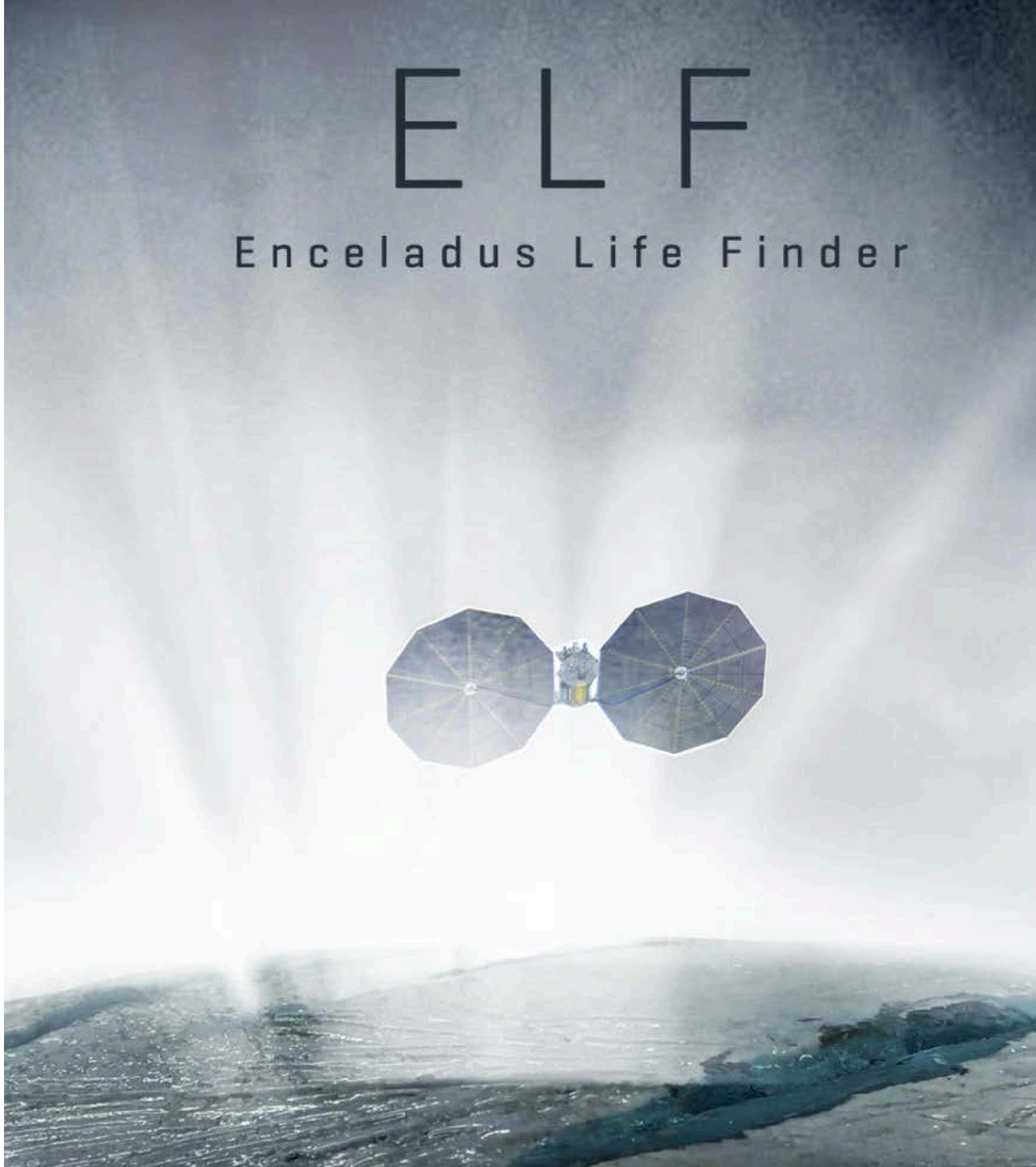
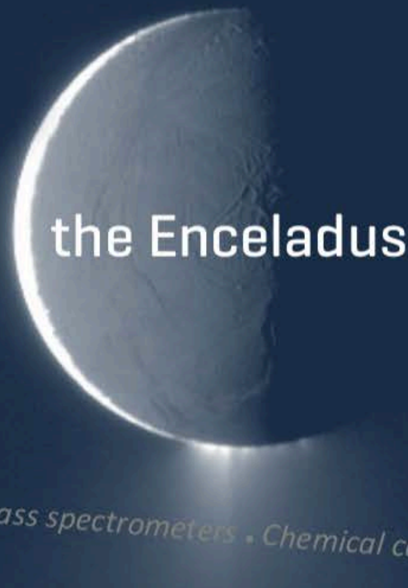
Beyond ELF

Jonathan Lunine

1. Major strengths and major weaknesses (up to a point) for ELF New Frontiers
2. Molecular fragmentation in mass spectrometry
3. Where do we go from here with ocean worlds?



E L F the Enceladus Life Finder



10 flybys • 3 complementary mass spectrometers • Chemical composition of ocean-plume gas and grains

How habitable is the ocean?

- Extent of ongoing hydrothermal activity
- Hydrothermal-vent temperatures
- Acidity of the ocean water
- Availability of CHNOPS elements

Is life active there now?

- Metabolic use of chemical energy
- Amino Acid abundance pattern
- Membrane-molecule carbon-number pattern
- Carbon-isotope enrichment

"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 Science Decadal Survey

1. Major strengths and major weaknesses (up to a point) for ELF New Frontiers

Form A

<u>Major Strengths</u>

The proposed ELF investigation has the exciting and scientifically compelling goals of 1) assessing whether Enceladus' subsurface is habitable, and 2) determining whether life is present on Enceladus. ELF would make

ELF would significantly improve our understanding of Enceladus' plumes and subsurface, and is a logical 'next step' following the Cassini mission. The

The proposed investigation to determine the extent of hydrothermal chemistry, particularly serpentinization, would be crucially important in characterizing the habitability of Enceladus. Hydrothermal activity will be characterized by 1)

The two main science goals for this investigation are very well aligned with the science objectives for an Enceladus mission as laid out in the New Frontiers AO

This investigation directly addresses one of the most exciting Key Questions among NASA's cross-cutting themes given in Chapter 3 of the Vision and Voyages Decadal Survey, and is relevant to another three of the remaining nine Key Questions, as well as all three Science Goals for Planetary Satellites given in Chapter 8 of that document. This investigation is most directly relevant

Form A

Major strengths, continued

The proposed investigation would yield information about the interior of Enceladus that would synergistically support the Europa Clipper Mission and enable comparative planetology of icy moons. For example, ELF would provide

The requirements specified for the proposed high-resolution mass spectroscopy measurements are well motivated and will ensure that the science goals are met. The proposal demonstrates that the three instruments onboard the

The suite of proposed measurements does not require evidence for life to be found in the plume for the mission objectives to be successfully met. By

The proposal thoroughly discussed using a well-motivated and robust array of chemical indicators to provide important multiple cross-checks that are essential in assessing habitability and identifying potential extant life. The

Major Weaknesses

Although not a fatal flaw, the proposal provided insufficient discussions about how the multiple models needed to translate the plume measurements into assessments of the subsurface ocean's habitability would be developed. The

Form B

Major Strengths

All three science instruments are complementary to one other and together would provide valuable information about the composition of all components in Enceladus' plume. The three complementary mass spectrometers (MASPEX,

Major Weaknesses

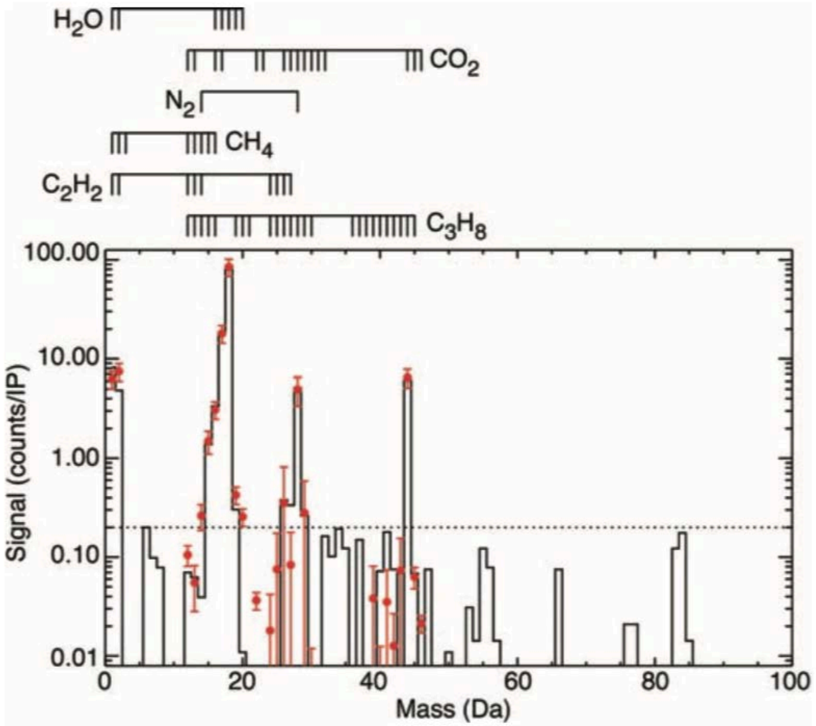
The proposed investigation assumes that amino acids and fatty acids remain intact after the 5 km/s impact collision required to collect the host ice grains, but there is not much evidence presented that this will be the case in practice.

The remainder of the major weaknesses are instrument-specific—not technique-specific…. hence I cannot make them a matter of OPAG record.

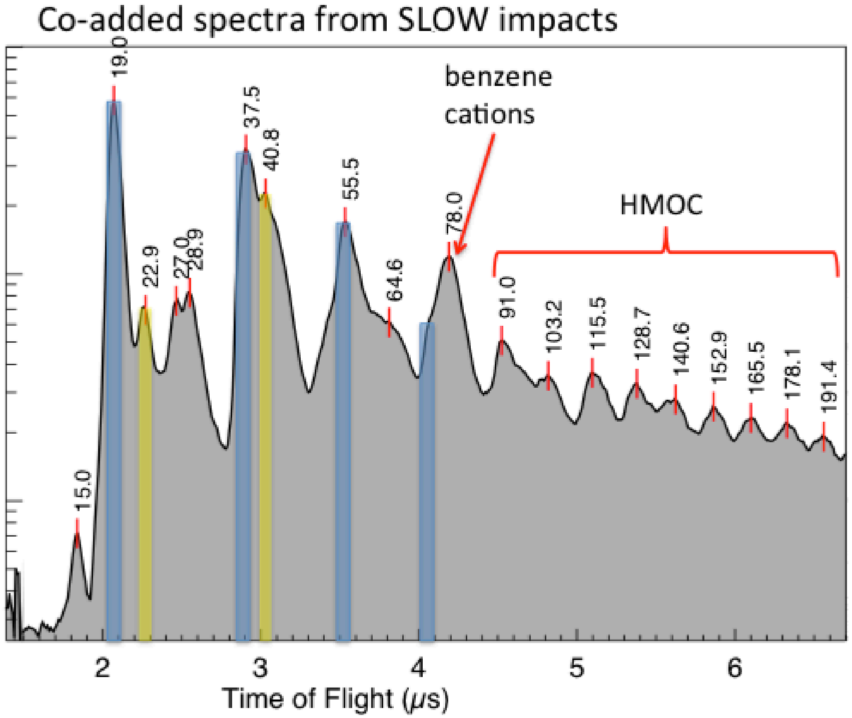
The issue of a lack of confidence in hypervelocity mass spectrometry was a common theme across several New Frontiers proposals to multiple targets, ***even though Cassini did this at Enceladus and Titan.***

2. Molecular fragmentation in mass spectrometry

- All of the in situ compositional results on Cassini were obtained by hypervelocity mass spectrometry at speeds well above ELF's 5 km/s.



Waite et al 2017



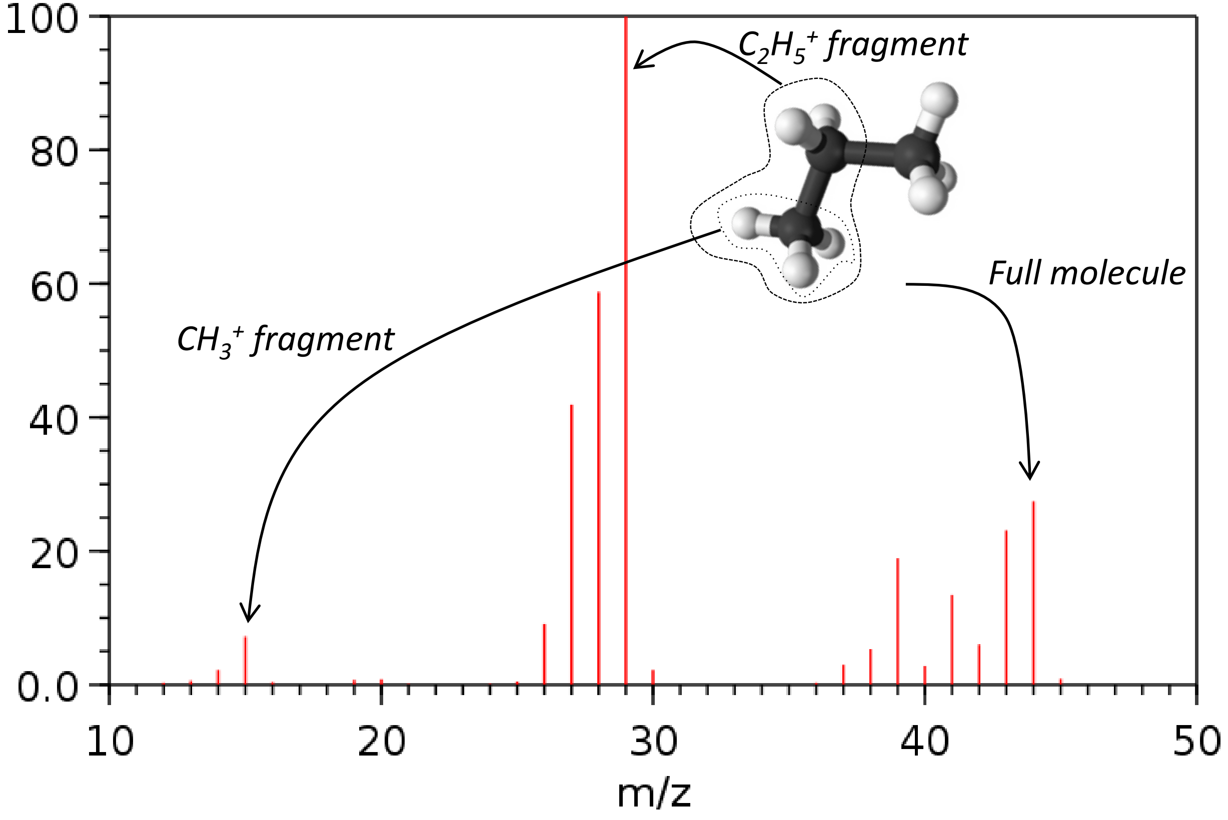
Postberg et al 2017

HMOC = high molecular weight organic compounds

- This included the key indicators of habitability-- light organics, heavy organics, salts, molecular hydrogen and silica—that motivated *both* the addition of Enceladus to the New Frontiers list and the two proposals that responded to the call.

Fragmentation as a diagnostic tool: Electron-impact mass spectra of organic compounds

- Molecule collides with moderately high energy e- (~10's of eV)
- Becomes electronically excited and 'decays' into mixture of various metastable molecular and fragment neutrals and positive and negative ions
- Secondary reactions may occur (e.g., H adduction; hydration; oxidation)

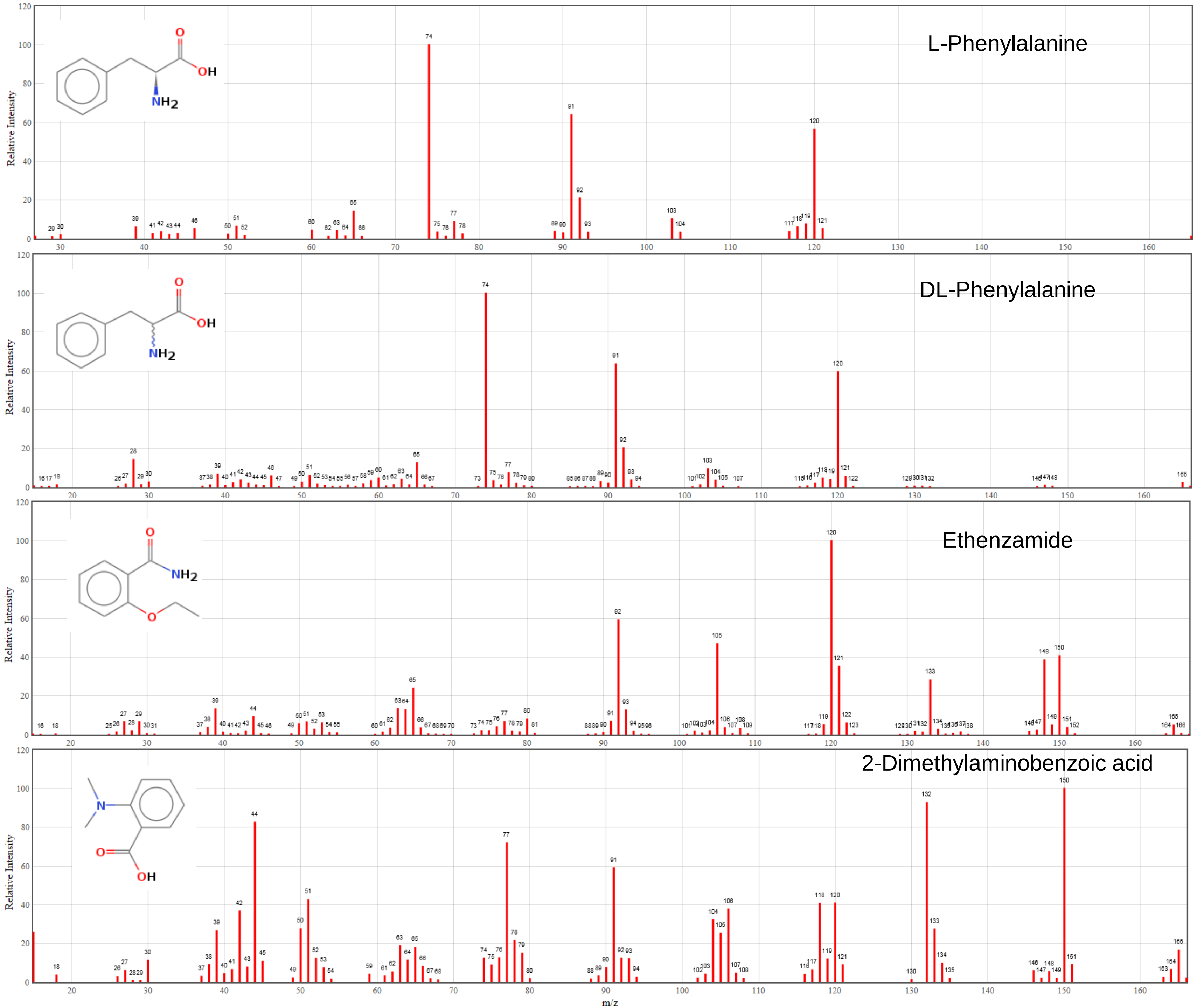


- Fragments are generally (much) more abundant than full molecular peaks

$C_9H_{11}NO_2$

How fragment ions diagnose the original chemical structure.

Fragmentation is the friend, not the enemy!



Ryan Blase, SWRI

3. Where do we go from here with ocean worlds?

Steps to find and understand life elsewhere

1. Find liquid water (or some other liquid) (Stage 0)
2. Quantify the habitability of the environment (Stage A)
3. Detect biosignatures (Stage B)
4. Confirm life is present and understand its biochemistry (Stage C)

Status of ocean worlds exploration

	Stage A Habitability	Stage B Biosignatures	Stage C Discover life
Europa	Europa Clipper	Europa Lander	
Enceladus	Cassini (basic hab)	ELSAH/ELF	
Titan	Dragonfly		

Blue-- completed missions; Green--under development; Yellow-- under study; Red-- declined by NASA

Schedule for this NF

- Selection for Phase A 2017
- Selection for flight 2019
- Launch 2024
- Arrival at Saturn 2034
- Science complete 2036

Schedule for next NF

- Selection for Phase A 2022
- Selection for flight 2023
- Launch 2028
- Arrival at Saturn 2038
- Pump down complete 2039-2041
- Science complete 2041-2043

Major flight program content (A-D)

• Mars 2020	through 2020	$2 B
• Europa Clipper	through 2024	$2 B
• NF 4 (DrF or CR)	2019-2025	$1 B
• Ice giants	2020-2026	$2 B
• Europa Lander	2021-2027	$2 B
• MSR part II	2022-2028	$2 B
• NF 5 (Enc Pl)	2023-2029	$1 B

Total major program content A-D 2018-2030 $12 B

~ 1 B/yr or 50% of the annual planetary budget

Notional view of the author

Notional view of the author

Current notional numbers:

$M	PBR 2018	2019	2020	2021	2022
Planetary total	1930	1920	1920	1910	1910
New Frontiers	80	120	170	230	310
Mars 2020	370	360	320	150	120
Mars future missn	--	10	40	50	180
Europa Clip (2025)	430	300	220	430	250
Total	880	780	750	860	860
Remain from 1 B	120	220	250	140	140
Result Pl. budg	2050	2140	2170	2050	2050
Avail for $2200M planetary 2019-2022*:		280	280	290	290

*Based on 2019 NASA PBR

Conclusion: one of EL, IG, MSR-2 can be developed beginning in 2019 timeframe if Clipper launches 2025

The "best of all possible worlds*" for the ocean worlds (completed by 2043)

	Stage A Habitability	Stage B Biosignatures	Stage C Discover life
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Notional view of the author