RETURNING SAMPLES FROM ENCELADUS FOR LIFE DETECTION

could answer one of the **biggest questions** of our time at a range of **reasonable costs**

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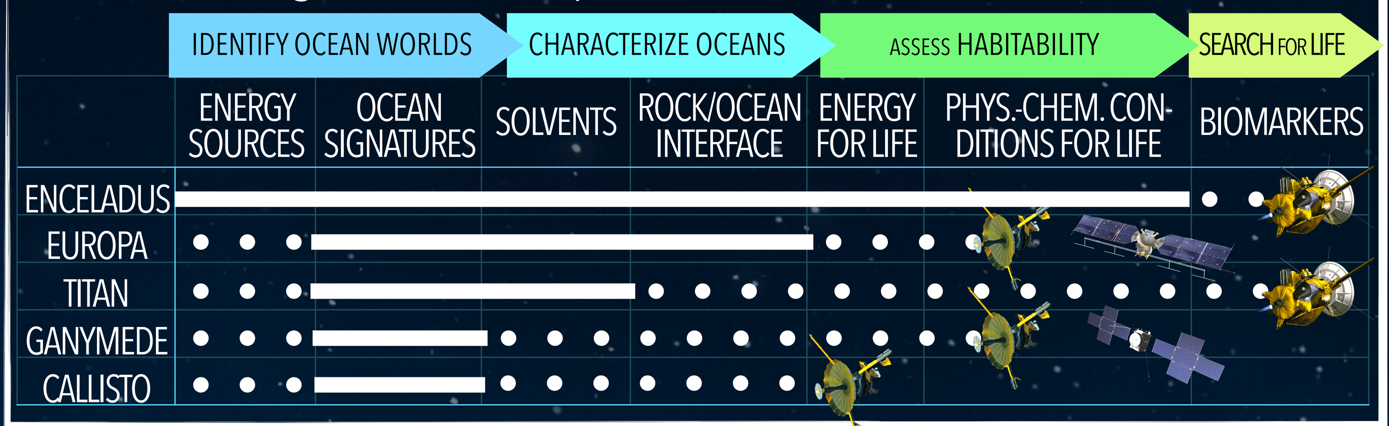
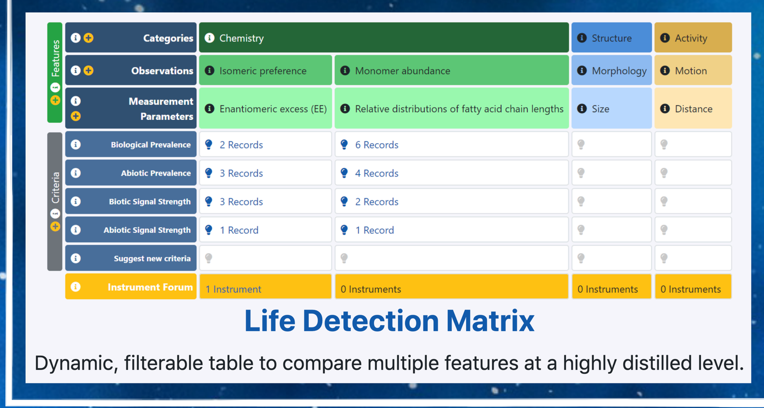
WHY ENCELADUS?

Farthest along the Roadmap to Ocean Worlds (Hendrix et al. 2018)



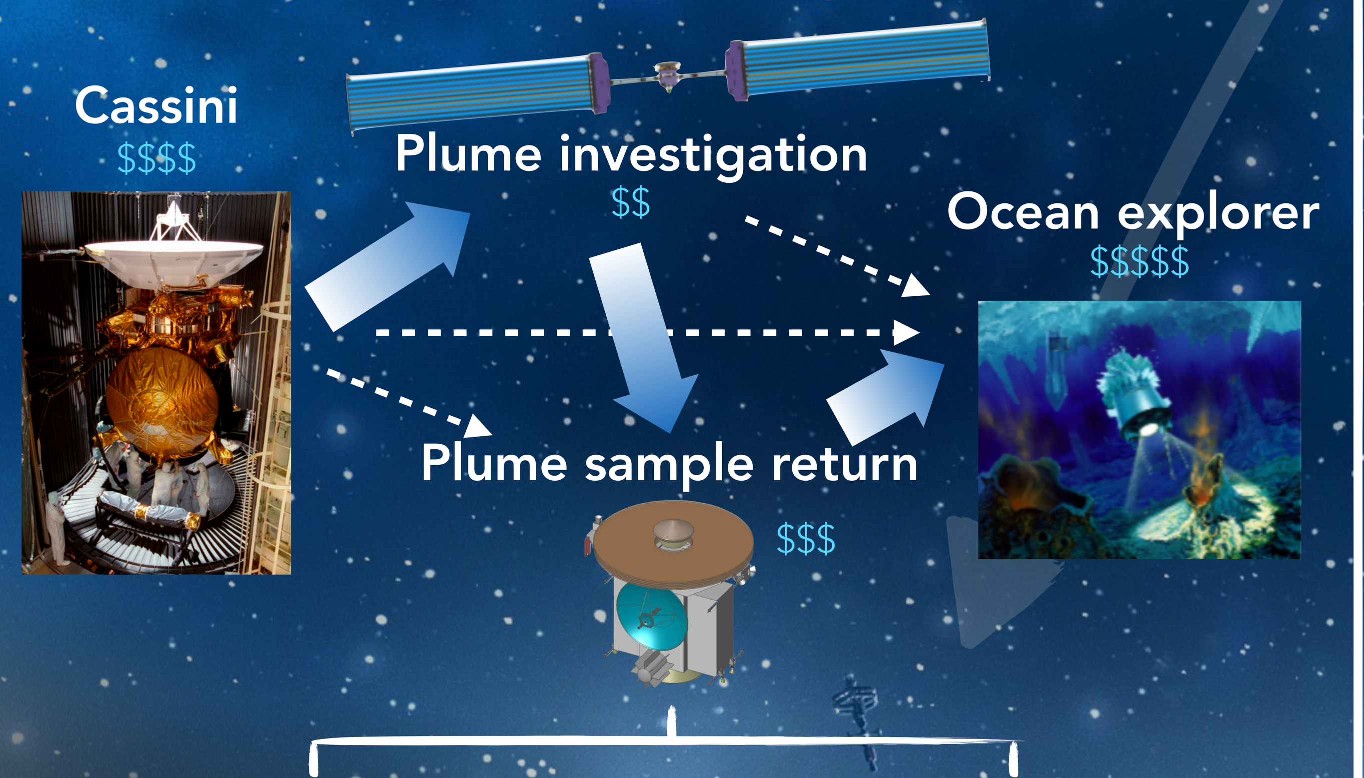
WHY SAMPLE RETURN?

1. Ocean samples **easily accessible** in the plume
2. Life detection: **complex, path-dependent**
   Adapt to unexpected findings.
3. Unmatched, **cutting-edge instruments**
   Sample archive benefits from future analytical developments.


Life Detection Matrix
Dynamic, filterable table to compare multiple features at a highly distilled level.


MegaSIMS (UCLA)

SAMPLE RETURN ON THE ROADMAP (Sherwood, 2016)



SCIENCE QUESTIONS / MEASUREMENTS / SAMPLE NEEDS

/compound /analysis

1. **How habitable** is Enceladus' subsurface ocean?
   - Elemental & stable isotope composition up to U (z=92) — ICPMS: <fmol
   - Chemical forms of inorganic compounds up to 500 amu — IC-MS: <fmol?
2. **How far toward life** has chemistry progressed?
   - Molecular distribution up to 10000 amu — MALDI: <fmol
   - Molecular structures — LCMS: <fmol
3. **Is there life** in Enceladus' ocean?
   - Isotope composition: H, C, N, O (±1‰) on specific organics — { nano-SIMS: 20 fmol; **GC-IRMS: 3 nmol**
   - Enantiomeric excess: D/L at ±5% precision — LCMS: <fmol
   - Sequencing of polymers — MALDI: <fmol
   - Imaging for morphology and activity signatures — [preserved, thawed sample]

FROM SCIENCE QUESTIONS TO ARCHITECTURES

3 nmol /compound /analysis
x (100 g/mol)
x (3 analyses + 80% archival = 15 analyses)
x 30 compounds
= 0.1 mg of organic material

How much of the plume material is organic?

In vapor: ≈1% (Waite et al. 2009) >> Earth seawater: TOC=0.5 ppm (Thurman 1985)
In solids: ≥0.1% (Postberg et al. 2018)
Assuming 0.1%, **we need to collect 100 mg of plume material.**

How much plume material can be collected in 1 flyby?

From ISS & CDA: 0.1 mg/(m^2 collector) @ altitude 200 km; 1 mg/m^2 @ 20 km

$$N_{flybys} = 100 \times (N_{compounds}/30) \times (altitude/20\ km) \times (A_{collector}/1\ m^2)$$

How much falls back on the South Polar Terrain?

Mass flux of solids: 50 kg/s (Ingersoll & Ewald 2011), SPT: 130000 km^2

$$m_{fallback} = 3\ mg/day \times (fallback/10\%) \times (A_{collector}/1\ m^2)$$

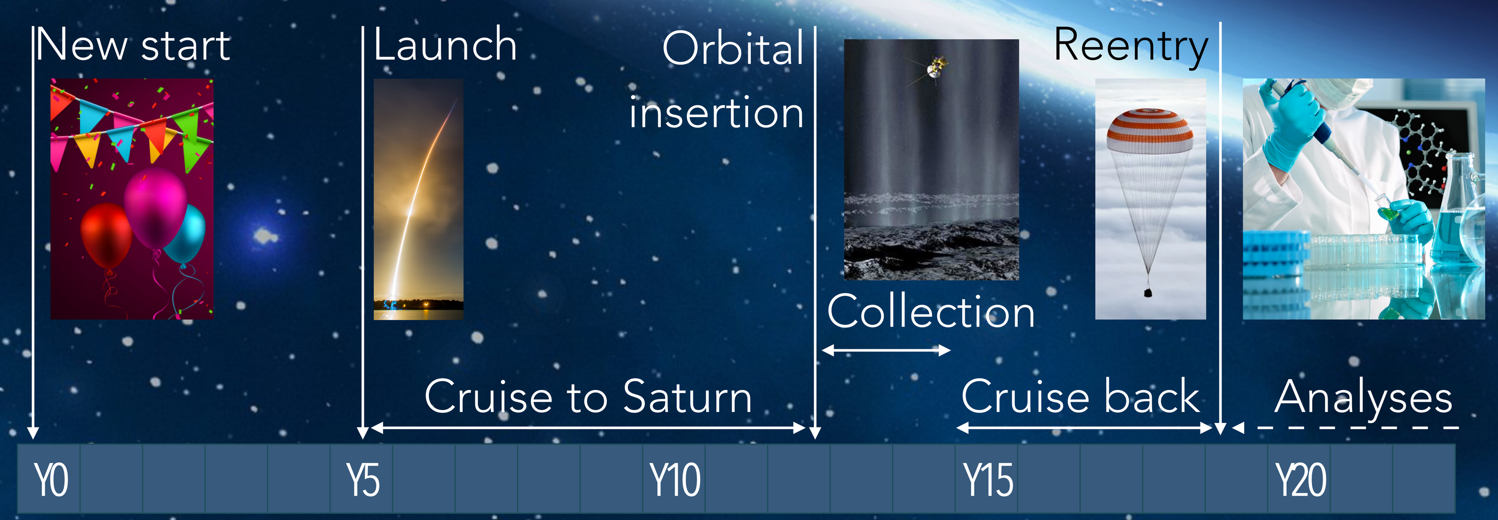
ARCHITECTURE TRADES

MULTI-FLYBY	HOVER	ORBITER	LANDER
ΔV ≈ *Cassini* Several plume locations	Capture @ plume ejection speed	Context science More sample	Context science Snow+surface Large sample
Capture @4 km/s Many flybys for small sample	70% more ΔV	50% more ΔV	70% more ΔV 1 location

PLANETARY PROTECTION →

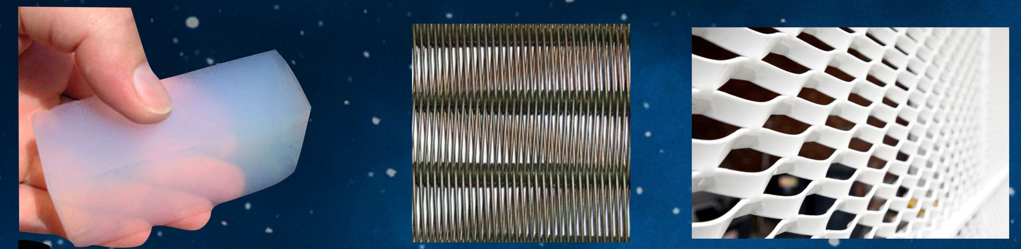
NEW FRONTIERS — $ — FLAGSHIP →

TIMELINE



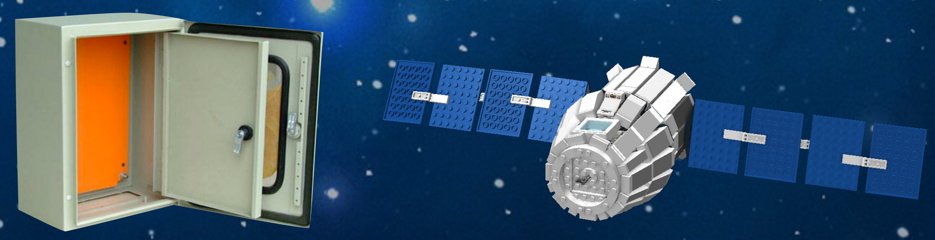
AREAS OF FOCUS

Collector material (Glavin et al. 2014)



Maintain cryogenic temperatures through reentry

Break the chain (Neveu et al. 2018)



Sample receiving facility (Takano et al. 2014)

AFFILIATIONS

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REFERENCES

Glavin, D.P. et al. (2014) Plume collection strategies for future icy body sample return missions. *Int. Workshop on Instr. for Planetary Missions*, #1012.
Hendrix, A.R., Hurford, T.A., et al. (2018) The NASA Roadmap to Ocean Worlds. *Astrobiology* **19**, 1-27.
Neveu, M. et al. (2018) Quantitative planetary protection for sample return from ocean worlds. *42nd COSPAR Scientific Assembly*, #B5.3-18.
Postberg, F. et al. (2018) Macromolecular organic compounds from the depths of Enceladus. *Nature* **558**, 546-568.
Sherwood, B. (2016) Strategic map for exploring the ocean-world Enceladus. *Acta Astronautica* **126**, 52-58
Takano, Y. et al. (2014) Planetary protection on international waters: An onboard protocol for capsule retrieval and biosafety control in sample return mission. *Adv. Sp. Res.* **53**, 1135-1142.
Thurman, E.M. (1985) Amount of organic carbon in natural waters. In *Organic geochemistry of natural waters*, Springer.