惑星物質科学のフロンティア研究集会2016

たんぽぽ初年度宇宙運用の現状と地球帰還後初期分析・キュレーションの準備状況

2016年4月8日
東京大学宇宙線研究所 柏キャンパス 6階大会議室

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Introduction: Needs for Intact Capture of Micrometeoroids in Space

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Stardust Earth Return 10th Anniversary at LPSC in March 2016

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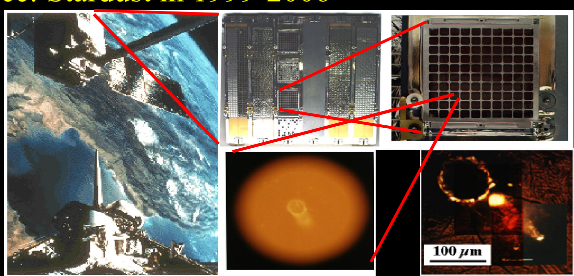
A Quarter Century History of Intact Capture for Microparticle Samples by Aerogels

- The World`s first space aerogel of 0.06 g/cc: EuReCa in 1992-1993
- The World`s first cometary dust sample return wit
g/cc: Stardust in 1999-2006



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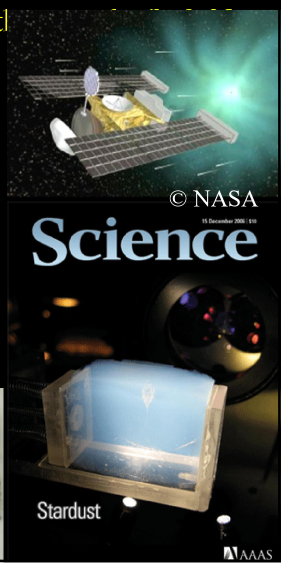
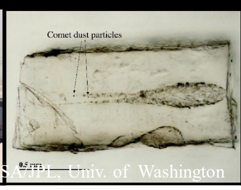


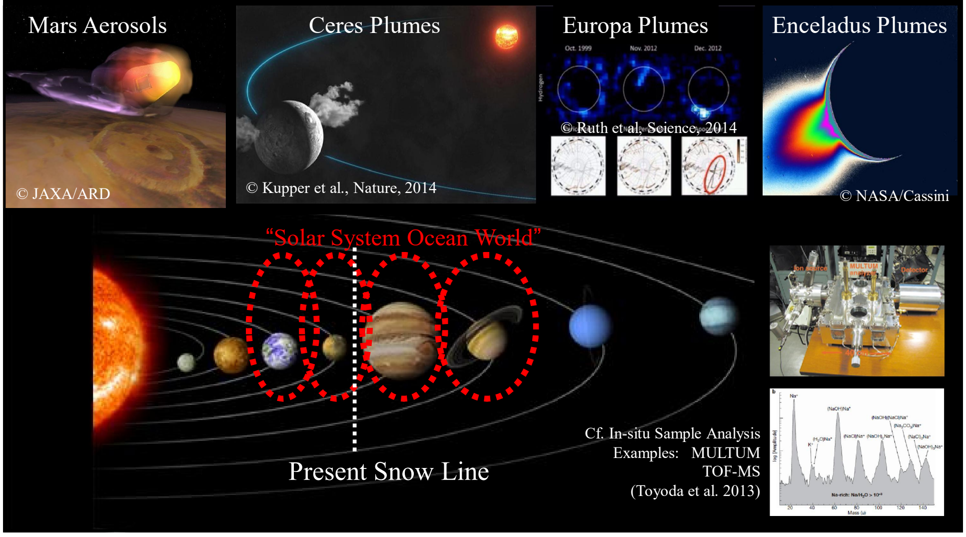
© NASA

- **Stardust (1999-2006)**
- Comet Wild/2 coma flyby
- Launch: Feb. 1999
- Interstellar Capture: 2002
- Cometary Capture: Jan. 2004
- Earth Return: Jan. 2006
- Curation: NASA/JSC
- "Intact" capture of hypervelocity impacted dust(6.1 km/s) into 0.03 g/cc aerogel
- Collected cometary dust of > 15 microns x >>1000 particles

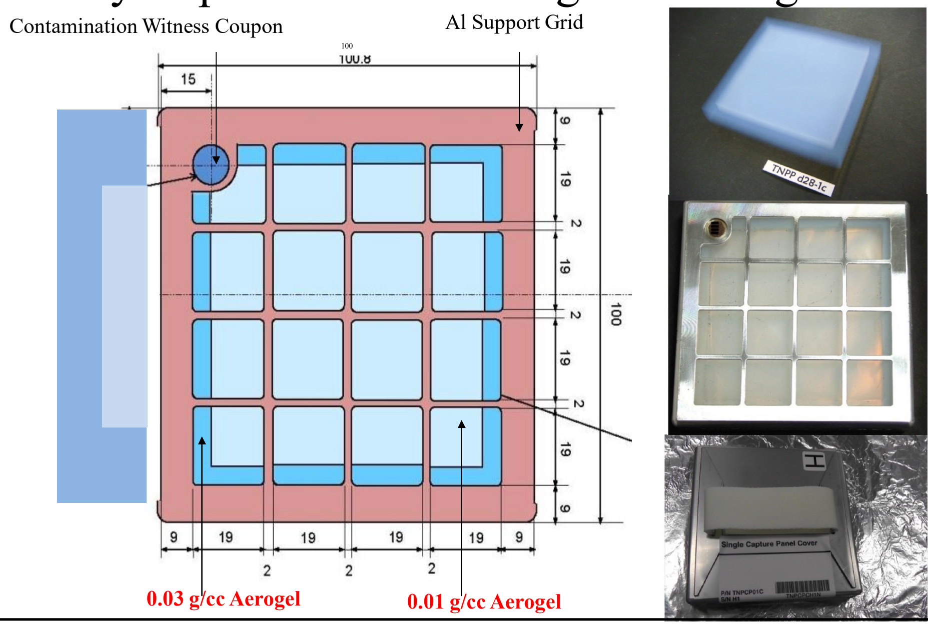


(c) NASA/JPL, Univ. of Washington

Upcoming Prospects to Ocean World "Flyby" Hypervelocity In-situ Sample Analyses and Sample Returns with Aerogels and Other Media



Japanese Original: Double-Layered, Hydrophobic Silica Aerogel of 0.01 g/cc



Current Status of the Tanpopo Operation

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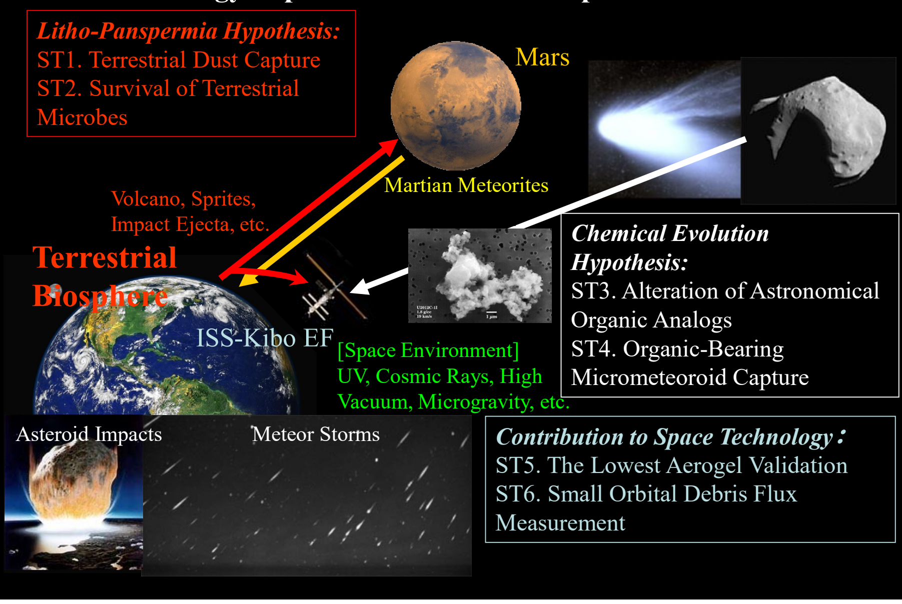
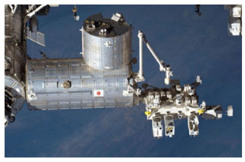
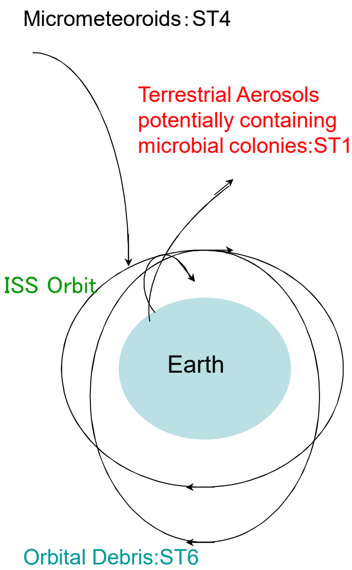
TANPOPO: The First Japanese Astrobiology Space Experiment since 2015

Astrobiology Exposure & Meteoroid Capture onboard ISS



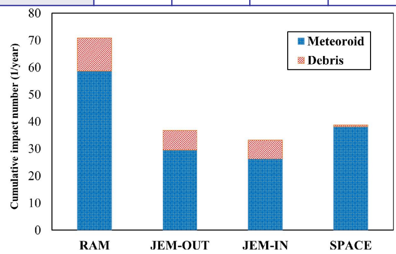
Meteoroid and Debris Impact Flux Estimates on the ISS Kibo Exposed Facility





Collection Area＝400 cm^2/Face

Particle diameter	RAM	JEM-OUT	JEM-IN	SPACE	WAKE
Over 100µm	0.18	0.11	0.092	0.093	0.012
Over 10µm	**14.1**	**6.16**	**7.08**	**8.43**	**1.10**
Over 1µm	70.8	36.7	33.1	38.6	4.68



（Kurihara, Yano, et al.,2014)

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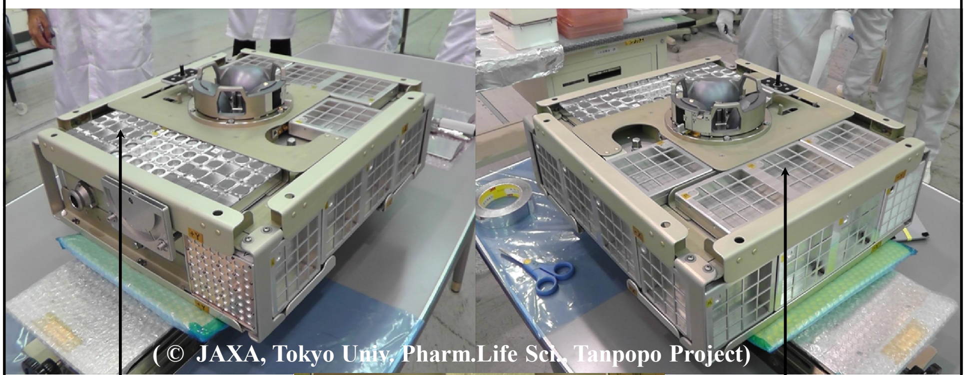
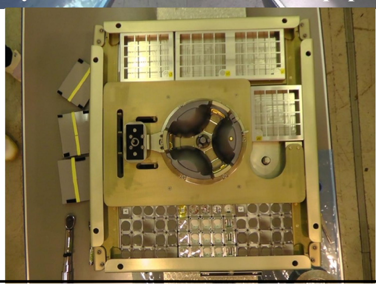
Tanpopo Flight Model System Architecture and FM Fit Check



Exposure Panel x3
(Space Face)

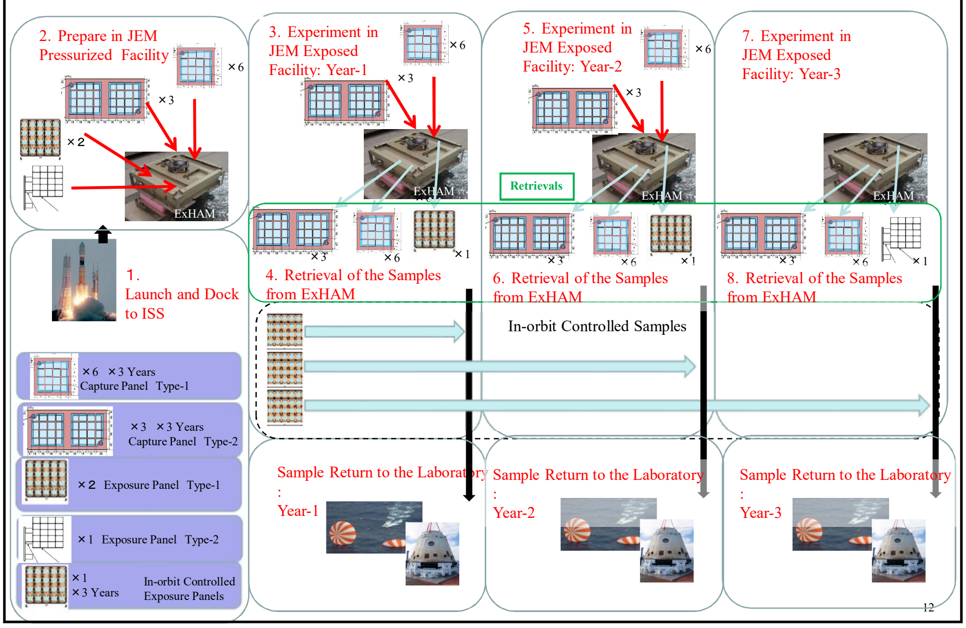


Single Capture Panel x12 Units (1x6＋2x3) (Space, Leading, North Faces)

The Two ExHAM Platforms to Carry the Tanpopo Panels until 2019

> Sample returns in 2016, 17 &18 allow research collaborations for sample analyses
> Post-Tanpopo plan to start soon; Self-sustained cubesats attached on ExHAM?

In-Orbit Operation Plan in 2015-2018: Retrieve Samples Back the Earth Every Year for 3-Year-Long Mission Duration

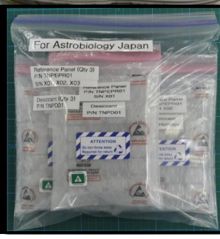


Tanpopo Development and Operation Schedule

2007-8	Selected as a Kibo-EF experiment candidate and conducted MDR/SRR/SDR
2008-9	Development of the 0.01 g/cc double-layer aerogels
2011-3	Development of ExHAM
2012	ISAC facility allocated at ISAS
	Tanpopo Keystone Machine (KM) concept design started
2013.09	Tanpopo granted as the official Kibo-EF experiment (equivalent to delta MDR, PDR, Project formulation)
12	Tanpopo CDR
2014.02	JAXA-NASA Safety Review Ph.0/1/2
Fall	Tanpopo FM development completed
12	Tanpopo PQR&PSR
2015.01	PQR&PSR Follow-Up
02	FM Nominal Delivery to Space-X
04	Space-X6 Launch & Docking to ISS

Crew Training for Installation of the Tanpopo Panels onto the ExHAM Platform and FM Packaging at Tsukuba

© JAXA, NASA



All Tanpopo Apparatus Successfully Launched and Installed at ISS in 2015

(1)

Launch at Cape Canaveral by Space-X Falcon 9 on April 15, 2015

(2)

Dragon CRS-6 Arrival to the ISS on April 17, 2015

(3)

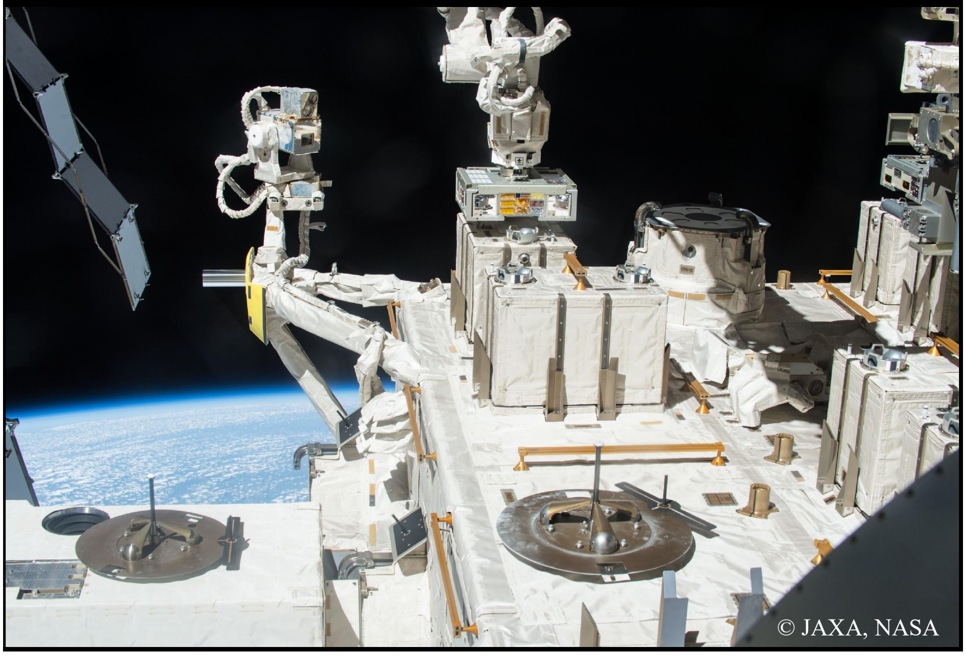
Installation of the Tanpopo Panels to the ExHAM-1 inside the Kibo-PM on May 14, 2015

(4)

Ground Support for the ExHAM-1 First Exposure Operation on May 26, 2015

ExHAM-1 Transferred by JEM-RMS

ExHAM-1 & 2 Operated on the JEM-EF



Tanpopo Development and Operation Schedule

2015 05 The first year ExHAM-1 exposure started
11 The first year ExHAM-2 exposure started
2016 01 ISAC Rehearsal started
03 CLOXS system completed

05 The first year ExHAM-1 samples to be retrieved
Summer The first year ExHAM-1 samples to be returned to the Earth
Summer ISAC for the first year ExHAM-1 samples for 3 months
Winter The first year ExHAM-2 samples to be returned to the Earth
2017 Summer The second year samples to be returned for ISAC
2018 Summer The third year samples to be returned for ISAC
2019 Summer The last/fourth year sample to be returned for ISAC
Fall Completion of the ISAC activities
(Detailed analyses will continue)

Preparation for the Post-Retrieval Initial Sample Analysis and Curation

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Detailed Schedule for the First Year ISAC

PET-1 PHASE-1 (2016 Fall to Winter)

ExHAM-1-1 sample retrieval at JEM
ExHAM-1-2 sample exposure at JEM
ExHAM-1-1 sample Earth Return
ExHAM-1-1 Sample Arrival to ISAS CR
PET-1A(ExHAM-1-1) starts at ISAS
PET-1A(ExHAM-1-1) delivers the first samples to all sub teams
ExHAM-1-1 samples preserved in ISAS CR
ExHAM-1-1 samples data archived
Press Release

Detailed Schedule for the First Year ISAC

PET-1 PHASE-2 (2016 Winter to 2017 Spring)

ExHAM-2-1 sample retrieval at JEM
ExHAM-2-1 sample Earth Return
ExHAM-2-1 Sample Arrival to ISAS CR
PET-1B(ExHAM-2-1) starts at ISAS
PET-1A the initial publication submission
Press Release

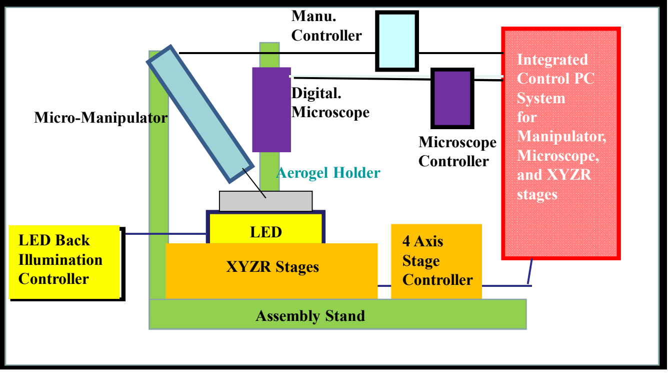
Requirements for Initial Sample Analysis and Curation (ISAC) Activities:

1) *Photo-documentation and 2D Mapping*
2) *Impact Candidate Locating and Observation*
   - 2-1) Common coordinates log among different analysis tools
   - 2-2) Identification of impact track candidates
   - 2-3) Revisit to the candidates for confirmation
   - 2-4) Non-destructive, 3D info acquisition
   - 2-5) Select high priority tracks to be extracted
3) *Extract samples for detailed analyses*
   - 3-1) Define extraction volume and shape
   - 3-2) Extract samples with >10-micron Particles
4) *Allocate the extracted samples for detailed analysis teams*

➔ Procedures 1-4 should be completed in the first 100 days after receiving the returned samples at ISAS/LABAM, under total contamination control and monitoring

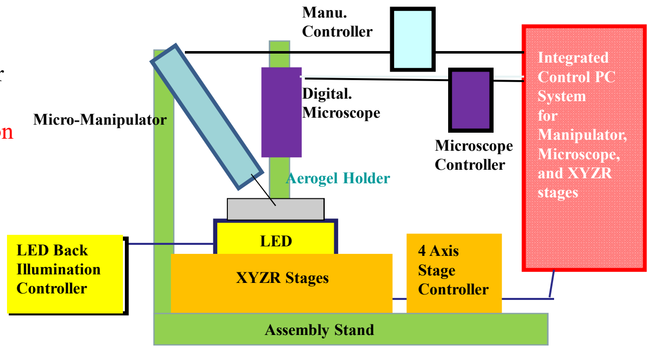
CLOXS: Captured particles Locating, Observation, and eXtraction System,

Developed under the NINS Project Support



CLOXS Needs, Specification and NINS Support

- Maximum extracted sample: 10 x 10 x 10 mm
- Minimum captured particles to be analyzed for the first round of the detailed analysis: 10 micron
- Coordinate precision: < 10 micron in XY space
- Must be operable by non-aerogel experts with practical training
- Must complete the first round of ISAC within 100 days after the sample return



Optical Microscope (as is): VH-5000 (Capture: VH-E500); 640 x480px, x35mag(~x245max)

Manipulator: DMA-1510

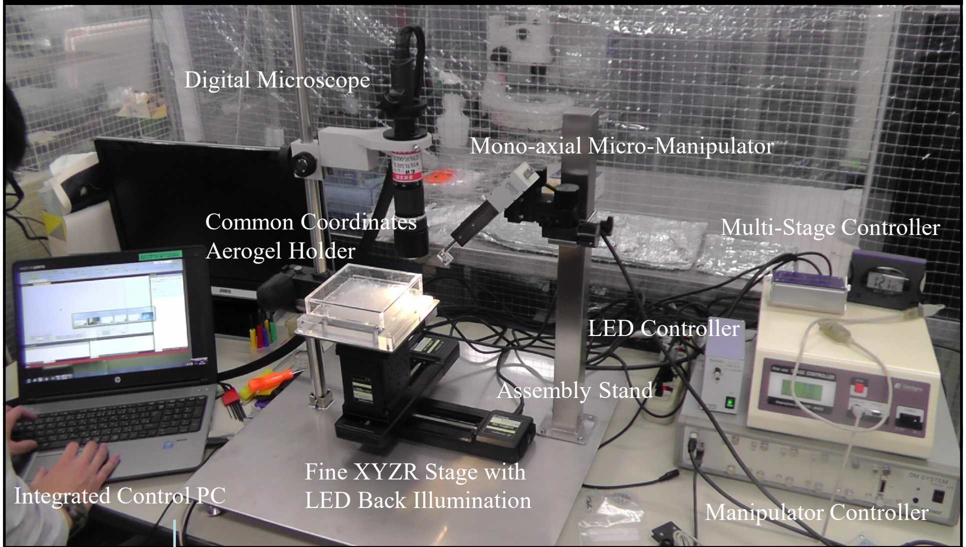
Aerogel Holder (other funding): Original design

Stages: Sigma Koki: SGSP-26-100, SGSP-80-YAW with SHOT-304 controller 0.1 micron step accuracy LED Back Illumination (Shimatec)

Assembly Stand: Original design

Original Integrated Control System:
Lang.: Visual C# 2013
Lib.: OpenCV 4.2.9. (OpenCVSharp + Nuget)
PC: HP Prolite (Core i5 2.5 GHz,32GB Mem.)
Image ca.: I-O data GV-USB2

Tanpopo CLOXS under the Integration Test

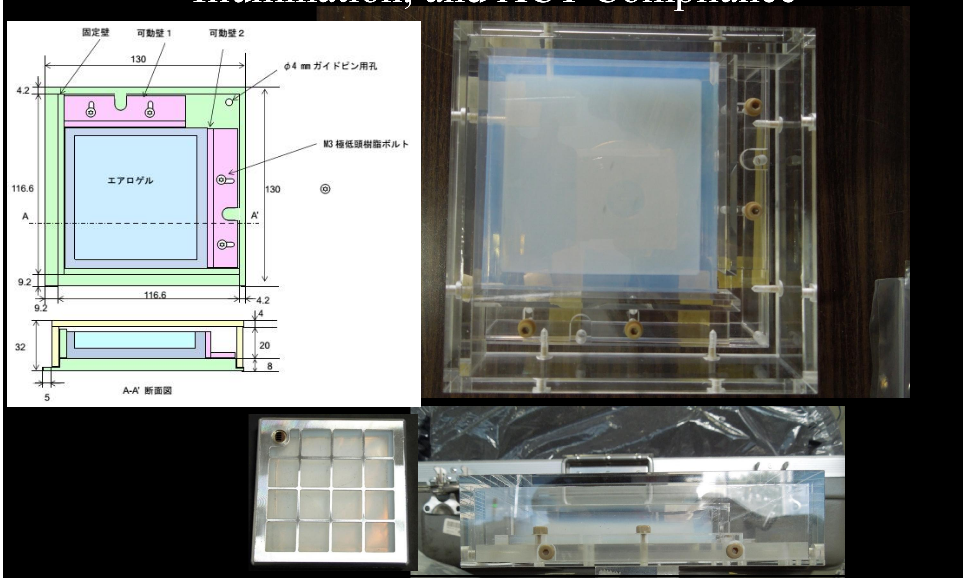


Microscope Controller

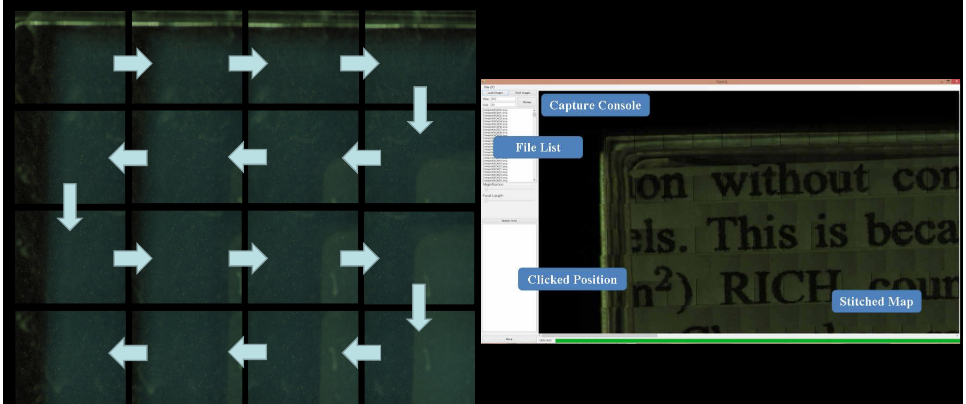
CLOXS Function (1)
Locating Maps
for Common Coordinates

26

Transparent Aerogel Holder for Contamination Control, CLOXS Common Coordinates, Back-Side Illumination, and XCT Compliance



Continuous Imaging Synchronized with 0.1- Micron-Precision Fine XY Stages and Creating 2D Coordinates Map for Locating Impact Site Candidates by Clicking

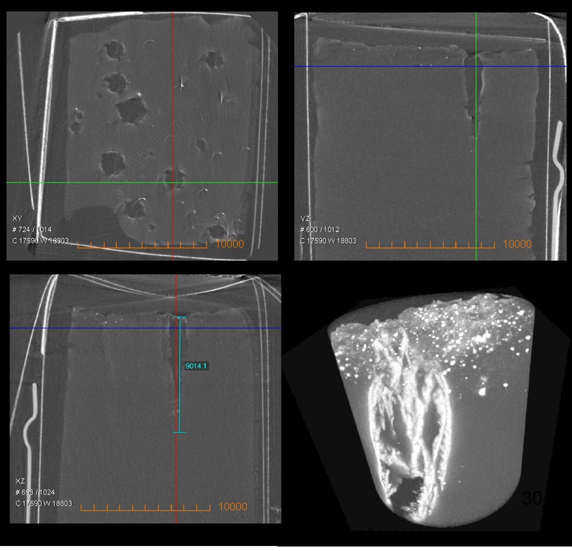


Scanning Direction up to 100 mm x 100 mm ➔ ~70 minutes/panel

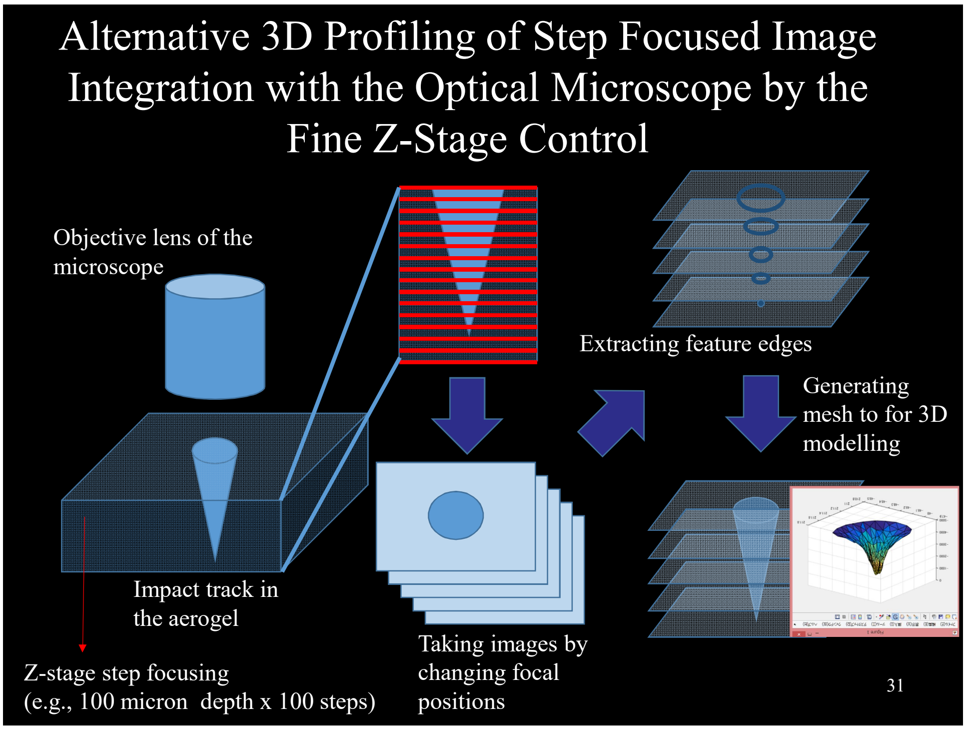
CLOXS Function (2)
3D Observations and Reconstructions

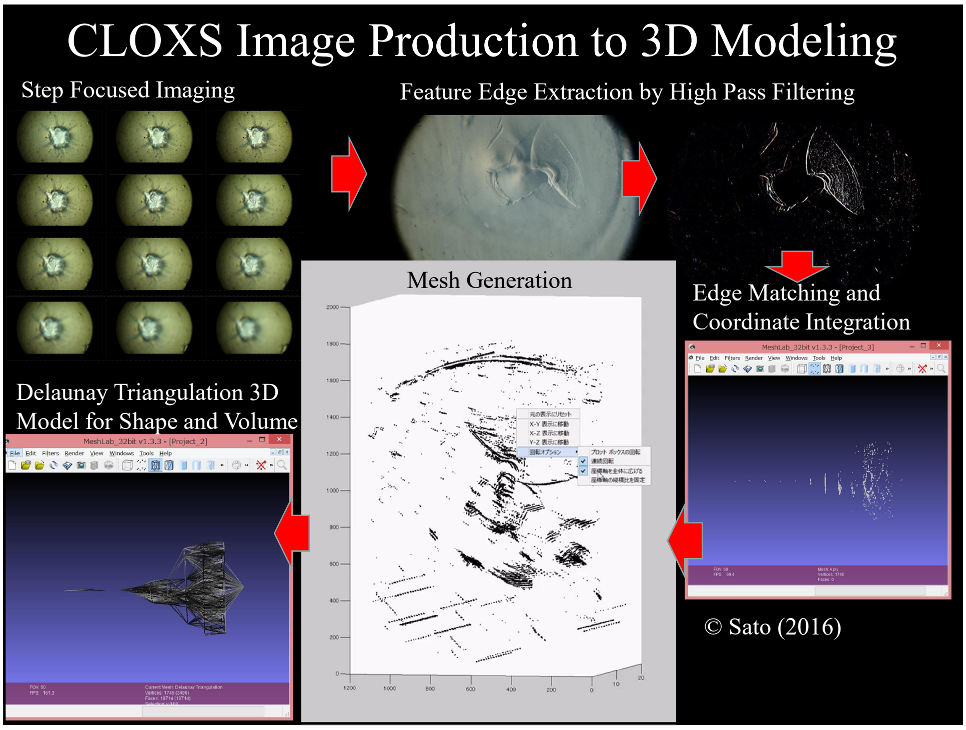
29

Non-Destructive, 3D Data Acquisition of Impact Tracks: High Resolution X-ray CT Requires Off-Loop from ISAC by CLOXS



30


Alternative 3D Profiling of Step Focused Image Integration with the Optical Microscope by the Fine Z-Stage Control
Objective lens of the microscope
Extracting feature edges
Generating mesh to for 3D modelling
Impact track in the aerogel
Z-stage step focusing
(e.g., 100 micron depth x 100 steps)
Taking images by changing focal positions
31


CLOXS Image Production to 3D Modeling
Step Focused Imaging
Feature Edge Extraction by High Pass Filtering
Mesh Generation
Edge Matching and Coordinate Integration
Delaunay Triangulation 3D Model for Shape and Volume
© Sato (2016)

CLOXS Function (3)
Aerogel Sample Extraction by the Micro-Manipulator

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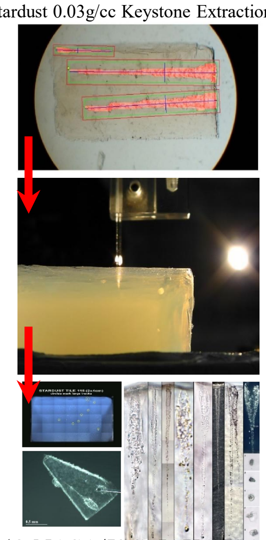
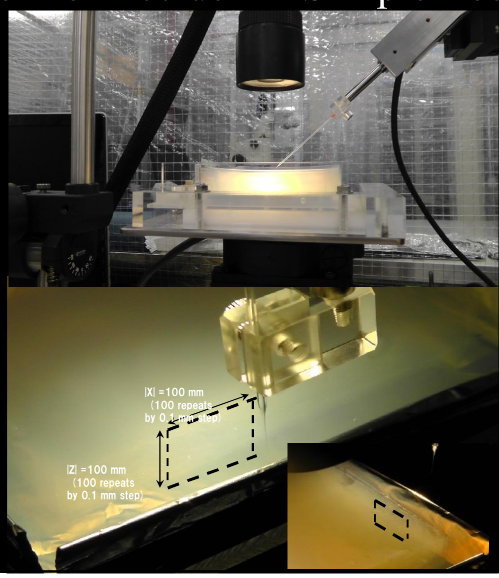
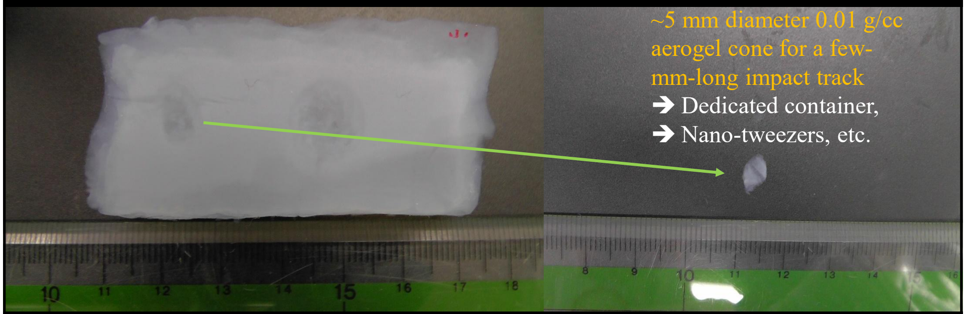
CLOXS to Extract 0.01 g/cc Aerogel Ranging from 10x10x10 mm Block to 1-2 mm Diameter Cone, without Human Error nor Accidental Sample Lost

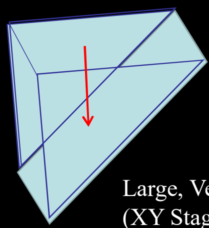
Stardust 0.03g/cc Keystone Extraction



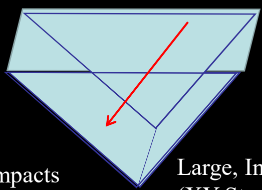


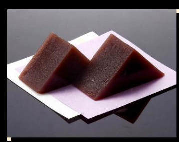
Output Examples: Extracted Samples (Conical Shape by R-Stage Control)



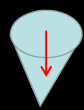


Large, Vertical Impacts
(XY Stage Control)





Large, Inclined Impacts
(XY Stage Control)



Small Impacts
(R Stage Control)

ISAC Rehearsal and Detailed Analysis Prospects

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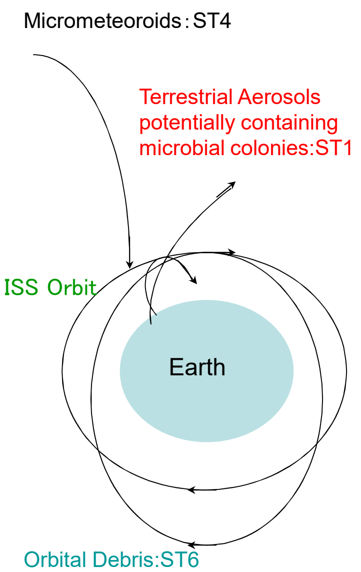
On-going ISAC Rehearsals of the First Year

Block	Dates	Theme	Locations
Prep	01/25-29	CLOXS & Clean Level Preparation	ISAS
1	02/01-09	Aerogel Measurement, Impact Site Candidate Mapping & Image Analysis	ISAS, Univ. Aizu
2	02/15-19	Transport ~XCT Imaging & Data Archiving	ISAS, JAXA Chofu, Kyushu U.
3	03/09-11	Aerogel Holder Handling & Contamination Monitoring	ISAS
4	03/30-04/08	CNT Analysis & CP Lid Crater Analysis	ISAS, Nitto, JAXA Chofu
5A 5B	04/11-15 04/18-22	Sample Extraction	ISAS
6	04/25-28	Dry Run for All Steps (1)	ISAS, JAXA Chofu, Nitto
7	05/09-13	Sample Delivery to Microbe & Debris Sub Team (East Face)	ISAS, Toyaku, JAXA Chofu
8	05/14-22	Sample Delivery to Cosmic Dust Sub Team (Space & North Faces)	ISAS, YNU, Osaka U
9	05/30-06/03	Dry Run for All Steps (2)	ISAS, JAXA Chofu, Nitto, Toyaku, YNU
10	06/06-10	Final Refurbishment for ISAS CR & Facilities	ISAS
Ext.	06/13-08/05	Contingency Period: Detailed Analysis Dry Run CLOXS Operator Trainings	ISAS, Various

Analysis Priority Policy by Pointing Faces



<Aerogels>

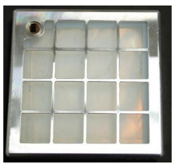
Leading (East) Face:
ST1: Microbe Sub-Team
ST5: Debris Sub-Team

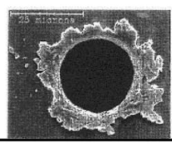
Zenith (Space) Face:
ST4: Meteoroid Sub-Team

Anti-PM (North) Face:
ST4: Meteoroid Sub-Team

<CP Al Frames>

All Faces:
ST5: Debris Sub-Team





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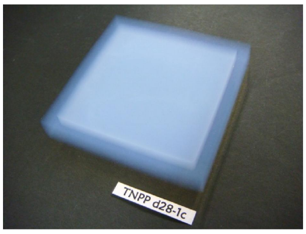
Hypervelocity Impact Tests for Recovering Microbial Bearing Clay Particles onto Tanpopo Aerogels



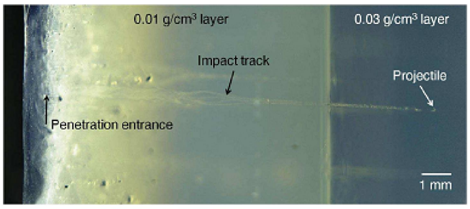
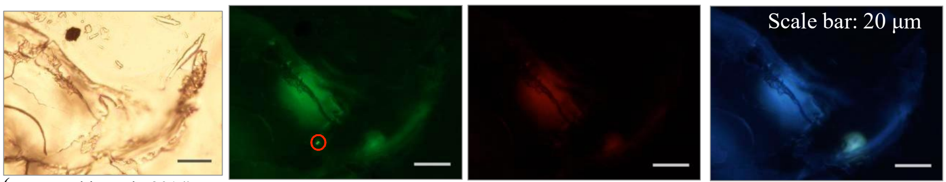


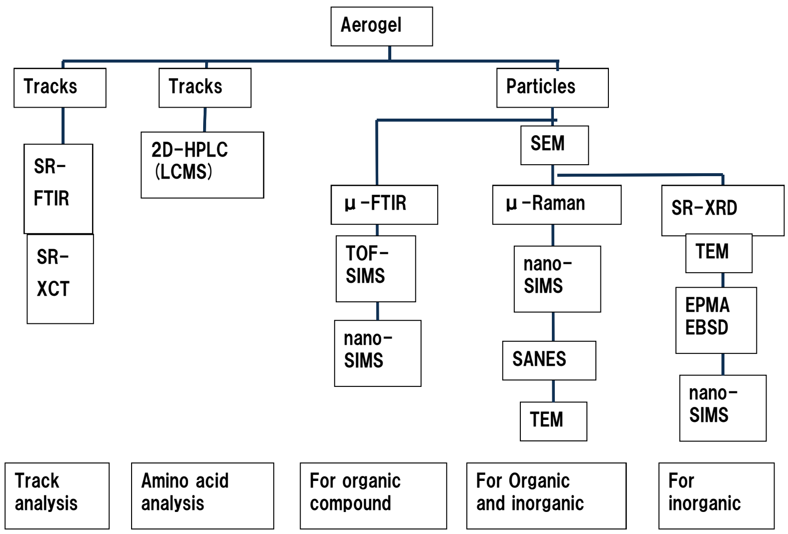
Figure 4: The microscope image of the double-layered aerogel used the hypervelocity impact experiment (magnification: × 30, shot No. 0677, track No. 2). The projectile of soda lime glass with 30 μm in diameter and 2.44 g/cm^3 in density impacted the aerogel from left at a velocity of 5.97 km/s, penetrated the boundary between 2 layers of the aerogel and stopped at the far right of the impact track. The length of the impact track measured 13 mm. (Tabata, et al., 2011)

Captured microbe colony embedded in clay minerals, which were shot into the Tanpopo aerogel at 6km/s: Bleaching of green fluorescence from stained *D. radiodurans* R1 is faster than fluorescence from the glass



(Kawaguchi, et al., 2014) Green fluorescence Red fluorescence Blue fluorescence

Example of Detailed Analysis Sample Flow (ST4)



From Yabuta et al. (2015)

Conclusions

• In-situ investigation and intact sampling of microparticles have a quarter century history and are now recognized as game-changing technologies for astrobiology-driven, ocean world missions in coming decades.

•Tanpopo is Japan's first astrobiology space experiment, in order to test subsets of chemical evolution and panspermia hypothesis, by employing the world's lowest density aerogel.

• Captured samples will be retrieved back from LEO to terrestrial laboratories every year in 2016-2018 time frames for both ISAC and detailed analyses.

• The CLOXS, an autonomous initial inspection and extraction tools for the aerogel samples, is a critical path for timely and successful deliveries of the early results of the Tanpopo project and its lessons will directly serves as a foundation of future astrobiology-driven sample returns.

• The CLOXS has been successfully integrated and demonstrated its performance to meet the major requirements by this March

• ISAC dress rehearsals have been conducted since this January until June, for both aerogels and Al frames.

• Sub-sequent detailed analysis will be conducted after the ISAC activities, ranging from meteoritics, space debris, microbial sub-teams. AO sample allocations are planned after then.