Photonics, Space, Lasers: Designing the Future Society– Vision 2040
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Analytical Chemistry in Space: Sample Return and Onboard Mass Spectrometry

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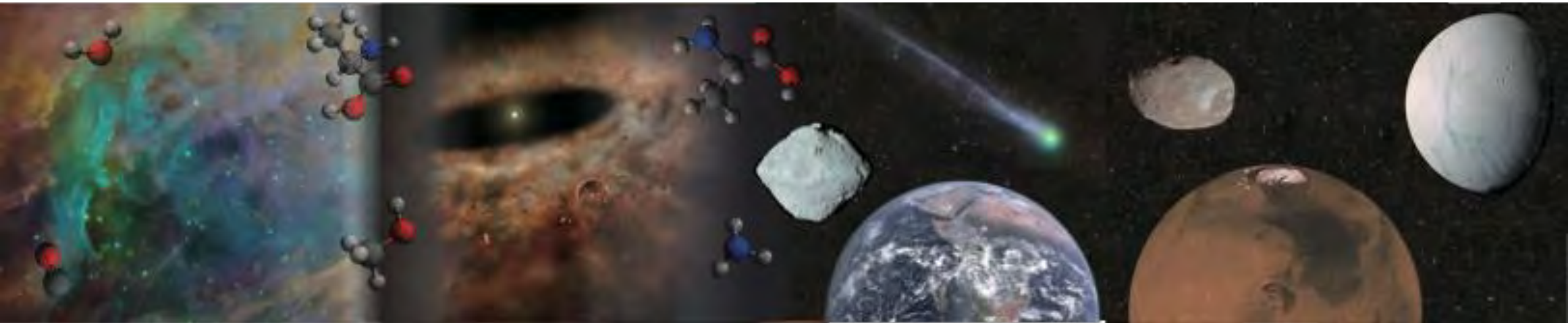
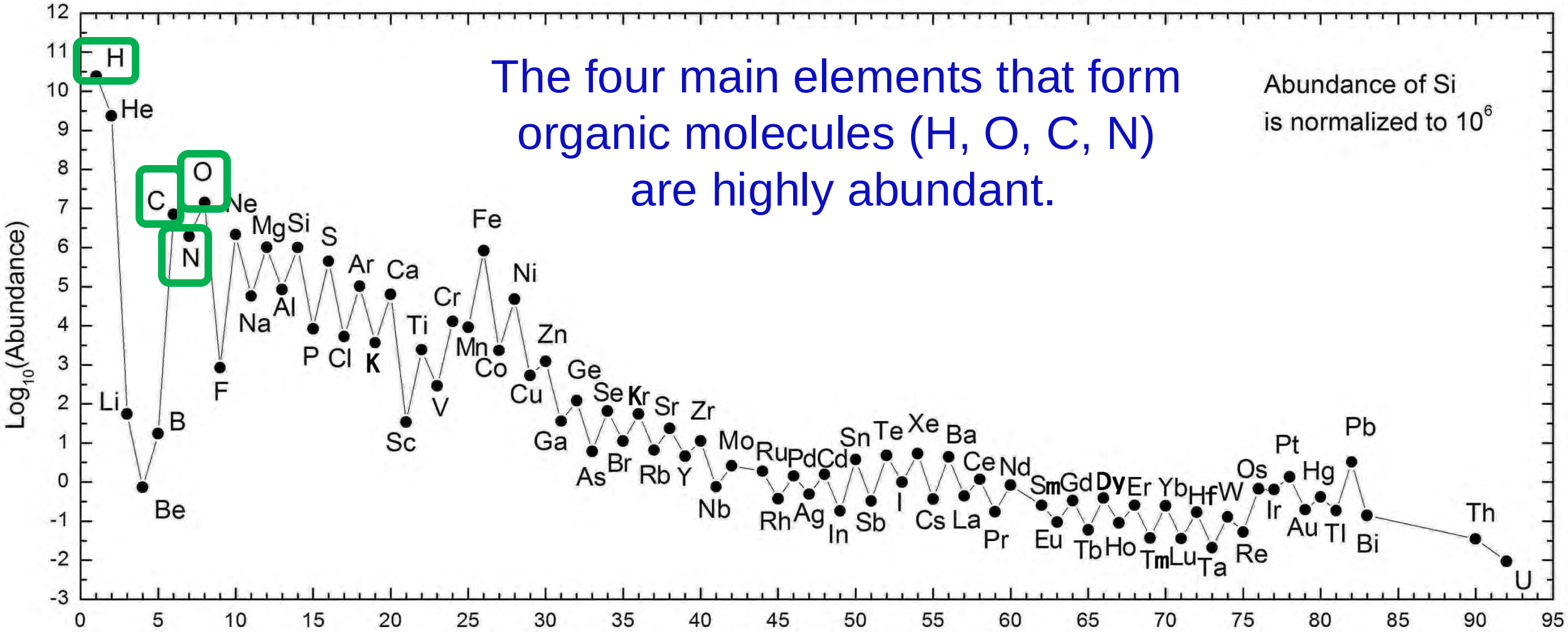
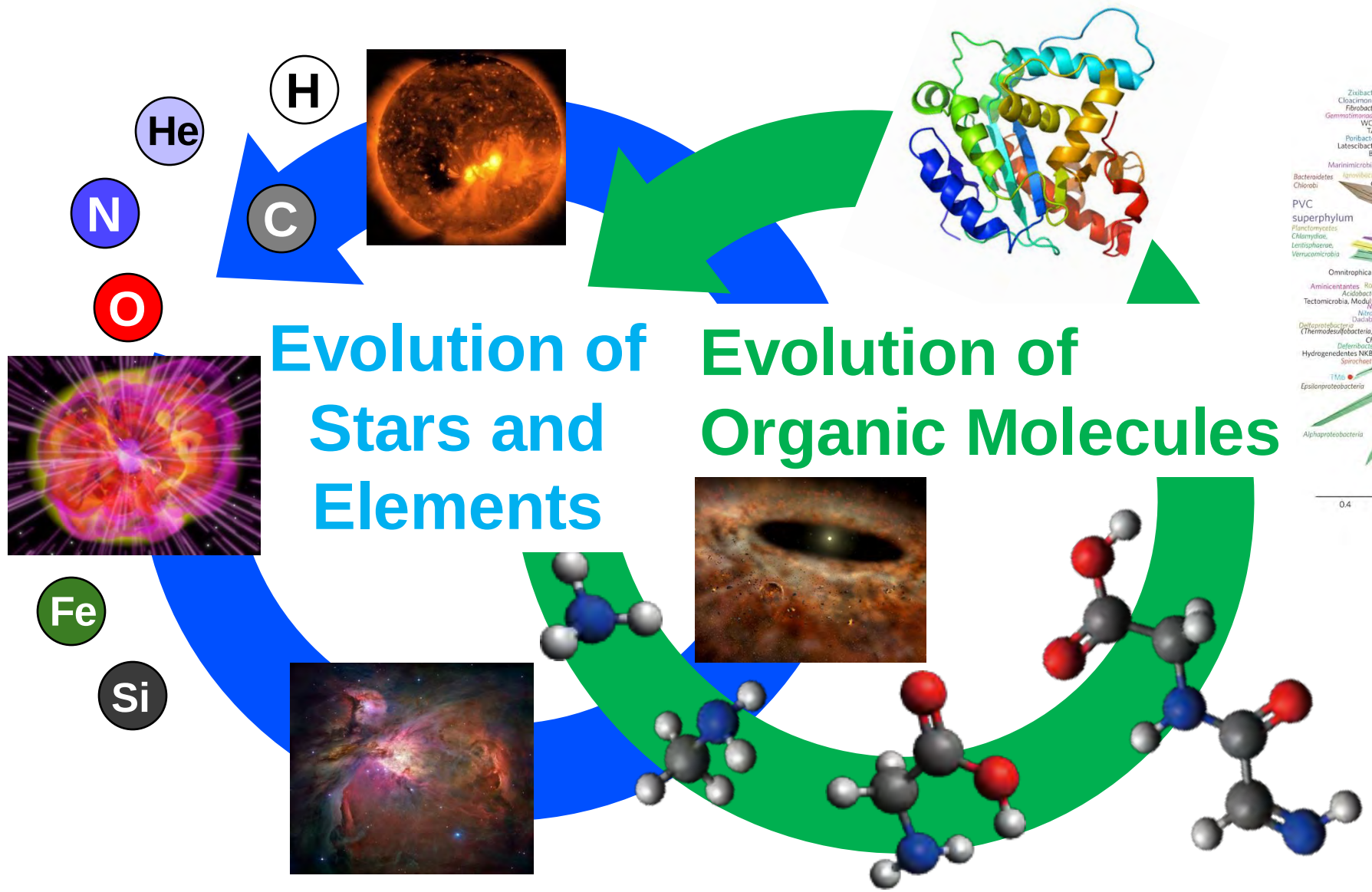


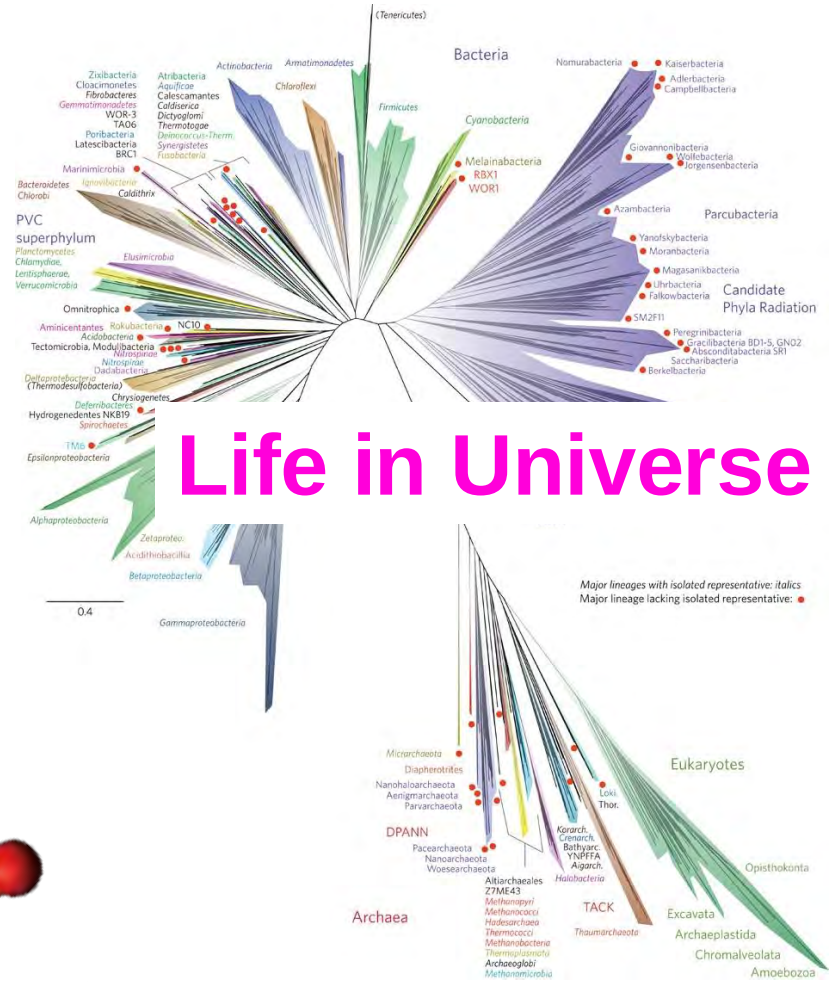
Elemental Abundance in the Solar System



The elements that constitute life exist abundantly in the universe.

How, when, where did organic molecules evolve in the universe, and lead to the emergence of life?





Tree of life, Hug (2016) *Nat Microbiol*

Sample Return Mission: Hayabusa2

Carbonaceous (C)-type Asteroid:
A time capsule preserving information from the early Solar System

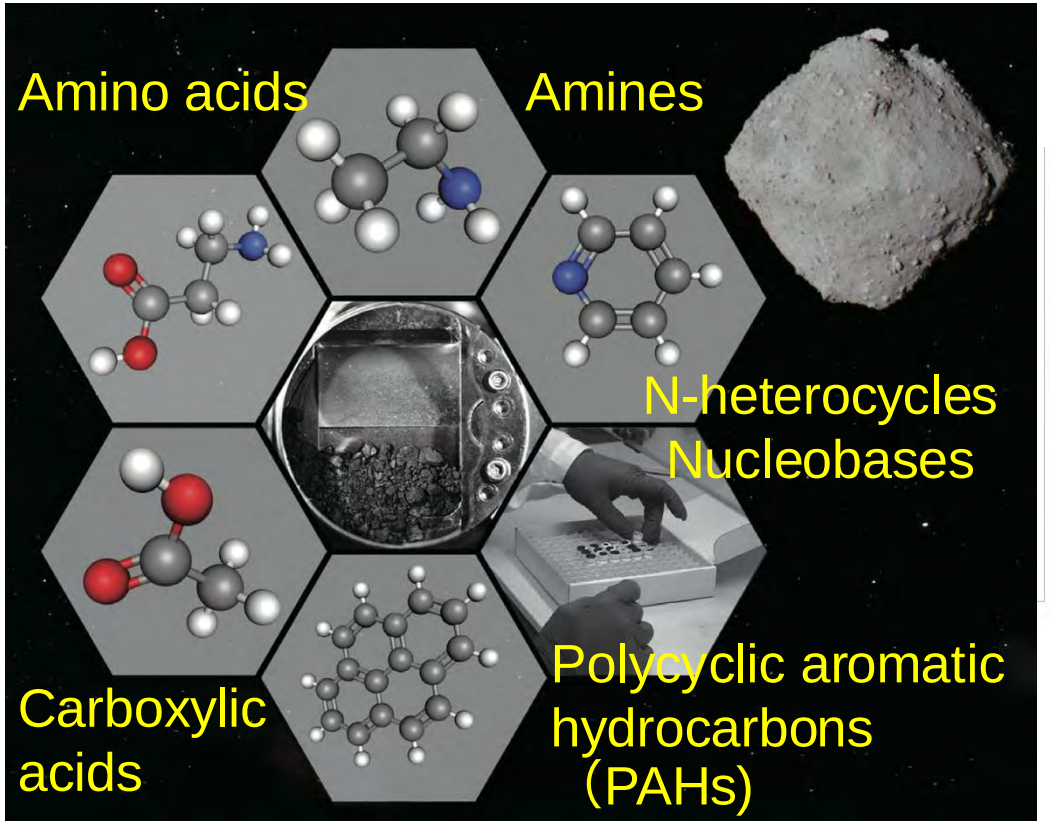
Launch: December 2014

Earth Return: December 2020

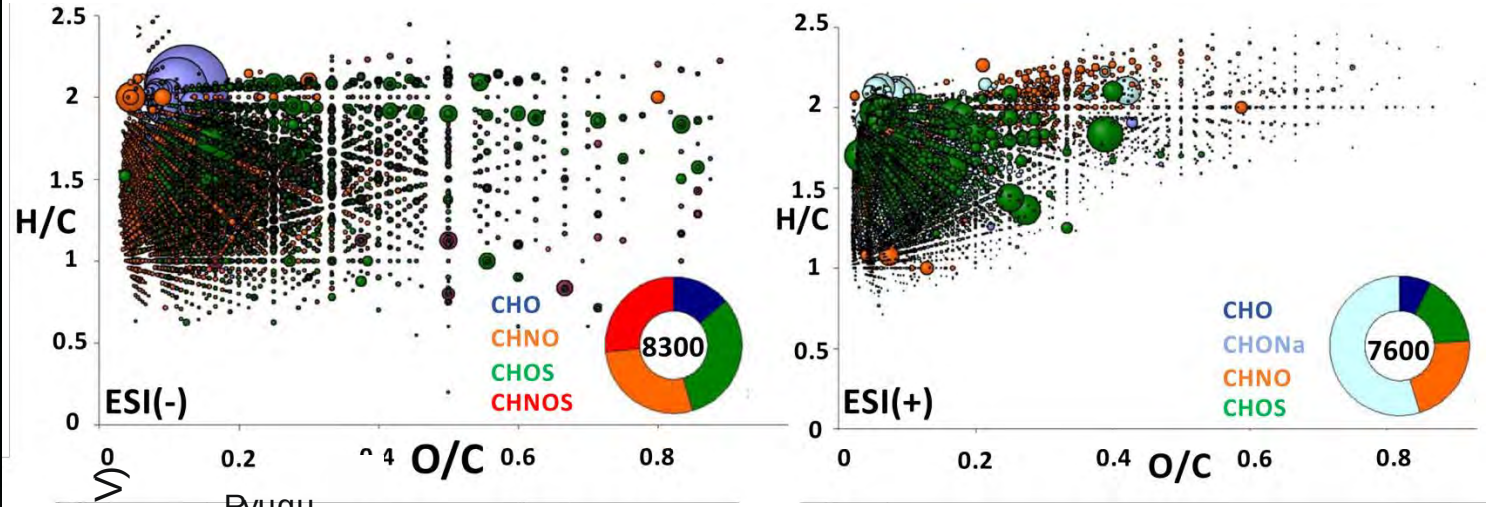
Near-Earth C-type Asteroid Ryugu

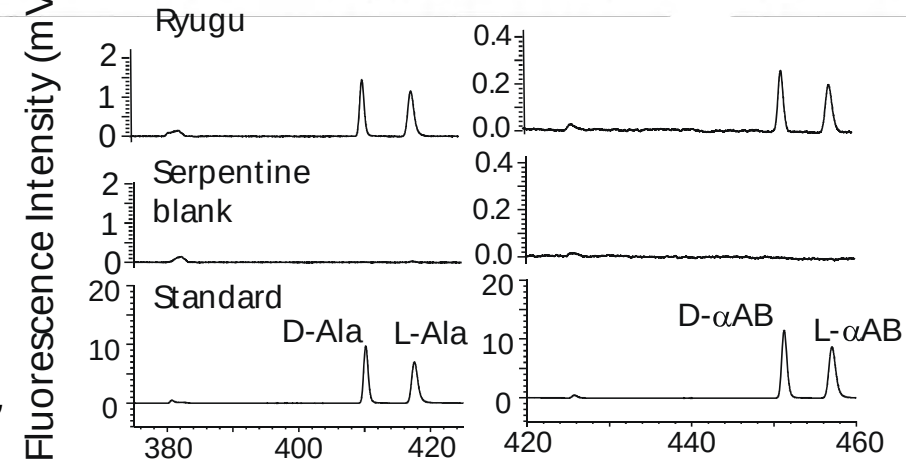
Collection of >5g of sample by two times of touch down

Analytical Results of Organic Molecules in Ryugu



>20,000 Molecular species that contain C, H, N, O, S have been detected.





Diverse Organic Molecules Exist in Ryugu.

Naraoka *et al*. (2023) *Science,* Takano *et al*. (2024) *Nature Comm,* Schmitt-Kopplin *et al*. (2023) Nature Comm,

Amino acids are racemic. (D/L =1:1)

Aqueous alteration on the Ryugu parent body plays an important role in the formation of organic molecules.

Our Next Upcoming Mission:
Martian Moons eXploratin

MMX
Martian Moons eXploration

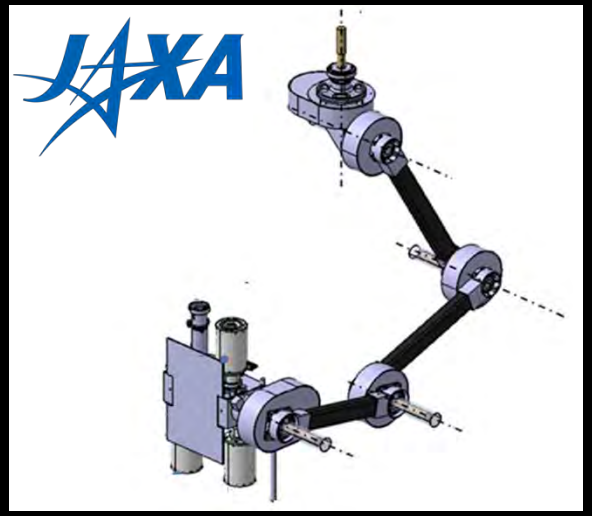
Sample Return Mission from the Martian Moon Phobos

(1) Origin of Martian Moons

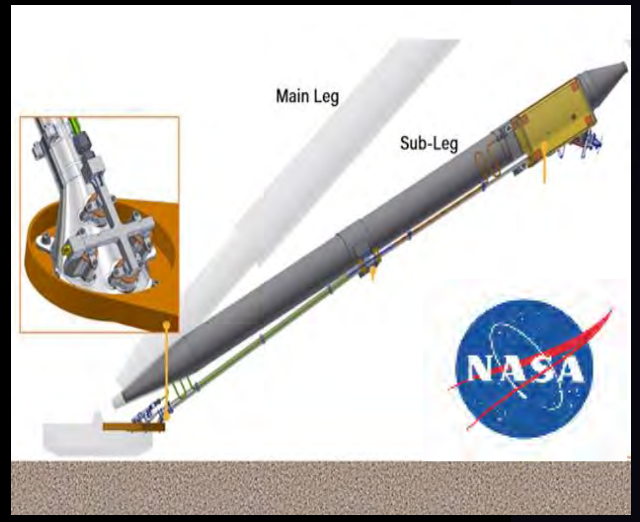
(2) Delivery of Water and Organic Molecules

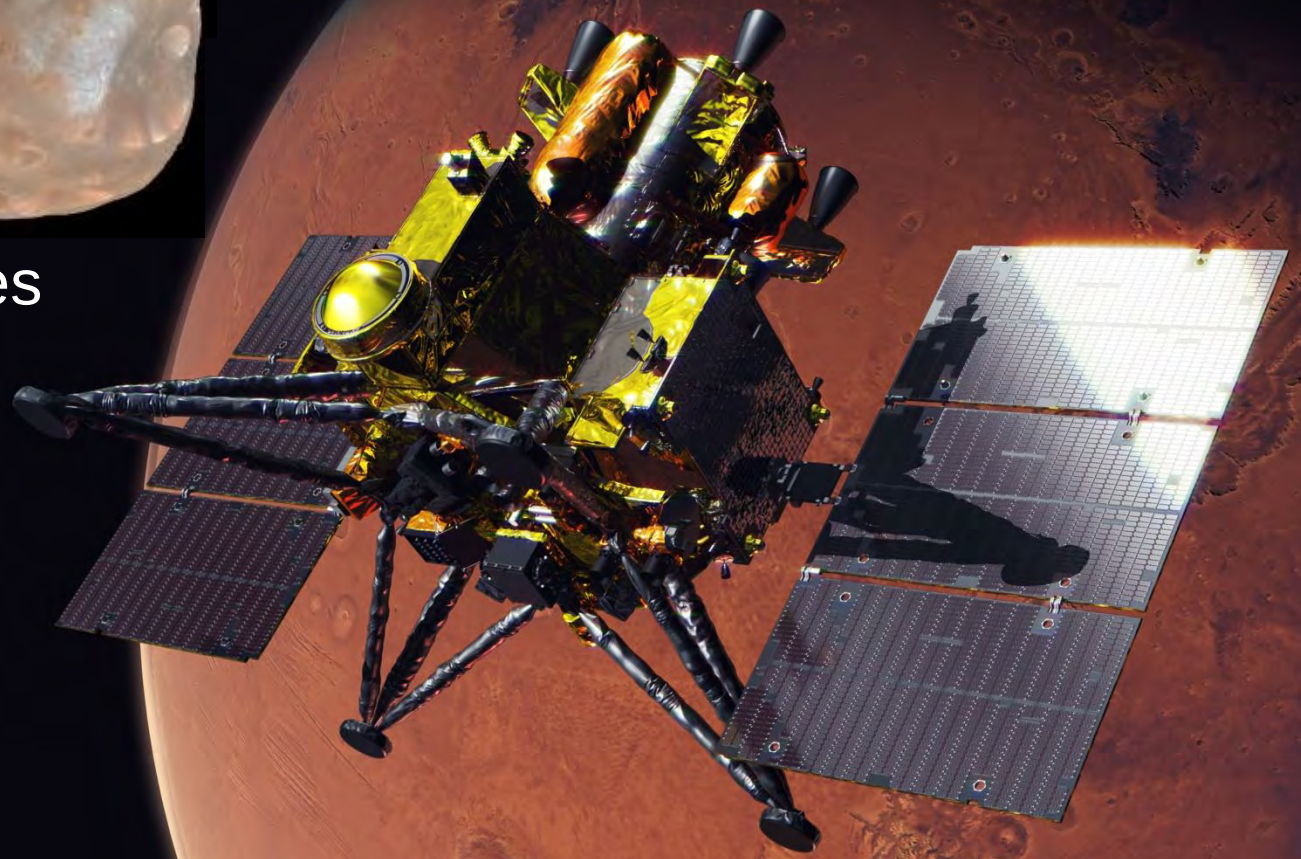
Two Sampling Systems

Coring (C)-Sampler



Pneumatic (P)-Sampler





Launch: Fall 2026!

Earth Return: 2031

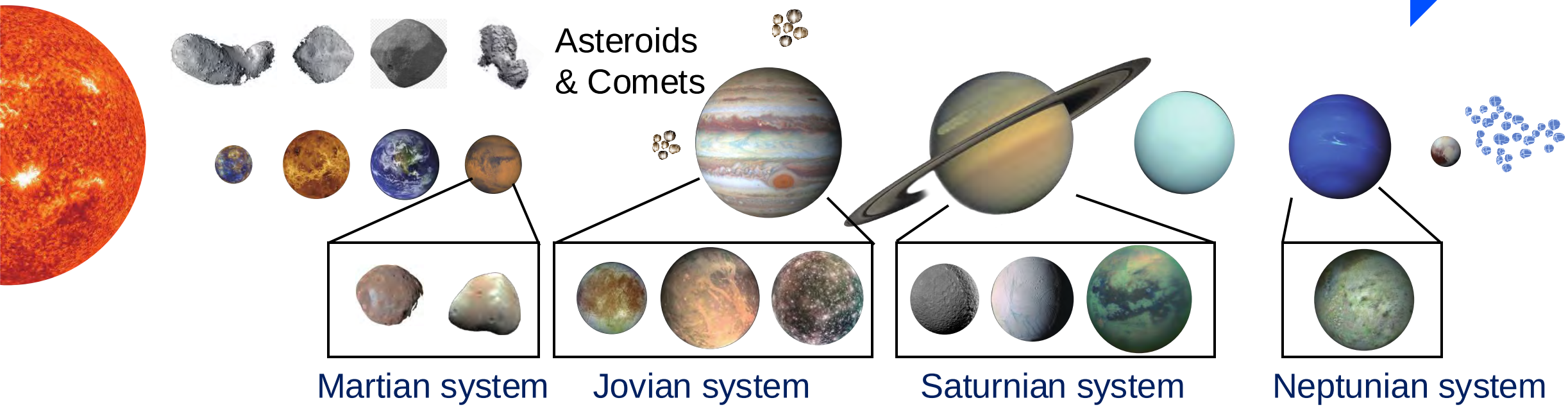
Sample return mission can provide a lot of information. However, there is a limit to the number of times and the distance we can go.

Round trip 5-10 years

Sample Return

One way 5-10years

Onsite analysis on the celestial bodies

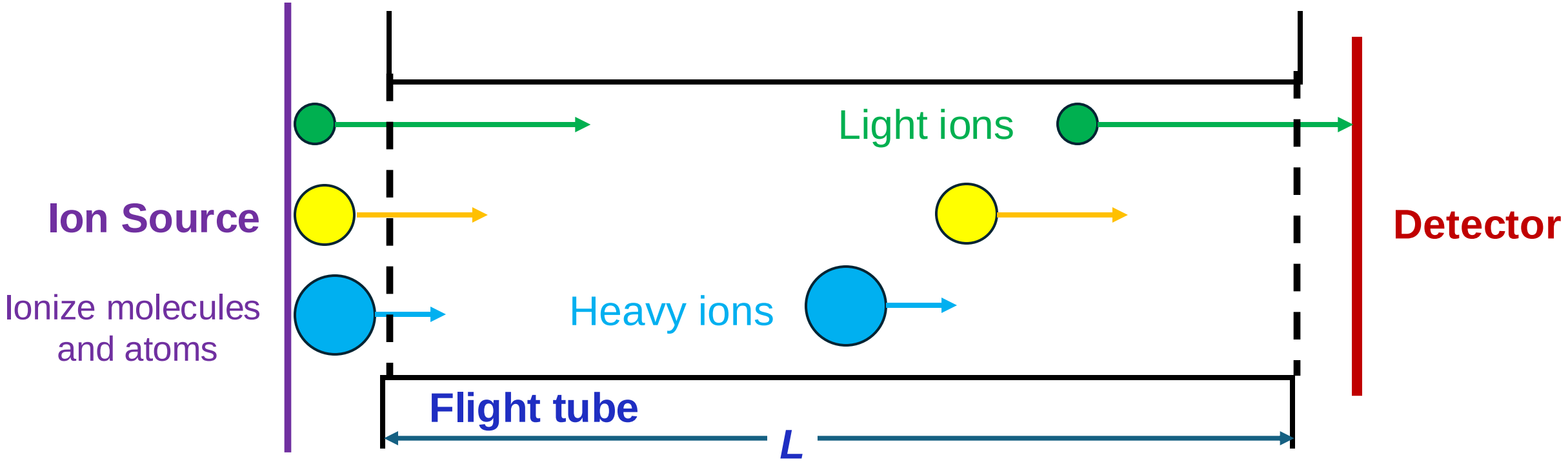


Onboard Mass Spectrometer can achieve **Chemical Analysis** on the celestial bodies.

Onboard Mass Spectrometer

An analytical instrument that ionises molecules and atoms and analyze their mass (*m/z*) and the amount of ionic current to qualify and quantify the substances in the sample

Time-of-flight Mass Spectrometer (TOFMS)



Acceleration voltage *V*

Ions are accelerated by a certain voltage.

Mass Separation Section

The accelerated ions with smaller masses fly faster and those with larger masses fly slower.

By measuring the travel time of ion to reach the detector in a flight tube, mass of the ion can be determined.

Development of a Compact Ultra-High Mass Resolution Onboard Mass Spectrometer

MULTUM (Multi-turn Time of Flight Mass Spectrometer)

TOFMS with multiple orbits of ions in the same orbit in a figure-of-eight configuration. The multiple orbits of the ions allow very long flight distances in a compact space and realize a high mass resolution. MULTUM was once considered for ESA's Rosetta Mission.

Powerful instrument for on-site organic chemical analysis in future solar system exploration.

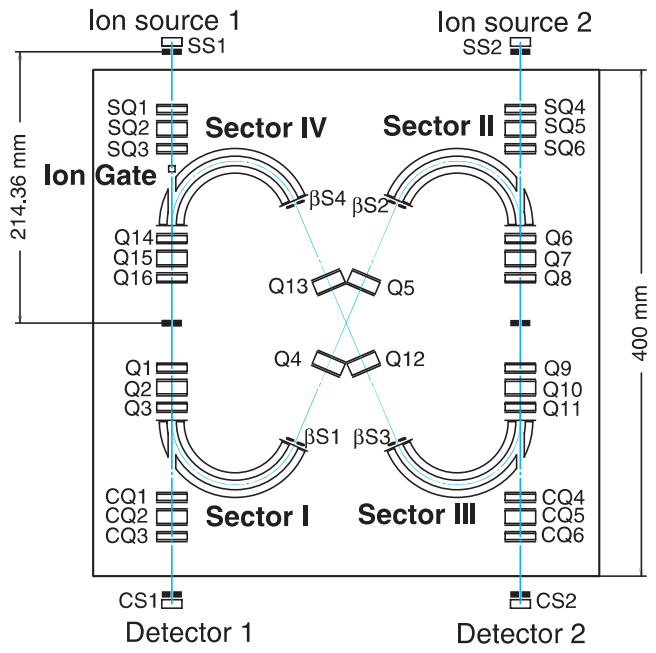


Figure 6. Schematic drawing of the MULTUM Linear plus.

Toyoda *et al.* (2019) *J Mass Spectrom*

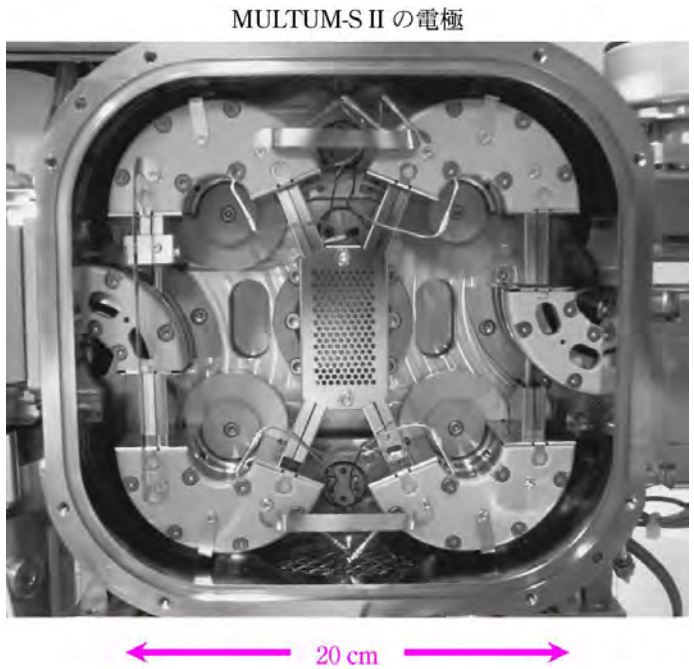
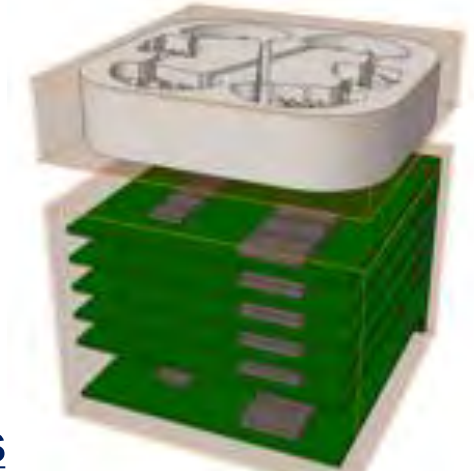


図 4　MULTUM−S II の電極

Aoki (2019) Bunseki

MULTUM-Sp (Under development)

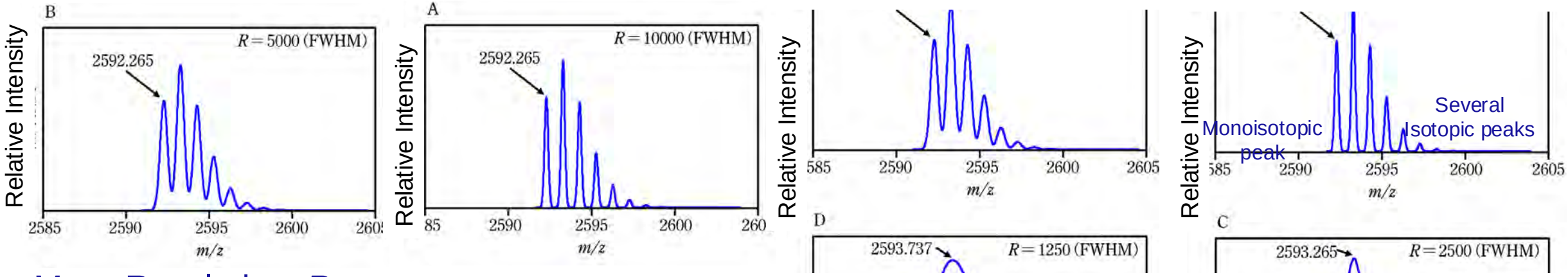


Target Specs

- **Size：10 cm cube**
- **Mass: TBD (~1.5 kg)**
- **Mass Resolution: >10,000**

What MULTUM-Sp can do?

with Ultra-high Mass Resolution



Mass Resolution: *R*

Low resolution
1 broad peak

→

High resolution
7 peaks

1. Precise isotopic analysis of small molecules

Yoshino (2017) Bunseki

Methane CH_4 : Molecular Weight 16 Integral mass (6 patterns) and Exact mass (10 species)

m/z 16
- $^{12}CH_4$ (16.0313)

m/z 17
- $^{13}CH_4$ (17.0347)
- $^{12}CDH_3$ (17.0376)

m/z 18
- $^{12}CD_2H_2$ (18.0439)
- $^{13}CDH_3$ (18.0409)

m/z 19
- $^{12}CD_3H$ (19.0501)
- $^{13}CD_2H_2$ (19.0472)

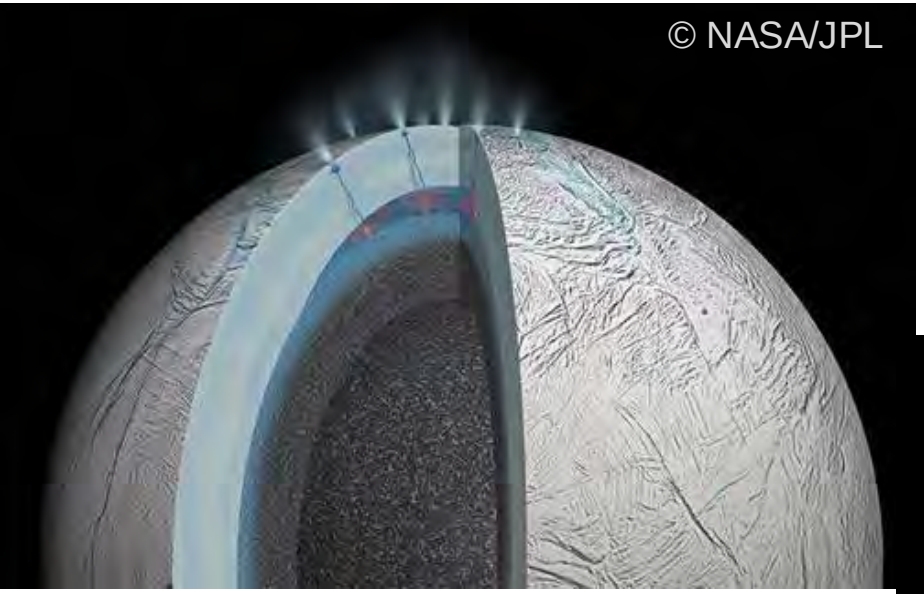
m/z 20
- $^{12}CD_4$ (20.0564)
- $^{13}CD_3H$ (20.0535)

m/z 21
- $^{13}CD_4$ (21.0598)

2. Analysis of Organic molecules with high molecular weight

Chemical Analysis that MULTUM-Sp can Realize

Flyby Analysis of the Plume materials of Icy Moons



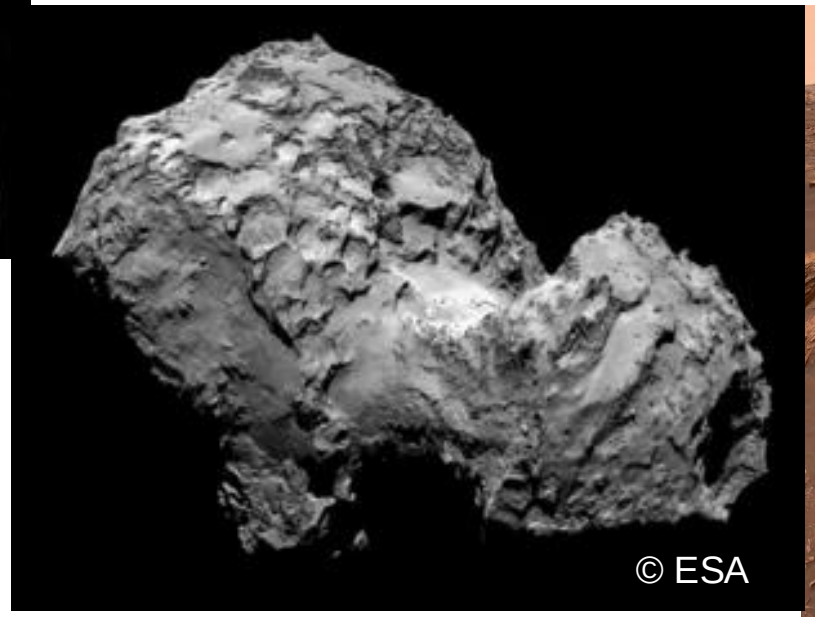
Saturnian satellites:
Enceladus

Habitability

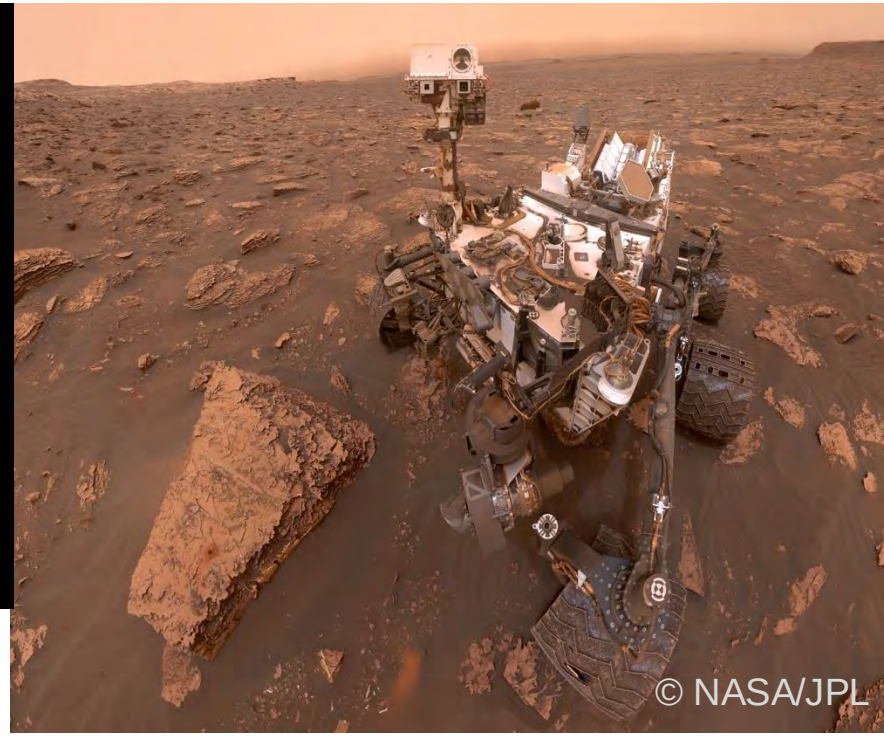
Evolution of Organic Molecules

Analysis of Solid Materials though Landing on Comet, Mars, Moon, etc.

By combining with various pre-treatment system
(e.g., Pyrolizer and Gas Chromatograph)

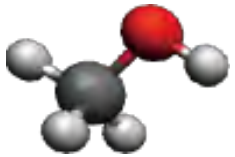


Comet
67P/Churyumov-Gerasimenko



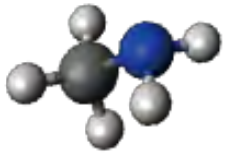
Mars

Take-home Messages



Sample return mission provide valuable samples that contain various and precise information about the Solar system.

However, the number of time and the distance we can go by sample return mission has limitation.



Onboard mass spectrometer with high mass resolution will expand the possibility for chemical analysis in space missions.