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Spin-off Application of Silica Aerogel in Space: Capturing Intact Cosmic Dust in Low-Earth Orbits and Beyond

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On behalf of the Tanpopo Team

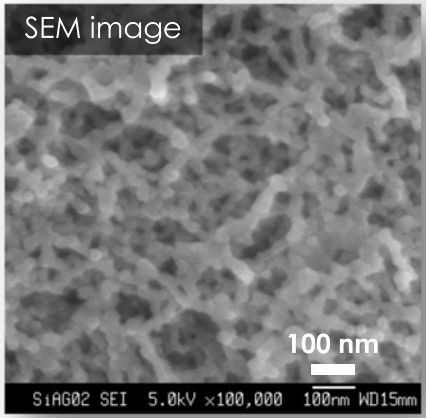
Outline

- **Introduction**
  - Application of silica aerogel in HEP experiments
  - Spin-off application of aerogel as dust-capture media
- **Application of Silica Aerogel in Space Science**
  - Experiments in low-Earth orbits
  - Cometary dust sample return mission in deep space
- **Astrobiology Mission: Tanpopo**
  - Objectives and status
  - Aerogel-based capture instruments

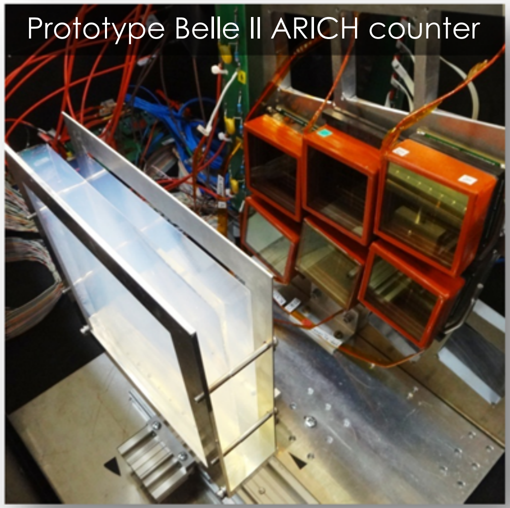
Introduction

HEP Application of Silica Aerogel

- **Silica aerogel:**
  Colloidal foam of nanoscale SiO_2 particles
  - **Transparent**
  - **Tunable refractive index** [i.e., bulk density]
    n = 1.003–1.26 Journal ref. / M. Tabata et al., Nucl. Instrum. Methods A 623 (2010) 339.
    - Density determined by silica–air volume ratio



- **Application in high-energy physics: Cherenkov radiator**
  - Threshold-type Cherenkov counter;
    Ring imaging Cherenkov [RICH] counter
  - Particle identification;
    Velocity measurement
  - Accelerator-based particle- and nuclear-physics experiments: e.g., Belle II, LHCb, etc.;
    Space- and balloon-borne cosmic-ray experiments: e.g., BESS, AMS-02, etc.



- Presentation ref. / M. Tabata *et al.*, in: Session R1-Particle identification(1) on May 23.

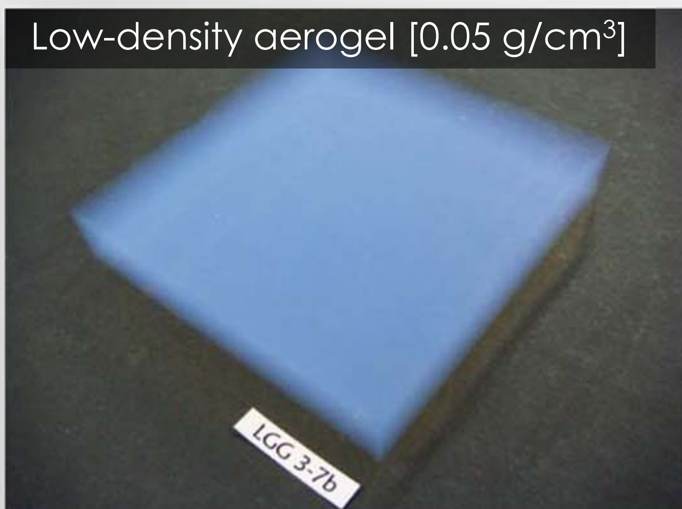
Spin-off Application of Aerogel in Space

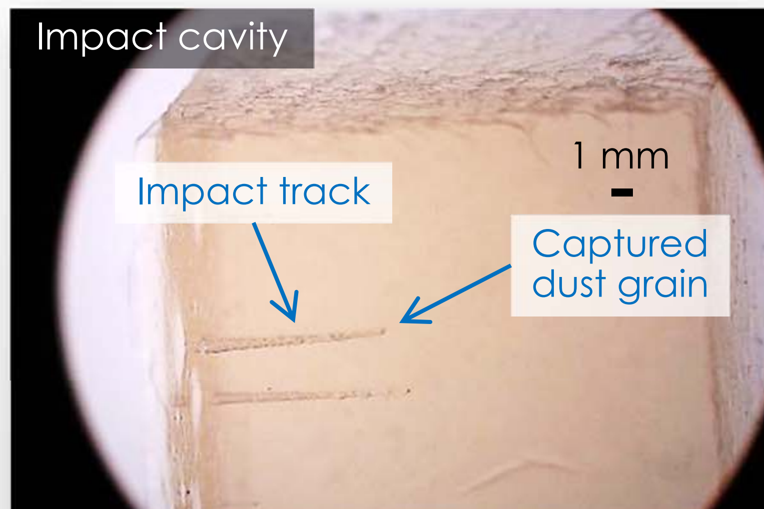
Q: How can we retrieve intact cosmic dust from space?

- Cosmic dust = **Micron-size** [~10 μm dia.]
  = **Hypervelocity** [Max. ~16 km/s in low-Earth orbits]

A: Expose "silica aerogel" in space!

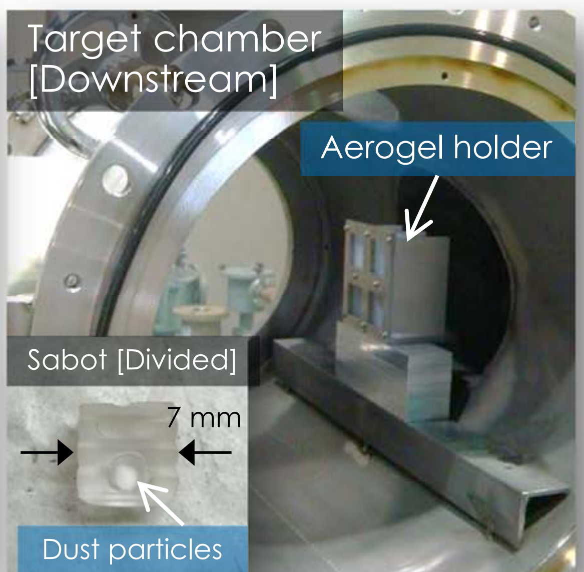
- **Why aerogel?**
  - **Ultralow density** → Intact dust capture inside the aerogel
  - **Transparent** → Visible impact cavity/captured dust grain





Laboratory Impact Experiment

- **Test beam experiment? No, gas gun experiment.**
  - Ground-based laboratory simulation of dust capture in aerogel
- **Two-stage light-gas gun**
  - **Accelerator in the space science field**
  - 7-mm dia. bullet [Max. 7 km/s]
  - Acceleration mechanism:
    Gunpowder [1st stage] → Piston → H_2 gas [2nd stage] → Projectile → Target



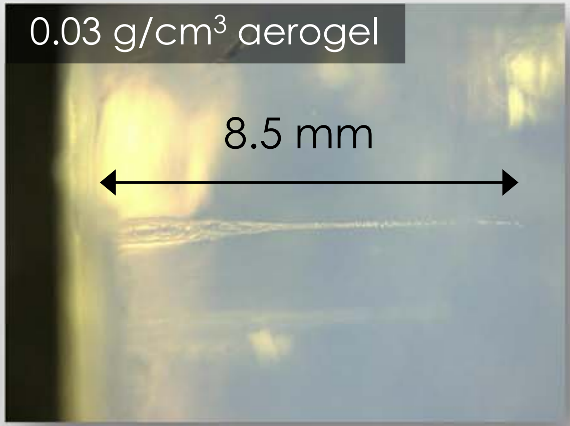
Hypervelocity Impact Physics

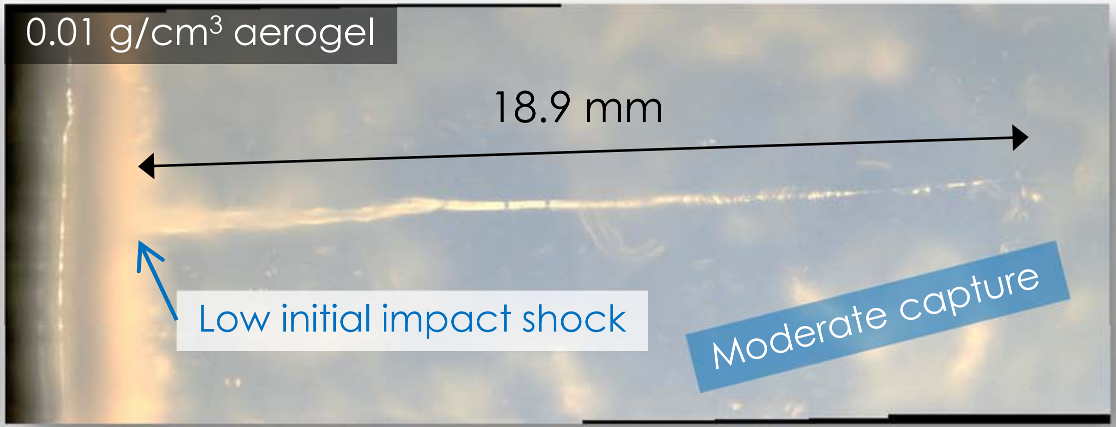
- **Morphological analysis of impact tracks under an optical microscope**

Track length Entrance width Maximum track width Track volume	Empirical association ⟷	Aerogel density Impact energy – Impact velocity – Particle size and density

- **Lower-density aerogel to absorb impact shock**

30 μm glass beads shot at 6 km/s by the gas gun





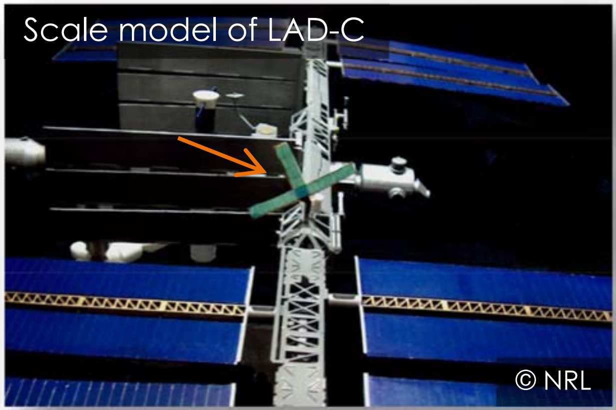
Application of Silica Aerogel in Space Science

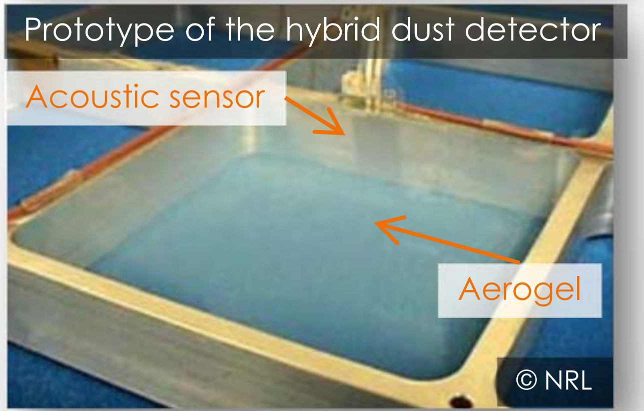
Cosmic Material Sample Return

- **Cosmic sample material return is very important.**
  - Planetary science, astrochemistry, astrobiology, space debris research, and etc.
- **Ground-based state-of-art analysis instruments are used.**
  - Biochemical analysis, mineralogical analysis, and etc.
- **Aerogel was first recognized as promising cosmic dust capture media in the 1980s.**
  - Use of aerogel in space since the 1990s.
  - First space missions in near-Earth orbits:
    - **NASA's space shuttle cargo bay** [0.02 g/cm³, 9-day exposure]
    - **ESA's Eureca freefrying spacecraft** [0.05 g/cm³, 11-month exposure]

LAD-C: Debris Collection Project in LEO

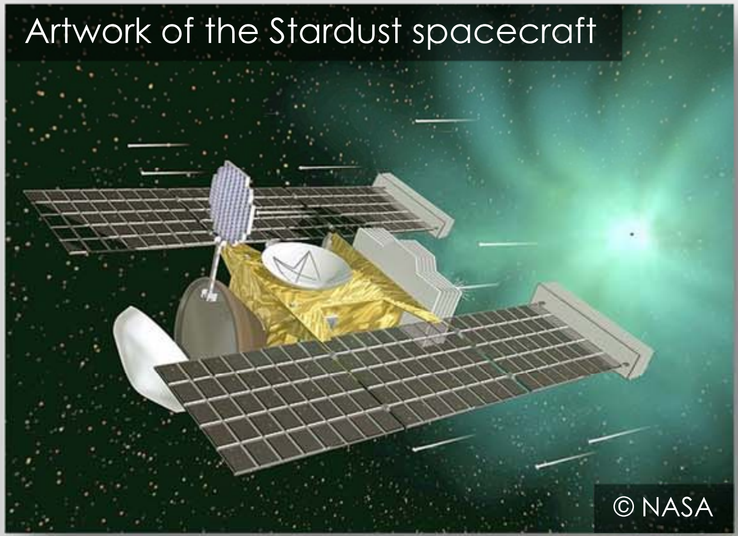
- **LAD-C: Large Area Debris/Dust Collector aboard the International Space Station**
  - **Project unfortunately canceled** before building the system due to a political reason in 2007
- **Observation of ~100+ μm debris**
  - Potential risk of impact to orbital satellites
  - No ground-based observation by radar
  - Use of **10 m^2 aerogel-based collector**
- **Hybrid dust detection**
  - **Sample return** by 0.06 g/cm^3 large-volume aerogel tiles
  - **Real-time detection** by an impact sensor [using acoustic vibration of aerogel by dust impacts]





Stardust: Deep Space Mission to a Comet

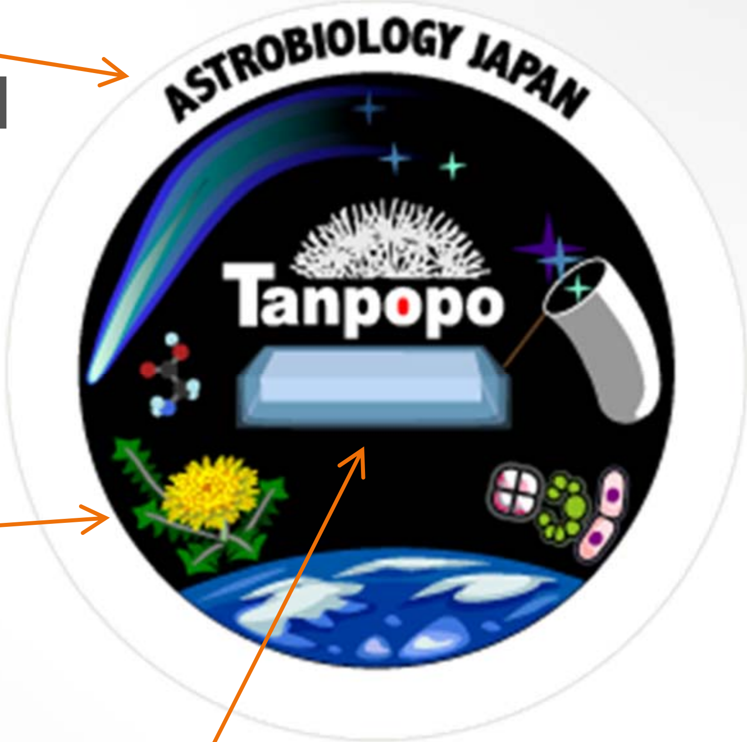
- **Stardust: NASA's comet Wild-2 dust sample return mission**
  - Launched in 1999 and returned to Earth in 2006
  - **First extra-terrestrial object's sample other than the Moon**
  - Interplanetary and interstellar dust at cruising phase
- **Flyby dust collection by a density-gradient aerogel-base sampler**
  - Aerogel density: ~0.01 g/cm^3, [Surface], ~0.05 g/cm^3 [Bottom]
  - Flyby speed: 6.1 km/s



Astrobiology Mission: Tanpopo

Tanpopo Mission Objectives

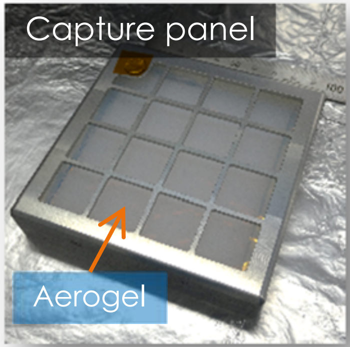
- **Japan's first astrobiology mission in space [International Space Station]**
  - Proposed in 2007
  - Launched in 2015
  - Retrieved in 2016, 2017, and 2018
- **Test of interplanetary transfer of life or its precursor**
  - Tanpopo (in Japanese) = Dandelion
  - Spread of dandelion's seeds on Earth
    → Transfer of life in space
- **Multifaceted sample return mission**
  - **Cosmic dust capture experiment by silica aerogel**
    - **Microbes** in terrestrial dust
    - **Organic compounds** in interplanetary dust
    - **Space debris**
  - **Space exposure experiment**
    - Terrestrial microbe and organic compound samples

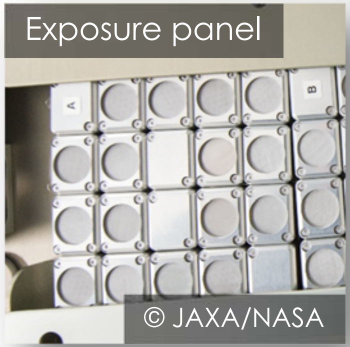


- **25+ institutes**
- **50+ collaborators**
  - Biologist
  - Chemist
  - Physicist
  - Planetary scientist
  - Engineer

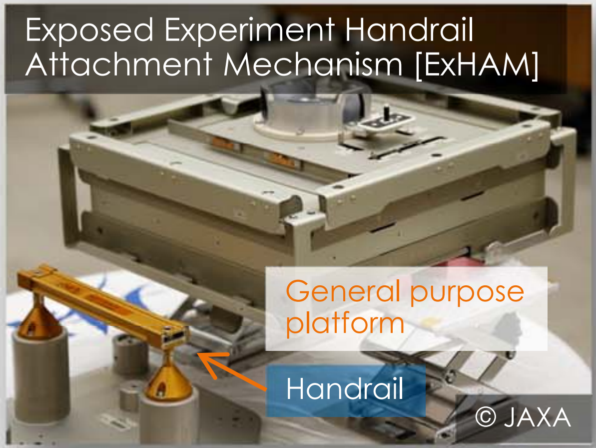
Tanpopo Instruments

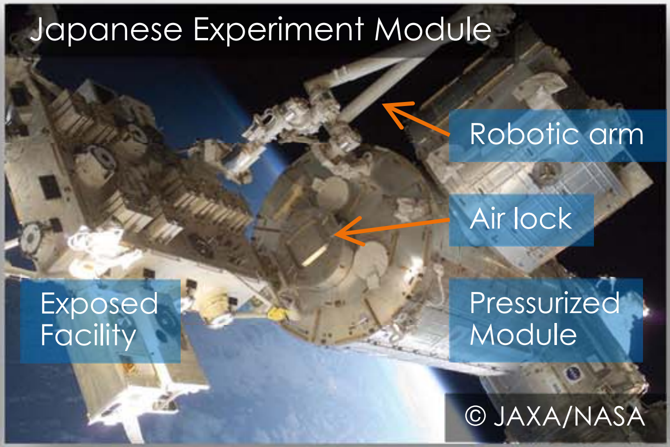
- **Instruments dedicated to the Tanpopo mission: Capture panels [CP] and exposure panels [EP] developed by the Tanpopo team**
  - CP: 12 units X 3 years = **36 units**
  - EP: 1 unit X 3 years = 3 units
  - **10 X 10 X 2 cm^3** per unit
  - Cost-effective sample return instruments





- **Use of the exposure experiment opportunity provided by JAXA collaborating with NASA and SpaceX**

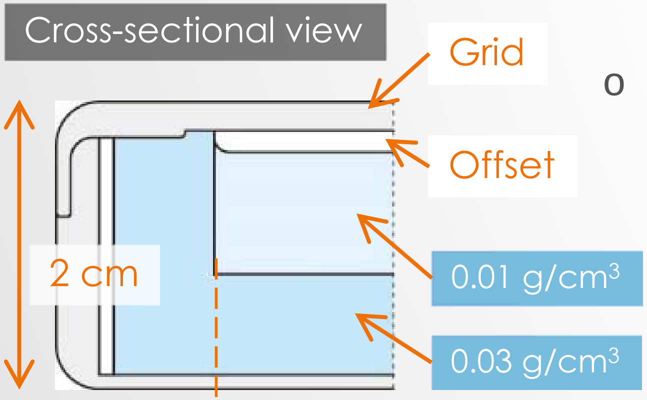




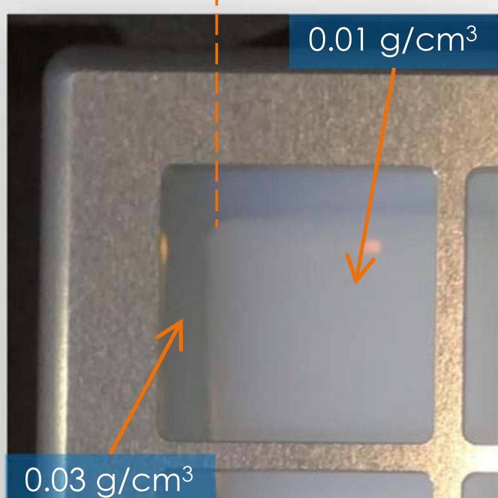
Ultralow-density Double-layer Aerogel

Capture panel design

Cross-sectional view

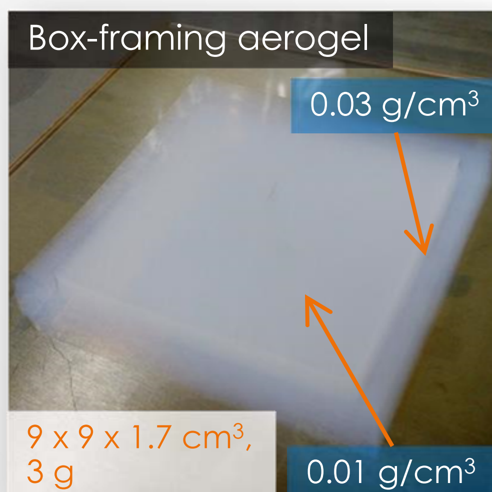


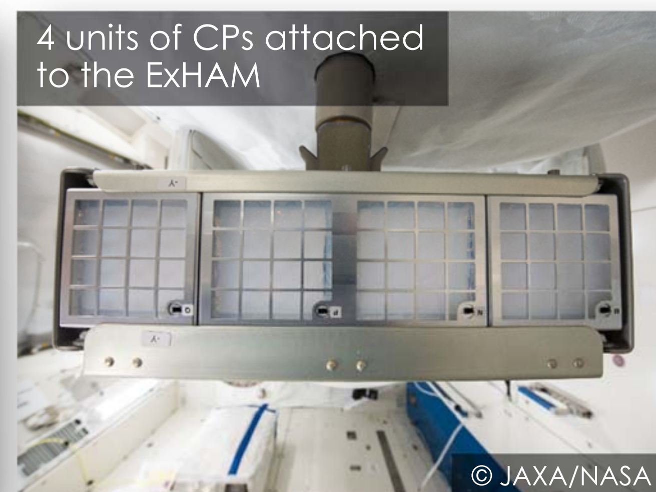
Top view



- **0.01 g/cm³ ultralow-density aerogel**
  - World's lowest density used in space
- **Double-layer [box-framing] aerogel**
  - Surface layer: 0.01 g/cm³ [Brittle]
    - Capture ~10 μm dust particles
  - Base layer: 0.03 g/cm³ [Relatively tough]
    - Protect the surface layer from vibrations
    - Capture high-energy dust particles
  - Both the layers chemically combined

Journal ref. / M. Tabata *et al.*, J. Sol–Gel Sci. Technol. 77 (2016) 325.





Tanpopo Mission Status

SpaceX's Falcon 9 rocket launch

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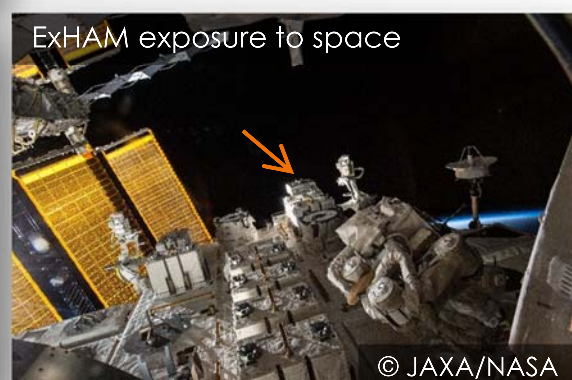
Dragon docking to the ISS

© NASA

- **Rocket launched in Apr. 2015**
  - 2016, 2017, and 2018 samples
  - Arrival in the ISS
- **ExHAM exposed in May 2015**
  - CPs for 2016 attached to the ExHAM
- **ExHAM recovered in Jun. 2016**
  - CPs for 2016 stored in the Pressurized Module
- **Cargo spacecraft retrieved in Aug. 2016**
- **2016 sample analysis and 2017 sample exposure in progress**

CP attachment to the ExHAM

© JAXA/NASA



ExHAM exposure to space

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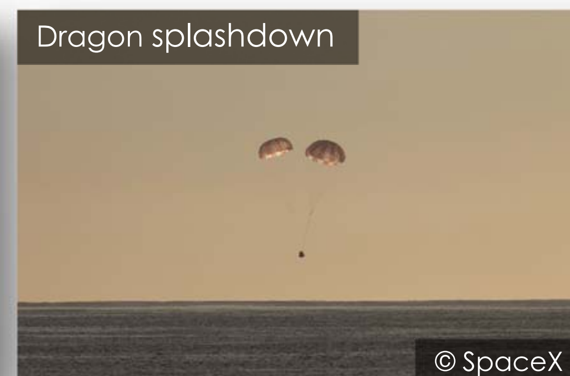
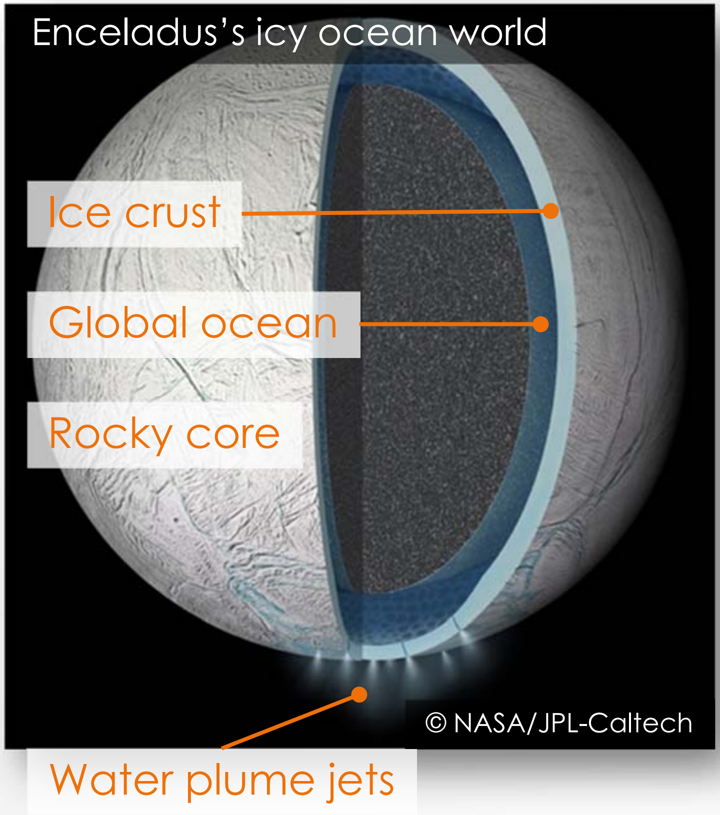


Dragon splashdown

© SpaceX

Beyond Low-Earth Orbits

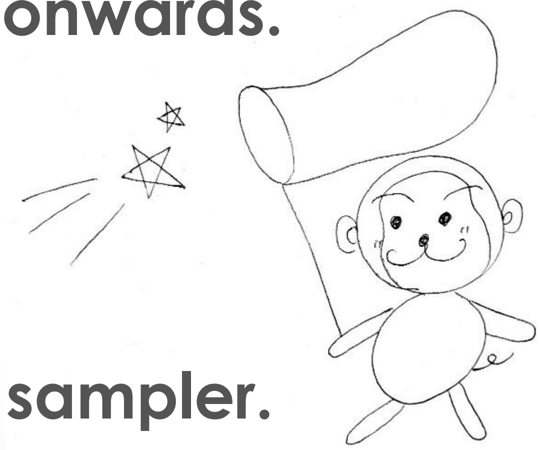
- **Another possible habitable zone in our solar system: Saturn's moon Enceladus**
  - NASA's Cassini mission [Saturn and its satellite system observation]
    - Gravity field analysis suggested:
      - Underground ocean [Liquid water]
    - Plume analysis detected:
      - Organic molecules
      - Nano-silica particles
      - Hydrogen molecules [Free energy]
  - **Hydrothermal environment** by tidal heating → **Possible extra-terrestrial life**



- **Enceladus flyby missions proposed by NASA and JAXA**
  - Plume particle in-situ analysis and sample return based on the **aerogel intact capture technique**

Summary

- **A spin-off application of silica aerogel as intact cosmic dust collection media was recognized in the 1980s.**
  - Laboratory gas gun experiments support the application of aerogel to hypervelocity particle capture.
- **Aerogel has been used in several missions in low-Earth orbits and deep space since the 1990s onwards.**
  - Retrieved dust samples are useful in **planetary science**, **astrochemistry**, and **space debris research** fields.



- **Recent astrobiology missions employ high-performance aerogel-based dust sampler.**
  - The **Tanpopo mission** will create new knowledge about the **origin of terrestrial life**, and the proposed **Enceladus mission** will explore **possible extra-terrestrial life**.