Retrieving Intact Interplanetary Dust from Low-Earth Orbits: A Silica Aerogel-based Capture Technique

Makoto Tabata

(Dept. of Physics, Chiba Univ.)

On behalf of Tanpopo Collaboration

16th Workshop on Fine Particle Plasmas

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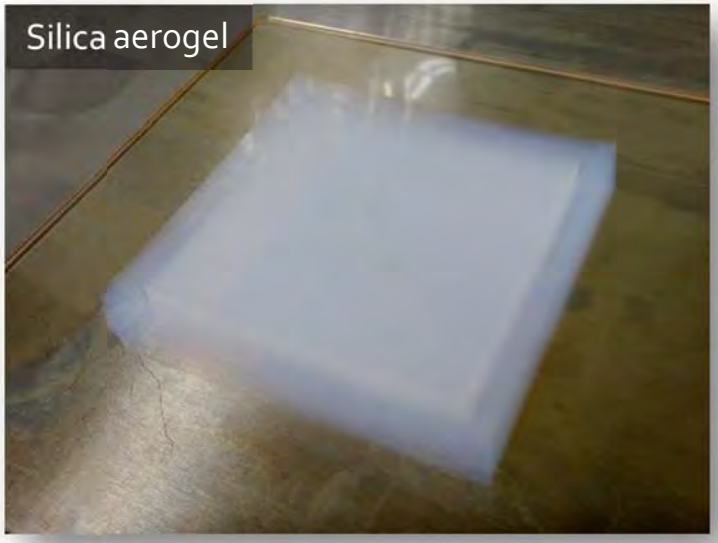
Highlights

- The astrobiology experiment, Tanpopo requires hydrophobic silica aerogel with a density of 0.01 g/cm^3.
- The ultralow-density aerogel is used for intact capture of cosmic dust in low-Earth orbits.
- Box framing structure to protect the 0.01 g/cm^3 aerogel from rocket launch vibrations was designed.
- Cosmic dust capture panels with the box-framing aerogel tiles were developed.
- The Tanpopo capture panels were successfully launched in low-Earth orbits and deployed to the International Space Station.

Tanpopo mission patch


Silica aerogel

Dragon supply spacecraft

Outline

1. **How to Capture Cosmic Dust in Space**
   - Hypervelocity impact experiment in lab
   - Tanpopo mission
2. **What Silica Aerogel Is**
   - Characteristics
   - Fabrication method
3. **Development of the Tanpopo Capture Panels**
   - Design
   - Fabrication and assembly

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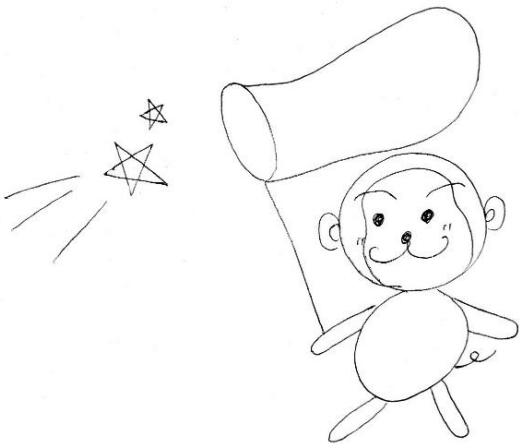

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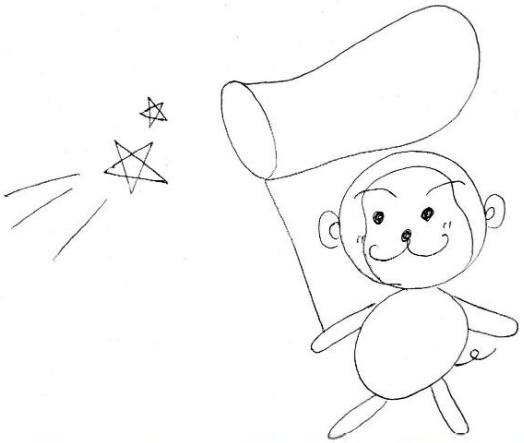
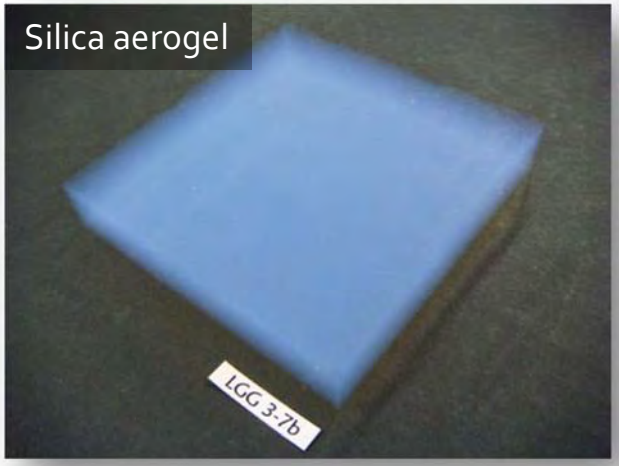
How to Capture Cosmic Dust in Space

How can we retrieve cosmic dust from space?



- Comic dust → Microparticle grain
  e.g., 30 μmϕ
- Cosmic dust capture → Hypervelocity impact phenomenon
  e.g., 6 km/s collision

Yes, use "silica aerogel."



- Ultralow density → Intact capture
  e.g., 0.01 g/cm^3 (lowest density used in space)
- Transparent → Visible impact cavity

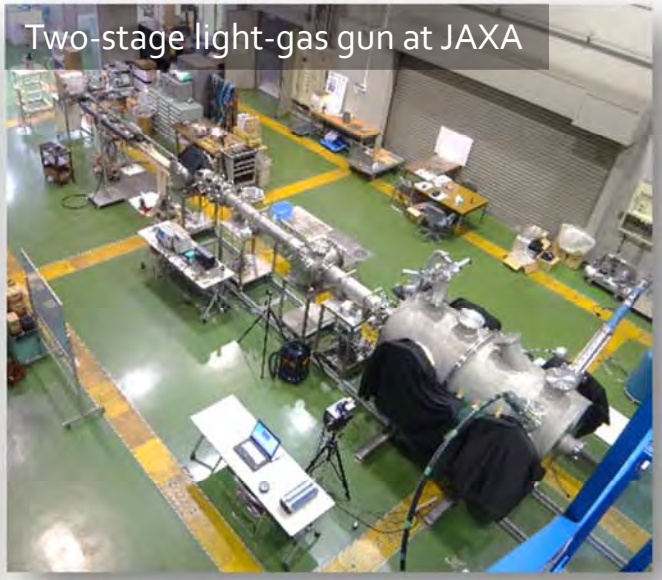
Cosmic sample return is very important!

- Planetary science
- "Astrobiology" → Biochemical analysis

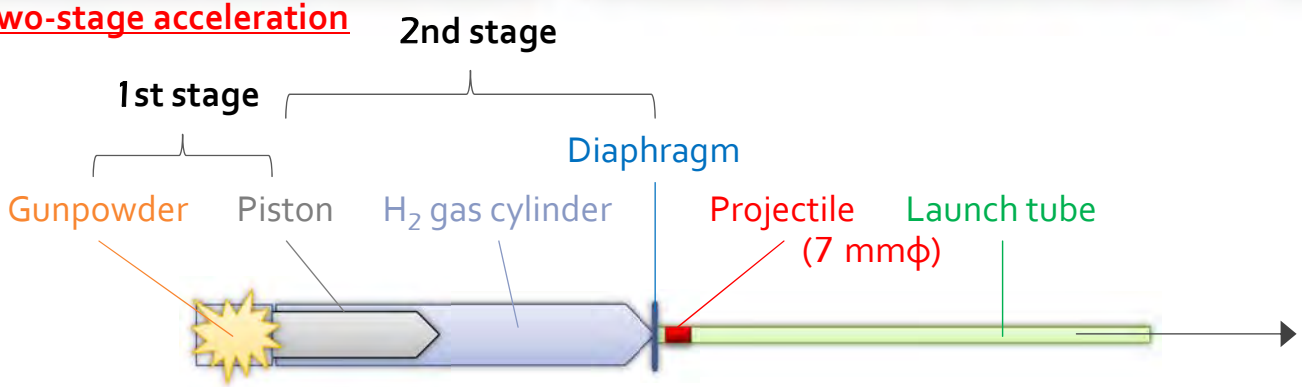
Silica aerogel was first employed as a cosmic dust capture medium in the 1980s.

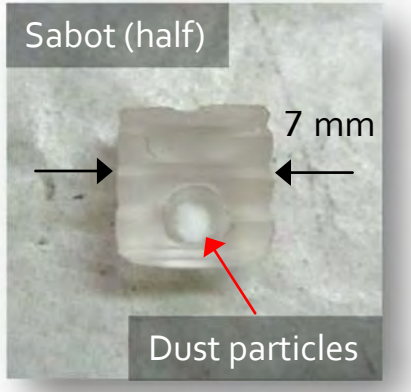
Hypervelocity Impact Experiment in Lab

Ground-based laboratory simulation of hypervelocity impact of cosmic dust to the aerogel
→ **Two-stage light-gas gun experiment (Max. 7 km/s)**

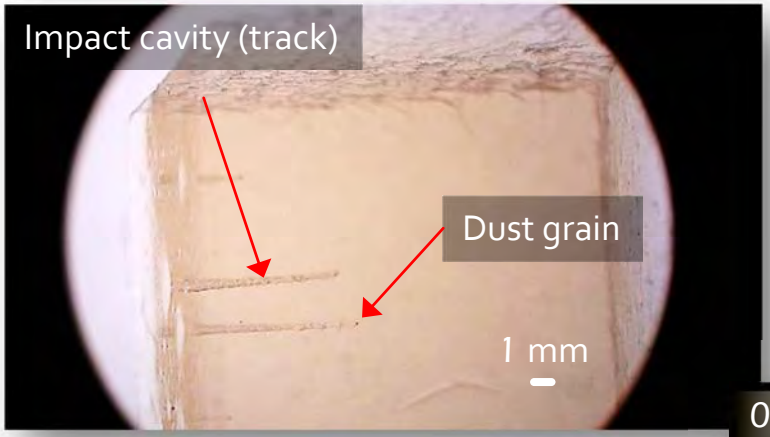


Two-stage acceleration



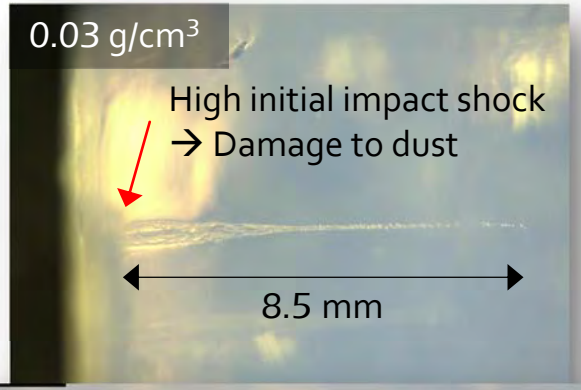


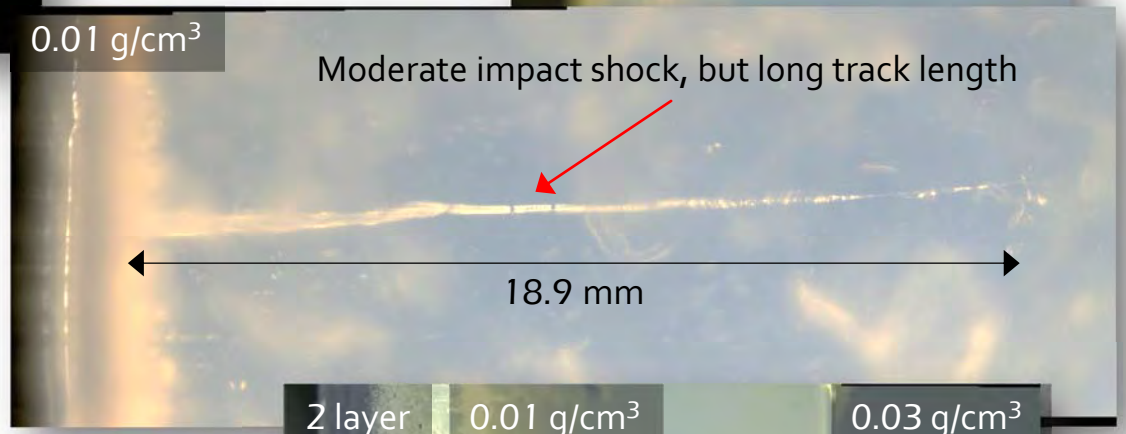
Dust Grain under a Microscope



Comparison of the aerogel density

30 μmϕ glass beads
6 km/s



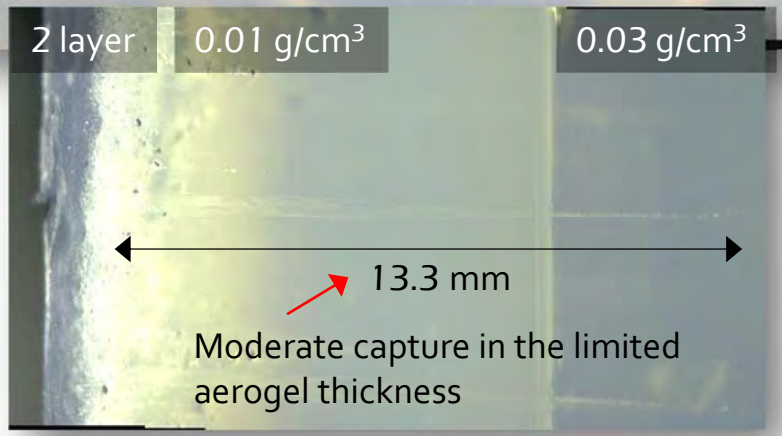


Impact physics in track morphology

Track length
Entrance width
Maximum track width

↕

Impact energy
Aerogel density



Tanpopo Mission

Japan's first astrobiology mission in space:

- Proposed in 2007
- Approved by JAXA in 2012
- Launched in 2015
- Retrieved in 2016, 2017, and 2018.

PI: Prof. A. Yamagishi at Tokyo University of Pharmacy and Life Science

Capture experiment of cosmic dust using silica aerogel:

- Terrestrial dust
- Interplanetary dust
- Space debris

Capture experiments:
10 institutes
~20 collaborators

Test of the Panspermia hypothesis:

- Possible interplanetary transfer of life
- Dandelion = Tanpopo (in Japanese)
- Seeds of Tanpopo = Mission concept

Exposure experiment to space:

- Microbes
- Organic matters

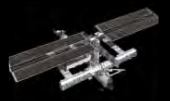
Objectives of the Tanpopo

6 missions of the Tanpopo experiment (sample return mission)

- Mission 1: Capture of terrestrial microbes in dust
- Mission 2: **Exposure** of microbes to space
- Mission 3: **Exposure** of organic matters to space
- Mission 4: Capture of organic matters in dust
- Mission 5: Verification of the **capture** performance of ultralow-density aerogel
- Mission 6: Capture of space debris

Solar system objects

International Space Station
(Low-Earth orbits)



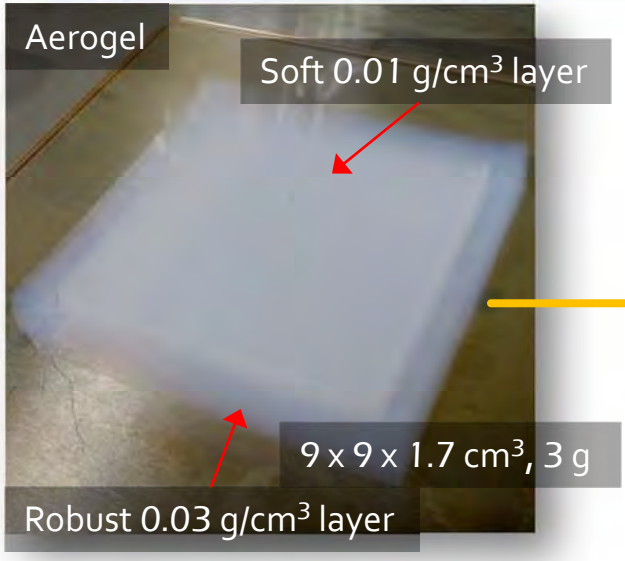
Earth

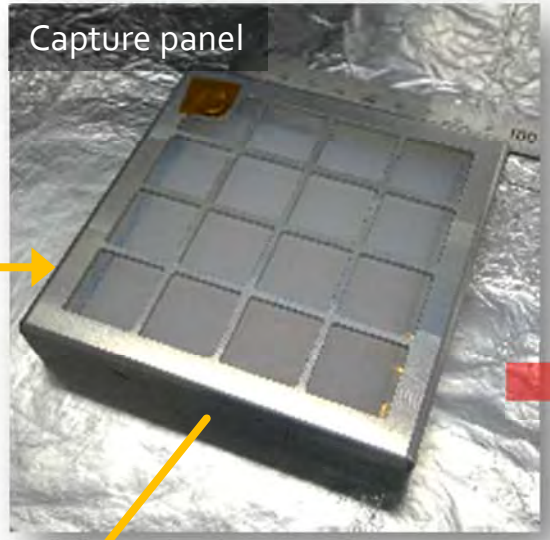
Tests of interplanetary transfer of life
(or its precursor)

Organic matters

Microbes

Tanpopo Capture Apparatus



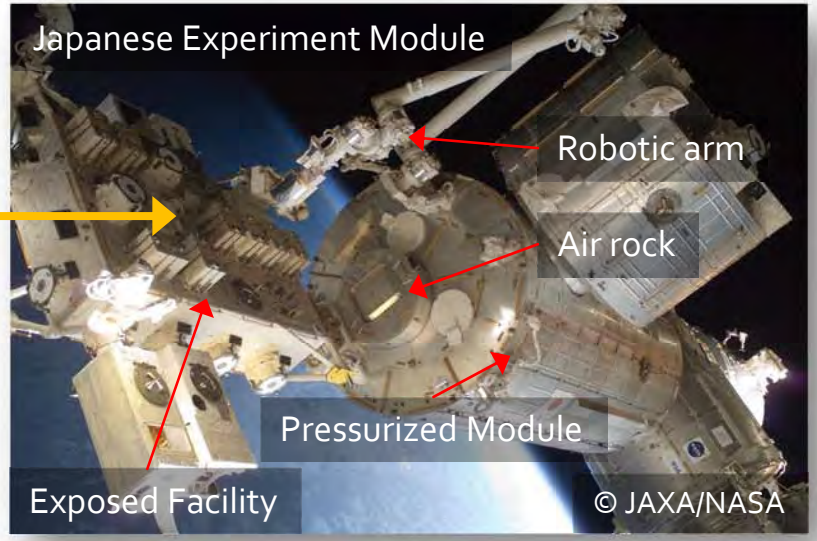


4 aerogels x 3 sides /year
1-year exposure x 3 years

Total 36 aerogels

International Space Station (ISS)
in low-Earth orbits (LEO)

Exposed Experiment Handrail Attachment Mechanism (ExHAM) developed by JAXA



Liftoff

SpaceX Falcon 9 rocket launch with Dragon supply spacecraft on Apr. 14, 2015

Movie available at: https://www.youtube.com/watch?v=csVpa25iqHo

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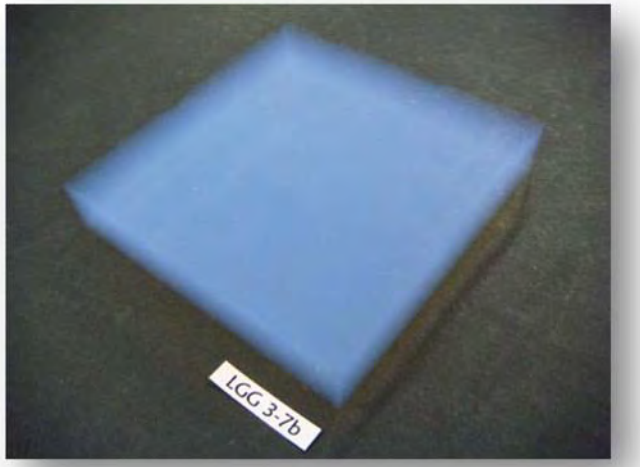

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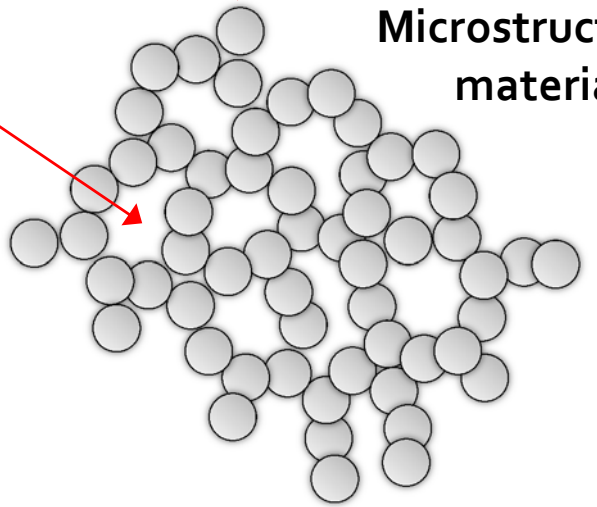
What Is Silica Aerogel?

Aerogel = **Aero (air)** + **Gel**

= **Pore air** + **Dispersoid particle network**

Silica aerogel = **Pore air** + **Silica (SiO_2) particle network**



Microstructured material

Solid state system

Aerogel

Silica aerogel

First produced
Well studied

Carbon aerogel

Alumina aerogel

⋮

etc.

Silica Aerogel under a SEM

Microscopic structure

Nanoscale, 3D networks of silica (i.e., quartz) particles

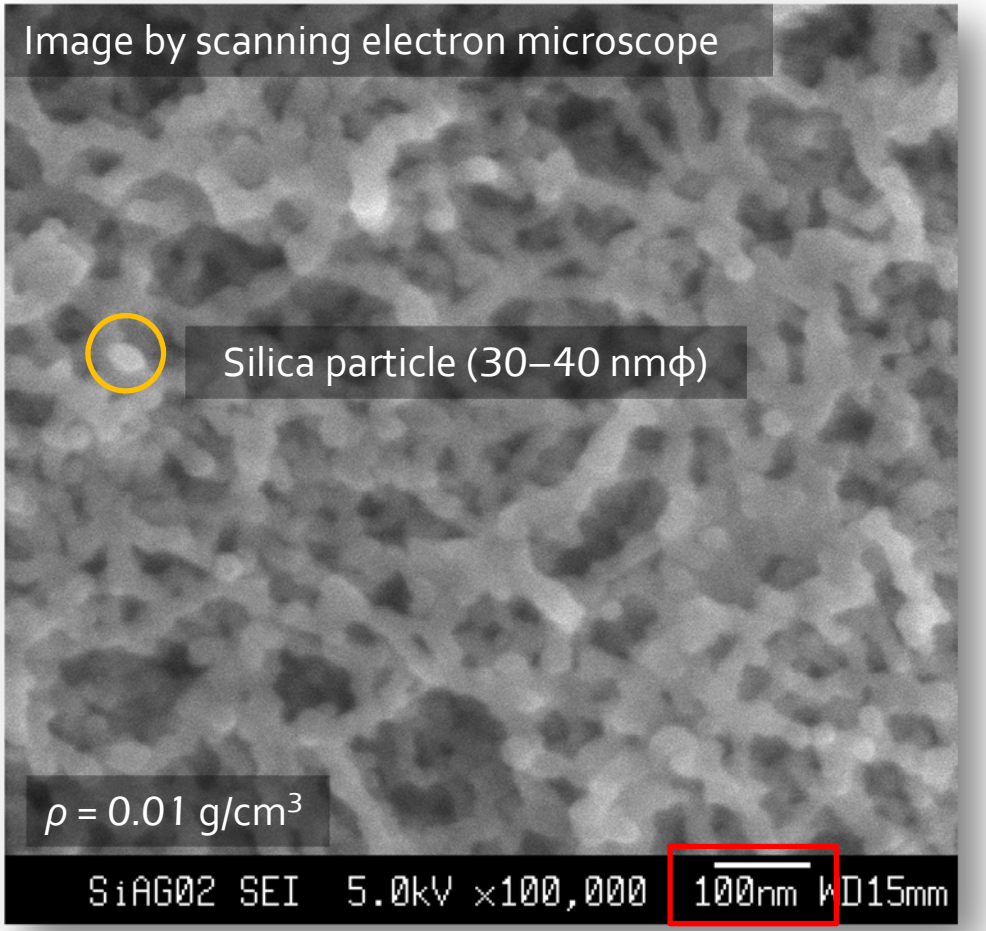
- Amorphous (non-crystalline)

Open pores

- Highly porous (max. 99.9% air)

Macroscopic structure

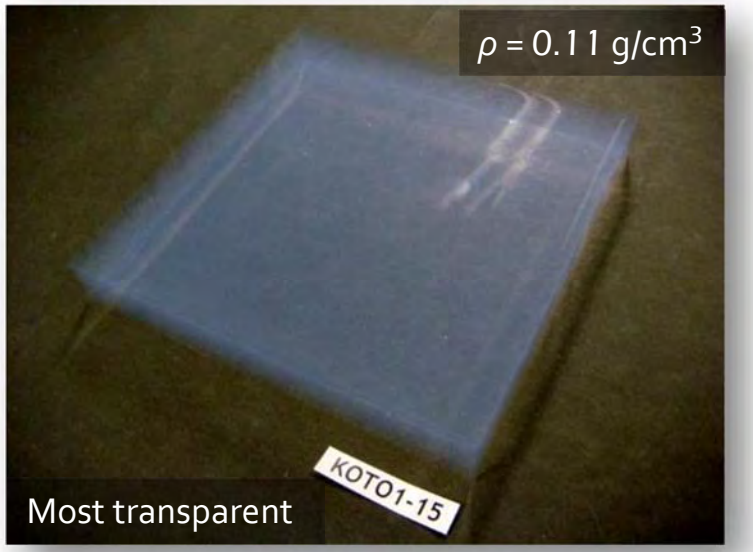
- Uniform material under visible light:
  Optical wavelength
  ~10 x Nanostructure
- Apparent density $\propto V_{silica}/V_{pore}$

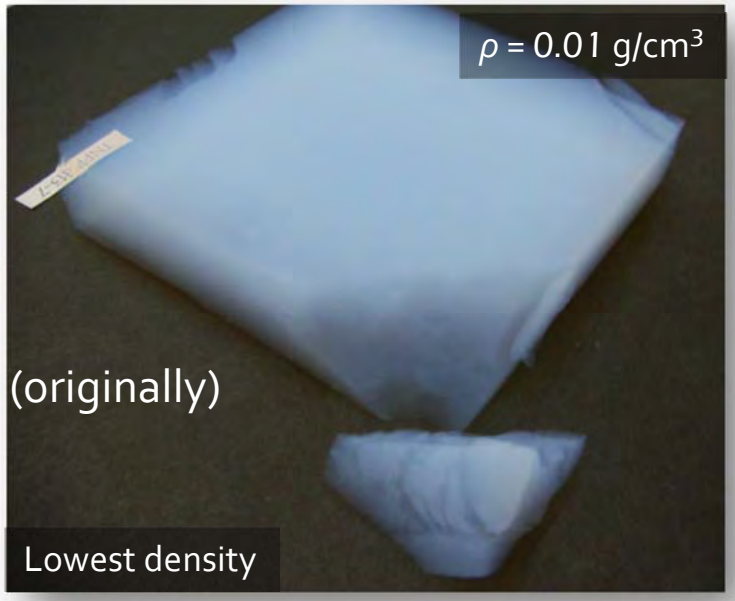


Characteristics of Silica Aerogel

Physical (optical)

- Transparent (depending on density)
  Rayleigh scattering
- Intermediate refractive index (n)
  $n = 1.003–1.26$
  $n - 1 = k\rho$ (k: constant)
- Tunable apparent density (ρ)
  $\rho = 0.01–1.0$ g/cm^3





Chemical

- Hydrophilic (originally)

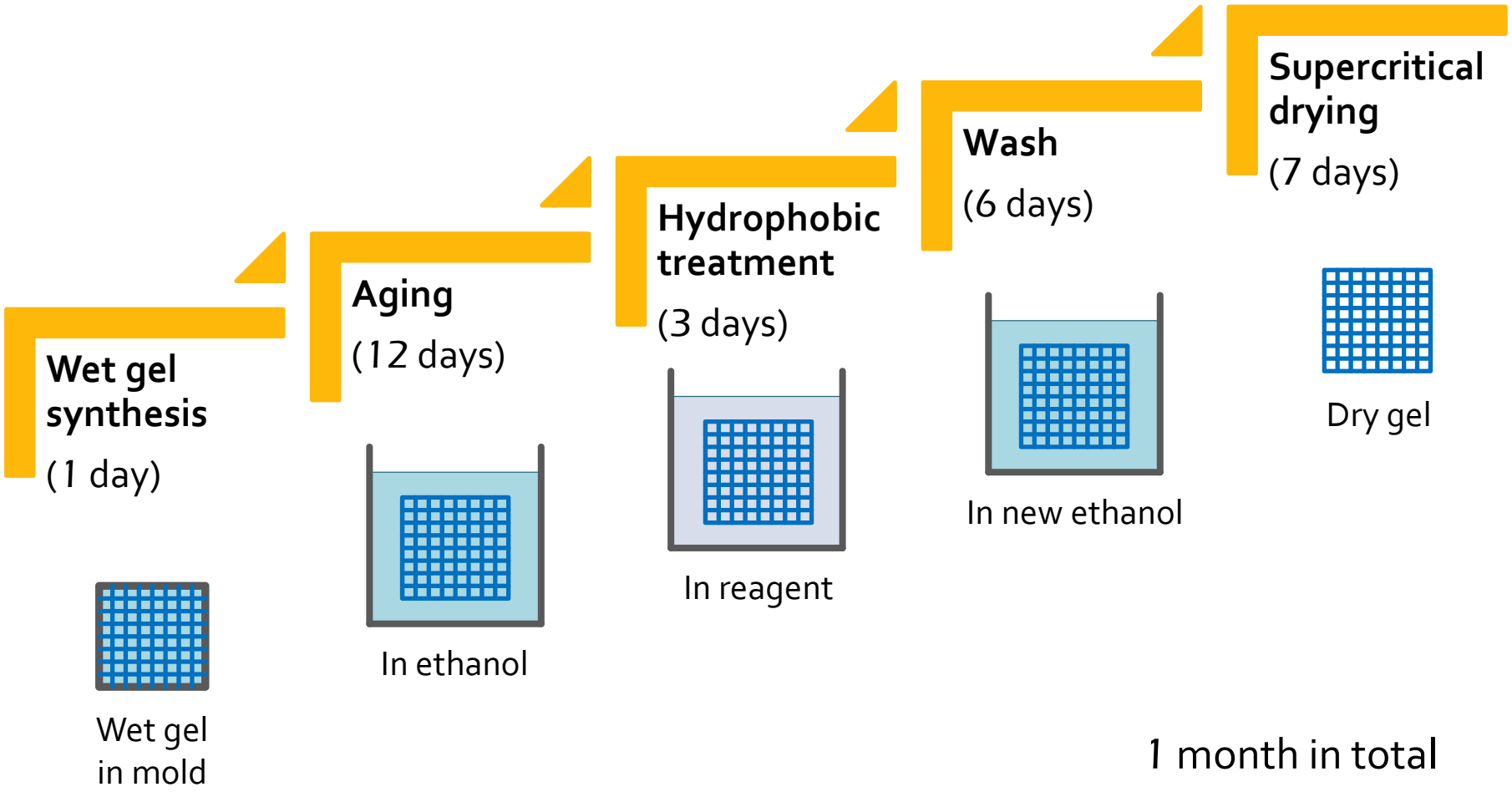
Texture

- Low density
  → "Frozen smoke"
- Intermediate density
  → Styrofoam
- High density
  → Plastic or glass

Aerogel Production Method

5-step silica-aerogel production procedure

(Low density version at Chiba University)



Wet Gel Synthesis

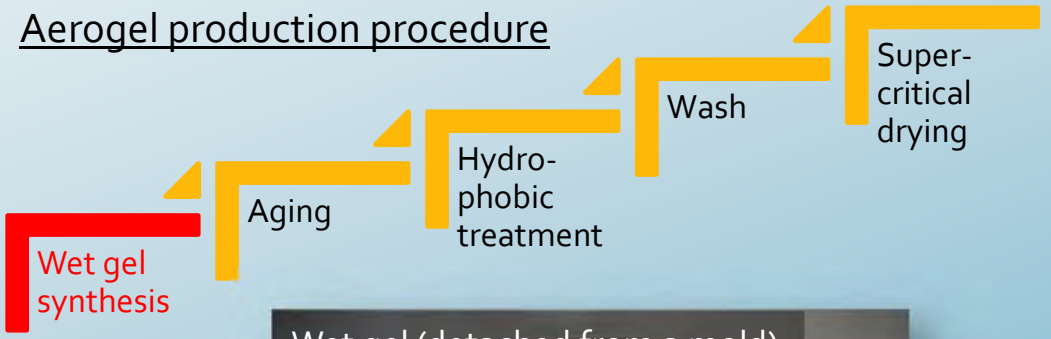
Use raw chemicals (liquids)

Polymethoxy siloxane
- Silica source (precursor)

28% Ammonia solution
- Water source, catalyst

Ethanol
- Diluent solvent

Aerogel production procedure



Sol–gel method

Sol–gel condensation polymerization reaction

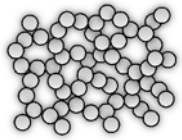
(~5 min. gelation)

Ethanol

Ammonia solution

$$CH_3O[Si(OCH_3)_2O]_nCH_3 + (n+1)H_2O \longrightarrow (SiO_2)_n + (2n+2)CH_3OH$$

Silica precursor — Water — Silica chain

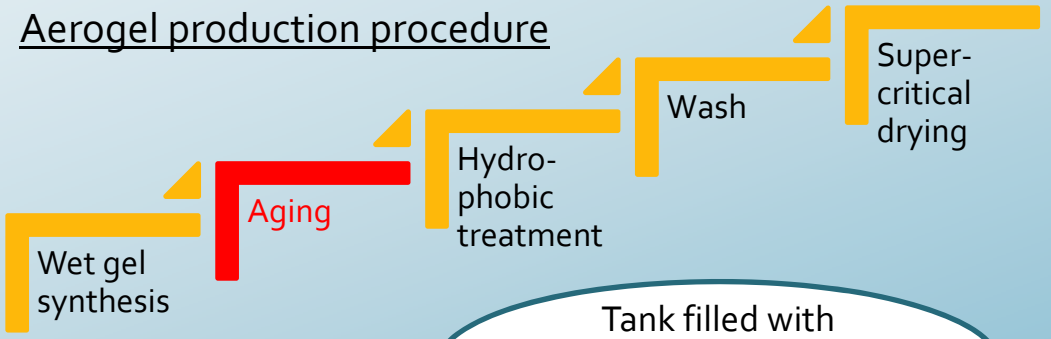


Aging

Strengthen 3D silica network

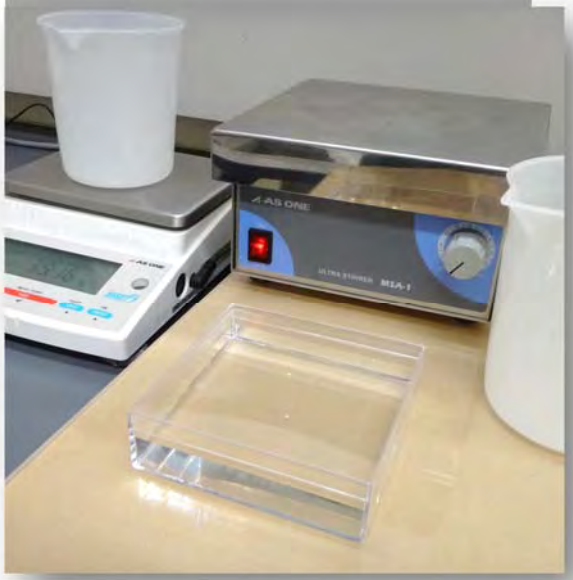
- 1st aging (in mold)
  6 days @20–25˚C
- 2nd aging (in ethanol)
  6 days @35˚C

Aerogel production procedure



Tank filled with ethanol to prevent the wet gel from drying

Complete wet gel synthesis in a mold



1st aging in a sealed tank at room temperature

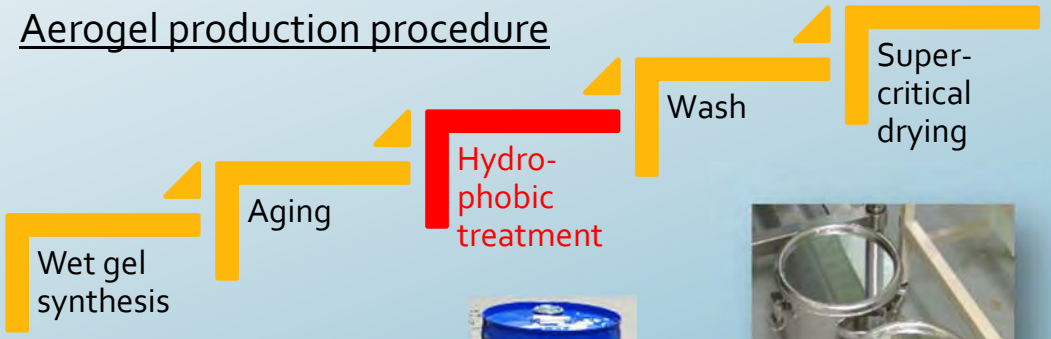
2nd aging using a water bath at 35˚C

Hydrophobic Treatment

Render the wet gel hydrophobic

- Suppress the density increase due to moisture absorption
- Add reagent hexamethyldisilazane (10 v/v%) to the wet gel in ethanol

Aerogel production procedure



Add

$$2(–OH) + [(CH_3)_3Si]_2NH \longrightarrow 2(–OSi(CH_3)_3) + NH_3 \uparrow$$

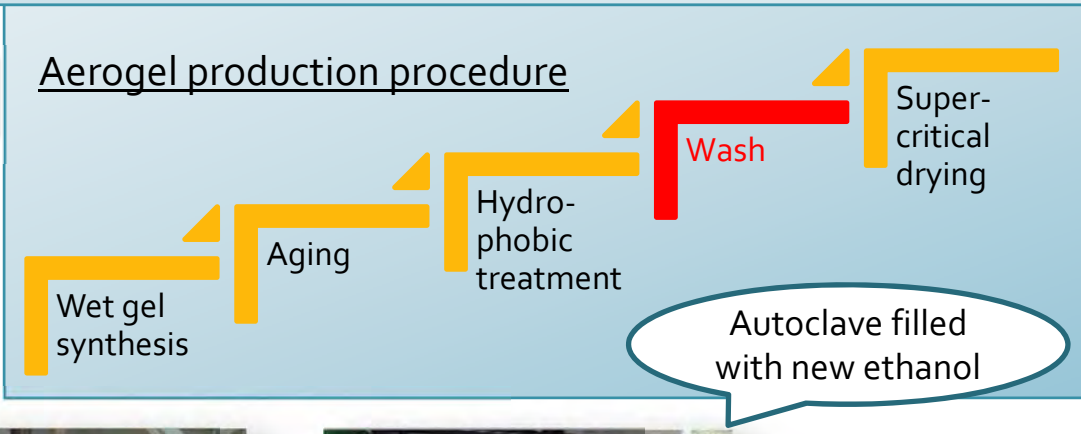
Wash

Remove impurities from the wet gel

4 step wash
= Replace ethanol in tank

Impurities

- Ammonia
- Methanol
- Water
- Silica precursor



New ethanol

New ethanol

New ethanol

New ethanol

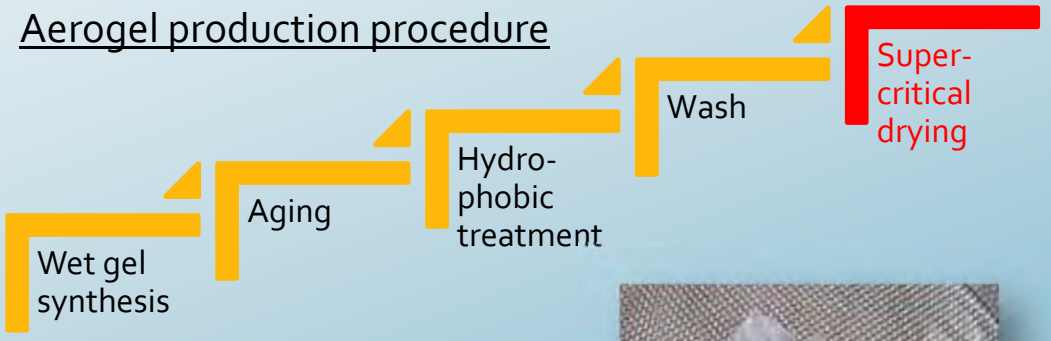
Supercritical Drying

Extract ethanol from the wet gel

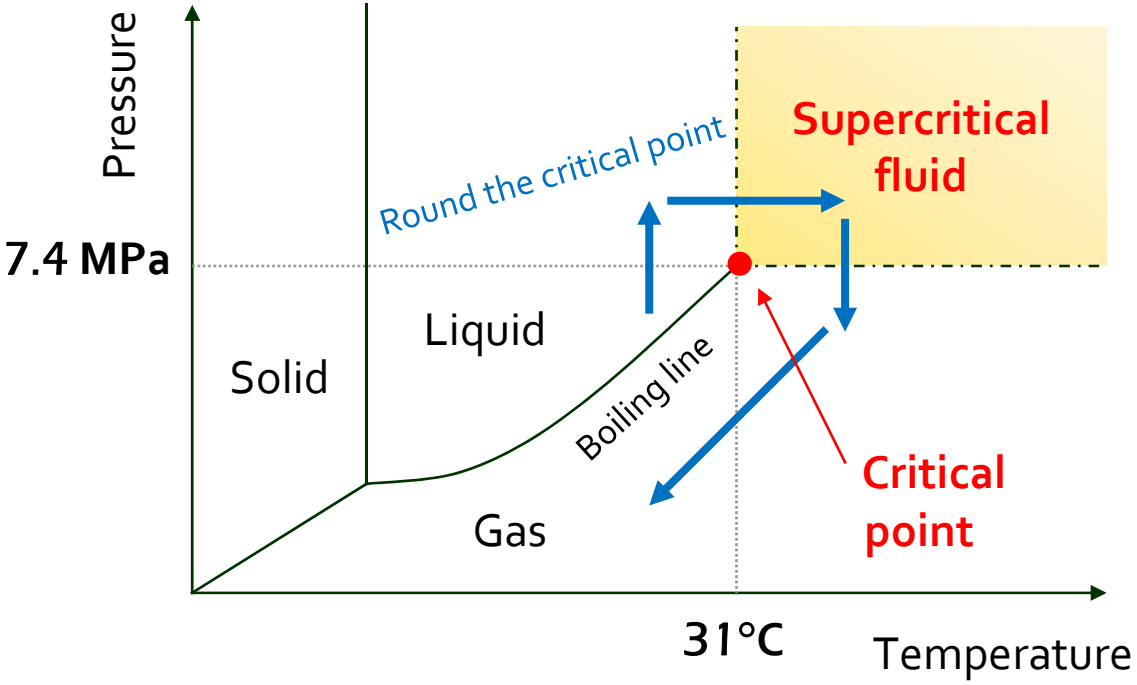
In an autoclave:

1. Replace ethanol with liquefied CO_2
2. Extract CO_2 under supercritical phase

Aerogel production procedure



CO_2 phase diagram



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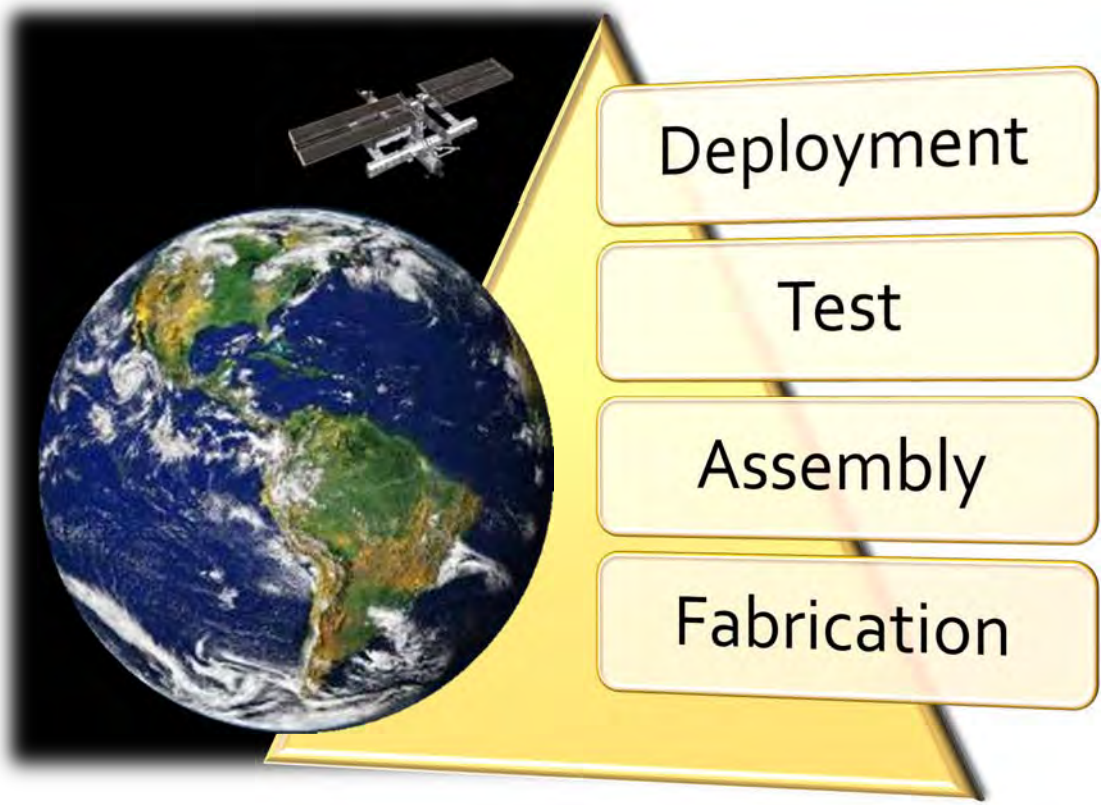
Development of the Capture Panel

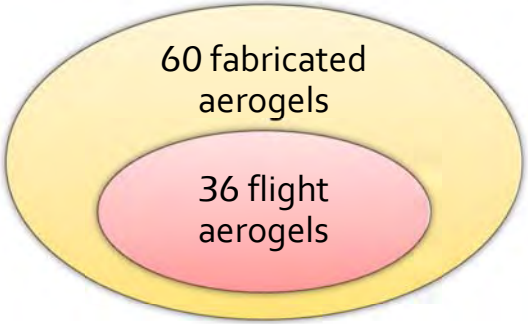
- **Aerogel fabrication**
  - Contamination control
  - Dual density layer configuration (Box framing)
- **Capture panel assembly**
  - Capture panel design
  - Contamination control
- **Acceptance tests**
  - Vibration test
- **Deployment to the ISS**

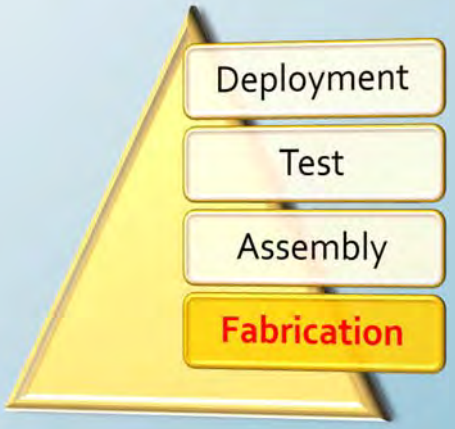


Aerogel Fabrication

Mass produce the aerogels

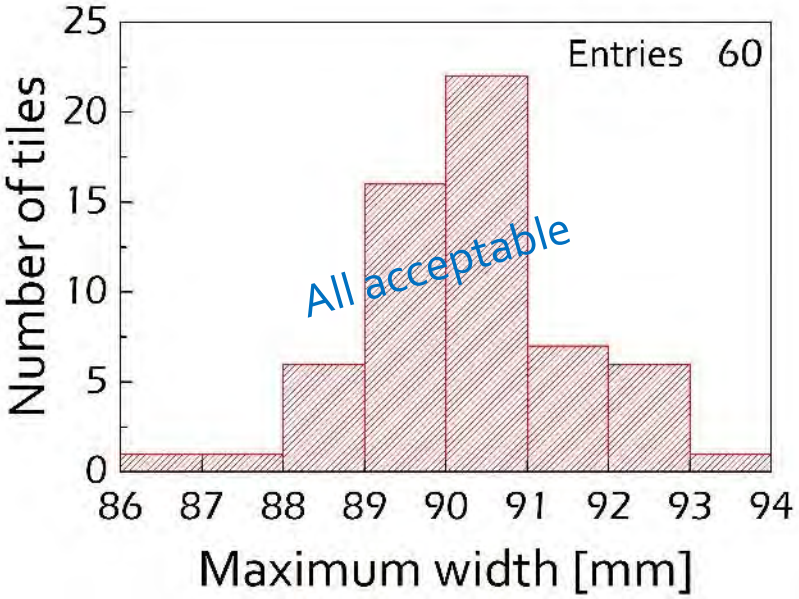
March–April 2013, at CHIBA UNIVERSITY





Tile dimension requirements:

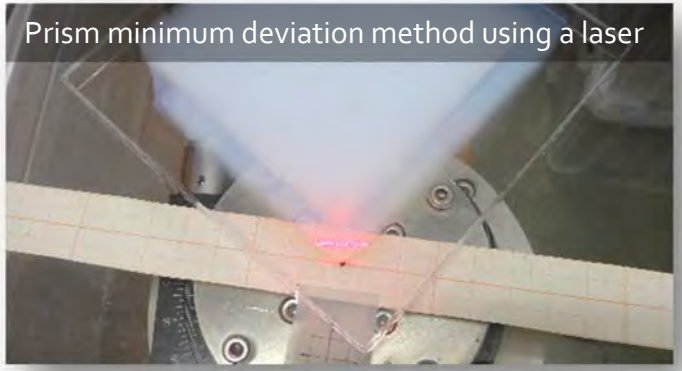
- Maximum width < 94 mm
- Minimum width > 84 mm
- Thickness at the tile corners: 16.5–18 mm



Indirect density analysis:

- Surface layer = **0.008** g/cm^3
- Base layer = **0.035** g/cm^3

➡ Close to the design values



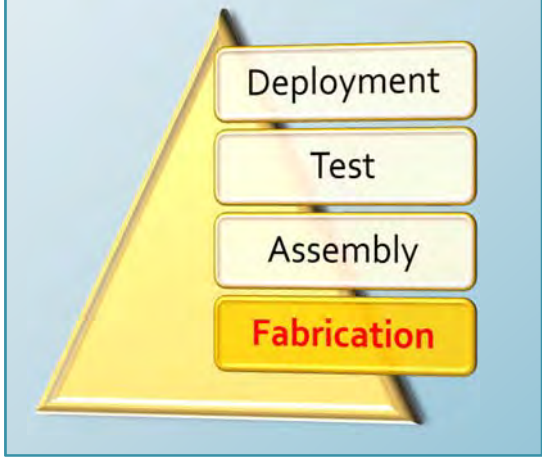
Contamination Control (Aerogel)

Fabricate the aerogels in clean environments

- Inhibit microbial contamination
- Reduce amino acid contamination

> Previously demonstrated

Class 1000 at CHIBA UNIVERSITY



Non-washable tools

Swab with sterile wiper absorbed with:

1. Extran® detergent
2. Ultrapure water
3. HPLC ethanol

Washable tools

Wash with:

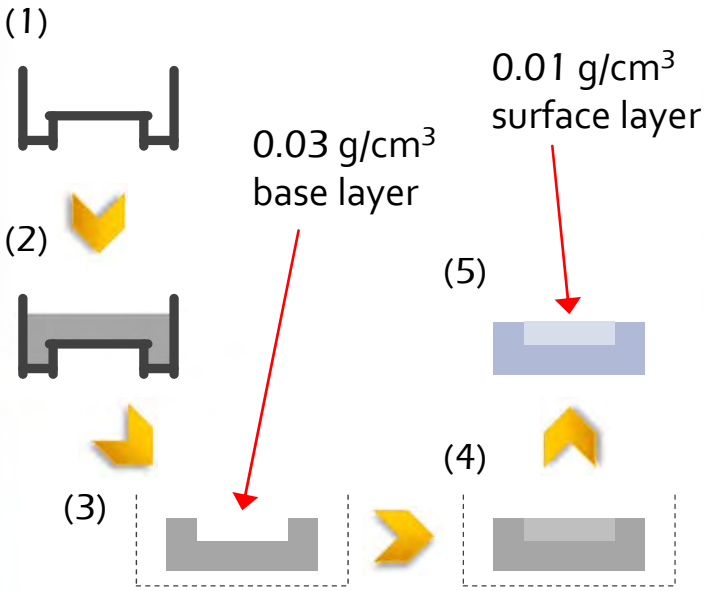
1. Extran® detergent
2. Tap water
3. Ultrapure water

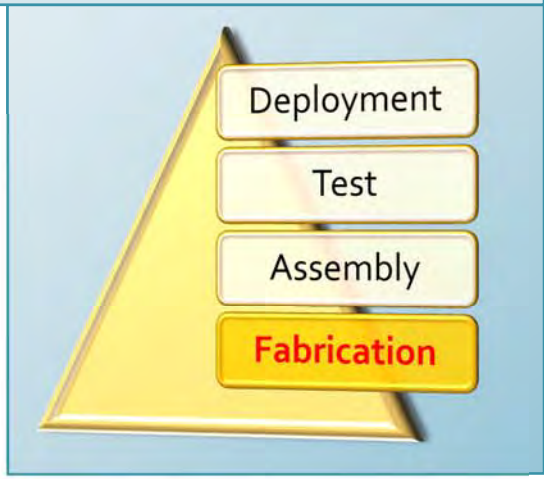
Use HPLC-grade ethanol

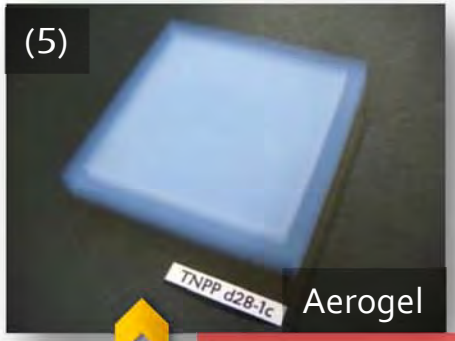
HPLC:
high-performance liquid chromatography

Box Framing Aerogel

Form the box-shape double-layer aerogel

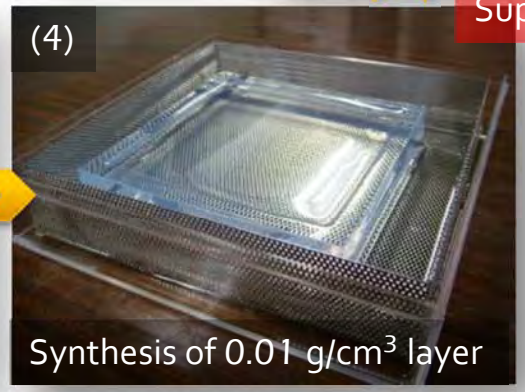






Supercritical drying

Turn the mold

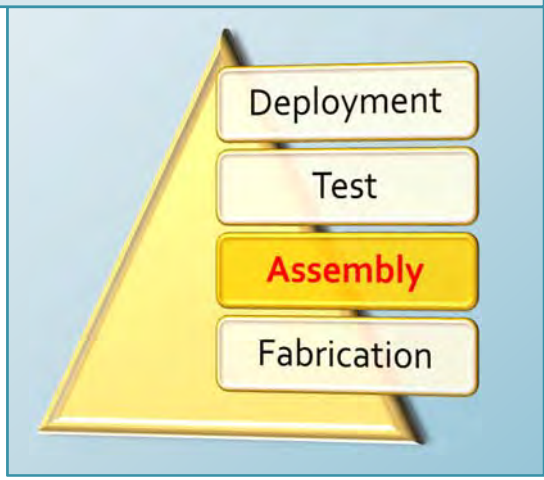


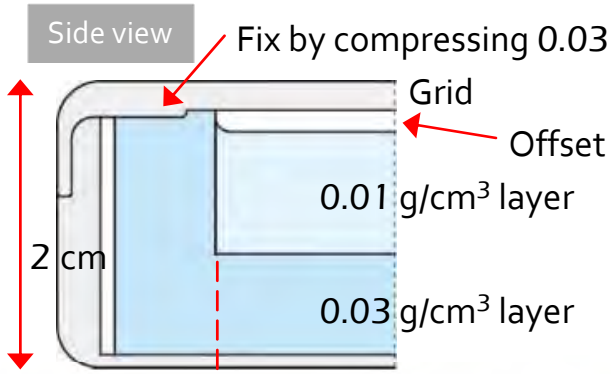
Two layers chemically combined in the wet-gel synthesis process

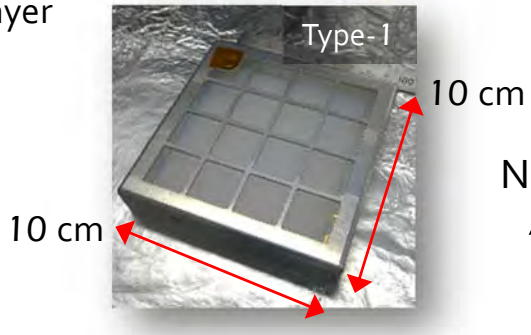
Capture Panel Design

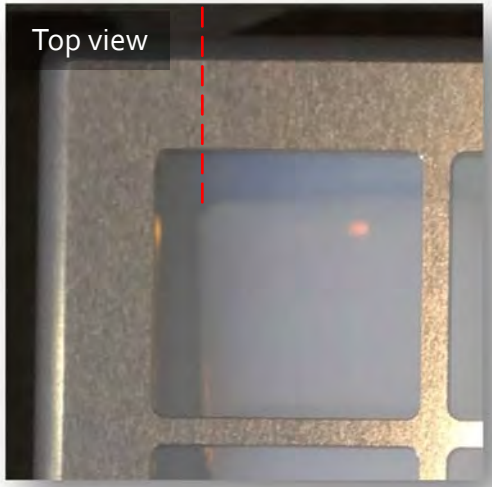
Design the aerogel holder

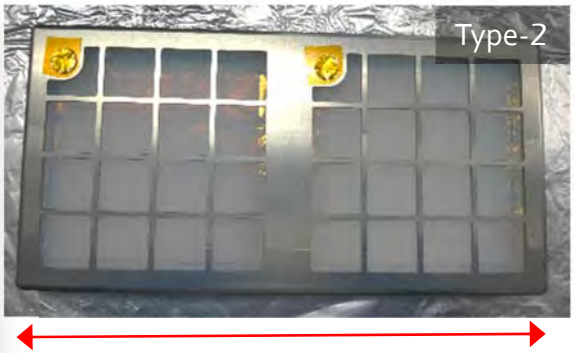
- Fit in the ExHAM: 1 segment = 10 x 10 x 2 cm^3
- Withstand rocket launch vibrations
- Maximize the dust capture performance: Large top window

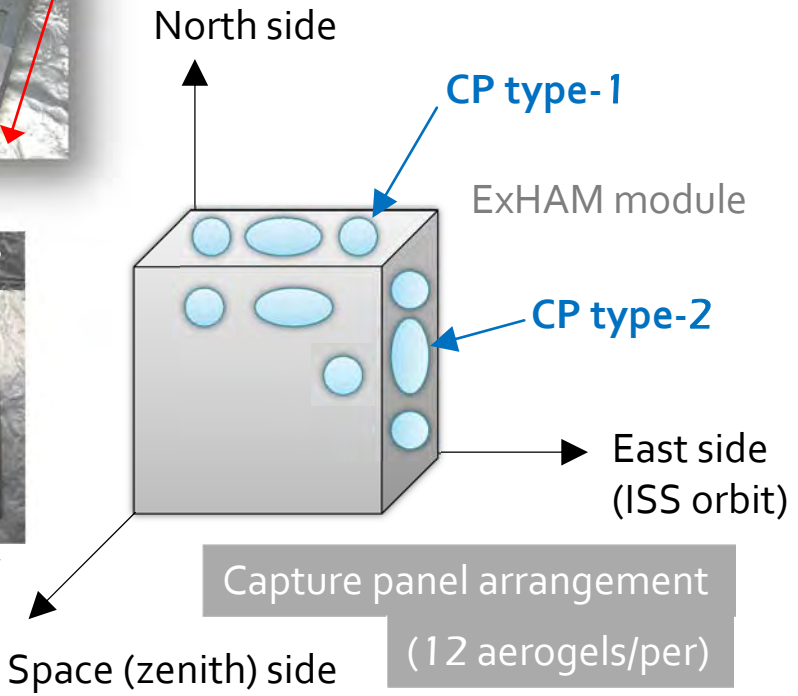




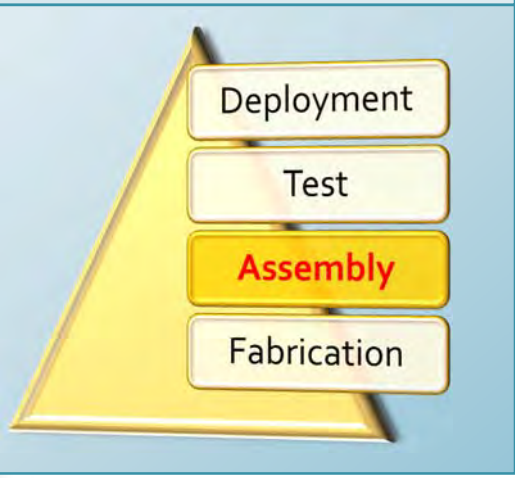








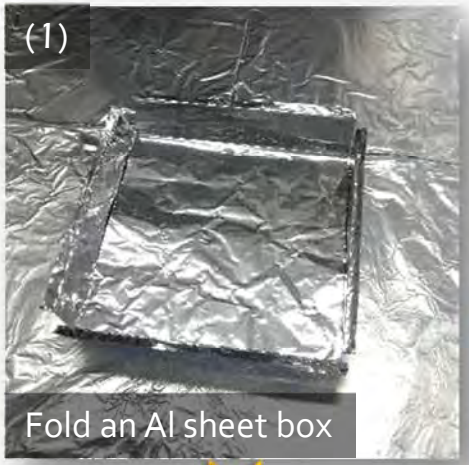
Capture Panel Assembly



Install the aerogels in their holders

December 2014, at JAXA

(1)



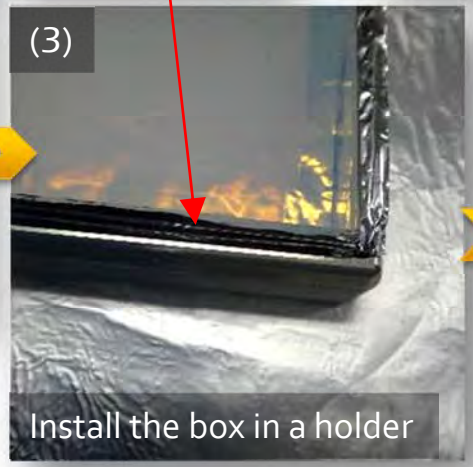
Fold an Al sheet box

Al spring spacer

(2)

Place an aerogel in the box

(3)

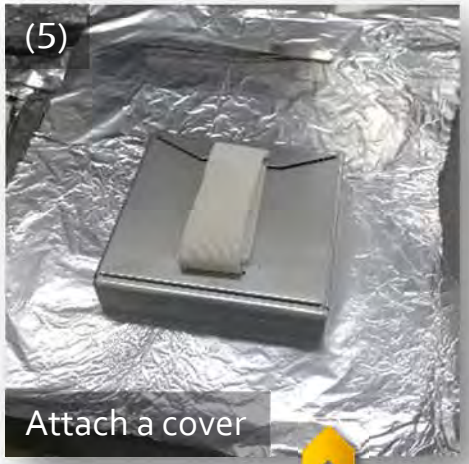


Install the box in a holder

(4)

Attach a lid

(5)



Attach a cover

Presenter

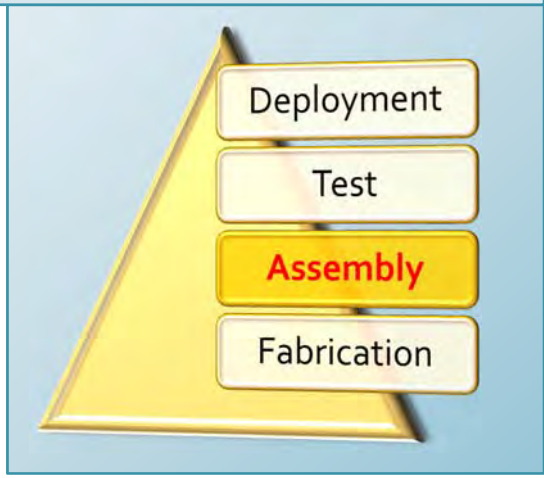
Screw

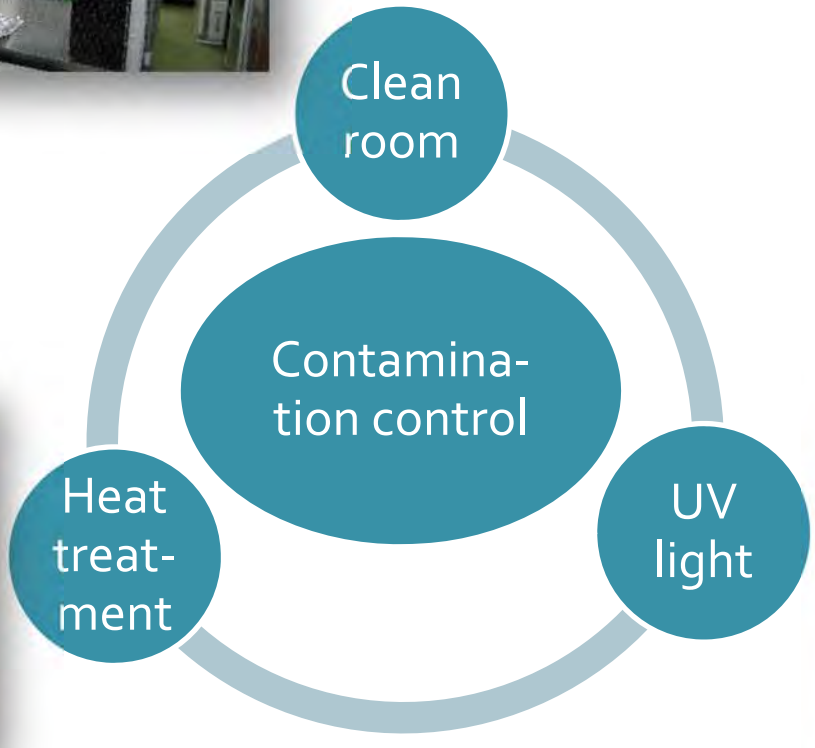
Contamination Control (Capture Panel)

Assemble the capture panels in clean environments

Class 1000

at JAXA





Use tools heat-treated at 500˚C

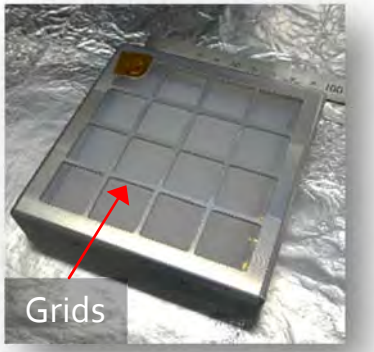
Sterilize the aerogel top surface by UV light

Acceptance Tests

Satisfy the requirements for an ISS payload

Safety requirement for the ISS crew

Scientific requirement for capturing dust



Aerogel:

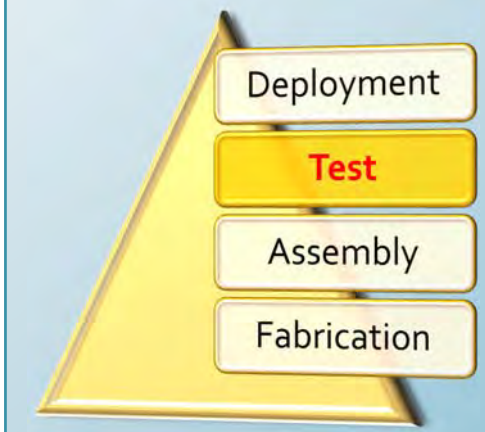
Not to disintegrate from the capture panel

CP design (Grid)

Vibration test

Vacuum test (1kPa/s)

Thermal test (−135–85°C)



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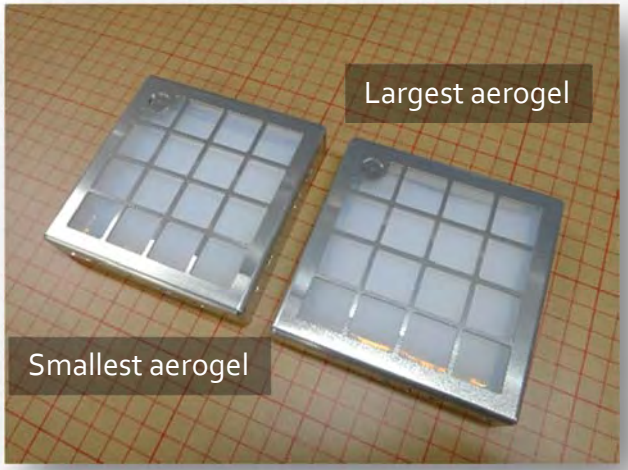
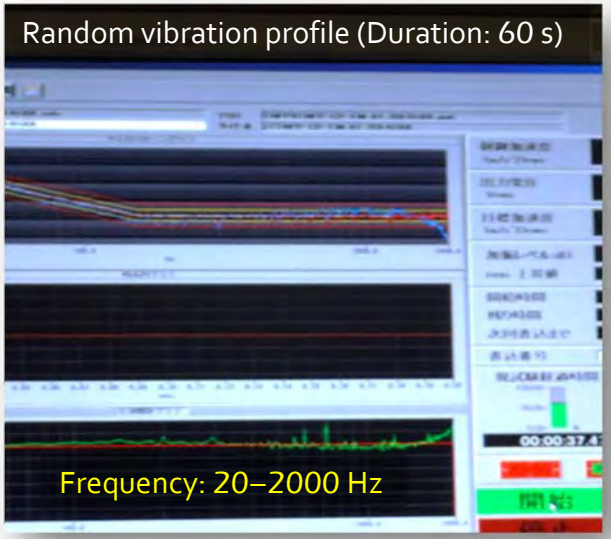
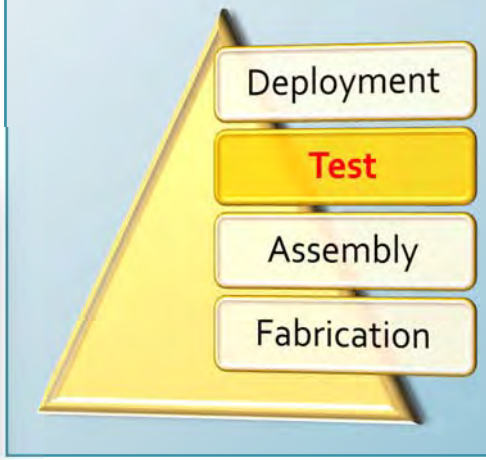
Sampling tests:
Avoid potential damage to the flight aerogels

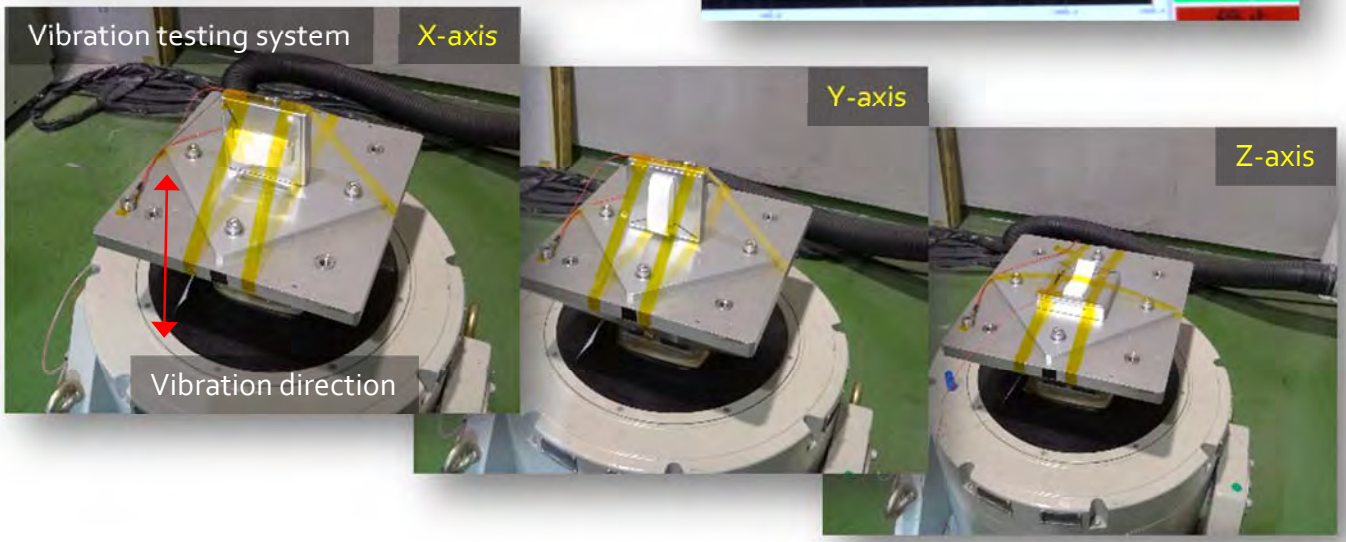
Vibration Test

Test rocket launch vibrations





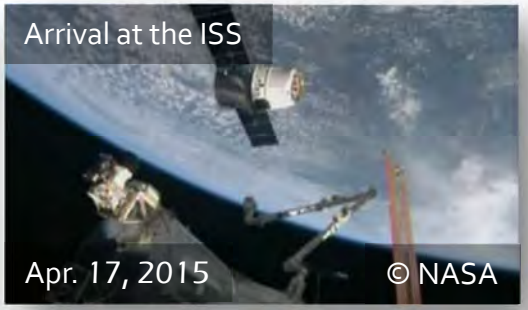


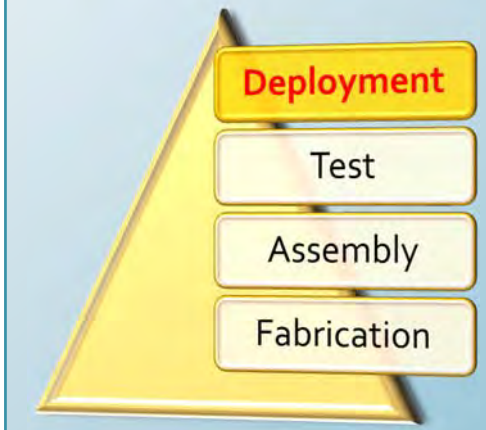


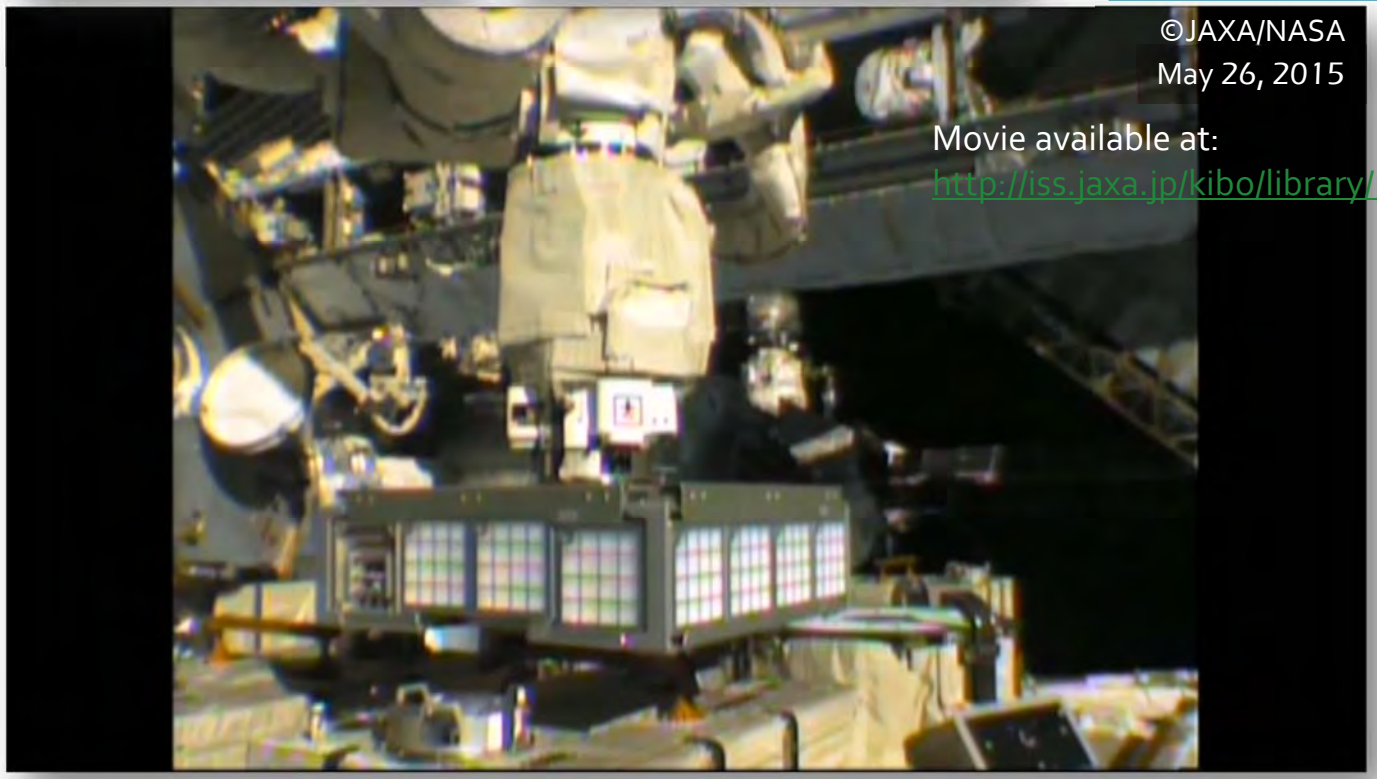
No damage to the aerogels

Deployment to the ISS

Deploy the ExHAM using the robotic arm







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May 26, 2015

Movie available at:
http://iss.jaxa.jp/kibo/library/press/#kiboexp

Summary

- To retrieve intact cosmic dust from low-Earth orbits in the Tanpopo experiment, a silica aerogel-based capture technique was employed.
- Ultralow-density box-framing aerogel and capture panels were developed for the Tanpopo experiment.
- The Tanpopo capture panels were launched and deployed to the International Space Station this year.
- The Tanpopo aerogel will be back to the Earth next year, and dust samples will be biochemically analyzed.