Complex instrumentation (requires automated plume particle capture and extraction of organics)

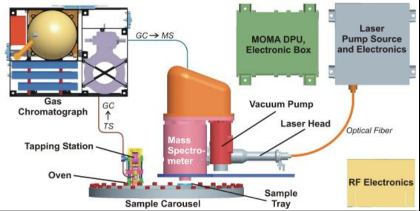
Image: NASA/JPL-Caltech

JPL

Instruments (Future)

Life detection on the fly

Type	Life-Specific Target(s)
Laser desorption ionization mass spectrometer (LDI-MS) (aka MOMA)	• Proteins • DNA, RNA • Lipids



Pros	Cons
• Soft ionization method, reduced fragmentation of complex organics	• Complex instrumentation (requires automated plume particle capture and exposure to LDI source)

Image: Max Planck Institute for Solar System Research

Instruments (Future)

Life detection on the fly

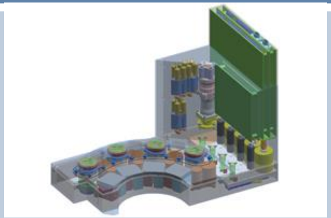
Type	Life-Specific Target(s)
Raman spectrometer	• Functional groups for key biomolecules (amines, carboxylic acids, ketones, etc.) 

Pros	Cons
• Can be coupled to other techniques (microscopic imaging) to provide spatial context	• Can identify functional groups, but not complex organic structures specifically • Complex instrumentation (requires automated plume particle capture and extraction of organics or cells)

Image: NASA/JPL-Caltech

Instruments (Future)

Life detection on the fly

Type	Life-Specific Target(s)
Immunoassay-based microfluidic chip (aka the LifeMarker Chip or similar)	• DNA • RNA • Proteins 

Pros	Cons
• High fidelity identification of complex, information-containing biomolecules	• Targets only 'Earth-centric' biomarkers • Complex instrumentation (requires automated plume particle capture and extraction of organics)

Image: Magna Parva Ltd

Instruments (Future)

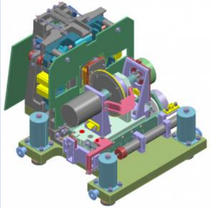
Life detection on the fly

Type	Life-Specific Target(s)	
Microchip capillary electrophoresis with laser-induced fluorescence	• Chiral amino acids • Lipids • Amines • Thiols	• Fatty acids • DNA • RNA • Proteins

Pros	Cons
• High fidelity identification of simple and complex organic molecules • Discrimination of chiral species • Multiple analyses performed on a single chip	• Complex instrumentation (requires automated plume particle capture and extraction of organics)

Instruments (Future)

Life detection on the fly

Type	Life-Specific Target(s)
Microscopic imager (holographic, AFM, visible)	• Individual cells, morphology • Motility, movement of cells 

Pros	Cons
• Could be a 'smoking gun' for life	• Complex instrumentation (requires automated plume particle capture and concentration of cellular/particulate material) • Good as a supporting life-detection technique, difficult to be convincing enough alone (aka ALH84001) • Whole cells may not be very common in plume grains

Image: ESA Rosetta

Plume Probe Parameters

Things to consider when designing your plume flythrough

- Flythrough altitude
  - Plume density and particle size distribution is highly dependent on size of the body
- Flythrough speed
  - Higher impact velocities can ionize molecules, but fragmentation may increase
- Sample capture medium
  - Hard capture materials (metal plate) – Easy to clean, can help to ionize on impact
  - Soft capture materials (aerogel, etc.) – Preserves particles but difficult to remove them after collection
  - Custom designs and materials – varied

Plume Probe Parameters

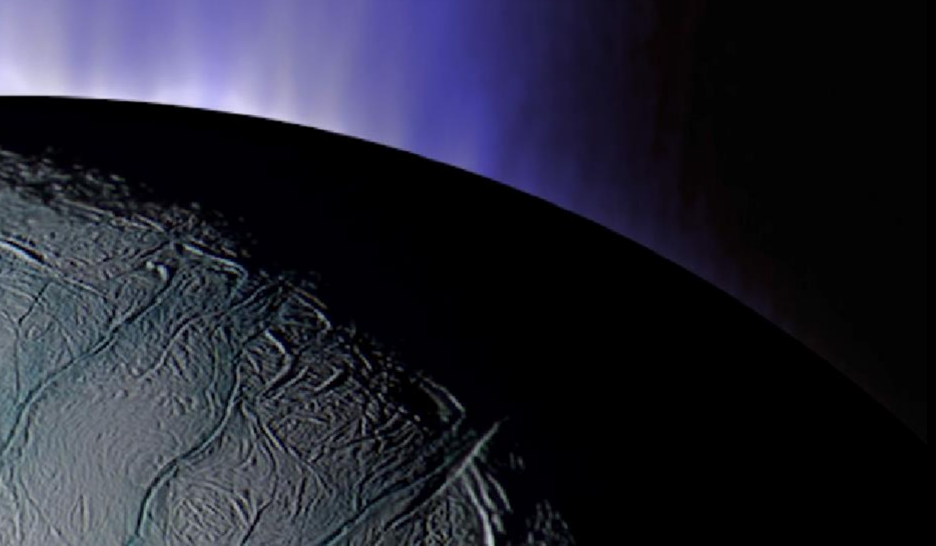
Things to consider when designing your plume flythrough

- Number of flythroughs
  - Repeated in situ measurements to build statistics?
  - Trapping species over multiple passes?
- Species you are targeting
  - Biomarker molecules or whole cells?
  - Are they concentrated in the gas or grains?
  - Susceptible to fragmentation?

Life Detection in a Plume

Keeping it in perspective

- Context is critical
- In situ life detection, while revolutionary, is only the first step
- **Any promising in situ result would justify sample return**



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