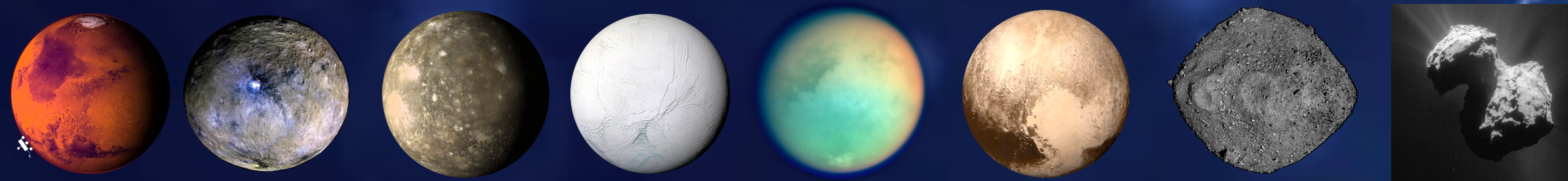


# Organics detected on spaceflight missions

**Marc Neveu**

University of Maryland / NASA Goddard Space Flight Center



**KISS Study “Next Frontiers in the Investigation of Extraterrestrial Organics” – Dec. 1, 2025**



# Organics detected on spaceflight missions

Review of organic compounds detected by spacecraft to date

Organic biosignatures

Upcoming missions, with focus on Enceladus and Ceres



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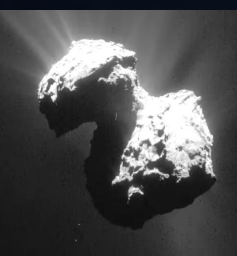
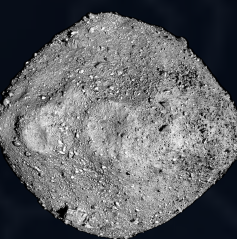
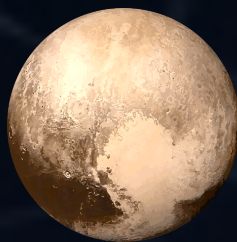
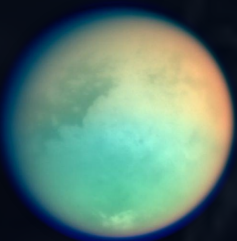
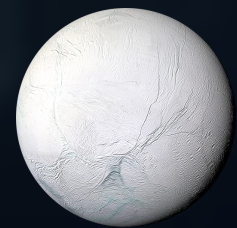
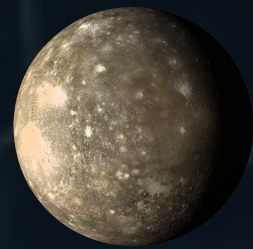
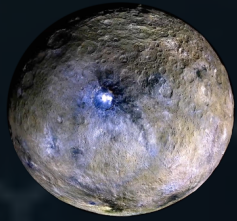
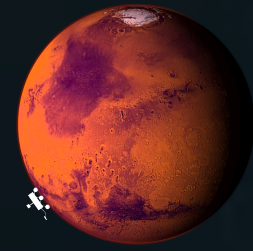
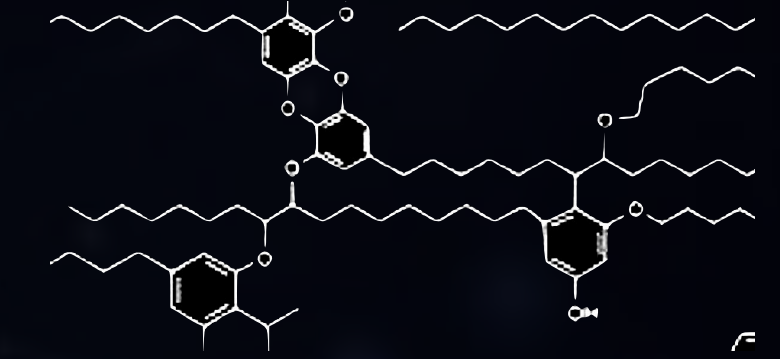
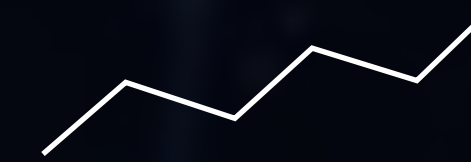
## What has been found to date?

# Remote

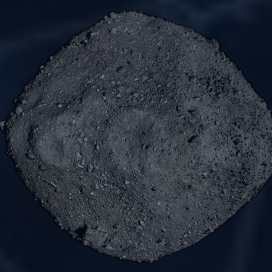
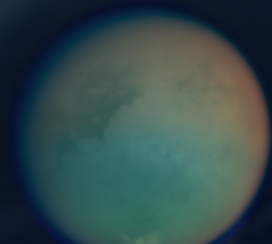
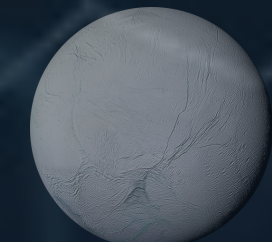
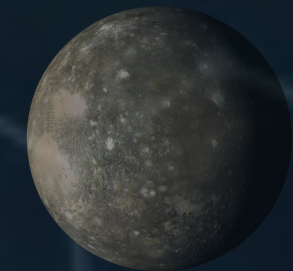
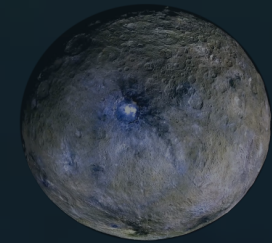
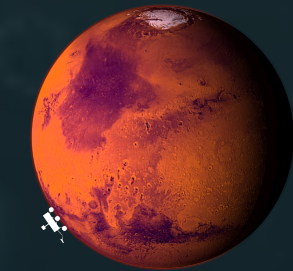
# In situ

org-N

org-O







# Mars: 50 years of searches

## III. Terrestrial contaminants

### Methyl chloride

limits)  
~ 15 ppb

Biemann et al. (1976, Science)

Navarro-Gonzalez et al. (2010, JGR: Planets)

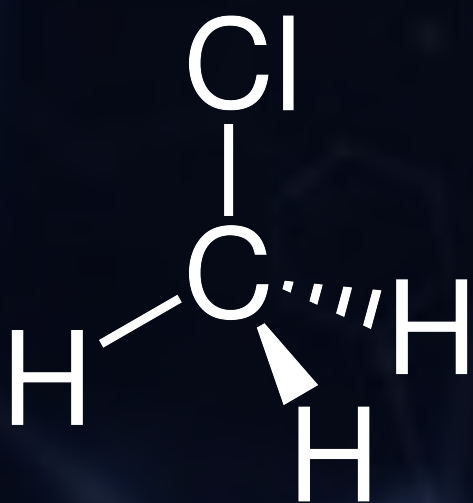
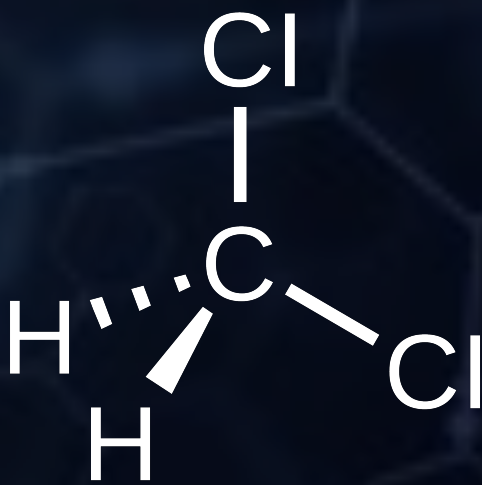


TABLE 3. Terrestrial Contaminants Identified in VL-2 Samples

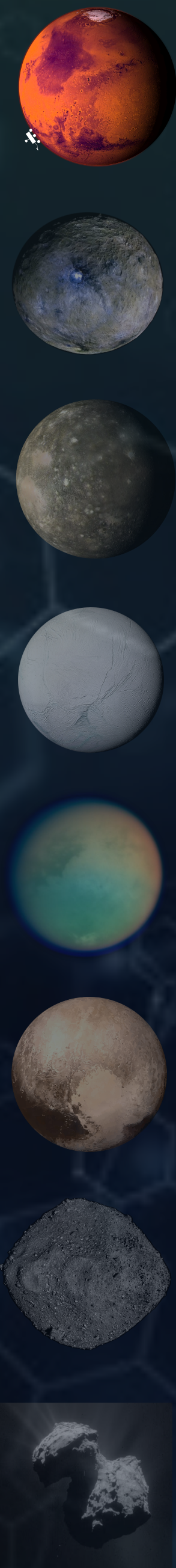
Sample	Temperature, °C	Mode	Methylene Chloride (89)	Acetone (92)	Frequency (40, 105)
Blank (oven 2)	500	CO <sub>2</sub>	ND	120–240	10–
Bonneville	200	H <sub>2</sub>	ND	60–120	6–
(oven 2)	350	H <sub>2</sub>	6–14	40–70	10–
	500	H <sub>2</sub>	6–14	10–20	10–
	500	CO <sub>2</sub>	2–6	1–2	10–
Under Badger	50	H <sub>2</sub>	ND	ND	ND
Rock	200	H <sub>2</sub>	0.04–0.08	200–400	4–
(oven 3)	350	H <sub>2</sub>	10–20	30–60	2–
	500	H <sub>2</sub>	<4	<5	0.04–
	500	CO <sub>2</sub>	20–40	5–10	5–



Values are in parts per billion, 100-mg samples being assumed.

Biemann et al. (1977, JGR:Planets)





# Mars: 50 years of searches

III. Terrestrial contaminants  
Methyl chloride  
limits)  
~ 15 ppb

Biemann et al. (1976, Science)  
Navarro-Gonzalez et al. (2010, JGR: Planets)

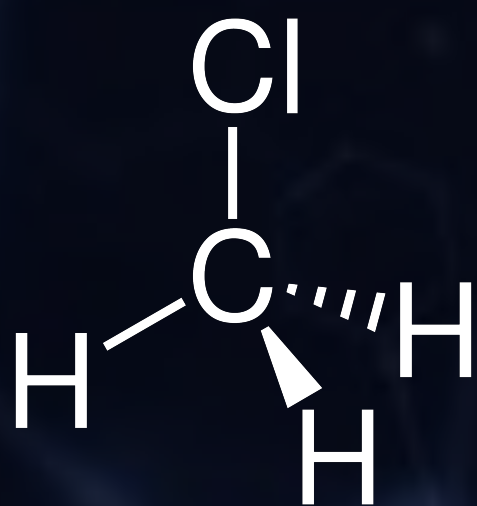
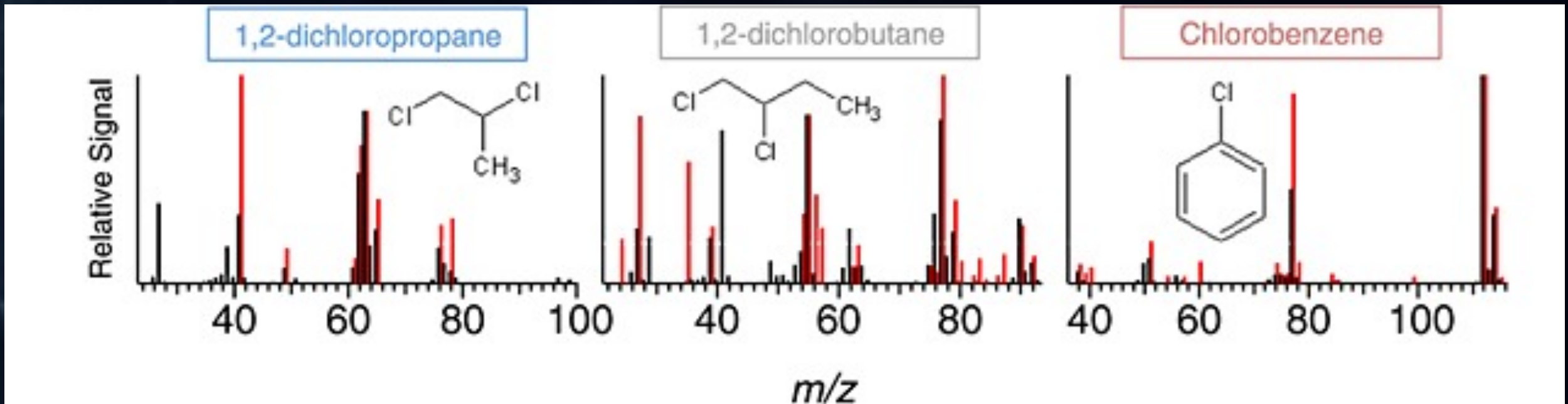
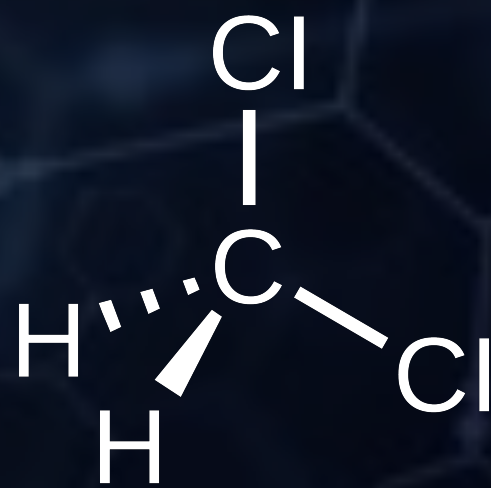


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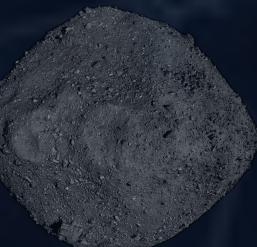
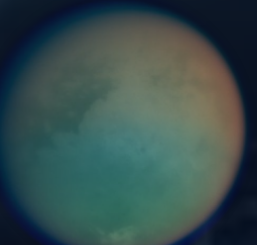
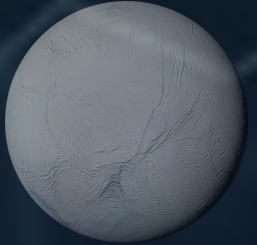
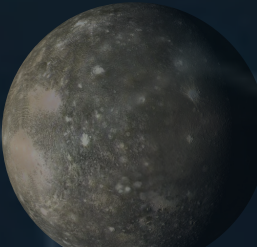
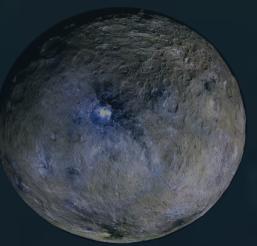
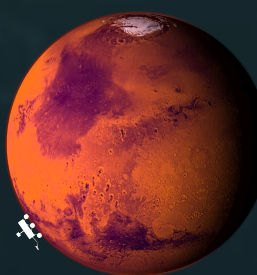
Values are in parts per billion, 100-mg samples being assumed.

Biemann et al. (1977, JGR:Planets)

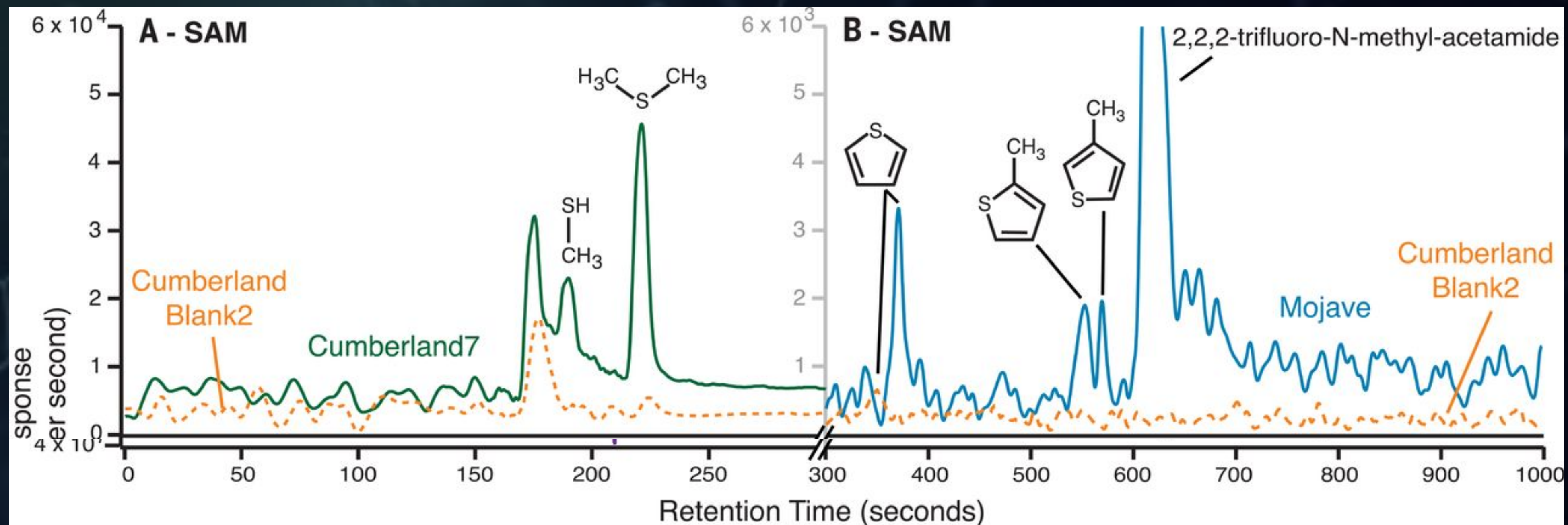


Freissinet et al. (2016, JGR: Planets)



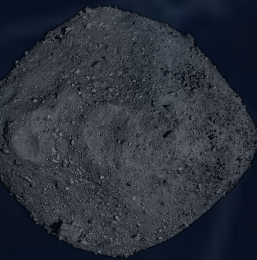
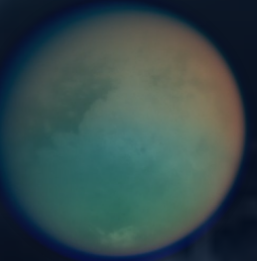
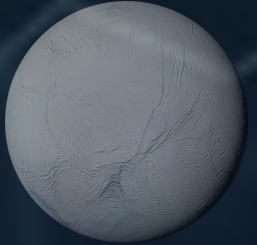
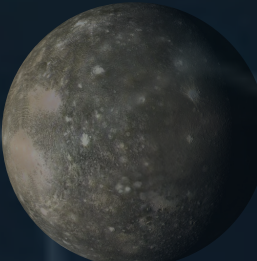
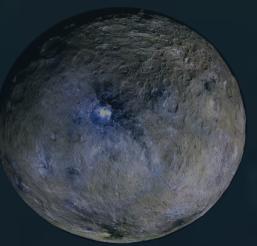
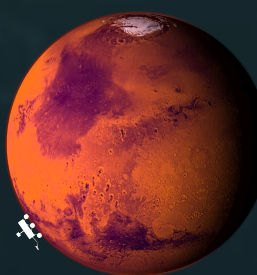


# Mars: progress in last 10 years

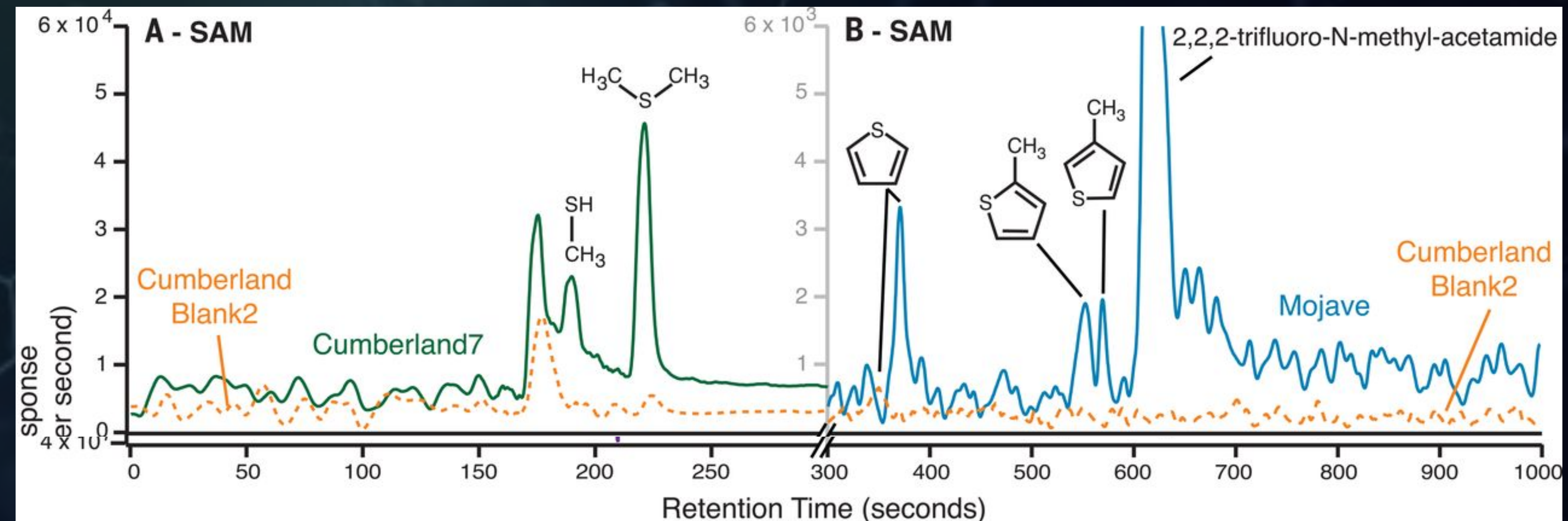


Eigenbrode et al. (2018, Science)

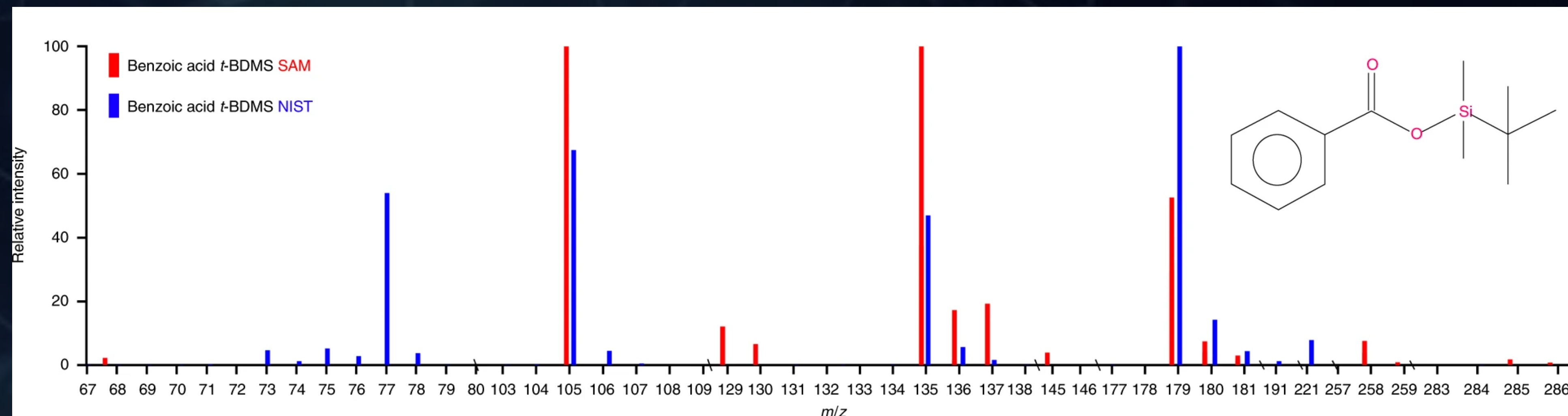




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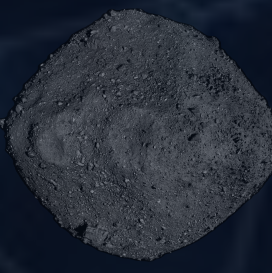
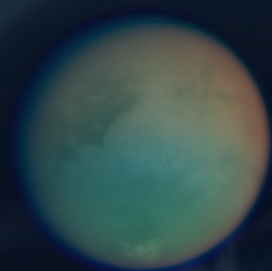
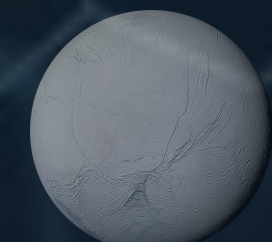
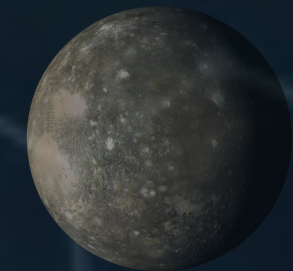
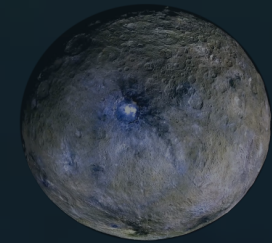
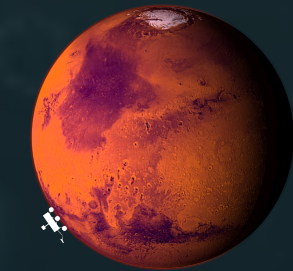


Eigenbrode et al. (2018, Science)

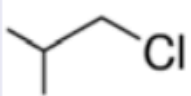
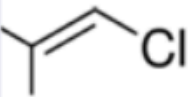
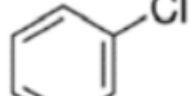
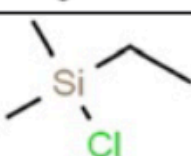
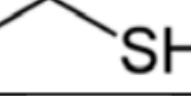
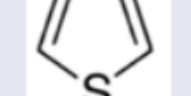




Millan et al. (2022, Nature)



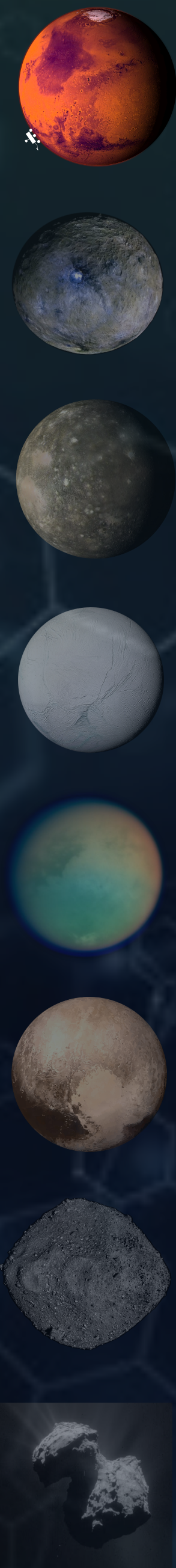


# Mars: progress in last 10 years

Cl-bearing organics	chloromethylpropane	C <sub>4</sub> H <sub>9</sub> Cl		Likely indigenous
	chloromethylpropene	C <sub>4</sub> H <sub>7</sub> Cl		MTBSTFA + chlorides or HCl
	chlorobenzene	C <sub>6</sub> H <sub>5</sub> Cl		Likely indigenous
	chlorodimethylethylsilane	C <sub>4</sub> H <sub>11</sub> ClSi		MTBSTFA + chlorides or HCl
S-bearing organics	ethanethiol	C <sub>2</sub> H <sub>6</sub> S		Likely indigenous
	thiophene	C <sub>4</sub> H <sub>4</sub> S		
	dithiapentane	C <sub>3</sub> H <sub>8</sub> S <sub>2</sub>		
	dithiolane	C <sub>3</sub> H <sub>6</sub> S <sub>2</sub>		Likely indigenous

Millan et al. (2022, JGR:Planets)

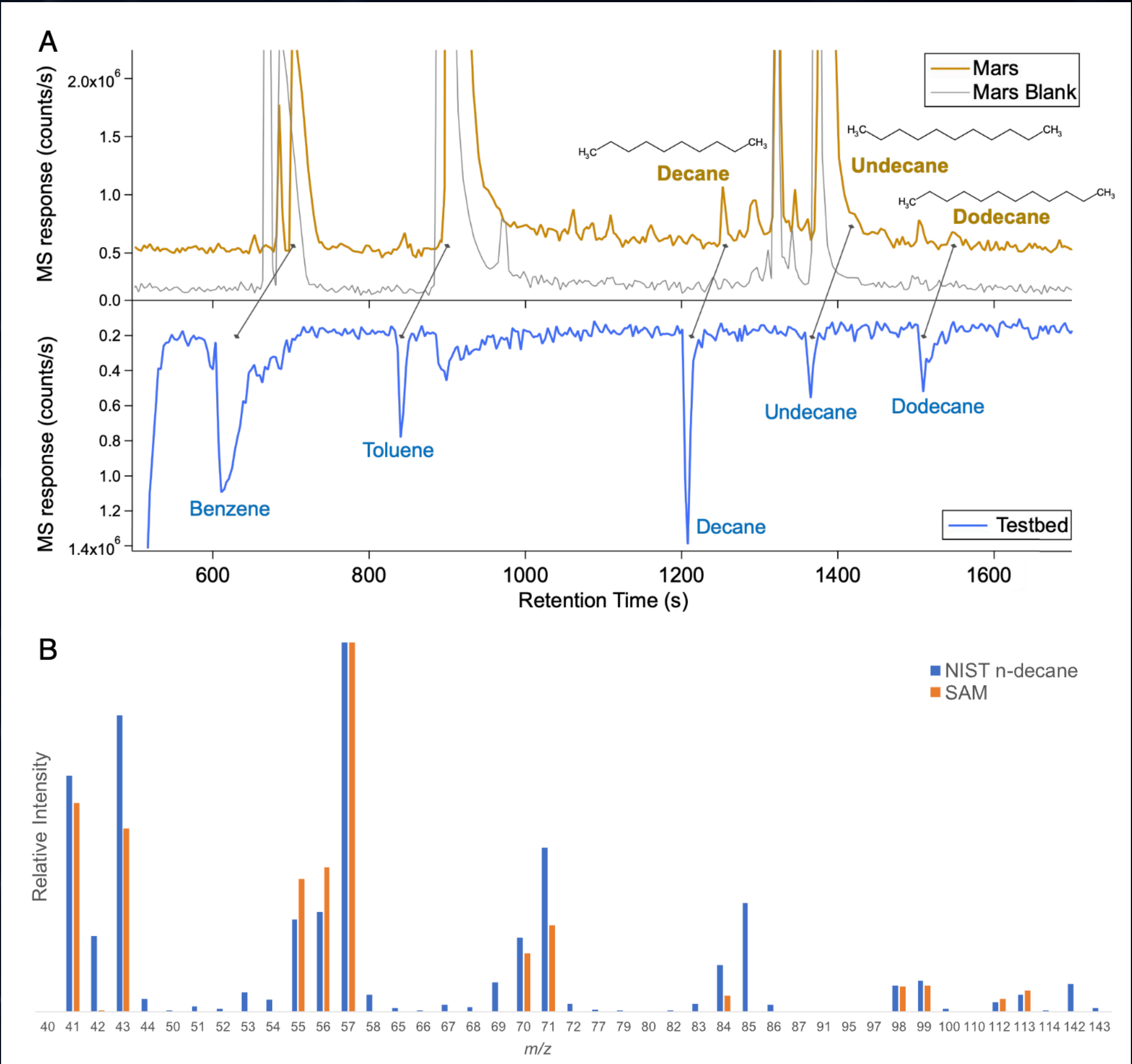




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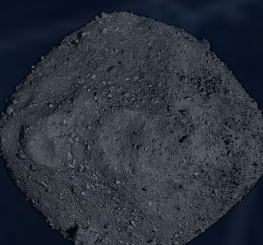
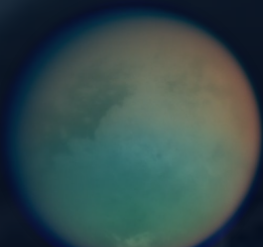
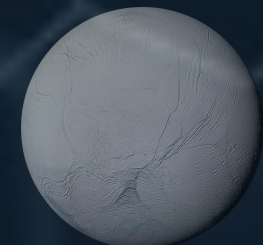
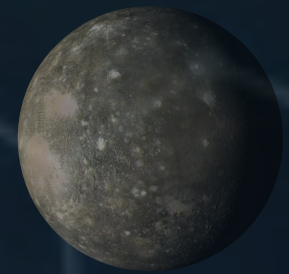
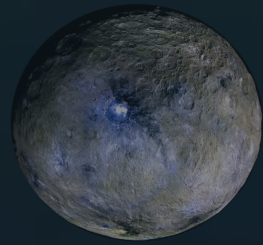
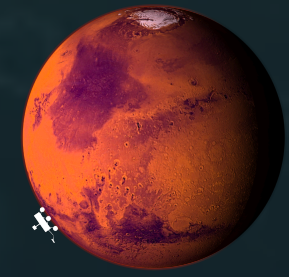
Millan et al. (2022, JGR:Planets)



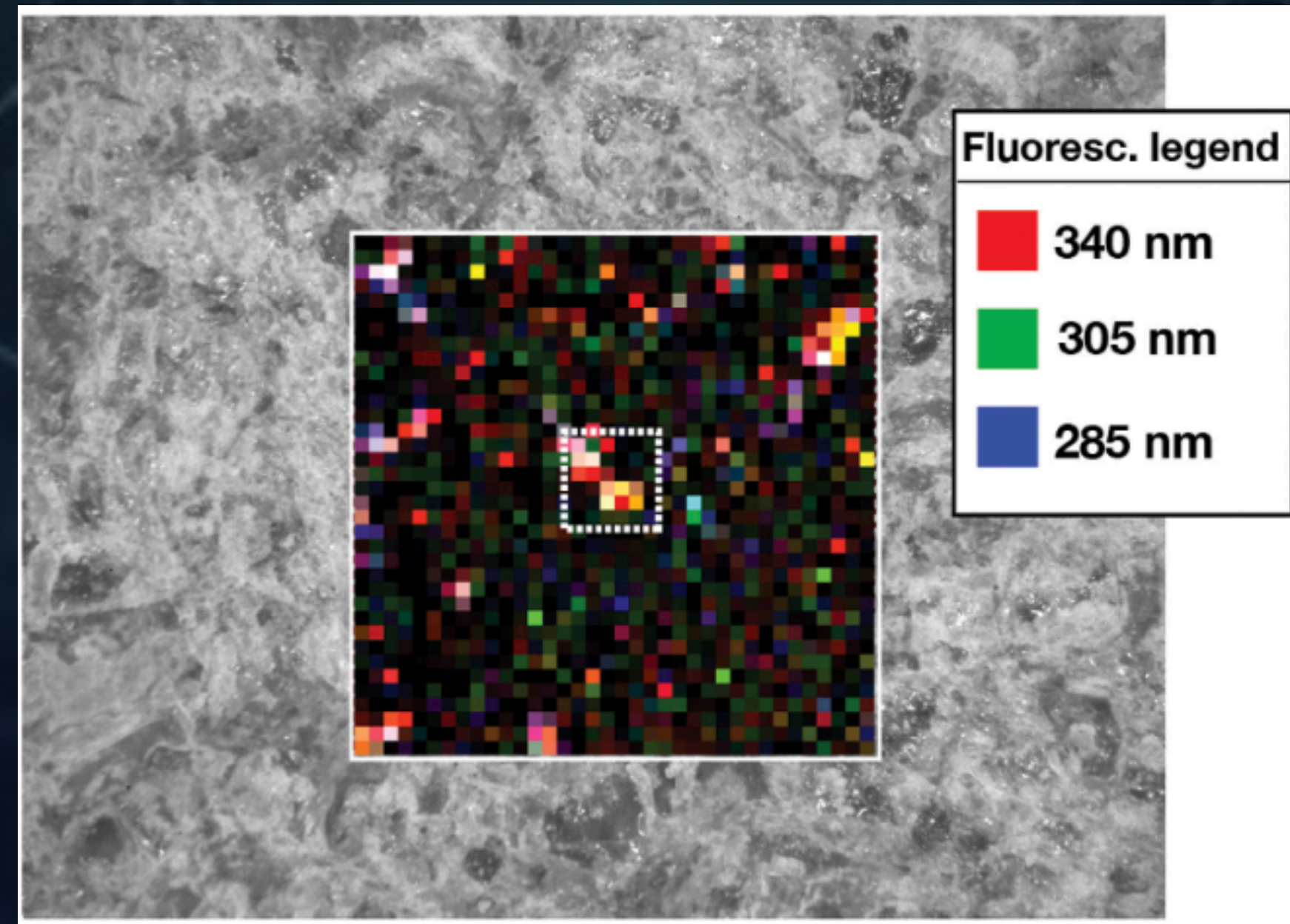
Freissinet et al. (2025, PNAS)

C<sub>10</sub>-C<sub>12</sub> alkanes





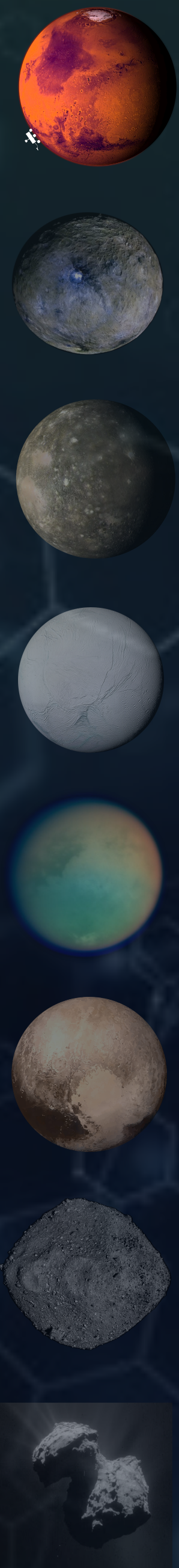
# Mars: macromolecular organic matter



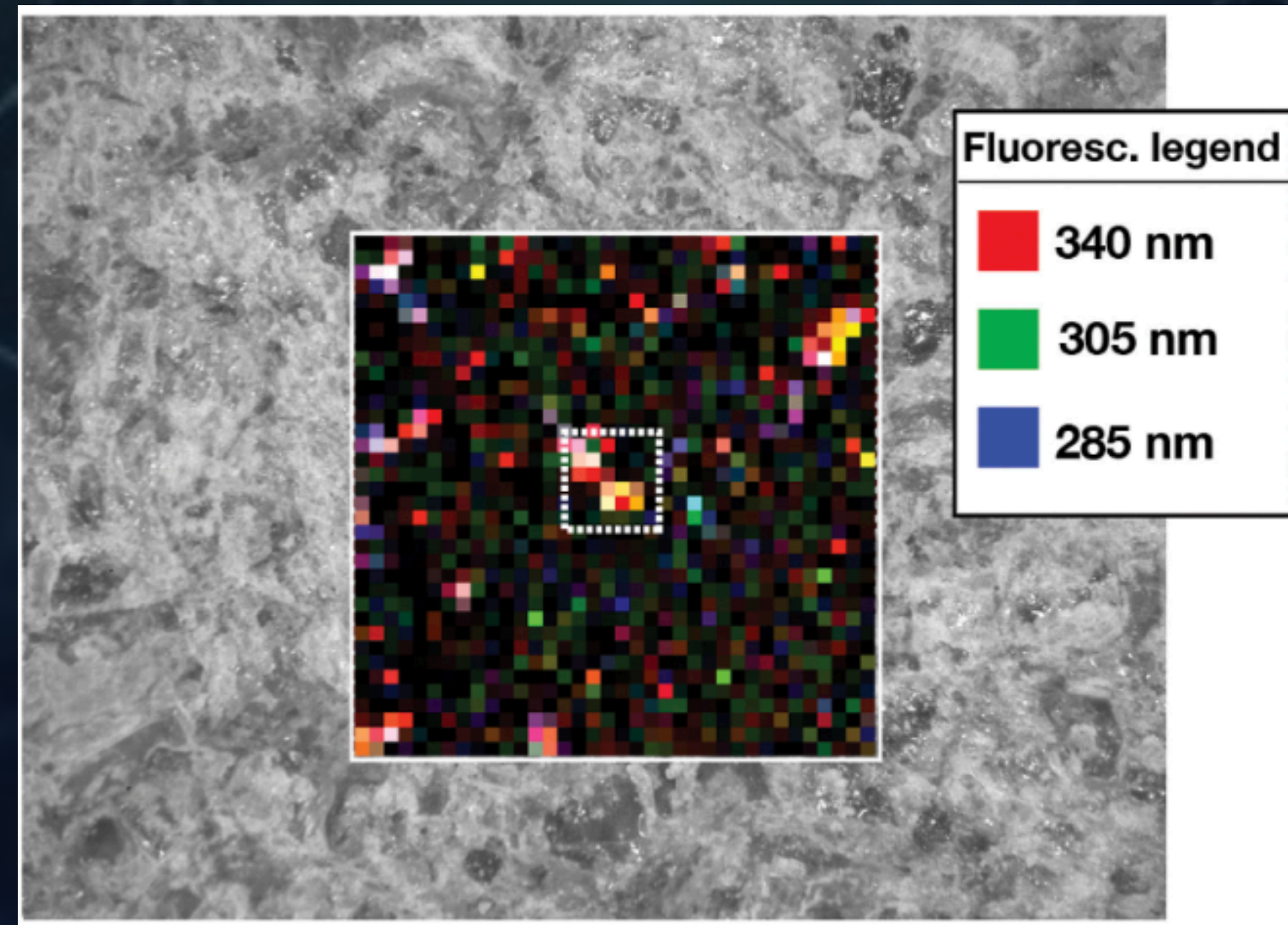
Scheller et al. (2022, Science)

Consistent with, but not uniquely attributable to organic material



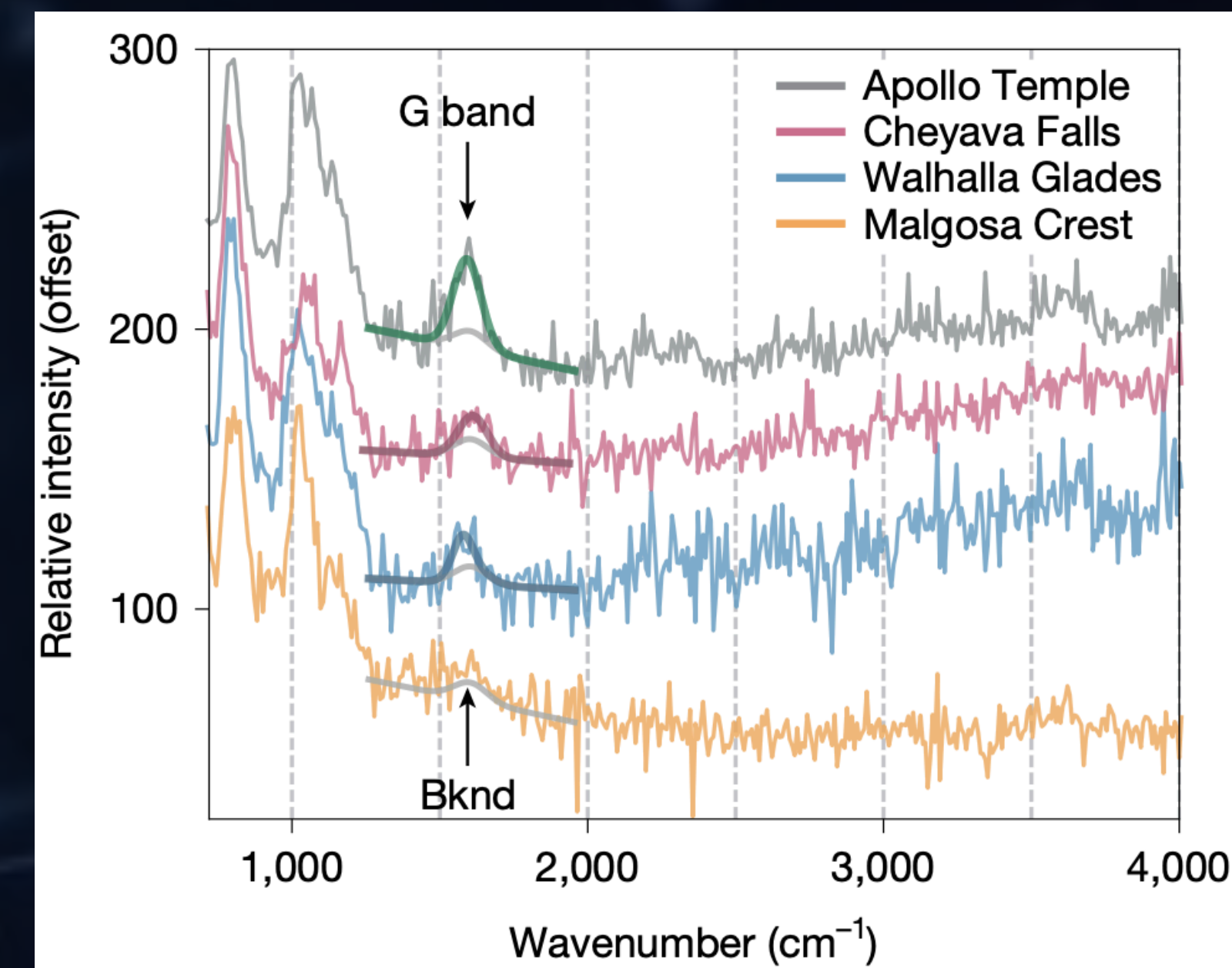


# Mars: macromolecular organic matter



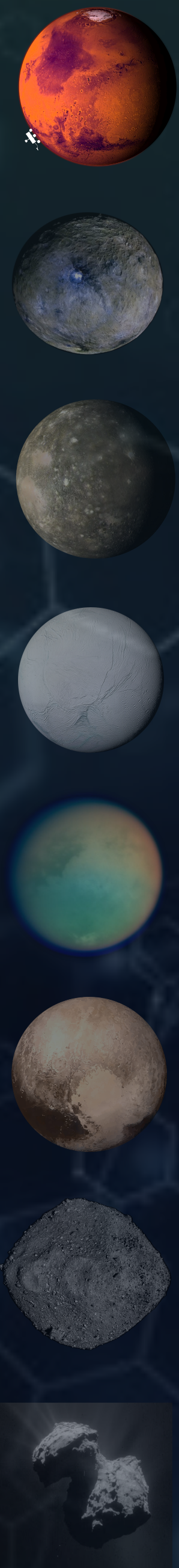
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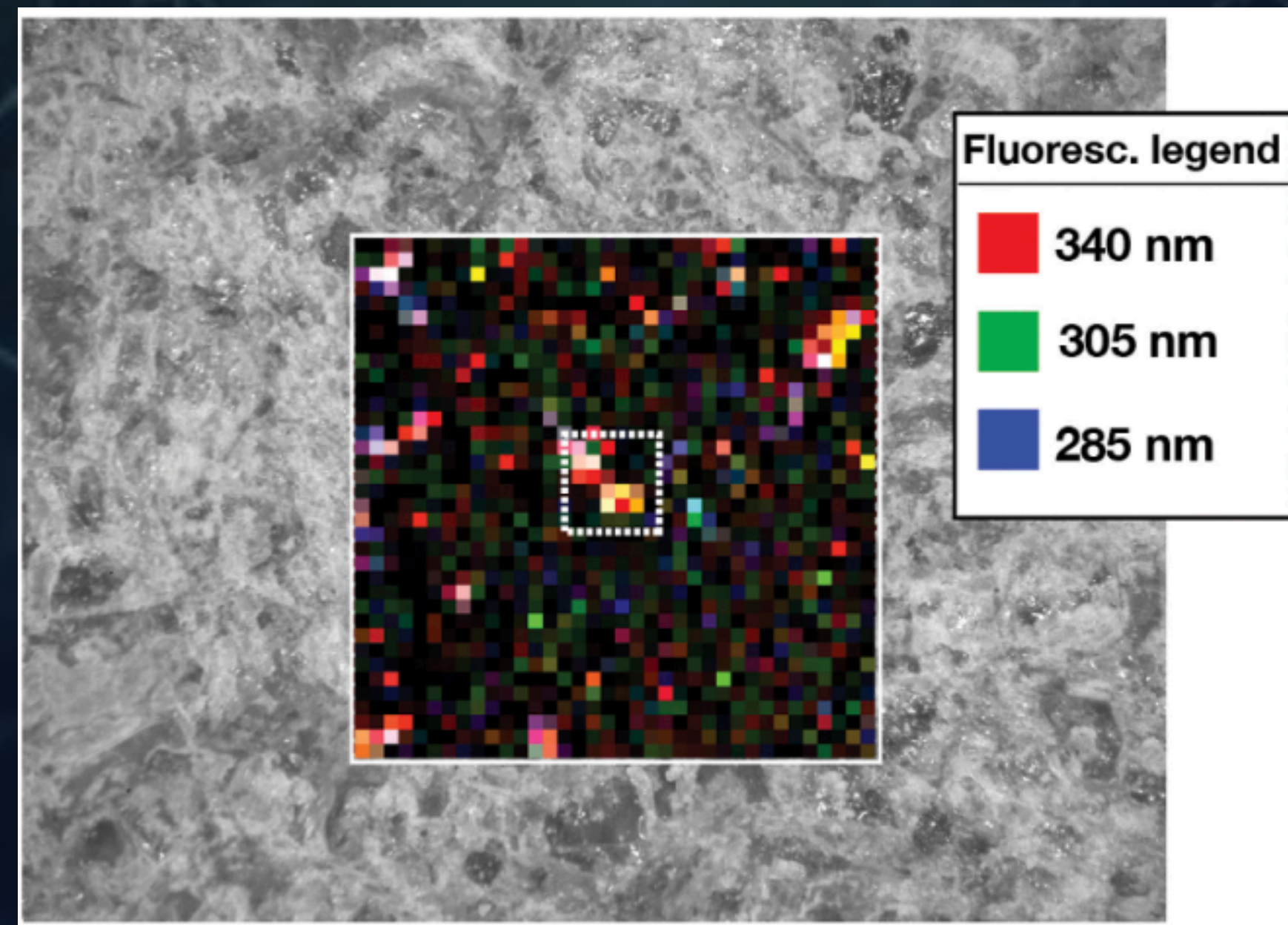


Hurowitz et al.  
(2025, Nature)



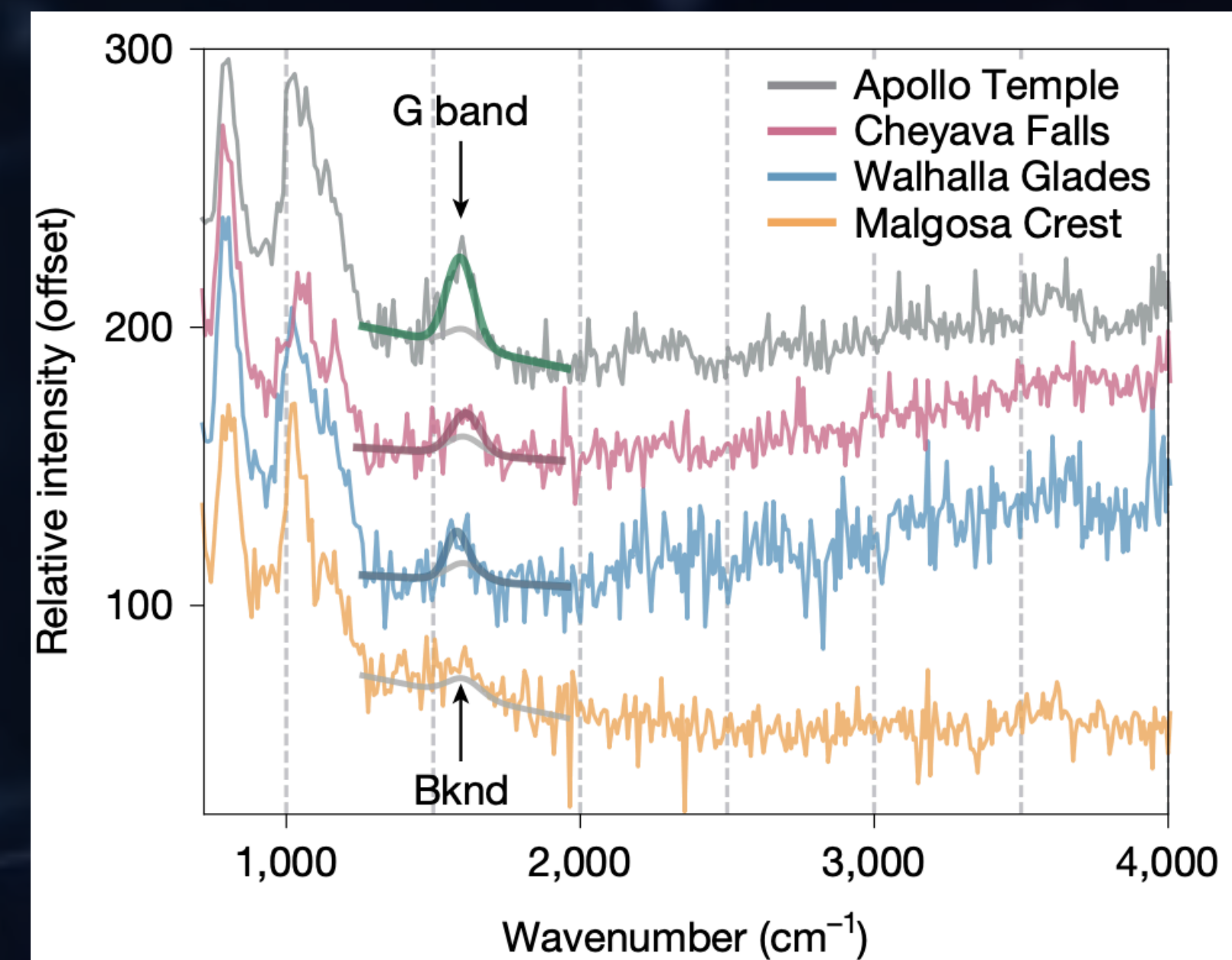


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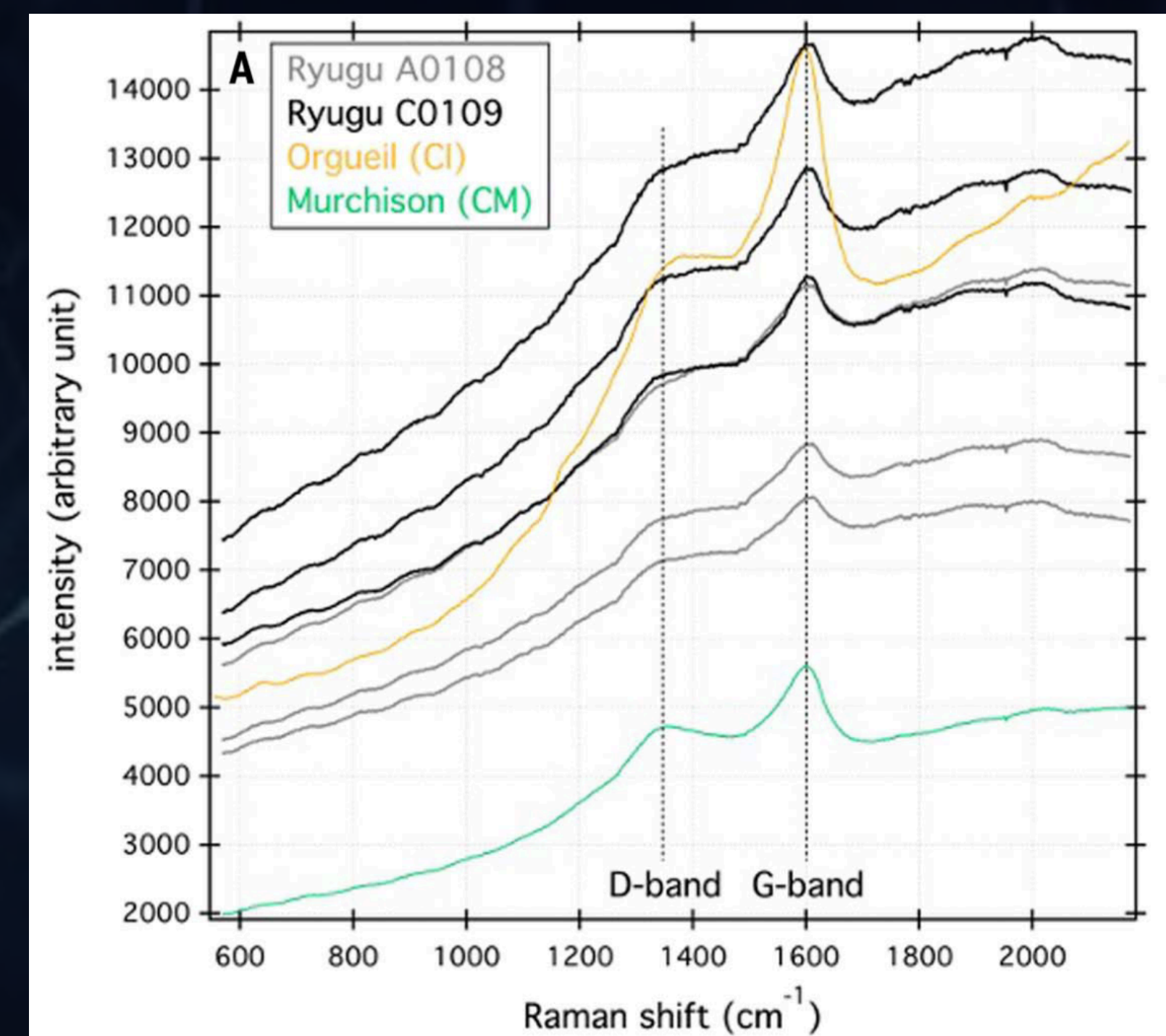


Scheller et al. (2022, Science)

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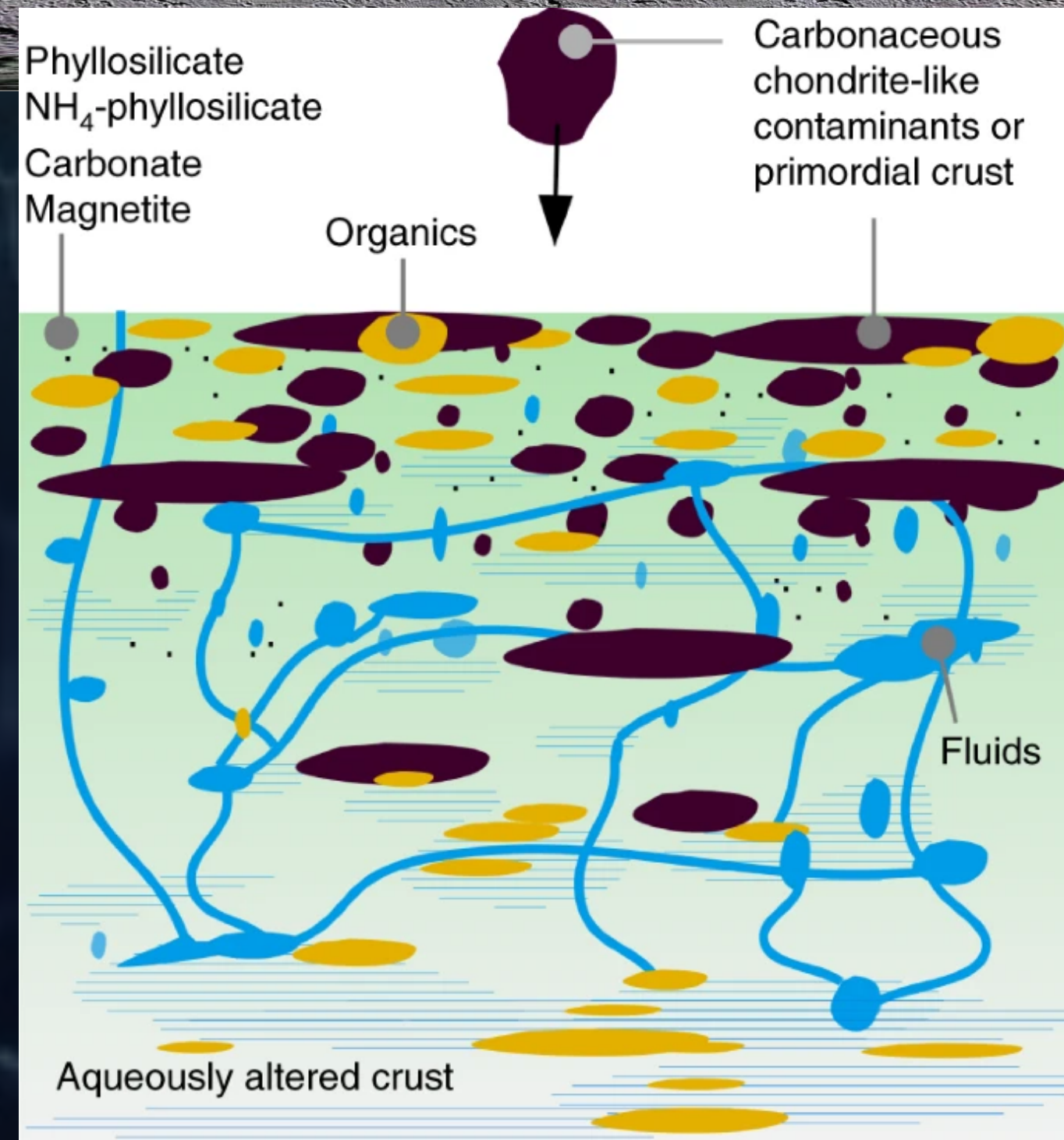
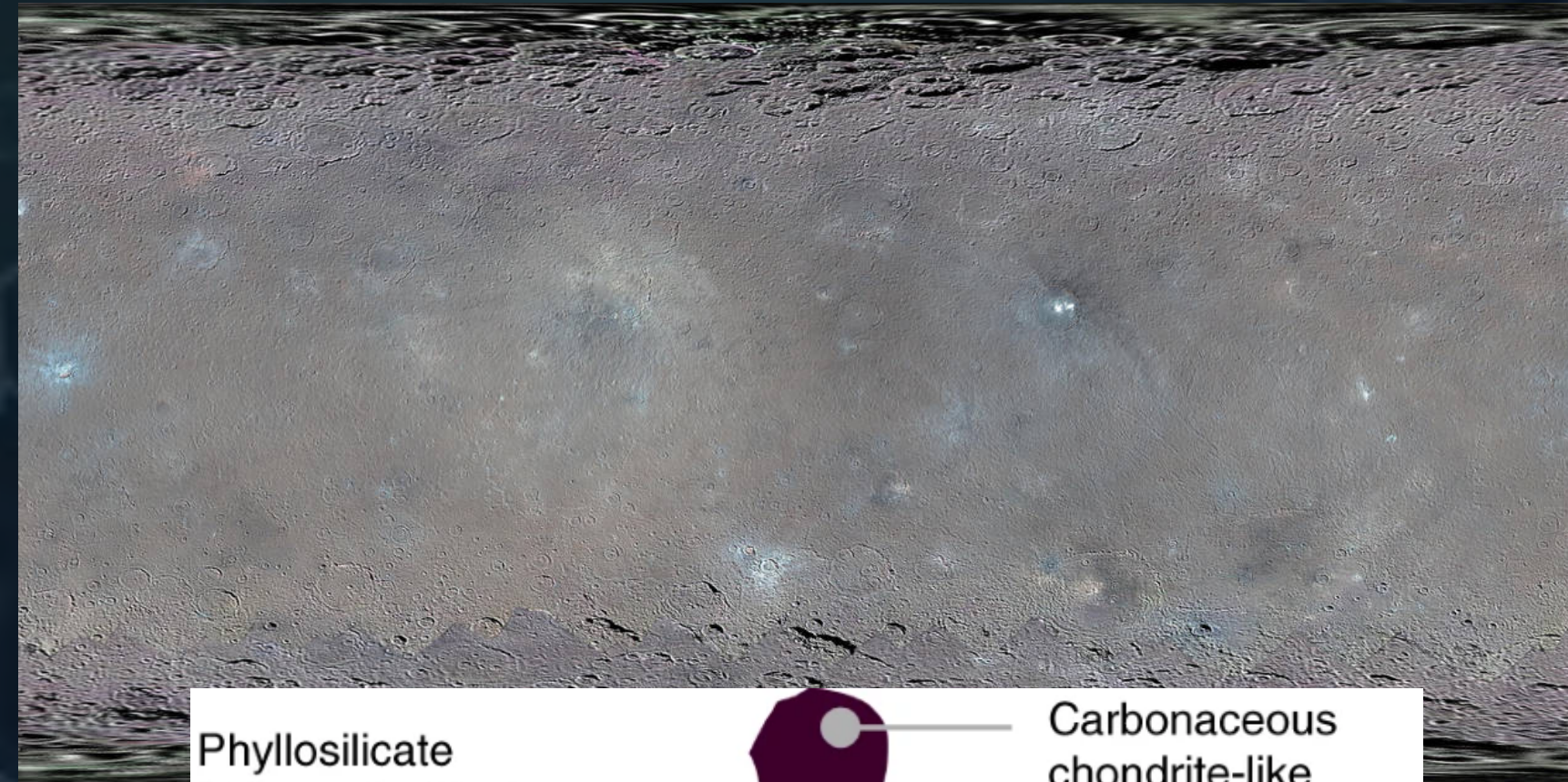
Hurowitz et al. (2025, Nature)



Yabuta et al. (2023, Science)



# Ceres: organic characterization from orbit!

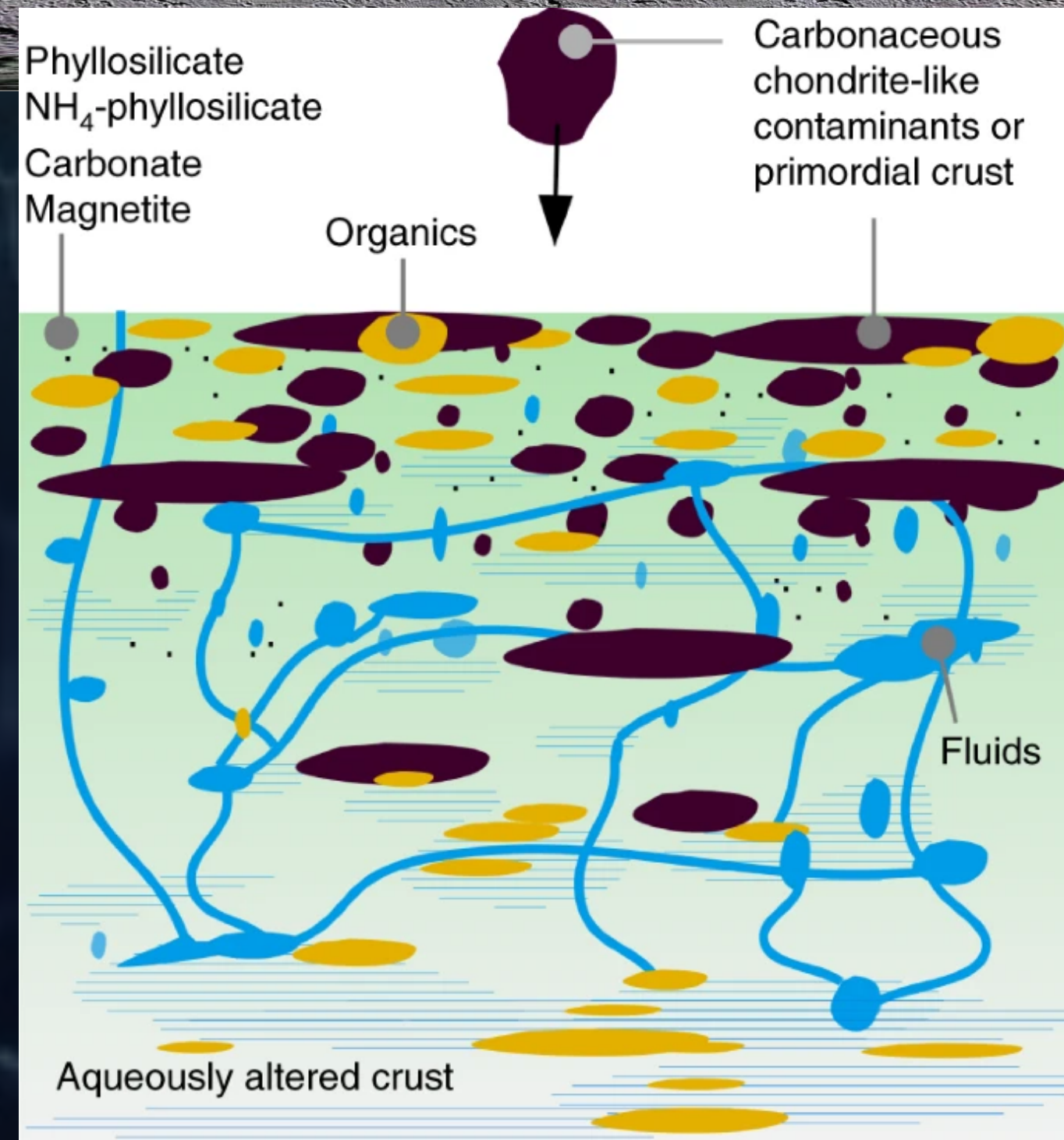
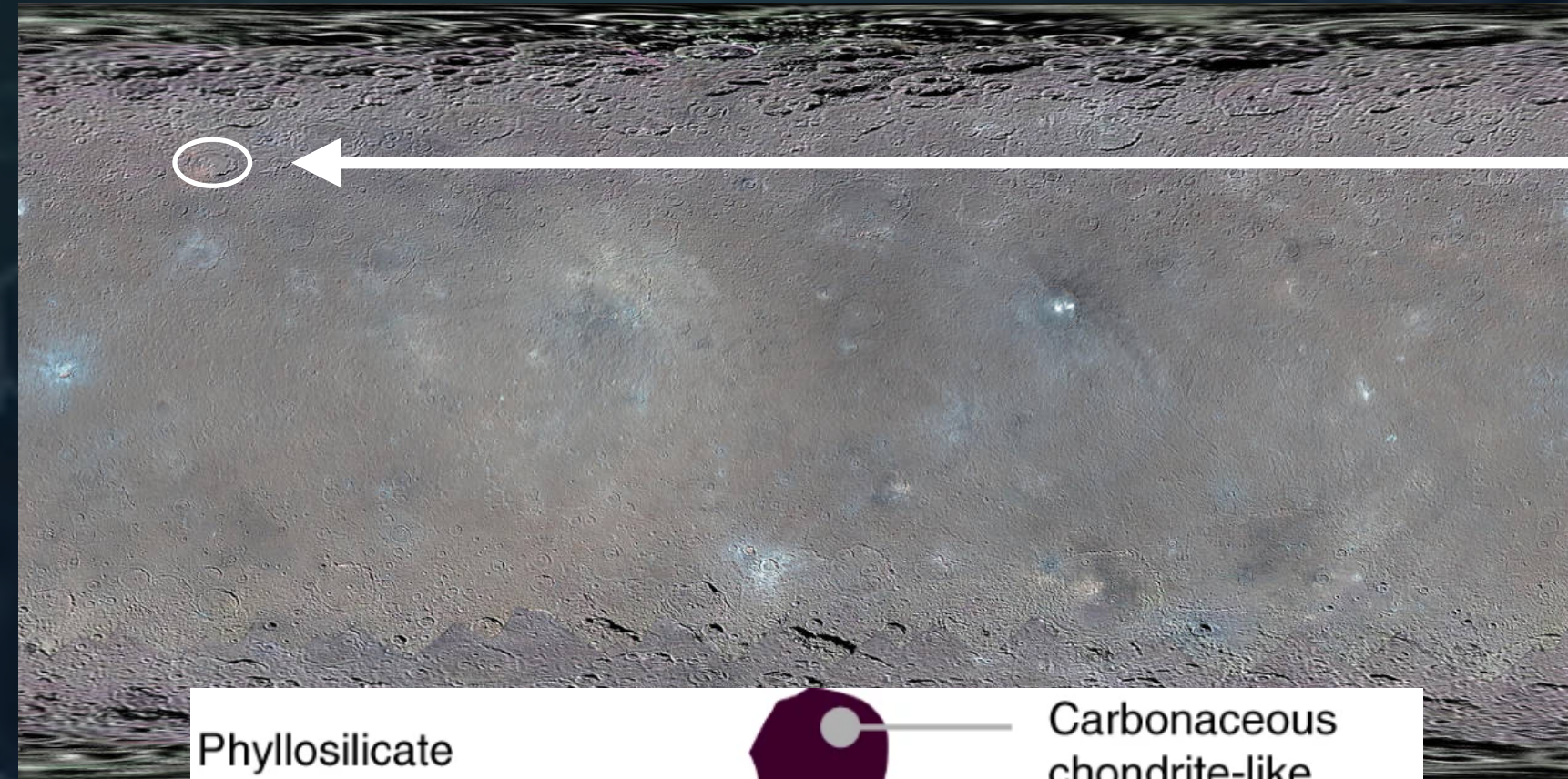


Marchi et al. (2019, Nat Astro):

**20-30% C**



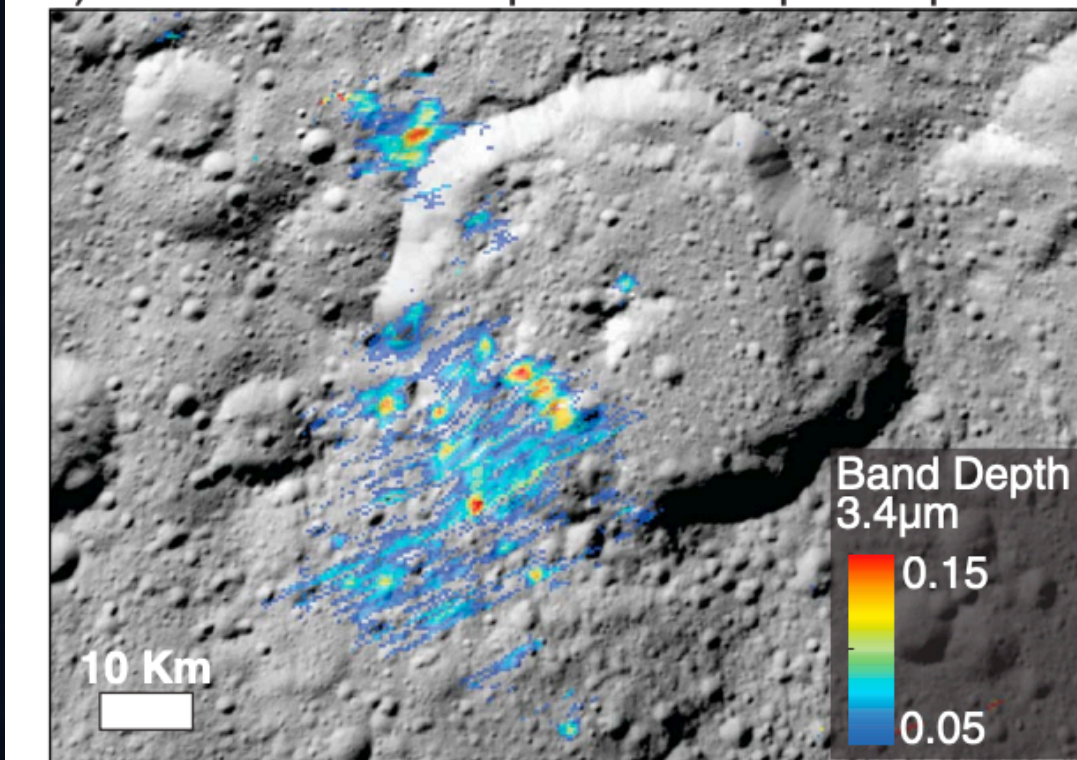
# Ceres: organic characterization from orbit!



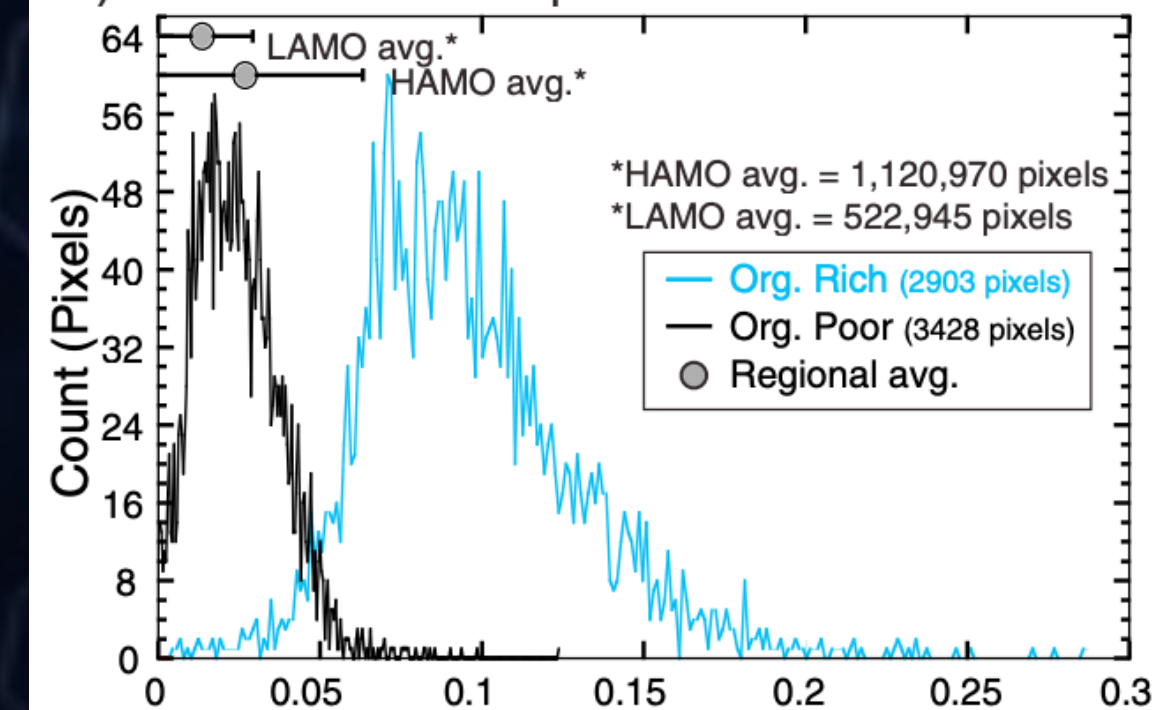
Marchi et al. (2019, Nat Astro):

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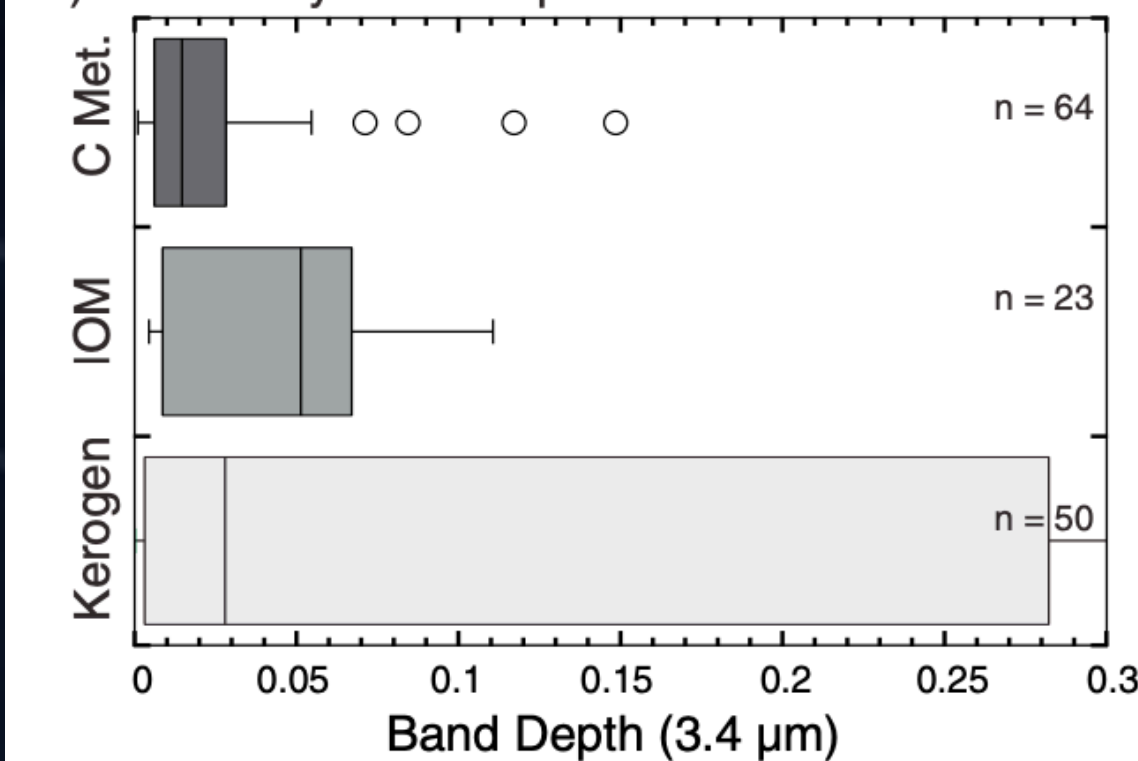
a) Ernutet Crater 3.4  $\mu$ m Band Depth Map



b) Dawn VIR Band Depths



c) Laboratory Band Depths

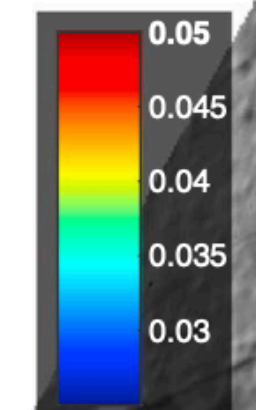


De Sanctis et al. (2017, Science)

Kaplan et al. (2018, GRL)

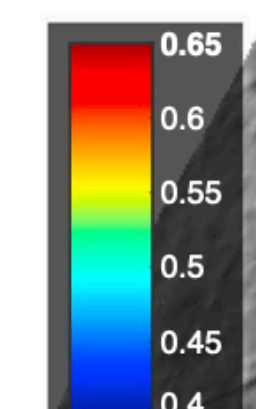
**Kerogen**

U4-153  
H/C = 0.99



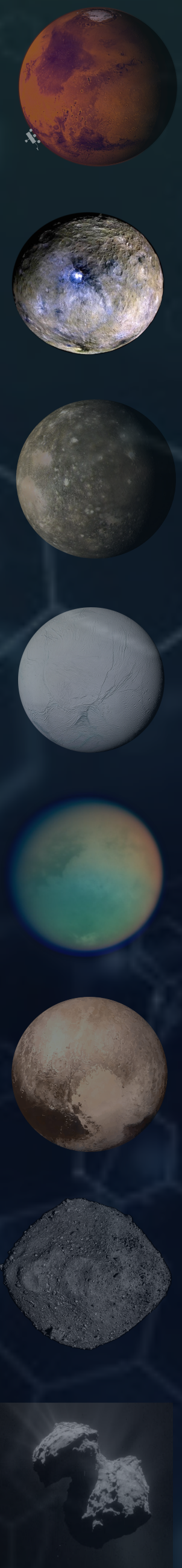
**IOM**

QUE 97008  
H/C = 0.38

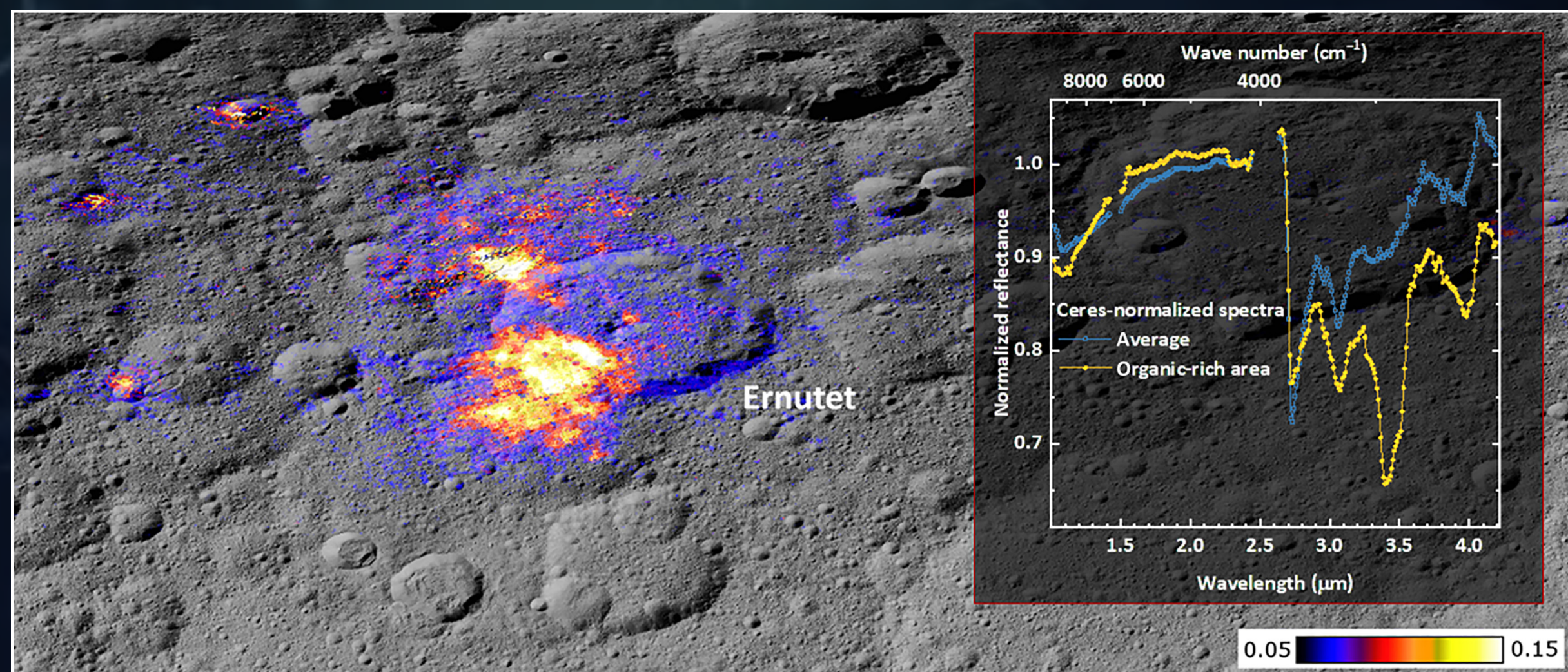


**Low H/C**

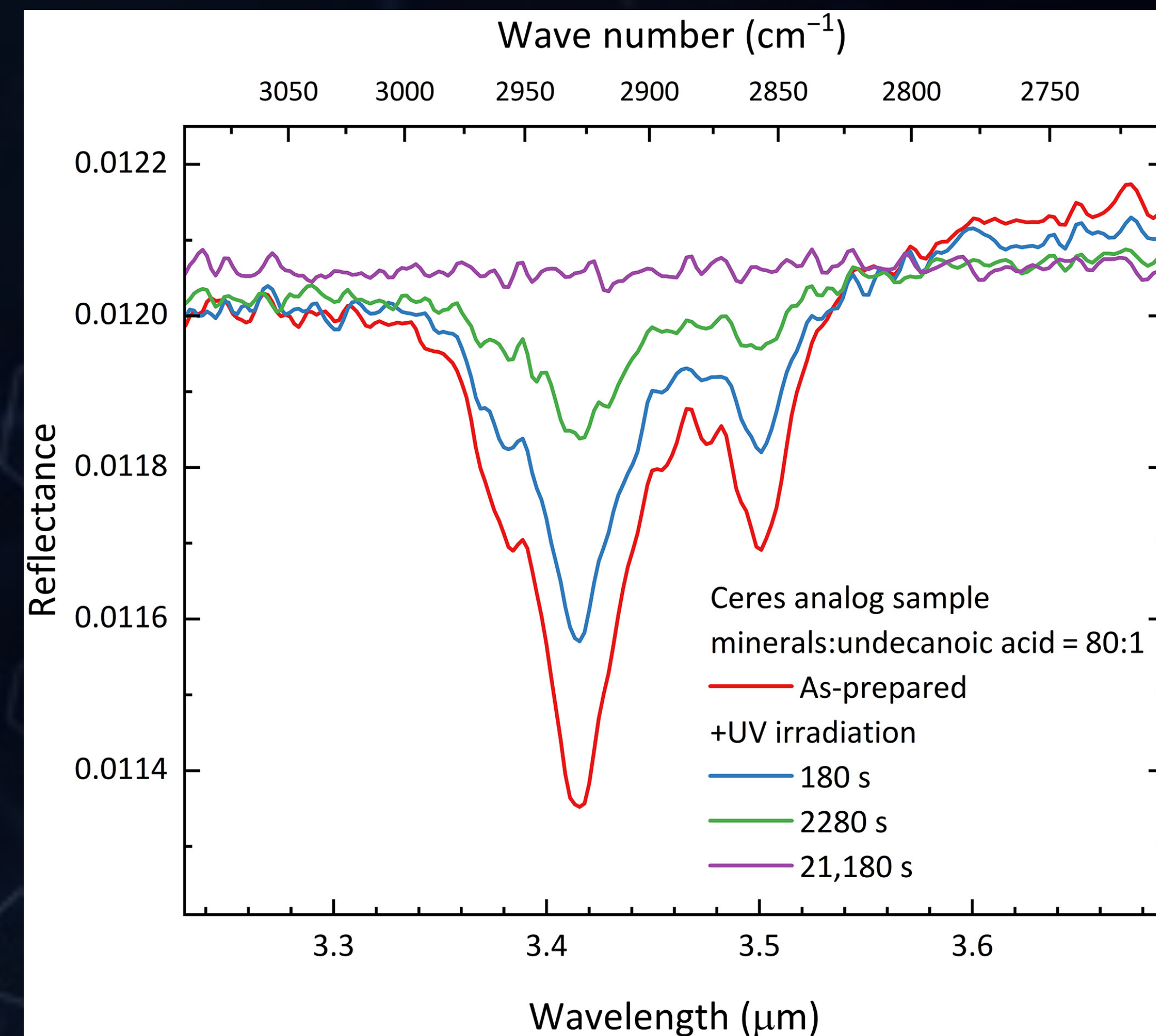




# Ceres: >30% abundance below the irradiated surface?



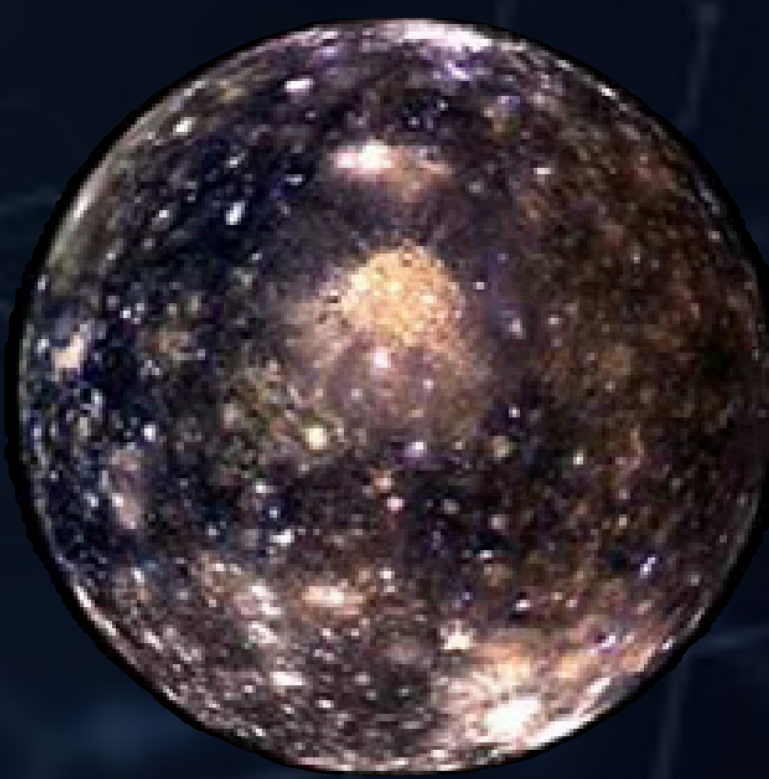
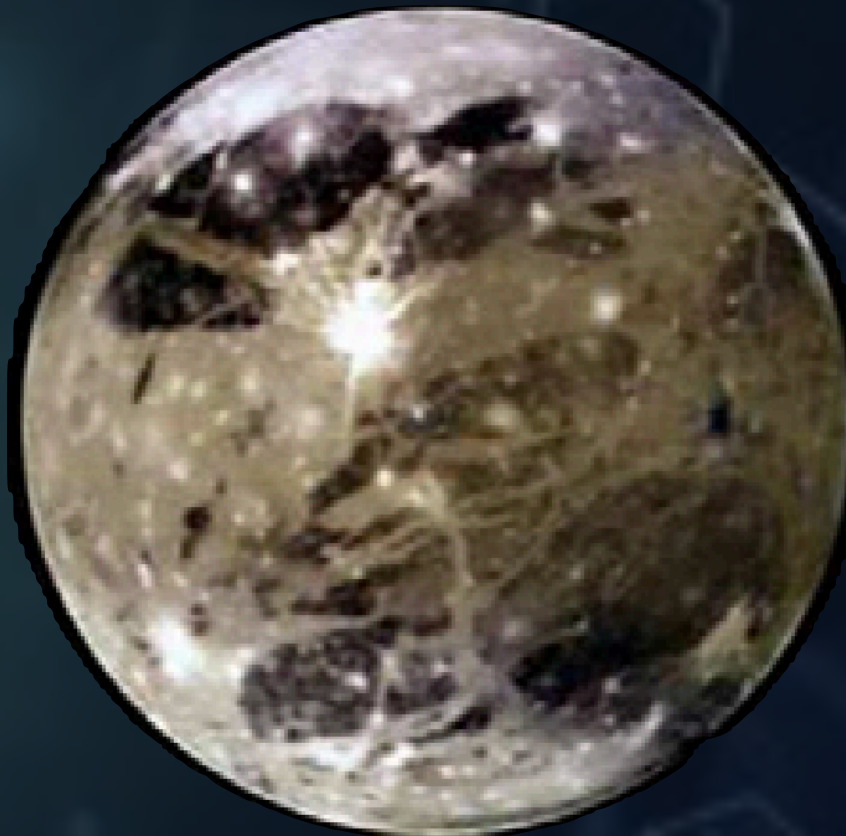
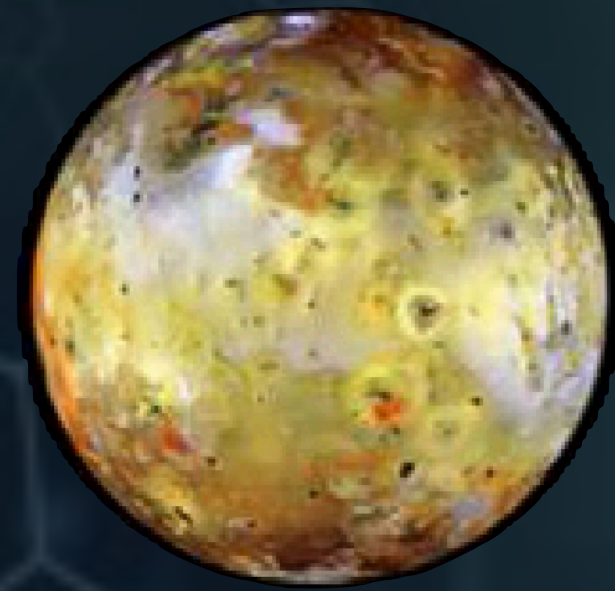
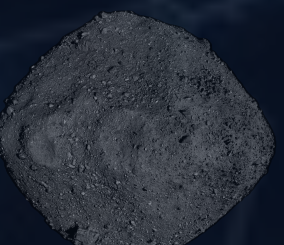
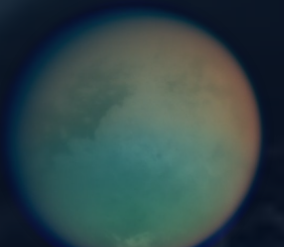
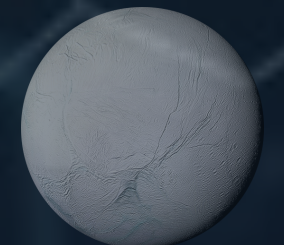
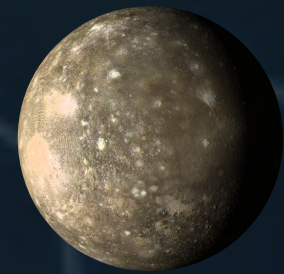
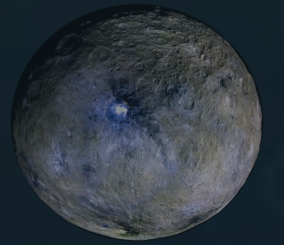
De Sanctis et al. (2024)





# Infalls: the 'black rain'

Galilean moons



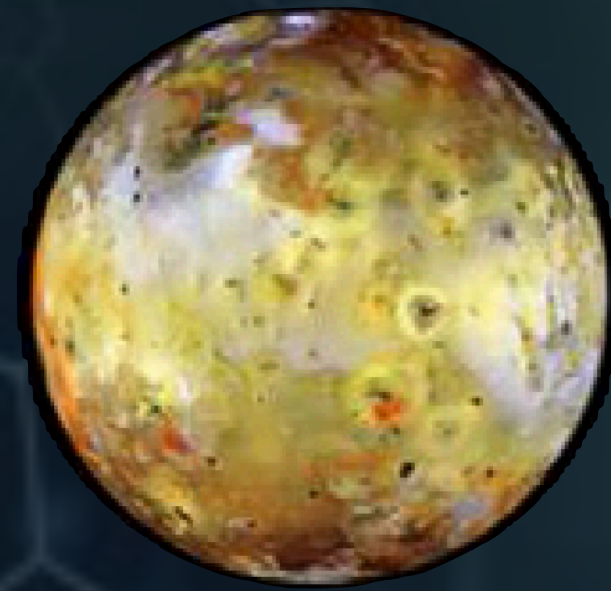
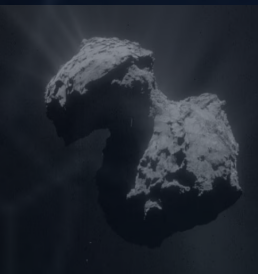
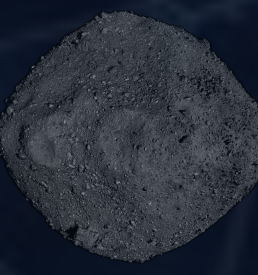
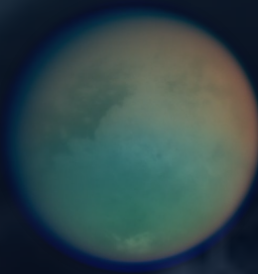
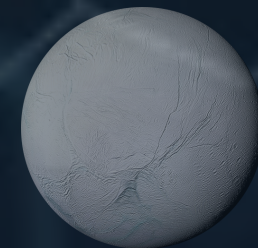
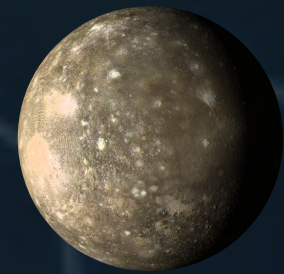
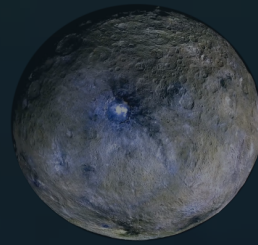
*Clipper*

Bottke et al. (2013, Icarus)

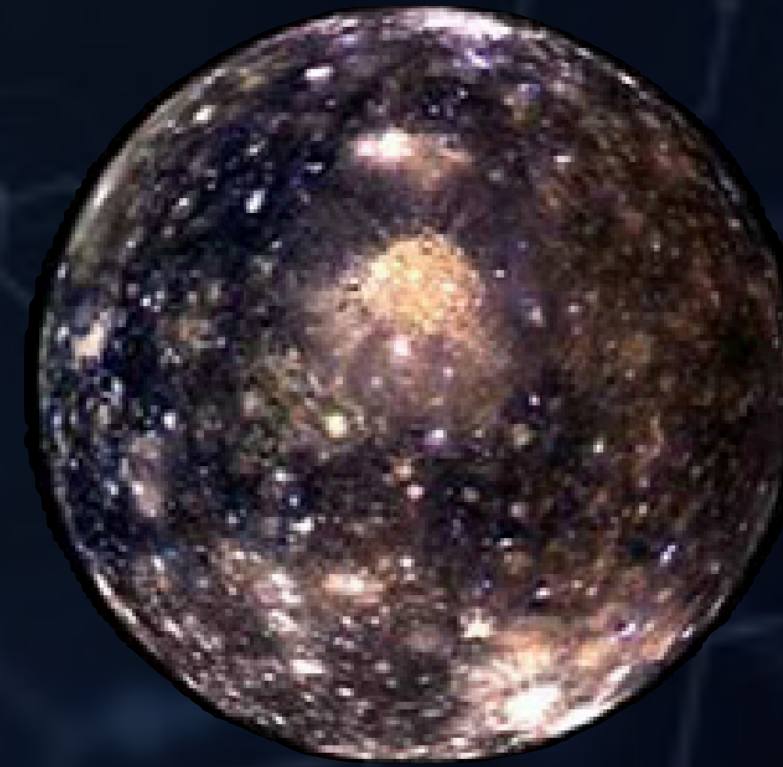


**Infalls: the 'black rain'**

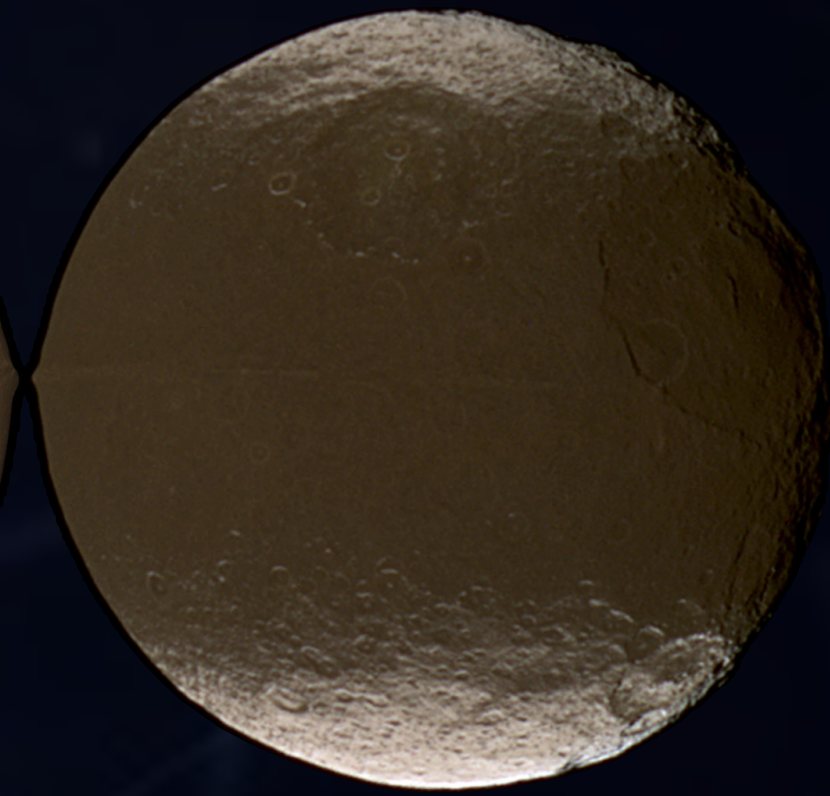
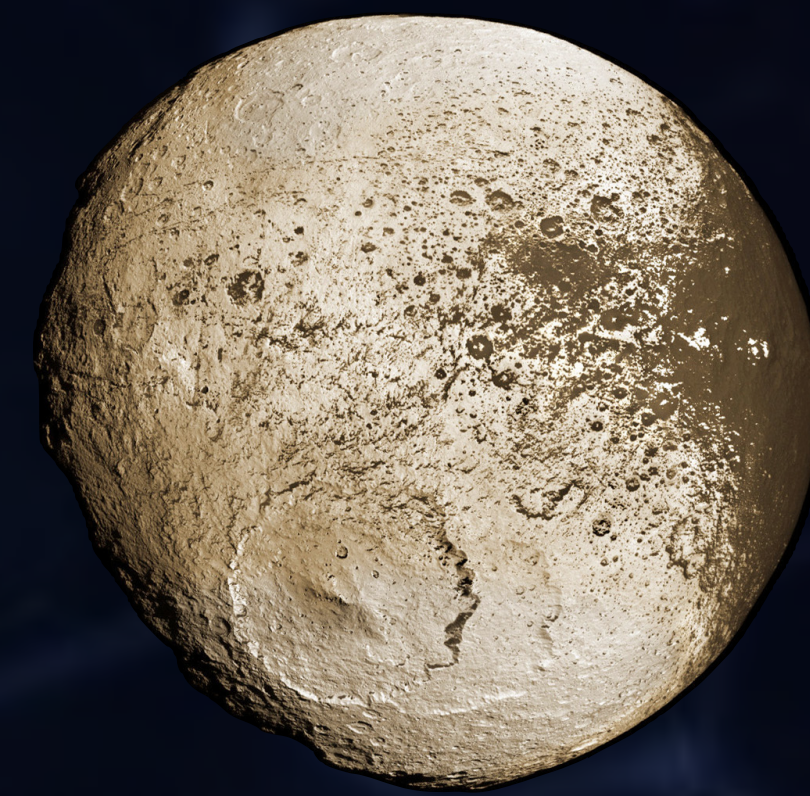
Galilean moons



*Clipper*



Bottke et al. (2013, Icarus)

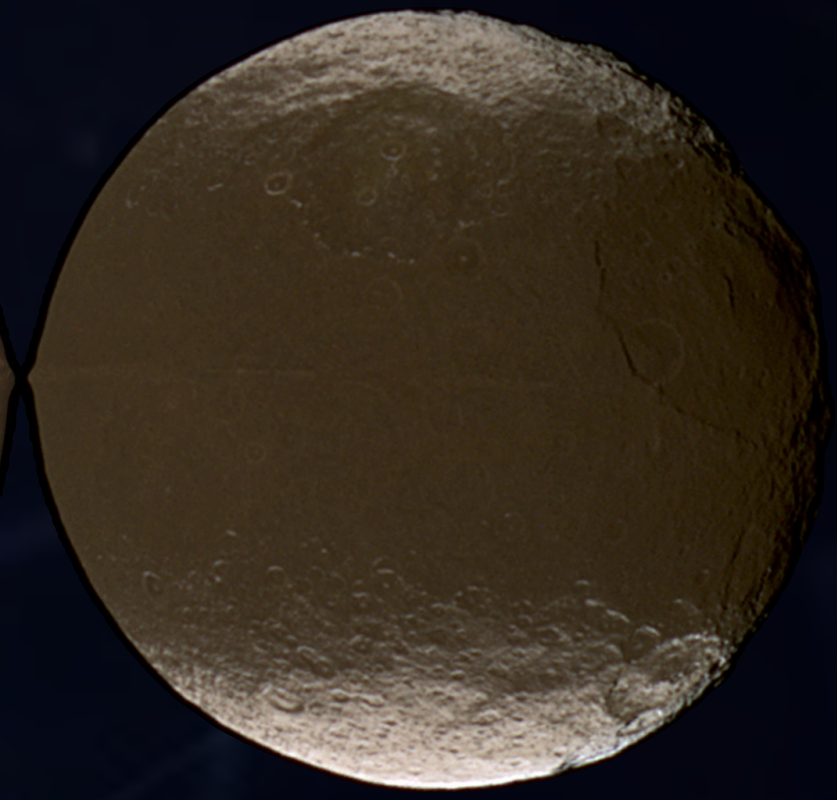
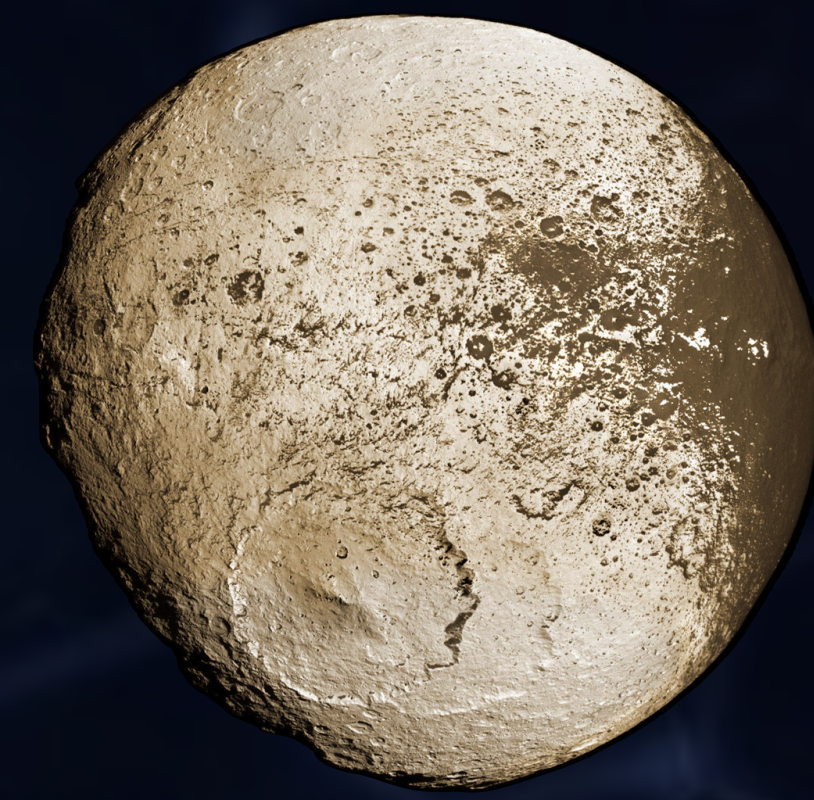
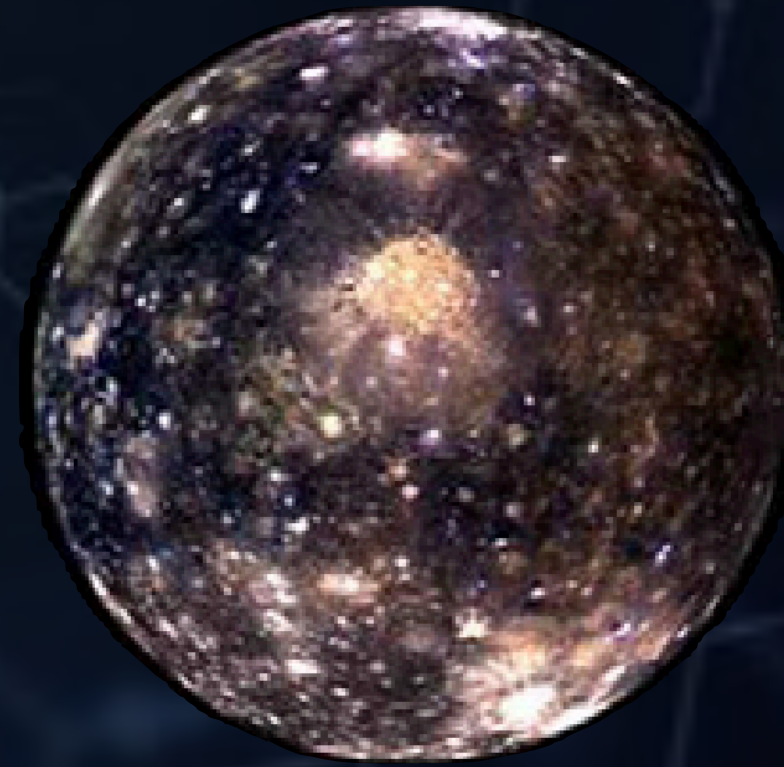
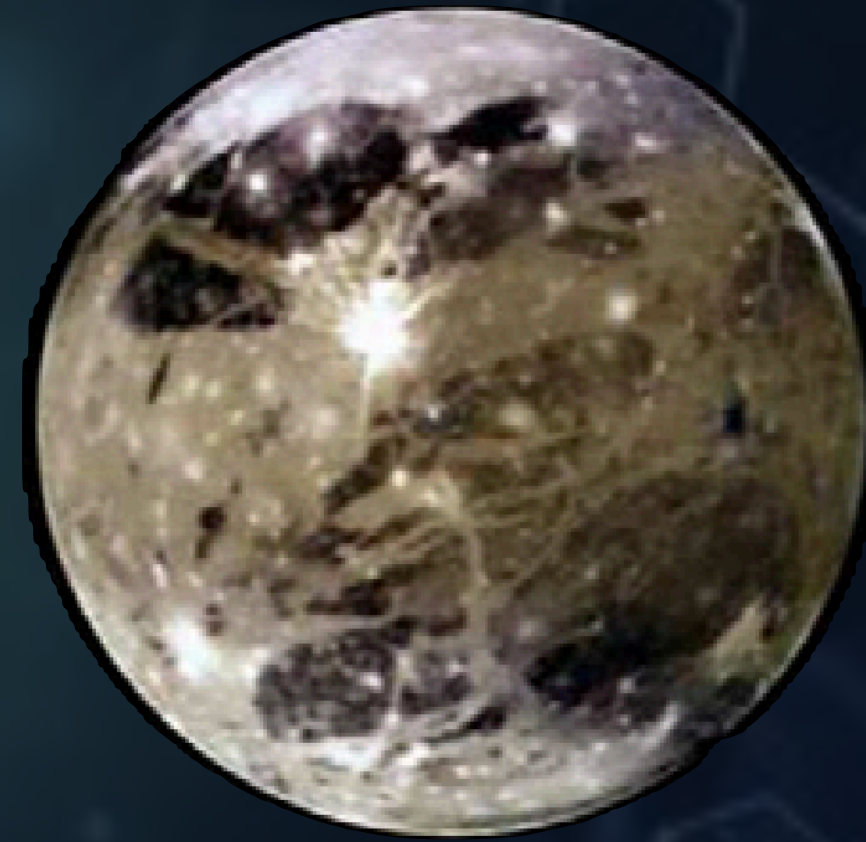
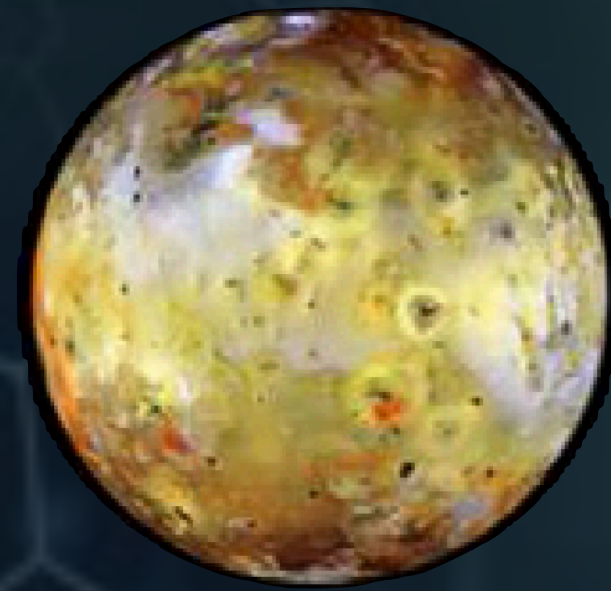
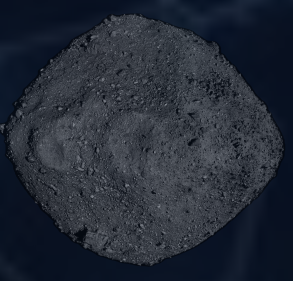
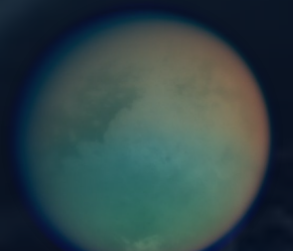
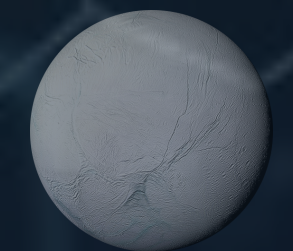
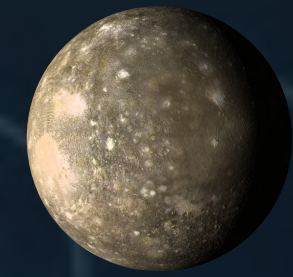
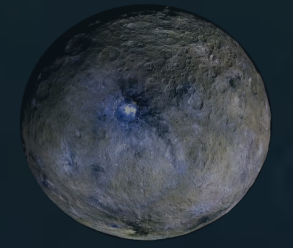
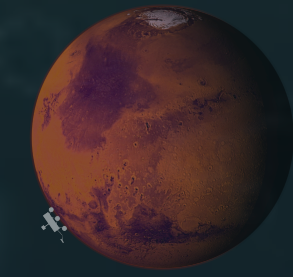


Phoebe dust on Iapetus



# Infalls: the 'black rain'

## Galilean moons



Phoebe dust on Iapetus

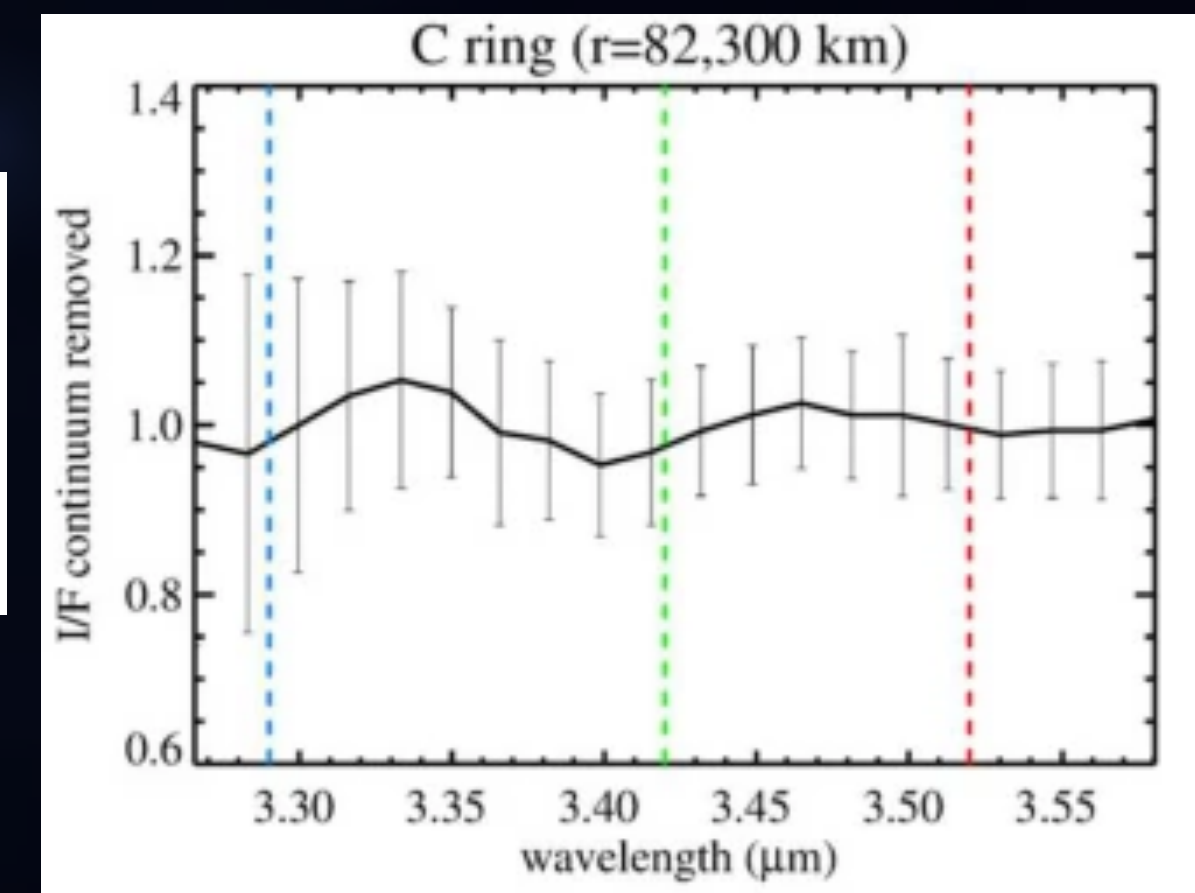
*Clipper*

Bottke et al. (2013, Icarus)

## Saturn rings



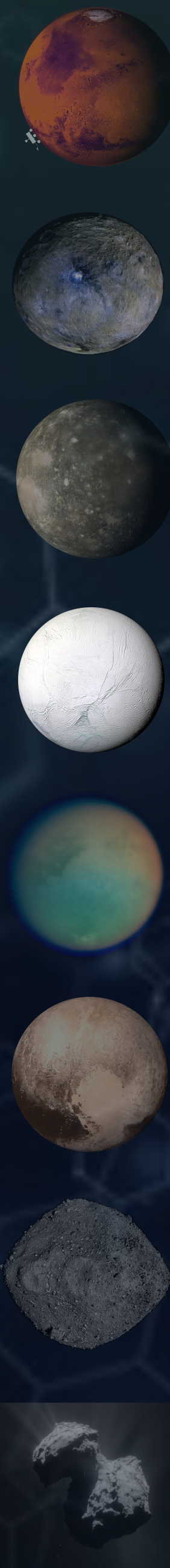
Crida et al. (2025, SSR) and refs therein





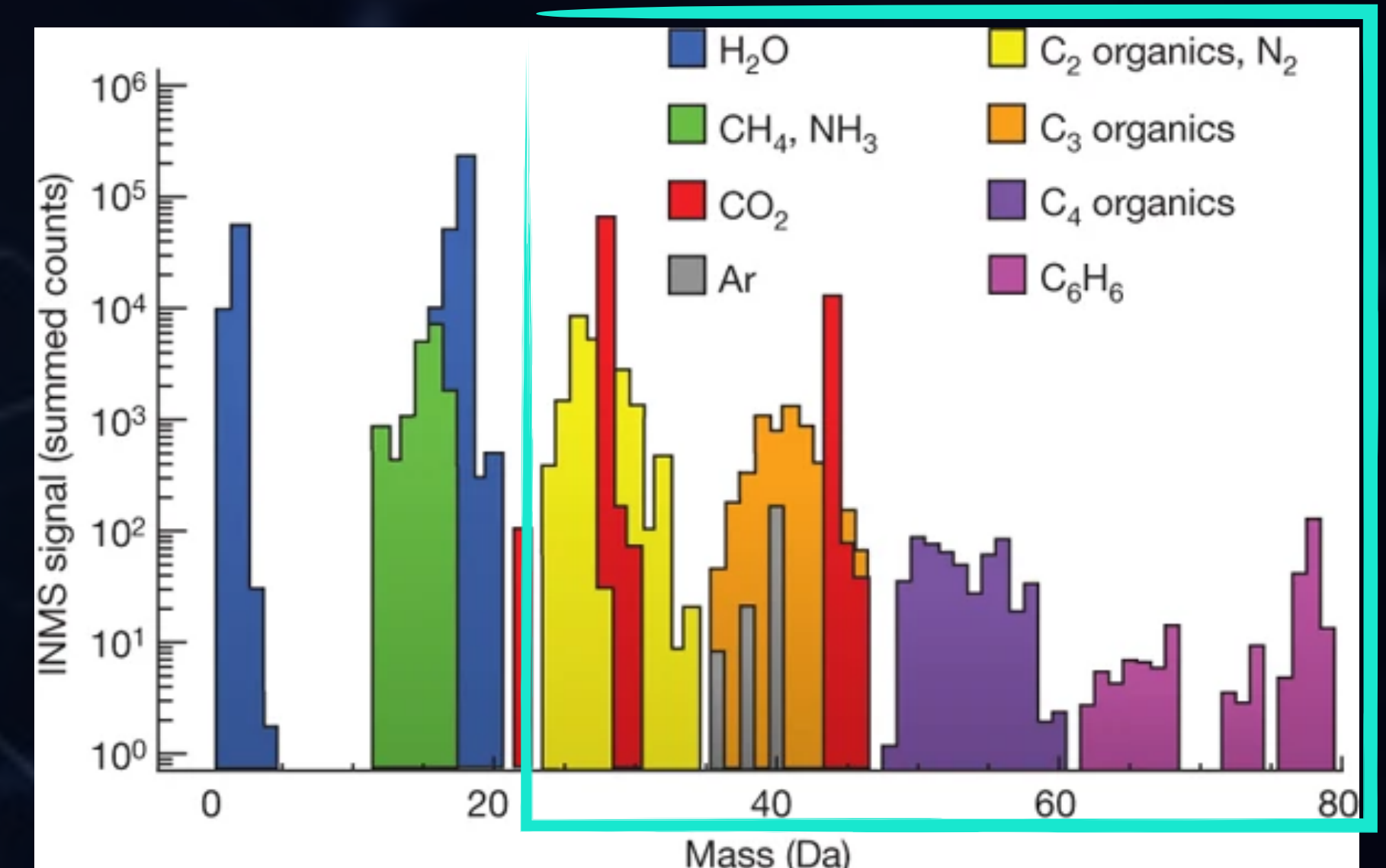






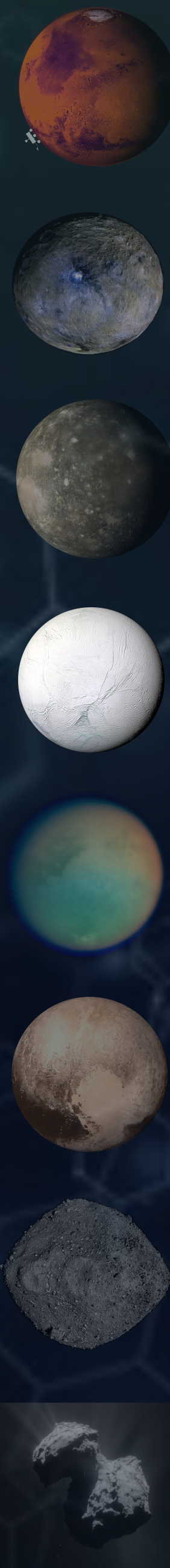
# Enceladus

< 100 amu



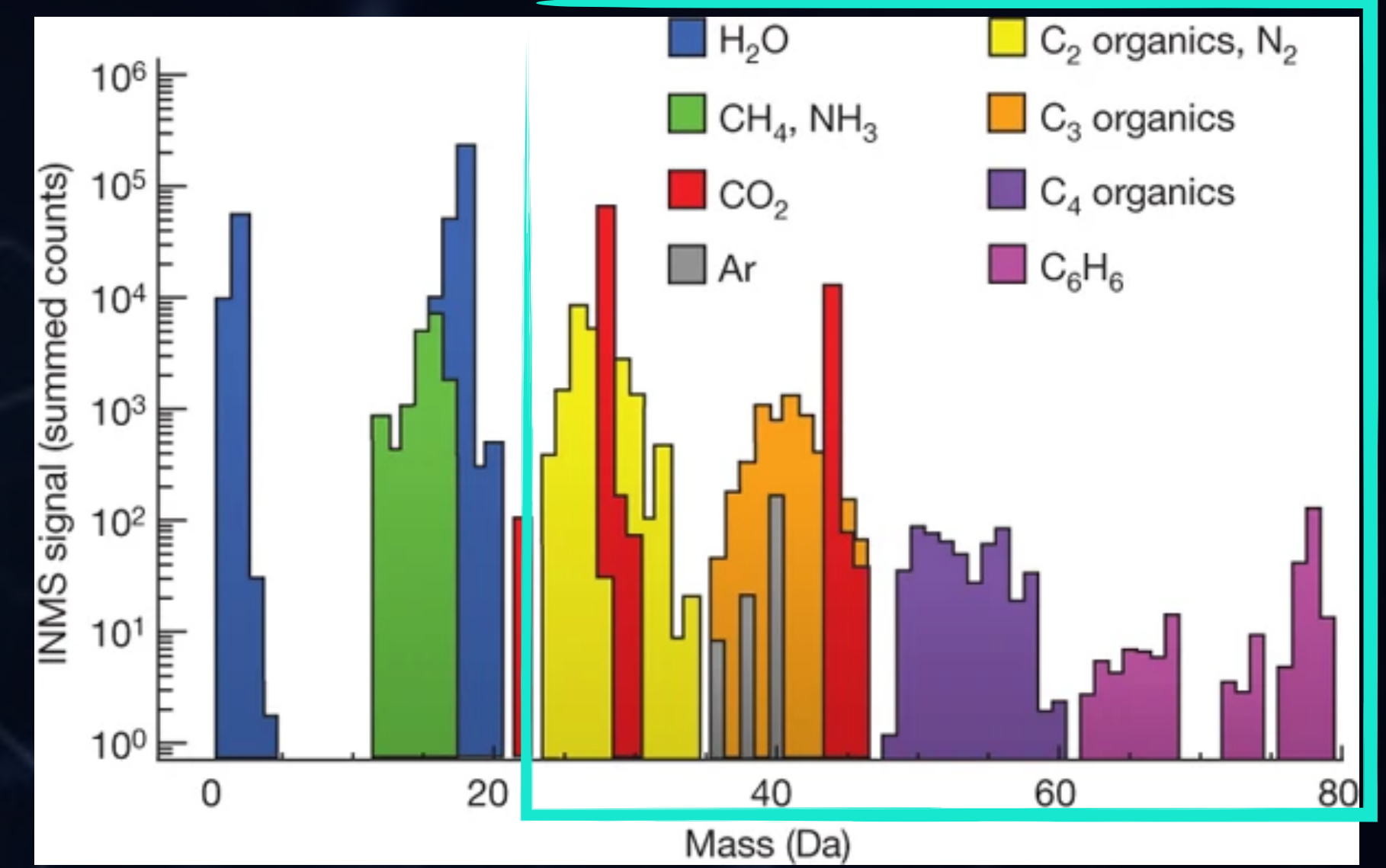
Waite et al. (2009, Science)



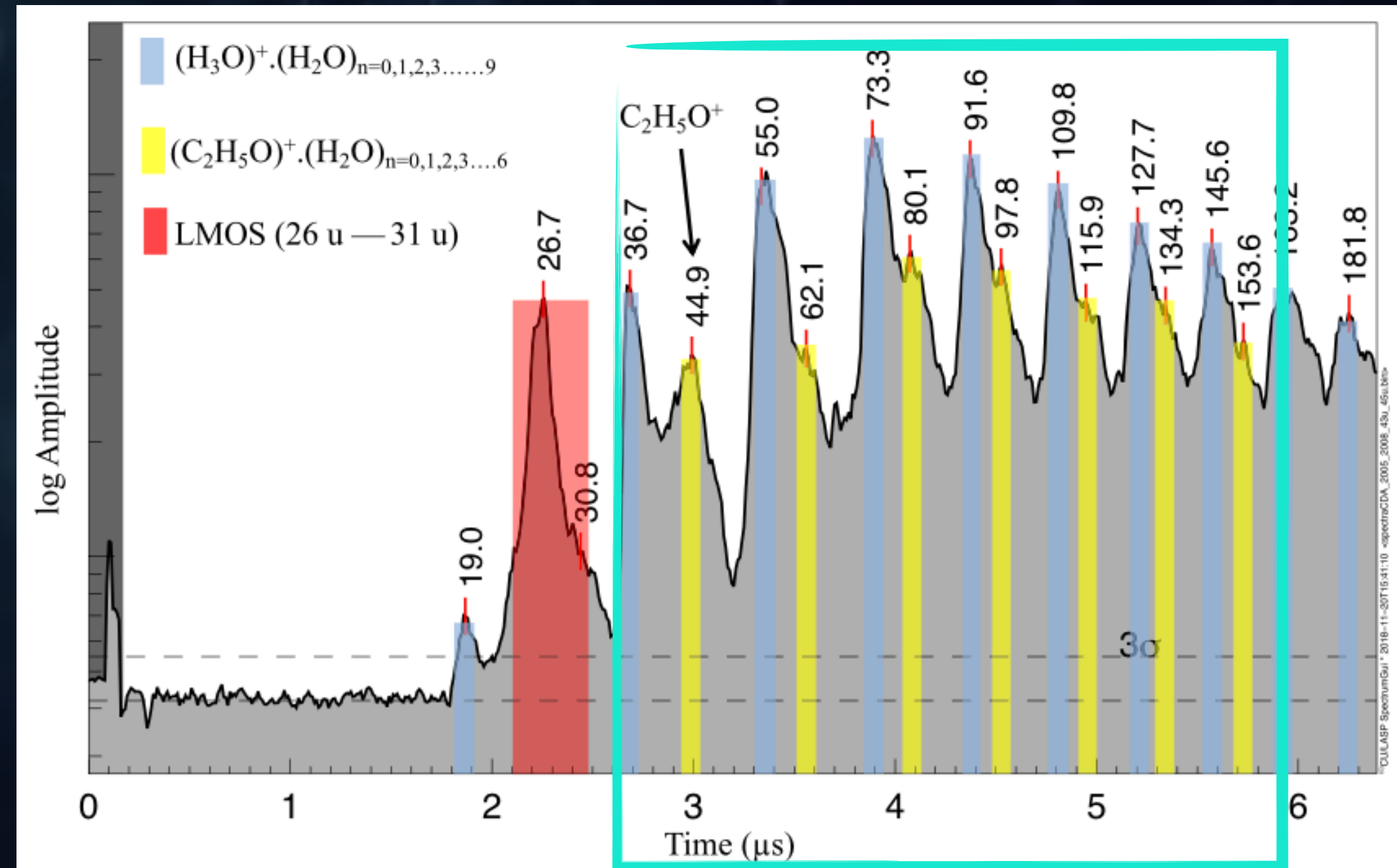


# Enceladus

< 100 amu

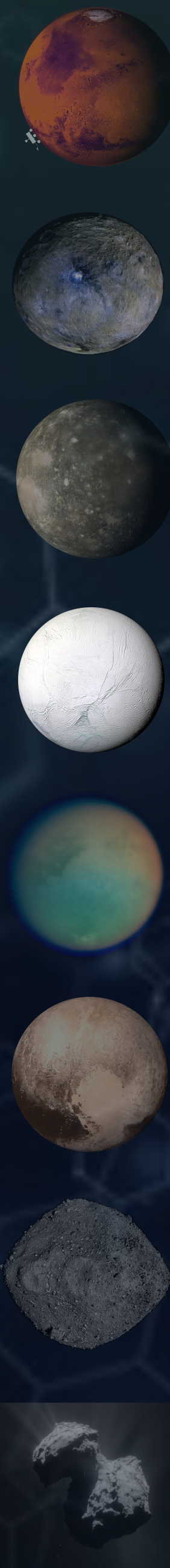


Waite et al. (2009, Science)



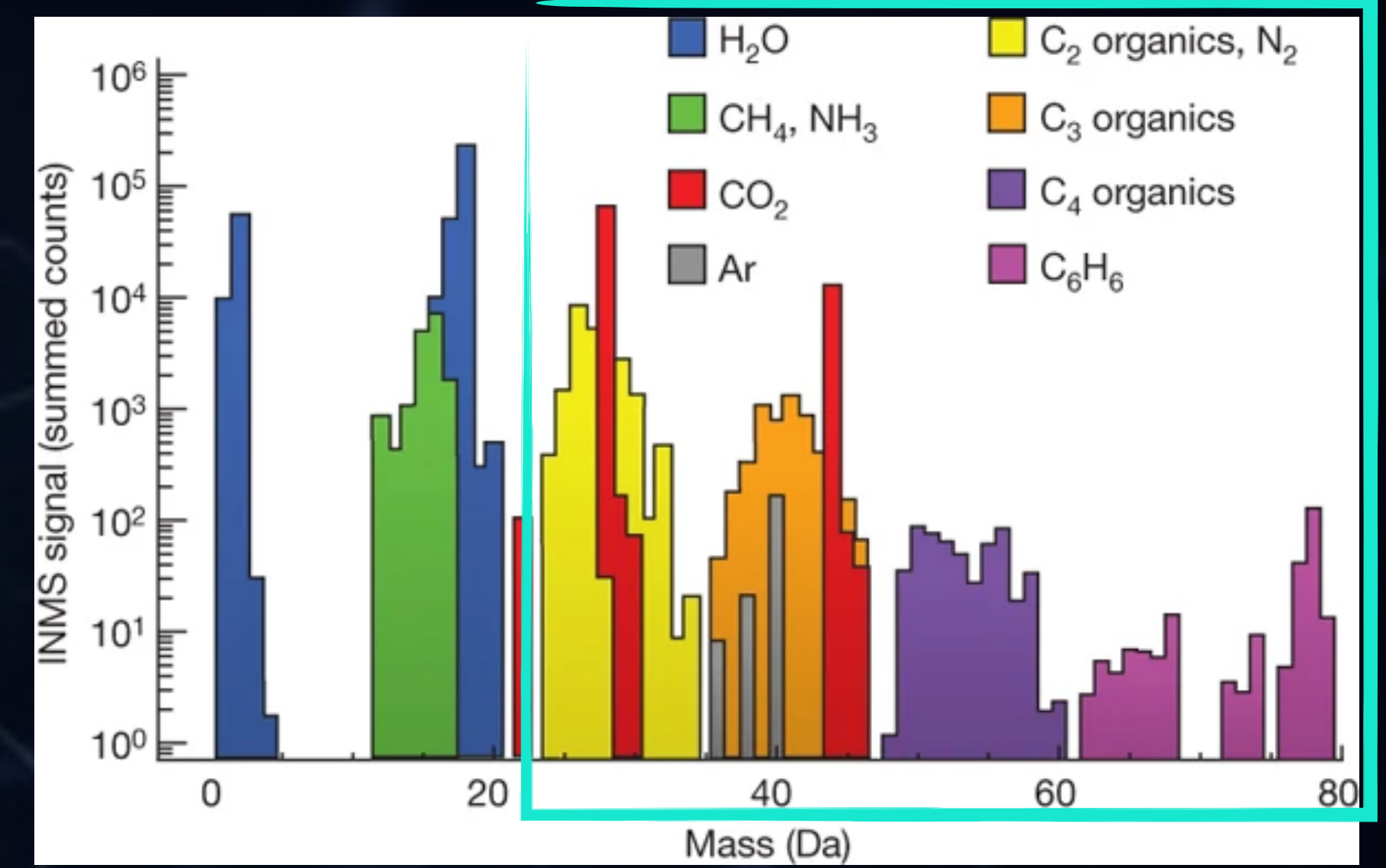
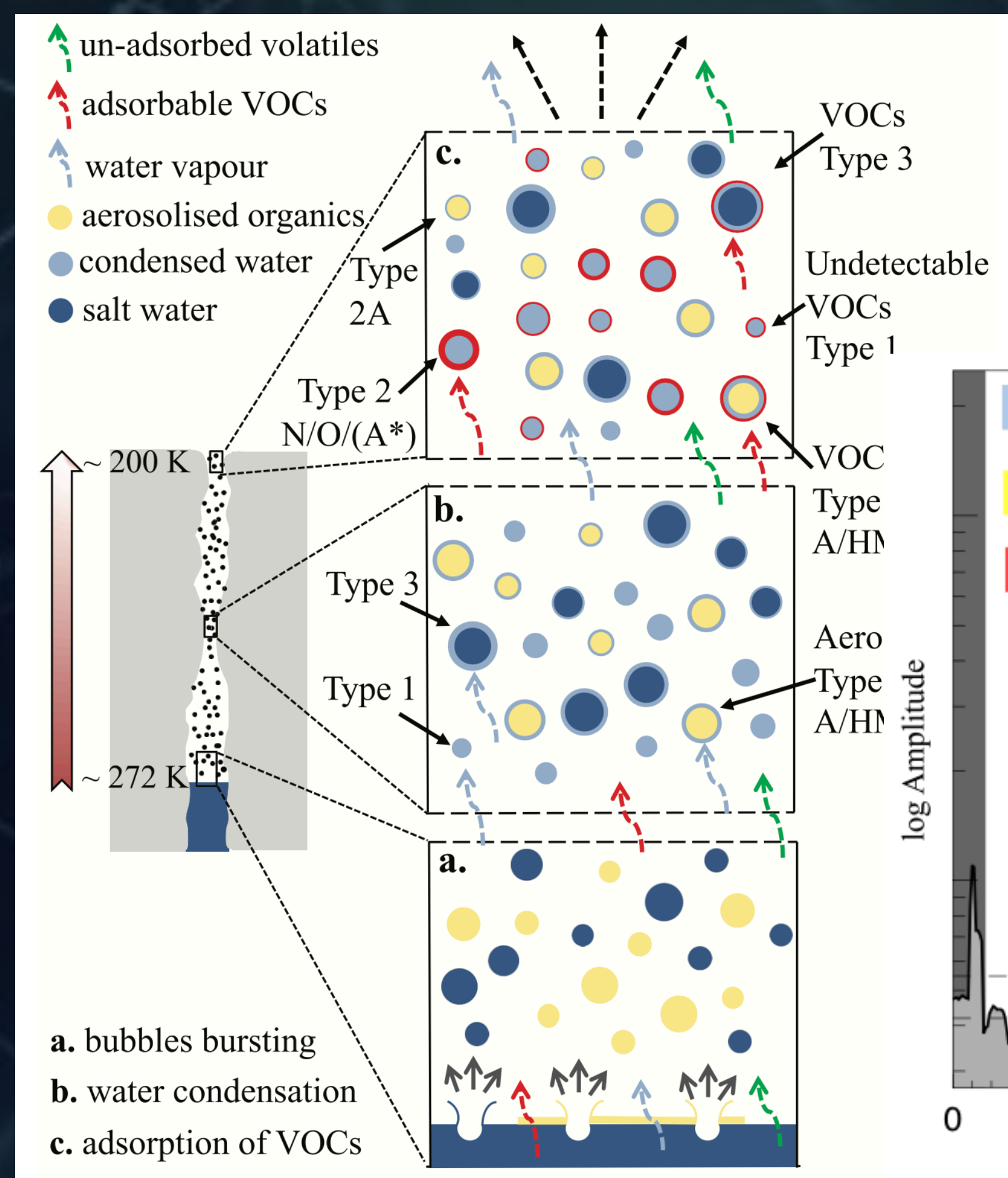
Khawaja et al. (2019, MNRAS)



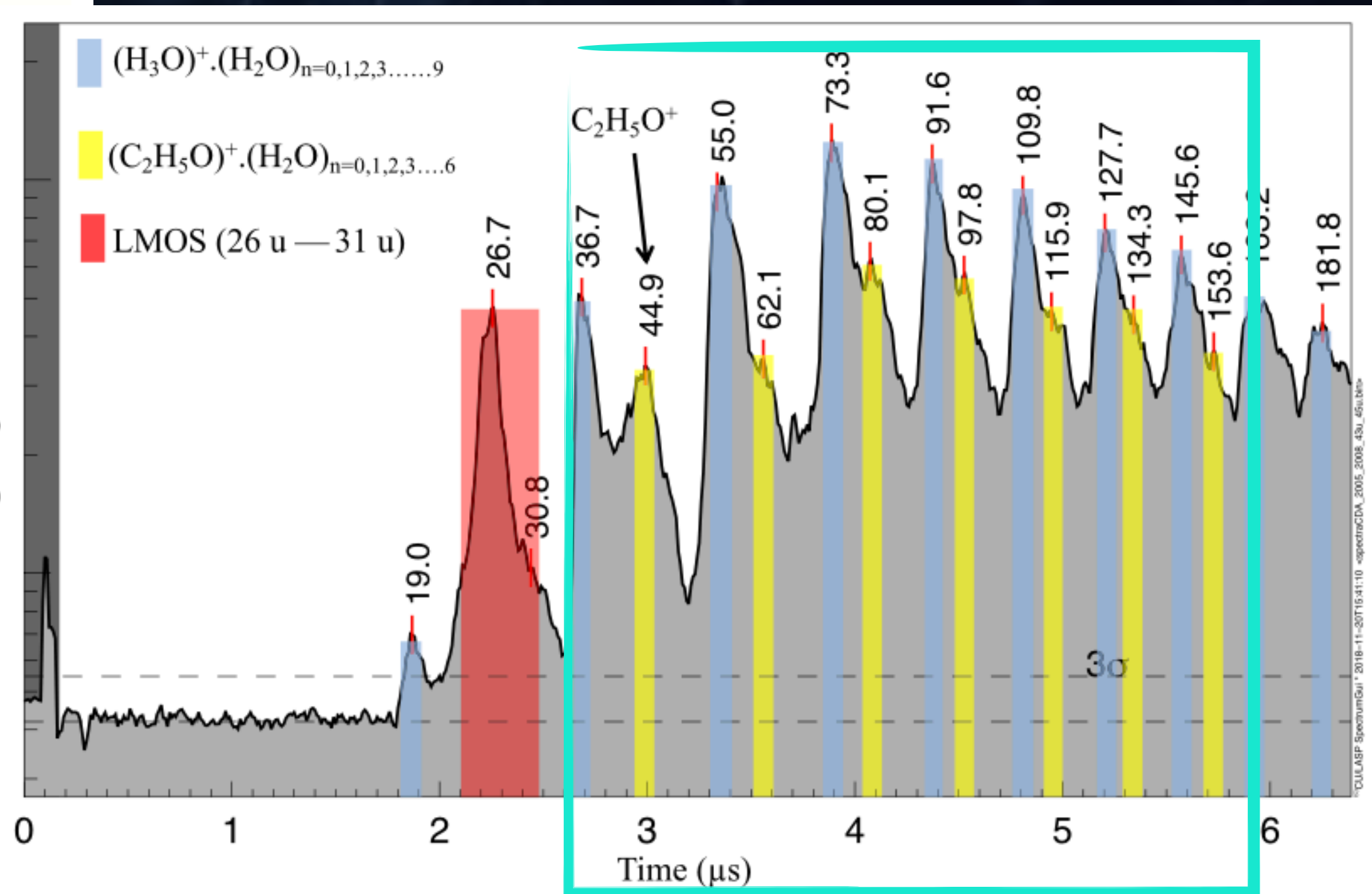


# Enceladus

< 100 amu

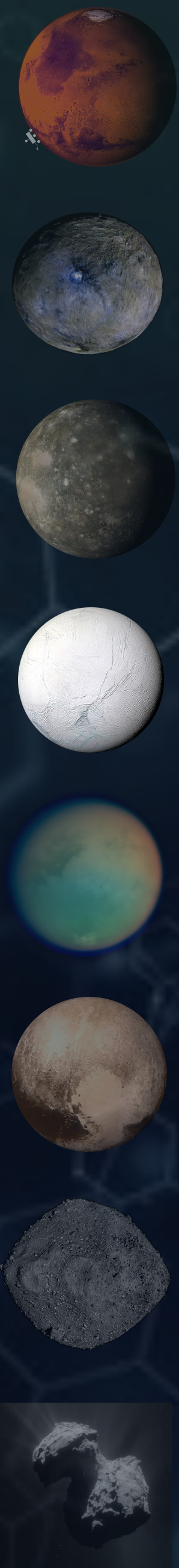


Waite et al. (2009, Science)



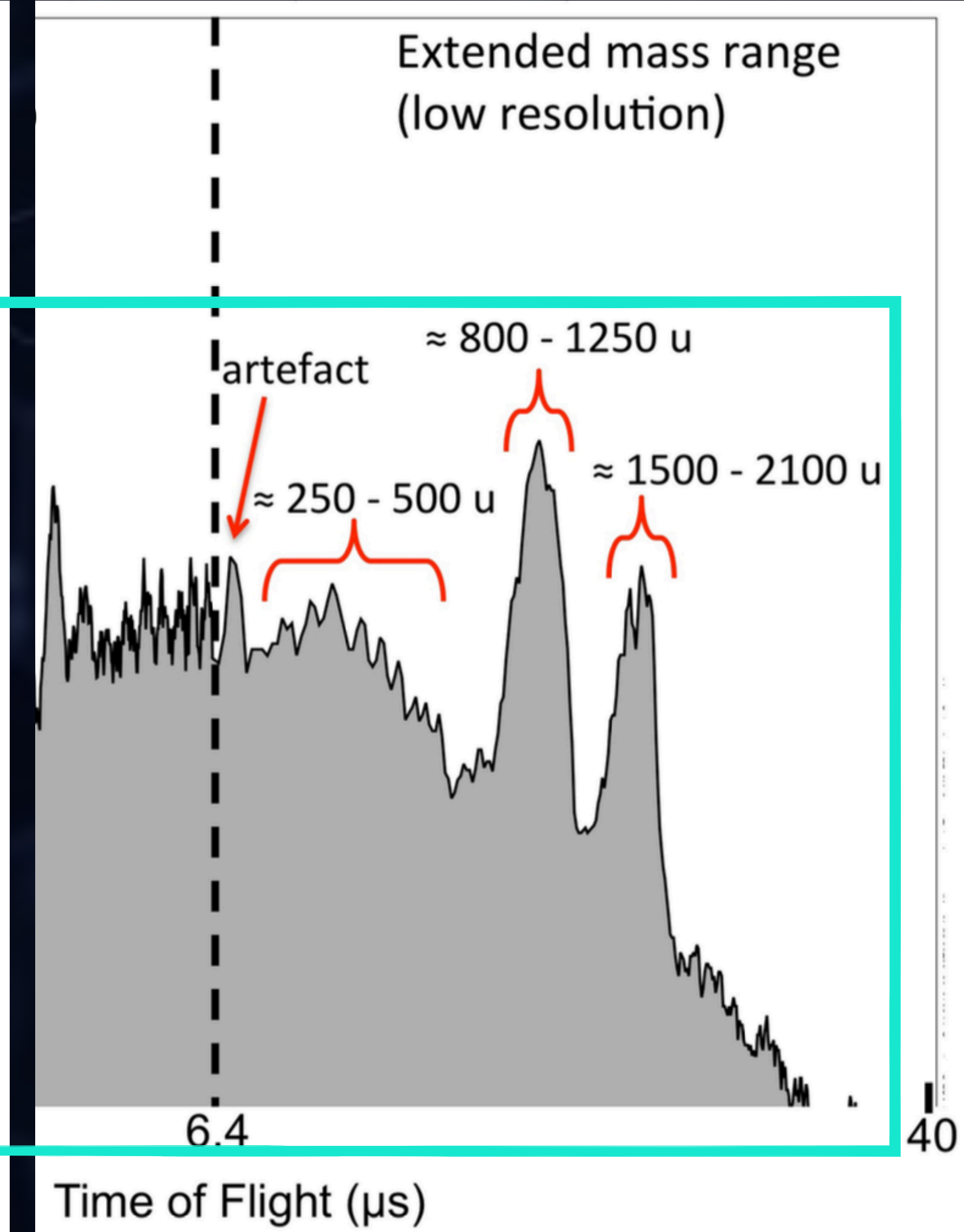
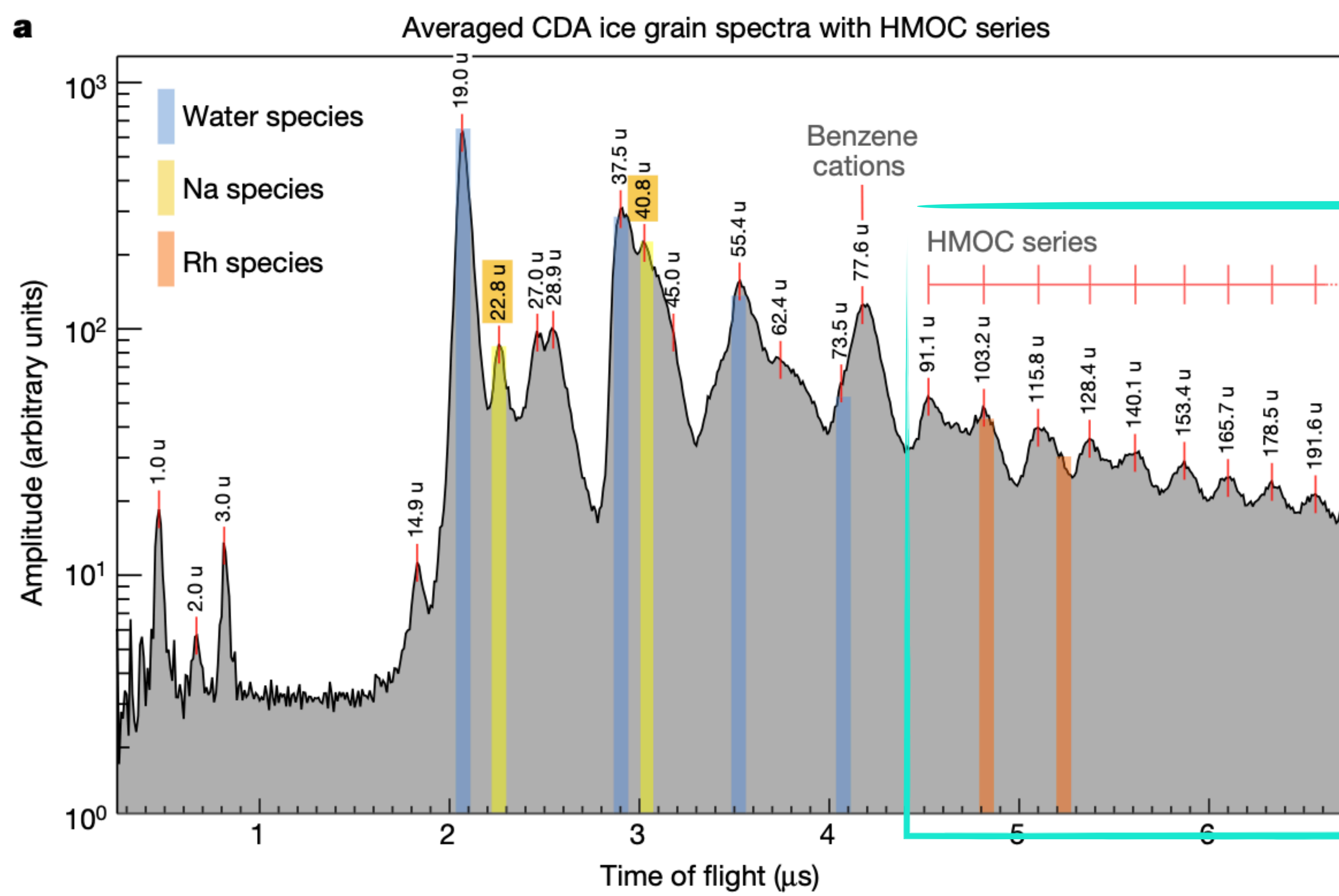
Khawaja et al. (2019, MNRAS)



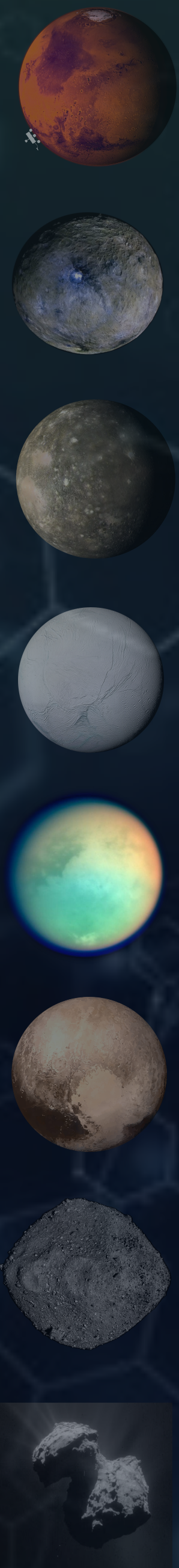


# Enceladus

> 100 amu

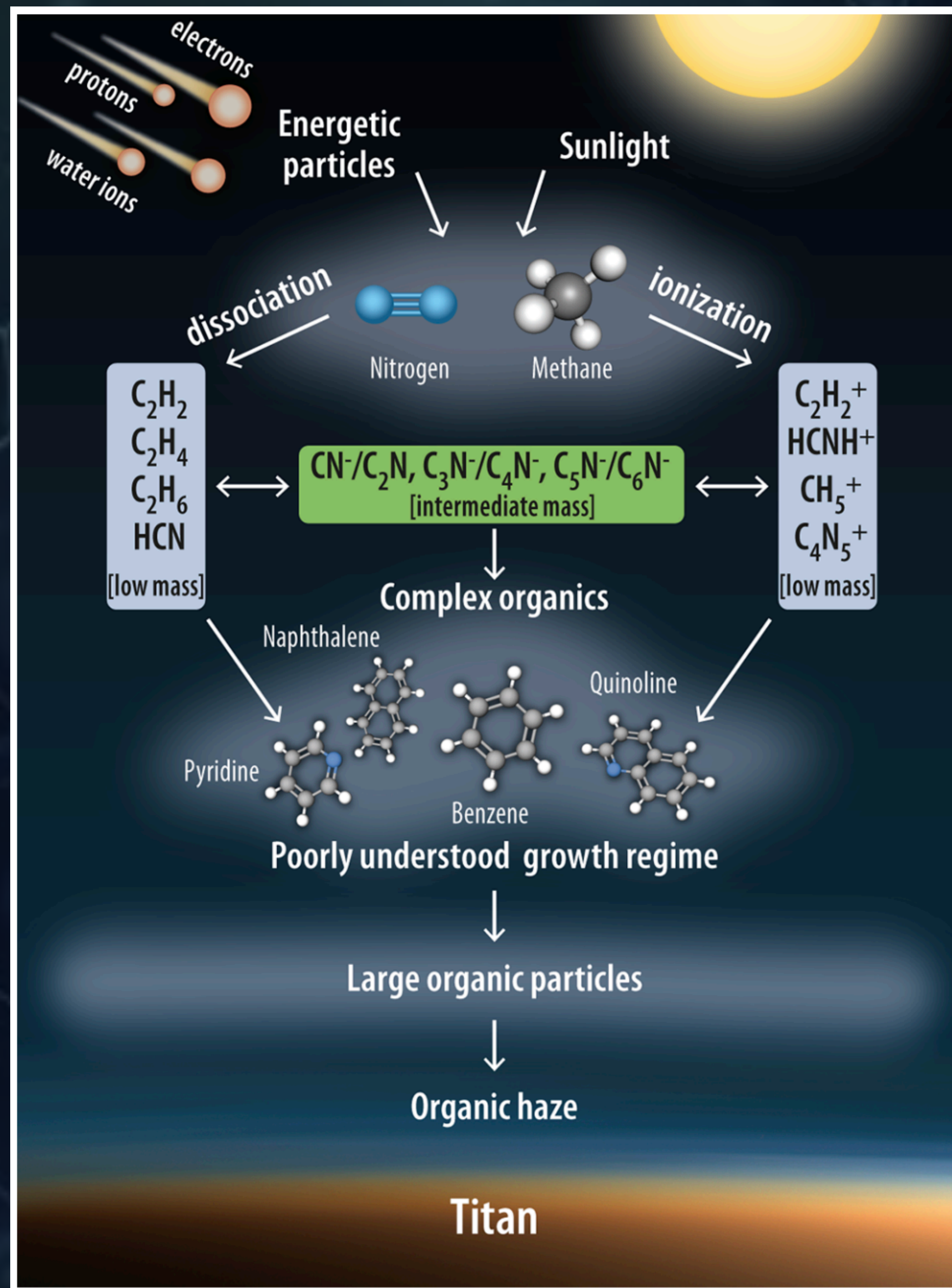






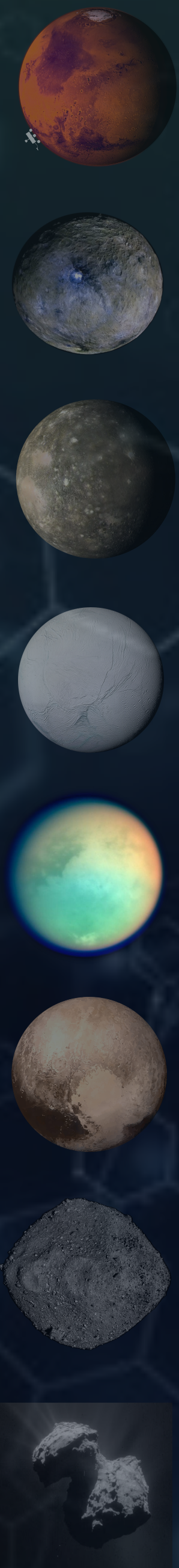
# Titan (& Triton, Pluto): atmospheric photochemistry

*Cassini,  
ALMA*



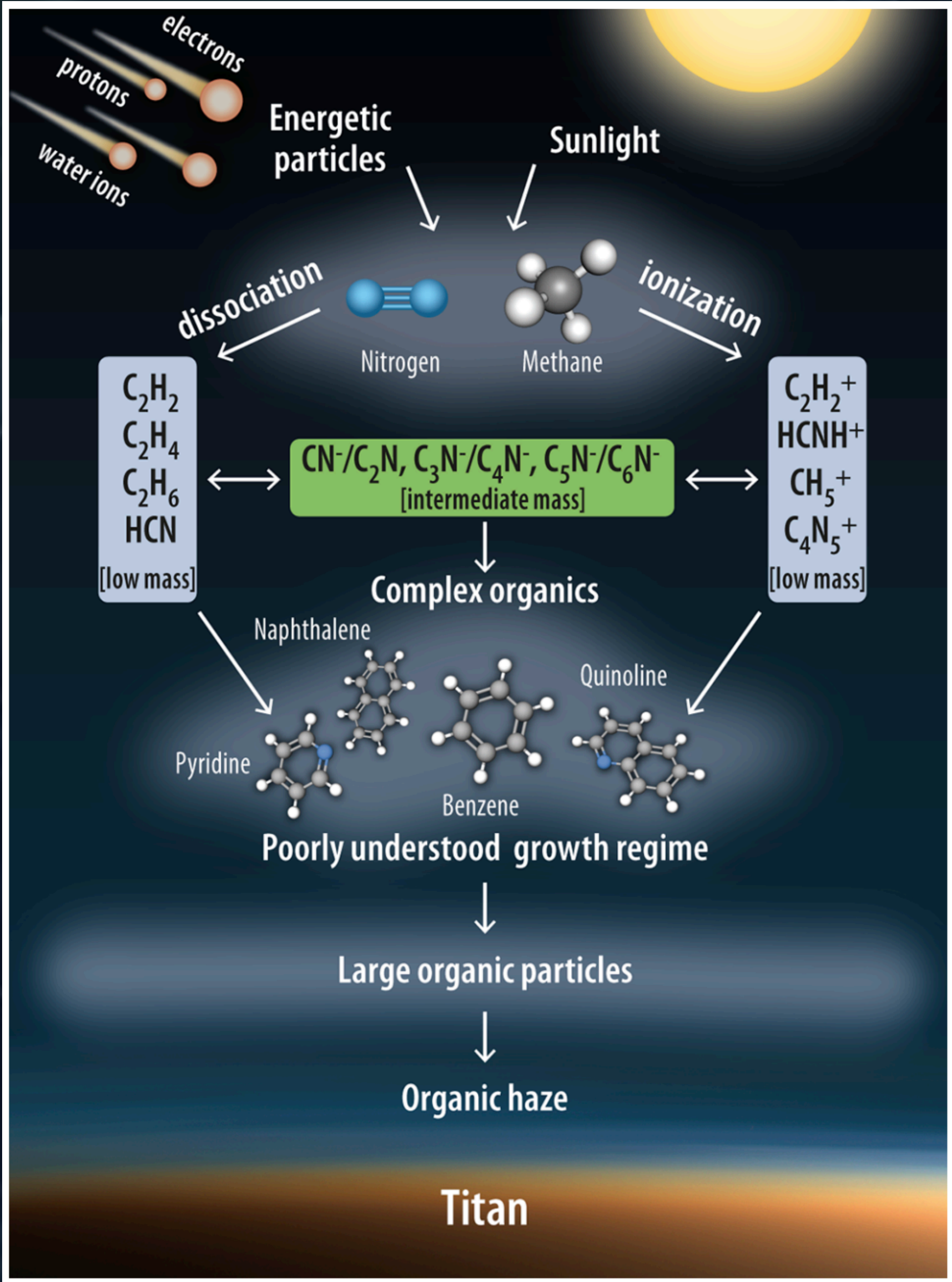
Nixon (2024, ACS Earth & Space Chem)



















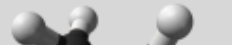
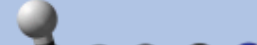








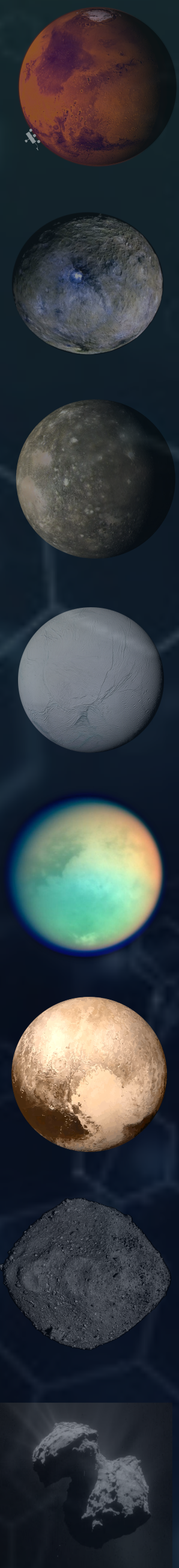
# Titan (& Triton, Pluto): atmospheric photochemistry

Cassini,  
ALMA

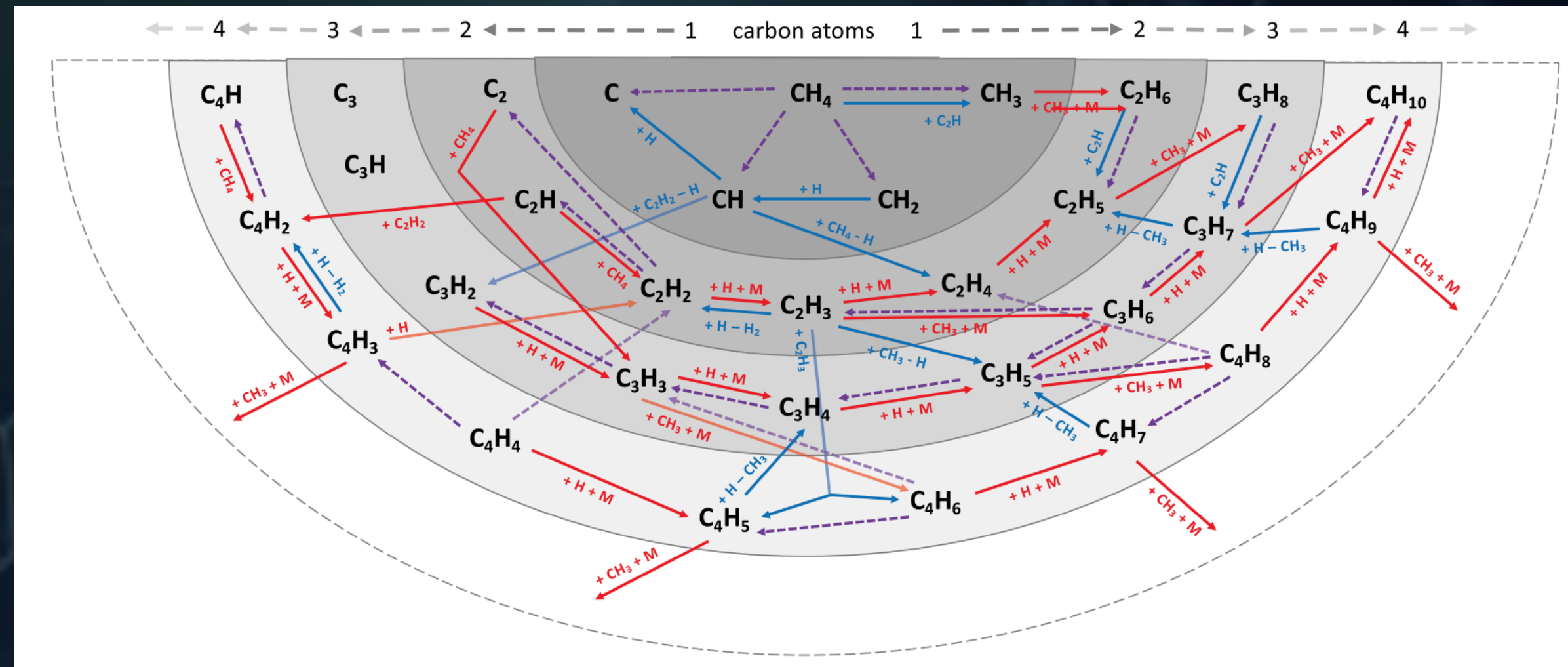


Atoms	Hydrogen and Hydrocarbons		Nitrogen Compounds		Oxygen Compounds	
2	 H <sub>2</sub>		 N <sub>2</sub>		 CO	
3			 HCN	 HNC	 H <sub>2</sub> O	 CO <sub>2</sub>
4	 C <sub>2</sub> H <sub>2</sub>		 C <sub>2</sub> N <sub>2</sub>			
5	 CH <sub>4</sub>	 C <sub>3</sub> H <sub>2</sub>	 HC <sub>3</sub> N			
6	 C <sub>2</sub> H <sub>4</sub>	 C <sub>4</sub> H <sub>2</sub>	 CH <sub>3</sub> CN			
7	 CH <sub>3</sub> CCH	 CH <sub>2</sub> CCH <sub>2</sub>	 C <sub>2</sub> H <sub>3</sub> CN			
8	 C <sub>2</sub> H <sub>6</sub>		 C <sub>3</sub> H <sub>3</sub> CN			
9	 C <sub>3</sub> H <sub>6</sub>		 C <sub>2</sub> H <sub>5</sub> CN			
10+	 C <sub>3</sub> H <sub>8</sub>	 C <sub>6</sub> H <sub>6</sub>				





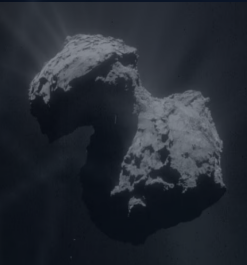

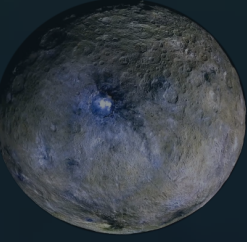
# Titan (& Triton, Pluto): atmosphere to surface



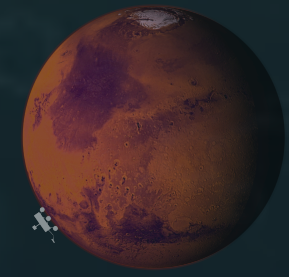
Nixon (2024, ACS Earth & Space Chem)

Gaps: C5+ hydrocarbons, N without triple bond, N+O compounds incl. amino acids, O beyond H<sub>2</sub>O/CO/CO<sub>2</sub>

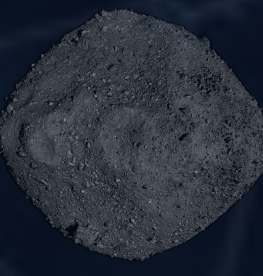
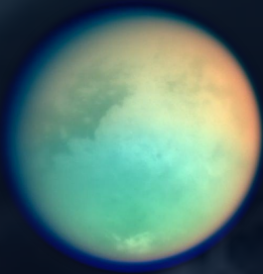
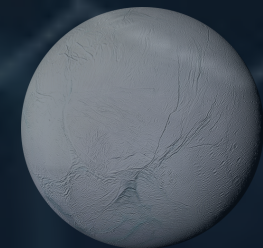
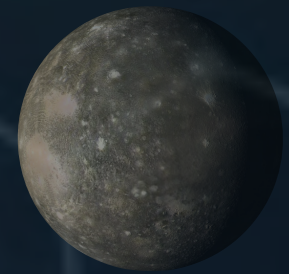
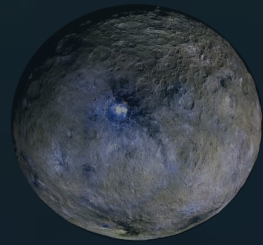






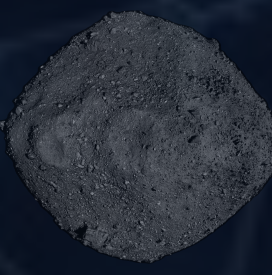
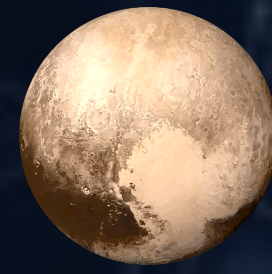
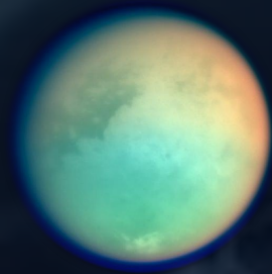
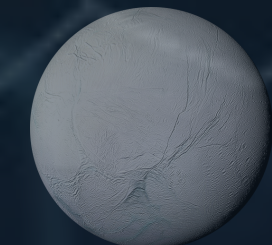
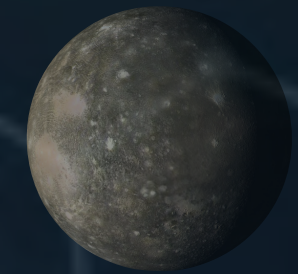
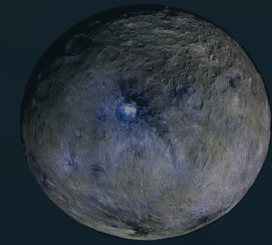
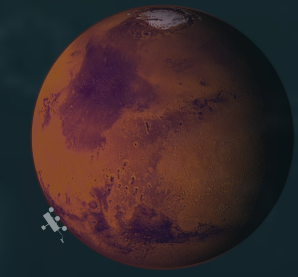


## Titan (and Triton, Pluto): surface



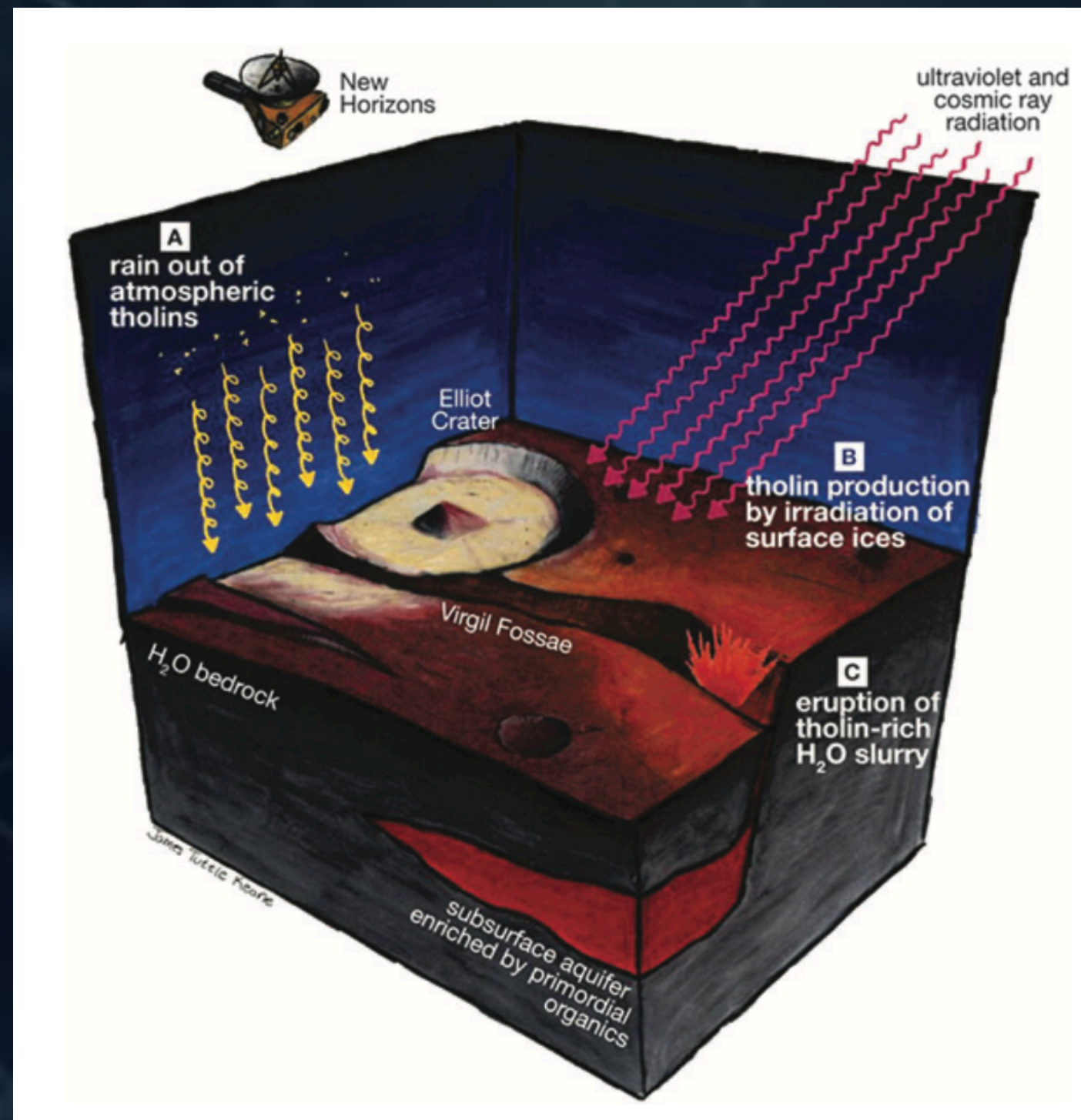
- Photochemical atmospheric fallout
- Photo-/radio-chemical reactions in ices
- Endogenic upwelling
- Impact heat polymerization of simpler compounds





# Titan (and Triton, Pluto): surface

- Photochemical atmospheric fallout
- Photo-/radio-chemical reactions in ices
- Endogenic upwelling
- Impact heat polymerization of simpler compounds

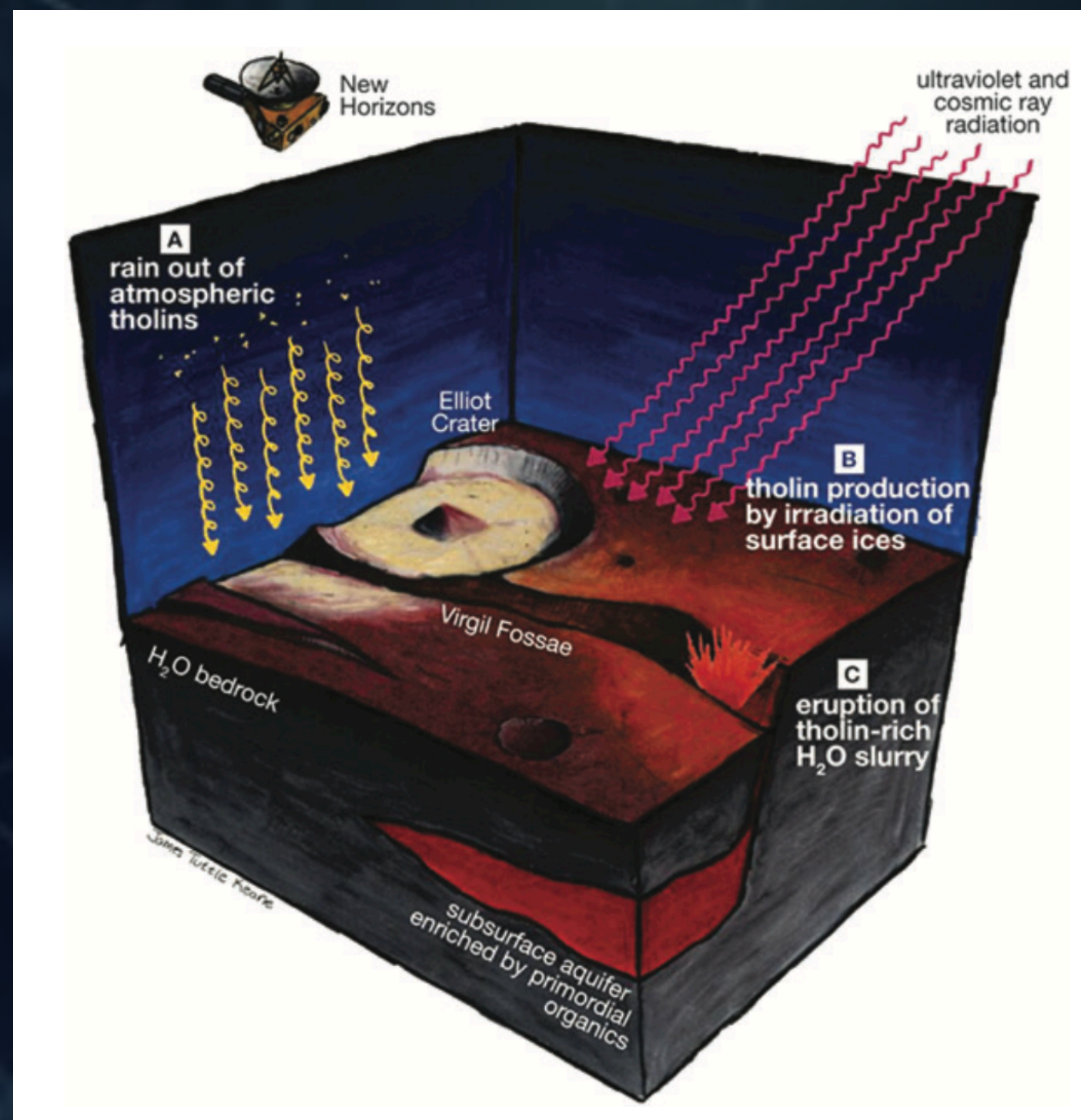


Cruikshank et al. (2019, Astrobiology)  
Lunine & Hörst (2011, Rendiconti Lincei)

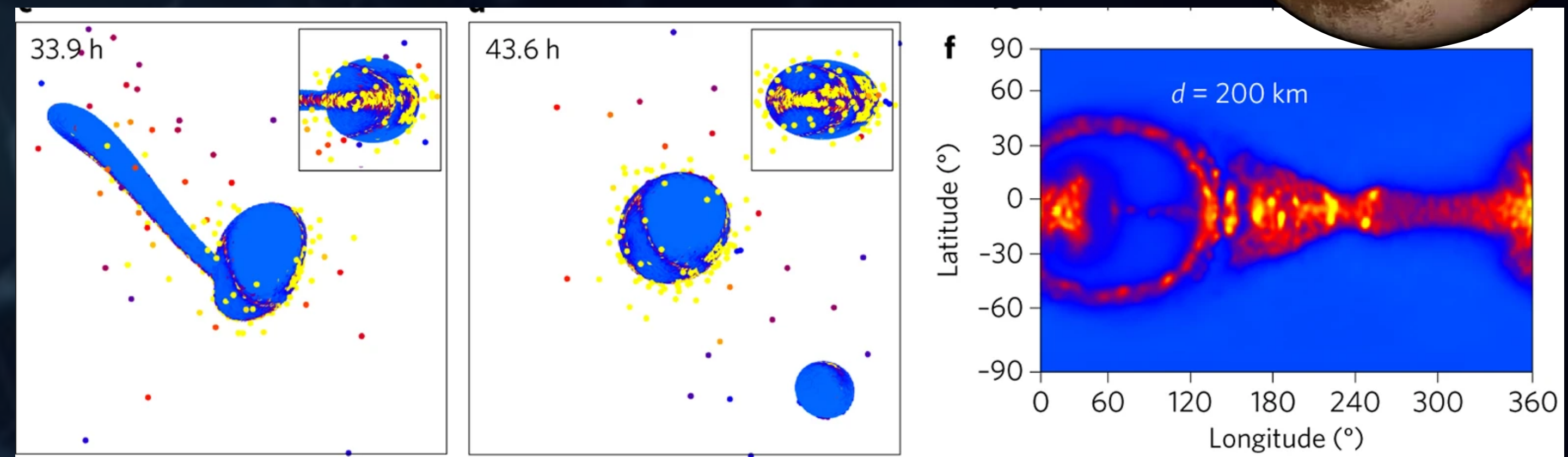


# Titan (and Triton, Pluto): surface

- Photochemical atmospheric fallout
- Photo-/radio-chemical reactions in ices
- Endogenic upwelling
- Impact heat polymerization of simpler compounds

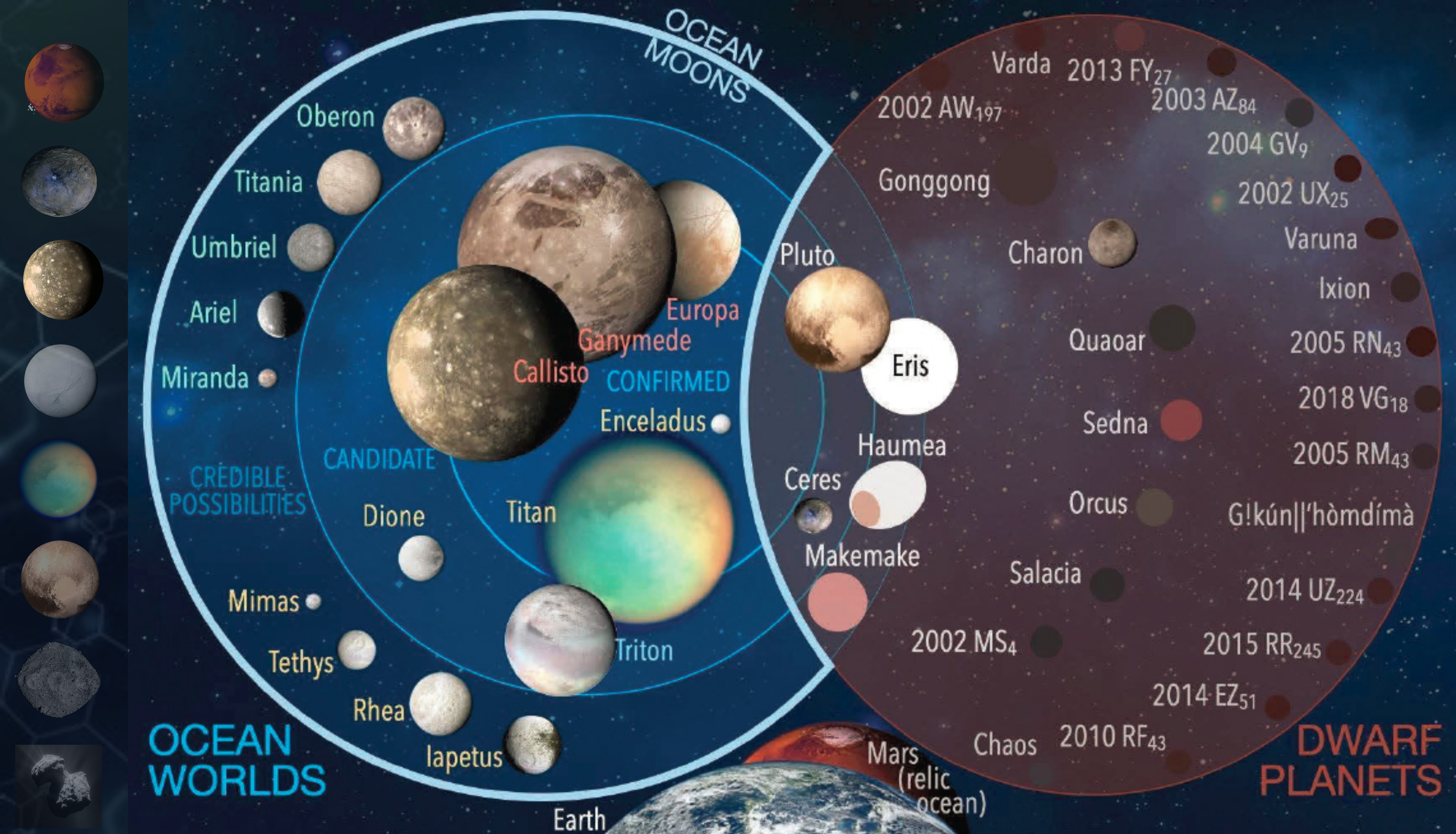


Cruikshank et al. (2019, Astrobiology)  
Lunine & Hörst (2011, Rendiconti Lincei)



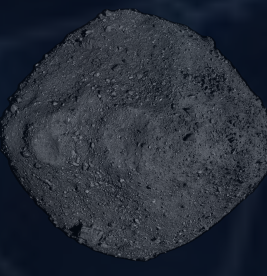
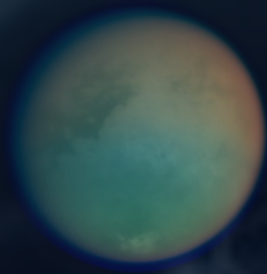
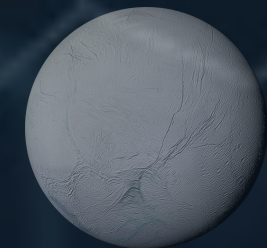
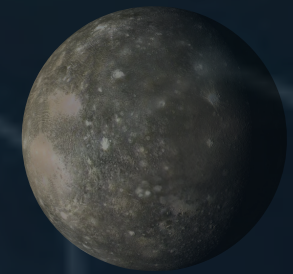
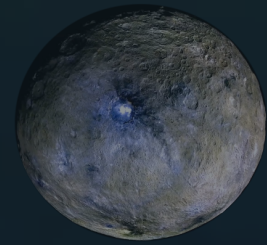
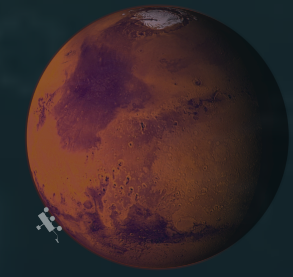
Genda et al. (2017, Nature Astro)







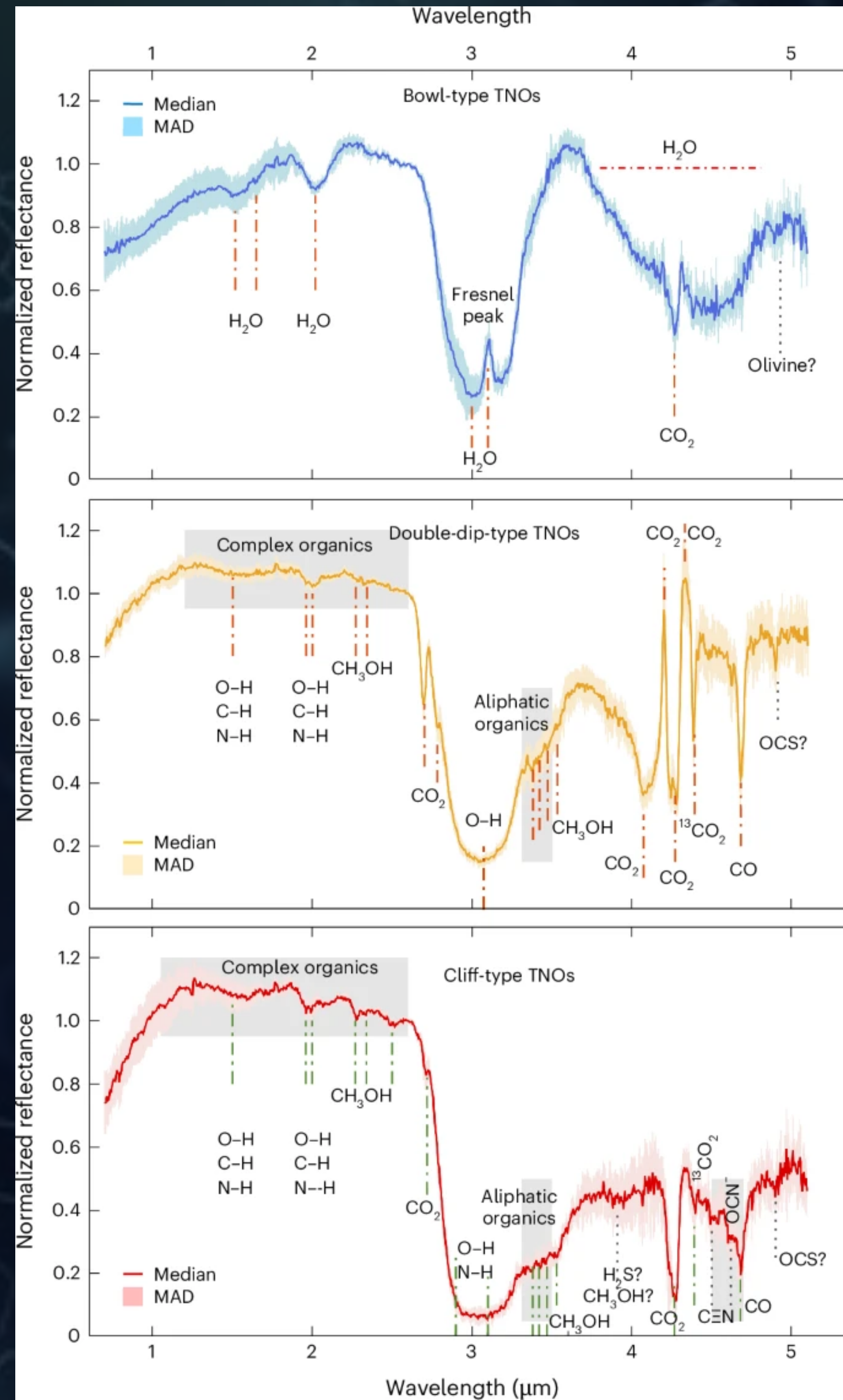
TNOs



Photochemical red/dark material:  $\text{CH}_3\text{OH}$  irradiation?  
Other TNOs, Trojans

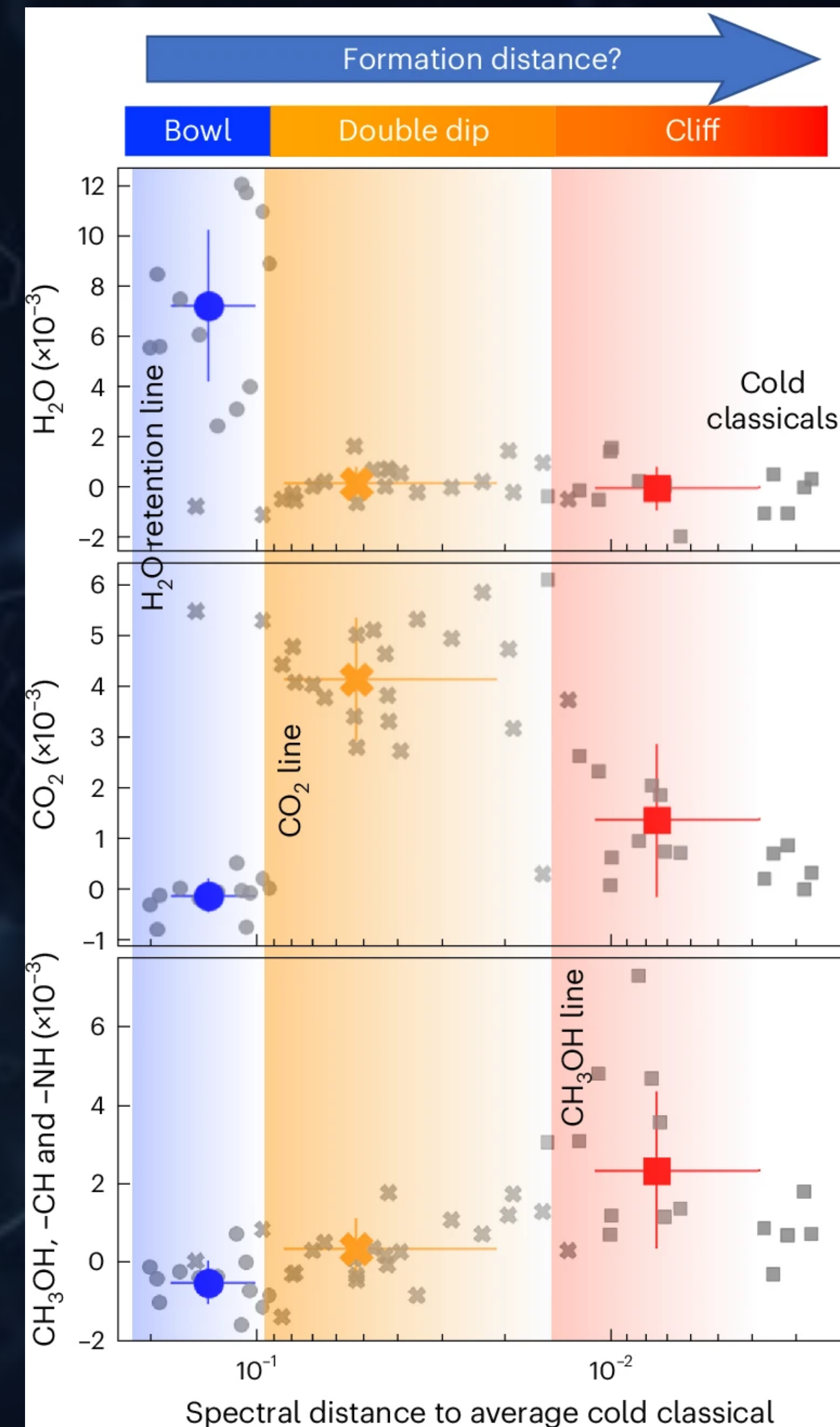
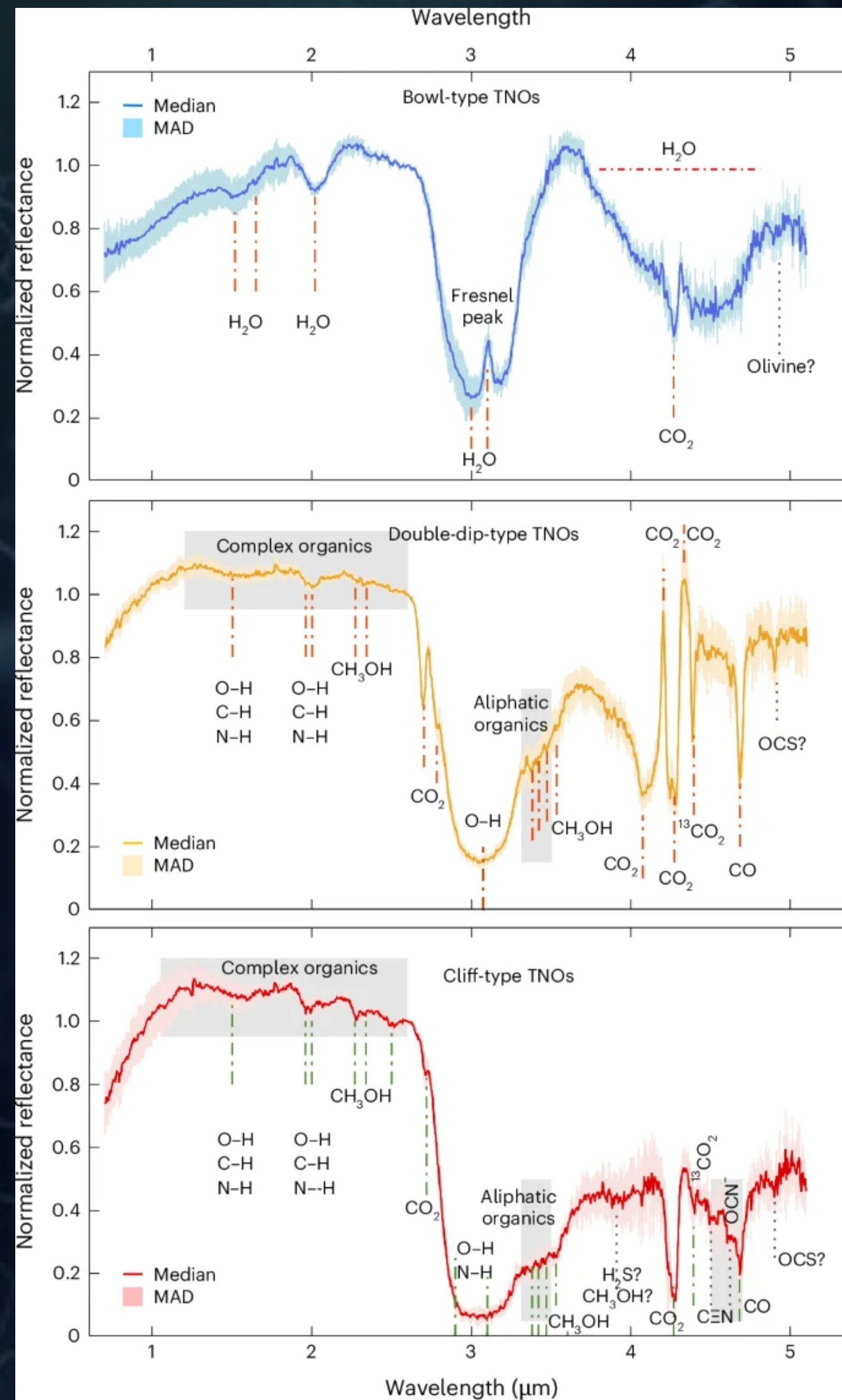


# TNOs: organic composition informs on dynamical origin





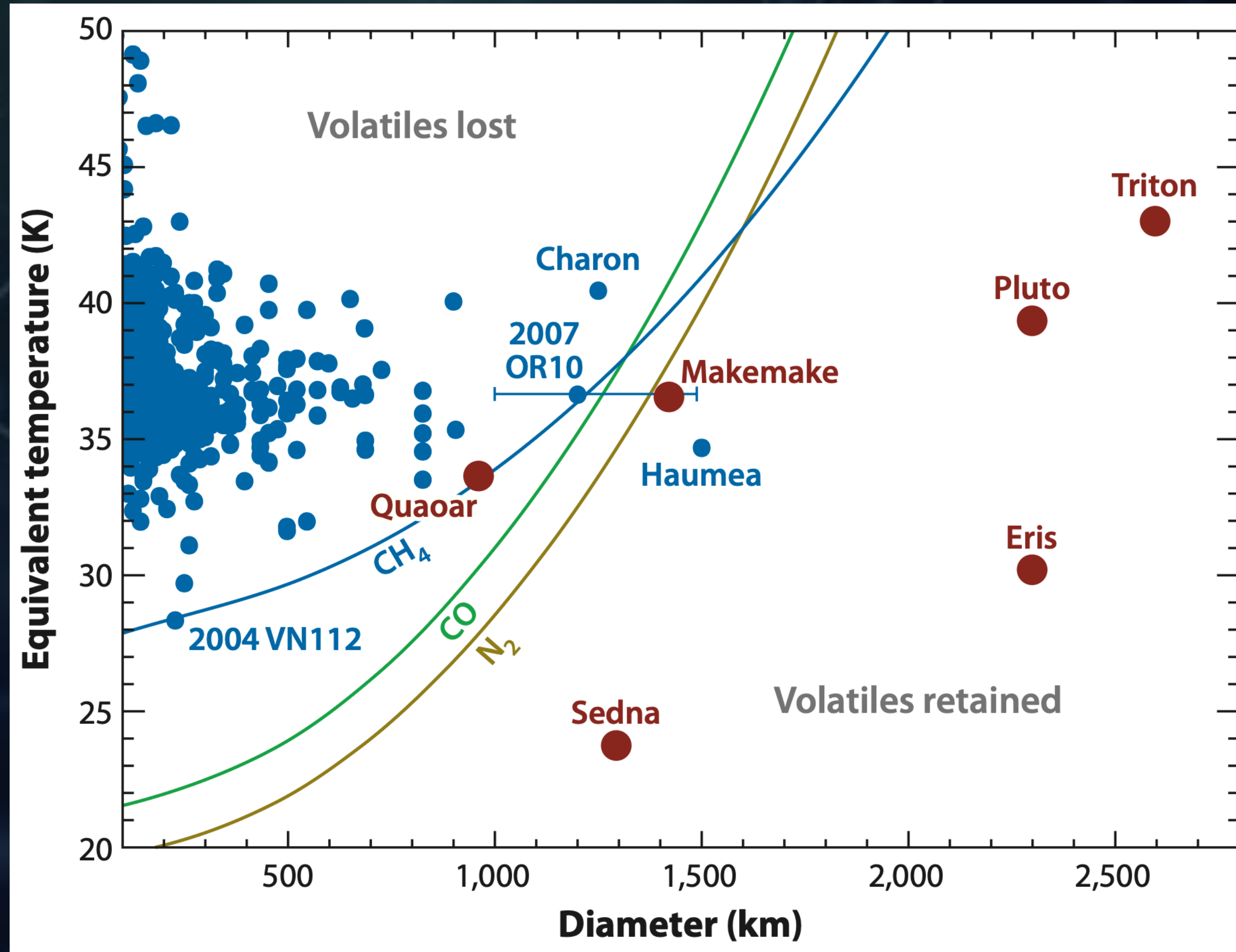
# TNOs: organic composition informs on dynamical origin



Pinilla-Alonzo et al. (2025, Nat Astro)



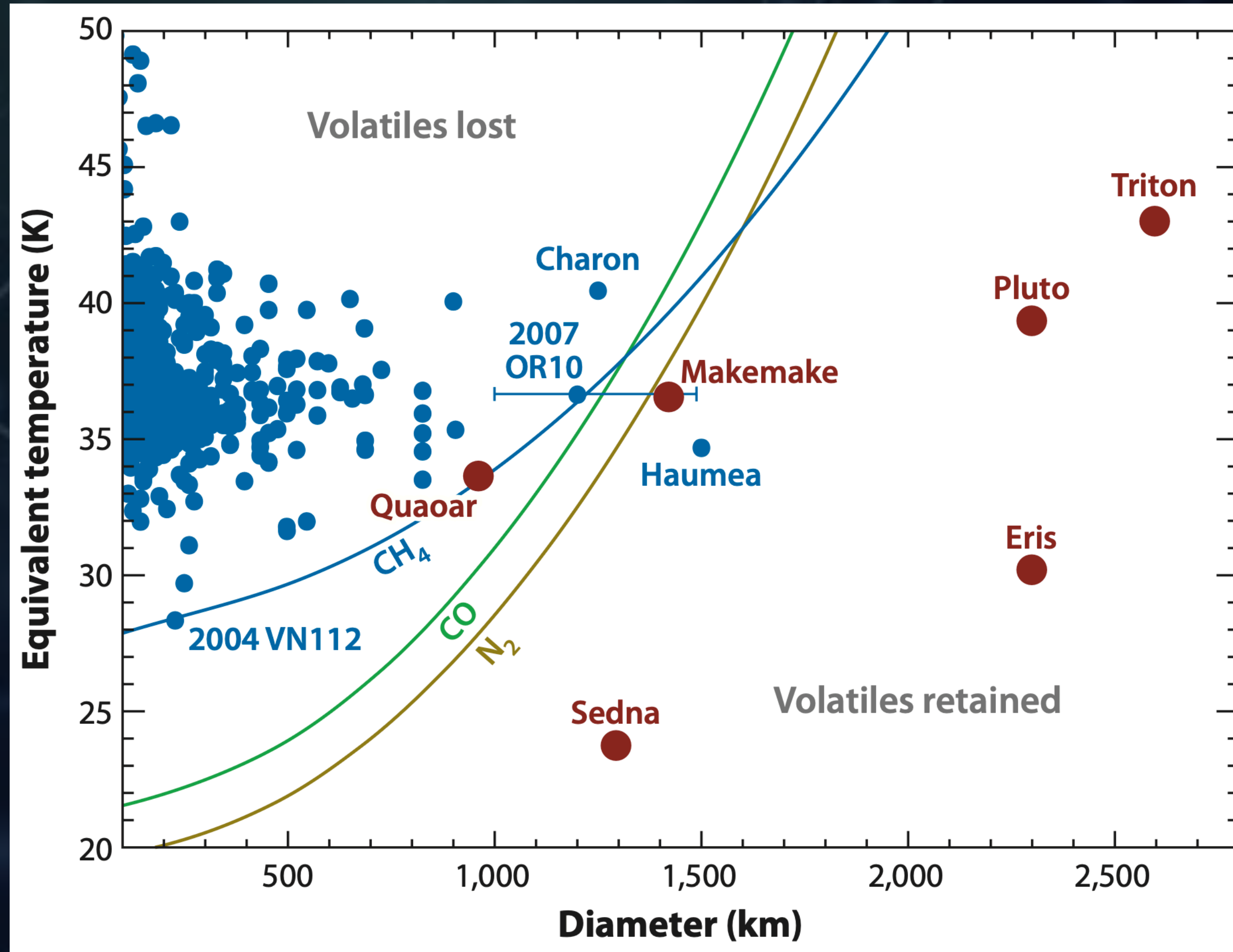
# TNOs: organic composition also informs on evolution



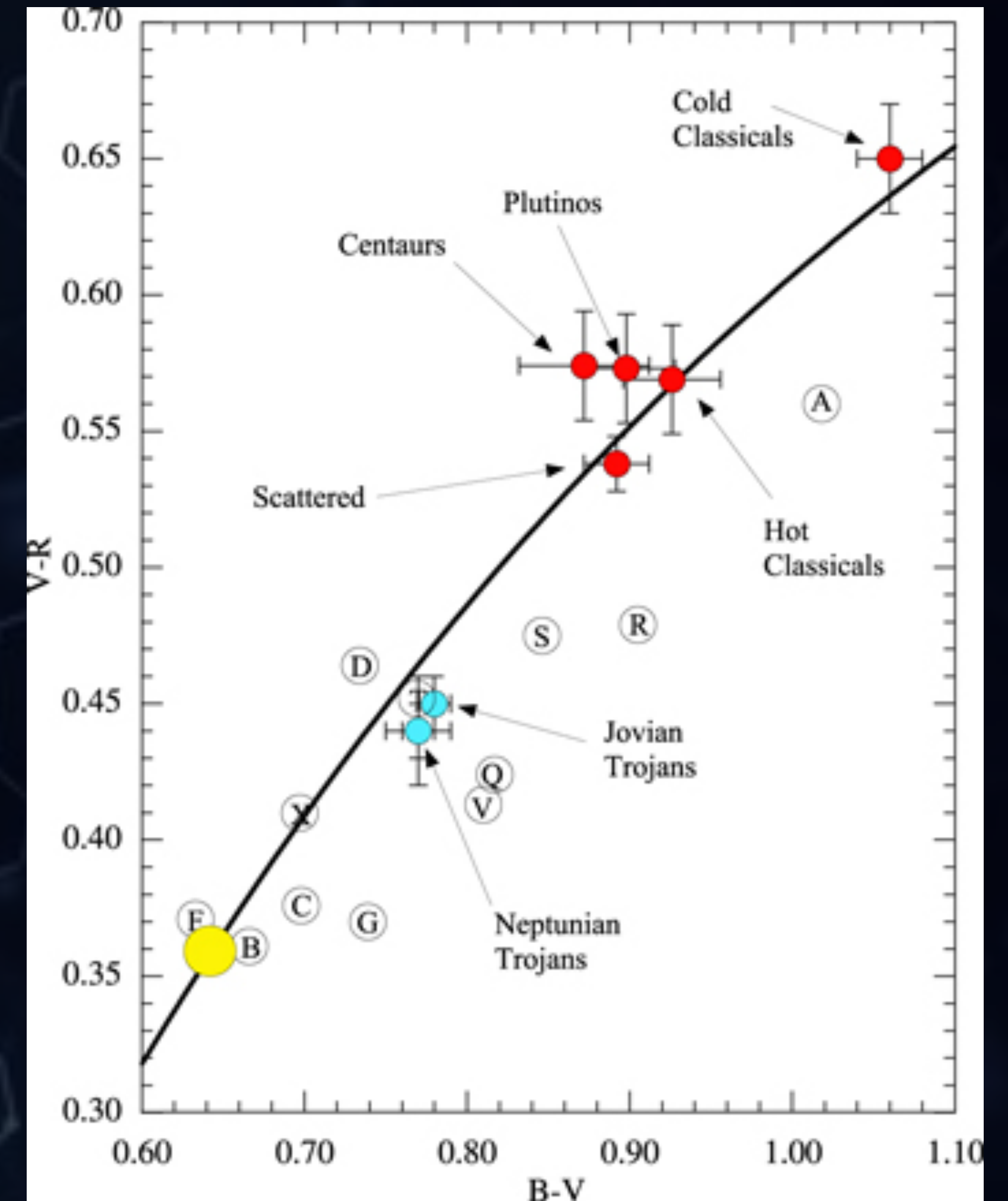
Brown (2012, AREPS)



# TNOs: organic composition also informs on evolution



Brown (2012, AREPS)

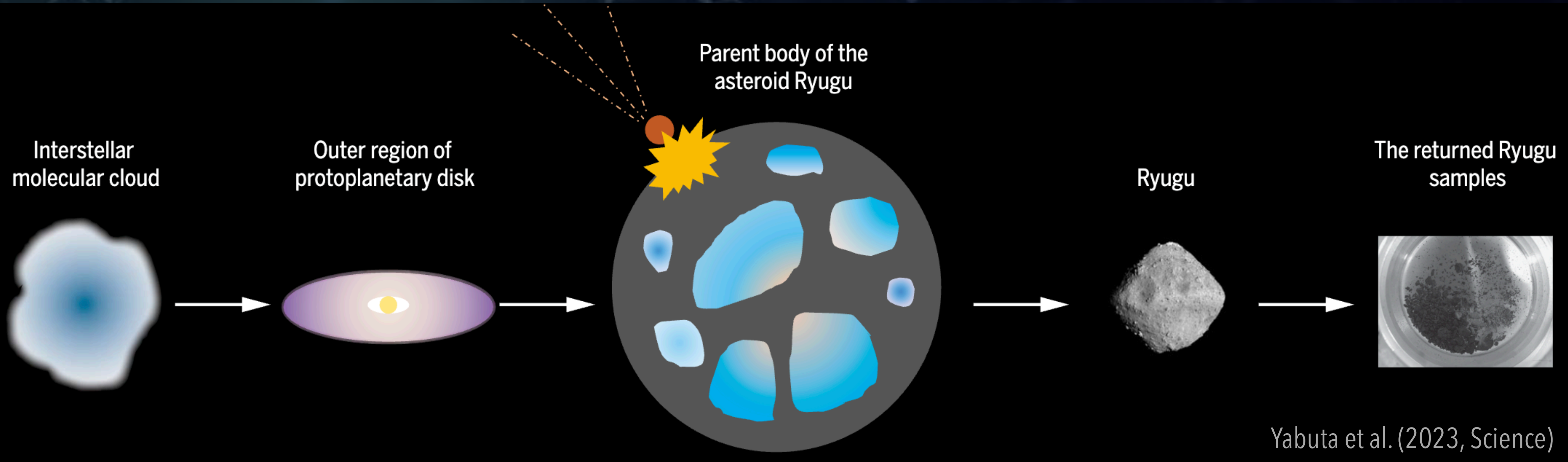


Jewitt (2018, Astron J)

*Lucy*

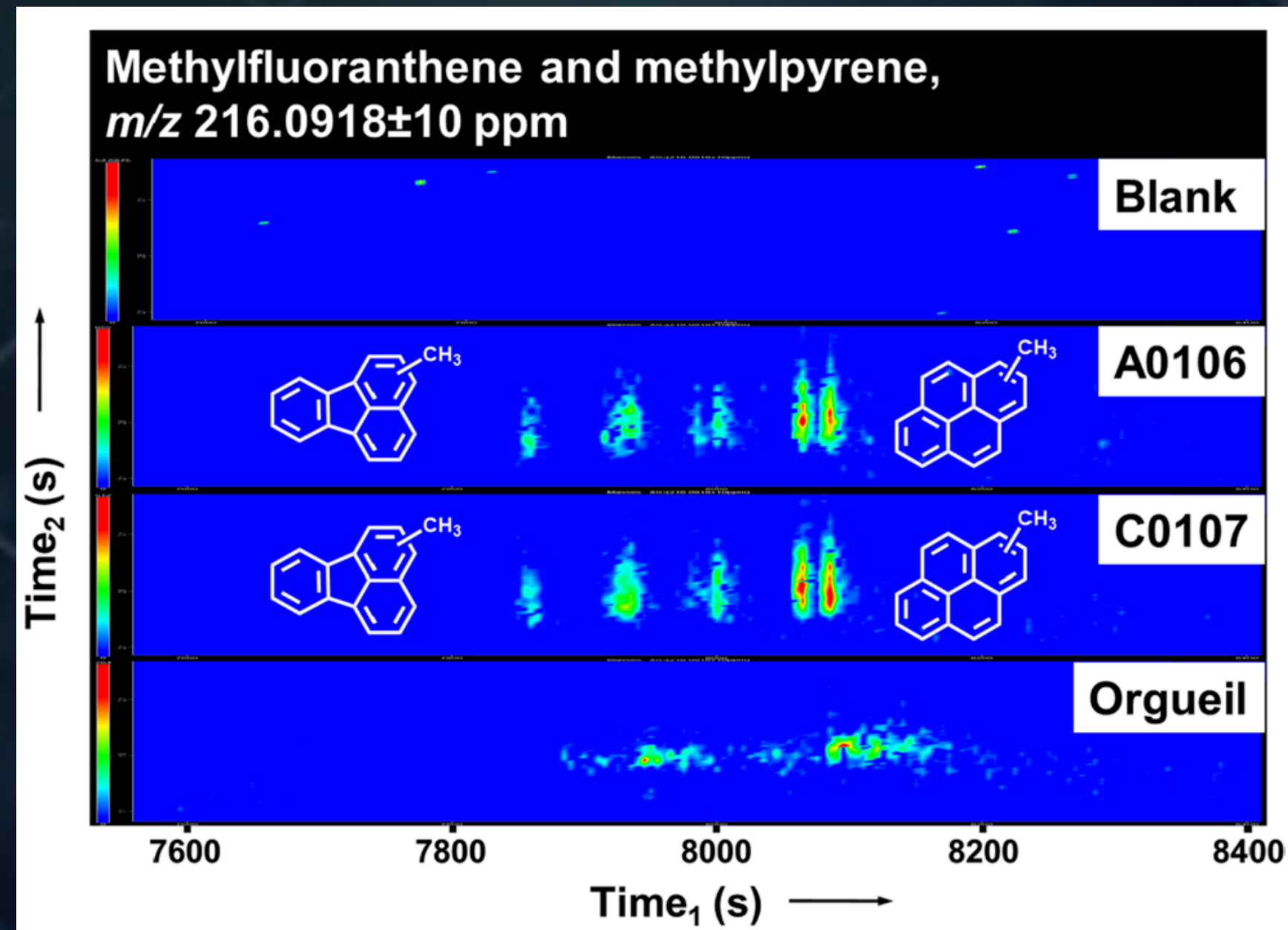


# Carbonaceous asteroids



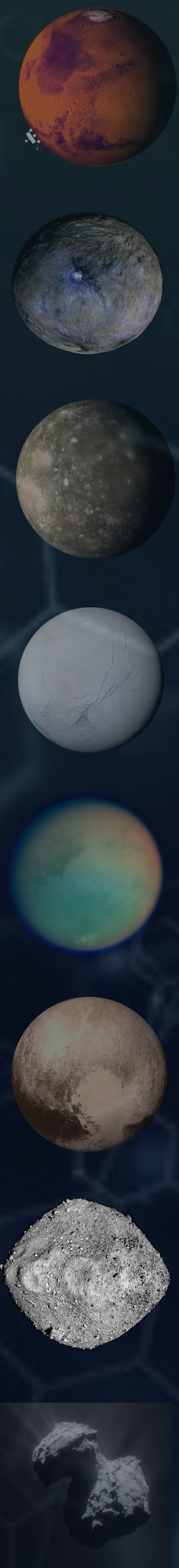


# Carbonaceous asteroids

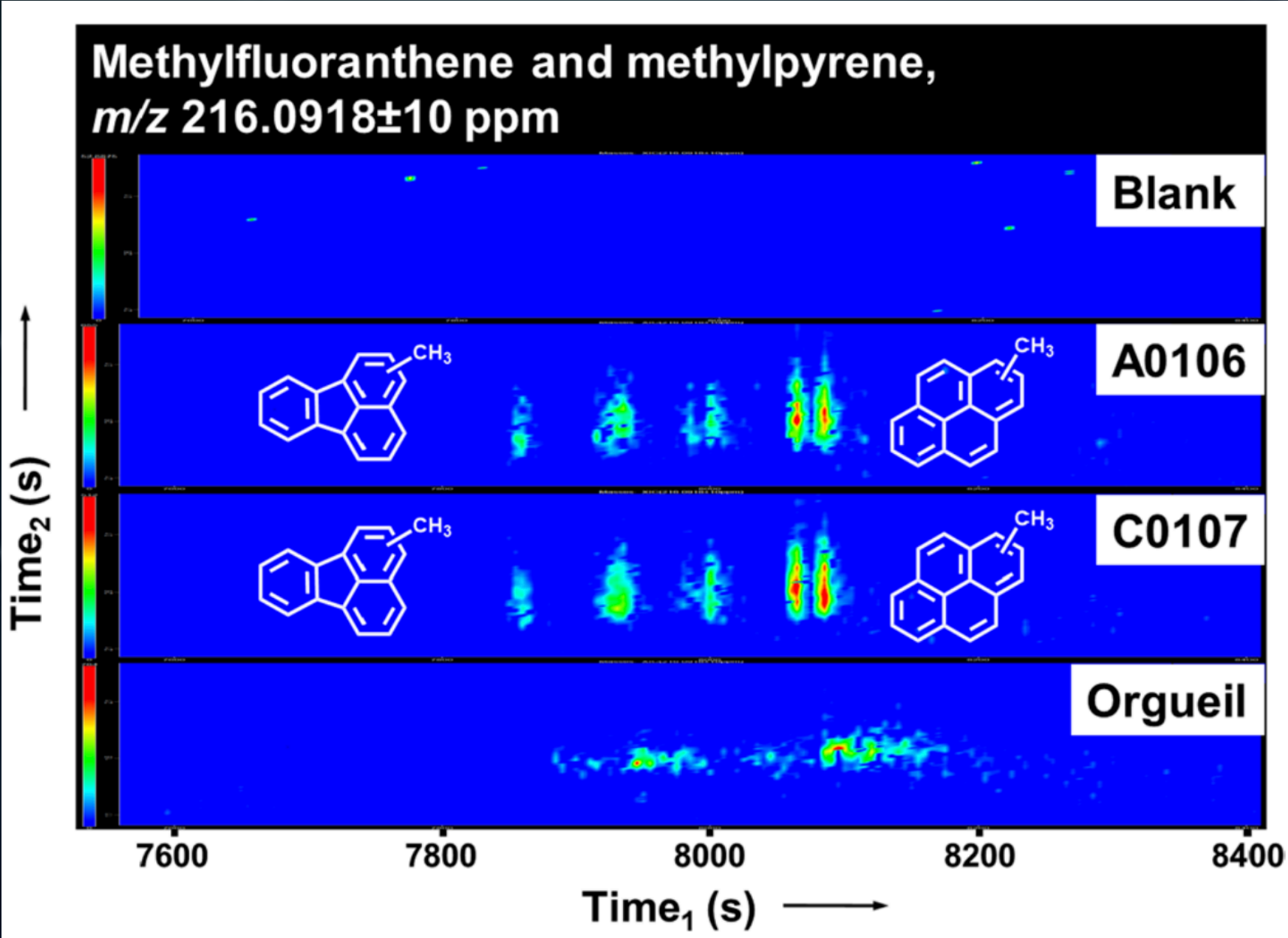


Aponte et al. (2023, Earth PI Space)

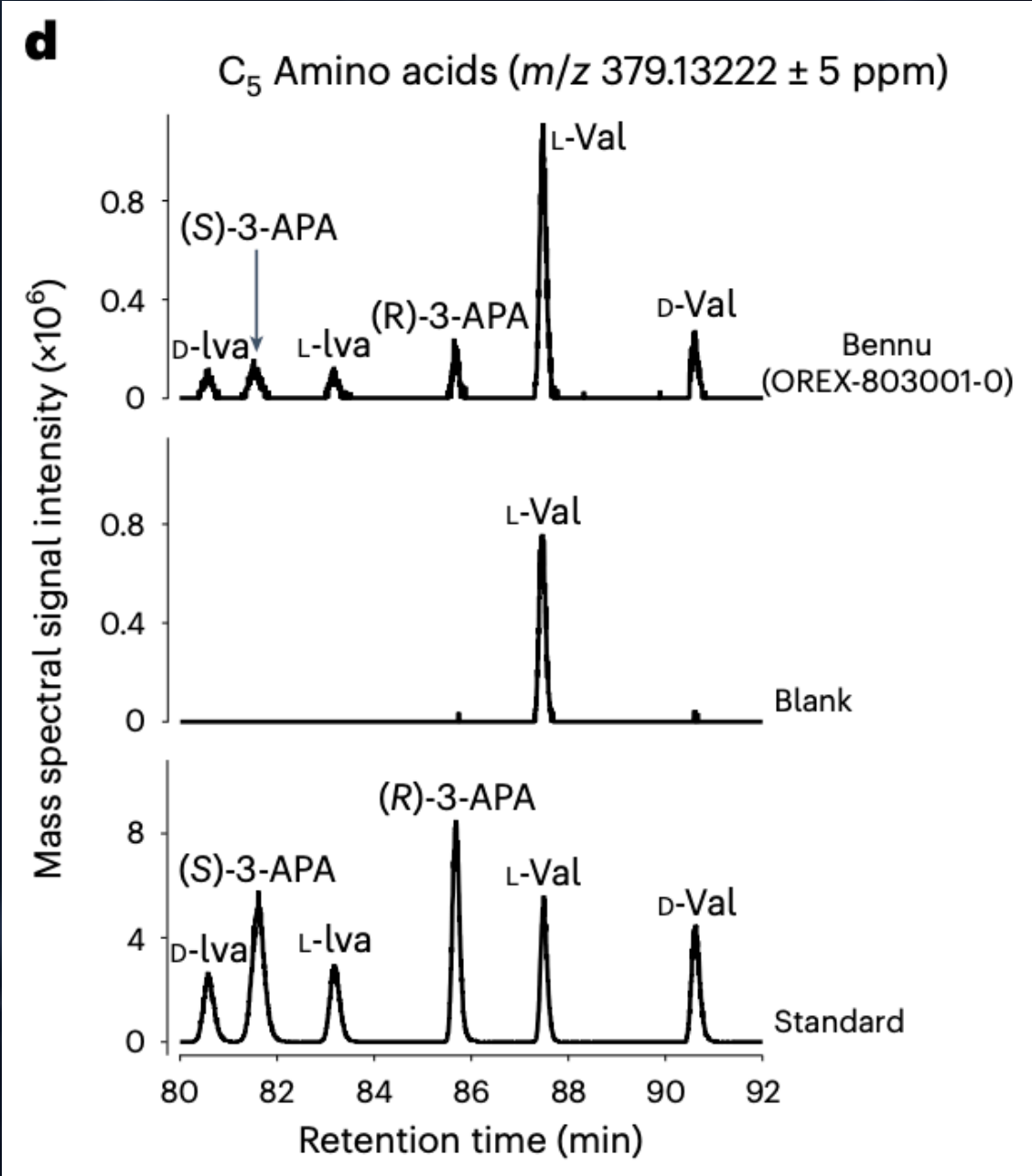




# Carbonaceous asteroids



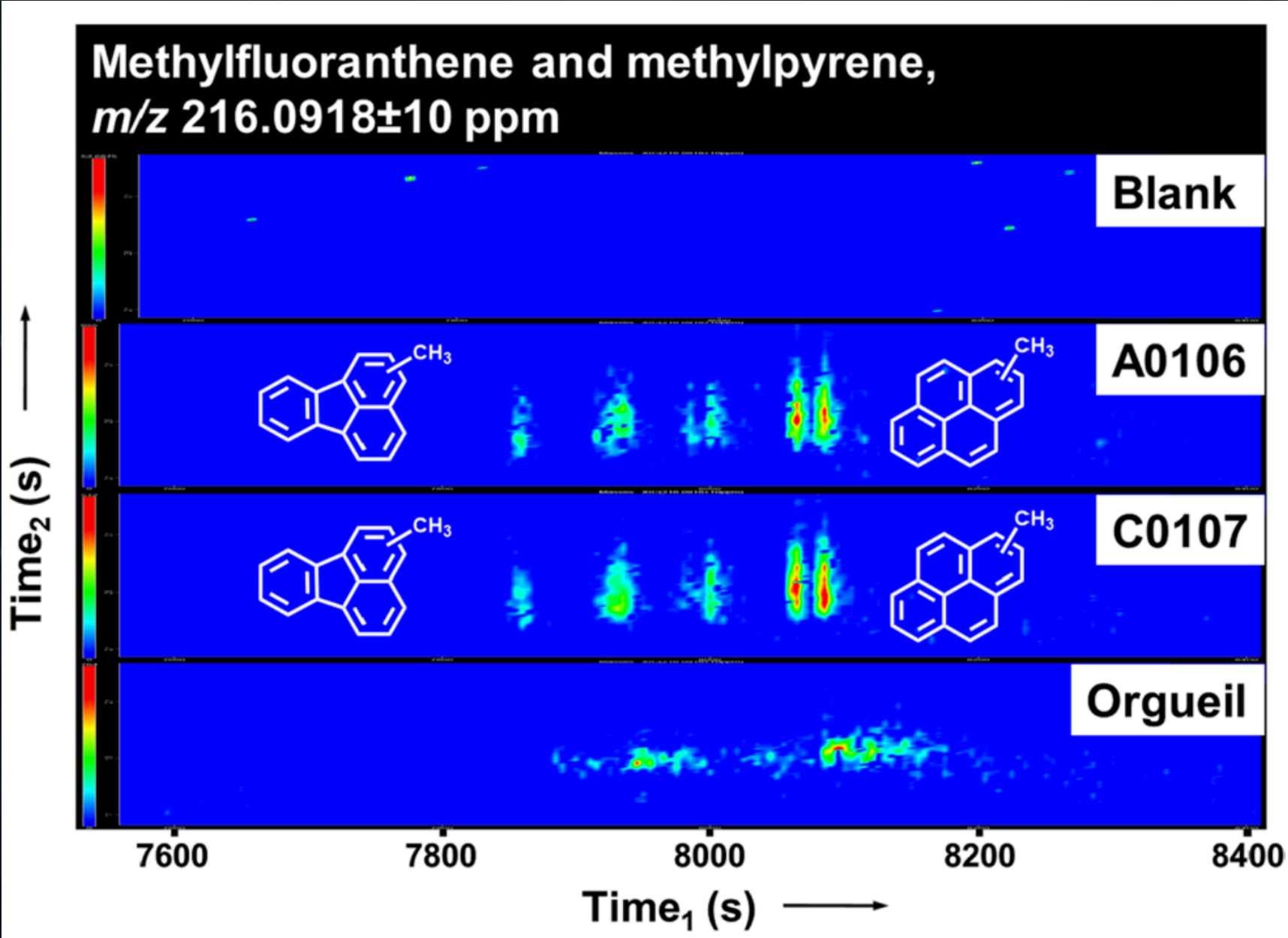
Aponte et al. (2023, Earth PI Space)



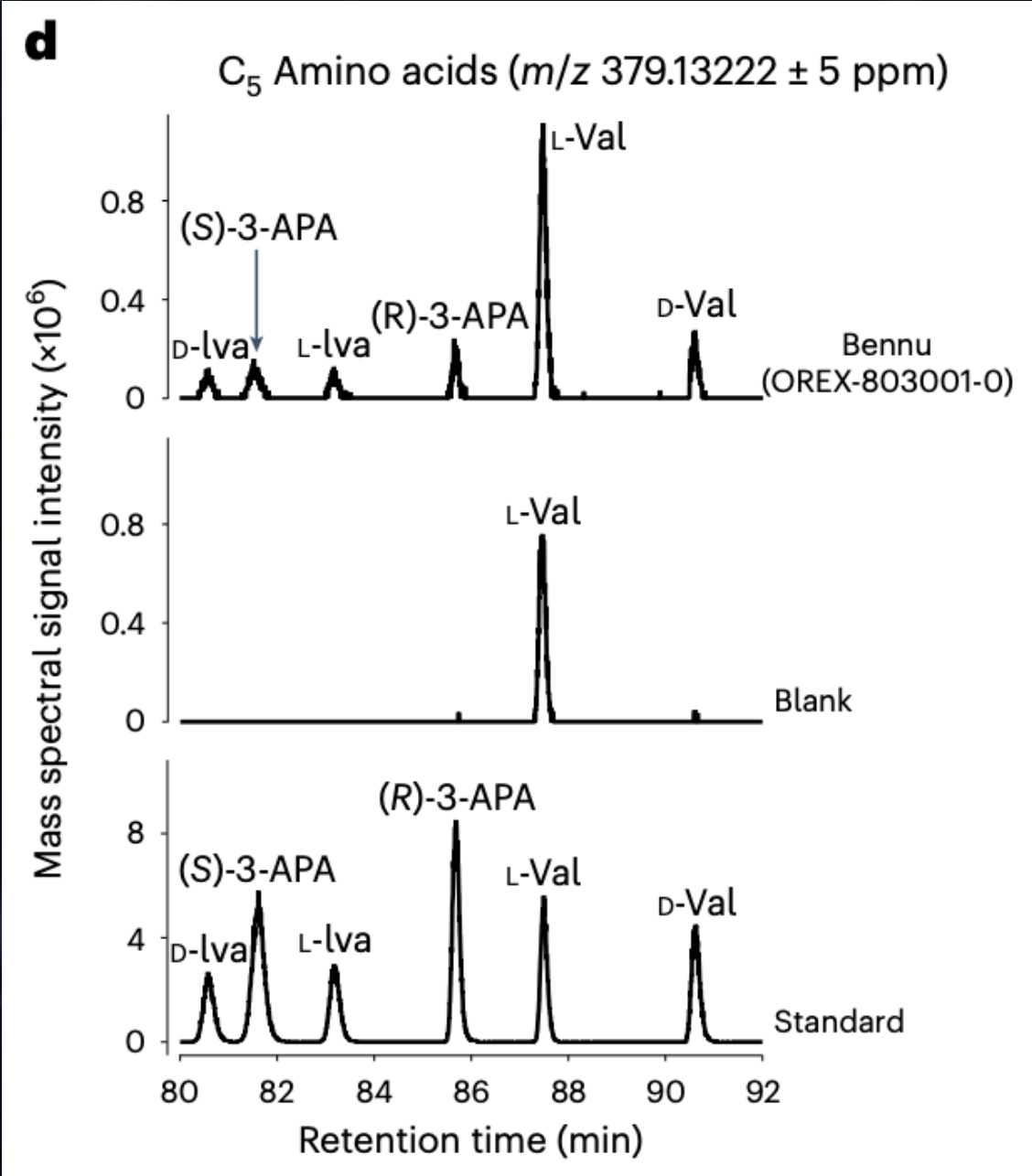
Glavin et al. (2025, Nat Astro)



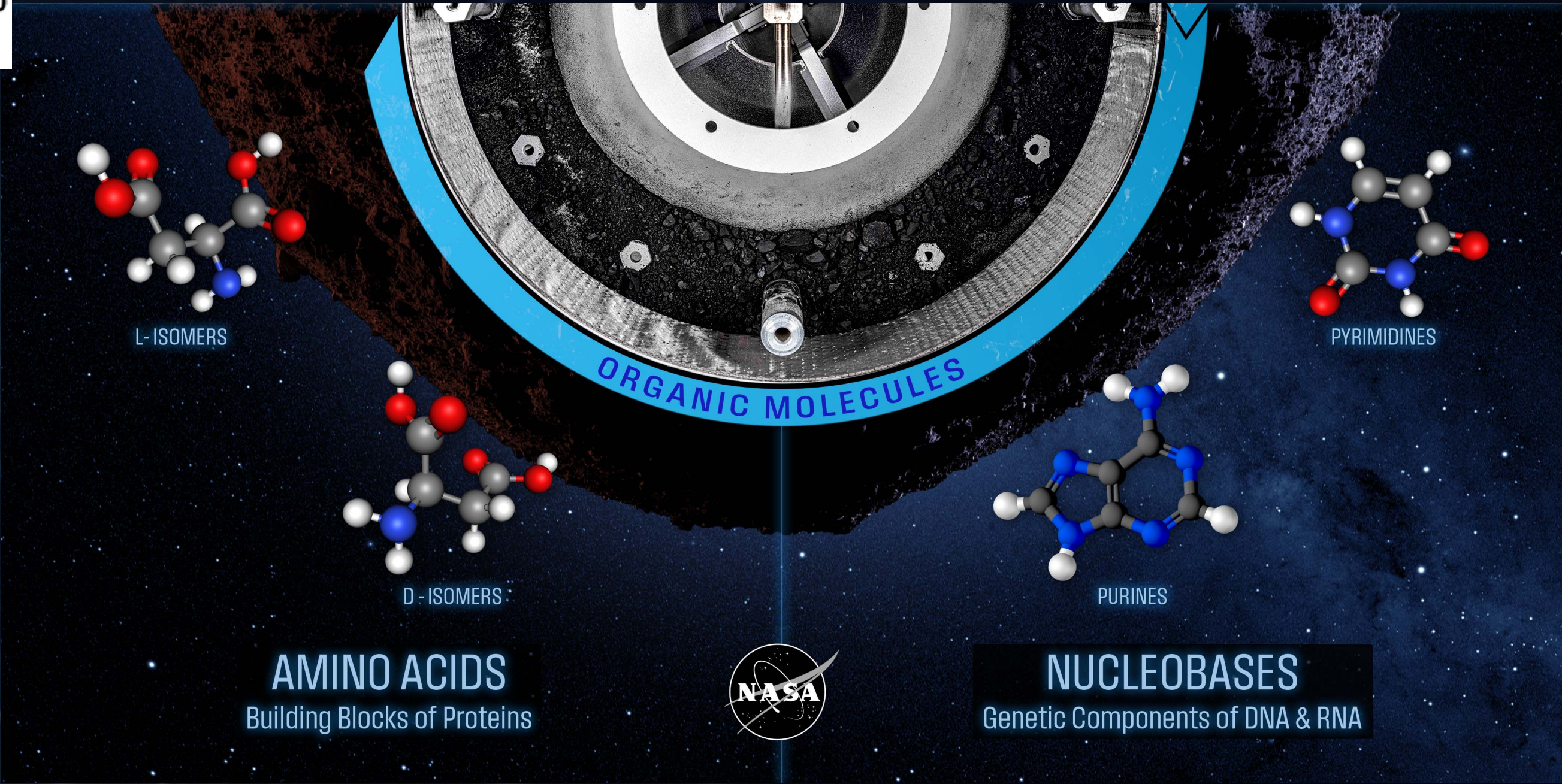
# Carbonaceous asteroids



Aponte et al. (2023, Earth PI Space)

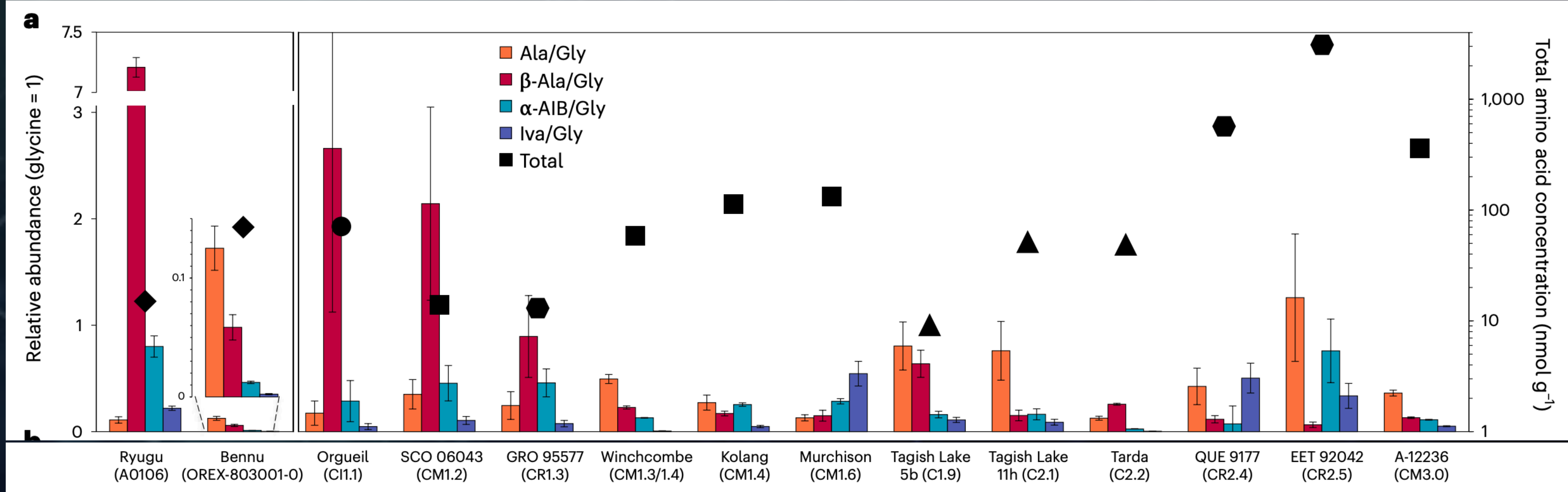


Glavin et al. (2025, Nat Astro)



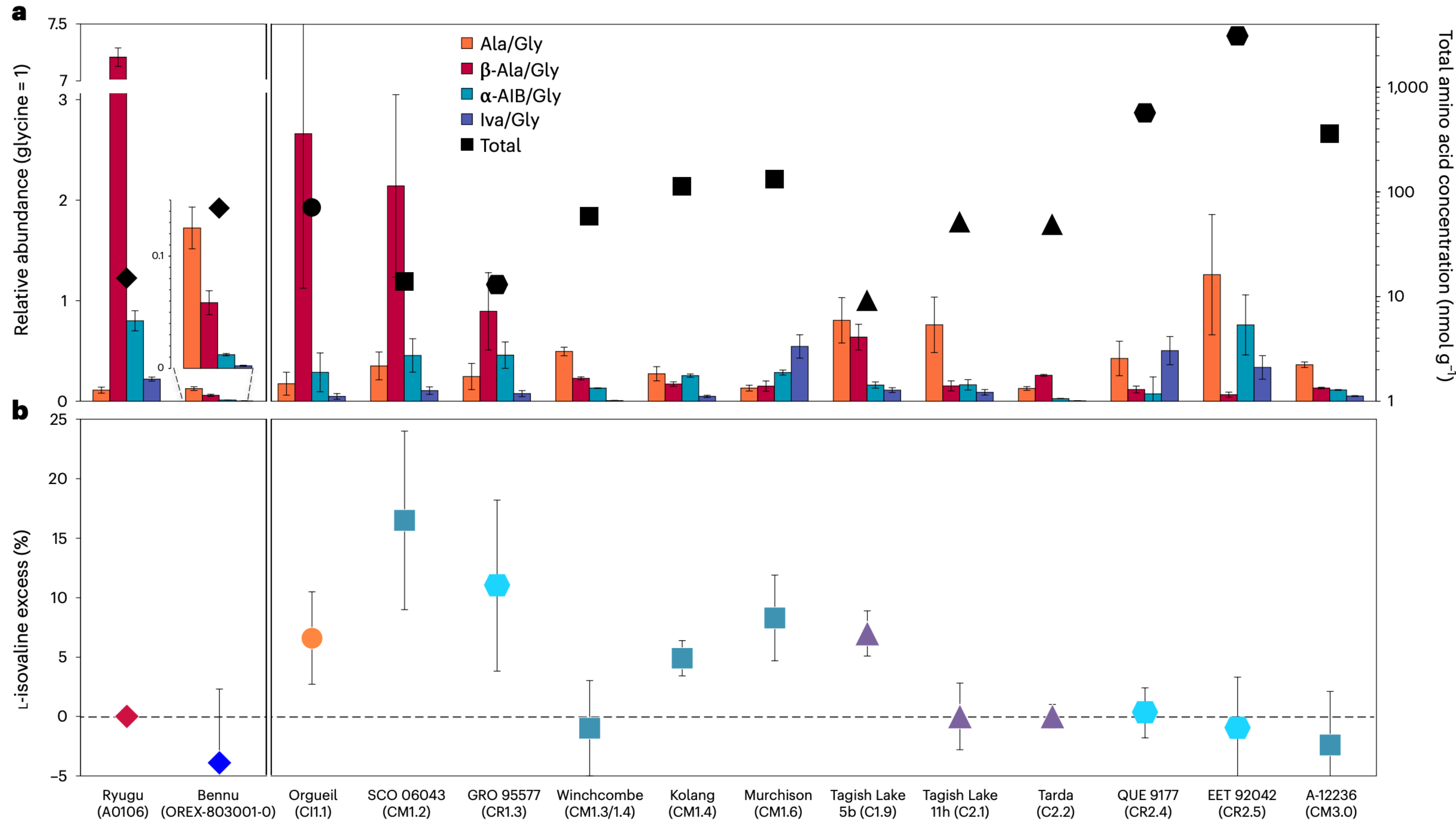


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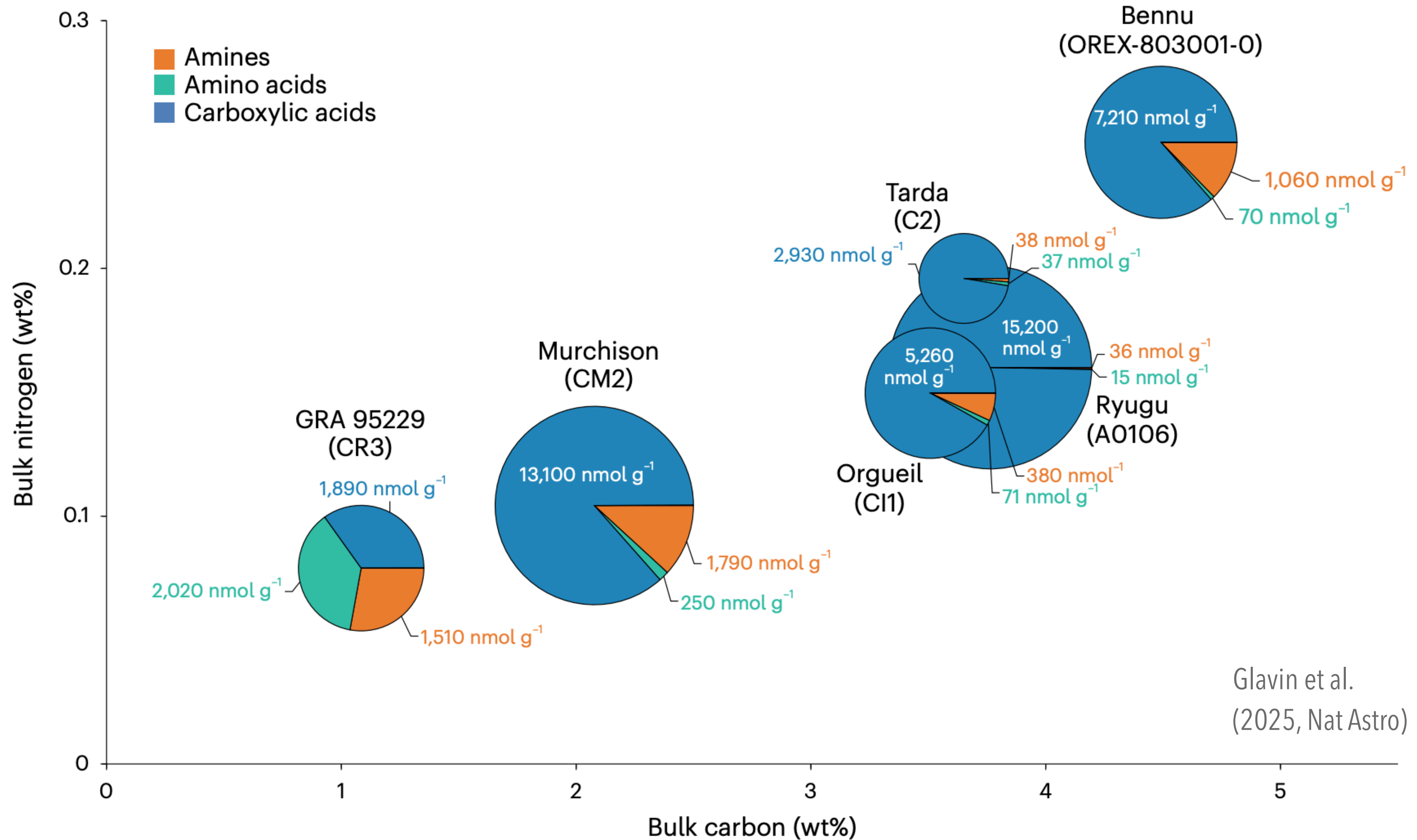


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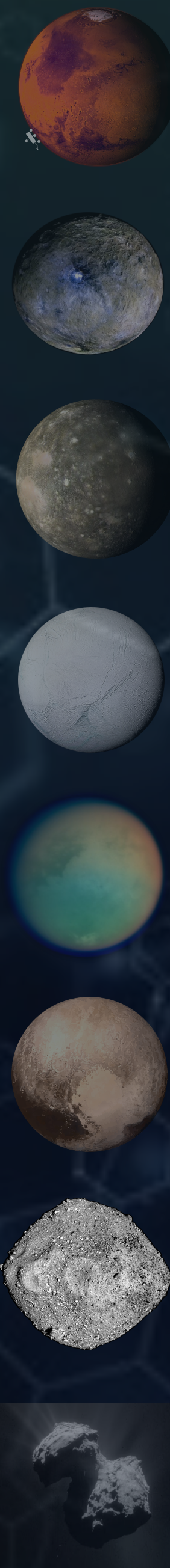




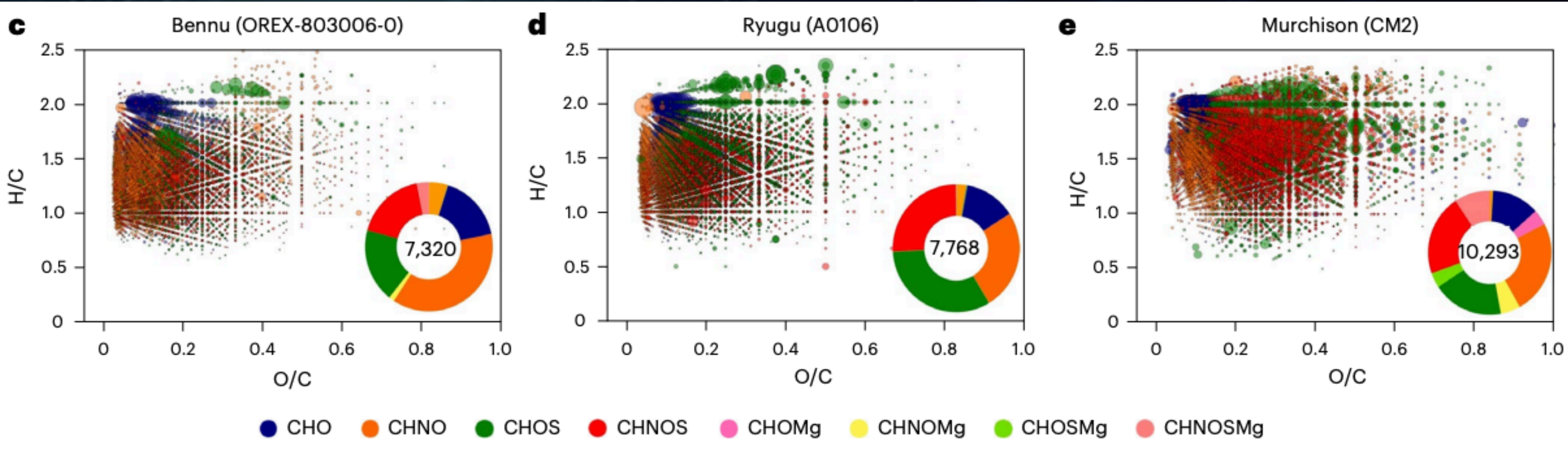
# Carbonaceous asteroids





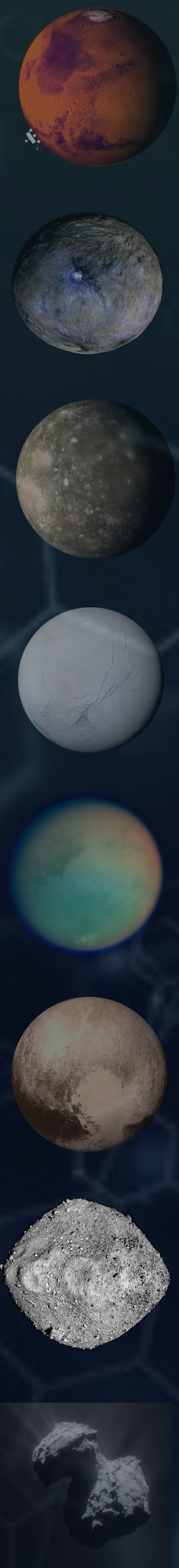


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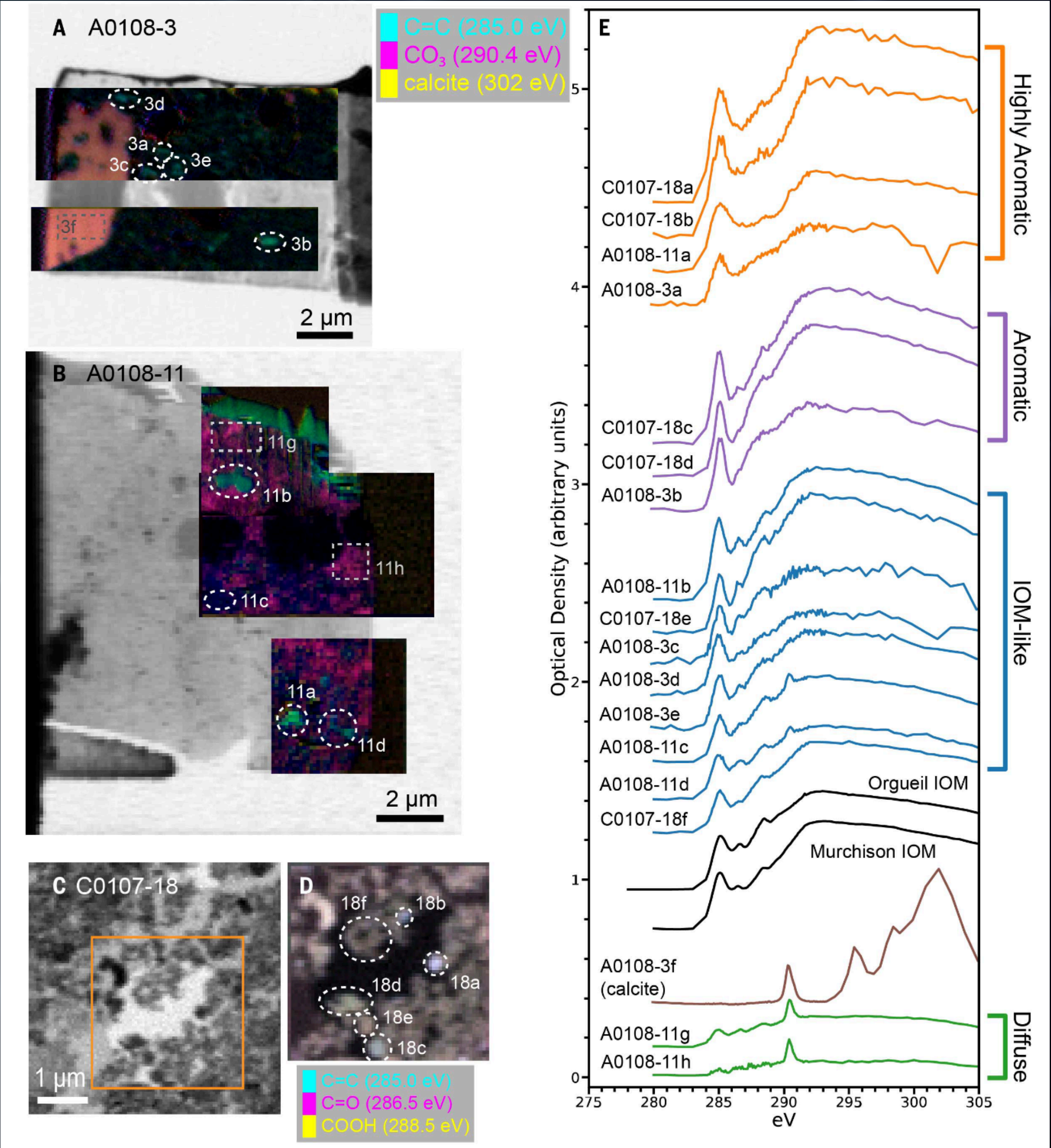
Glavin et al. (2025, Nat Astro)



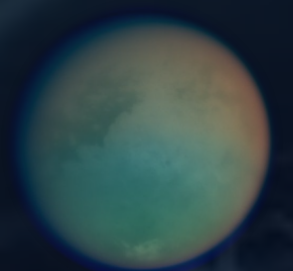
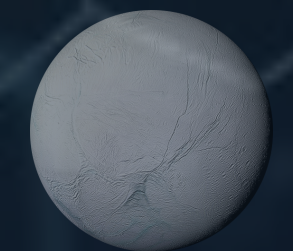
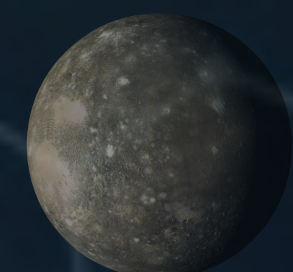
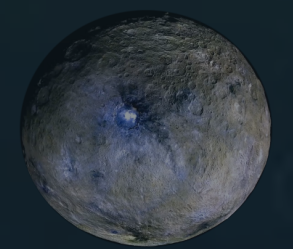
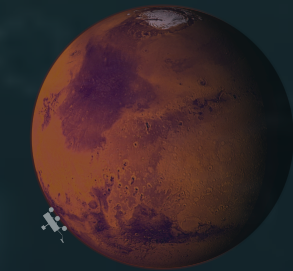


# Carbonaceous asteroids

## Macromolecular organic matter



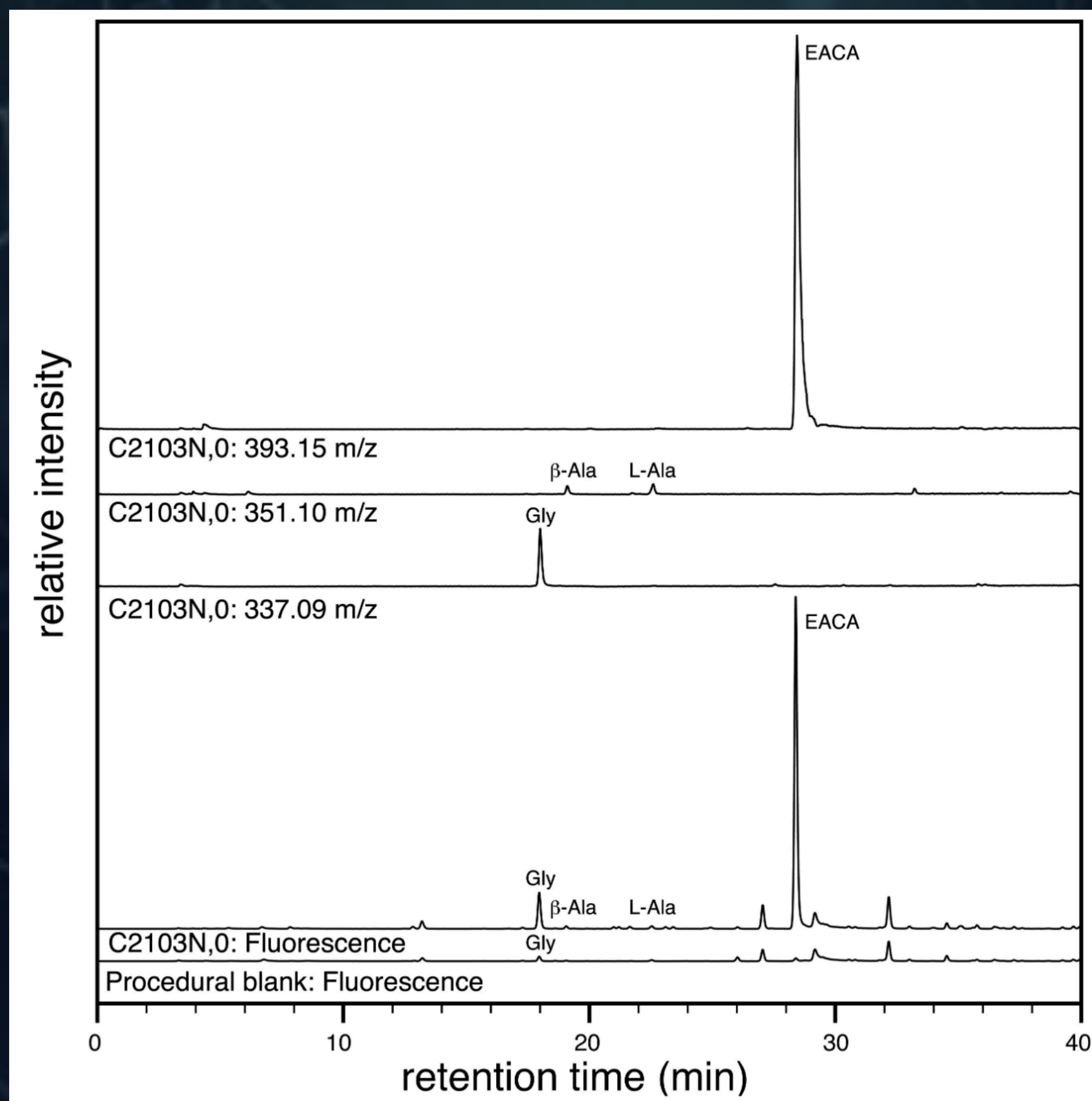




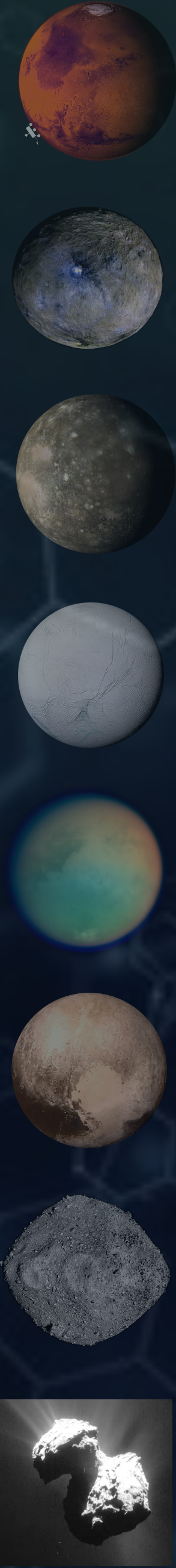
# Comets

## Glycine in Wild2

Elsila et al. (2008, MaPS)



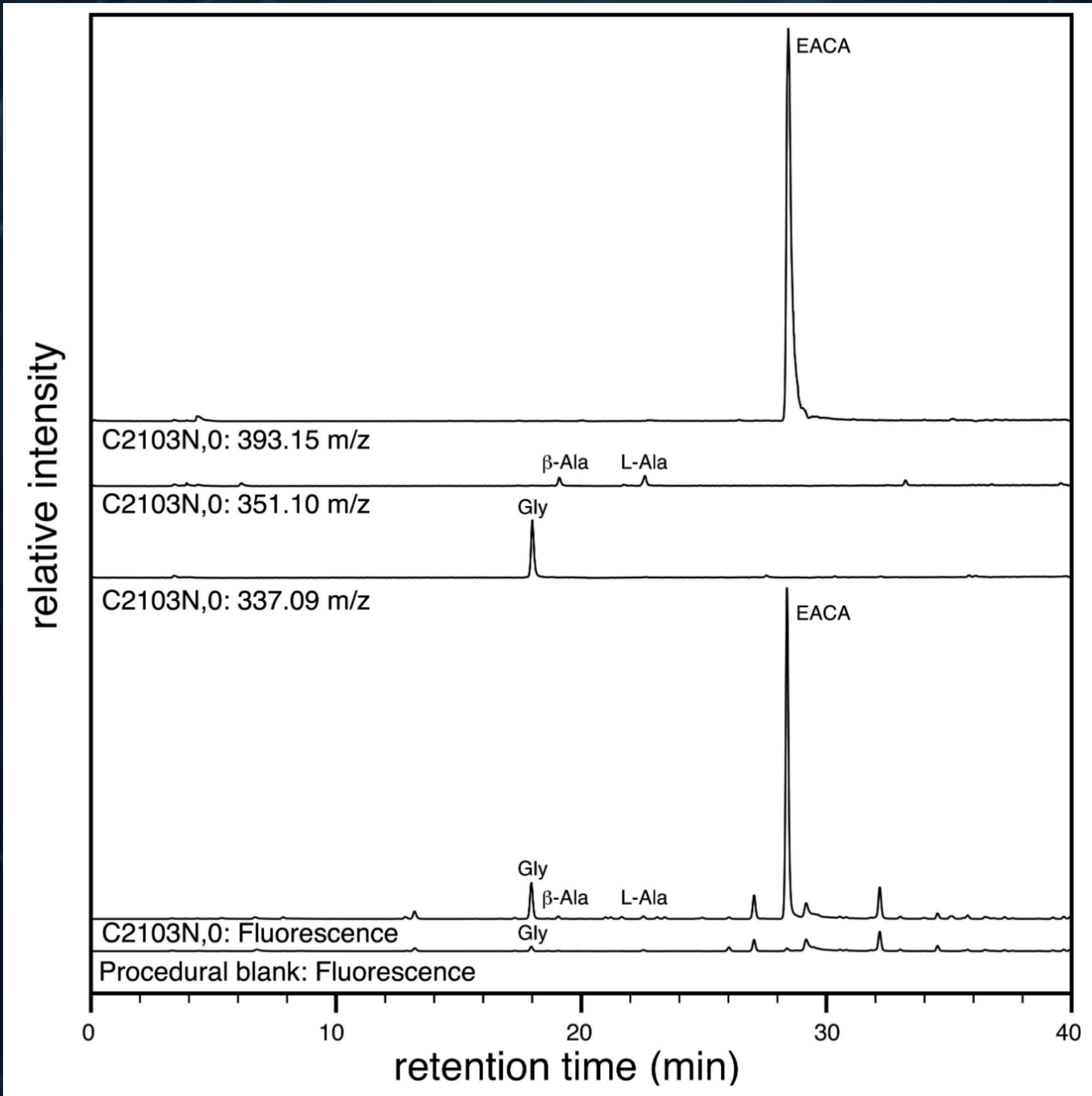




# Comets

## Glycine in Wild2

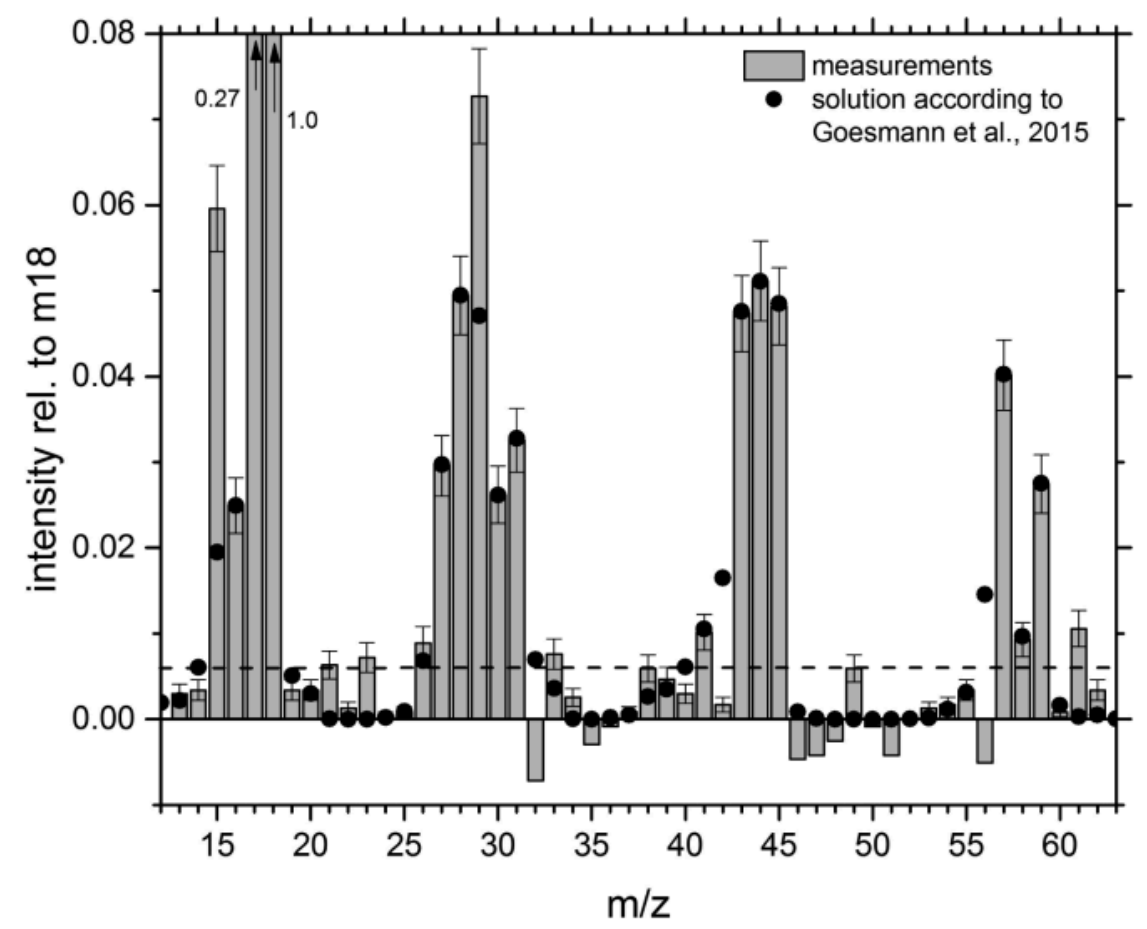
Elsila et al. (2008, MaPS)



## 67/P

Goesmann et al. (2015, Science)

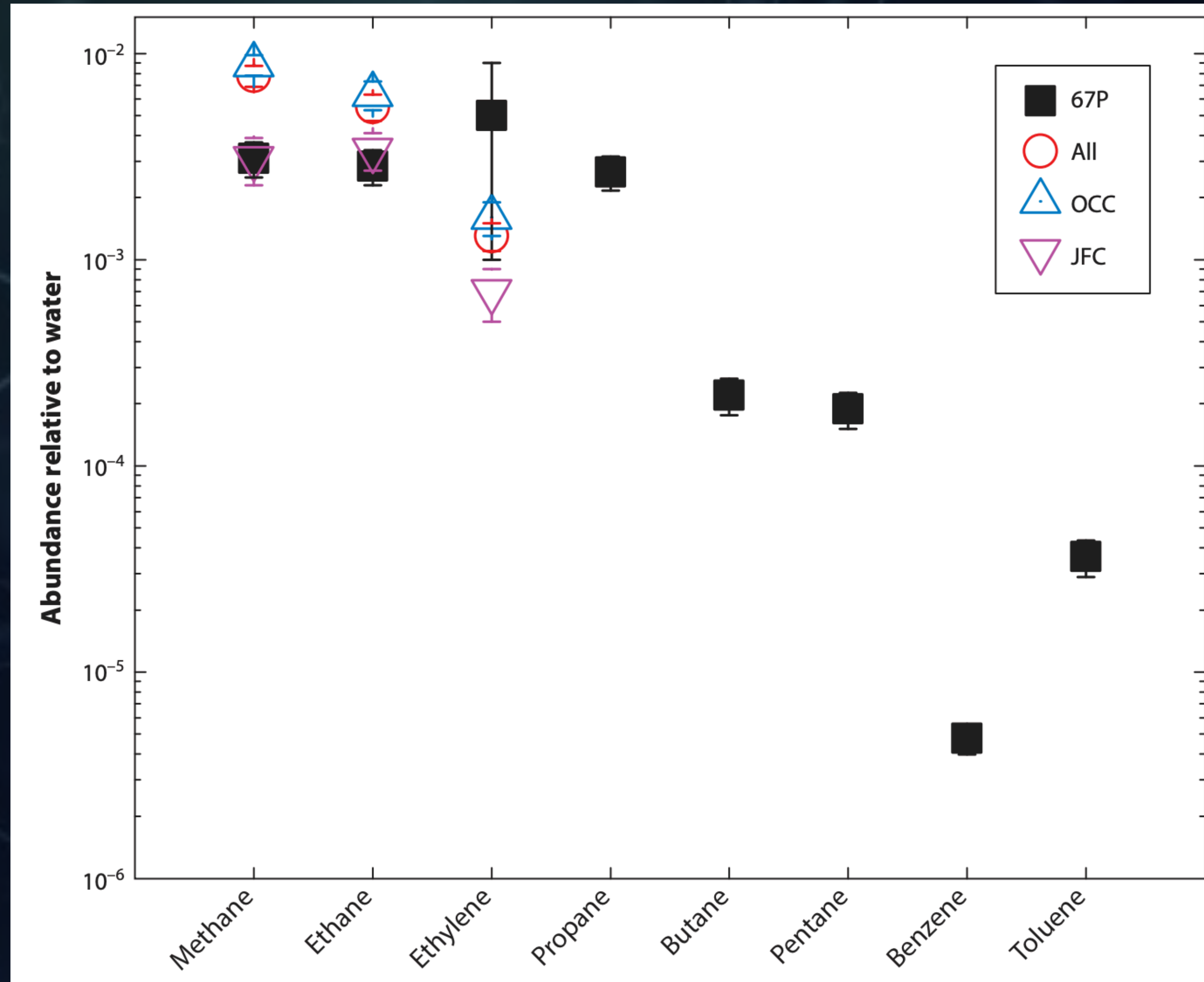
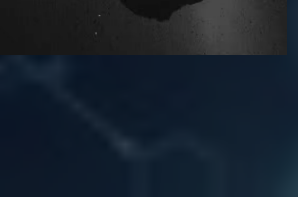
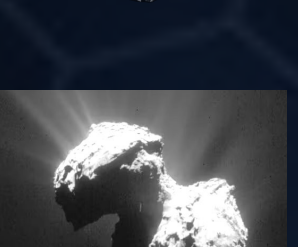
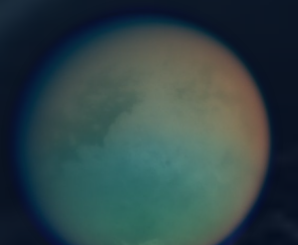
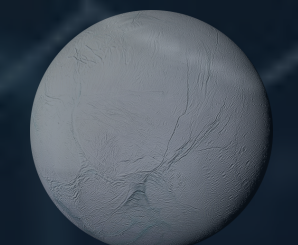
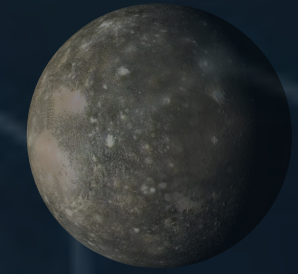
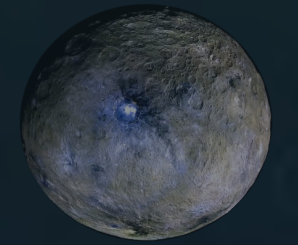
Altwegg et al. (2017, MNRAS)



Molecule		Mass (Da)	Rel. abundance (per cent)
CH <sub>4</sub>	Methane	16	0.7
H <sub>2</sub> O	Water	18	80.9
CHN	Hydrogencyanide	27	1.1
CO	Carbon monoxide	28	1.1
CH <sub>5</sub> N	Methylamine	31	1.2
CH <sub>3</sub> CN	Acetonitrile	41	0.5
CHNO	Isocyanic acid	43	0.5
C <sub>2</sub> H <sub>4</sub> O	Acetaldehyde	44	1.0
CH <sub>3</sub> NO	Formamide	45	3.7
C <sub>2</sub> H <sub>5</sub> NH <sub>2</sub>	Ethylamine	45	0.7
CH <sub>3</sub> NCO	Methyl isocyanate	57	3.1
C <sub>3</sub> H <sub>6</sub> O	Acetone	58	1.0
C <sub>2</sub> H <sub>5</sub> CHO	Propanal	58	0.4
CH <sub>3</sub> CONH <sub>2</sub>	Acetamide	59	2.2
CH <sub>2</sub> OHCHO	Glycol aldehyde	60	1.0
CH <sub>2</sub> (OH)CH <sub>2</sub> (OH)	Ethylene glycol	62	0.8



# Comets

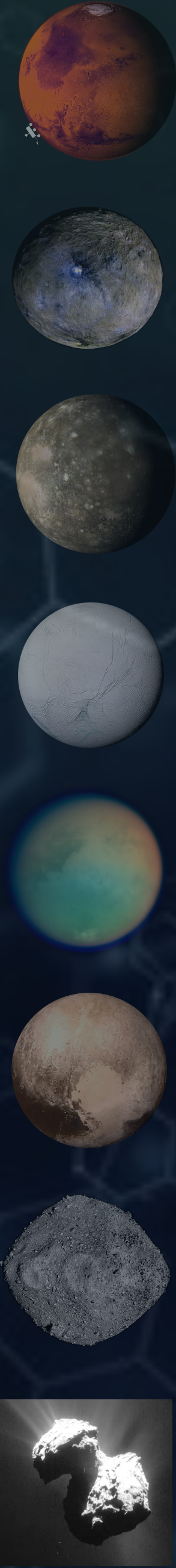


**67/P**

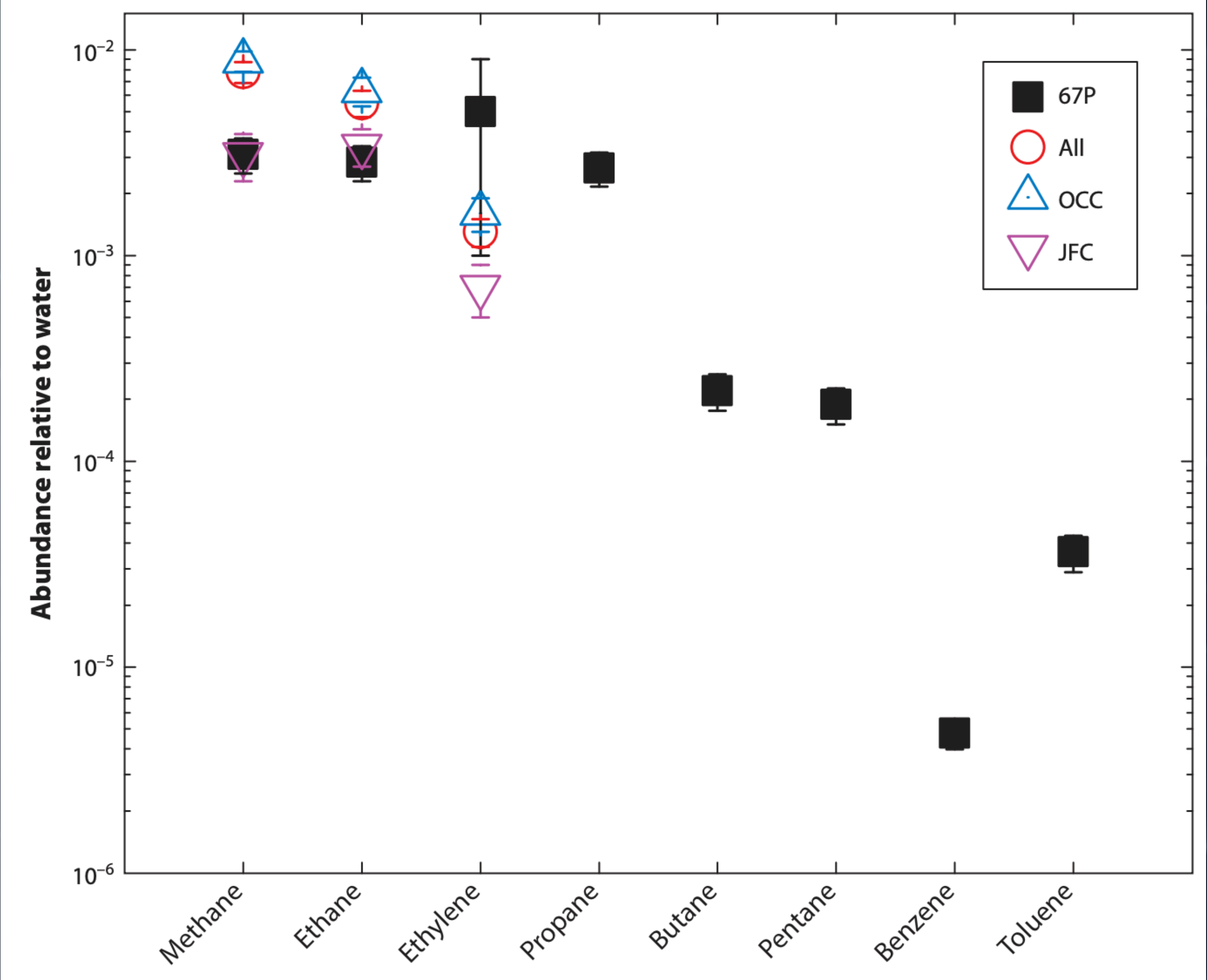
Schuhmann et al. (2019)

Altwegg et al. (2019, ARAA)





# Comets



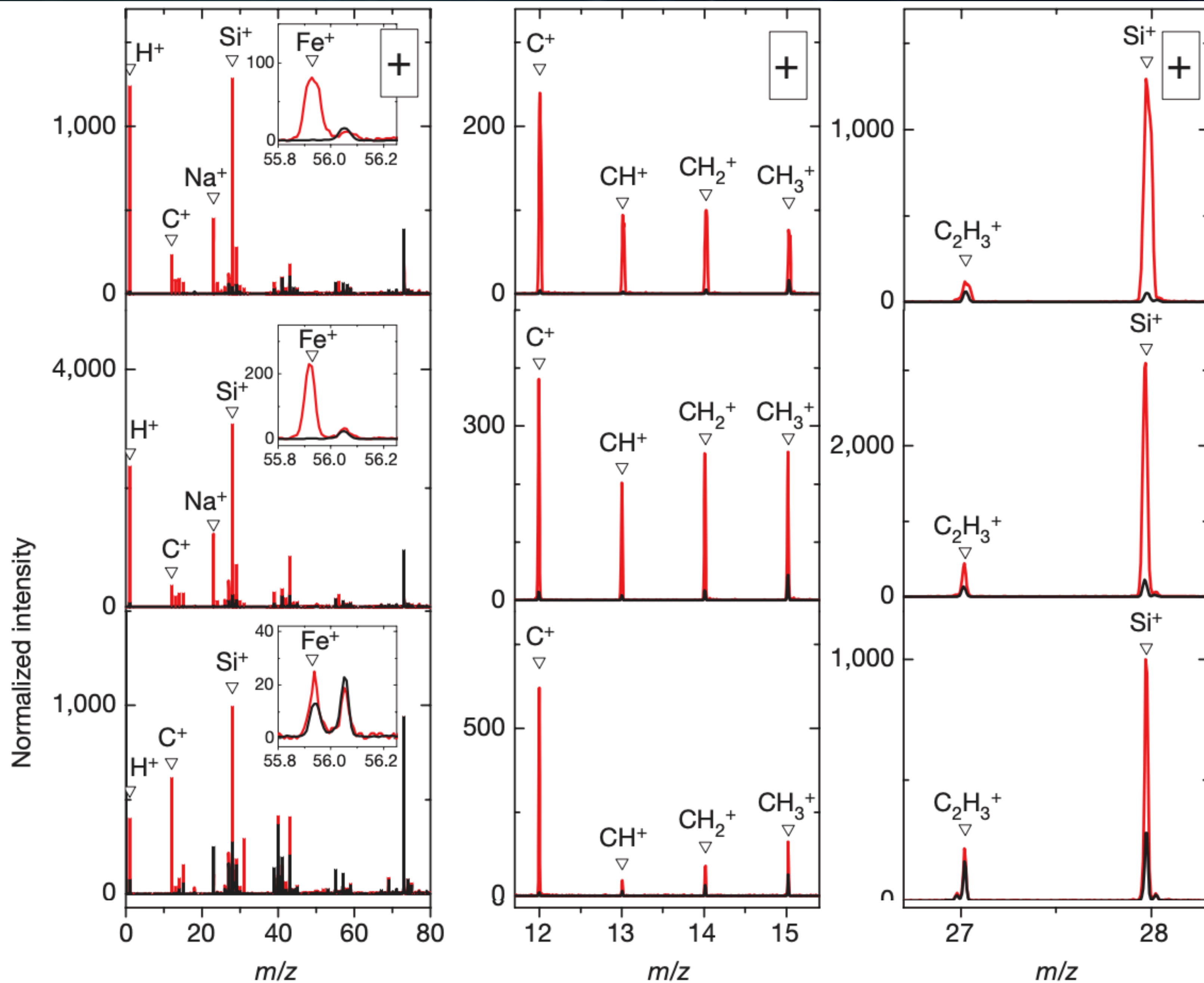
## 67/P

Schuhmann et al. (2019)  
Altwegg et al. (2019, ARAA)

CH compounds		CH compounds
CH <sub>4</sub>		CH <sub>4</sub>
C <sub>2</sub> H <sub>2</sub>		C <sub>2</sub> H <sub>2</sub>
C <sub>2</sub> H <sub>6</sub>		C <sub>2</sub> H <sub>6</sub>
C <sub>3</sub> H <sub>8</sub>		C <sub>3</sub> H <sub>8</sub>
C <sub>4</sub> H <sub>10</sub>		C <sub>4</sub> H <sub>10</sub>
C <sub>5</sub> H <sub>12</sub>		C <sub>5</sub> H <sub>12</sub>
C <sub>6</sub> H <sub>6</sub>		C <sub>6</sub> H <sub>6</sub>
C <sub>6</sub> H <sub>14</sub>		C <sub>6</sub> H <sub>14</sub>
C <sub>7</sub> H <sub>8</sub>		C <sub>7</sub> H <sub>8</sub>
C <sub>7</sub> H <sub>16</sub>		C <sub>7</sub> H <sub>16</sub>
C <sub>8</sub> H <sub>10</sub>		C <sub>8</sub> H <sub>10</sub>
C <sub>8</sub> H <sub>18</sub>		C <sub>8</sub> H <sub>18</sub>
C <sub>10</sub> H <sub>8</sub>		C <sub>10</sub> H <sub>8</sub>
CHN compounds		CHN compounds
HCN/HNC		HCN/HNC
CH <sub>5</sub> N		CH <sub>5</sub> N
CH <sub>3</sub> CN		CH <sub>3</sub> CN
C <sub>2</sub> H <sub>7</sub> N		C <sub>2</sub> H <sub>7</sub> N
HC <sub>3</sub> N		HC <sub>3</sub> N
C <sub>2</sub> N <sub>2</sub>		C <sub>2</sub> N <sub>2</sub>
C <sub>3</sub> H <sub>9</sub> N		C <sub>3</sub> H <sub>9</sub> N
		CH <sub>2</sub> (OH)CH <sub>2</sub> (OH)
		CH <sub>3</sub> COOCH <sub>3</sub>
		C <sub>7</sub> H <sub>6</sub> O <sub>2</sub> <sup>b</sup>
		CHON compounds <sup>e</sup>
		CHNO
		CH <sub>3</sub> NO
		CH <sub>3</sub> CONH <sub>2</sub>
		C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub>
		CHS compounds
		CH <sub>2</sub> S
		CH <sub>4</sub> S
		C <sub>2</sub> H <sub>6</sub> S
		(CH <sub>3</sub> )S(CH <sub>3</sub> )
		CHS <sub>2</sub> compounds
		CH <sub>4</sub> S <sub>2</sub>
		CHCl compounds
		CH <sub>3</sub> Cl



# Comets



**67/P**  
macromolecular  
organics

CI chondrite for  
reference



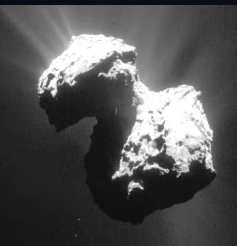
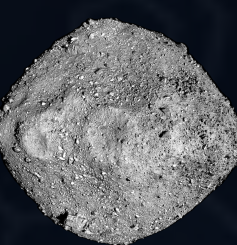
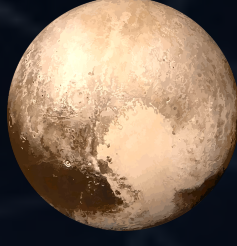
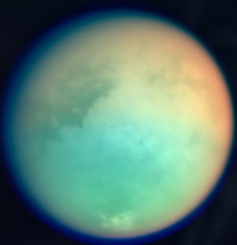
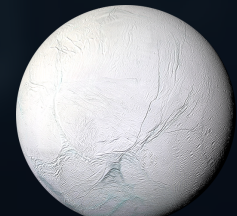
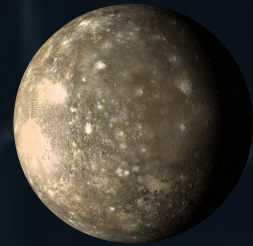
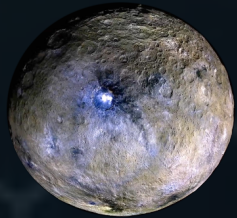
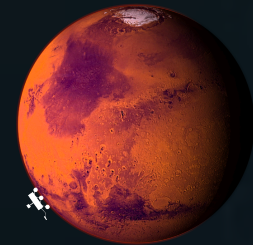
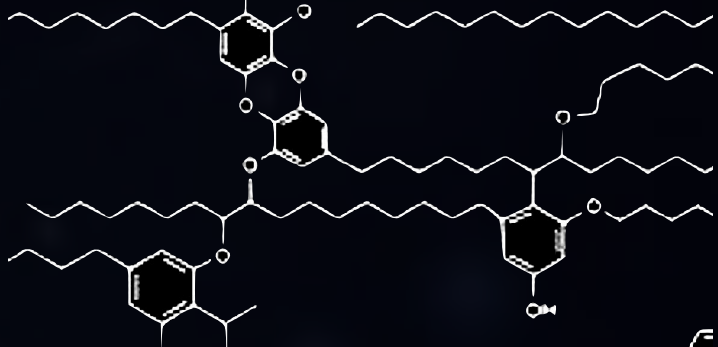
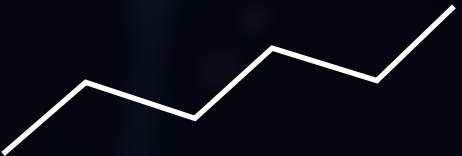
# Summary

Remote

In situ

org-N

org-O





# Organics detected on spaceflight missions

Review of organic compounds detected by spacecraft to date

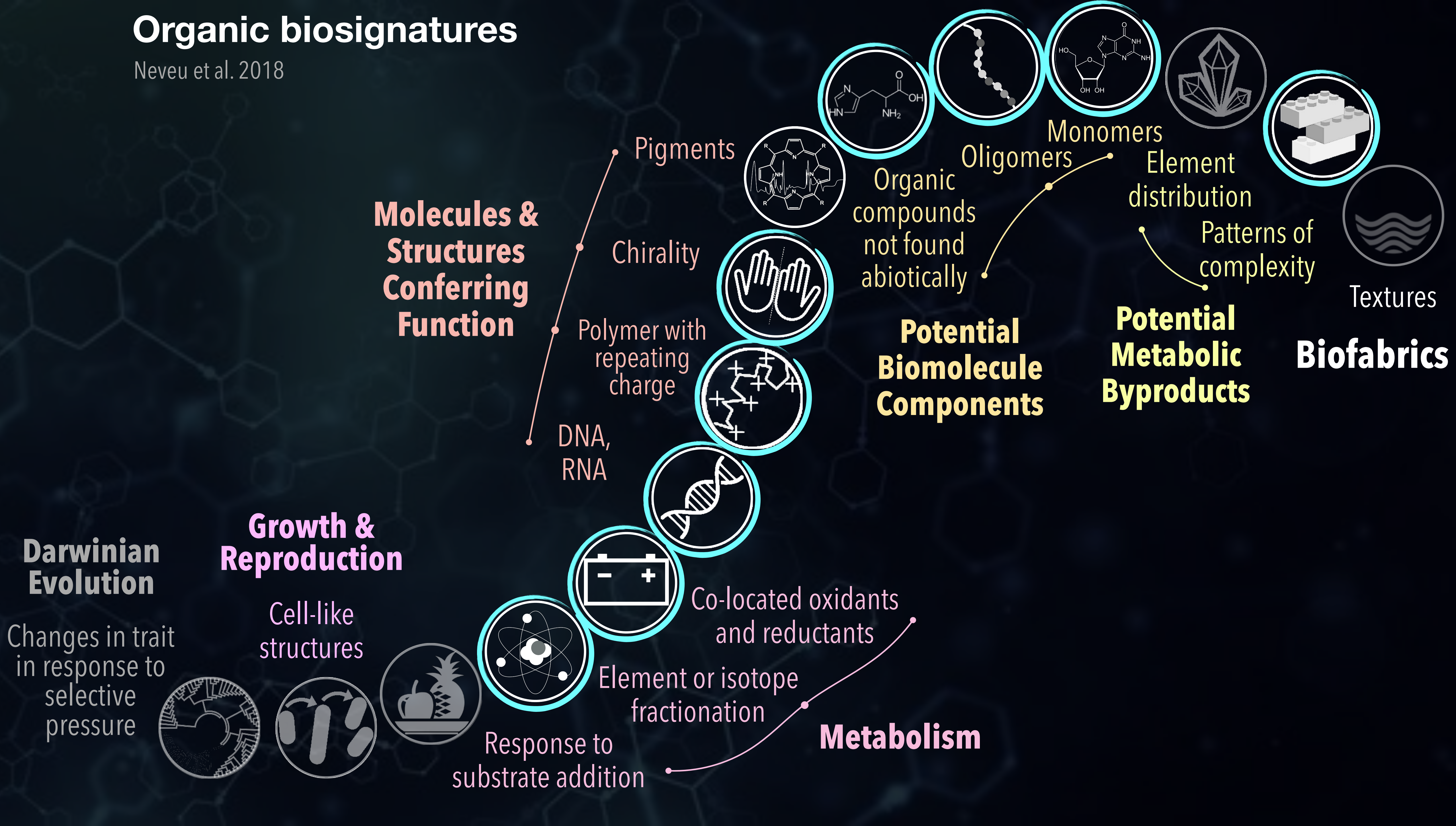
Organic biosignatures

Upcoming missions, with focus on Enceladus and Ceres



# Organic biosignatures

Neveu et al. 2018





# Organic biosignatures

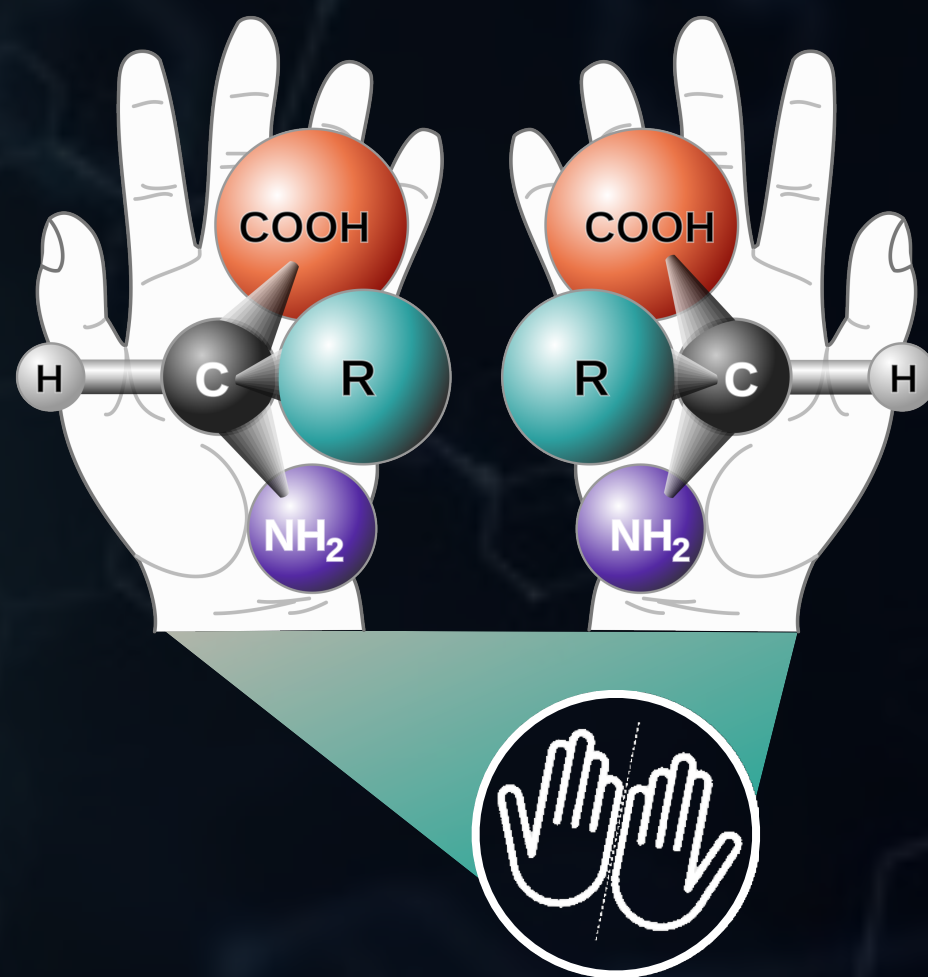
Modified from Origins,  
Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

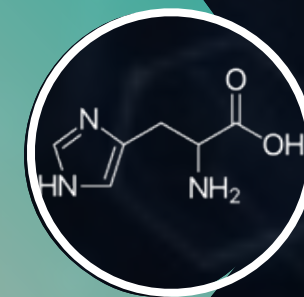
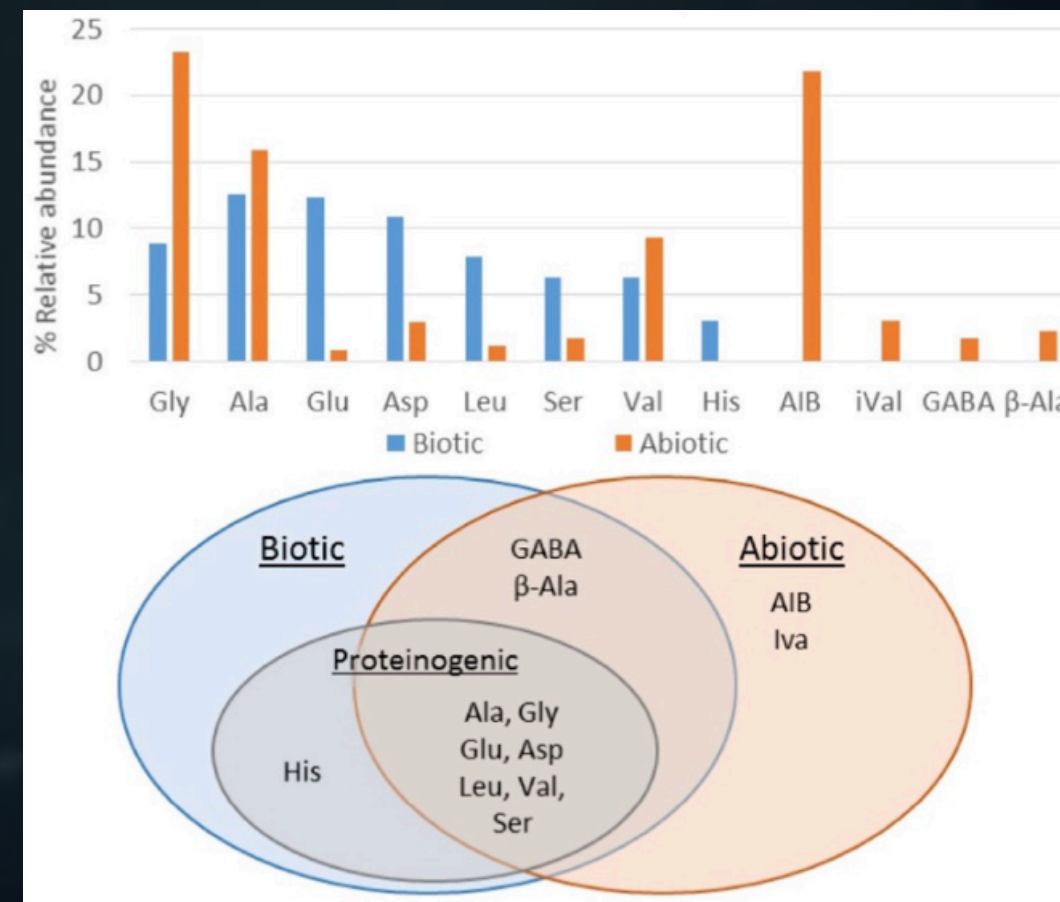
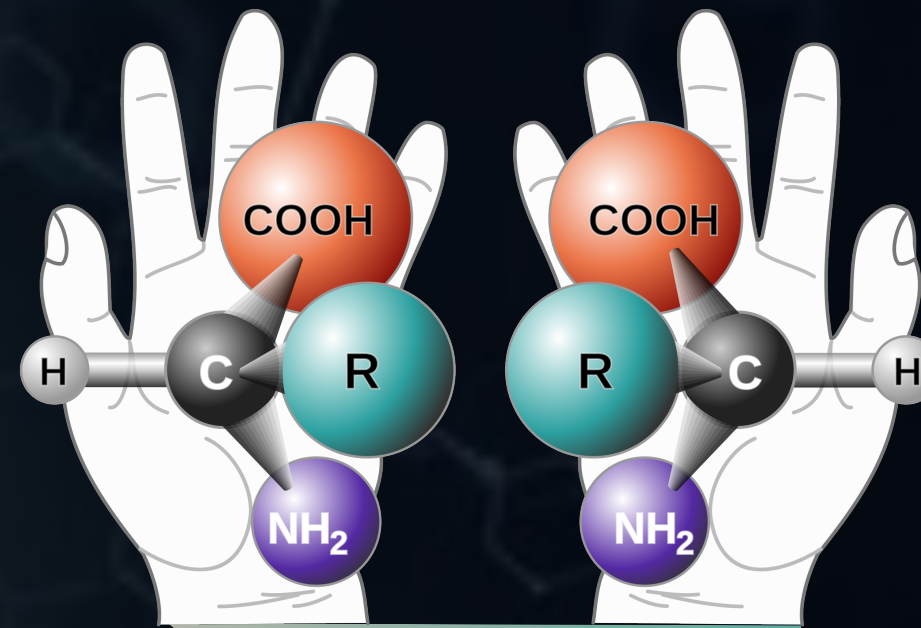
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Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

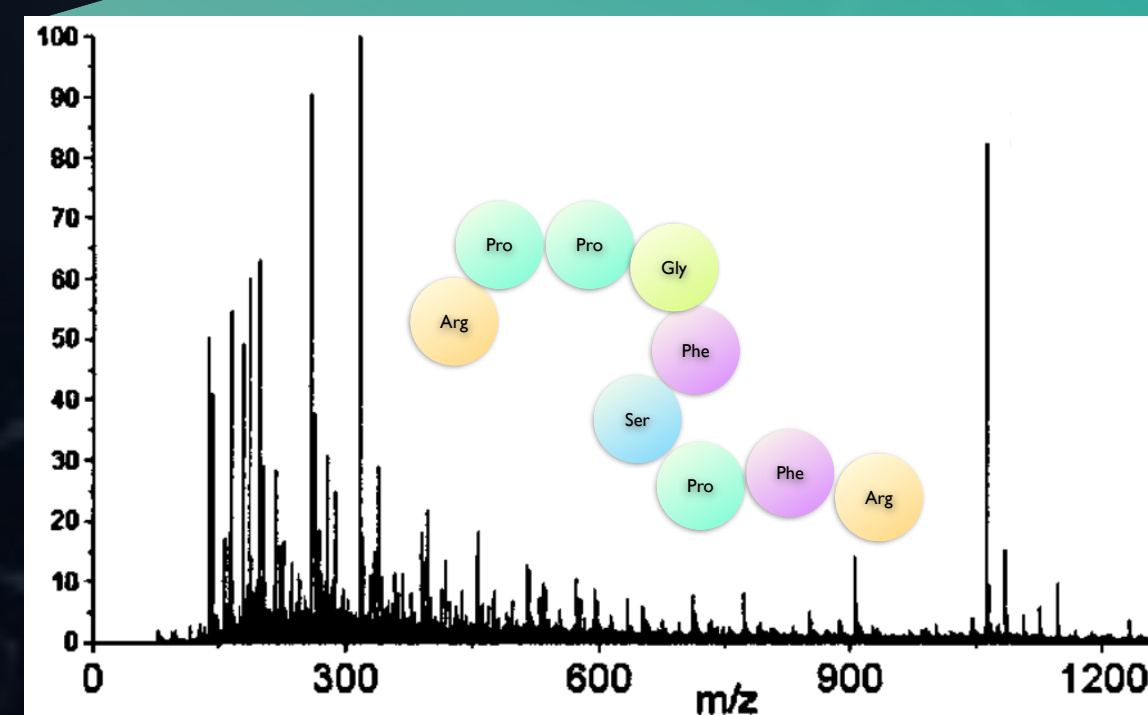
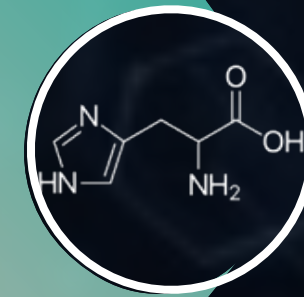
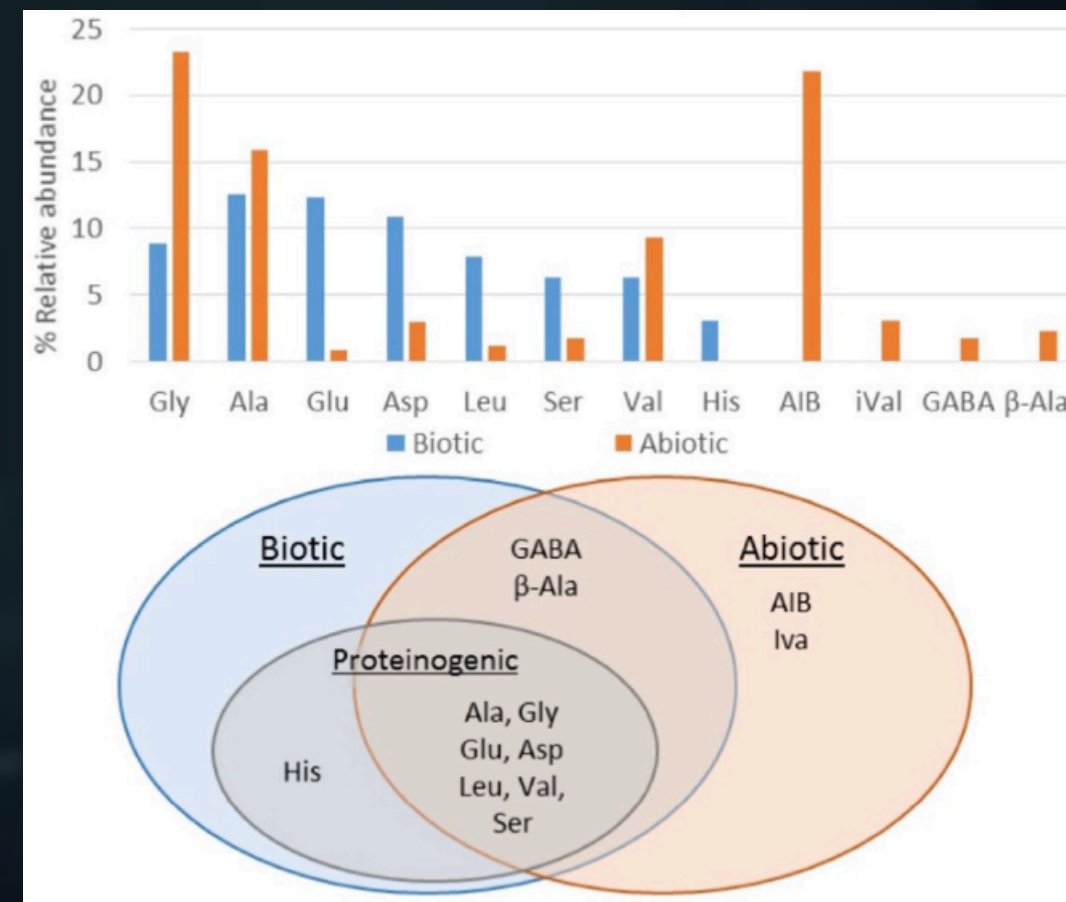
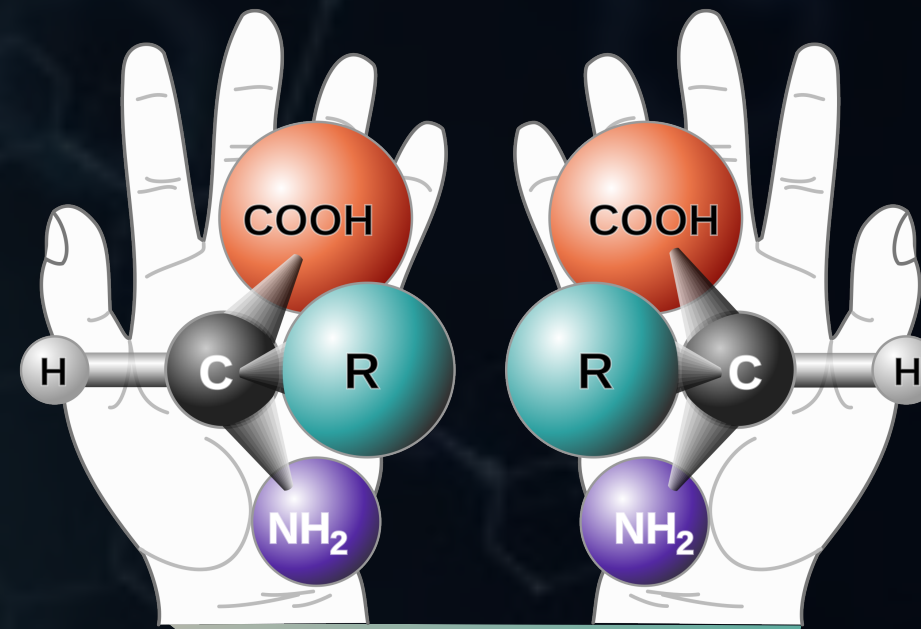
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Survey 2023-2032





# Organic biosignatures

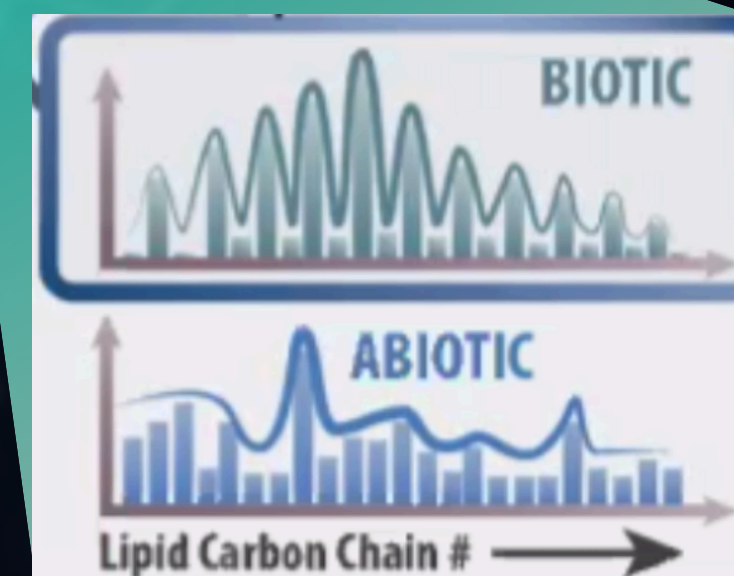
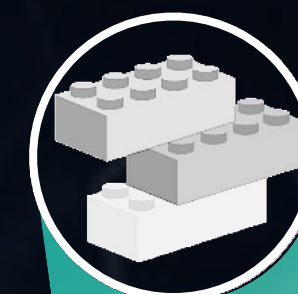
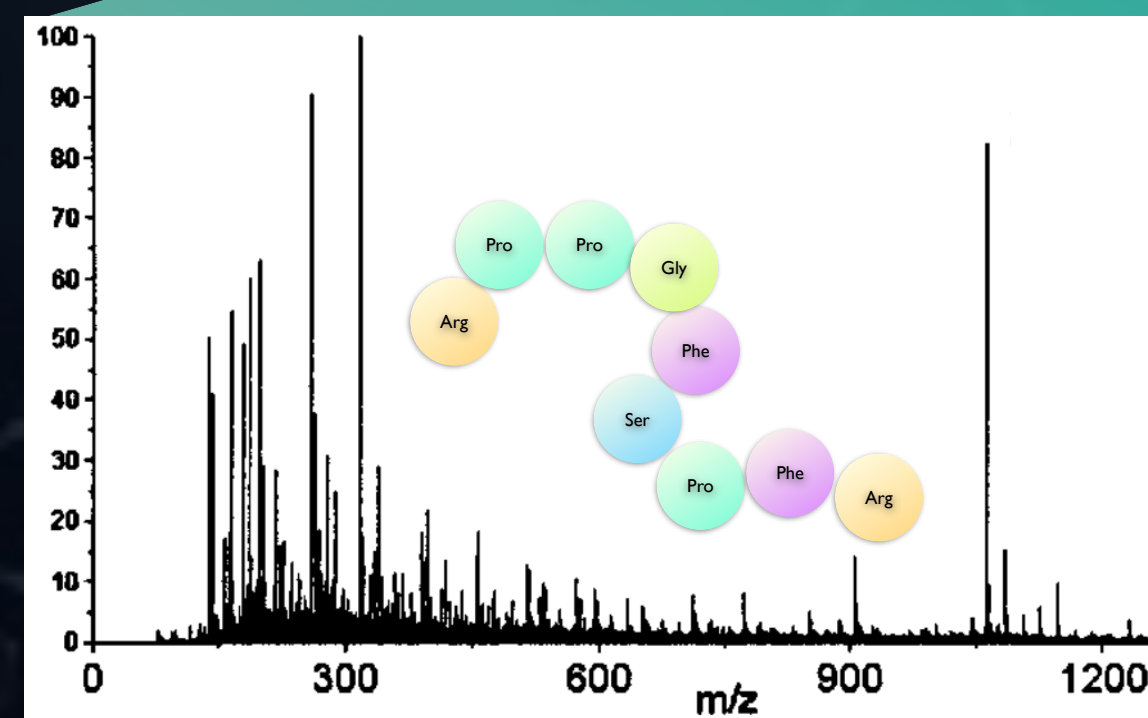
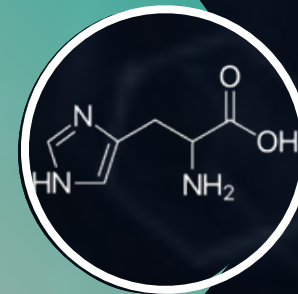
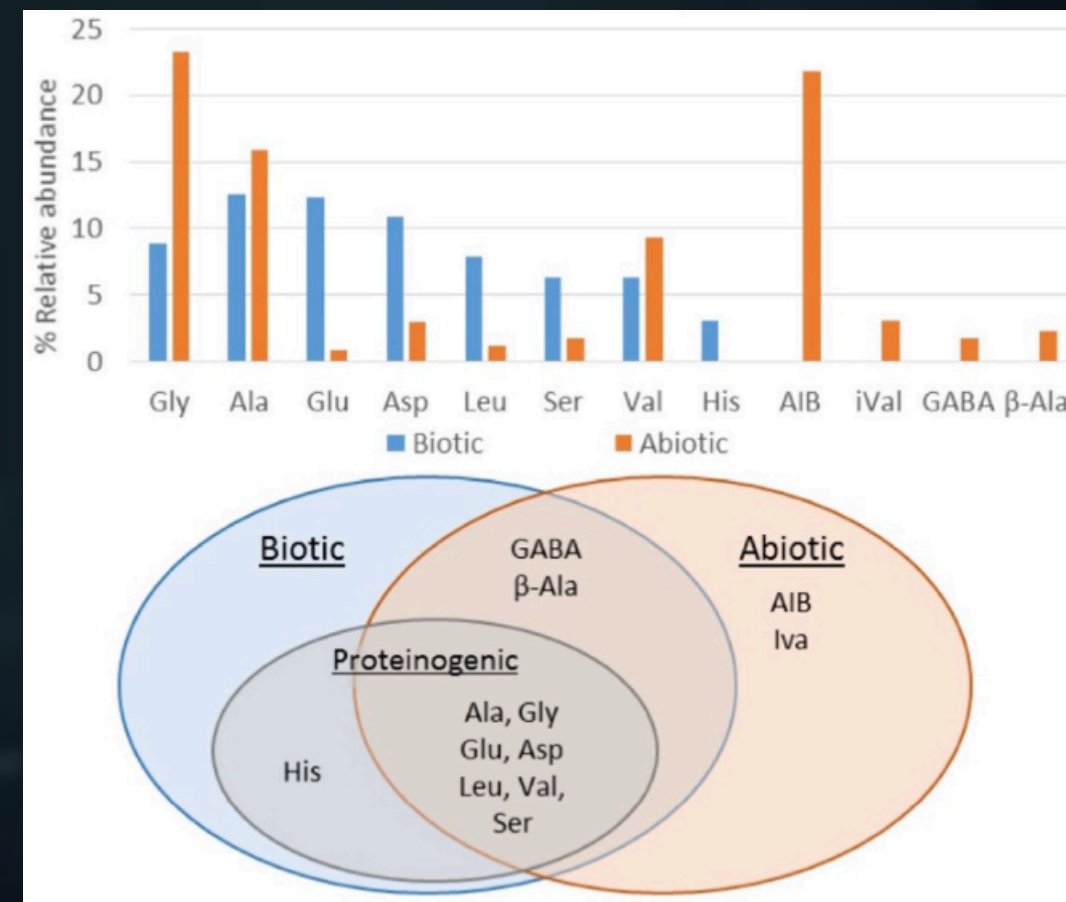
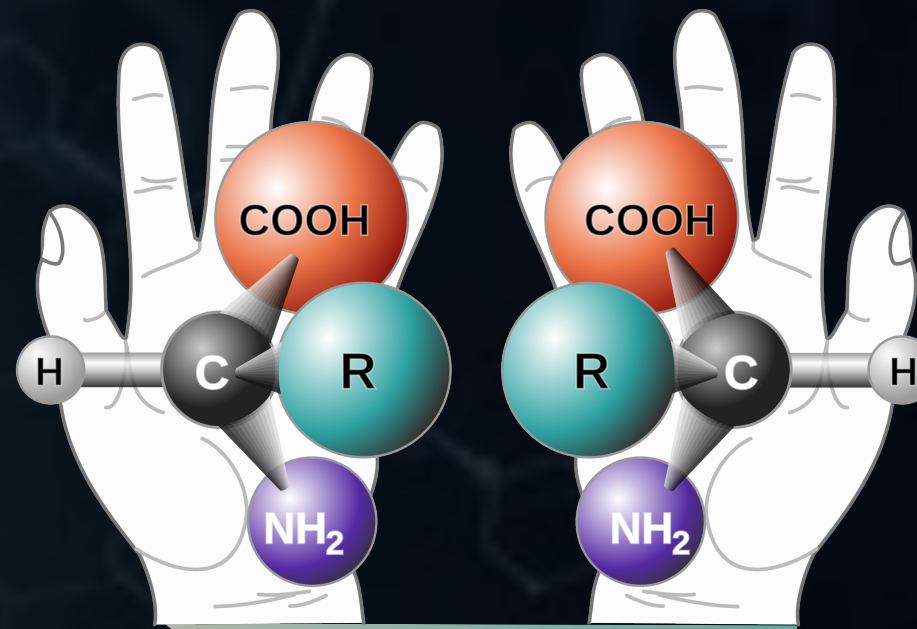
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Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

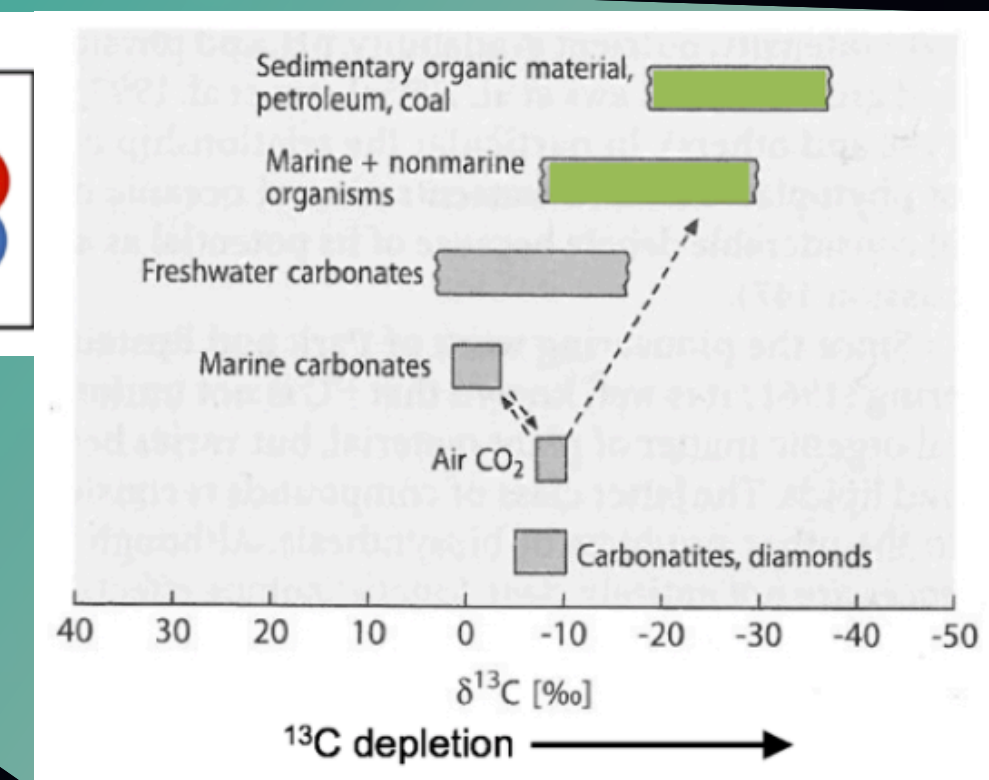
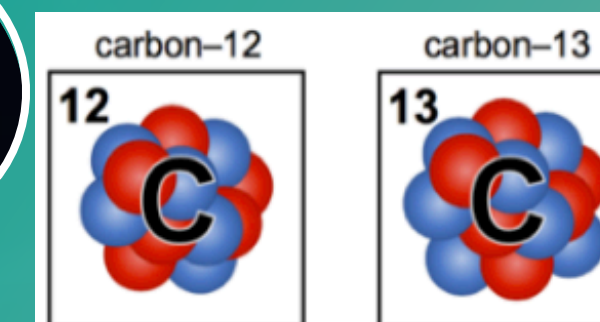
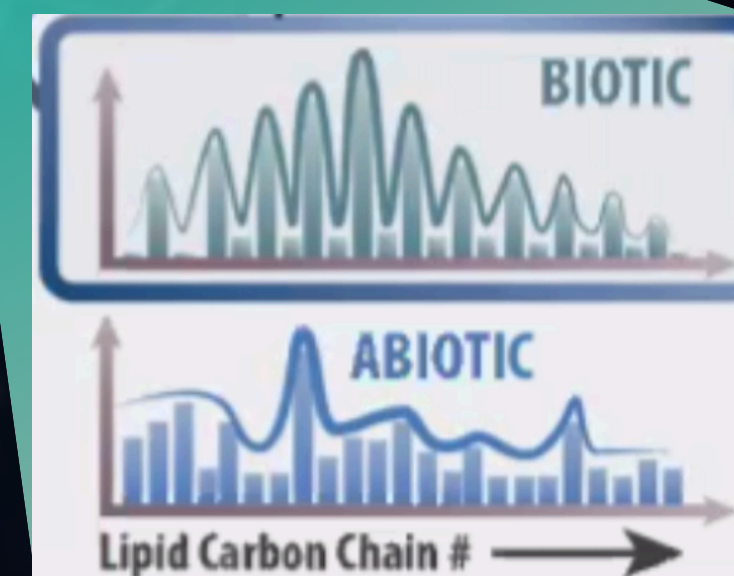
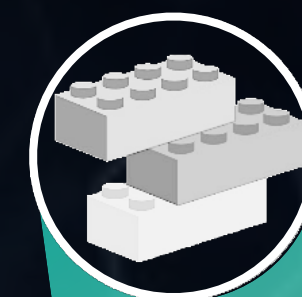
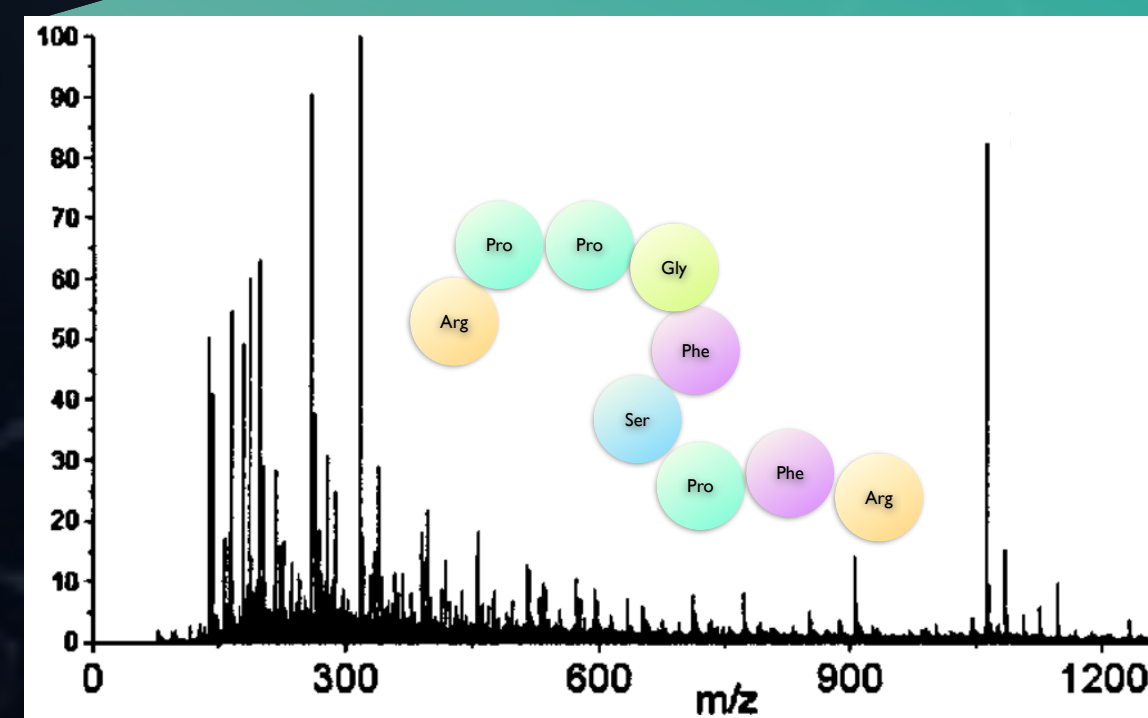
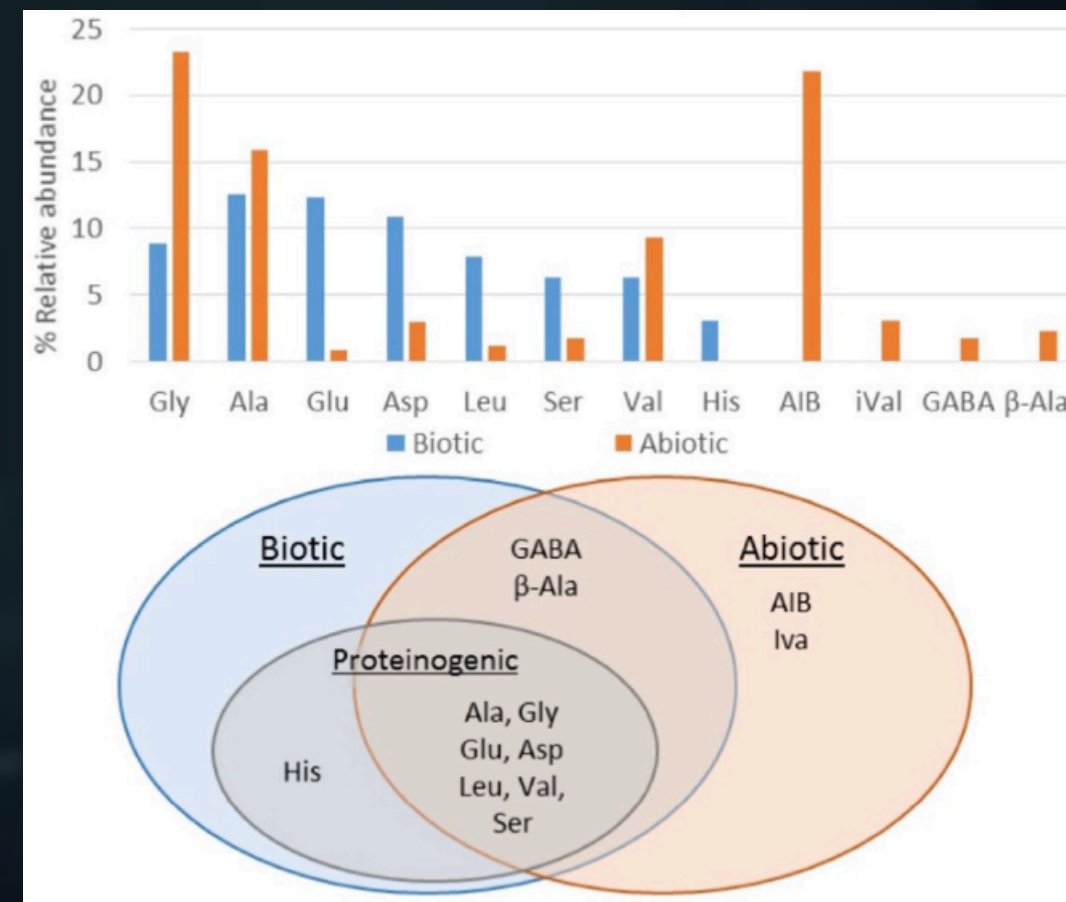
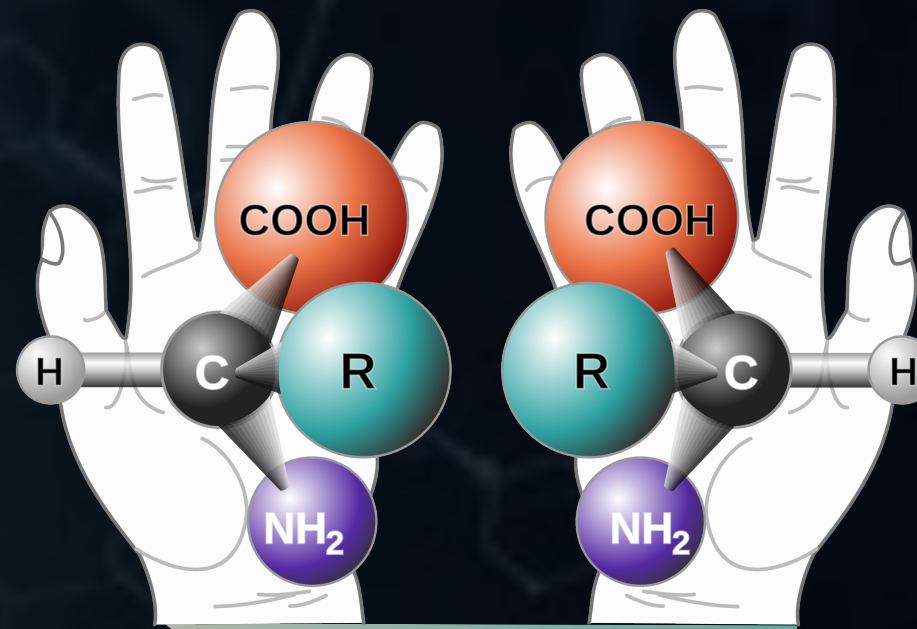
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Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

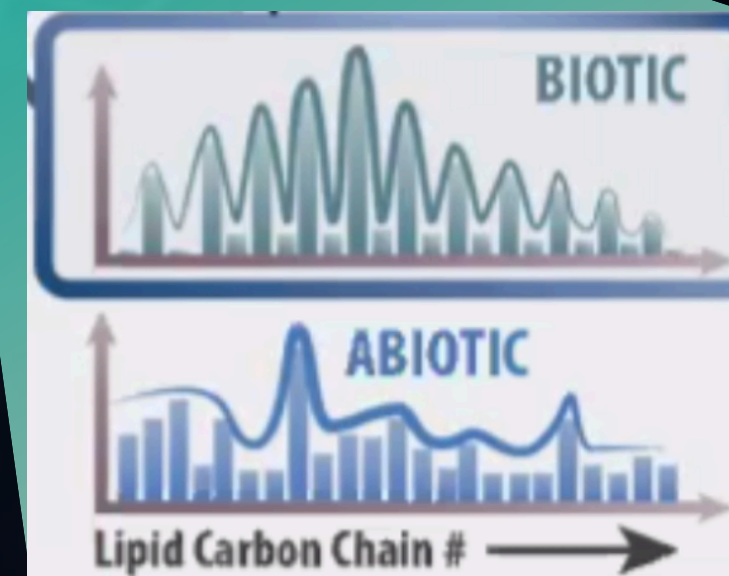
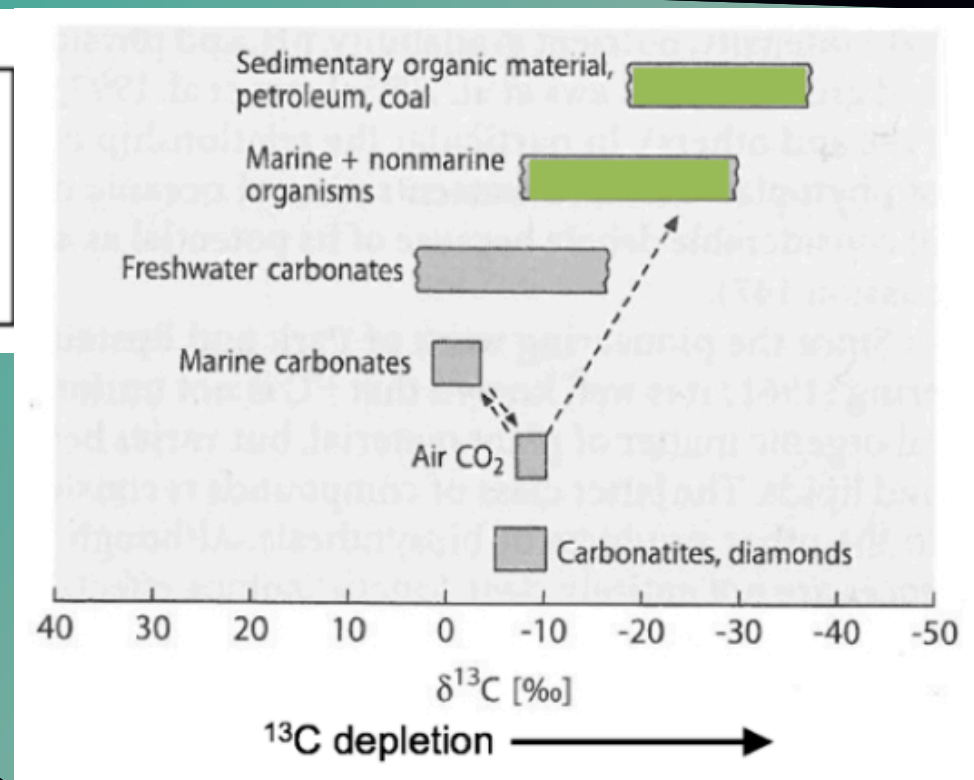
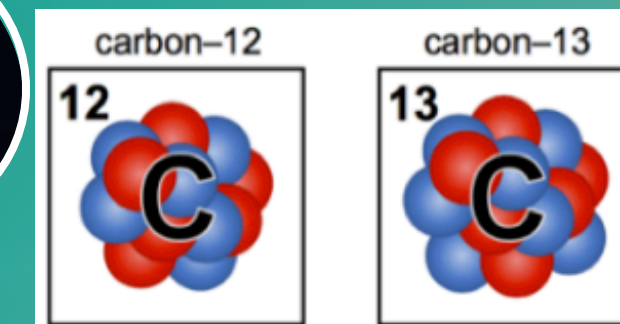
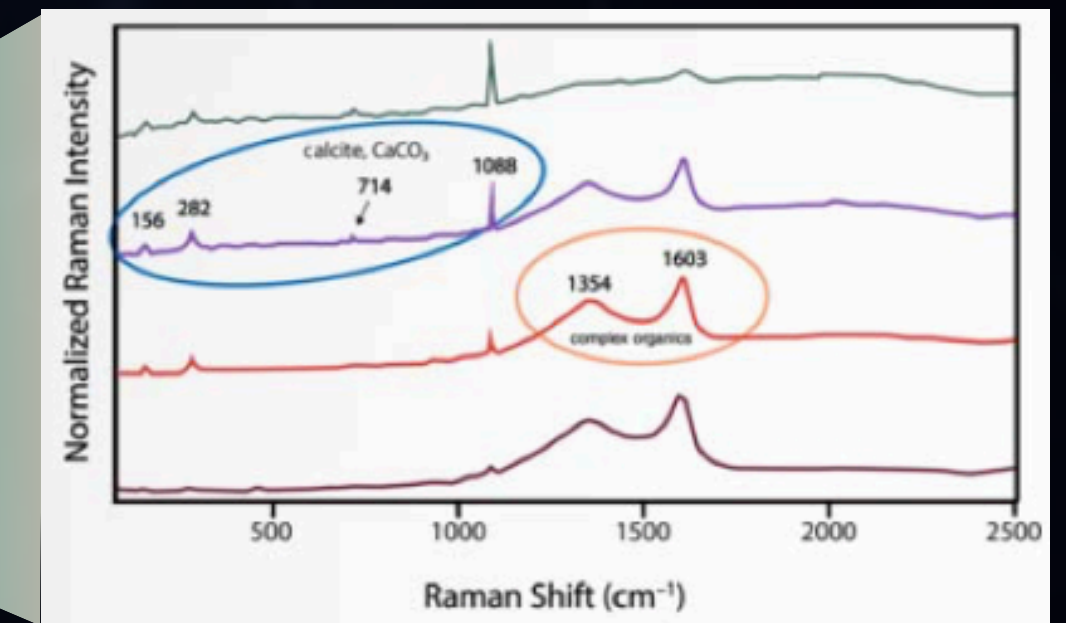
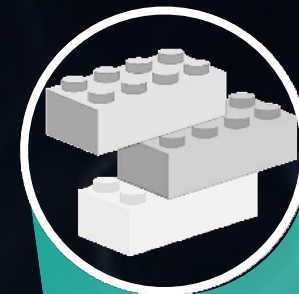
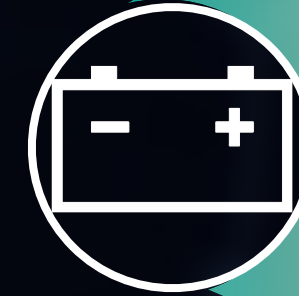
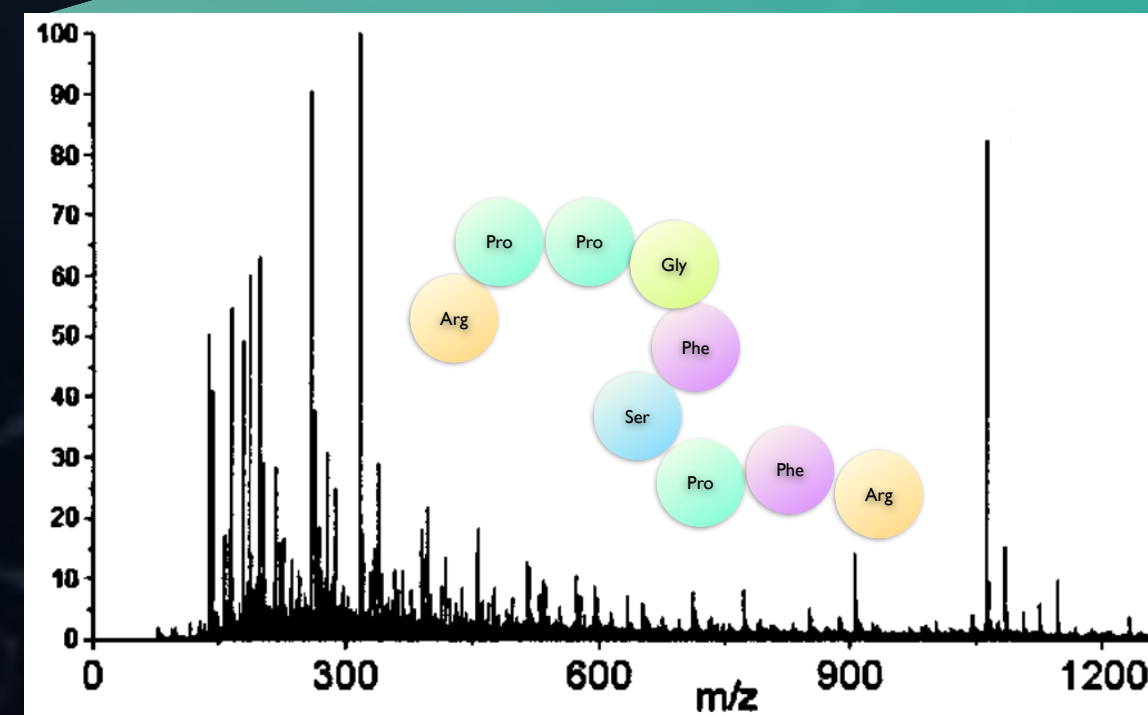
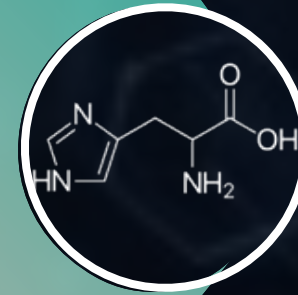
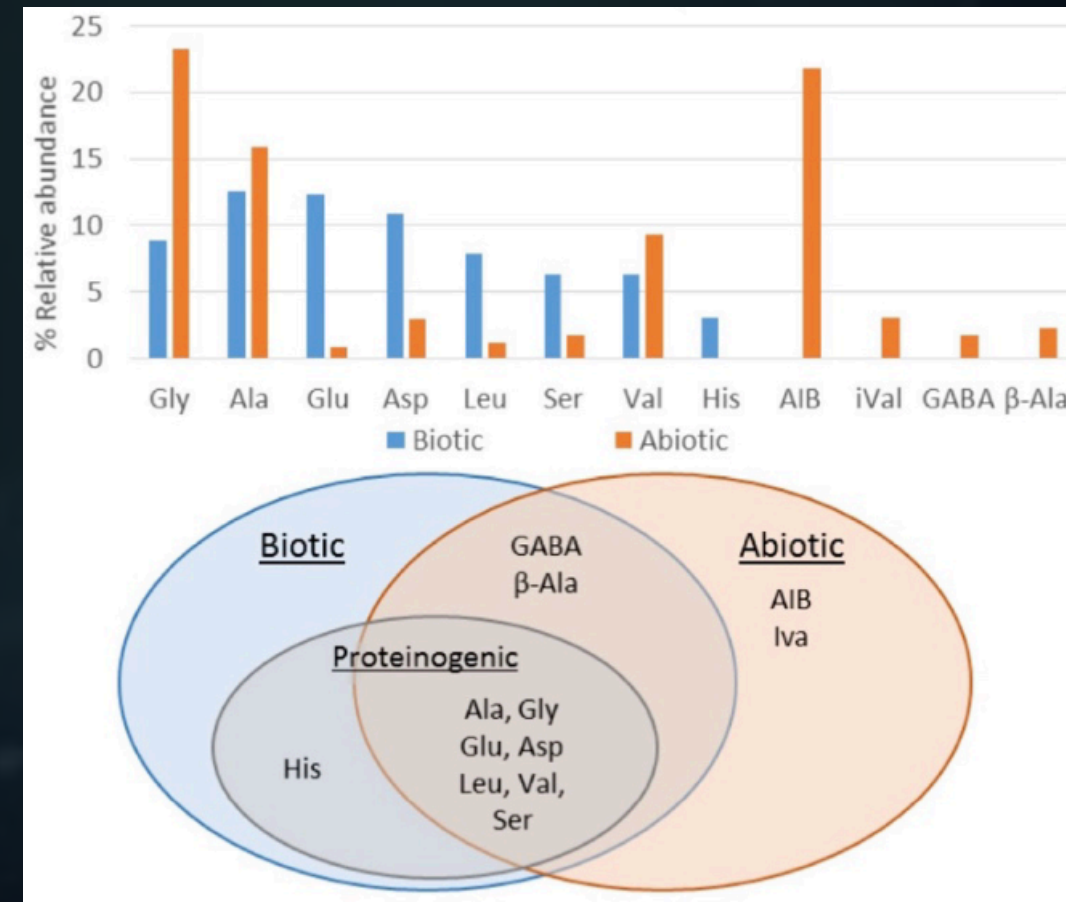
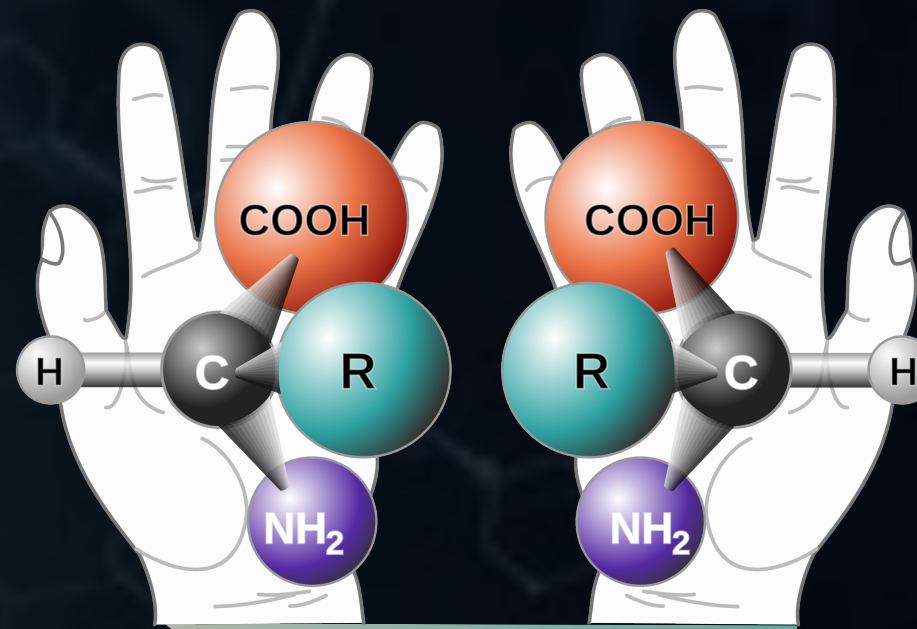
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Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

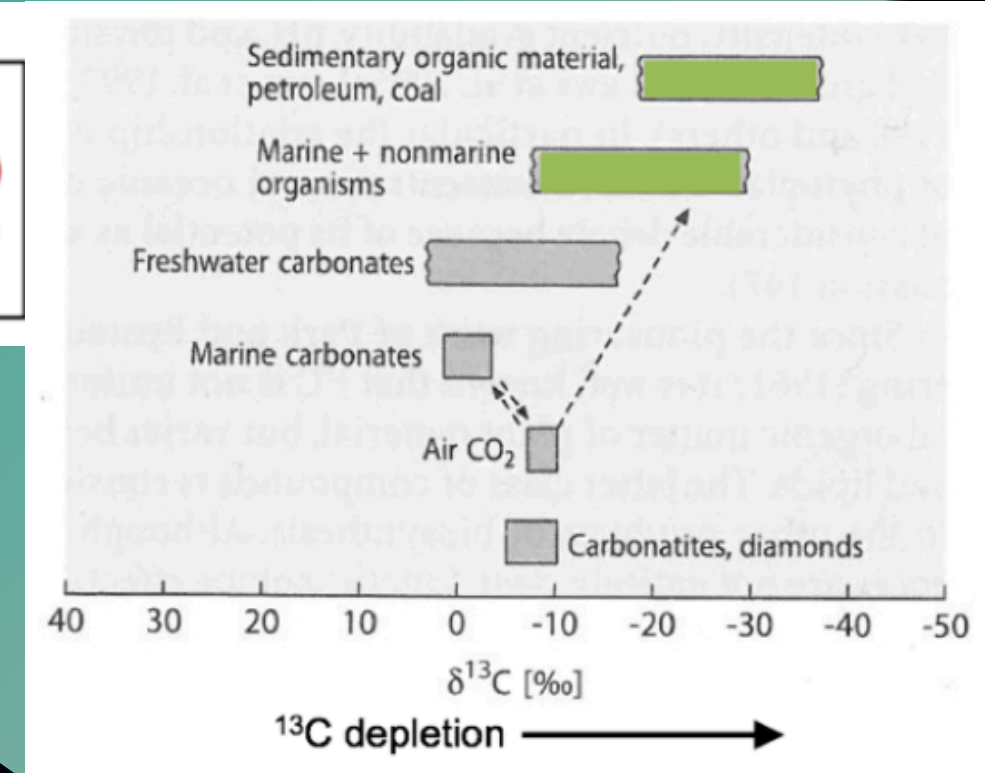
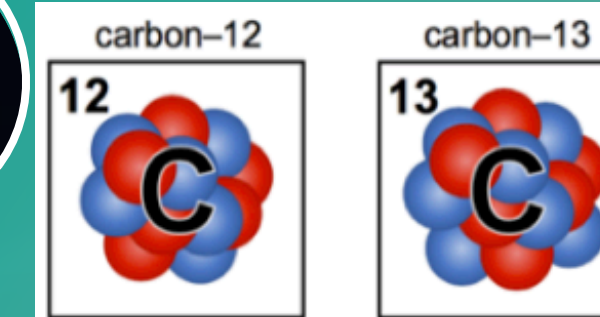
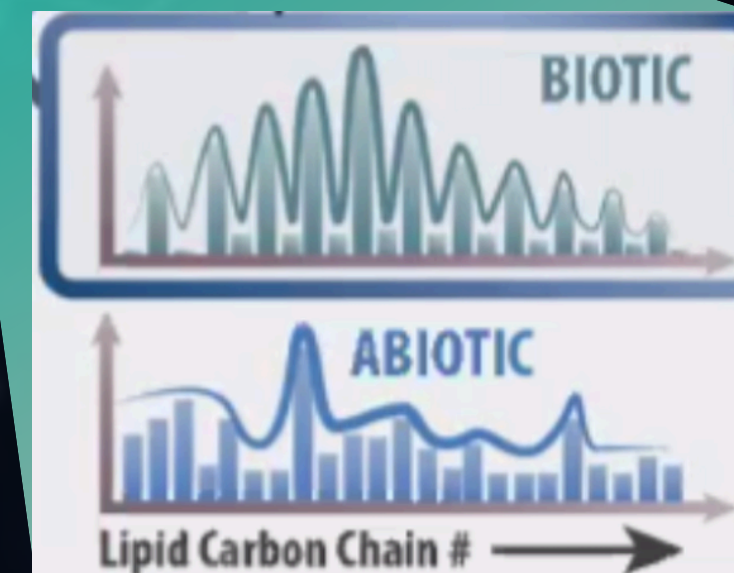
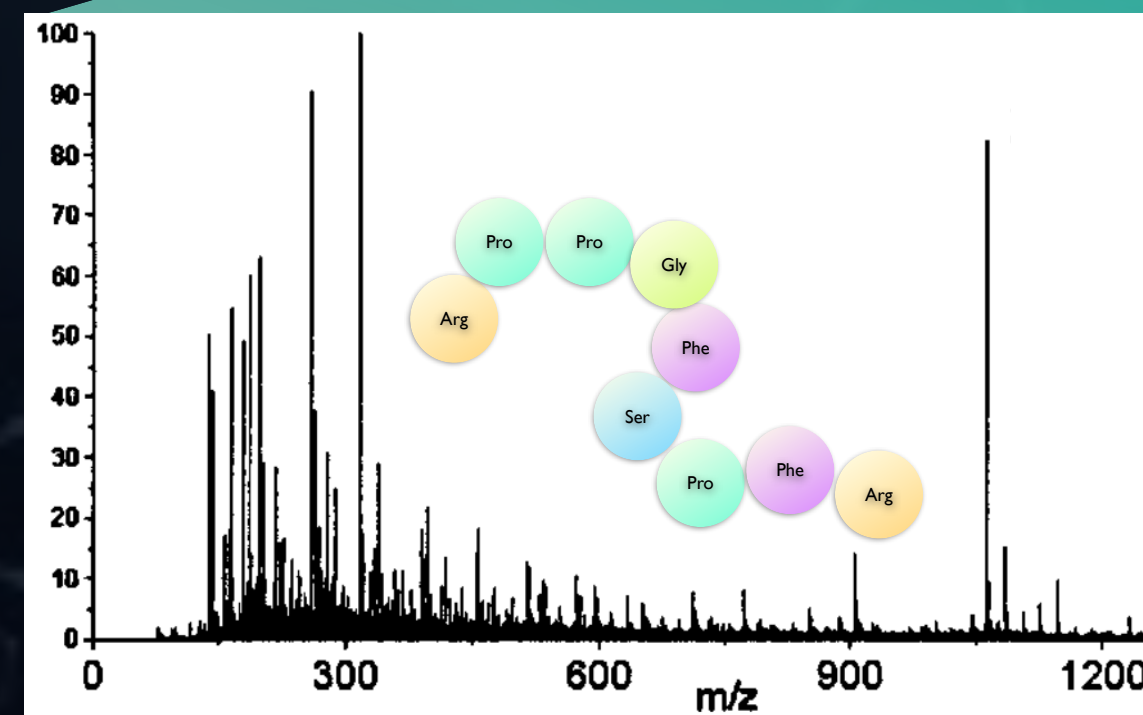
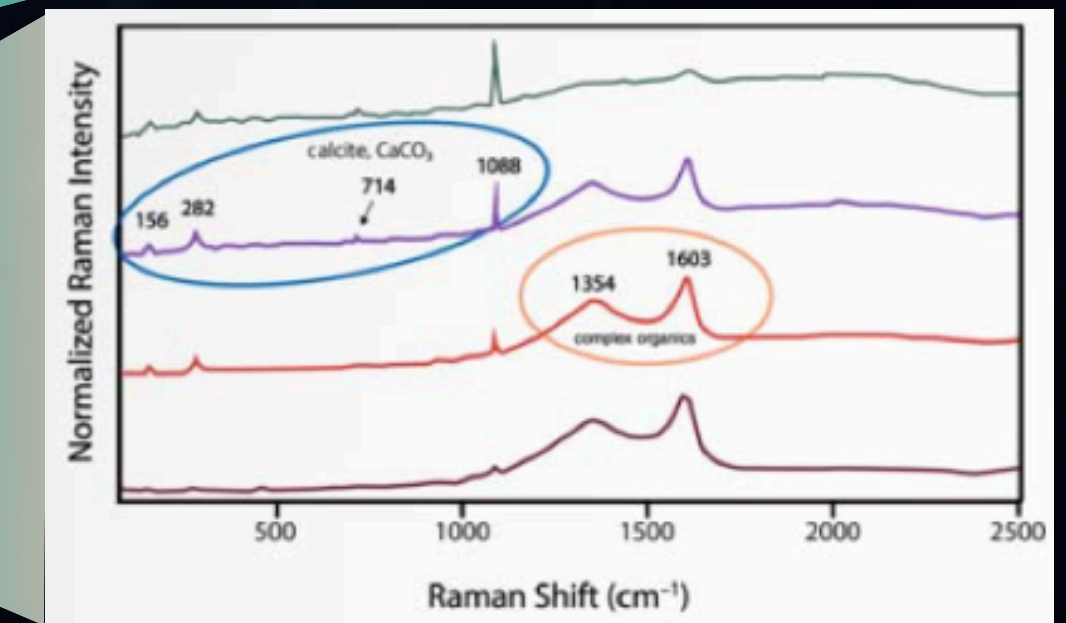
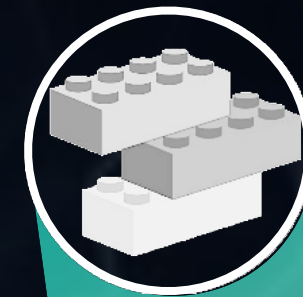
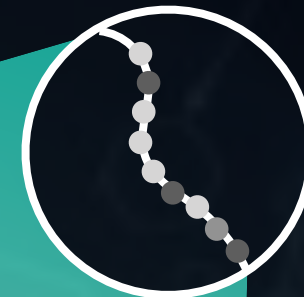
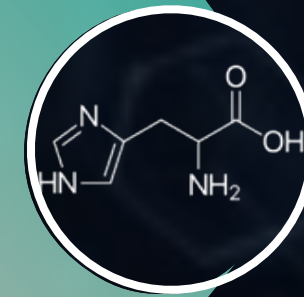
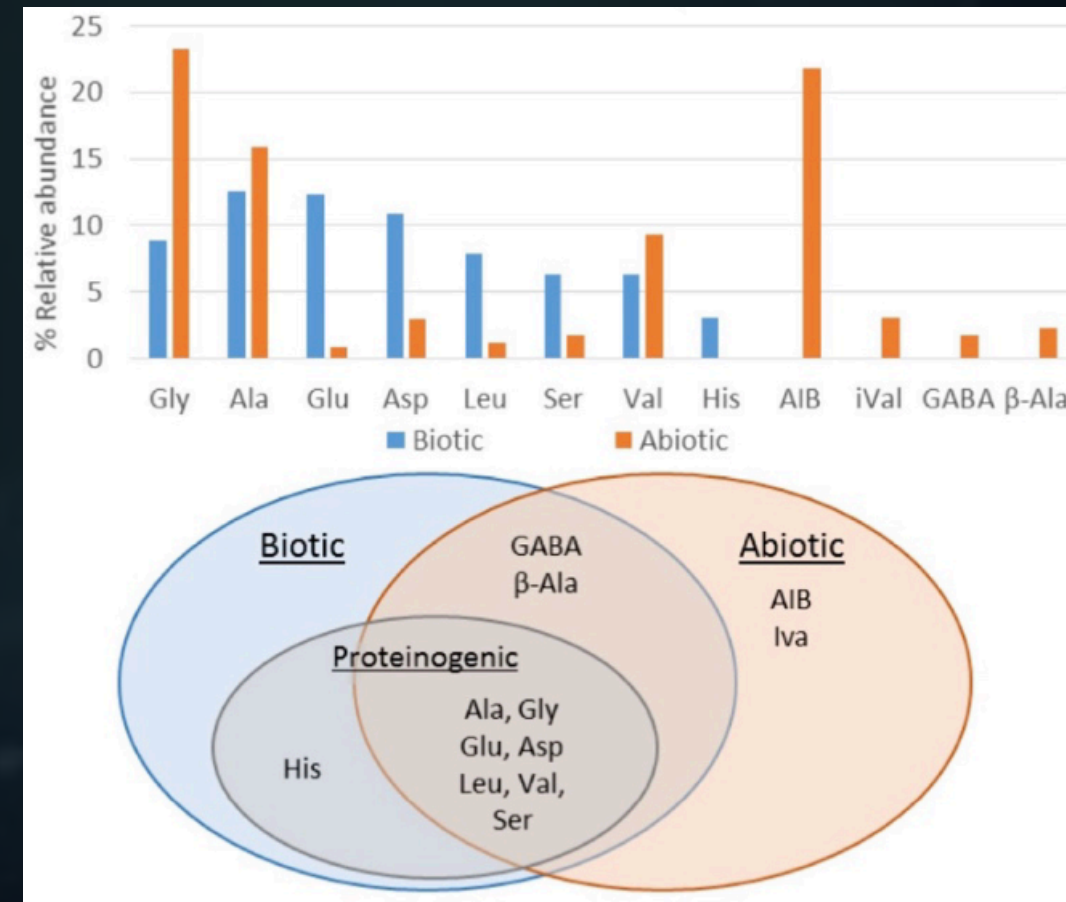
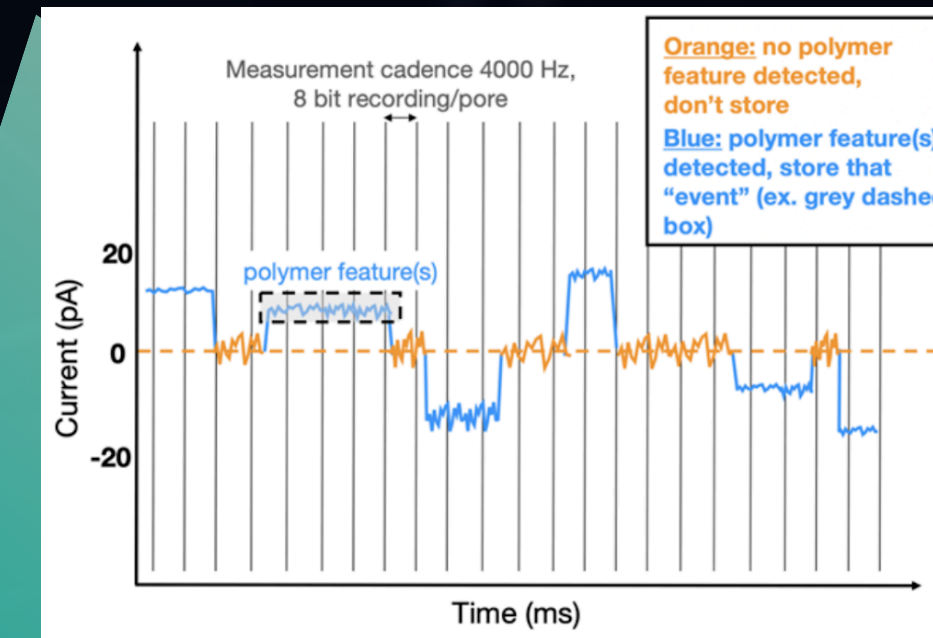
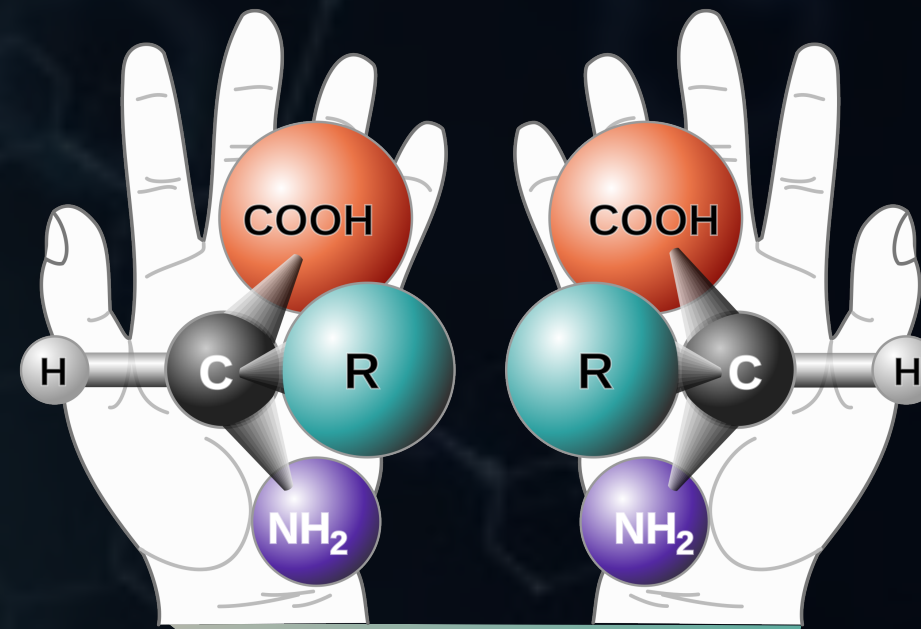
Modified from Origins,  
Worlds, & Life Decadal  
Survey 2023-2032





# Organic biosignatures

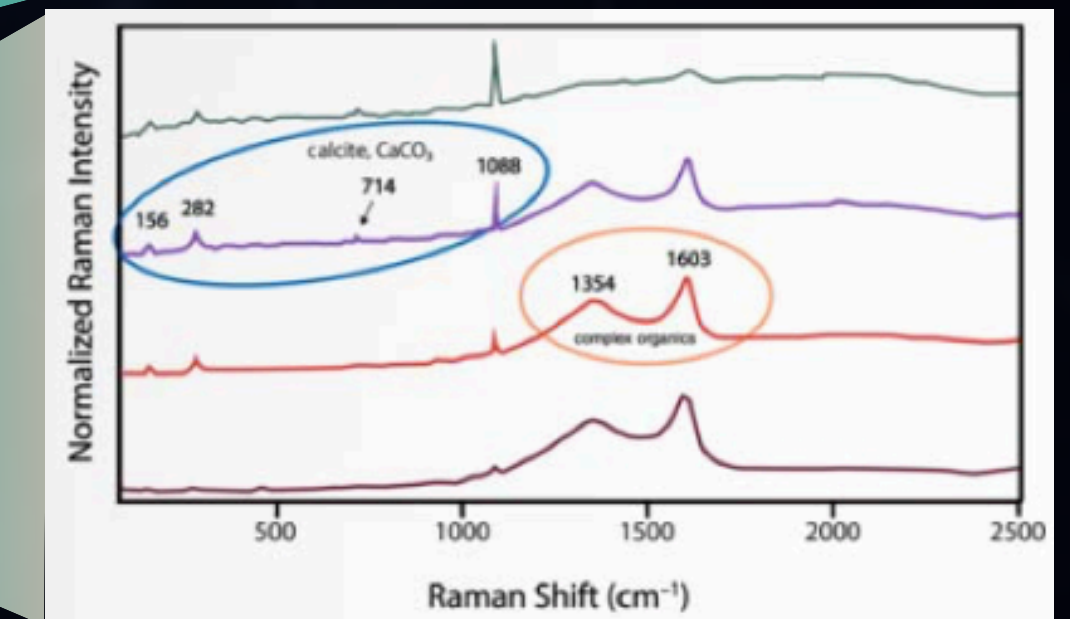
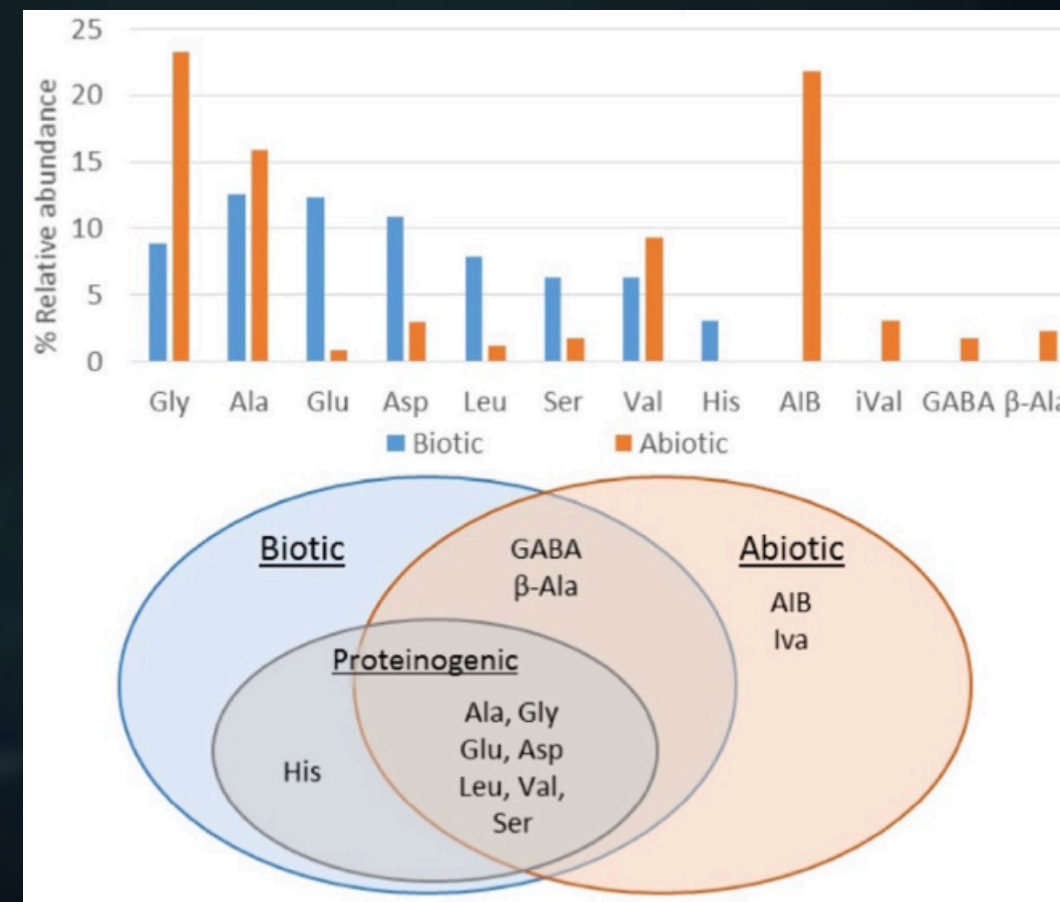
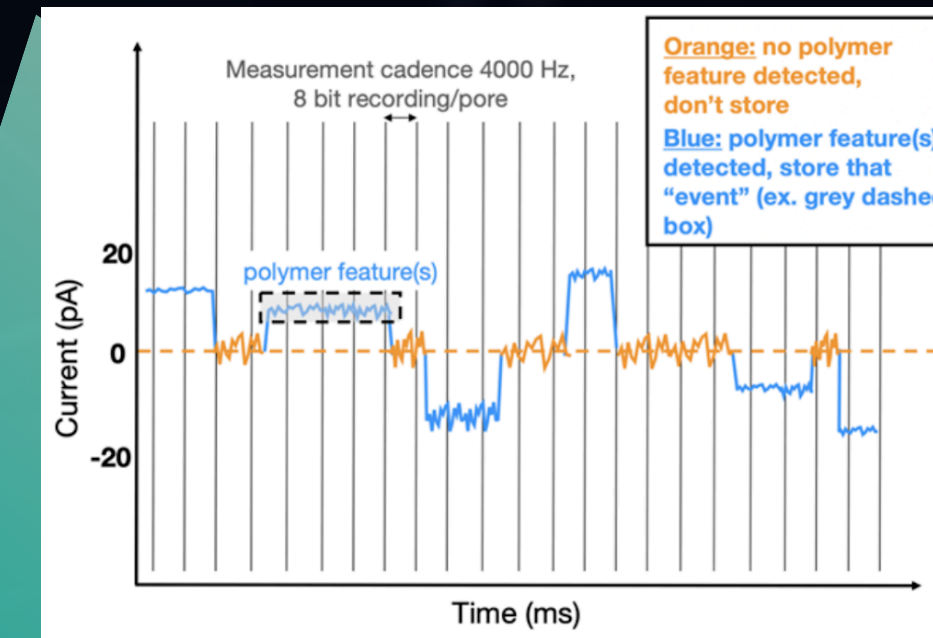
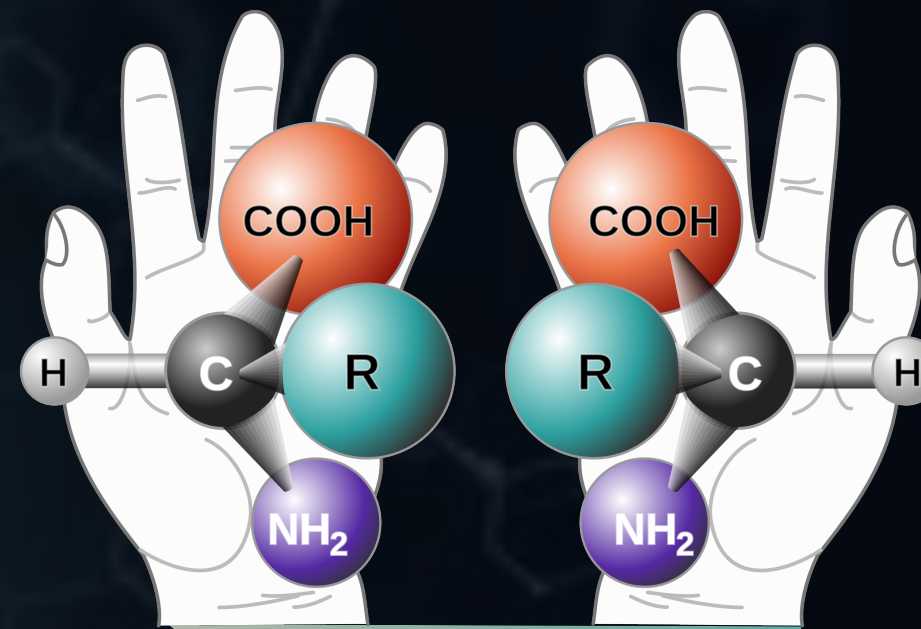
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# Organic biosignatures

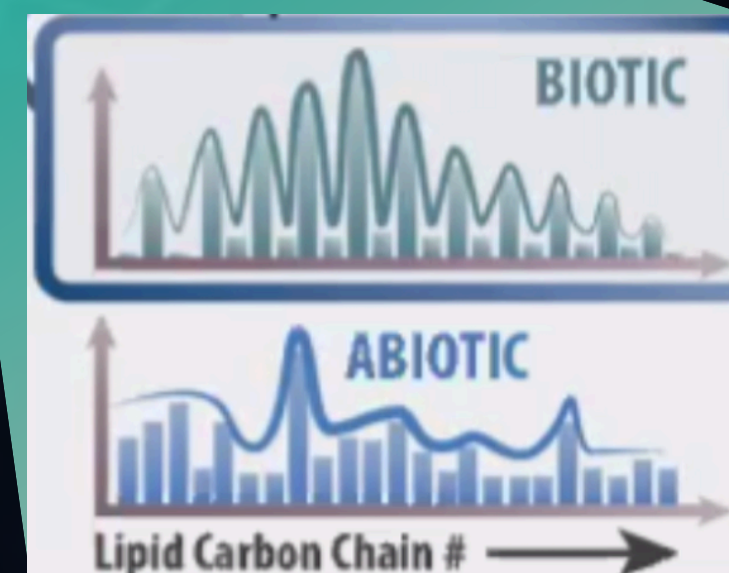
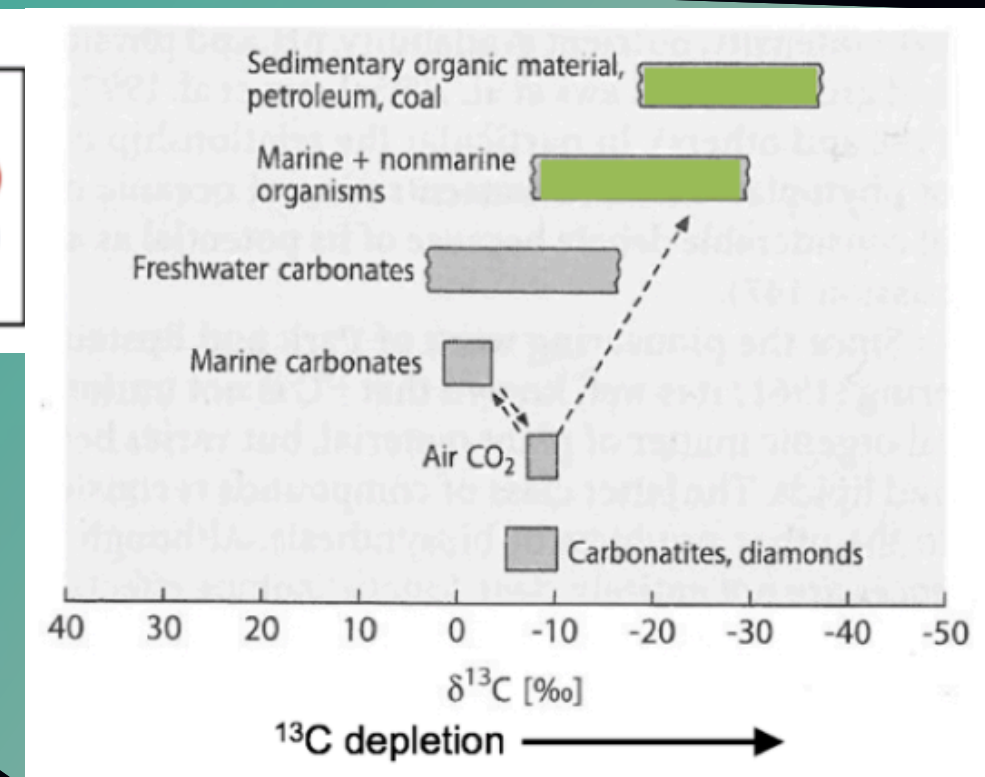
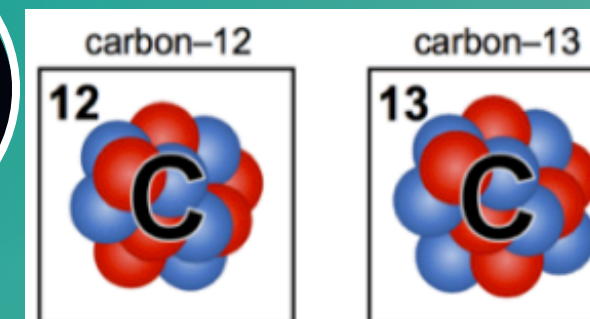
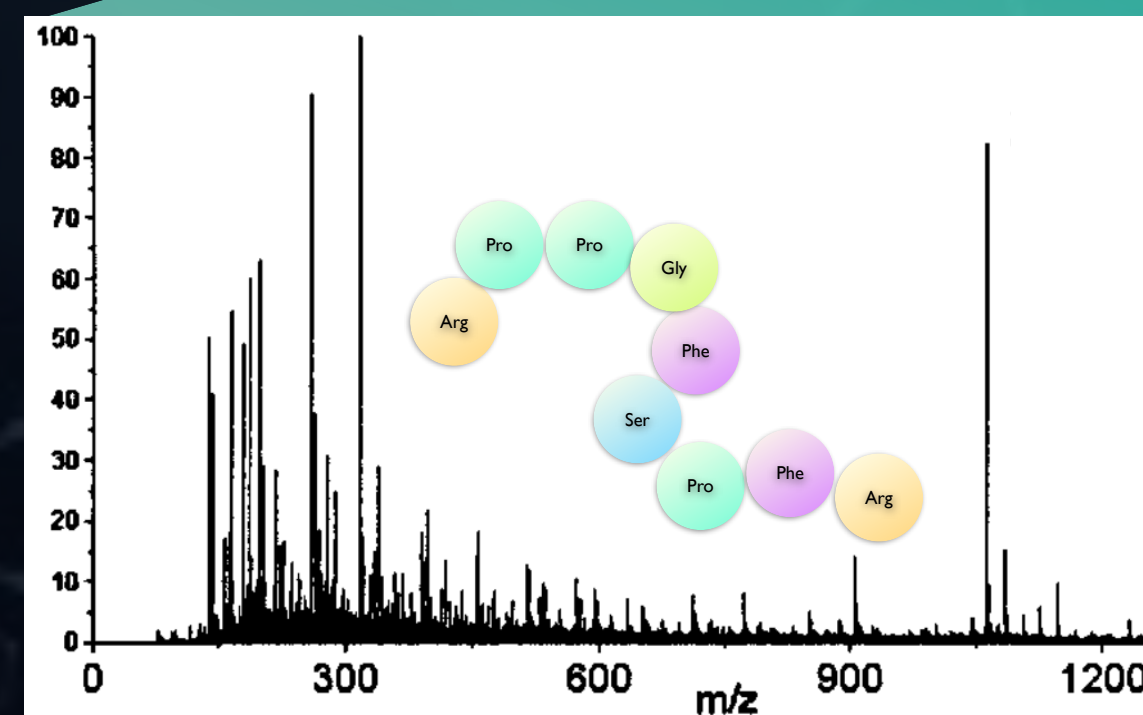
Modified from Origins,  
Worlds, & Life Decadal  
Survey 2023-2032



**Chiral Asymmetry**  
(D > L or L > D)

**Light Isotopic Composition**  
(relative to inorganic matter;  
enantiomers show similar values)

**Simple Distribution**  
(structural isomer preference)





# Organics detected on spaceflight missions

Review of organic compounds detected by spacecraft to date

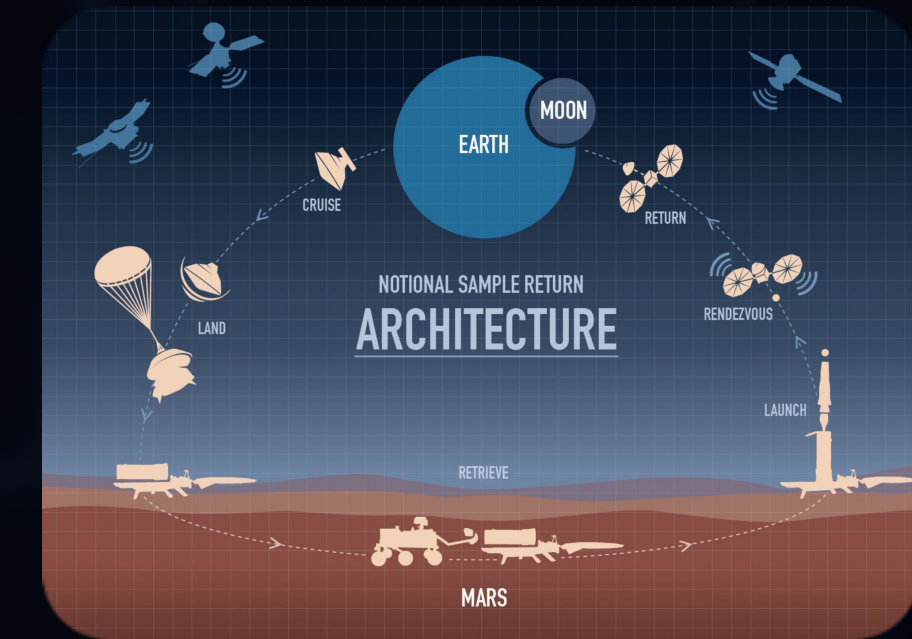
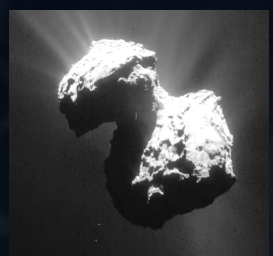
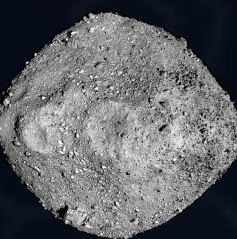
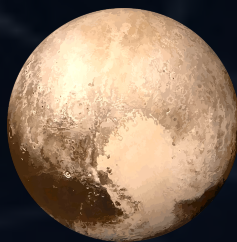
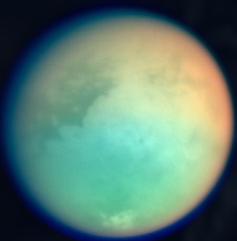
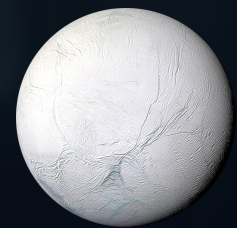
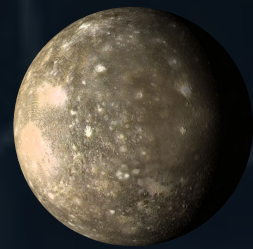
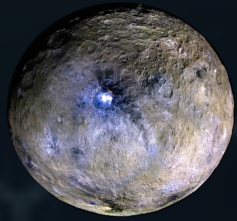
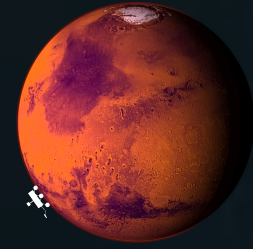
Organic biosignatures

Upcoming missions, with focus on Enceladus and Ceres



# What's next: Mission concepts

## Mars Sample return, Mars Life Explorer

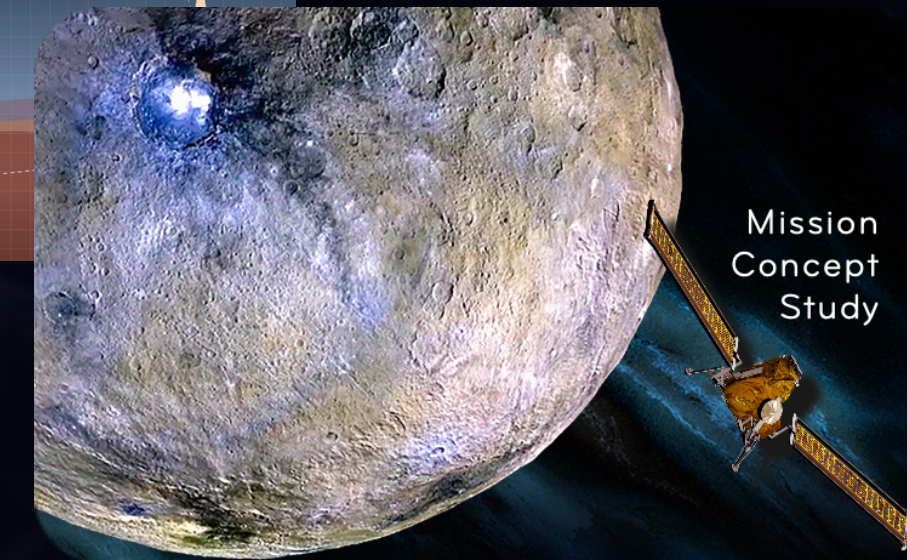
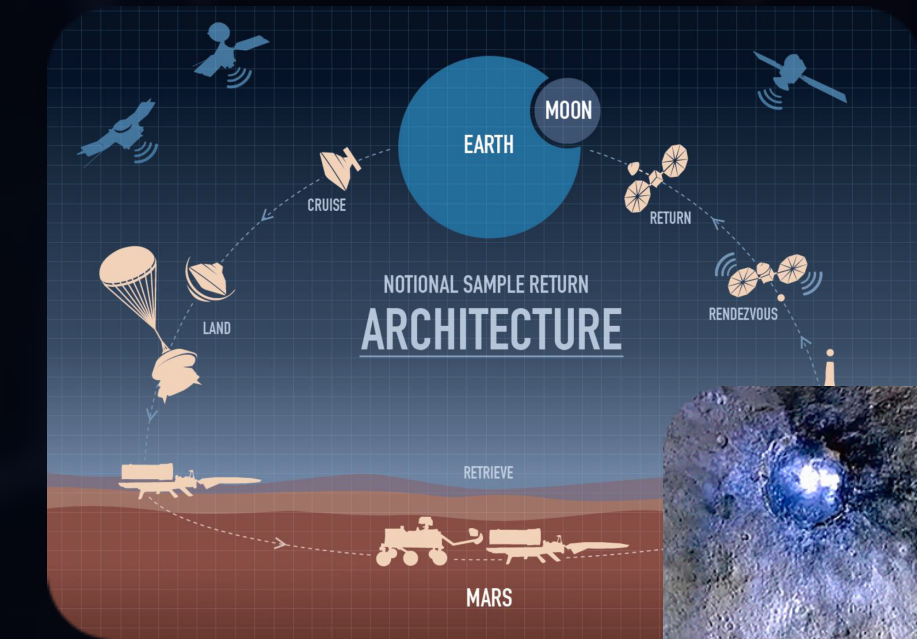
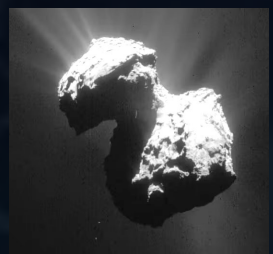
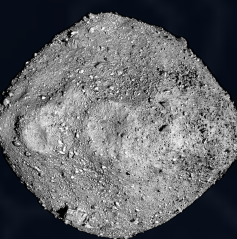
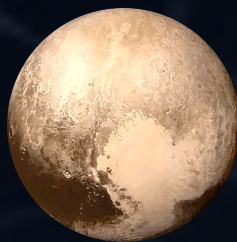
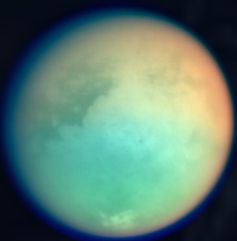
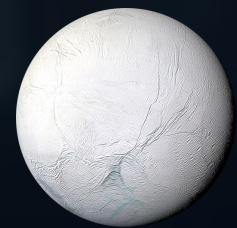
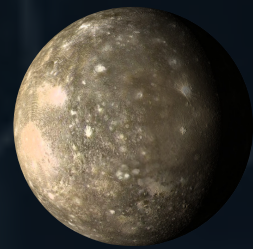
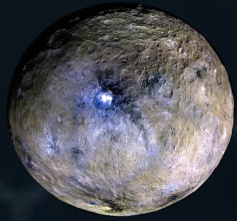
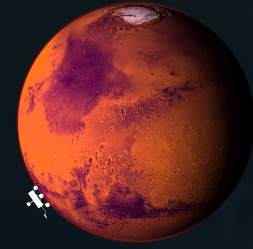




# What's next: Mission concepts

Mars Sample return, Mars Life Explorer

Ceres Sample Return



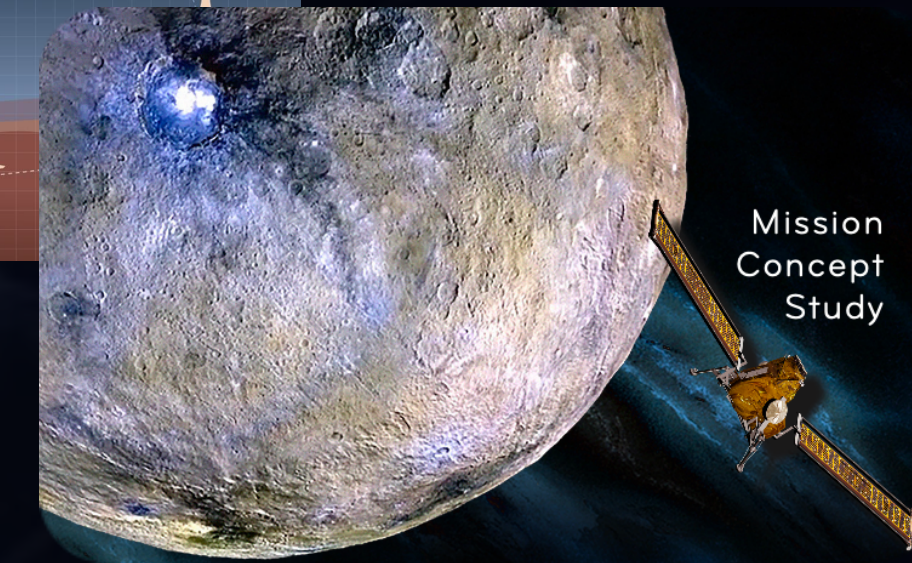
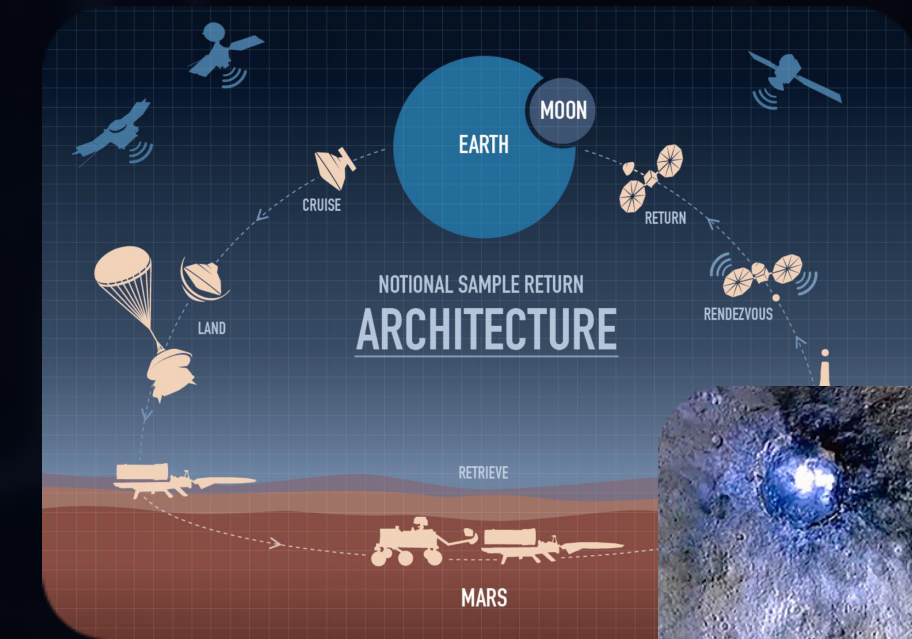
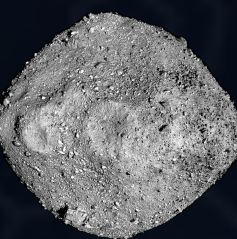
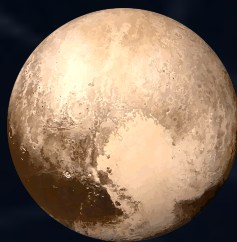
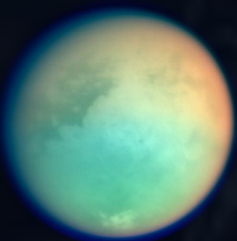
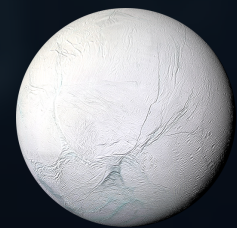
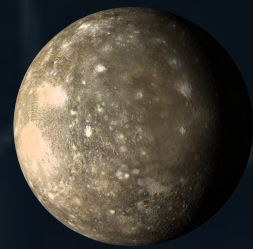
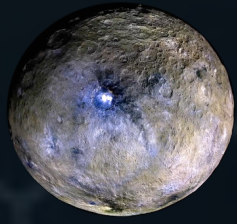
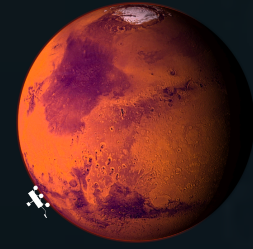


# What's next: Mission concepts

Mars Sample return, Mars Life Explorer

Ceres Sample Return

Europa Clipper





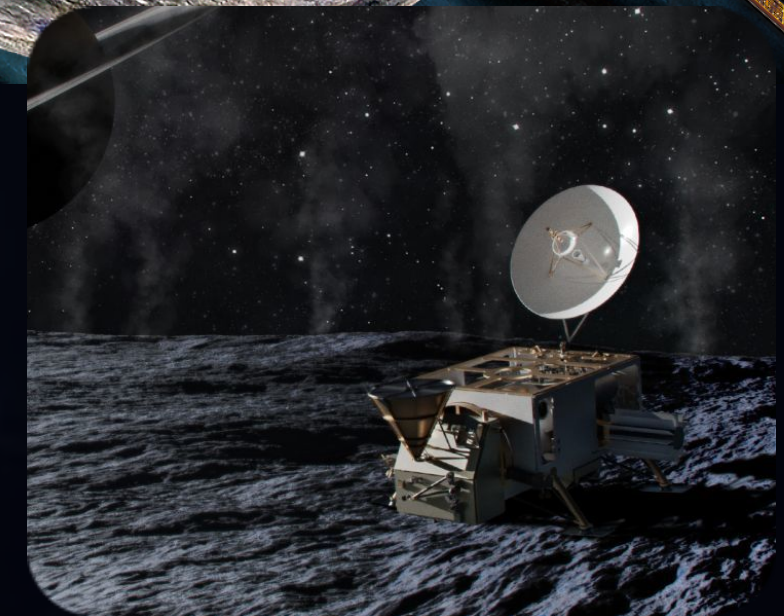
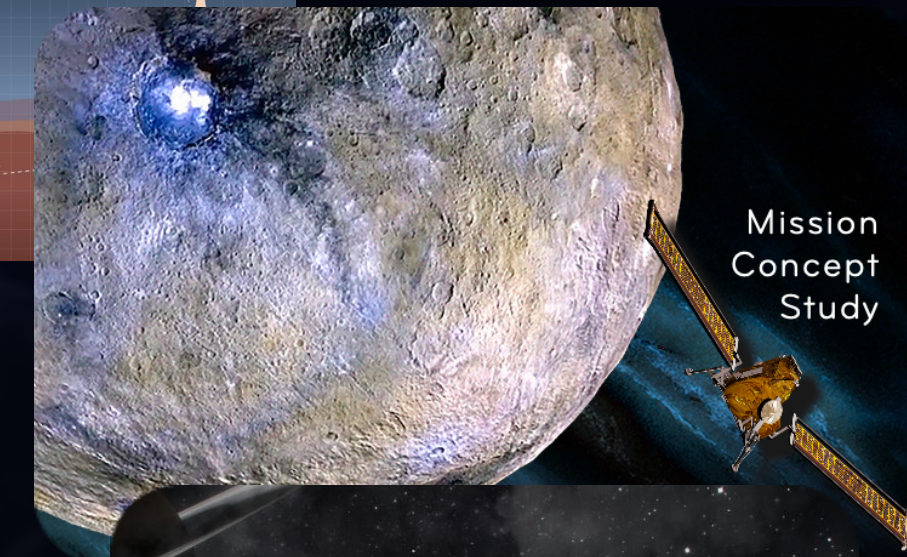
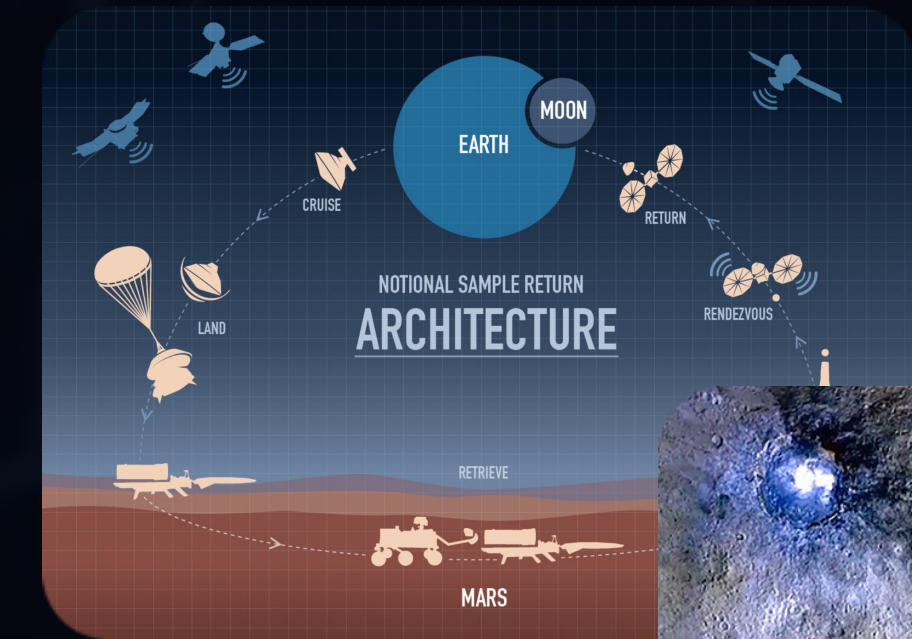
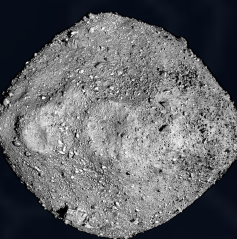
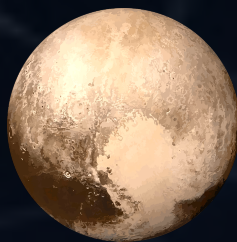
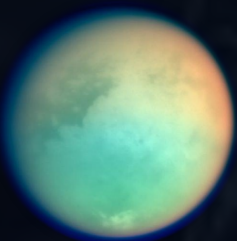
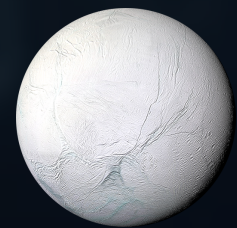
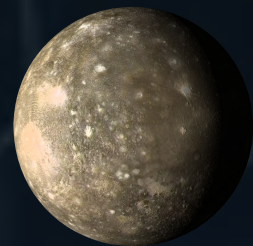
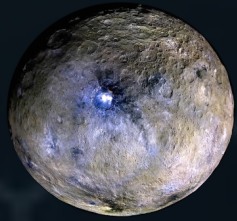
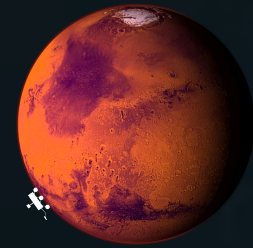
# What's next: Mission concepts

Mars Sample return, Mars Life Explorer

Ceres Sample Return

Europa Clipper

Enceladus Orbilander / Multi-Flyby





# What's next: Mission concepts

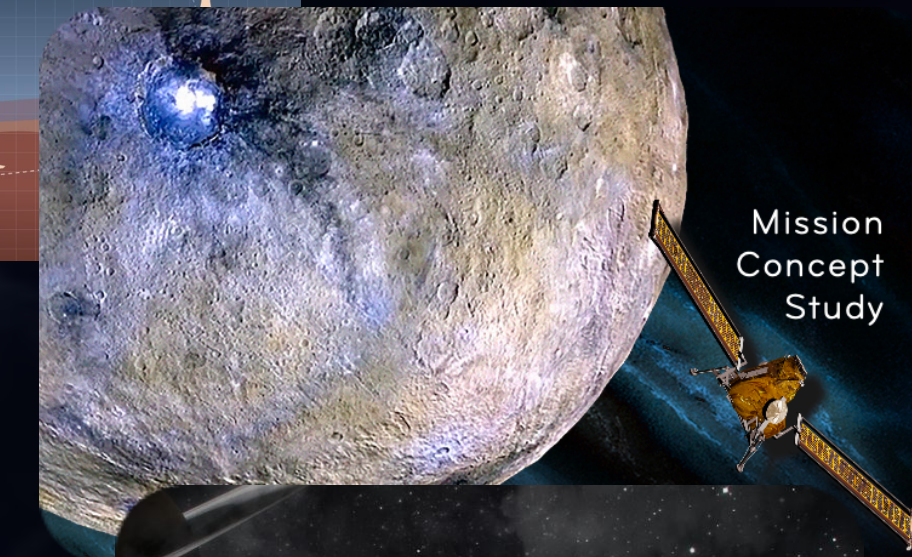
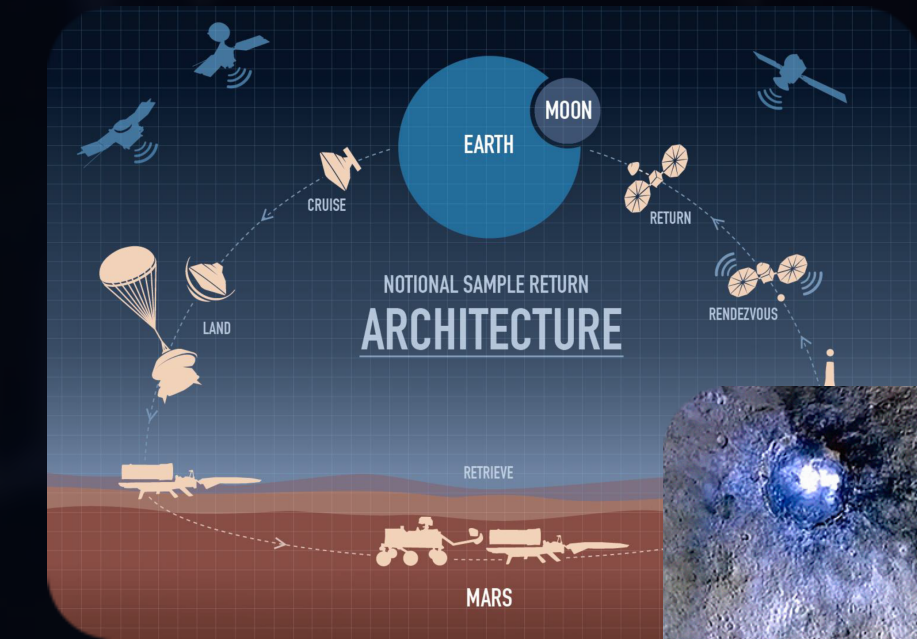
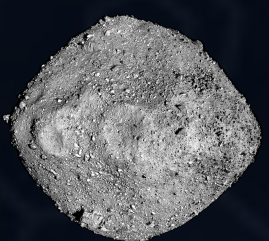
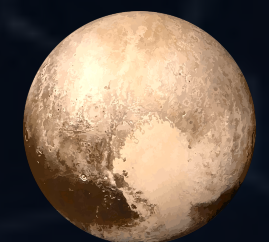
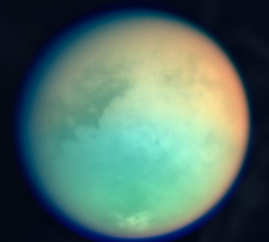
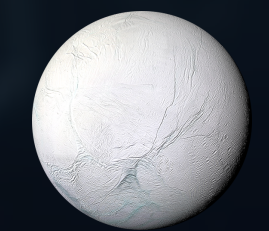
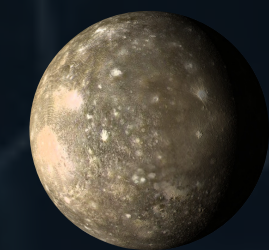
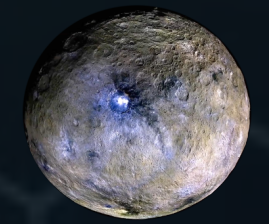
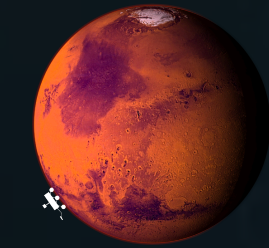
Mars Sample return, Mars Life Explorer

Ceres Sample Return

Europa Clipper

Enceladus Orbilander / Multi-Flyby

Dragonfly





# What's next: Mission concepts

Mars Sample return, Mars Life Explorer

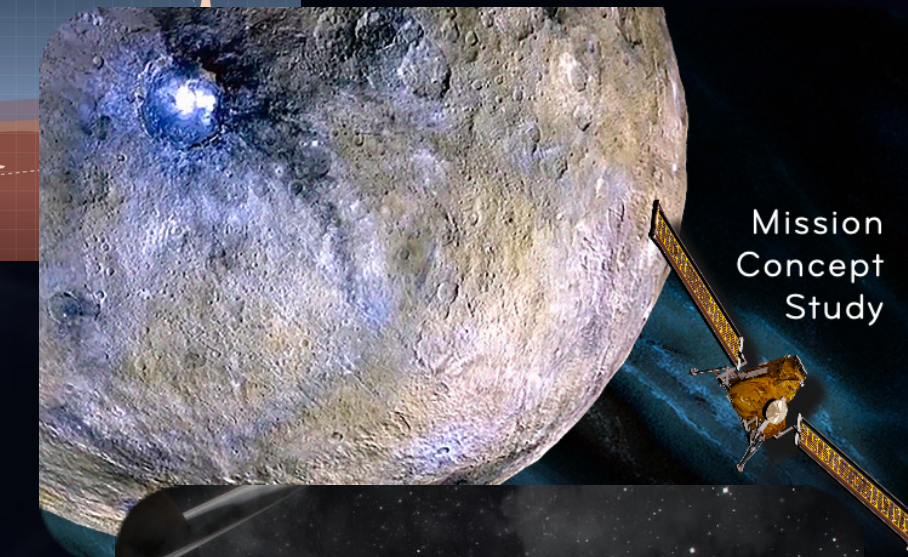
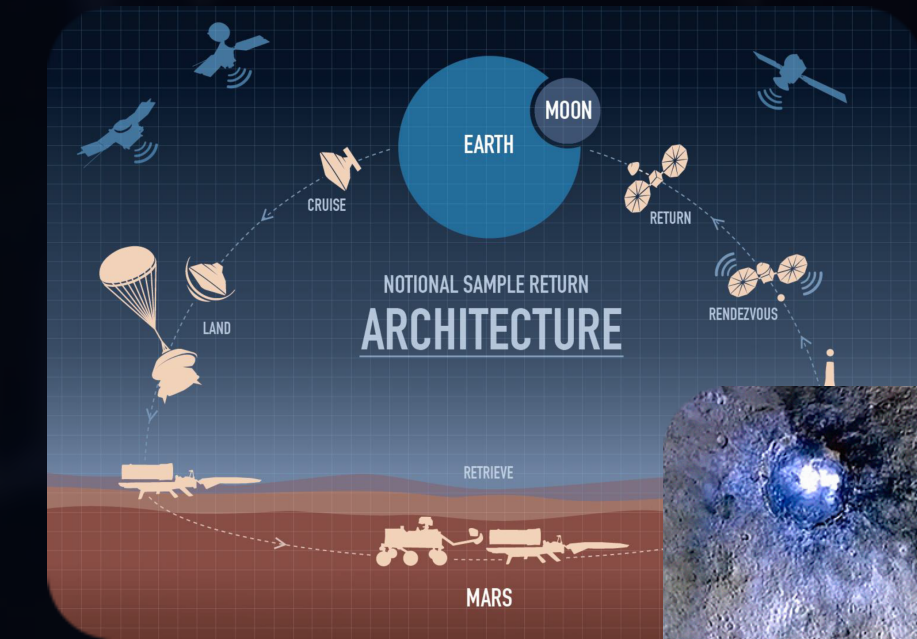
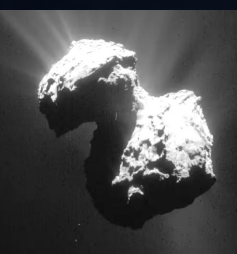
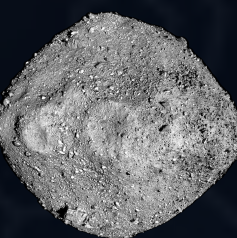
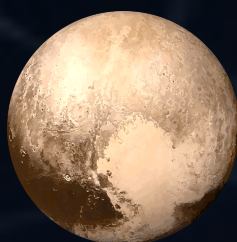
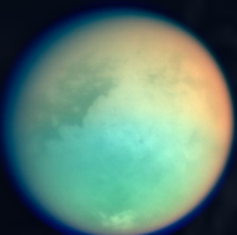
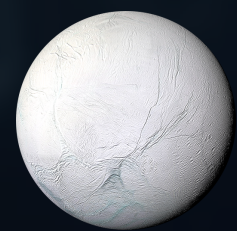
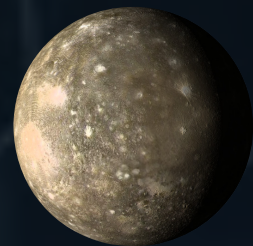
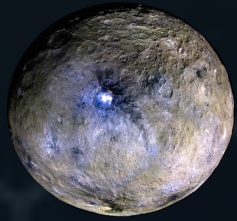
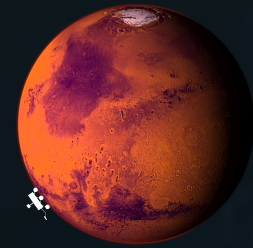
Ceres Sample Return

Europa Clipper

Enceladus Orbilander / Multi-Flyby

Dragonfly

Centaur Orbiter And Lander





# What's next: Mission concepts

Mars Sample return, Mars Life Explorer

Ceres Sample Return

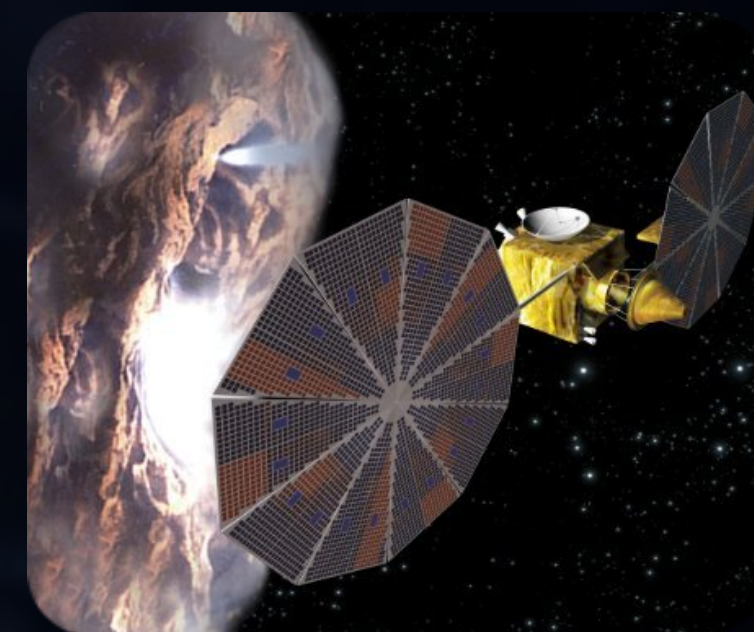
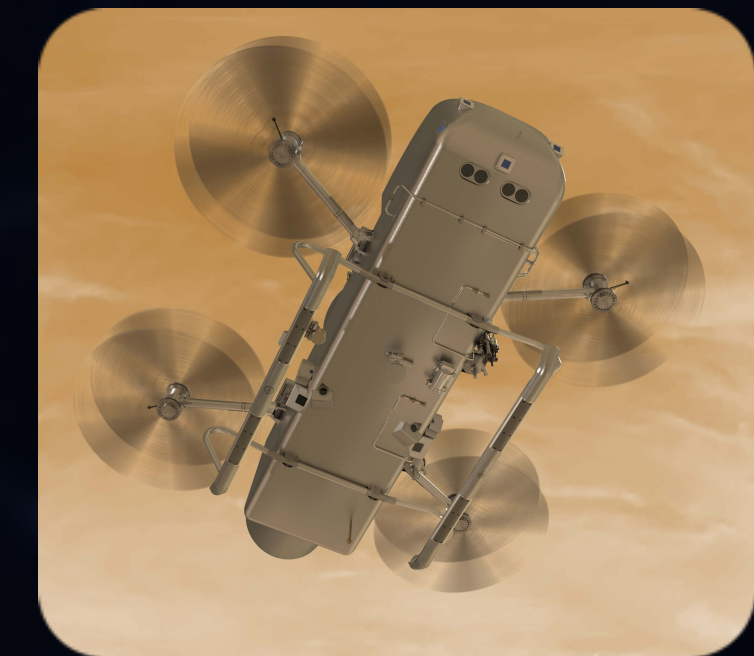
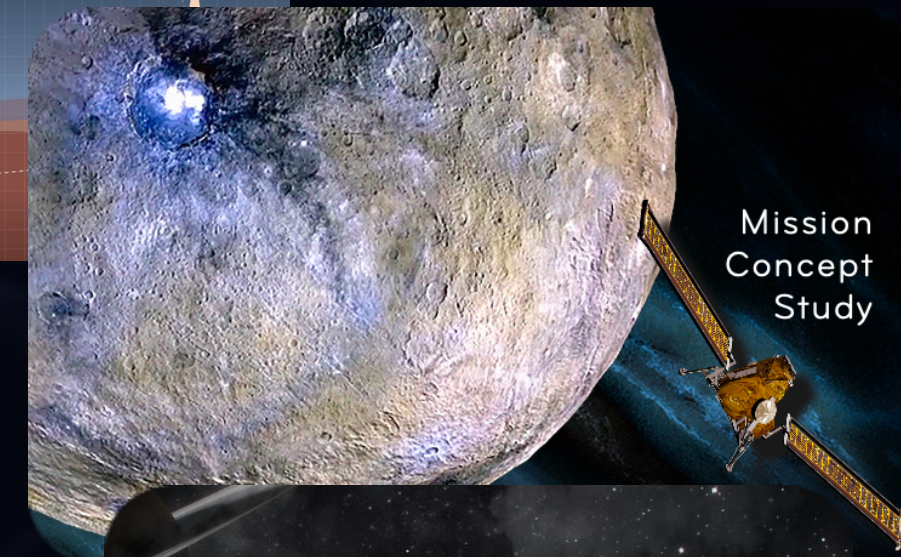
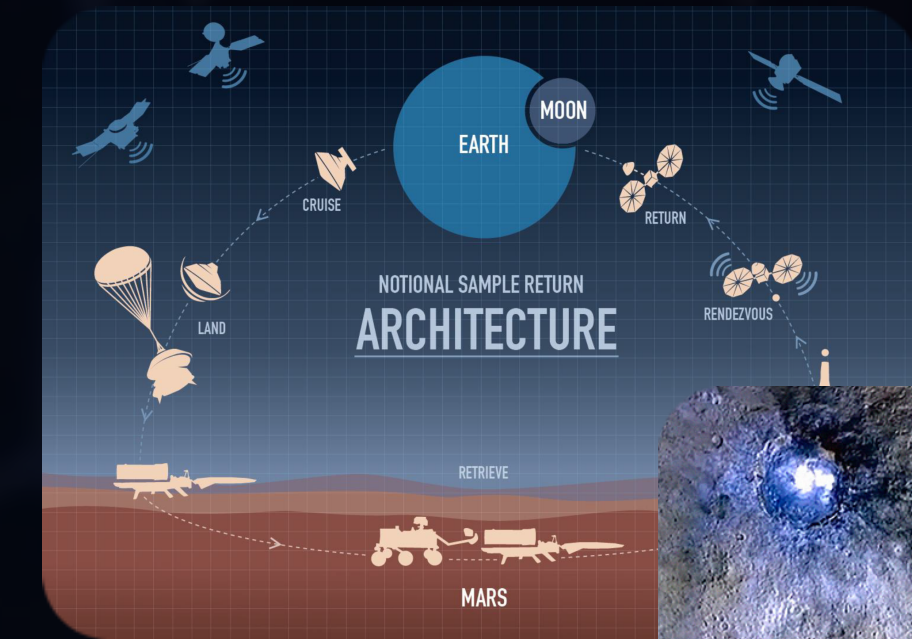
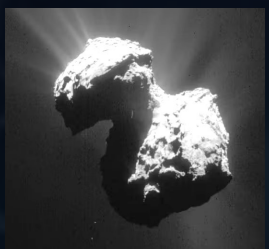
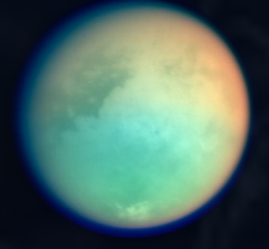
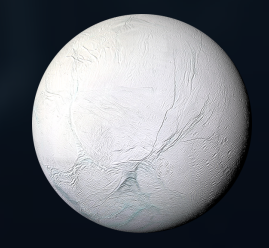
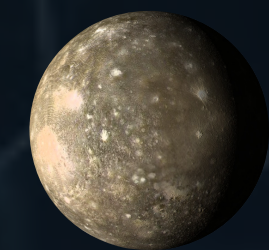
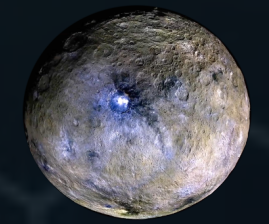
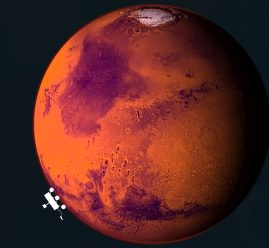
Europa Clipper

Enceladus Orbilander / Multi-Flyby

Dragonfly

Centaur Orbiter And Lander

Comet Surface Sample Return





A detailed rendering of the Orbilander spacecraft in orbit around Saturn. The spacecraft is a complex of various instruments, including a large white dish antenna and several smaller sensors. It is positioned in the upper left corner of the frame, with the planet's rings and surface visible in the background.

# ENCELADUS ORBILANDER

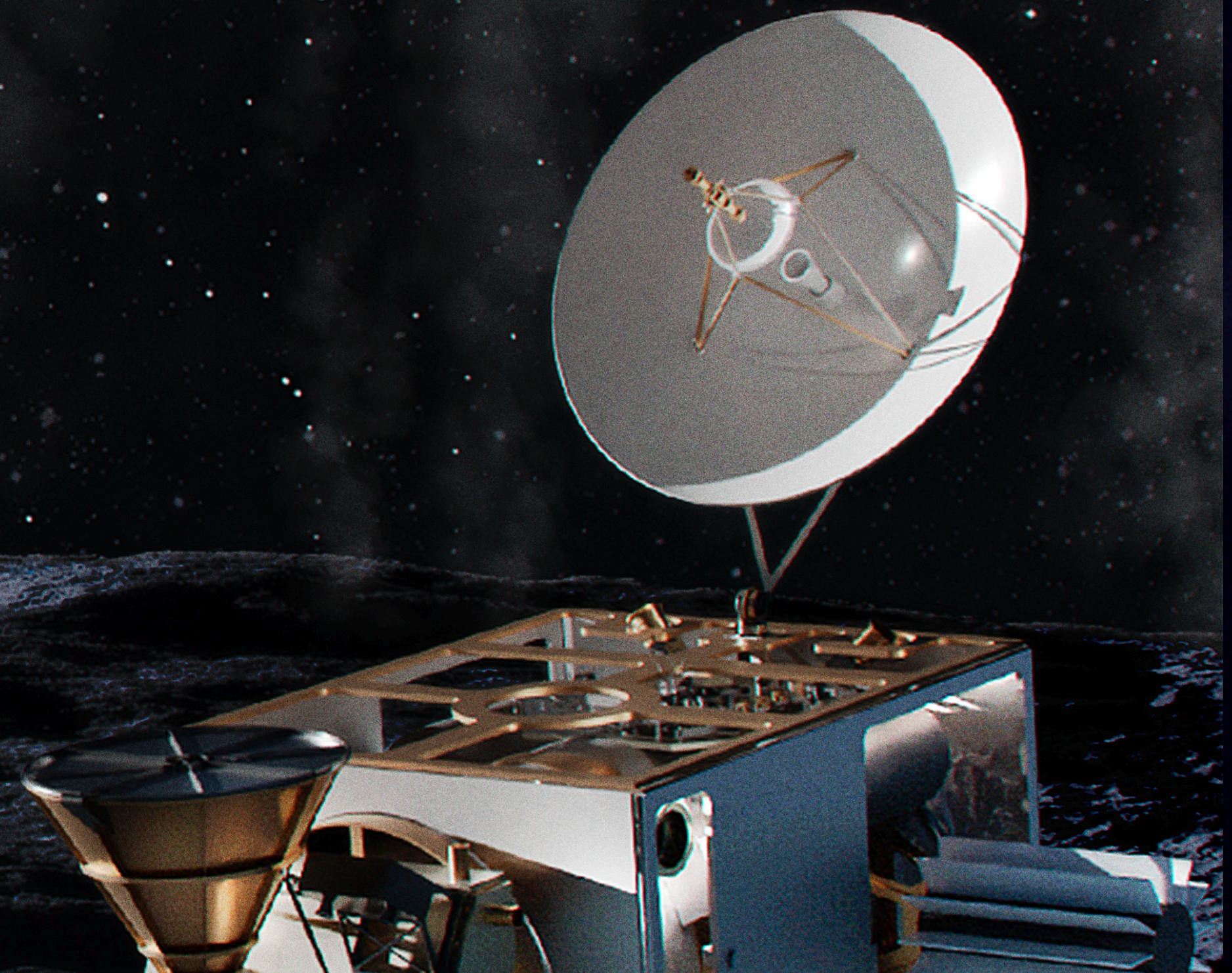
A FLAGSHIP MISSION CONCEPT TO SEARCH FOR LIFE



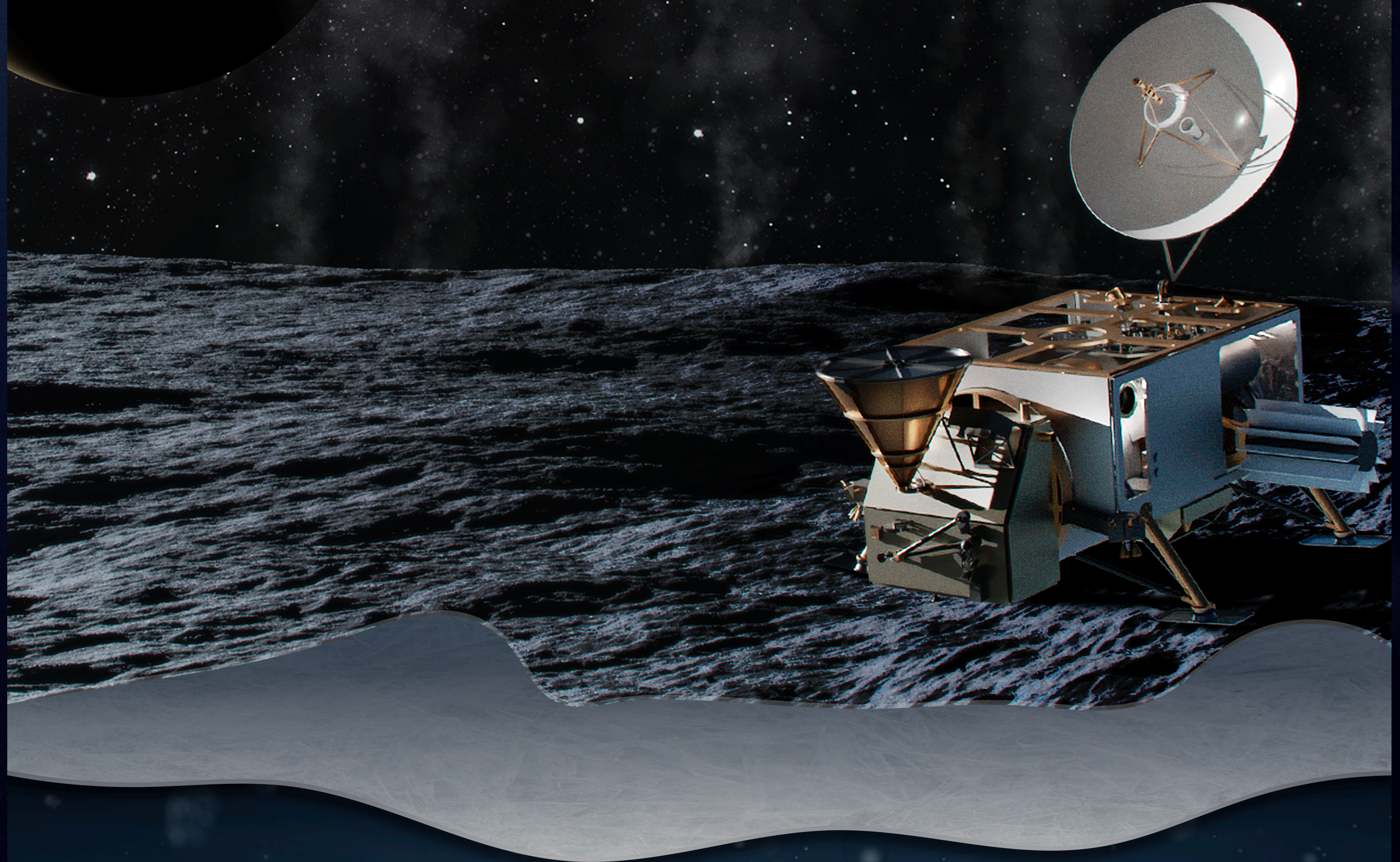
The Orbilander can detect life from orbit at levels  $\sim 500\times$  scarcer than in Earth's oceans,  
and from the surface at levels  $\sim 500,000\times$  scarcer than in Earth's oceans.

Life at these detection levels can be sustained by Enceladus' supply of energy and CHNOPS measured by *Cassini*.

Whether or not Enceladus is found to be inhabited, the Orbilander measurements will tell us why.









# Science Objectives

Determine whether or not Enceladus is *inhabited* and why

- In plume materials:

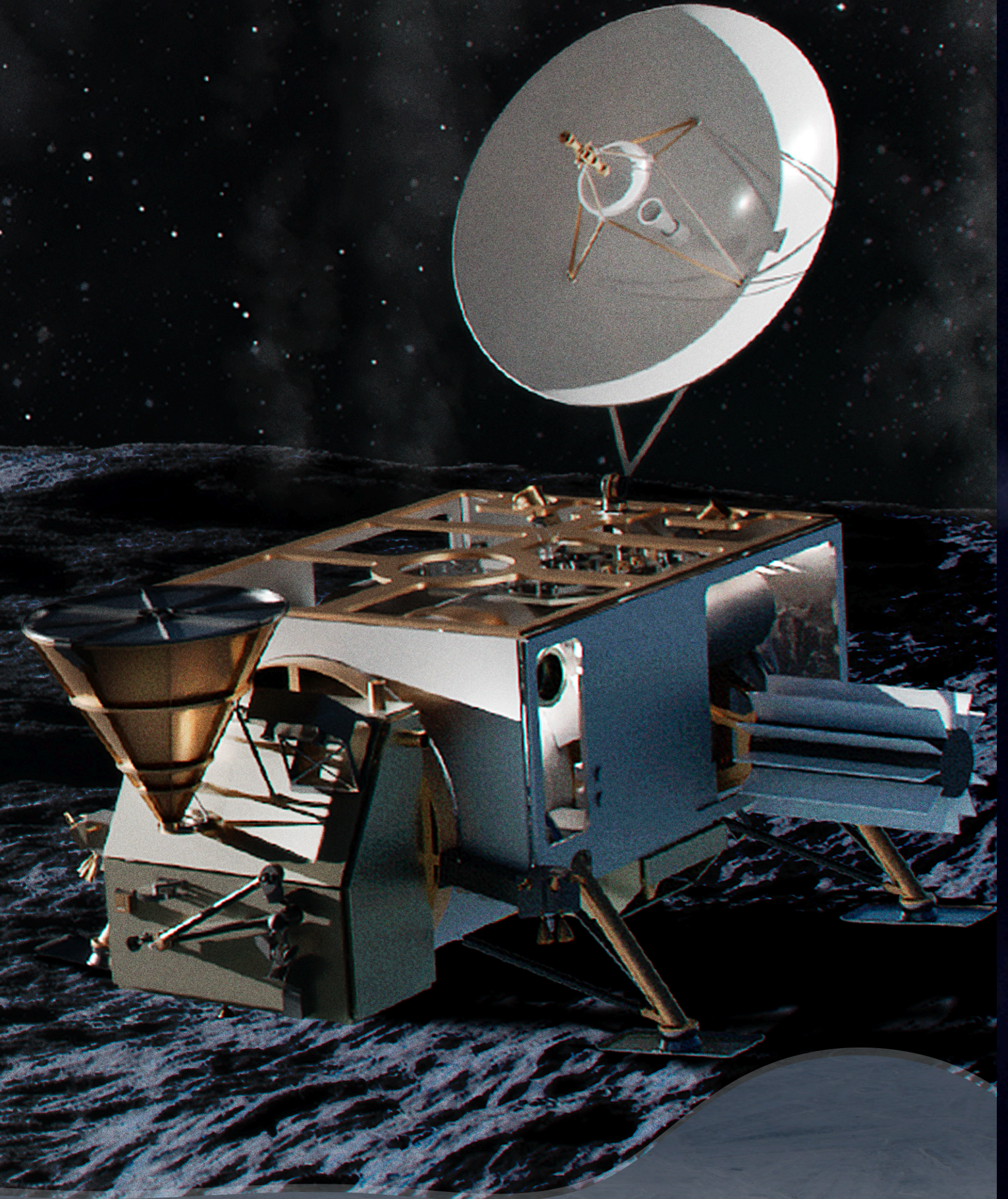
1. **characterize** the **bulk organic fraction**  
(distribution, pathway complexity,  
component-level isotopic composition)

2. **characterize amino acids**  
(relative abundances, handedness)

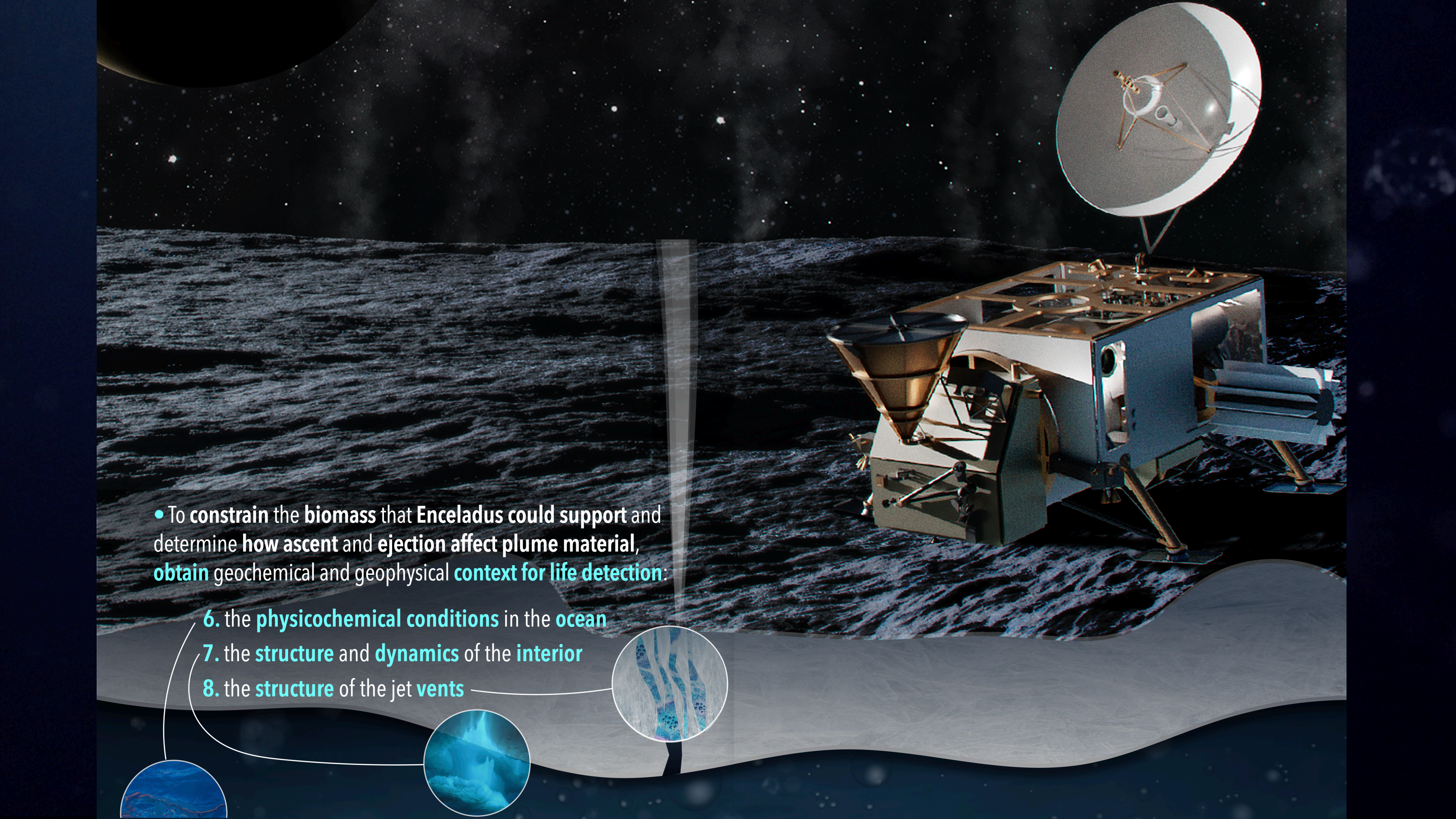
3. **characterize lipids** (commonalities  
among long-chain hydrocarbons)

4. **search** for a **polyelectrolyte**  
capable of storing genetic information

5. **search** for any **cell-like morphologies**







- To **constrain the biomass** that **Enceladus** could support and determine **how ascent and ejection** affect plume material, **obtain** geochemical and geophysical **context for life detection**:

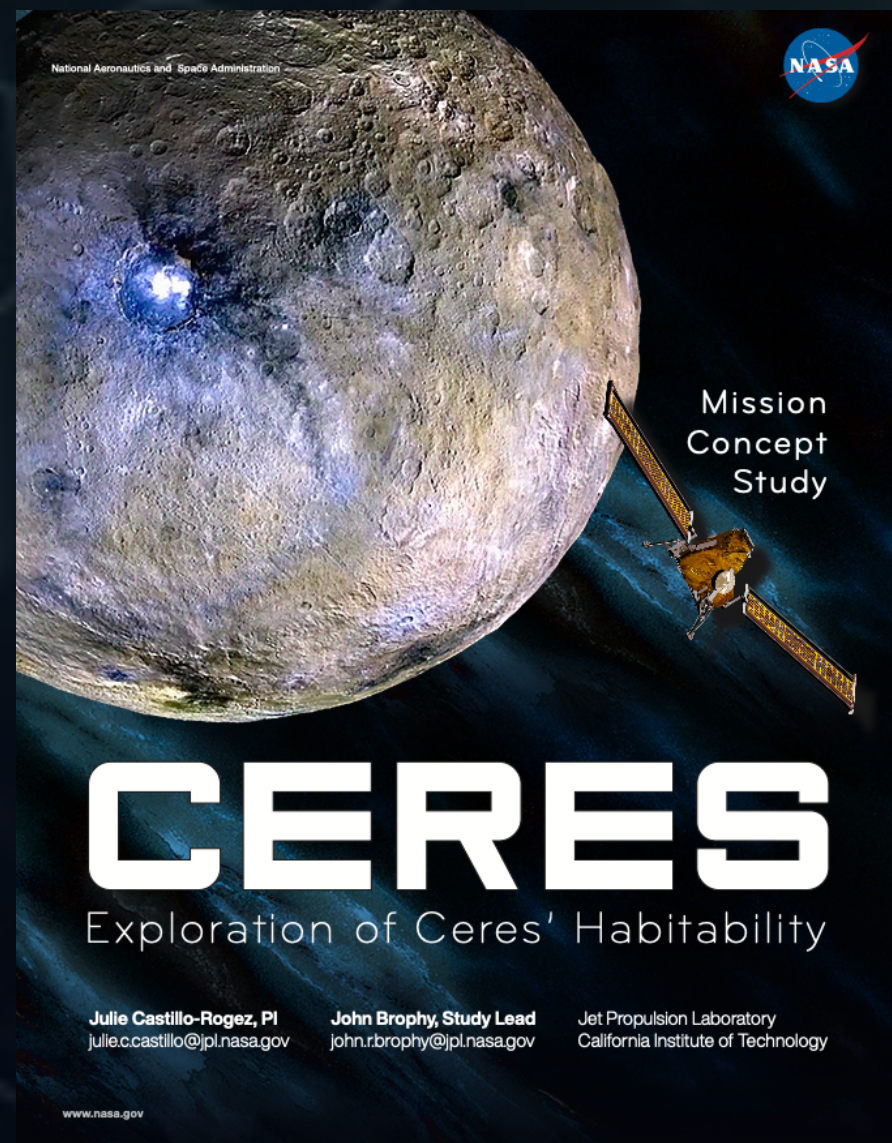
6. the **physicochemical conditions** in the **ocean**

7. the **structure** and **dynamics** of the **interior**

8. the **structure** of the jet **vents**



# Ceres sample return



Characterize the depth and extent of potential deep brine layer(s) to determine whether liquid exists beneath Ceres today near hypothesized brine extrusion zones;

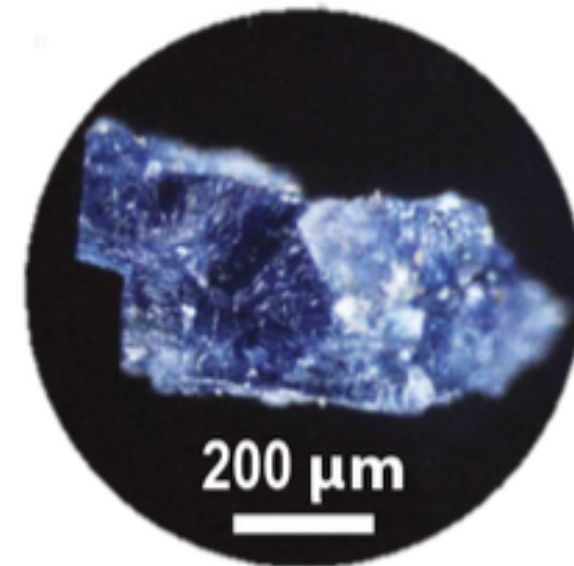
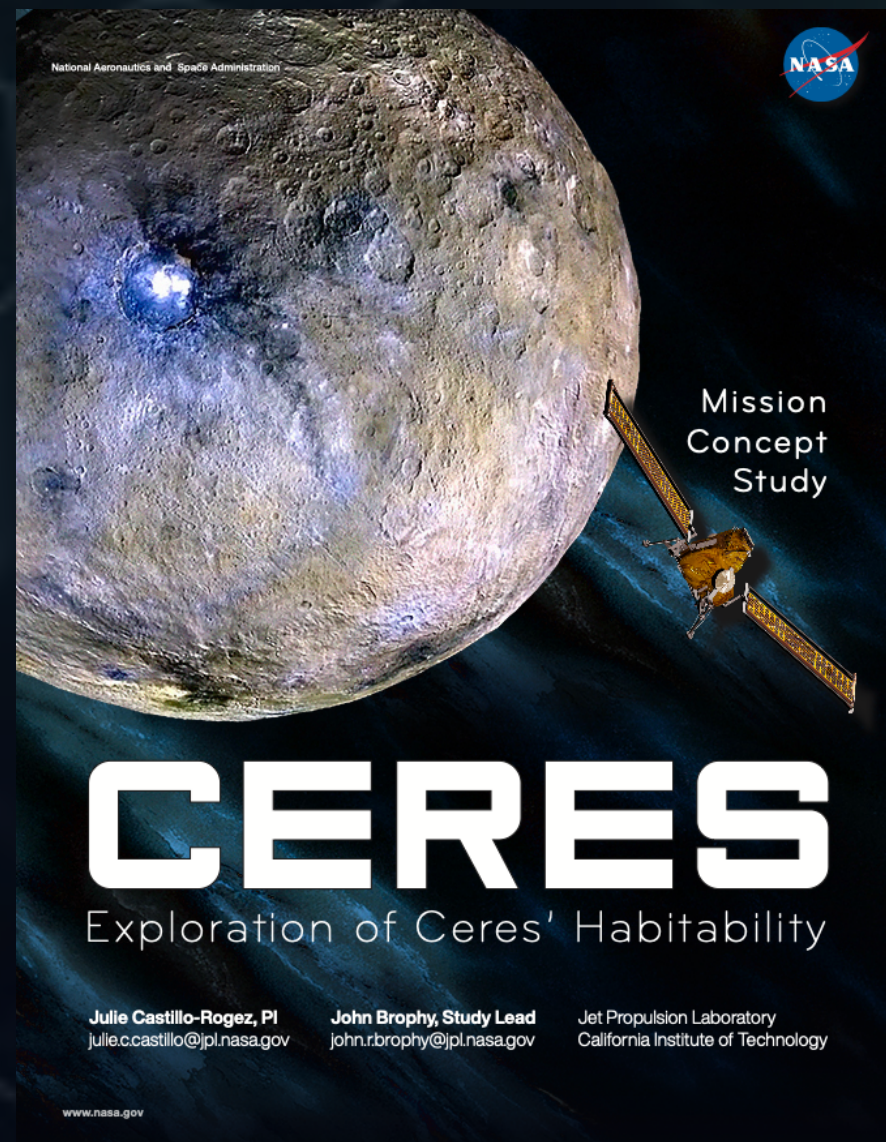
Characterize the nature of Ceres's brines from salt deposits to determine the **chemistry of waters and their potential habitability**;

**Determine the composition, structure, and isotopic composition of Ceres's organics to understand processes of abiotic organic synthesis and evolution;** and

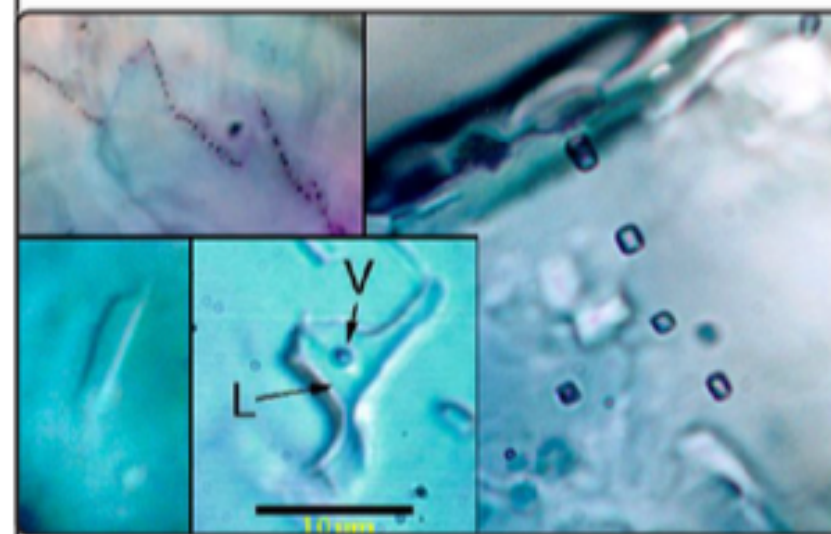
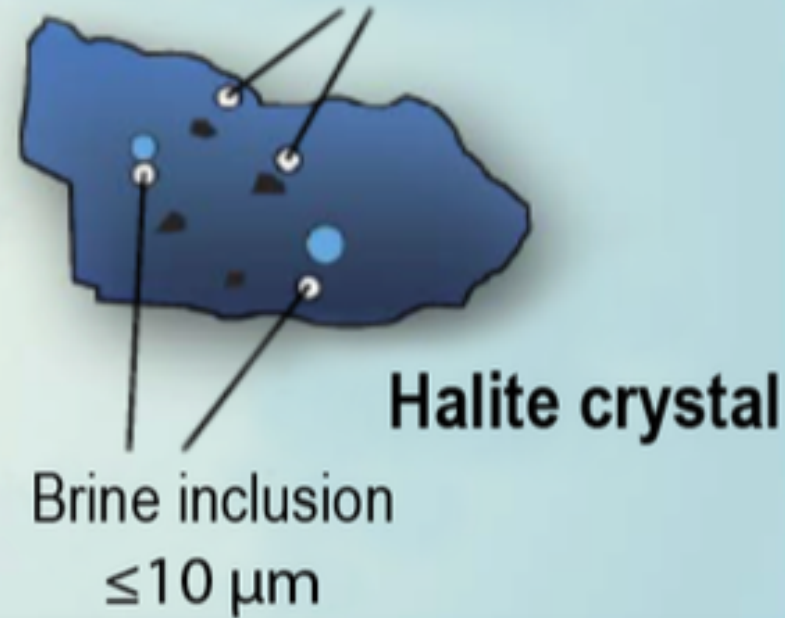
Determine the **elemental abundances and isotopic ratios** of Ceres's materials via measurements on returned samples to determine its accretional environment.



# Ceres sample return



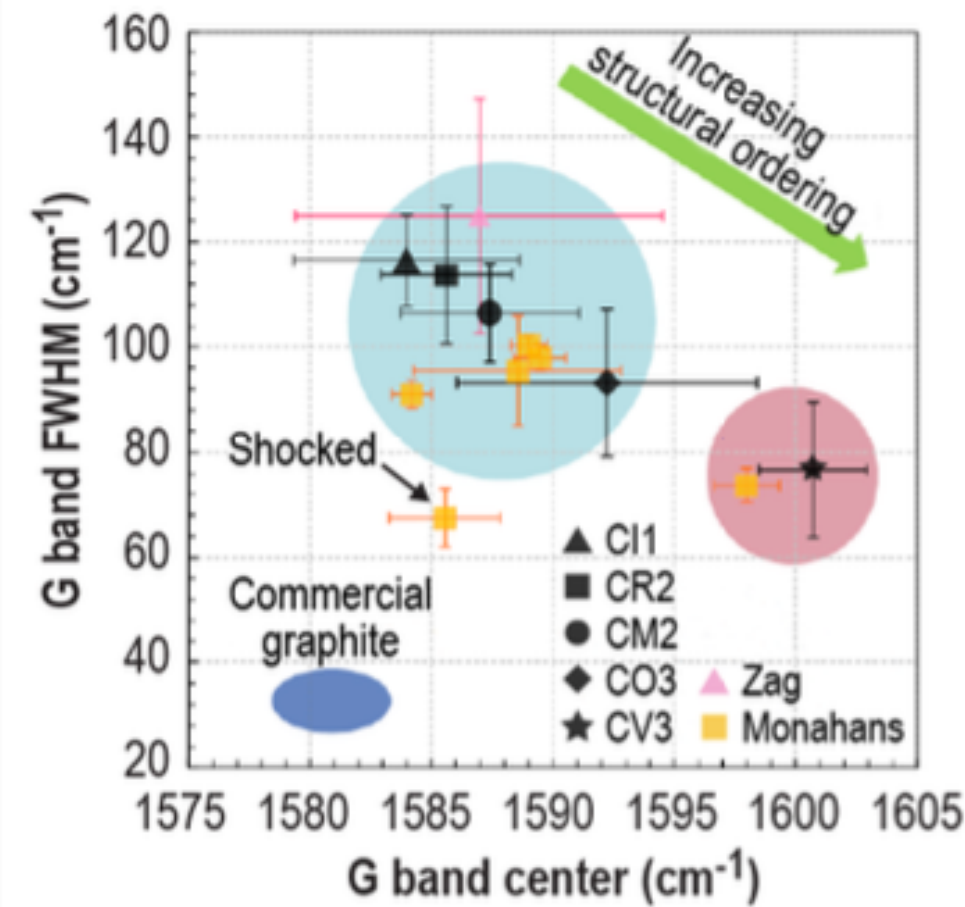
Abundant solid inclusions including organic-rich components



Fluid inclusions in Zag halite

## Raman

Functional groups, structural ordering of organics



## TEM

$\sim 10\text{s}$  of nm mineral-organic spatial relationships

## STMX-XANES

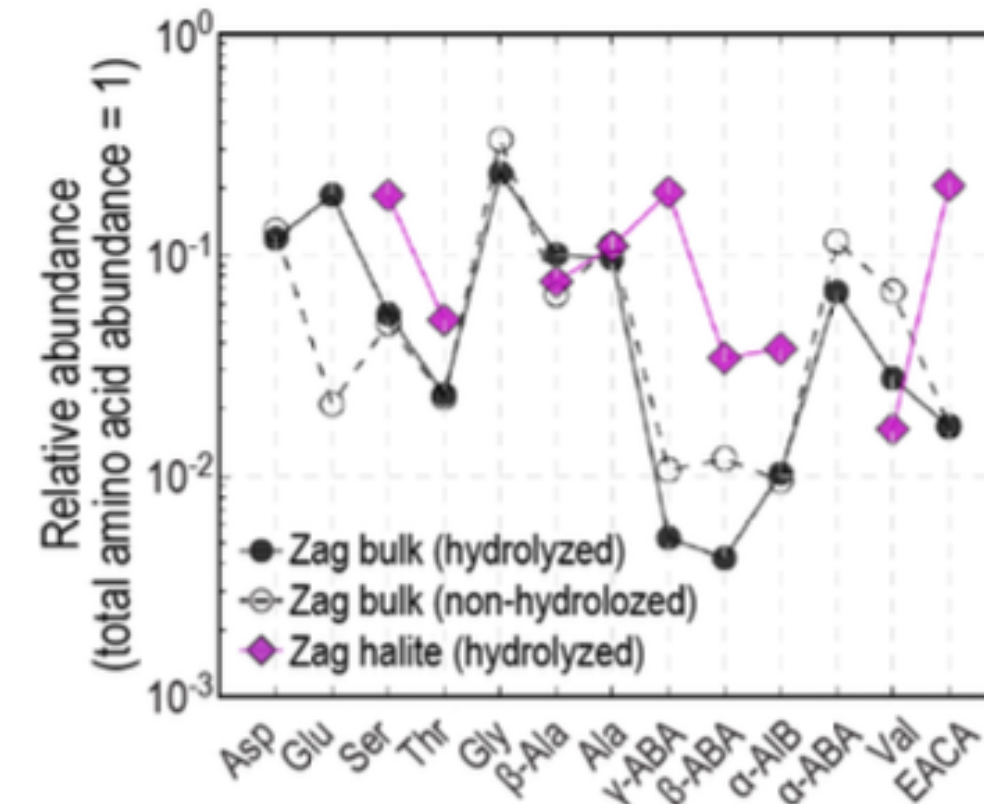
Functional groups "Bulk"  
O/C and N/C at fine scales

## NMR

Molecular Structure

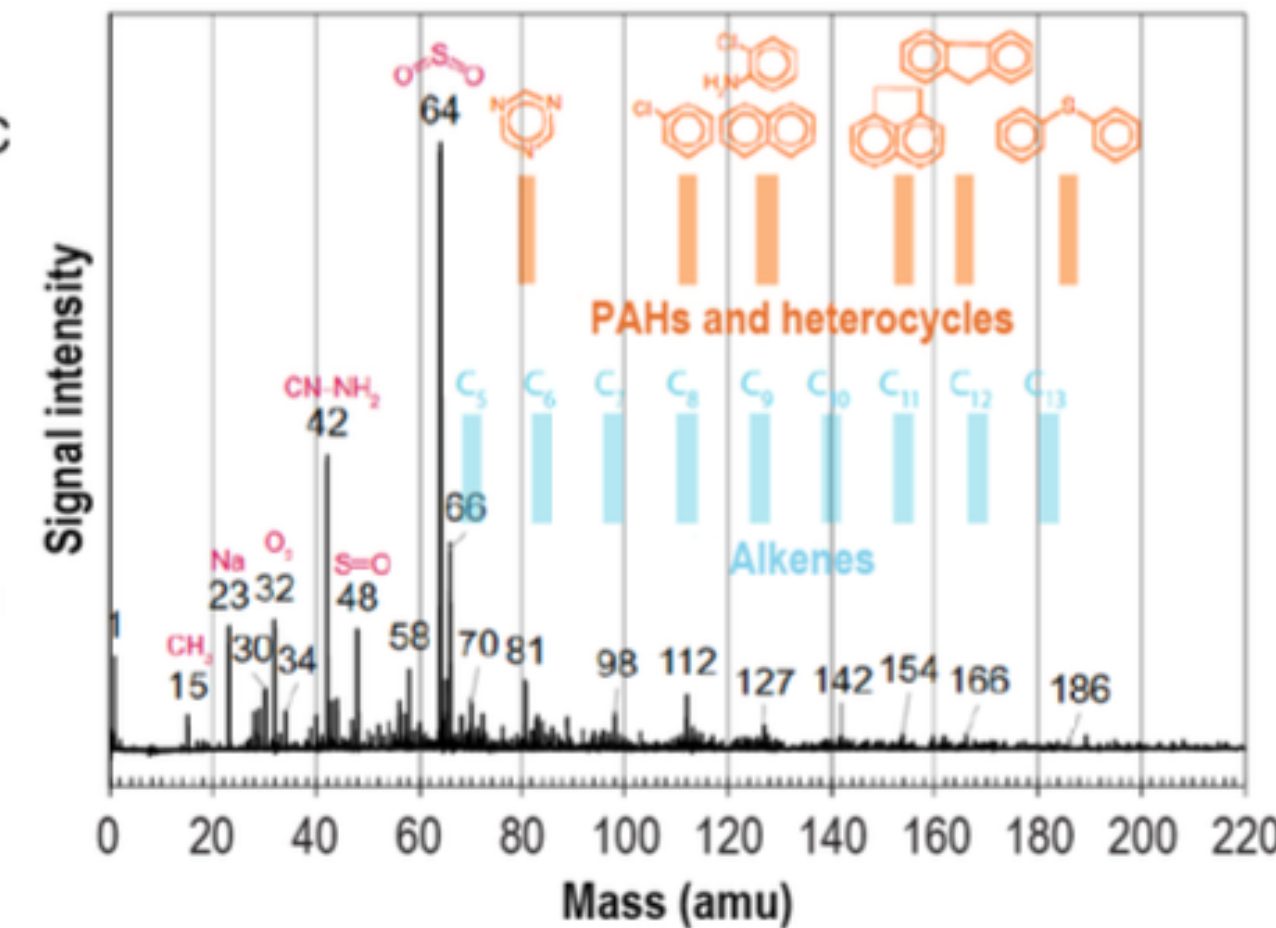
## UPLC-FD/QToF-MS

Amino acid types and abundances



## MS (L2MS)

Individual Compounds



## MS (GC/C/IRMS)

### (pico-CSIA)

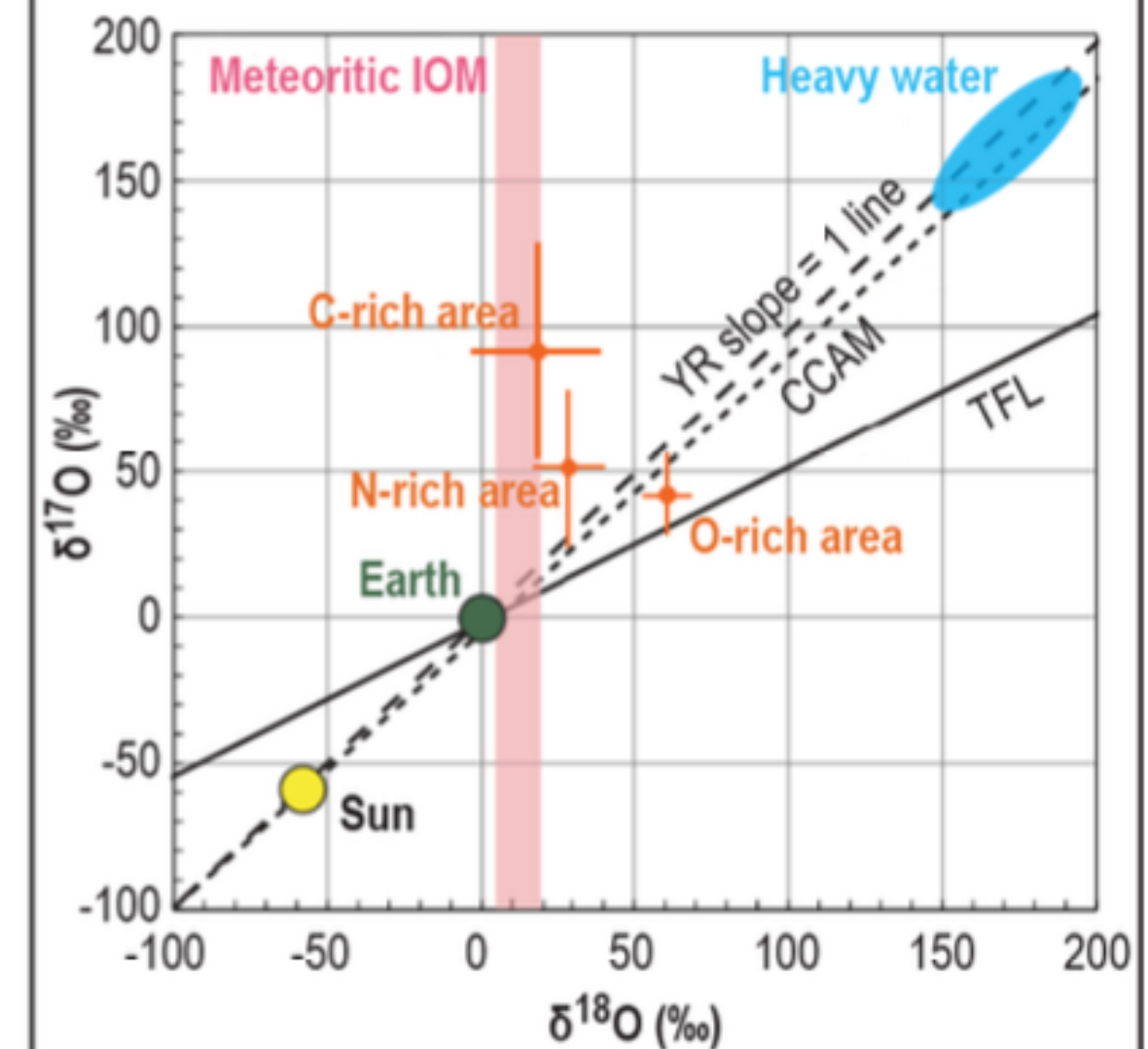
Isotopes of SOM  
(Individual compounds)

### EA-GC-MS

Isotopes of IOM  
(Bulk)

## Nano-SIMS (100 nm)

Map of CHON isotopes and relationship to mineral grains



O 3-isotope diagram for comparison to other materials

Non-Destructive

Semi-Destructive

Destructive



