Database of Space-Captured Samples in Tanpopo: Astrobiology Exposure and Micrometeoroid Capture Experiments

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Scientific Targets of Tanpopo

Tanpopo experiment (2015-2018) is the first Japanese astrobiology mission conducted in space, being onboard the Exposed Facility of Japanese Experiment Module "Kibo" (JEM-EF) on the International Space Station (ISS) [1]. The experiments were designed to address two critical hypotheses in astrobiology, namely “the panspermia” and “the chemical evolution” processes toward the generation of life. These experiments also tested ultra-low-density aerogel to study the microparticulate environment in the low Earth orbit (LEO). The following six sub-themes were identified to address the respective goals: (1) Capture of terrestrial microbes in space: Estimation of the upper limit of microbial density in LEO; (2) Exposure of terrestrial microbes in space: Estimation of the survival time-courses of extremophile microbes in the LEO environment; (3) Capture of cosmic dust in space: Search for a possible presence of organic compounds within micrometeoroid captured outside the terrestrial environment; (4) Alteration of organic compounds in space: Evaluation of decomposition time-courses of organic compounds in the LEO environment; (5) Space verification of the ultra-low-density aerogel: Durability and particle capturing capability of the world’s lowest density aerogel ever flown to space; (6) Monitoring of micrometeoroid and orbital debris flux in LEO: Temporal flux variation in micrometeoroid and orbital debris environment. The sub-themes 1 and 2 address the panspermia hypothesis, whereas sub-themes 3 and 4 address the chemical evolution. The last two sub-themes contribute to space technology development as well as planetary science.

Four-Year Operations of Tanpopo

Four-year operations of the Tanpopo project have been reported [2]. We deployed three Exposure

Panels (EP), each consisting of 20 Exposure Units that contained microbes, organic compounds, an alanine UV dosimeter, or an ionizing radiation dosimeter. The three EPs were situated on the zenith face of the Exposed Experiment Handrail Attachment Mechanism (ExHAM) that was pointing in the zenith direction or anti-Earth face toward outer space. The ExHAM is a multipurpose exposure platform that can be attached to an external handrail of the JEM-EF of the ISS which is under the Earth-gravity gradient, three-axis attitude control. After each exposure period concluded, the three EPs were retrieved one by one and returned to the ground after approximately 1, 2, and 3 years of total exposure time in space. On the contrary, the Capture Panels (CPs), each of which contained one or two blocks of amorphous silica aerogel, were exposed to collect hypervelocity impact microparticles [3]. Possible captured particles may include micrometeoroids, human-made orbital debris, and natural terrestrial particles. Each year, a group of CPs containing from 11 to 12 aerogel blocks was attached to the three pointing faces of the ExHAM (S: Space face pointing to zenith (anti-Earth), E: East face pointing to the ram direction, N: North face pointing to the port side away from the JEM module); they remained in place for about 1 year and were then returned to the ground laboratory. This process was repeated three times in total during 2015–2018. Additional exposure of one CP that faced the ram direction was conducted between 2018 and 2019. Once the aerogel blocks were returned to the ground laboratory at the Laboratory for Astrobiology and Astromaterial (LABAM), JAXA/Institute of Space and Astronautical Science (ISAS), each aerogel block was extracted from the aluminum protection structure and encapsulated in a dedicated transparent plastic case and optically inspected by a specially designed microscopic system [4]. The apparatus, operation, and environmental factors of all the Tanpopo experiments are summarized in the article [2].

Space-Captured Samples of Tanpopo

In the capture experiment of Tanpopo, micrometeoroids entering the Earth or terrestrial particles reaching to the LEO altitude and orbital debris are collected by silica aerogel blocks in the CPs [1-3]. In the whole mission period, a total of 36 silica aerogel blocks in the CPs have been returned to the ground without damage [2]. Cavities within the aerogel blocks formed by hypervelocity impact are called "(penetration) tracks", and their morphologies roughly correlate with the particle size, impacting velocity, impact angles, and physical properties of the captured particles [e.g., 5]. The aerogel blocks and the identified tracks were observed and processed with the CLOXS (Captured particles Locating, Observation and eXtraction System) [4], originally developed by the Tanpopo team for initial analysis, and the generated data are archived in a unified database. As of this writing, more than 800 impact features, which are larger than 0.1 mm as track candidates, were identified.

The Database of the Space-Captured Samples of Tanpopo

The current database summarizes the basic data of Tanpopo Capture Experiment samples, and the selected images of the tracks taken by a microscopic optical camera of the CLOXS [4]. The detailed information and sequential images with different depths for each track will be deposited in another database in the near future.

Initial analysis of the Tanpopo aerogels and tracks was systematically conducted as follows:
1) After the initial inspection and quick-look imaging of the CPs, each aerogel block was transferred to a transparent plastic case, specially developed for Tanpopo aerogel initial analysis by CLOXS [4].
2) All the top surface of each aerogel block was imaged by a digital microscope with x100 magnification.
3) A total of 2500 images per the top surface of the aerogel were integrated into one "map" image.
4) The integrated map image was inspected with maximum digital magnification to identify candidates of impact tracks and recorded major features and potential morphological classifications.
5) Each candidate track was imaged with x245 magnification with a series of different depths in focus at a few micron depths per step, in order to construct pseudo-3-D images.
6) Each candidate was judged as a True impacting track, False impacting track, or Unidentified track, based upon scientific criteria of hypervelocity impact features on aerogels. The Unidentified class may turn out to be True tracks if more investigations other than morphological characteristics are granted.
7) The data associated with each track were listed: Capture Panel ID, track ID, track morphology type (i.e., Pit craters, Carrot tracks, Straight tracks, and Teardrop tracks), the existence of terminus residues or residues on internal walls, location coordinated of the track within the aerogel block, and impact directionality of the track. Some of these data are presented in the list of this database. The others will be available in another database, which is in preparation for future releases.

Explanation of the Terms Used in the Sample List

In the Tanpopo mission, the CPs, each of which contains an aerogel block, were attached to the three pointing faces (S: Space, E: East, N: North) of the ExHAM, which is a multipurpose exposure platform, employed in Tanpopo experiment [2]. The ExHAM was attached to the handrail of the JEM-EF onboard the ISS. Locations, where the Tanpopo CPs were installed, were designated as the positions D, E, F, G, H, J, K, L, M, N, P, and Q. The panels were exposed for about one year, retrieved, and returned to the ground four times from 2015 to 2019, once per year. The detailed operation of the CPs can be seen in the reference [2].

The columns and the terms used in the list are as follows.

Impact track ID: Unique sample ID is given to each track, which was formed by hypervelocity impacts of microparticles in aerogel. Some tracks contain captured impactor residue(s). The ID was given according to the following rules: The first letter corresponds to the pointing face to which the Capture Panel is attached on the ExHAM, (S: Space, E: East, N: North). The combination of the second letter and the third number represents the Capture Panel ID. For instance, "D1" means "the panel attached to the position D on the ExHAM and was exposed in the first year of the Tanpopo mission". The next letter "A" represents that the impact occurs on an "aerogel", as opposed to the metal support structure of the CPs. The next four-digit number (such as"0104") are given uniquely to each track in the aerogel block, while "T", "F" and "U" correspond to "True", "False" and "Undefined" of hypervelocity impact tracks by microparticles, respectively.

Capture Panel ID: As described above, the Tanpopo CPs have unique IDs with the positions (D, E, F, G, H, J, K, L, M, N, P, and Q) on the ExHAM and the exposed year of the four-year-long mission (1,2,3,4).

Track Morphology Type: In the Tanpopo mission, four typical types of track morphologies were classified as follows.

(1) "Pit" Type: It is a hemispherical pit crater or bulbous in shape, where captured particles were usually not obvious, suggesting the incoming particle(s) had burst or/and sublimated.
(2) "Carrot" Type: It is widely known as carrot-shape track which is a typical morphology of a hypervelocity impact by a single solid particle on porous media in laboratory experiments and space missions like EuReCa and STARDUST missions [e.g., 5]. There is a shoulder structure that has a larger diameter than the entrance hole. Captured particles are often found at the terminus of the track as well as its inner wall.
(3) "Straight" Type: It is a straight, narrowly long tube-like track without a shoulder that is seen in the carrot type. The track diameter is similar to that of the entrance diameter. A terminal particle with a similar diameter is often observed.
(4) "Teardrop" Type: It has a narrower entrance hole than its track diameter which can become the largest at the terminus. Scattered materials are often seen on the track wall and its terminus.

It is noted that sometimes there are intermediate, transitional types between two typical types such as "Carrot-Pit" or "Straight-Carrot". These types are decided not quantitatively but qualitatively by the Tanpopo researchers at the stage of the initial sample analysis phase, using sequential images taken by the CLOXS optical microscope. The information can be used to estimate the possible properties of the captured materials.

Residue Locations:

T: One or more impact residues are seen at the terminal end of the track.

W: Impact residues are seen only on the inner wall of the track.

W&T: Impact residues are scattered both on the inner wall and at the terminal end of the track.

N: No apparent residues are seen in the track at optical microscopic levels.

Surface: The objects are found on the surface of the aerogel block. They include fibrous, bar-like, possible aerogel fragments, and so on. These objects cannot be formed by hypervelocity impacts. Since they were identified as "F" (false) samples, they are not included in this sample list.

Future Prospect: Tanpopo Series after the First Tanpopo

The current database list the tracks obtained during the Tanpopo experiment operated from 2015 to 2019. Even after 2019, following Tanpopo series experiments have been conducted onboard ISS. As of 2022, the Tanpopo2 and 3 experiments returned to the Earth for subsequent sample analysis, and the Tanpopo 4 experiment is in progress in LEO. The data to be obtained in these follow-on experiments will be presented elsewhere.

References:

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