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Publisher

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency
http://www.isas.jaxa.jp/en/
3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa
252-5210, Japan

Contact

Management and Integration Department,
Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa
252-5210, Japan
TEL: +81-50-3362-2697

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Annual Report of the Institute of Space and Astronautical Science

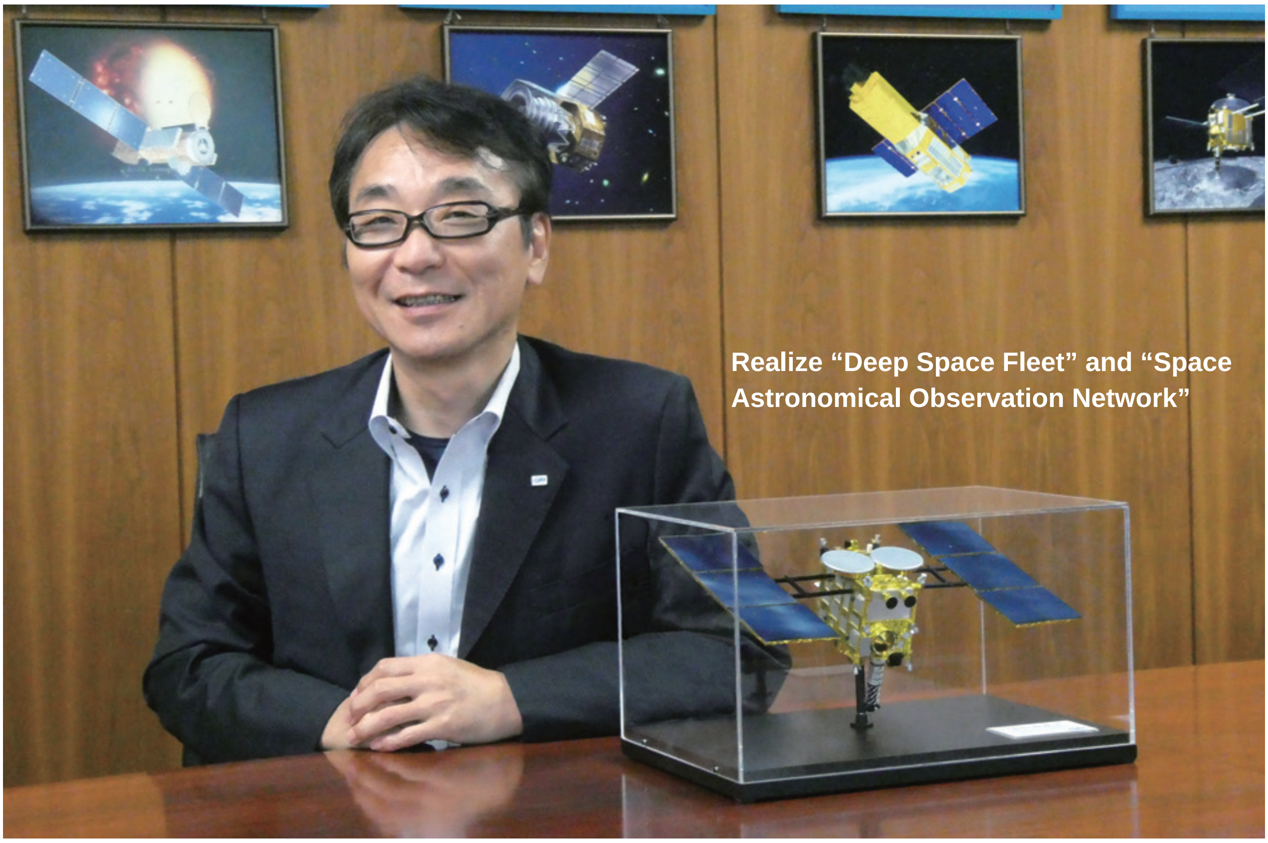
Fiscal Year 2018

(Apr 2018 - Mar 2019)

Message from the Director General

Hitoshi Kuninaka
Director General

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency



The Institute of Space and Astronautical Science (ISAS) would like to share with the world the success of our current missions and contribute to the glorious future of space research. The currently operating Venus Climate Orbiter Akatsuki and Arase Geospace Probe have generated observational data that has led to the publication of numerous scientific papers. In October 2018, BepiColombo/Mio was launched from the Guiana Space Centre and is currently sailing towards Mercury. Asteroid explorer Hayabusa2 rendezvoused with Asteroid Ryugu in June 2018 after its ion engine-powered flight, deployed three robots, namely - MINERVA-II1A, MINERVA-II1B, and MASCOT in October 2018, performed its first touch-down in February 2019, formed an SCI artificial crater in April 2019, and executed its second touch-down in July 2019. The X-Ray Imaging & Spectroscopy Mission (XRISM) and Smart Lander for Investigating Moon (SLIM), which we are aiming to launch in FY2021, and the JUpiter ICy moons Explorer (JUICE), scheduled for launch in 2022, are on schedule. The Martian Moons eXploration (MMX) and Demonstration & Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby & dUSt science ($DESTINY^+$) continue to make progress in their projects. The construction of the Misasa Deep Space Antenna, following that of Usuda, is also progressing steadily. We have also received many external commendations. The results from FY2018 are encouraging and have accelerated the construction of a “Deep Space Fleet” and the “Space Astronomical Observatory Network”, which will result in a number of new satellites and explorations ranging from Mercury and extending to Jupiter. The aim of the missions is to elucidate the history of the solar system and the cosmos, dating back 4.6 and 13.8 billion years, respectively.

We will develop a number of attractive future plans. The above-mentioned programmed concepts of a "Deep Space Fleet" and "Space Astronomical Observation Network" will act as a baseline for the planning of future projects. A number of working groups and in-house preparation teams have formulated multiple prospective plans, and prepared proposals as a conceptual study stage for project progress procedures. In May 2019, through a number of studies, ISAS selected Lite satellite for studies of B-mode polarization & Inflation from cosmic background Radiation Detection (LiteBIRD) and Japan Astrometry Satellite Mission for INfrared Exploration (Small-JASMINE) as future projects. In light of the proposed projects, increased cooperation and collaboration with domestic and overseas organizations is crucial.

I am also committed to building a relationship between ISAS and society. By sharing real-time information via the press center, and broadcasting the crucial operations of Hayabusa2 online, we have managed to gain significant media coverage. We would like to believe that as a result, our activities have garnered attention, empathy, and encouragement from the world. We will continue to make efforts to disseminate the results of space science and raise awareness of its significance. Although it is difficult to immediately implement the knowledge and technology gained by space science and exploration in everyday life, we will continue to cooperate with other departments of JAXA, such as the Space Exploration Innovation Hub Center and the New Business Promotion Department, regarding technology development and social implementation.

We appreciate your understanding of the activities of ISAS and will continue to provide guidance and encouragement.

October 2019

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ON THE COVER

Ryugu, the target asteroid of the sample-return mission “Hayabusa2”

On the 27th of June 2018, the asteroid explorer Hayabusa2 arrived at Ryugu, about three and half years after its launch in December 2014.

From the home position (altitude of 20 km), the Hayabusa2 spacecraft descended to an altitude of about 6 km as part of the BOX-C operation on July 20–21, 2018.

This image of the equatorial area was taken with the ONC-T (Optical Navigation Camera-Telescopic) during the BOX-C operation.

Many craters and boulders can be seen on Ryugu, and the theme for the nomenclature of the observed topographical features was selected to be “names that appear in stories for children”.

The crater in the center of the image, which is the largest crater on Ryugu, was named “Urashima”.

I
Scientific Highlights in FY2018

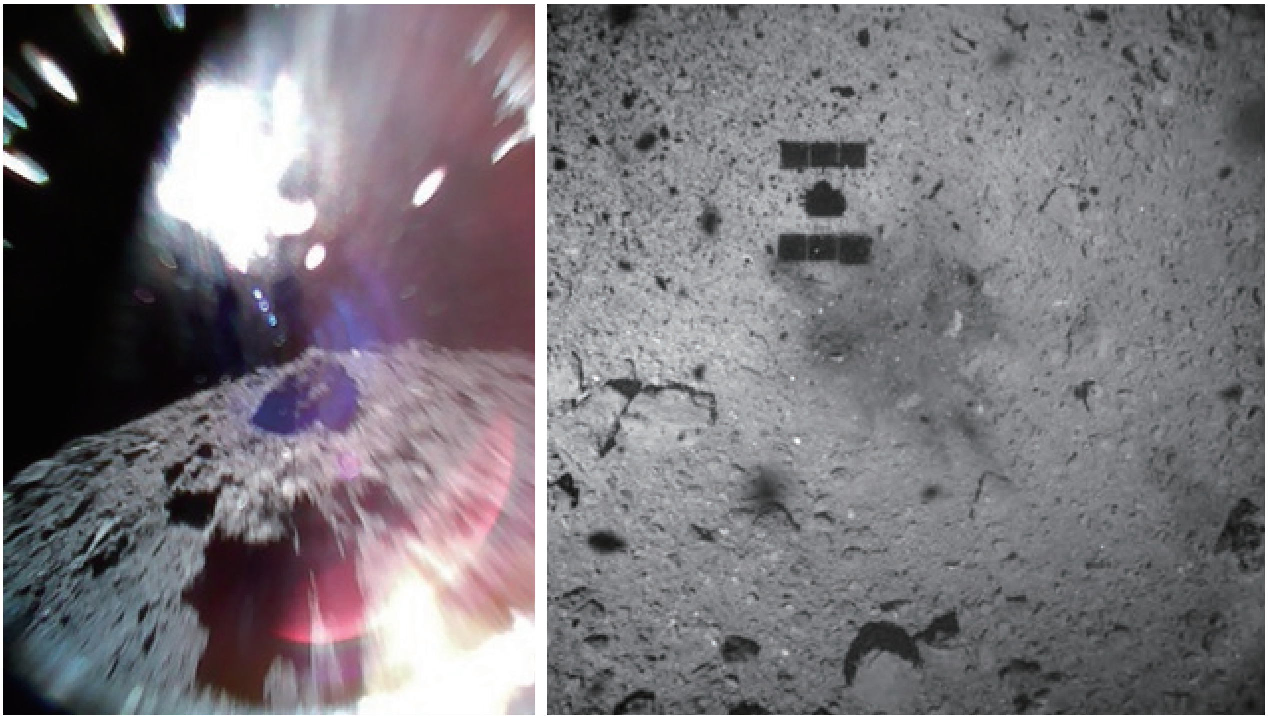
Asteroid Explorer Hayabusa2

【Release of Rover/Lander and Touch Down Operations】

The asteroid explorer "Hayabusa2" was launched on December 3, 2014. Its mission is to collect samples from a C-type asteroid and return them to Earth. The spacecraft used an ion engine to reach the C-type asteroid "Ryugu", and succeeded in arriving at the asteroid in June 2018. To make the spacecraft reach accurately to a point 20 km above the asteroid, a hybrid system of optical and radiometric observations and high-precision radio navigation (delta differential one-way ranging: DDOR) was used.

In September 2018, two rovers (Rover1A and Rover1B of MINERVA-II1) were successfully separated from the spacecraft. The two rovers landed on the asteroid and explored the surface using a unique hopping method. They were the world's first artificial objects moving on an asteroid surface, and they took precise images and temperature measurements. In October, the separation and landing of the MASCOT lander developed by DLR / CNES was successful, and it made observations on the asteroid for about 17 hours, as planned.

The asteroid surface is much rougher than expected. Because the mission found no flat area larger than about 100 m in diameter, the accuracy of data about the height of individual boulders and the accuracy of topographical data needed to be improved. When the descent operation was performed in February 2019, landing navigation control was accurate within 1 m. Overall, the touch-down operation was successful and we confirmed that the impact projectile was fired successfully. Considering the ejecta visible in an image taken immediately after the touchdown, we are very confident that material was collected from Ryugu.



(left) image taken by Rover-1A on the surface of Ryugu while hopping.
(right) image taken by Hayabusa2 just after the touch down. The shadow of the spacecraft can be seen.
(C) JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University. University of Aizu, AIST.

The cover page of "Science".
(c) JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST

Three papers with preliminary scientific results from the Hayabusa2 project have been published in Science. They make a major contribution to our understanding of the formation of planetary bodies and the origin of water on Earth.

Watanabe *et al.*：Science 19 Apr 2019: Vol. 364, Issue 6437.
Kitazato *et al.*：Science 19 Apr 2019: Vol. 364, Issue 6437.
Sugita *et al.*：Science 19 Apr 2019: Vol. 364, Issue 6437.
（see pages 4-6）

Press center opened by JAXA

When the vehicle arrived at Ryugu, about 360 journalists gathered at the press center opened by JAXA for the touch-down operation. In addition, 490,000 Japanese and 166,000 English-speaking viewers viewed the live broadcast of the event online. The public reach of this event was impressive. Furthermore, special-feature television programs were broadcast by the Japan Broadcasting Corporation (NHK). These outreach efforts attracted much attention from the public and have increased public understanding of the significance of space exploration.

Dr. Yoshikawa, the mission manager of the "Hayabusa2" project team

Dr. Yoshikawa, the mission manager of the "Hayabusa2" project team, has been honored by Nature magazine as one of their most-influential scientists of 2018.

Achievements over many years in the technological development of ion engines have also made a great impact in the science community, and Dr. Kuninaka, the previous project manager, was awarded the 2018 Toray Science and Technology Award.

The Hayabusa2 Project received the "2019 Aviation Week Laureate Award" (Space, Technology & Innovation).

The award recognizes the arrival at the asteroid Ryugu and the success of the three small rovers and lander (MINERVA-II1 and MASCOT).

The award ceremony was held on March 14, 2019, in the hall of the National Building Museum in Washington, DC.

The award ceremony

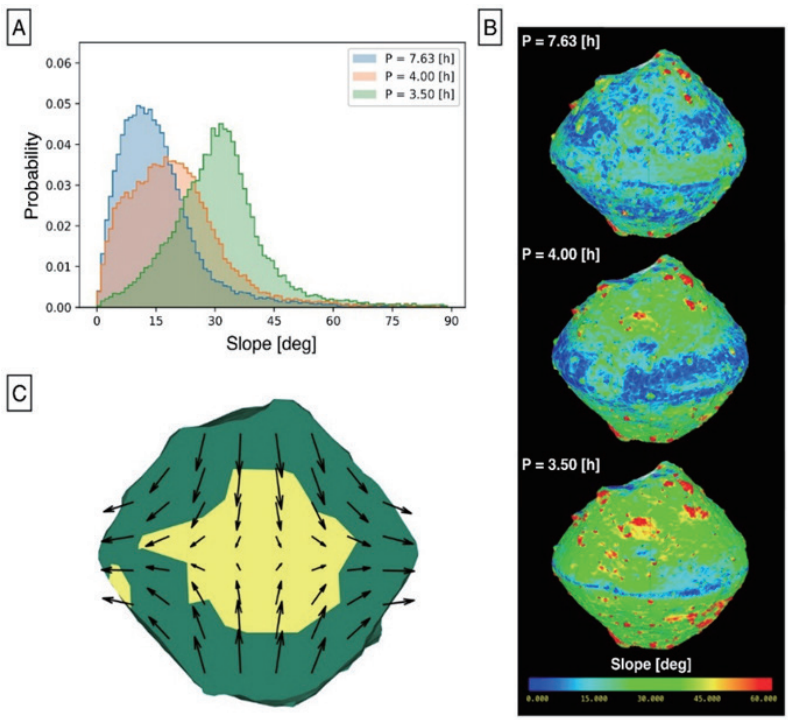
Hayabusa2 Arrives at the Carbonaceous Asteroid 162173 Ryugu – A Spinning Top-shaped Rubble Pile

【Asteroid Explorer Hayabusa2】

Asteroids and comets are primitive bodies that have preserved materials and physical states since the early days of the solar system. C-type asteroids are thought to be the parent bodies of carbonaceous meteorites that are enriched with volatile materials like water and organics. These volatiles are the building blocks of life, and originate beyond the solar system's snow line. Though these bodies are of great scientific significance, no C-type asteroid had never been explored at close range. The Hayabusa2 spacecraft arrived at the near-Earth carbonaceous asteroid 162173 Ryugu in 2018. This was the very first successful rendezvous with a C-type asteroid in history. After its arrival at the home position 20 km above the asteroid, remote sensing observations were performed using four instruments: an optical navigation camera system (ONC), a laser altimeter (LIDAR), a near infrared spectrometer (NIRS3), and a thermal imager (TIR). This report introduces Hayabusa2's plan for remote sensing observations around the asteroid and discusses initial results. These results are focused on Ryugu's shape, mass, and geomorphology.

A model of the overall shape of Ryugu was constructed using the structure from motion (SfM) and the stereo-photoclinometry (SPC) methods. Ryugu has an oblate spinning top shape with a prominent circular equatorial ridge. The asteroid's bulk density is 1.19 +/− 0.02 g/cm^3, which was inferred from shape observations and gravitational measurements. This density value indicates that Ryugu has a porosity of >50%, assuming the carbonaceous chondrite meteorites. The surface of Ryugu does not exhibit the smooth terrain that was found on Itokawa. It is covered in boulders, including one named Otohime, which is the largest boulder with the size of 160 m. The many large surface boulders on Ryugu suggest that it has a rubble-pile structure, which would have been reaccreted from impact fragments. The global homogeneity of Ryugu in conjunction with local spectral variation in its surface rocks support the hypothesis that the asteroid has the rubble-pile structure.

Analysis of the surface slopes suggests that the shape of Ryugu may have formed when it once spun at twice its current rate. In conjunction with the observed global homogeneity of material making up the asteroid, this evidence suggests that Ryugu was reshaped by centrifugally induced deformation during a period of rapid rotation. From these remote-sensing observations, a suitable sample collection site was identified on the equatorial ridge.



Distribution of slopes on the surface of Ryugu as modeled with the rotation periods of 7.63, 4.0, and 3.5 h (A), and plots of surface slope on a 3D model (B). Displacements (arrows) and the yield region (yellow) calculated by the finite element method are also plotted for the meridian section of Ryugu (C).

- S. Watanabe *et al.*: 2019, Hayabusa2 arrives at the carbonaceous asteroid 162173 Ryugu - A spinning top-shaped rubble pile. *Science*, 364 (6437), 268-272.
doi: 10.1126/science.aav8032

Hydroxide minerals on the primitive asteroid Ryugu: Implications for the hydration and thermal history on C-type asteroids

【Asteroid Explorer Hayabusa2】

Ryugu, the target asteroid of the Hayabusa2 spacecraft, is classified as a C-type asteroid. Based on their spectral characteristics, C-type asteroids are considered to be composed of minerals similar to those of carbonaceous chondrites, which contain hydrated and hydroxide minerals. Nevertheless, since it is difficult to observe near-infrared bands at ~3 μm, which is where the absorption by hydrated and hydroxide minerals occurs, detailed information about the composition of C-type asteroids is unknown. The Near Infrared Spectrometer (NIRS3) onboard Hayabusa2 has overcome this issue by observing the C-type asteroid, Ryugu.

NIRS3 detected an absorption feature centered at 2.72 μm, which suggests the existence of hydroxyl-bearing minerals on Ryugu formed by aqueous alterations. This feature is almost uniform over the entire surface of the asteroid in terms of band depth and position. Additionally, it is remarkable that the albedo of Ryugu is the lowest among all the asteroids ever explored. Comparing the spectra of NIRS3 and carbonaceous chondrites, the absorption features of Ryugu resemble those of thermally metamorphosed CI-chondrites and shocked CM-chondrites. This suggests that the aqueously altered Ryugu asteroid experienced shock-induced dehydration, or thermal alteration, as part of its evolution.

The model that proposes that terrestrial water was brought by carrier celestial bodies after the formation of the solar system is garnering much attention. C-type asteroids are being hailed as promising water carrier candidates. The results from Hayabusa2, which show the presence of hydroxide minerals on Ryugu, brings us one step closer to proving this model. More detailed verification is expected to be obtained from the analyses of the samples returned by Hayabusa2.

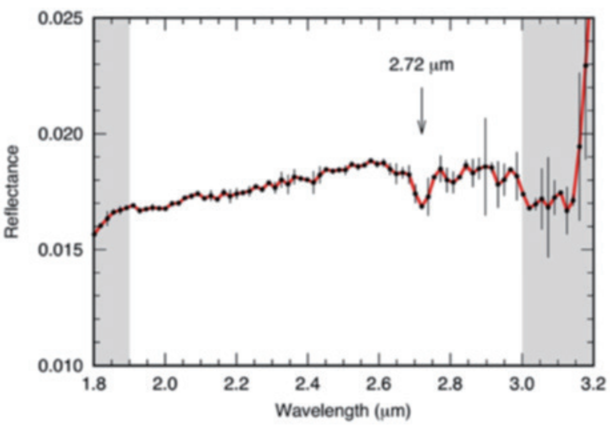


Fig. 1. Reflectance spectra of Ryugu observed by NIRS3. The absorption of the hydroxyl -bearing minerals is shown at 2.72 μm. The shaded areas represent regions having large calibration residuals.

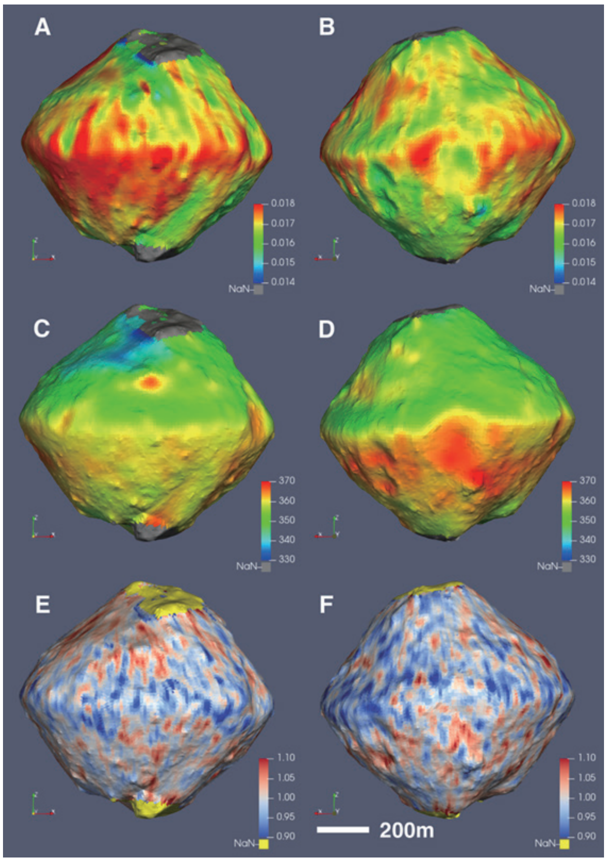


Fig. 2. NIRS3 spectral features projected onto the modelled shape of Ryugu. The left and right images correspond to the western and eastern hemispheres, respectively. A and B show the reflectance factor at 2.0 μm. C and D show the surface temperature. E and F show the normalized absorption intensity.

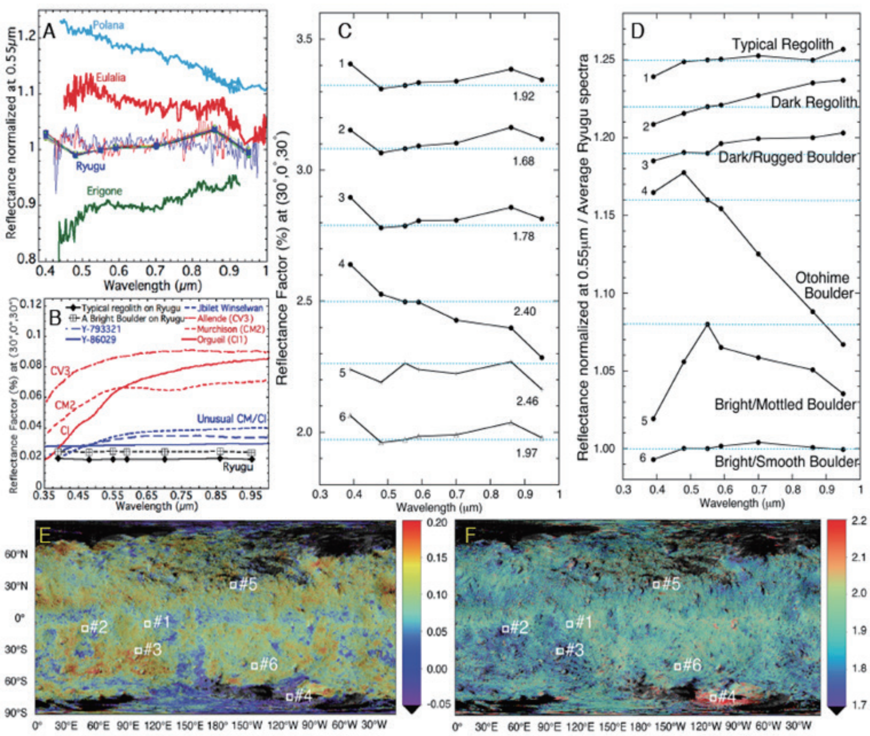
- K. Kitazato *et al.*: 2019, The surface composition of asteroid 162173 Ryugu from Hayabusa2 near-infrared spectroscopy. *Science*, 364 (6437), 272-275.
doi: 10.1126/science.aav7432

The Geomorphology, Color, and Thermal Properties of Ryugu: Implications for Parent-body Processes

【Asteroid Explorer Hayabusa2】

C-type asteroids are most common beyond the snow line, where water can exist as ice. These bodies have never been explored in detail, except for a flyby of 253 Mathilde by the NASA Near-Earth Asteroid Rendezvous Shoemaker mission. Hayabusa2 made the first-ever rendezvous with a C-type asteroid when it reached 162173 Ryugu in June 2018 and began to take remote-sensing observations. This paper describes geological and multicolor imaging recorded by Hayabusa2's optical navigation camera system (ONC-T). These data are supported with geometrical measurements taken by a laser altimeter (LIDAR) and temperature and thermophysical measurements recorded by a thermal infrared imager (TIR).

A variety of geomorphological features have been found on Ryugu. The asteroid has a circum-equatorial ridge, which is typical of an asteroid with faster rotation, indicating that the spin rate of Ryugu changed in the past. Ryugu's surface color is globally homogeneous, although it has a faint but remarkable east-west hemispherical dichotomy in surface albedo. Many boulders cover the entire surface of Ryugu, and it lacks the flat smooth terrain that was found on asteroid 25143 Itokawa during the Hayabusa mission. Small- to large-scale impact craters appear on the surface of Ryugu. Age estimates from these craters indicate a resurfacing age of $\lesssim 10^6$ years for the upper 1-meter layer. This young age may be explained by the easily deformable surface layer of loosely bound sedimentation of rocks. The geometric albedo of 4.5 ± 0.1% shows that Ryugu is among the darkest-known bodies in the Solar System. Its reflectance and thermal properties indicate that the surface is not covered with dust or fine regolith, but with porous rocky material larger than several centimeters. The high abundance of boulders and their spectral properties are consistent with those of moderately dehydrated materials. Therefore, this material is analogous to that of thermally metamorphosed meteorites found on Earth. The general uniformity in color across Ryugu's surface supports the hypothesis that the material was partially dehydrated by internal heating from the asteroid's parent body.



Relative reflectance of Ryugu and a comparison with reflectances at fixed angles of asteroids and meteorites (A,B). 7-band features and normalized features for 6 sites on Ryugu (C,D). Maps of spectral slope (E) and reflectance at 0.55 μm (F) at the 6 sites.

- S. Sugita *et al.*: 2019, The geomorphology, color, and thermal properties of Ryugu: Implications for parent-body processes. *Science*, 364 (6437), eaaw0422.
doi: 10.1126/science.aaw0422

Autonomous Exploration by the MINERVA-II Twin Rovers Over the Surface of Asteroid Ryugu

【MINERVA-II, Asteroid Explorer Hayabusa2】

The authors installed two small twin rovers (Rover 1A and 1B) carried by the Hayabusa2 spacecraft. The two rovers are almost identical, with a mass of approximately 1.1 kilograms, and were packed into a single container (Fig.1).

The rovers were designed to test two technical innovations on the asteroid surface. They moved by hopping in the microgravity environment of the small planetary body, and this novel locomotion strategy was tested on the asteroid surface. The rovers were also equipped with a fully autonomous system for moving over the surface while making scientific observations and measuring materials on the asteroid. This innovation was also tested on the asteroid surface.

The rovers were deployed to the northern hemisphere of asteroid Ryugu on 22 September 2018. They were released at the altitude of approximately 50 meters above the surface. The deployment operation was executed perfectly, and the rovers landed successfully on the asteroid.

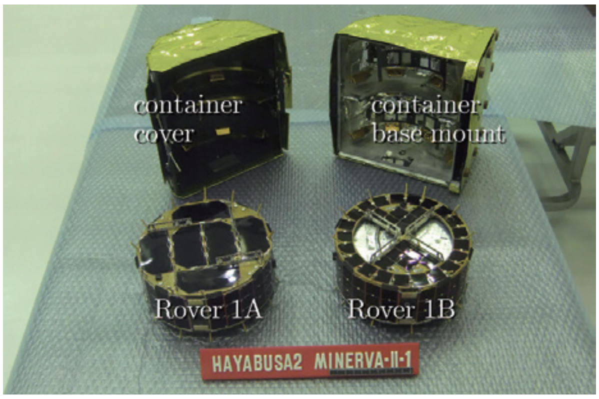


Fig. 1 Rover 1A and 1B

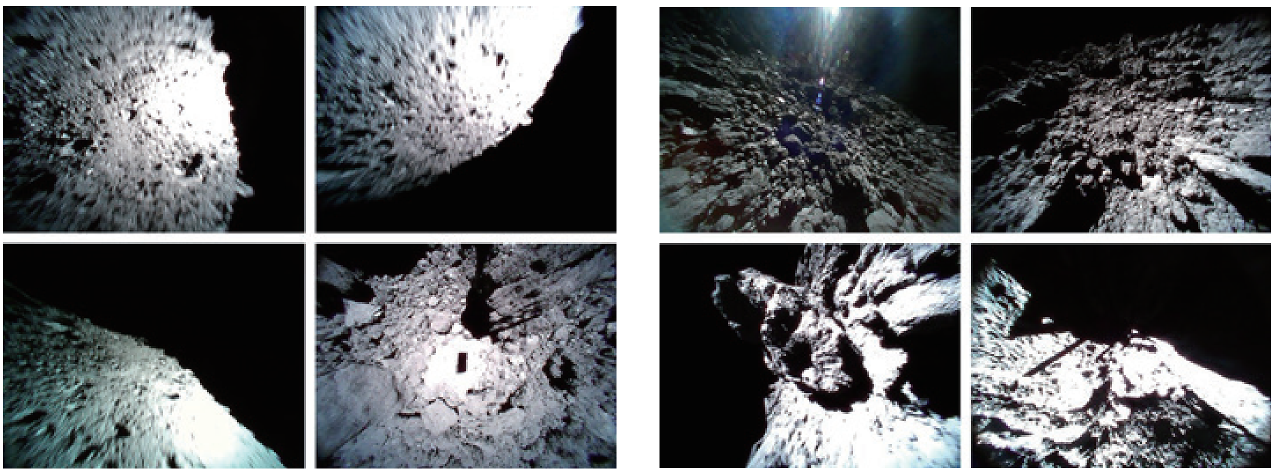
The rovers began moving autonomously once their capacitors were fully charged by solar illumination. As they moved across the surface, they took images of the surface at different positions while they were on the surface or while flying in free space after a hop.

The obtained data were transmitted to the relay module of Hayabusa2, which stayed at the altitude of 20 kilometers above the asteroid. No commands were transmitted to the rovers for executing procedures. The only commands transmitted to the rovers changed the parameters of their autonomous behavior.

Rover 1A survived for 113 asteroid days after deployment, whereas Rover 1B functioned for 10 asteroid days. A total of 609 images were transmitted to the Earth from Rover 1A, and 39 images from Rover 1B (Fig. 2).

The rovers also directly measured the temperature and electrical potential of the surface while they were resting on the surface. These measurements were recorded continuously for hours, from both the areas illuminated by the Sun and the areas in the shadow of the rovers. The objectives of the rovers were completely fulfilled. This mission achieved the world’s first mobile exploration of a small planetary body in addition to being Japan’s first planetary rover.

The images obtained by the rovers unveiled detailed surface features of Ryugu. Some of the images suggest that small particles on the surface were kicked up into free space by the hopping action of the rovers.


(a) images obtained by Rover 1A during orbital motion

(b) Images obtained on SOL 7 by the rovers when they were close to the surface

Fig. 2 Images taken by rovers

- Press Release by JAXA. MINERVA-II1 of Hayabusa2 Touches Down Ryugu. September 22, 2018.
- T. Yoshimitsu, *et al*., Readiness of Proximity Operation on MINERVA-II Rovers on-board Hayabusa2 Asteroid Explorer. *i-SAIRAS2018*. Madrid, Spain. June 4-6, 2018.

Discovery of Planetary-Scale Streaks and their Numerical Reproduction

【Venus Climate Orbiter AKATSUKI (PLANET-C)】

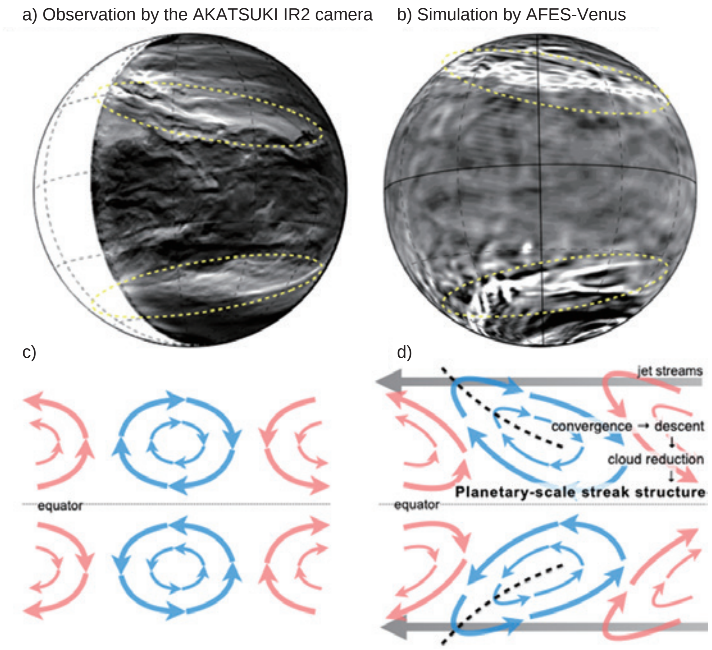
AKATSUKI's 2-μm camera, IR2, has discovered a bright planetary-scale streak structure in an image of the night side of Venus acquired on March 26, 2016 (Panel a). The night-side image taken at this wavelength shows the morphology of clouds at heights around 45-60 km in silhouette, using the lower hot atmosphere as an illuminant. Hence, bright regions in the image indicate regions with relatively thin cloud cover.

AKATSUKI's numerical modeling team, which consists of researchers from Kobe University and other institutes, has developed a computational code for simulating the Venusian atmosphere (AFES-Venus). This simulation code is highly optimized for the Earth Simulator supercomputer and high-resolution simulations have been performed. The numerical results include simulated regions of strong downward flows that form a streak structure resembling the streaks observed in the IR2 night-side image (Panel b). This downward flow can restrain the growth of clouds, so the simulated results are consistent with the IR2 observation.

The north-south temperature gradient over Earth's middle and high latitudes induces large-scale atmospheric movement known as baroclinic instability, which produces extratropical cyclones, migratory high-pressure systems, and polar jet streams. Interestingly, AFES-Venus simulations show that a similar mechanism may be at work in the Venusian atmosphere, producing jets over high latitudes. At low latitudes, on the other hand, atmospheric waves caused by the distribution of large-scale flows and planetary rotation, known as Rossby waves, tend to generate large vortices that extend from the equator to latitudes of 60 degrees in both hemispheres (Panel c). Such vortices are tilted and elongated by jets, resulting in a relatively narrow region in which poleward winds and equatorward winds collide (Panel d). In such a converging region, air needs to be transported either upward or downward. Strong downwelling is more prevalent in the simulations, and is consistent with the bright streaks seen in the IR2 image.

Our simulations also suggest that north-south symmetry is maintained by equatorial Kelvin waves that exist at lower altitudes.

This study demonstrated the appropriateness of the assumptions in the AFES-Venus code and the usefulness of high-resolution numerical simulations for these applications. Simulation results could allow researchers to infer the mechanisms behind novel atmospheric phenomena and phenomena for which causes are unknown.



Panel (a) shows the Venus night-side image acquired by IR2 (2.26 μm) on March 26, 2016. Thin-cloud regions appear as bright regions in the image, as they are illuminated by infrared radiation from below the cloud. Such bright regions form planetary-scale streaks that are symmetrical about the equator, as indicated by dashed circles. A high-resolution simulation successfully reproduced this structure as shown in Panel (b), suggesting that vortices due to atmospheric waves in low-latitudes (Panel c) are tilted toward the meridian by high-latitude jets to form convergence zones that appear as streaks (Panel d).

Kashimura et al. (2019) CC BY 4.0 (modified)

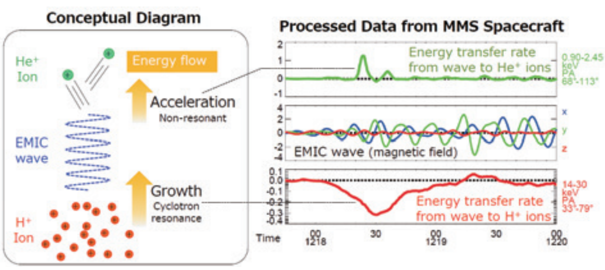
- H. Kashimura *et al.*:2019, Planetary-scale streak structure reproduced in high-resolution simulations of the Venus atmosphere with a low-stability layer. *Nature Communications*, Vol. 10(23), 1-11. doi: 10.1038/s41467-018-07919-y

Direct Measurements of Energy Transfer between Ions via Electromagnetic Waves in Space

【Magnetospheric Observation Satellite GEOTAIL/MMS】

Wave–particle interactions are thought to play a crucial role in the energy transfer in collision-less space plasmas in which particles do not collide with each other owing to their extremely low densities, and the motions of charged particles are controlled by electromagnetic fields. The co-existence of plasma waves and accelerated particles (or particle populations that have free energy for wave growth) has been studied for decades. However, such co-existence does not necessarily indicate that energy is transferred between the waves and particles at the observation sites and at the indicated times. In most situations, moving particles interact gradually with propagating waves in a spatially extended region, and it is unrealistic to track a certain particle or wave packet using a spacecraft. Thus, detection of the local energy transfer between fields and particles is necessary for quantitatively evaluating the magnitude of the interaction.

Fast Plasma Investigation Dual Ion Spectrometers (FPI-DIS), built by Meisei Electric Co., Ltd. under the direction of the GEOTAIL Project Manager Prof. Yoshifumi Saito on NASA's Magnetospheric Multiscale (MMS) spacecraft have a full-sky field of view and an unprecedented high time resolution sufficient to identify a local energy transfer between electromagnetic ion cyclotron (EMIC) waves and ions. The ion distributions observed by FPI-DIS during an EMIC wave event are not symmetric around the magnetic field direction but are in phase with the wave fields. The phase relations between waves and ions, along with composition-resolved ion measurements conducted using a different instrument, demonstrate that a cyclotron resonance transfers energy from anisotropic H^+ (a free energy source) to the waves, which in turn non-resonantly accelerates cold He^+ up to an energy level of ~2 keV. This provides direct quantitative evidence for a collision-less energy transfer between distinct particle populations through wave–particle interactions.



Conceptual diagram of energy transfer and processed data showing energy transfer

Such measurements allow a quantitative understanding of the effectiveness of various types of naturally generated wave–particle interactions in magnetized plasma based on direct observations using spacecraft. For example, a wave–particle interaction between electrons and electron cyclotron waves (called whistler mode waves), which have similar characteristics as EMIC waves but higher frequencies, are strongly suspected to be a generation source of "satellite-killer" electrons in radiation belts, whereas wave–particle interactions between such satellite-killer electrons and EMIC waves cause a loss (precipitation to the Earth) of electrons. Thus, a quantitative understanding of wave–particle interactions can contribute to an understanding of high-energy particle environments around the Earth, and the physics of wave–particle interactions are universally applicable to space plasma.

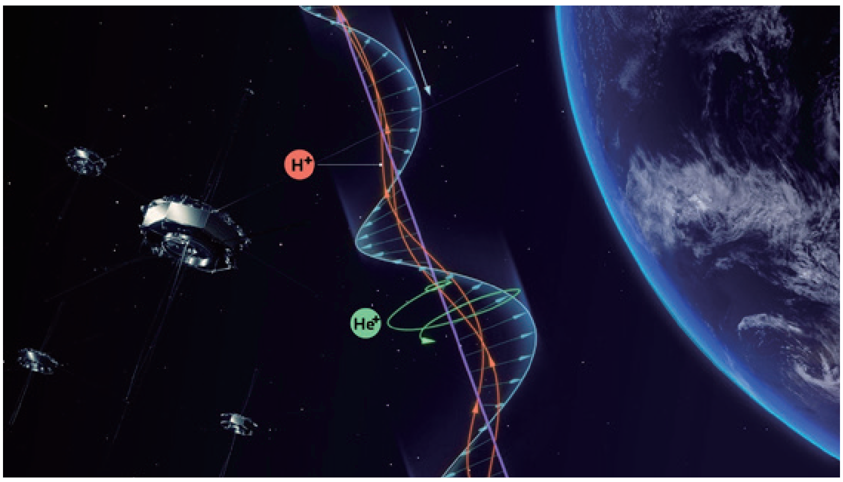
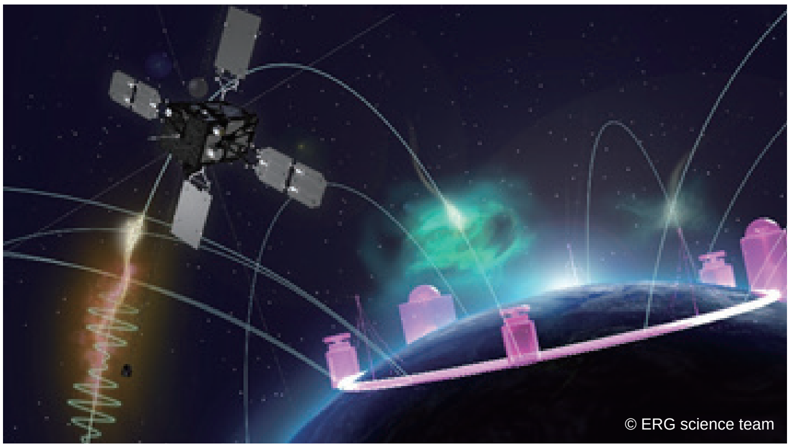


Image of wave–particle interaction observation using MMS spacecraft

- N. Kitamura *et al.*: 2018, Direct Measurements of Two-Way Wave-Particle Energy Transfer in a Collisionless Space Plasma. *Science*, 361 (6406), 1000-1003.
doi: 10.1126/science.aap8730
- JAXA Press Conference/ Joint Press Release by JAXA, University of Tokyo, Nagoya University, and Tohoku University. September 7, 2018.
- Joint Press Release by Kobe University, JAXA, Kyoto Sangyo University, Keio University, and Japan Agency for Marine-Earth Science and Technology (JAMSTEC). January 10, 2019.

Visualization of Region where Wave–Particle Interactions Occur between Electrons and Chorus Waves in Geospace

【Arase (ERG: Exploration of Energization and Radiation in Geospace)】



Arase observation and ground-based aurora imagers. The observation visualizes the wave–particle interaction region.

Combining the plasma wave measurements of Arase with ground-based high time-resolution aurora imaging*, we clarified for the first time the detailed spatial and temporal variations of the region where wave–particle interactions between chorus waves and energetic electrons occur. Information on the spatial distribution of possible wave–particle interaction regions between chorus waves and energetic electrons is essential for forecasting an increase in high-energy electrons in radiation belts.

On March 30, 2017, flash aurorae were observed at a ground station in Gakona in the southern part of Alaska, when Arase was located along a geomagnetic field line presumed to connect to Gakona. Simultaneously with the flash aurora observations, Arase observed chorus wave elements in geospace. As shown in Figure 1, the observed ground-satellite conjunction event indicates that the variations in the intensity and spatial scale of flash aurora emissions coincide with the chorus wave intensity within a few hundreds of milliseconds. These observations could not be realized without coordinated observations between our ultra-high time-resolution aurora camera and Arase.

The agreement extracted from the pure single chorus element with the auroral spatial scale suggests the possibility that the chorus-wave amplitude is associated with the transverse size of its wave packet and that the amplitude grows effectively and rapidly. The aurora measurements imply that the wave–particle interaction region quickly developed asymmetrically, on the order of a few tens of milliseconds, in the Earthward and anti-Earthward directions in the plane perpendicular to the geomagnetic field (Figure 2). That is, our results demonstrate that the flash aurora can be a display that enables us to visualize the electromagnetic environment in geospace.

We clarified that a flash aurora observation is a powerful tool to grasp the global activity of chorus emissions in geospace. Understanding a global distribution of chorus waves through common flash aurora observations will contribute significantly to space weather forecasts because the chorus wave is thought to be closely related with the increase/decrease of high energy electrons in the Earth's radiation belts.

* The aurora camera was developed by the PWING project for observations of the geospace phenomenon from the ground. PWING is promoted with the cooperation of researchers from universities and research institutes in Japan.

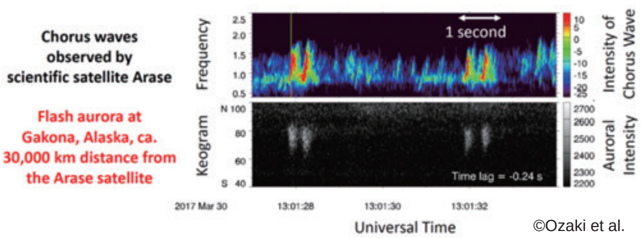


Fig. 1 Temporal variations of the chorus-wave intensity observed by Arase and the auroral intensity observed in Gakona in southern Alaska. Flash aurorae were simultaneously observed with emissions of strong chorus-wave elements. These variations coincide within an order of less than a second.

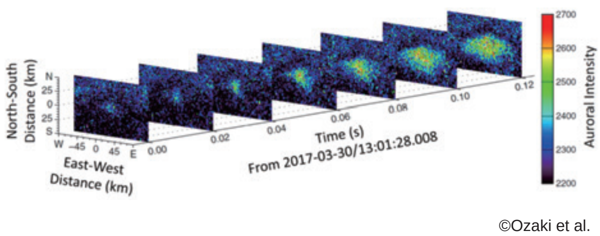


Fig. 2 Spatial and temporal evolution of the auroral emission. Variation of the shape of the auroral emission region corresponds to dynamics of charged particles in geospace, which cause an auroral emission, in the plane perpendicular to the geomagnetic field.

- M. Ozaki *et al*.: 2019, Visualization of rapid electron precipitation via chorus element wave-particle interactions, *Nature Communications*, 10(1), 257. doi: 10.1038/s41467-018-07996-z
- Joint Press Release by Kanazawa University, Nagoya University, The University of Electro-Communications, National Institute of Polar Research (NiPR), Kyoto University, Tohoku University, JAXA, and National Institute of Information and Communication Technology (NICT). January 16, 2019.

Moment of Rapid Electron Acceleration by Chorus Waves

【Arase (ERG: Exploration of Energization and Radiation in Geospace)】

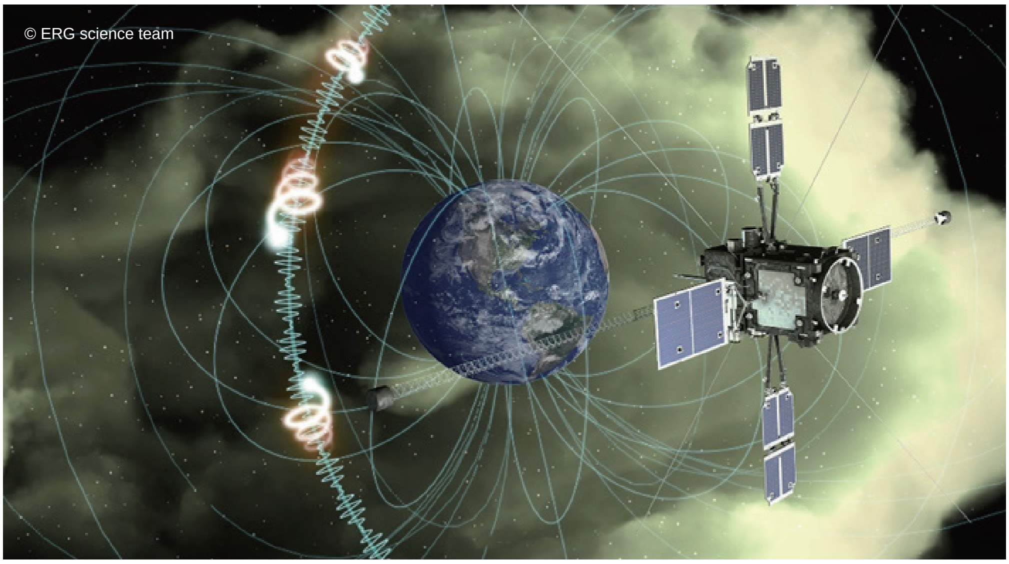


Image of electrons accelerated by chorus waves.

Arase discovered a rapid electron acceleration process. That is, the electron acceleration process through a wave–particle interaction with chorus waves can rapidly occur within a few tens of seconds, although it has been thought to be a much slower process on the order of a day.

The potential contribution of electron acceleration through a wave–particle interaction between electrons and chorus waves to the formation of the Earth's radiation belts has been an area of focus for many researchers. However, because the acquired energy of an electron in a single interaction is extremely small, it takes from several hours to a full day to achieve sufficient energy (slow acceleration).

Arase found a quick increase of energetic electrons within a short time of 30 s, associated with an occurrence of chorus waves. Figure (a) shows dynamical power spectra of chorus waves. Chorus waves were observed for approximately 1 min. Figure (b, c) shows snapshots of the electron energy distribution within a range of tens of keV obtained just before and after the emergence of the chorus wave. A comparison of these two energy distributions indicates that the numbers of electrons whose pitch-angles are approximately 60–80° or 100–120° increase. (The pitch-angle is defined as an angle between the particle velocity and the ambient magnetic field.)

The regions surrounded by the solid and dashed blue lines indicate the theoretical limits of the wave–particle interaction with the observed chorus wave. Because the observed increase in energetic electrons was found within the above theoretical range, we concluded that Arase observed a moment at which the chorus wave rapidly accelerated a portion of the electrons. Such observation may indicate the importance of nonlinear wave–particle interactions for electron acceleration. Such a quick acceleration process has yet to be considered, and thus this is an important finding in an understating of the dynamic variation of the Earth's radiation belts.

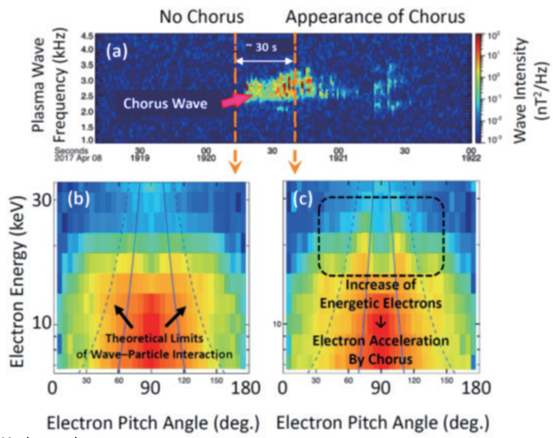
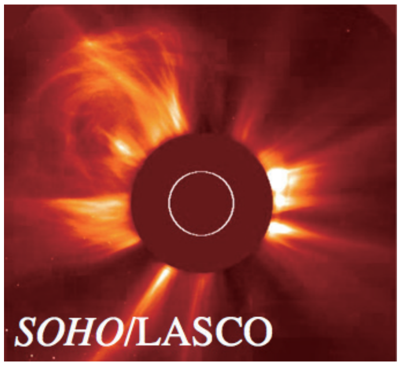


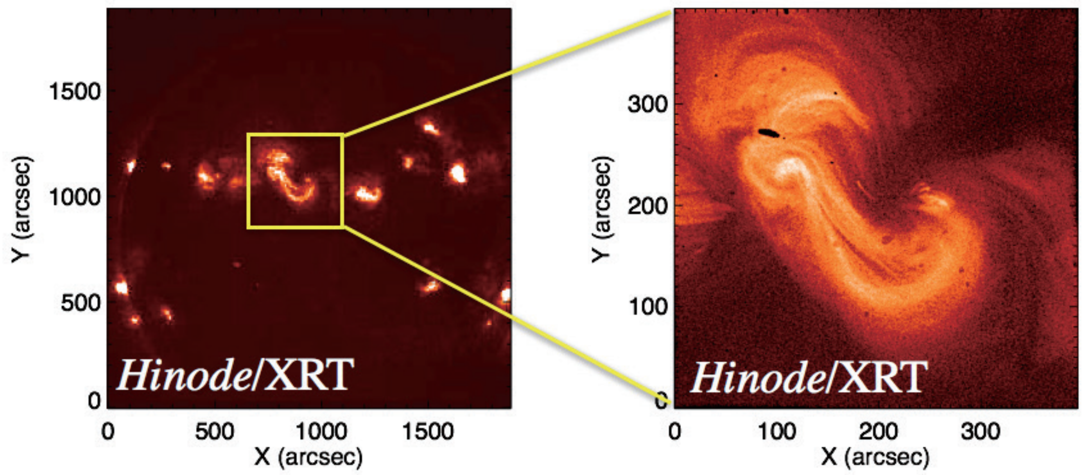
Fig. Arase observation of (a) temporal variation of chorus-wave power spectra, (b) electron pitch angle distribution obtained before the appearance of the chorus waves, and (c) electron pitch angle distribution obtained during the chorus-wave observation.

- S. Kurita *et al.*: 2018, Deformation of electron pitch angle distributions caused by upper band chorus observed by the Arase satellite. *Geophysical Research Letters*, 45 (16), 7996–8004. doi: 10.1029/2018GL079104
- Press Conference on ARASE observation report. January 24, 2019.

Sigmoidal Structures Observed by HINODE Contribute to Space-Weather Forecasting

【Solar Observation Satellite HINODE (SOLAR-B)】





Lower panels: example of a sigmoidal structure observed in a soft X-ray image. Top: coronal mass ejection from the sigmoidal structure observed with SOHO/LASCO.

The statistical relations between coronal mass ejections (CMEs) and sigmoidal structures in the solar corona have been investigated using more than ten years' worth of observations by the HINODE/X-ray telescope (XRT). The two phenomena are strongly correlated, suggesting that sigmoidal structures appearing in X-ray images can be used to improve predictions of CMEs, which have a great influence on the space environment. Predictions informed by these results will increase the safety of future social infrastructure in space.

- Coronal mass ejections (CMEs) are large amounts of plasma ejected from the solar corona into interplanetary space. They have a great influence on the space environment. A scheme for forecasting the occurrence of CMEs is very important both for planning space missions and for preparing for the effects of CMEs on various infrastructure on Earth.
- We developed an algorithm for detecting sigmoidal structures in soft X-ray images and we applied common correlation analysis methods to find correlations between the CME, flare, and sigmoid parameters in a sample of 211 flare events observed by HINODE.
- We found that CMEs are strongly correlated with sigmoidal structures in on-disk flare events. Since CMEs launched from on-disk locations are likely to have a great impact on Earth, sigmoidal structures are very useful for predicting approaching CMEs
- The sigmoidal structure proves to be an important feature for improving the accuracy of CME forecasts. These results are likely to improve the safety of future social infrastructure in space.

- Y. Kawabata *et al*.: 2018, Statistical Relation between Solar Flares and Coronal Mass Ejections with Respect to Sigmoidal Structures in Active Regions. *Astrophysical Journal*, 869 (2), 99. doi: 10.3847/1538-4357/aaebfc
- *Project for Solar-Terrestrial Environment Prediction (PSTEP) Science Nuggets No.18 (20190107)*. Correlation of Solar Flare Parameters and Sigmoid Structure with Coronal Mass Ejection. http://www.pstep.jp/news_en/nuggets18en.html

Near-Infrared Asteroid Spectroscopic Survey with AKARI

【Infrared Astronomical Satellite AKARI (ASTRO-F)】

Asteroids are generally thought to contain water in hydrated minerals. Hydrated minerals exhibit diagnostic absorption features at wavelengths around 2.7 μm. However, absorption by water vapor and carbon dioxide in the terrestrial atmosphere prevents the observation of this wavelength with ground-based telescopes. Hence it is necessary to make observations from outside the atmosphere, that is, in space. However, observations with space-borne telescopes have so far been limited by detection sensitivity and/or wavelength coverage. For this reason, scientists do not yet understand the amount of water that is carried by asteroids.

The AKARI satellite was equipped with the Infrared Camera (IRC) that could capture spectra at near-infrared wavelengths from 2 to 5 μm. Using this unique function, spectroscopic observations of 66 asteroids were carried out and their near-infrared spectra were recorded. This mission provides the first opportunity to study the features of hydrated minerals in asteroids at the wavelength of around 2.7 μm. The observations showed absorption at 2.7 μm, which could be attributed to hydrated minerals for 17 C-type asteroids. The absorption intensity detected at around 2.7 μm varies for each asteroid. When examining C-type asteroids in more detail, we found that the wavelength of the deepest absorption and the depth of absorption of 2.7-μm light are clearly related. This trend indicates a process in which hydrated minerals are losing water as they are gradually heated up. Many C-type asteroids display this behavior. This finding suggests that C-type asteroids were formed by the agglomeration of rocks and water ice, after which aqueous alteration occurred in the interior of asteroids to form hydrated minerals. After this process, C-type asteroids were heated, and the minerals dehydrated.

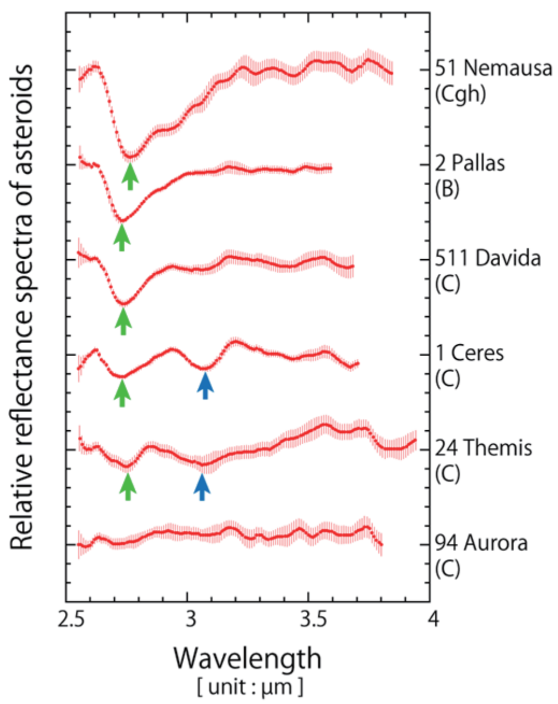


Fig.1 Near-infrared spectra of C-type asteroids obtained from the AKARI observations. Absorption at wavelengths of around 2.7 μm (indicated by the green arrows) is attributed to hydrated minerals. Signatures of water ice or ammonia-rich material at around 3.1 μm (indicated by the blue arrows) also appear.

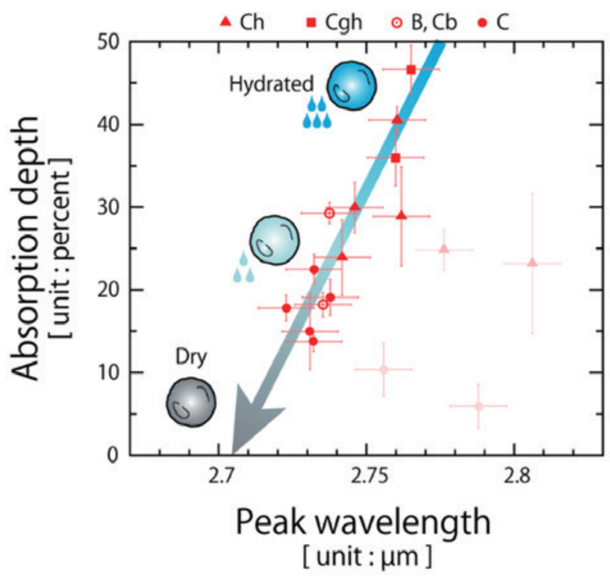
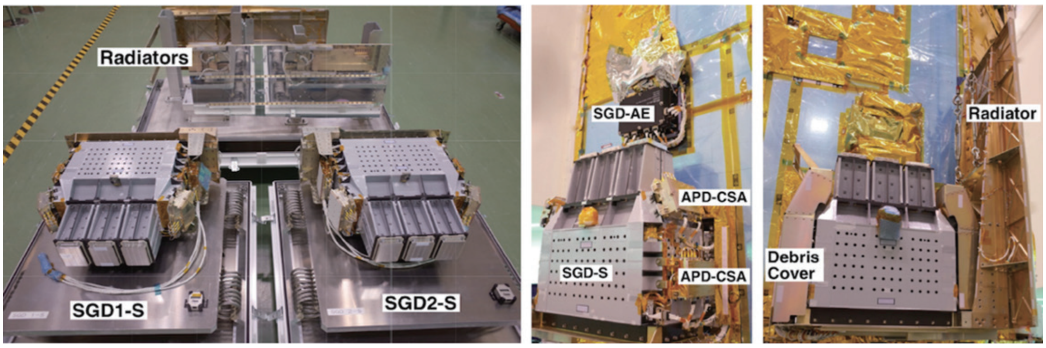


Fig.2 Relationship between the depth of absorption and the peak wavelength of the deepest absorption at around 2.7 μm in different C-type asteroids (shown by the green arrows in figure 1). The trend from top right to bottom left, indicated by the arrow, is explained by the asteroids heating up and drying out after formation.

- F. Usui, S. Hasegawa, T. Ootsubo, and T. Onaka: 2019, AKARI/IRC near-infrared asteroid spectroscopic survey: AcuA-spec. *Publications of the Astronomical Society of Japan*, 71(1), 1. doi: 10.1093/pasj/psy125

Detection of Polarized Gamma-Ray Emissions from the Crab Nebula Using Soft Gamma-Ray Detector (SGD) Onboard the ASTRO-H Satellite

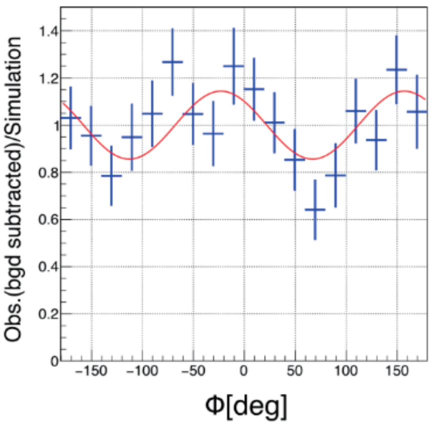
【X-ray Astronomical Satellite ASTRO-H (HITOMI)】



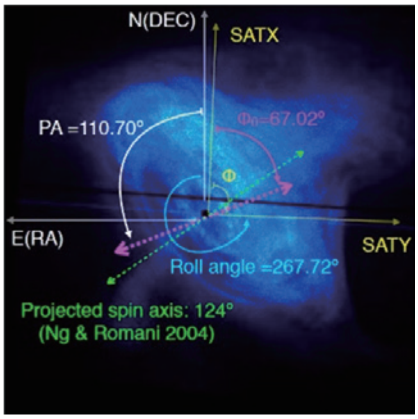
Photographs of the SGD flight model and SGD attached to the ASTRO-H satellite.

We successfully measured the polarization of soft gamma-ray emissions from the Crab nebula through an observation using a soft gamma-ray detector (SGD) onboard on the X-ray astronomical satellite ASTRO-H (HITOMI). Although the observation was for a short period of 2.5 h (9,000 s, with an effective SGD observation time of 5,000 s) during the initial test observation phase, significant polarized gamma rays could be detected by combining a careful data analysis, a background estimation, and SGD Monte Carlo simulations. The obtained polarization fraction of the Crab emissions is 22.1±10.6%, and the polarization angle is approximately 111° within the energy range of 60–160 keV. The polarization angle is almost orthogonal to the disk of the Crab pulsar in the Crab nebula and is close to the direction of the jet. The SGD measurement is also consistent with previous observations in a soft gamma-ray, such as the PoGO+ balloon experiment and the INTEGRAL satellite observations. The polarization fraction and the polarization angle are well-described as soft gamma-ray emissions arising predominantly from energetic particles radiating through the synchrotron process in the toroidal magnetic field in the Crab nebula, which are roughly symmetric around the rotation axis of the Crab pulsar.

Using SGD onboard the ASTRO-H satellite, we tried to realize a high sensitivity observation of the sub-MeV soft gamma-ray region, which has yet to be achieved because good observation instruments have not been developed. The SGD inherits the concept of a low background with a narrow FOV and active shielding of the hard X-ray detector (HXD) onboard the previous Japanese X-ray astronomical satellite "Suzaku". The SGD also has a function allowing it to distinguish between gamma rays from the target and other background signals with high-precision Compton imaging using domestically developed Si/CdTe semiconductor Compton cameras. In particular, an SGD Si/CdTe semiconductor Compton camera utilizes a unique high-density assemble technology. Although difficult to develop, the cameras were finally completed and used for observation. Although the obtained data are limited to the test observation of the Crab nebula, and the observation time is only approximately 5,000 s, this result demonstrates that the SGD is a highly optimized instrument for gamma-ray polarization measurements.



Modulation curve of the Crab nebula observed using SGD.



Direction of the polarization angle as determined using an SGD is drawn over an X-ray image of the Crab nebula with Chandra.

- Hitomi collaboration: 2018, Detection of polarized gamma-ray emission from the Crab nebula with Hitomi Soft Gamma-ray Detector. *Publication of the Astronomical Society of Japan*, 70(6), 113. doi:10.1093/pasj/psy118

Unexpected Intermediate-Mass Exoplanets beyond the Snow Line

The favored core-accretion model of planet formation predicts a planet desert beyond the snow line. This desert refers to a deficit of planets with masses between those of Neptune and Saturn (17 and 95 Earth masses, respectively). While the predicted deficit is pronounced relatively closer to the host star such deficit still exist beyond the snow line, where ices condense and gas-giant planets like Saturn and Jupiter (318 Earth masses) are thought to have formed. This planet desert would be a consequence of the runaway gas accretion process, which is thought to cause protoplanetary cores of ~10 Earth masses to grow rapidly to ~ 300 Earth masses through rapid accretion of hydrogen and helium gas. This process would result in Jupiter-like planets and numerous failed cores of ~10 Earth masses, which would be left over from cases in which the gas disk dissipated before runaway accretion could begin. After gas dissipation, intermediate-mass planets in the mass range of 20 – 80 Earth masses could be formed by the accretion of residual planetesimals. However, this mechanism is not enough to erase the planet desert. This prediction can be tested by comparing results from ground-based microlensing exoplanet surveys, which are sensitive enough to detect small exoplanets orbiting beyond the snow line with masses as low as a single Earth mass.

We compared microlensing measurements of the planet-to-host mass-ratio distribution against the predictions of two different population-synthesis models based on the core accretion theory. We found that the models predict 7 - 10 times fewer planets at mass-ratios of $1–4×10^{-4}$ than are observed by the microlensing observations (indicated by a green arrow in Fig. 1). This mass-ratio range corresponds to 20-80 Earth masses if we assume that the mass of the host star is half that of the Sun. Such cold planets with sub-Saturn mass (See Fig. 2) do not exist in our solar system, and the standard planet-formation models predict a desert at this mass range, but planets of this size are common in other planetary systems.

This result implies that the formation of gas giants may involve more-complicated processes than those assumed by the standard core-accretion theory. Alternatively, the planet-formation process may vary significantly as a function of the mass of the host star, because population-synthesis models were calibrated for planets forming around solar-type stars while microlensing observations are biased toward systems around lower-mass stars. The resolution of this discrepancy may have important implications for the study of planetary habitability because the runaway gas-accretion process may be responsible for the delivery of water to the inner solar system.

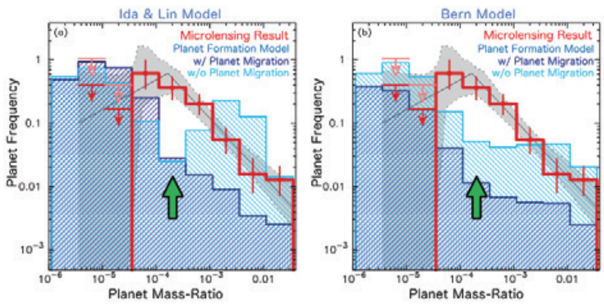


Fig. 1 Planet mass-ratio distribution from microlensing observations (red) and planet population-synthesis models (blue). Dark and pale blue show models with and without the effect of planets' orbital migration. Left is the Ida & Lin model and right is the Bern model. (Suzuki *et al.* 2018)

Fig. 2 Comparison of Saturn and Neptune to an artist' s conception of planet OGLE-2012-BLG-0950Lb, which is included in the sample of microlensing observations. The mass ratio and mass of this planet is 2×10-4 and 39 Earth masses.

- D. Suzuki *et al.*:2018, Microlensing Results Challenges the Core Accretion Runaway Growth Scenario for Gas Giants, *Astrophysical Journal Letters*, 869(2), L34.
doi: 10.3847/2041-8213/aaf577
- ISAS webpage Topics on January 9, 2019

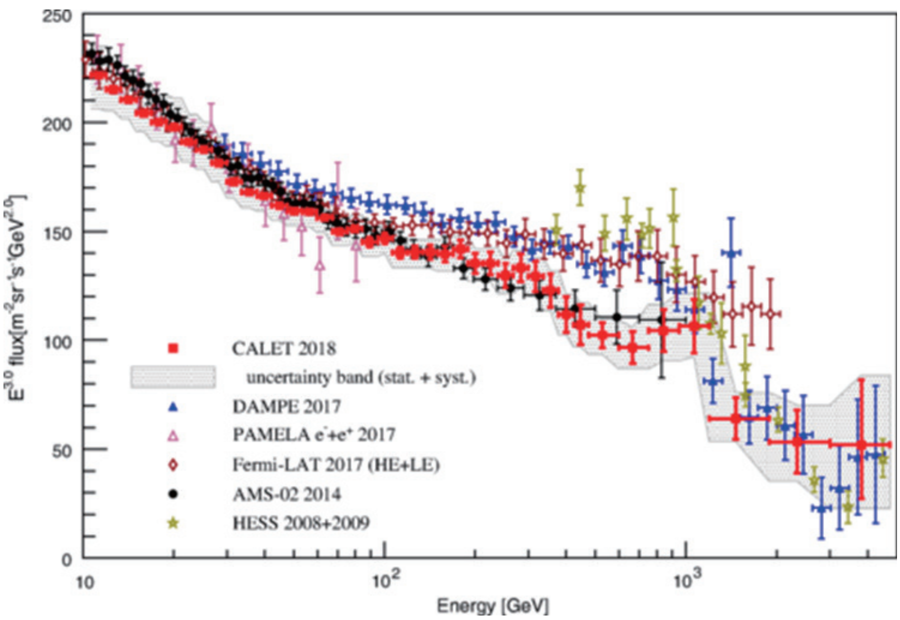
Extended Measurement of High-Energy Cosmic-ray Electrons and Positrons on the ISS

【CALorimetric Electron Telescope (CALET) aboard the ISS Kibo】

The CALorimetric Electron Telescope (CALET) is an international project aimed at revealing the acceleration and propagation mechanisms of cosmic rays, identifying nearby cosmic-ray accelerators, and detecting dark matter through observations of high-energy cosmic rays. The CALET started operating in October 2015; since then, it has been performing continuous and precise observations from the Japanese experiment module Kibo, which forms part of the International Space Station (ISS).

In FY2017, the CALET produced its first data from the analysis of the cosmic-ray electron and positron (all-electron) spectrum. In FY2018, by doubling the data statistics, the precision of the CALET measurements on the all-electron spectrum was improved and the correspondent energy range was extended up to 4.8 TeV (the highest energy ever measured through direct and precise measurements in space). The spectrum obtained through the latest measurements did not show any significant feature around 1.4 TeV, which appeared in the data collected by the Dark Matter Particle Explorer (DAMPE). In the future, it is planned to collect more data through the CALET, obtaining a wealth of high-quality science outputs.

The CALET has been searching for the gamma-ray counterparts of five gravitational-wave events that were identified by the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo scientific collaborations. The derived upper limit of gamma-ray emissions indicates a high probability of detecting high-energy gamma-ray emissions in future observations of gravitational wave events within CALET's field-of-view.



The cosmic-ray electron and positron energy spectrum data obtained from the CALET (between 11 GeV and 4.8 TeV) are shown as red points. The combined statistics and the systematic uncertainties of the CALET data are indicated by a gray band. The data obtained from other recent experiments are superimposed. *Physical Review Letters*, Vol. 120, 261102 (2018).

- O. Adriani *et al.* :2018, Extended Measurement of Cosmic-ray Electron and Positron Spectrum from 11 GeV to 4.8 TeV with the Calorimetric Electron Telescope on the International Space Station. *Physical Review Letters*, 120, 261102. doi: 10.1103/PhysRevLett.120.261102
- O. Adriani et al.:2018, Search for GeV Gamma-Ray Counterparts of Gravitational Wave Events by CALET. *Astrophysical Journal*, 863(2), 160. doi: 10.3847/1538-4357/aad18f

Nucleation Process of Cosmic Dust Revealed by Microgravity Experiments

【Sounding Rocket】

Measured spectra of nucleated Al_2O_3 taken with a specially designed infrared spectrometer in the microgravity environment of a sounding rocket show a sharp feature in the 13-μm band. This feature's width is comparable to that observed near oxygen-rich AGB stars. Our finding that α-Al_2O_3 nucleates under certain conditions will help researchers to elaborate upon models of dust condensation around oxygen-rich evolved stars.

Data about the composition, size, and mass of cosmic dust is needed to clarify both the physical and chemical processes involved in the formation and evolution of stellar and planetary systems. An interdisciplinary research team from the Institute of Low Temperature Science, Hokkaido University, ISAS/JAXA, Division of Theoretical Astronomy, and the National Astronomical Observatory of Japan (NAOJ) has formed the DUST Project to develop plans for rocket-based microgravity experiments that will elucidate the nucleation mechanism and infrared spectral characteristics of cosmic dust particles. We are particularly interested in iron dust, oxide dusts such as silicates and alumina, and carbon dust in the form of graphite and silicon carbide.

Alumina (Al_2O_3) is believed to be the first major condensate to form in the gas outflow from oxygen-rich evolved stars because of its refractory properties. Corundum (α-Al_2O_3), the most stable polymorph of this molecule, may explain the 13-μm feature that appears close to stars. However, no one has directly reproduced the 13-μm feature experimentally, and it remains as a noteworthy unidentified infrared band.

The DUST Project included an ideal nucleation experiment of Al_2O_3 dust in a microgravitational environment aboard the S-520-30 sounding rocket (Fig. 1). This experiment successfully reproduced a 13-μm band with the very narrow width of 0.5–0.6 μm (Fig. 2). The temperature, partial pressure, and IR spectra of evaporated Al_2O_3 during nucleation were measured simultaneously with an in-situ observation system onboard the rocket. We also calculated the 13-μm feature assuming the properties, temperature, surface contamination, anisotropy, and coagulation of α-Al_2O_3 using Mie theory and the discrete-dipole approximation. The experimental data will aid in the identification of unidentified stellar IR bands.

Fig. 1 Noncontact real-time measurements of the nucleation process

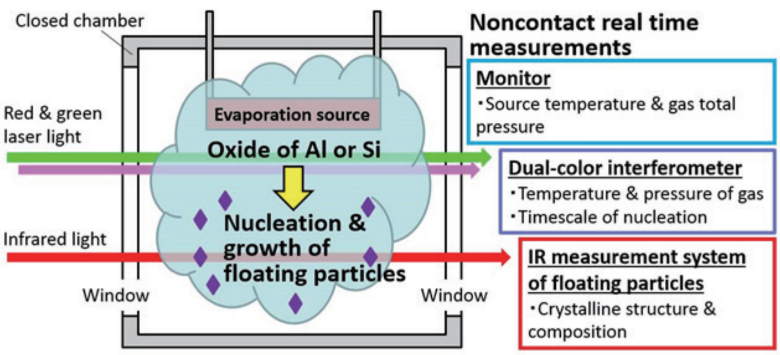
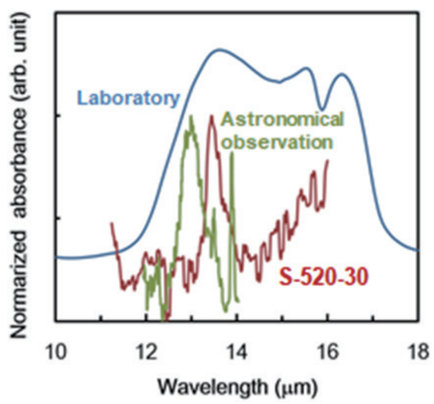


Fig. 2 Comparison of IR spectra.



Result of S-520-30 experiment: In comparison with the spectra obtained in laboratory measurements (blue), from observations of AGB stars (green) and from the rocket-borne experiment (red), the red curve shows a sharp feature the 13 μm band and it is comparable in width to the same feature of the green line. The difference in the peak position in the red line from that of the green line is possibly a combination of the effects of the shape of the particle and the surface conditions and differences in temperature and/or anisotropy of the α-Al_2O_3 nanoparticles.

- S. Ishizuka, Y. Kimura, I. Sakon, H. Kimura, T. Yamazaki, S. Takeuchi, and Y. Inatomi: 2018, Sounding-rocket microgravity experiments on alumina dust. *Nature Communications*, 9, 3820. doi: 10.1038/s41467-018-06359-y

Total Hemispherical Emissivity and Constant Pressure Heat Capacity of Molten Titanium Measured by an Electrostatic Levitator

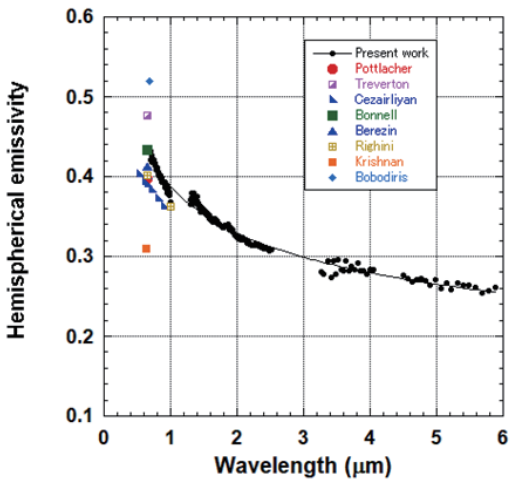
Owing to their lightweight strength and ability to withstand extreme temperatures, titanium and its alloys are important in the manufacturing of aircraft and aerospace structures. They have also been utilized in ship propeller shafts, riggings, and electrodes, and have potential use in desalination plants because of their excellent corrosion resistance to seawater. To optimize the material processing of titanium-based alloys such as casting and welding, computer simulations are employed. To improve the accuracy of the simulations, precise thermophysical properties of molten titanium and its alloys are necessary. However, owing to its high melting temperature and the risk of chemical reactions between samples and containers, property measurements of titanium melts are very difficult with conventional equipment such as crucibles. Containerless techniques including levitation have been applied to overcome the problems associated with crucibles, and have enabled the thermophysical property measurements of molten refractory materials, including titanium.

Among the various thermophysical properties, the constant pressure heat capacity (C_p) is one of the most significant properties for numerical simulations on heat transfer. Moreover, C_p is needed to calculate thermodynamic state functions such as enthalpy, entropy, and the Gibbs free energy.

In our developed technique, spectrometers were combined with an electrostatic levitator to measure the radiation intensity of a levitated molten sample over a wide wavelength range, from which the spectral hemispherical emissivity ($\varepsilon(\lambda)$) of the sample was obtained (shown in figure). Subsequently, ε_T was obtained by integrating $\varepsilon(\lambda)$. C_p was then calculated using ε_T and the time-temperature data collected during radiative cooling of the sample.

The ε_T of titanium at its melting temperature was found to be 0.33. Moreover, the C_p of liquid titanium was calculated to be 44.9 $J{\cdot}mol^{-1}{\cdot}K^{-1}$ at 1943 K.

The C_p of molten Ti was recommended to be 33.47 $J{\cdot}mol^{-1}{\cdot}K^{-1}$ (8.0 $cal{\cdot}mol^{-1}{\cdot}K^{-1}$) in most data books that compiled high-temperature thermal data in the 1960s. Even though a value of 45.5 $J{\cdot}mol^{-1}{\cdot}K^{-1}$ was reported in 1971, the recommended value remained approximately 35 $J{\cdot}mol^{-1}{\cdot}K^{-1}$. The recommended value in the compilation data book was changed to approximately 45 to 47 $J{\cdot}mol^{-1}{\cdot}K^{-1}$ in the 1980s. However, there are some reports which support the lower value, while our results support the higher one.



Spectral hemispherical emissivity of molten titanium at its melting temperature

- T. Ishikawa, C. Koyama, Y. Nakata, Y. Watanabe, and P.-F. Paradis: 2019, Spectral emissivity and constant pressure heat capacity of liquid titanium measured by an electrostatic levitator. *Journal of Chemical Thermodynamics*, 131, 557-562 doi: 10.1016/j.jct.2018.12.002

A Novel Tandem Methanation Reactor Combined with a Water Electrolyzer

-For the development of an energy carrier based on renewable energy-

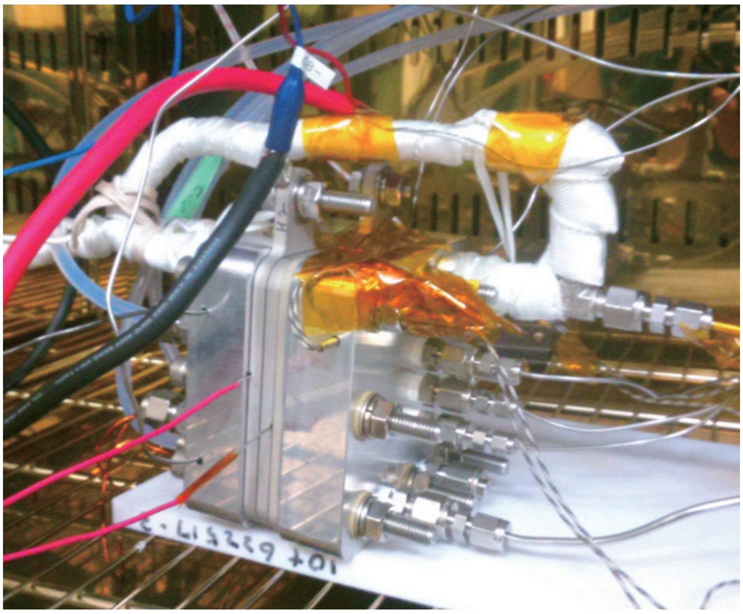
Japan Aerospace Exploration Agency (JAXA) has developed a novel tandem methanation reactor combined with a water electrolyzer as a spin-off technology from the life support system used in a closed environment, such as a space station.

JAXA has been developing an oxygen generator based on the water electrolysis reaction, and a CO_2 reduction device to produce water based on the Sabatier reaction. As an application of these techniques to ground usage, we collaborated with the JST CREST project to develop an energy carrier based on renewable energy. Hydrogen, which is generated by the water electrolysis reaction, can react with CO_2 to produce water and methane via a process well known as the Sabatier reaction. By the combination of these two reactions, we attempted to create a device that generates methane as an energy carrier.

First, we calculated the optimum conditions to combine the water electrolysis and Sabatier reactions, and found that a temperature of 200 °C in the latter reaction is ideal for utilizing the total exergy. However, the Sabatier reaction is typically initiated at higher temperatures of above 300 °C. We developed a Ru-type nanocatalyst supported onto TiO_2 so that the reaction could be triggered above 200 °C[1)].

Furthermore, we focused on the exothermic thermodynamics of the Sabatier reaction and attempted to introduce the exotherm to the water electrolyzer. The theoretical minimum voltage for water electrolysis is 1.23 V, but the actual reaction always starts above 1.48 V, which is the thermo-neutral voltage including the entropy change. This entropy change can be compensated by the introduction of heat energy from the Sabatier reaction, and then, hydrogen can be produced with minimum energy and further used for the reduction of CO_2. Thus, we also developed a specially designed water electrolyzer that facilitates the endothermic water electrolysis reaction.

By combining the water electrolyzer with the Sabatier reactor, we eventually developed a tandem device that can produce methane via the introduction of water and CO_2 with renewable energy.



Tandem reactor to generate methane from water and CO_2.

- 1) OS. Mendoza-Hernandez, A. Shima, H. Matsumoto, M. Inoue, T. Abe, Y. Matsuzaki, and Y. Sone: 2019, Exergy valorization of a water electrolyzer and CO_2 hydrogenation tandem system for hydrogen and methane production. *Scientific Reports*, 9, 6470. doi: 10.1038/s41598-019-42814-6

Ground Firing Tests for Reusable Rocket Flight Demonstration by RV-X

【Reusable Vehicle Experiment】

To make space more accessible for scientific research and increase opportunities for rocket launches, we proposed a fully reusable sounding rocket. The reusable sounding rocket differs from currently used expendable rockets. Some key technologies have sufficiently matured such that the reusable sounding rocket project advanced to Phase A from 2010 to 2016. After these technical demonstrations, system-level verifications by a small flight demonstrator Reusable Vehicle Experiment (RV-X) has been conducted since FY2016. The objectives of RV-X are (1) system architecture study for repeated flight operation, including quick-turnaround operation and fault tolerant design; (2) life-cycle management and frequent, repeated use of a cryogenic propulsion system and its flight demonstration; (3) development of an advanced return flight method and vertical landing and flight demonstrations; and (4) demonstration of advanced technology for future reusable launch vehicles, such as increased onboard use of composites, in-flight fuel management, gaseous hydrogen/oxygen auxiliary propulsion, system health management, and a high-performance engine with a long service life. Two flight campaigns are planned in this flight demonstration study. In the first flight test campaign, we will demonstrate a pump-fed and deep-throttling engine, gimbaling attitude control for vertical landing by lift-off and landing with powered flight, quick turnaround operation, and so on.

The RV-X was designed and developed by harnessing the technical outcomes obtained from ISAS RLV-related studies. Before the flight demonstration, we planned two series of ground firing tests of RV-X. The first series of tests was conducted in 2018 at the Noshiro Testing Centre. The objectives are (1) to understand characteristics of the reusable engine onboard the RV-X such as throttling capability, responsiveness, etc.; (2) to obtain data on environmental conditions surrounding RV-X such as temperature, acoustic vibration from engine plum; and (3) to establish a procedure for the repeated operation of RV-X to realize quick turnaround flight operation. Six consecutive stage firing tests have been conducted, and we successively obtained the following results. (1) The engine was stable under various throttling levels, and 149 cumulative firing tests were conducted (past component test included). The engine test achieved consecutive throttling levels ranging from 40% to 100% by staging configuration. (2) We achieved quick turnaround with the least number of personnel using quick and efficient operation methodology. (3) We obtained engine and propulsion system characteristics, vehicle vibration environment, and vehicle maintenance record. (4) Technical issues specific to reusable vehicles were determined. Information/Data on the new technology was collected, which will be essential to realize the future space vehicles, e.g., health management data.

Flight demonstrator
Reusable Vehicle Experiment
(RV-X)

Ground firing test at Noshiro Testing Center

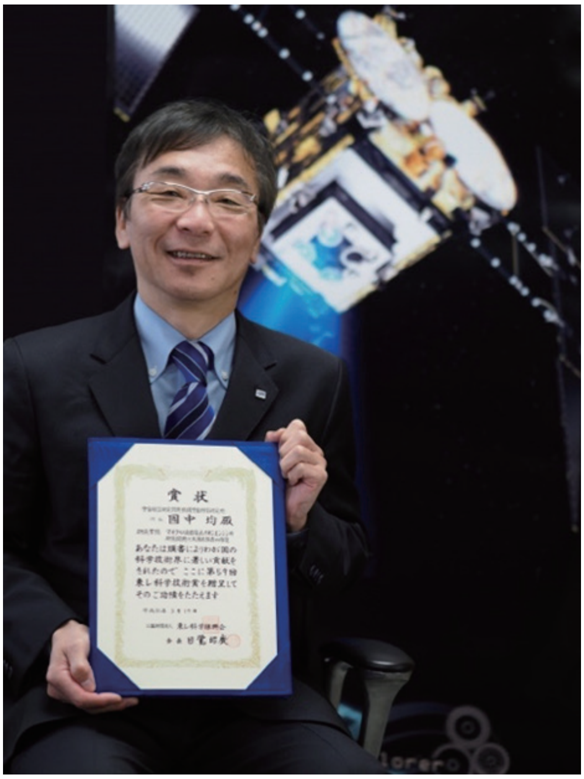
- S. Nonaka: The 59th Conference on Aerospace Propulsion and Power. Gifu, Japan. March 6, 2019.

R&D on Future Electric Propulsion

Electric propulsion is the key technology for interplanetary missions at ISAS. The strong heritage of the microwave ion engine onboard HAYABUSA (2003-2010) was succeeded by Hayabusa2, on which four microwave ion engines paved the way to successful proximity observations and touchdowns on the asteroid RYUGU. Operation of the ion engine during the outbound trip to RYUGU lasted more than 18,000 hours, which proves the uniqueness and reliability of the space propulsion system. Owing to his outstanding contributions to R&D of microwave ion engines and successful promotion of solar system exploration, director general Hitoshi Kuninaka received the Toray science and technology award in 2018.

In 2018, with strong support from Japanese academic communities and JAXA, the lineup of electric propulsion technology was aggressively extended, targeting highly demanding future space science and exploration missions as well as various Earth orbiting missions. Major achievements in three categories are listed below:

- Thrust enhancement of the 10 mN class microwave engine for future small deep space probes: For the 500 kg class deep space probe DESTINY+, challenging asteroid fly-by missions by Epsilon launch vehicle are under development, and the new design resulted in a 50% increase in its thrust level compared with the original engine.
- Micro (0.1 mN class) ion engine development with a wide throttling rage: Targeted at formation flying observation missions in the fields of far-infrared and gravitational-wave physics, wide throttling ranges from 0.1 micro-N to 100 micro-N was established using a newly-arranged duty control method.
- Continuous operation of 300–400 mN class Hall thruster for ETS-9: After its 6 kW and continuous operation for 4,048 hours, the thruster showed 386 mN and approximately 60% efficiency. This experiment demonstrated the low degradation feature of new thruster and its potential application in an interplanetary mission that requires longer operational hours.



Director general of ISAS, Hitoshi Kuninaka received Toray Award.

a) b) c)

New electric propulsion for future missions: a) microwave ion engine for DESTINY+, b) super-small ion engine for formation flying space observations, and c) Hall thruster for large-scale orbital transformations.

Ultra-Light Power Generation System Performance Review

The Solar Power Sail (SPS) is the core innovative component of the proposed Solar Power Sail-Craft. A breadboard was built for the electrical components of the SPS, in order to assess its properties. The results indicate that, adopting this approach, it would be possible to build the world's lightest solar array (kW/kg class).

- While solidifying our experience on the mechanical aspects of the SPS, we have breadboarded its electrical components (Fig. 1).
- The breadboard consists of a 14-m long single petal (one of four), whose size is equal to that flown on the IKAROS Solar Power Sail. Half of the surface area of each breadboard is filled with thin-film solar cells, reflectivity control devices, and the electrical harness connecting these components. (Currently, IKAROS has only 5% of its surface area covered with solar cells).
- The IV characteristics of the assembled array were assessed, finding that they match the expected performance. The results of the assessment suggest that it possible to achieve a kW/kg class (Fig. 2): a two orders of magnitude improvement over conventional solar panels.
- The activity of the reflectivity control devices was verified, turning them on and off.
- The experiment described in the previous points, combined with our past experience in assembling a mechanical breadboard model for a 50-m petal, have built the experience and know-how necessary for the assembly a new 40-m petal proposed for OKEANOS.

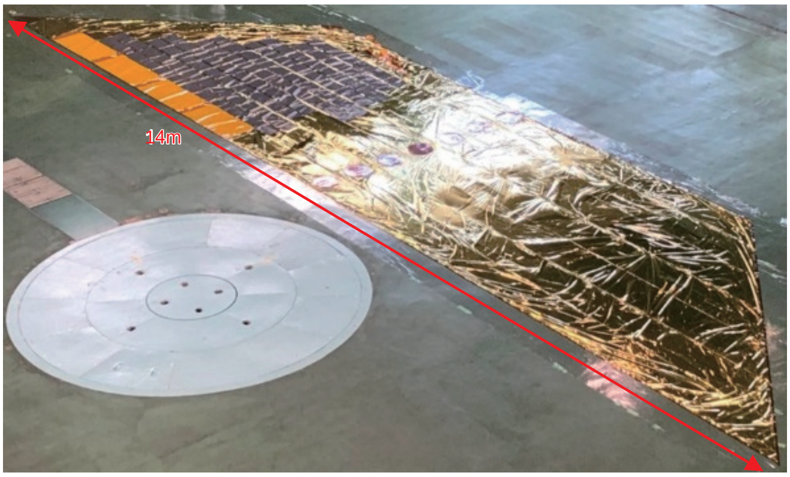


Fig. 1 Breadboard for the electric components of the SPS

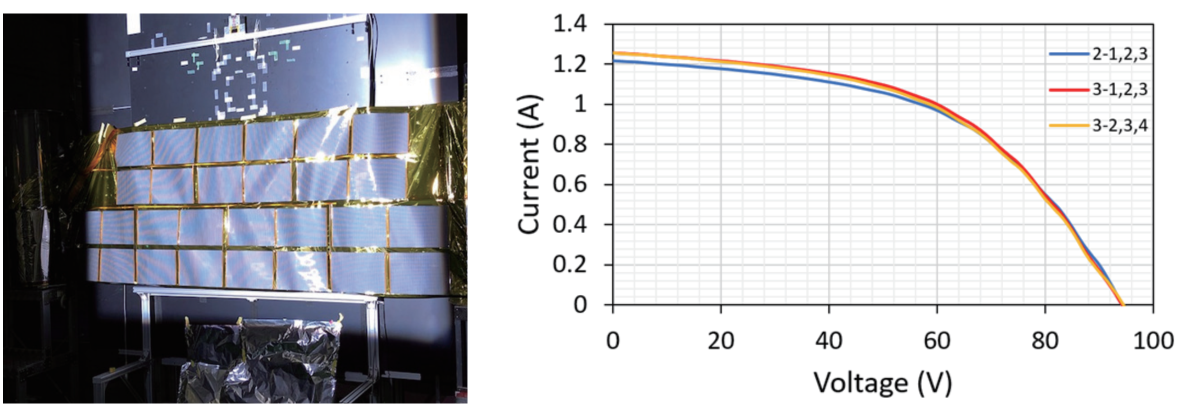


Fig. 2 IV characteristics of the assembled array

- M. Matsushita *et al.* *62nd Space Science and Technology Conference*. Kurume, Japan. October 2018.

Establishment of Planetary Protection Organization and Approval of Unrestricted Earth Return for Martian Moons Exploration (MMX)

Planetary protection is the conservation of target celestial bodies and protection of the terrestrial biosphere from potential extraterrestrial biohazards. In past JAXA missions, each project has handled their own planetary protection protocols. However, JAXA has decided to systematically develop agency-wide planetary protection protocols in consideration of an increase in space-exploration missions and in response to recently implemented space activity laws. A planetary protection organization was established in the Safety and Mission Assurance Department in December 2018, and related regulations were written. ISAS played a major role in coordinating experts from universities and research institutes all over Japan for this project. The establishment of the planetary protection organization is expected to have a great influence on JAXA's future exploration missions, its participation in international exploration missions, and on commercial missions such as UAE's Mars Orbiter. The organization will also strengthen the influence of JAXA's policies on international agreements about a new planetary protection policy at COSPAR.

As the organization's first achievement, a research team consisting of experts from ISAS, the Chiba Institute of Technology, and the Tokyo Institute of Technology successfully closed an international agreement on a new planetary protection policy that allows Unrestricted Earth Return for the Martian Moons Exploration (MMX) mission. In 2017, Martian moons were found to have a potential risk of microbial contamination, since Martian rocklets containing potential indigenous microorganisms could have been produced by gigantic meteoroid impacts and transported to Martian moons. If this were the case, sample return from Martian moons would not be allowed without complete sterilization of the samples and the spacecraft, or without complete confinement of the contaminated materials. In order to solve this problem, as shown in Fig. 1, the research team conducted a comprehensive statistical analysis of potential mass transportation from Mars to Martian moons and the likely sterilization of that material by hypervelocity impacts and cosmic radiation on Martian moons. This analysis yielded novel proof that the probability of microbial contamination of samples taken from the surface of Martian moons is sufficiently smaller than the upper limit of 10^{-6}, as shown in Fig. 2, which is recommended by COSPAR as a global standard. Based on this result, Martian Moons Exploration (MMX) was able to reach an international agreement for Unrestricted Earth Return, in which no sterilization nor confinement of the samples and spacecraft will be required before returning to Earth. This is a great advancement towards the realization of the Martian Moons Exploration (MMX).

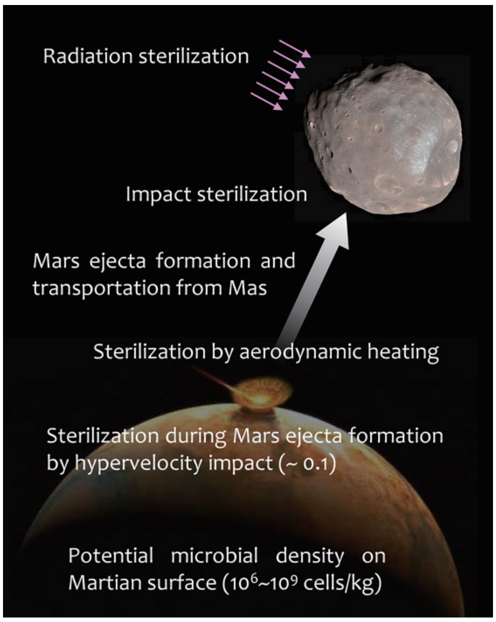


Fig. 1 Potential microbial contamination and sterilization processes.

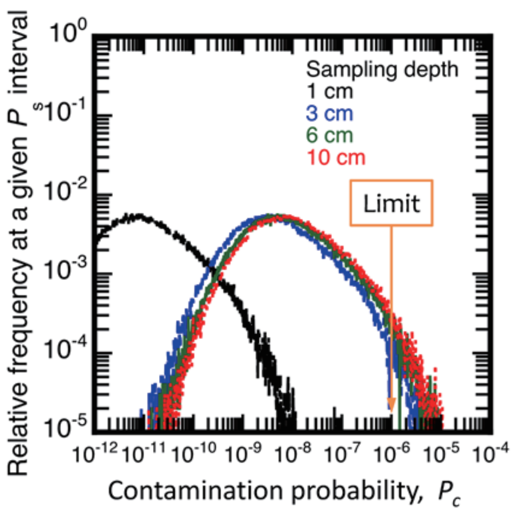


Fig. 2 Probability density distributions of microbial contamination probability for 30-g cores taken from the surface of Phobos.

Successful Launch of BepiColombo
Blast-off for "MIO" on mission to Mercury

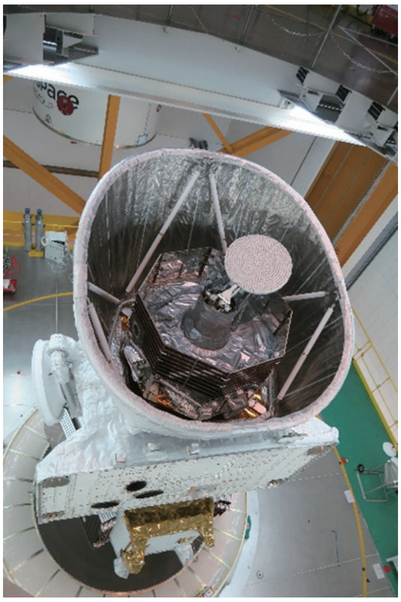
The BepiColombo mission to Mercury was successfully launched on an Ariane 5 rocket from Europe’s Spaceport in Kourou, French Guiana (Centre Spatial Guyanais - CSG) at 01:45:28 GMT on 20 October, 2018.

BepiColombo is a joint mission between the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA), executed under ESA leadership. The mission includes two spacecraft, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO, or "MIO"). The ESA-built Mercury Transfer Module (MTM) will carry the orbiters to Mercury using a combination of solar-electric propulsion and gravity-assist flybys – one around Earth, two around Venus, and six around Mercury. The MPO and "MIO" craft will be inserted into Mercury orbit in late 2025. "MIO" and ESA’s modules were transported from the European Space Technology and Research Centre (ESTEC) to CSG in April and May. Final assembly, integration, and testing were performed at CSG, and then the modules were packed together into the Mercury Composite Spacecraft (MCS).

After the launch and early orbit phase (LEOP) was completed on 22 October, an extensive series of in-orbit commissioning activities began. During this near-Earth commissioning phase (NECP), which was successfully concluded on 16 December, the European and Japanese mission teams ran tests to ensure the health of BepiColombo's science instruments and spacecraft systems. On 26 March 2019, the mission teams confirmed that the spacecraft meets the mission requirements.

After 7.2 years cruising toward the planet, MTM will be jettisoned a few months before arriving at Mercury, leaving the two science orbiters – still connected to each other – to be captured by Mercury's gravity. Their altitude will be adjusted using MPO's thrusters until MIO's desired elliptical polar orbit is reached. Then MPO will separate and descend into its own orbit using thrusters.

The orbiters will take measurements that should reveal the internal structure of the planet, the nature of the surface and the evolution of geological features on it, and the interaction between the planet and solar wind. BepiColombo will build on the discoveries of NASA's Messenger mission to provide humanity’s best understanding of Mercury and the Solar System evolution to date, which in turn will be essential for understanding how planets orbiting close to their stars in exoplanet systems form and evolve. The international BepiColombo Science Working Team has discussed the plans for observations and science while orbiting Mercury, as well as plans for observations during the Venus flyby.



Last-minute photograph of "MIO" before fairing closure.

BepiColombo liftoff.

II
Status Report

1. Space Science Roadmap

a. Goals and Basic Frameworks

The goals of space science are to expand our knowledge of human life in regard to origins of the Earth and the solar system, origins of cosmic space, time and matter, the possibility of extra-terrestrial life, and at the same time to lead technology revolutions which will cause a paradigm shift in space engineering. Space projects are a primary means to enable space science to achieve these goals.

Space science projects are presently categorized into three classes: strategic Large missions (L class), competitively-chosen Medium-size focused missions (M class) and Strategic participation to foreign-agency flagship missions (S class). In addition, we also have small missions conducted with universities or other organizations using matching-funds and project-like schemes.

b. Strategic Large Missions under development

MMX (Mars's Moon eXploration) is a Martian moon sample return mission. The mission is now a pre-project of JAXA and in Phase A (concept-development and project- formulation phase). This year the MMX pre-project team completed the concept development with the system requirement review and conducted a selection process to determine which company will be responsible for the spacecraft system. The XARM (X-ray Astronomy Recovery Mission), which was also a pre-project in April 2018, completed the system definition review, entered the project phase, and changed its name to XRISM (X-Ray Imaging and Spectroscopy Mission). On March 2019, the XRISM project team completed Phase B (preliminary design phase) and entered Phase C (final design phase).

Two mission candidates, LiteBIRD (Cosmic Microwave Background B-mode observation) and Solar Power Sail (Jupiter and Trojan asteroids explorer) are in Pre-Phase A2 (mission definition phase). These missions have been under review since November 2018 to confirm the completion of their Pre-phase A2. Although these reviews could not be completed in this fiscal year, they are expected to be completed early next fiscal year. Following this, one of the two missions will be selected for the pre-project phase. SPICA (Infrared Astronomy Mission) is a mission candidate led by the European Space Agency (ESA) and Japan will participate as L class. This mission is also in pre-phase A2 in JAXA. In May 2018, the mission concept was selected as one of the three missions in the first selection round of the ESA M5. Since then, an ESA-JAXA coordinated concept study has been conducted.

c. Competitively-chosen Medium-size Focused Missions under development

Smart Lander for Investigating Moon (SLIM), M-class mission 1, was in Phase B and its preliminary design review was completed in March 2019, after which it entered Phase C. DESTINY^{+}, an M-class mission 2 candidate, is a flyby mission to the meteor-shower parent body, Phaethon. It will also characterize planetary dust on the way to the asteroid. This mission is currently in transition from Pre-Phase A2 to Phase A.

Small JASMINE, one of the candidates for M-class mission 3, is an infrared astrometry mission dedicated to the astrometry of stars in the Galactic bulge. It moved from Pre-Phase A1 (concept investigation phase) to Pre-Phase A2 in August 2018. The research team is contemplating adding the photometric observation of exoplanets as the second mission objective.

ISAS issued last year an announcement of opportunity (AO) for mission candidates for M-class missions 3 or 4. In June 2019, in response to the AO, the Advisory Committees for Space Science and Space Engineering recommended that the Solar-C EUVST (Extreme UV Solar Telescope mission) and HiZ-GUNDAM (High redshift Gamma-ray Burst Monitor mission) concepts be progressed. As a result, both concepts have started a concept study to move from Pre-phase A1 to Pre-phase A2.

d. Strategic participation to foreign-agency flagship missions under development

Japan's contribution to the ESA's Cosmic-Vision L1 mission, JUICE (JUpiter ICy moons Explorer) was in transition from Phases B to C depending on the subsystems of contribution. The team conducted developments of the mission instruments in collaboration with the PI institutes. CAESAR (Comet Astrobiology Exploration Sample Return) is a candidate for NASA's flagship mission, New Frontier 4, As part of Japan's contribution to the mission, JAXA conducted a concept study (Pre-Phase A2), provided a return capsule, and completed the study in March 2019 before moving onto the pre-project phase (Phase A).

e. Missions close to deployment and in operation

GREAT (GRound station for deep space Exploration And Telecommunication) is a ground facility. However, its development is pursued as a space science project. It is in Phase C to D and the construction of the 54-m antenna started in mid-2017.

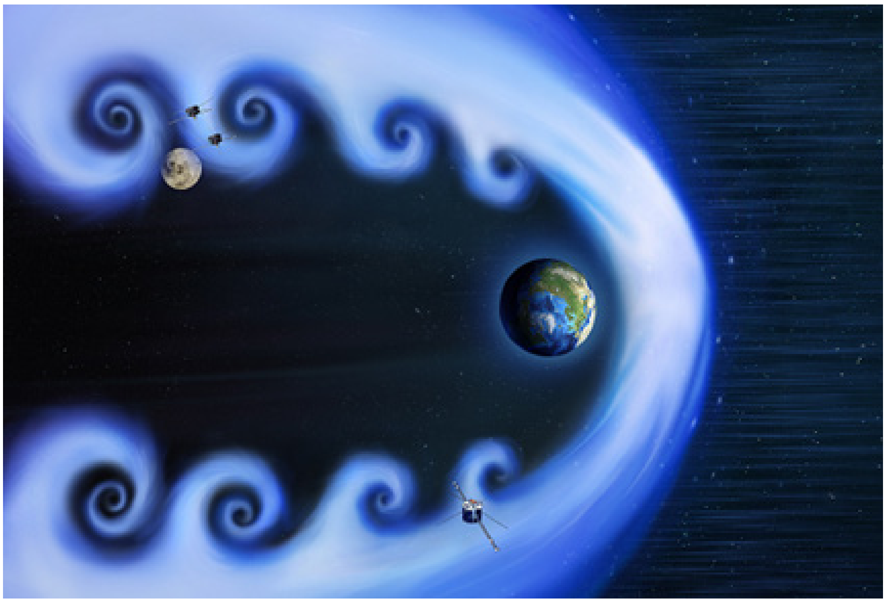
MMO (Mercury Magnetospheric Orbiter) was shipped to ESTEC and integration and tests of the BepiColombo system were carried out. Hayabusa2 performed its approach operation to the asteroid, Ryugu, successfully. The five spacecraft in orbit, the Geo-space explorer, ARASE, the planetary spectroscopy mission, HISAKI, the Venus climate explorer, AKATSUKI, the solar observatory, HINODE, and Geo-magnetosphere explorer, GEOTAIL all conducted their observations safely and successfully.

f. Small missions conducted with matching funds with external organizations

ISAS selected five small missions to start this fiscal year, (1) DUST Nucleation (sounding rocket experiments), (2) GAPS (General Anti-Particle Spectrometer, balloon experiment), (3) Small Solar program CLASP2 (sounding rocket experiment) and SUNRISE-3 (balloon experiment), (4) OHMAN-JP (MAXI-NICER joint project), and (5) FERMI support. OHMAN-JP completed its development to communicate with NICER on board the ISS, and we are currently waiting for preparations from NICER. All four other missions will continue into the next fiscal year.

2. Space Science Programs

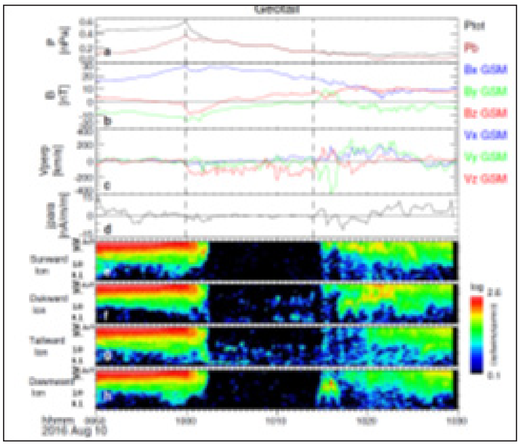
a. Earth Magnetosphere Observation with GEOTAIL



(C) Quanqi Shi (Shandong University)

Kelvin-Helmholtz vortices simultaneously observed by GEOTAIL on the dawn side of Earth's magnetosphere and by NASA's ARTEMIS spacecraft near moon on the dusk side [1].

Since the launch of the joint U.S.-Japan satellite GEOTAIL in 1992, it has been operating continuously for more than two solar cycles. The major purpose of GEOTAIL is to make direct observations of plasma in the Earth's magnetotail. Except for the failure of one of the two data recorders at the end of December 2012, other spacecraft systems and instruments are in good condition. The effect of the data recorder failure was minimal, with a data loss of about 10–15%, thanks to the support from NASA's Deep Space Network (DSN). One to two years after data acquisition, the data are calibrated, archived, and made available to researchers all over the world.



GEOTAIL and MMS simultaneous observations of the magnetotail in both the northern and southern hemispheres on 10 August 2016 have revealed that magnetic field-aligned currents associated with magnetotail reconnection had similar structures in both hemispheres [2]. The figure shows the field-aligned current in the northern magnetotail seen by GEOTAIL.

NASA's formation-flying four Magnetospheric Multiscale (MMS) spacecraft successfully launched on March 12, 2015. Japanese researchers from the GEOTAIL project have been deeply involved in the MMS project by designing, fabricating, and performing initial tests of 16 fast plasma investigation–dual ion spectrometer sensors in Japan. All 16 sensors have been fully operational since September 2015. The GEOTAIL operation time in Japan has been increased for collaboration with MMS since July 2015. GEOTAIL has been providing opportunities to make simultaneous multiscale plasma measurements with MMS and coordinated observations with ARASE and THEMIS/ARTEMIS in space.

As a result of cooperative observations with the MMS satellites, it was shown that magnetic field-aligned currents generated in association with magnetotail reconnection during a magnetospheric substorm had similar structures in both the northern and southern hemispheres [2]. The result is important for understanding how the large-scale electric current system associated with aurora explosion is formed. Simultaneous observations of both the dawn- and dusk-flank magnetopause by GEOTAIL and ARTEMIS revealed that magnetopause Kelvin-Helmholtz vortices can have dawn-dusk asymmetric structure, a clue to elucidate how solar wind mass and energy enters the magnetosphere.

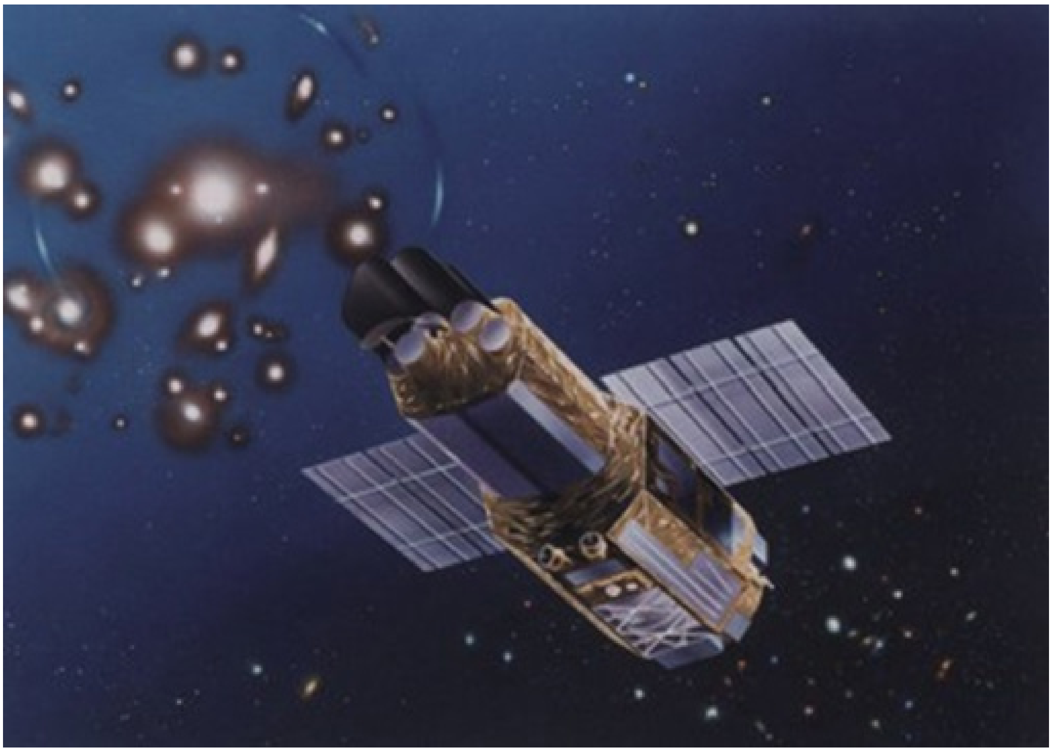
([1] Journal of Geophysical Research Space Physics, May 2018, and [2] Journal of Geophysical Research Space Physics, February 2018).

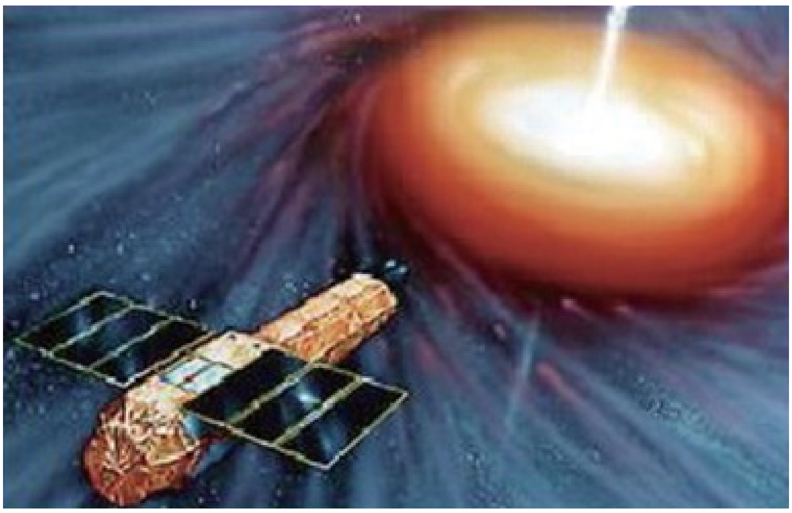
b. X-ray Astronomy with SUZAKU

SUZAKU (formerly called ASTRO-E II) is the fifth Japanese X-ray astronomy satellite, developed under Japan-USA international collaboration and launched on July 10, 2005, from JAXA's Uchinoura Space Center. SUZAKU is a red bird in Asian mythology, one of the four guardian animals protecting the southern skies. The SUZAKU satellite is designed to perform various kinds of observational studies of a wide variety of X-ray sources, with higher energy resolution and a higher sensitivity than ever before, over a wider energy range of soft X-rays to gamma-rays (0.4-600 keV).

Due to aging of the onboard power supply system, communication with the satellite has only been intermittent since June 2015. Recovery operations were unsuccessful, so a decision was made to end the science observations on August 26, 2015, considering the age and status of the onboard hardware associated with communications, power supply, and attitude control. Since then, the project has continued operation to shut down the onboard S-band radio transmissions. To terminate the S-band transmission from the spacecraft, normal functioning of the command decoder, the data handling unit, and the peripheral interface module of the telemetry command interface are required. Due to the aging of these instruments, however, no progress has been made since August 2015. The S-band termination operation will be continued until it is realized. The S-band termination operation is being carried out under control of the Ministry of Internal Affairs and Communications.

In FY2018, 50 peer-reviewed papers were published related to SUZAKU. The cumulative number of peer-reviewed papers is 1059.



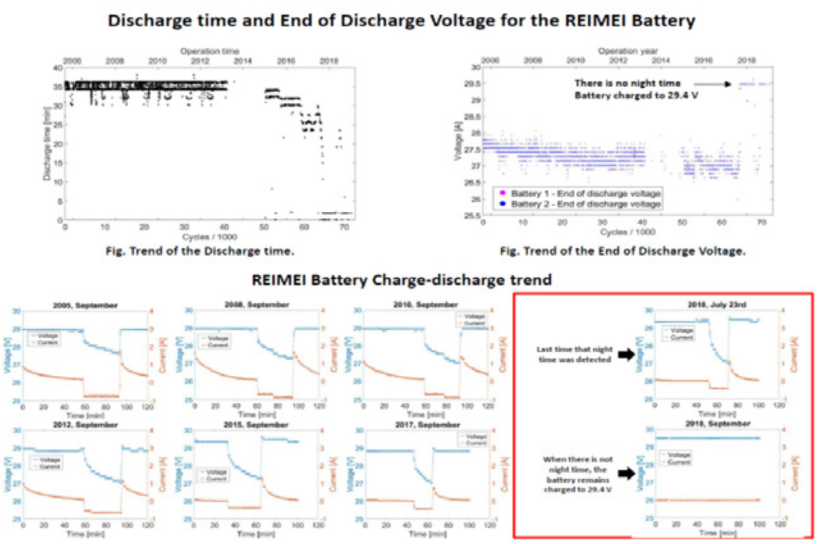


c. Small Satellite INDEX

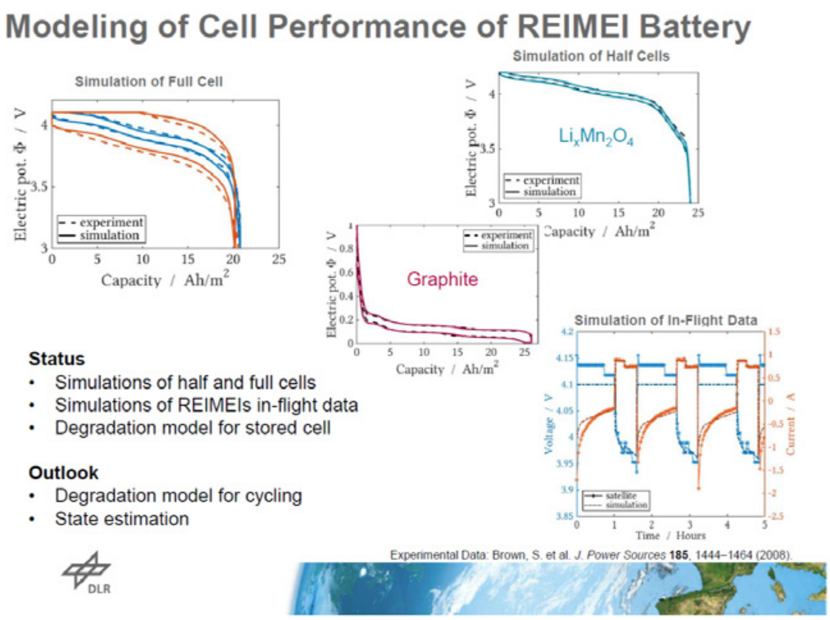
A small scientific satellite, INDEX (INnovative-technology Demonstration Experiment, code name "REIMEI") is a piggy back satellite with a mass of 72kg launched in 2005. It has remained in orbit for 13 years. The scientific purpose is observation of fine structure of aurora phenomena by means of three-spectral imagers and particle energy analyzers. The engineering purpose is to demonstrate small satellite technologies. The highlights of INDEX in FY2018 are as follows.

The method of constant-current and constant-voltage is widely used to charge onboard batteries. Constant current is provided at the initial constant-current phase of charging. After the battery voltage reaches a specific voltage, its voltage is maintained by the power supply circuit to recover voltage loss due to internal battery impedance. The current of this constant-voltage phase can be approximated as an exponential decay curve. We found with ground tests that the time constants of the exponential decay curve seem to be a decreasing function of battery capacity loss. Figure shows tapering decay of charge current during the constant- voltage control for the charge of the REIMEI onboard battery in 2005 immediately after launching, and up to 2018. The tapering or the slope of the charge current depends on the capacity and the time constant for the chemistry of the cells. By understanding the relationship among the parameters, we can calculate the residual capacity we obtained today.

Deutsches Zentrum für Luft und Raumfahrt (DLR) performs 3D electro-chemical simulations of the REIMEI battery based on its initial parameters in the development phase. They include thermochemical parameters and degradation phenomena of separator and electrolytes. We will compare the onboard charge-discharge data with the electro-chemical simulation by DLR.



Charge and Discharge performance of the REIMEI Battery obtained by JAXA.



Charge and discharge performance of the REIMEI battery cell simulated by DLR.

d. Solar Observation with HINODE

The HINODE satellite (formerly called SOLAR-B) was designed to take observations that will improve our understanding of space weather in the solar system. Specifically, we are observing the solar processes of magnetic field generation, energy transfer from the photosphere to the corona and how this transfer affects the heating and structuring of the chromosphere and the corona, and eruptive phenomena. HINODE is a follow-up to the YOHKOH satellite, operated from 1991–2001, which revealed that the high-temperature corona is highly structured and dynamic and that rapid heating and mass acceleration are common. HINODE is designed to address the fundamental question of how magnetic fields interact with the ionized atmosphere to produce dynamic behaviors. It will accurately measure the magnetic fields at the photosphere with simultaneous X-ray and extreme ultraviolet (EUV) measurements of coronal behavior.

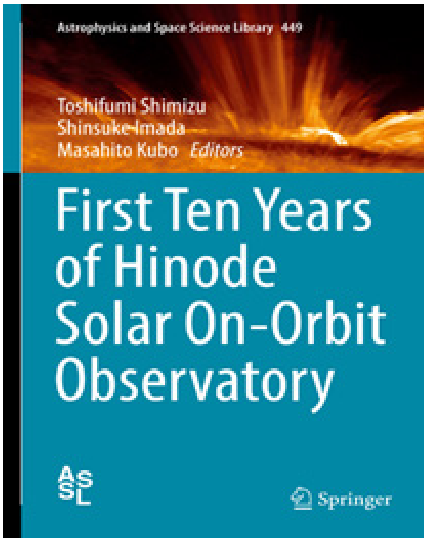
HINODE was launched in September 2006 and has been operated as an on-orbit solar observatory continuously for over 12 years. The observatory can be used by the global research community and 18 new observing proposals were delivered to the HINODE operations team in FY2018. In addition to regular closely coordinated observations with NASA's Interface Region Imaging Spectrograph (IRIS) satellite and coordinated observations with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, the HINODE team has begun coordinated observations with NASA's Parker Solar Probe every 3 months, when the explorer makes a close approach to the Sun. All data acquired by HINODE is made fully available to the international research community immediately after observations.

In FY2018, 88 articles were published in refereed journals based on HINODE observations, resulting in a cumulative total of 1,248 published papers to date (as of December 2018). This publication record makes HINODE one ISAS's most-productive missions.

A review book entitled "First Ten Years of HINODE Solar On-Orbit Observatory" was published as Astrophysics and Space Science Library no. 449 by Springer Nature Singapore. This book includes more than 20 articles and a collection of beautiful highlight photographs that review major advances in our understanding of the Sun made possible by HINODE.

So far, JAXA has confirmed the continuation of HINODE operations until March 2021. HINODE operations are supported by NASA (operation of onboard instruments and ground tracking support), ESA, the Norwegian Space Center (ground tracking support at polar regions and data center in Europe) and the U.K. Space Agency (UKSA) (operation of EUV imaging spectrometer).

The Hinode mission on orbit



The review book entitled "First Ten Years of HINODE Solar On-Orbit Observatory" published by Springer Nature Singapore, featuring advances in understanding of the Sun with ten years of observations by HINODE.

e. Venus Meteorology Observations by AKATSUKI

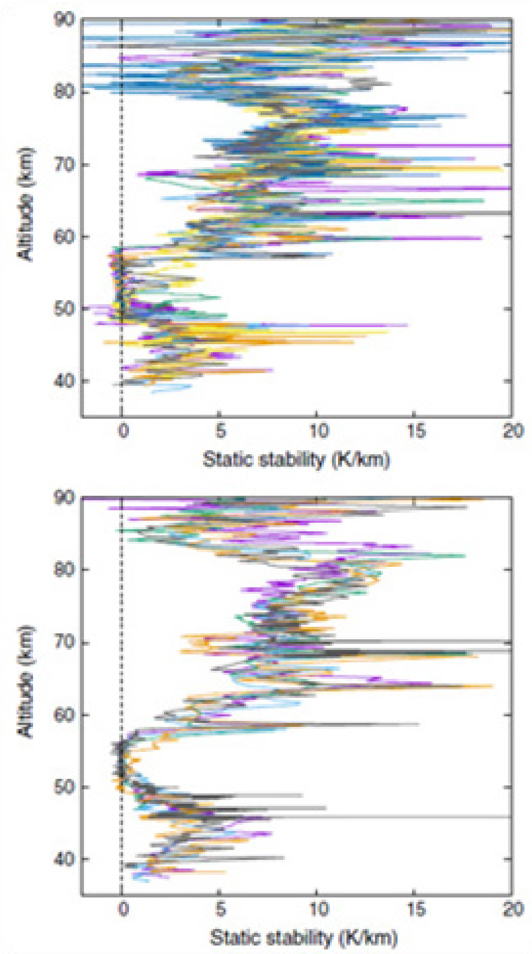
AKATSUKI, in the Venus orbit since December 2015, continued observations of the atmospheric motion of Venus. One primary objective of AKATSUKI is to understand the mechanism of super rotation, a high-speed wind blowing around Venus at 100 m/s. Unfortunately, of the five on-board cameras, IR1 and IR2 became un-operable in early December 2016. Other cameras (UVI, LIR and LAC) and the ultra-stable oscillator for radio occultation measurements have continued to operate normally. The spacecraft itself is in good health with very little signs of degradation of the system.

In the summer of 2016, observations, primarily by IR2 (Venus night-side, sensitive to 50-60 km altitudes) discovered accelerated winds (reaching over 80 m/s) near the equator in the middle-to-lower cloud layer (Horinouchi et al., 2017). Near-simultaneous day-side observations by UVI (sensitive to 65-70 km altitudes) show rather normal wind profiles. Such phenomenon, named the "equatorial jet", has never been reported before (some indication existed in previous ground-based measurements although with far larger error bars) while winds in these areas were previously believed to be somewhat uniform and stable at ~60 m/s. Similar data from March 2016 did not show such acceleration near the equator, but did show wind profiles consistent with our previous observations.

Therefore, the equatorial jet may be sporadic and confined to the middle- to-lower region of clouds.

Because the equator is farthest from the rotation axis, accelerating this region is not easy (decelerating is a natural consequence of atmospheric parcels transported from higher latitudes due to conservation of angular momentum). We do not yet have a simple mechanism to explain the equatorial jet, but are working with the modeling team to quantify its impact on super rotation.

While images are useful to visually study dynamics and morphology, inferring the sensing altitudes from images is in general difficult and often indirect. Radio Science (RS), on the other hand, provides "direct" measurements of atmospheric temperature, H_2SO_4 vapor abundance and ionospheric electron density in vertical profiles. Imamura et al. (2017) examined such profiles and have found that the layer of "low static stability" in the clouds becomes thicker in the morning and thinner in the evening. For the first time, this phenomenon is unmistakably clearly shown owing to advantages of AKATSUKI's orbit (near the equatorial plane of Venus). The RS data will be even more useful as we accumulate data and analysis (retrieval) techniques develop. This will somehow compensate for the loss of IR1 and IR2.



Vertical profiles of "static stability" of the Venus atmosphere as observed by AKATSUKI/RS. The upper panel is for the morning and the lower panel for the evening sectors. The near-zero static stability occurs around 48-58 km (thicker) in the morning while it is Approx. 52-56 km (thinner) in the evening. This demonstrates the advantage of the AKATSUKI orbit (near the equatorial plane of Venus) as well as the excellent performance of the on-board ultra-stable oscillator.

f. Solar Power Sail Demonstration with IKAROS

IKAROS, a small solar power sail demonstrator launched on May 21, 2010, achieved full success at demonstrating solar sail and solar power sail technology for the first time. Since 2012, it has alternated between hibernation and recovery, as has almost run out of fuel and cannot control its attitude. We still continue the IKAROS operation to obtain data that is valuable for the development and operation of new solar power sail spacecraft. In particular, camera images of the sail membrane and data of power generation by the thin-film solar cells will be useful for evaluating the long-term performance of solar power sail.

Achievements:

- We established a mechanical model of the solar sail, in order to analyze its orbit and attitude dynamics. In this model, the deflection and torsion of the membrane vary according to the spin rate (Fig. 1). Applying this model, we solved the sail attitude history and communication windows.
- In FY2015, we established a method to detect weak signals. In FY2016, we verified the validity of the orbit determined from the artificial range data using weak signals. In FY2017, as an extension of our activities over the last two years, we evaluated the attitude estimation using weak signals. We confirmed that the use of weak signals does not allow real-time communication; however, by integrating these signals with off-line signal processing, it could be possible to determine the solar sail orbit and attitude (Fig. 2).

Outcomes:

- A paper was published on an academic journal in FY2018. Total number of papers: 109.
- The method used to obtain the telemetry range data (by postprocessing the open-loop record data and extracting the radio waves) is expected to be applicable to a wide range of spacecraft operations, including solar sails.

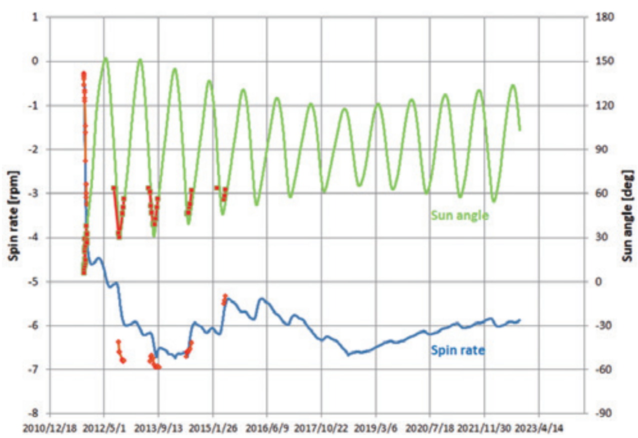


Fig. 1 Mechanical model of the solar sail

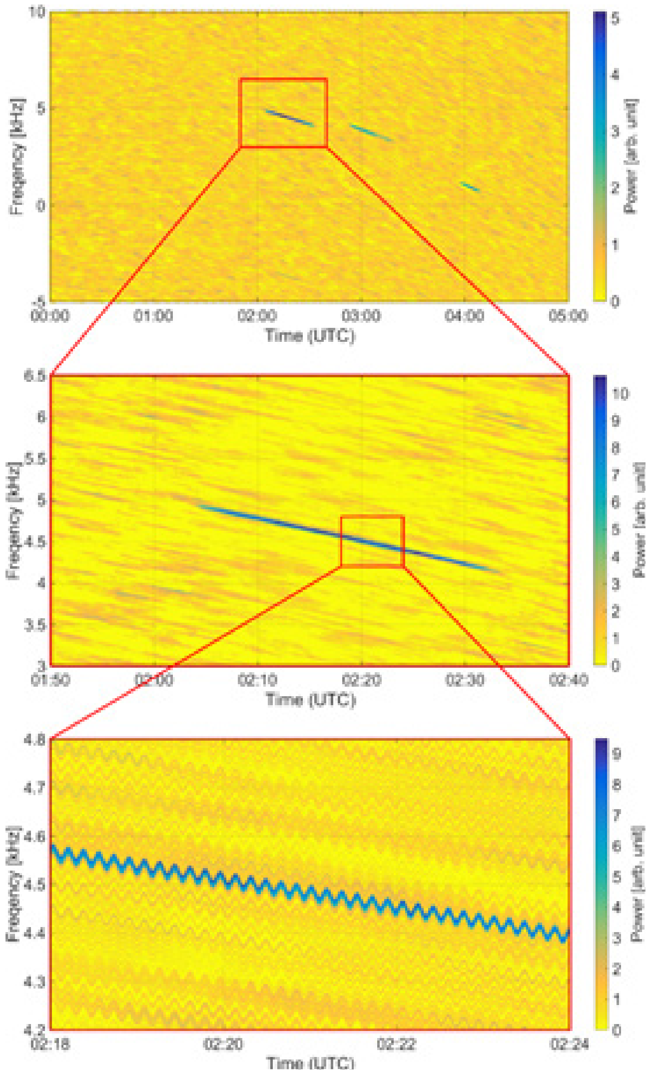


Fig. 2 Estimation of the solar sail orbit and attitude based on weak signals

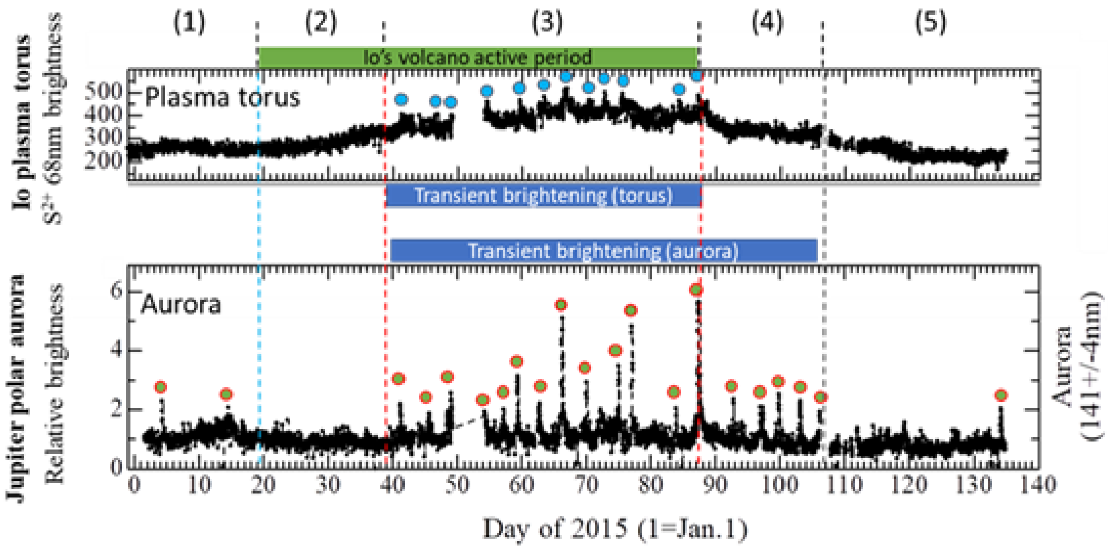
g. Extreme-ultraviolet Spectroscopic Planetary Observation with HISAKI

The extreme-ultraviolet spectroscopic planetary observatory HISAKI (formerly called SPRINT-A: Spectroscopic Planet Observatory for Recognition of Interaction of Atmosphere), which was launched on September 14, 2013, is a unique space telescope specialized for the observations of planetary atmospheres, ionospheres, and magnetospheres from low Earth orbit. Its primary instrument is the EUV spectroscopic system, which has the best time resolution and the longest observation duration in history. The EUV system is especially useful for understanding energy and plasma transportation in the Jupiter's magnetosphere and atmospheric evolution of the terrestrial planets.

Long-term HISAKI planetary observations of the Jovian magnetosphere and Venusian ionosphere were continuously made to provide unique and important data sets for EUV spectra. A joint observation with the Hubble Space Telescope (HST) was also performed when NASA's Jupiter space probe (JUNO) observed solar wind before its Jovian orbit insertion. After successful insertion, HISAKI proceeded with intensive Jupiter measurements and observations in the Jupiter magnetosphere by JUNO.

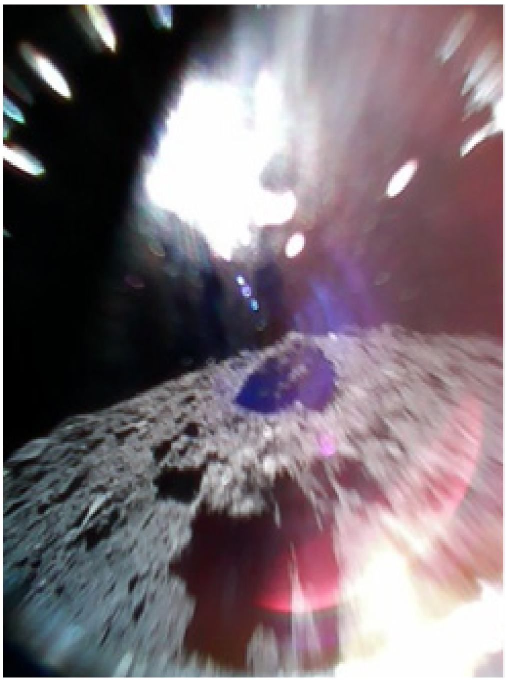
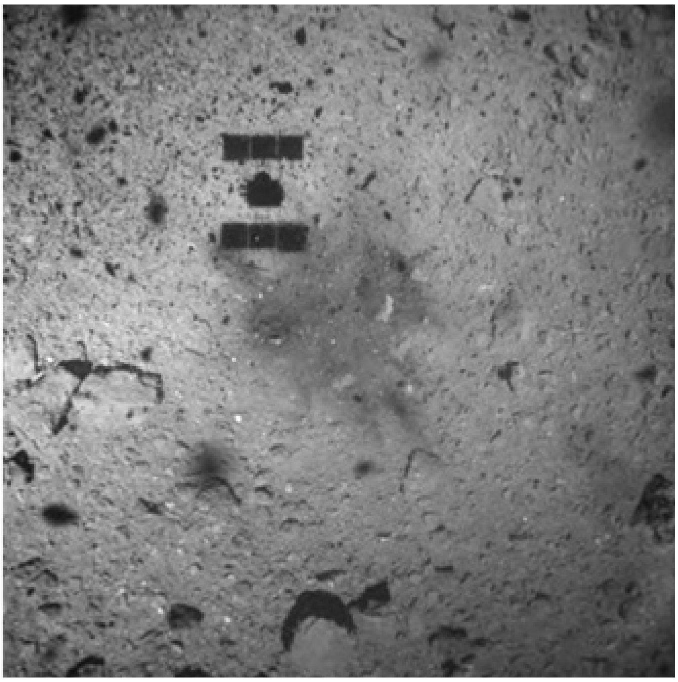
In this fiscal year, 10 peer-reviewed papers regarding HISAKI data were published, for a cumulative total of 40. Several articles using HISAKI observation during the Io volcanic eruption in 2015 were published to recognize the Jupiter's inner magnetospheric response. The HISAKI's quality of the long observation duration can observe the details of the response to Io eruption from beginning to end. It is clear that the quantity and the speed of plasma transportation was enhanced with the volcanic activity, and that the Jupiter's magnetosphere was also active.

The HISAKI science team takes a principal position among scientists of Jovian magnetosphere study at the international level, including international collaboration in NASA's Participating Scientist Program (planetary scientific research program of NASA using HISAKI data). Magnetospheric physics and aeronomy scientists, who are especially members of the Society of Geomagnetism and Earth, Planetary and Space Sciences in Japan, have been working with HISAKI observation results.



Time variation of in sulfur ion brightness in the Io plasma torus (upper) and the Jupiter's aurora brightness (lower) in the year 2015. (1) Normal steady state → (2) Plasma supply increase in the plasma torus → (3) Global plasma circulation → (4) Declining of the plasma circulation → (5) Return to the normal steady state conditions, which is a complete picture in this Io volcanic activity observed by the HISAKI satellite (Tsuchiya et al., 2018).

h. Asteroid Explorer Hayabusa2

(Fig.1: left) Image captured by Rover-1A on September 22 at around 11:44 JST. Color image captured while moving (during a hop) on the surface of Ryugu. The lower half of the image shows the asteroid surface. The bright white region shows sunlight. (Image credit: JAXA)
(Fig.2: right) Image captured around the touchdown point immediately after taking back off from the surface, at approximately 07:30 JST (onboard time) on February 22, 2019. Taken with the Optical Navigation Camera – Wide angle (ONC-W1), at an altitude of about 25 m. (Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.)

The asteroid explorer Hayabusa2, which was launched on Dec. 3, 2014 onboard a JAXA H2A launch vehicle, is the second-ever sample return mission from an asteroid. The target asteroid, 162173 Ryugu, is a C-type near-Earth asteroid. Hayabusa2 successfully performed a gravity assist maneuver around Earth on Dec. 3, 2015, and using its ion engine, Hayabusa2 finally arrived at Ryugu on June 27, 2018.

On Sep. 21, 2018, the miniature MINERVA-II1 rovers separated from the Hayabusa2 spacecraft. MINERVA-II1 consists of two rovers, Rover-1A and Rover-1B. We have confirmed that both rovers landed on the surface of asteroid Ryugu. The two rovers captured and transmitted many images and moved by hopping on the asteroid surface. Figure 1 shows an image taken with Rover-1A while it moved over the surface of Ryugu. MINERVA-II1 is therefore the world’s first human-made object moving on an asteroid surface.

MASCOT, developed in Germany and France, was successfully separated from the Hayabusa2 spacecraft on Oct. 3, 2018 and delivered safely to the surface of Ryugu. After landing, MASCOT acquired scientific data on the asteroid surface, which was transmitted to the MASCOT team via the spacecraft for about 17 hours, as designed.

The touchdown operation was initially planned to be held in 2018 on a large flat 100-m-square area. But the surface of Ryugu was so rough and covered with large boulders that no candidate area was available for touchdown. The mission plan had to be changed.

After counting the boulders on Ryugu, the smaller flat area "L08E1" was selected for touchdown. Also, the touchdown sequence was refined to achieve navigation accuracy within 3 m of the target. The touchdown operation (TD1-L08E1) on the surface of asteroid Ryugu was conducted on Feb. 22, 2019. Figure 2 shows an image taken with the Optical Navigation Camera – Wide angle (ONC-W1) during the spacecraft ascent after touchdown. This image was captured roughly 1 minute after touchdown at an estimated altitude of about 25 m (error is a few meters).

The touchdown point was just 1 m off the target point. After the touchdown, through checking telemetry data on the ground, the mission team confirmed from the status and temperature change of the projector that the projectile had been fired. So many ejecta particles were observed after touchdown that it many particles were certainly captured in the sampler horn.

In 2019, SCI operation to make artificial crater and the second touchdown operation is planned. After success in these operations, safe return to the earth is strongly expected.

i. Geospace Exploration with Arase

The geospace explorer Arase (ERG: Exploration of Energization and Radiation in Geospace) was developed as the second small science satellite from ISAS/JAXA in collaboration with institutions in Japan and Taiwan. The Arase satellite was successfully launched by the second Epsilon rocket on December 20, 2016, from the Uchinoura Space Center (USC) in the southern part of Kyushu.

The ERG science program is intended to shed light on the generation and loss of high-energy electrons in the Earth's radiation belts. This problem is a critical issue in understanding dynamic variation in geospace. The essential task of this program is using the Arase satellite to conduct detailed in-situ measurements of particles and electromagnetic fields in the radiation belts while monitoring the global variation of geospace with the ground-based measurements. These ground measurements involve a network of radar facilities, aurora cameras, and magnetometers. We also prepared strategic joint observations with the NASA Van Allen Probes. These systematic observations shed light on the scientific mysteries of the radiation belts. The anticipated experimental results are also expected to contribute to improvements in space-weather forecasting.

Arase is designed as a spin-stabilized satellite with a spin rate of approximately 7.5 rpm. Given its perigee altitude of approximately 400 km, apogee altitude of approximately 32,000 km, and inclination of approximately 31°, Arase's orbit allows it to cover all of the Earth's radiation belts. Its orbital period is about 570 minutes. The satellite system and all onboard mission instruments are in good condition even after over two years in space. All mission instruments achieved their expected performance as designed and have continued observations. Arase is providing data from comprehensive observations of the radiation belts.

The primary mission began on March 24, 2017 and was completed October 16, 2018. The primary mission period corresponds to the declining phase of Solar Cycle 24. Arase successfully observed a dozen geospace storms during the primary mission period. Most importantly, all instruments have provided scientific data from both normal and burst observations of these storms.

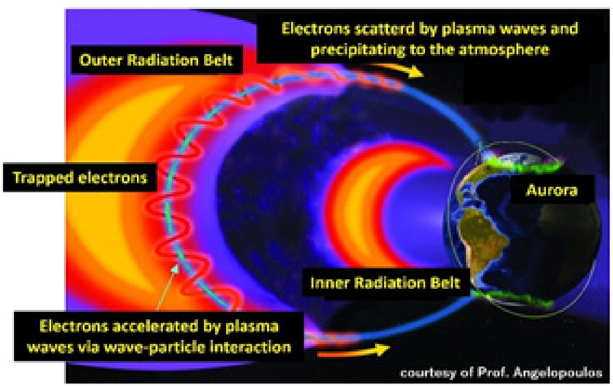
For the primary mission period, we conducted joint strategic observations with various ground-based scientific instruments to reveal the causes and consequences of wave-particle interactions and magnetosphere-ionosphere couplings. We have collaborated with various observatories of radar facilities, aurora cameras, riometers, VLF observations, standard radio networks, and magnetometers. Four campaign periods were set around the spring, autumn equinoxes, and the summer and winter solstices. More than 1,000 conjugate observations between Arase and ground-based observatories were realized. Arase has proven itself as a member of the international fleet of geospace satellites and has contributed to comprehensive observations of geospace plasma dynamics. More than 200 burst-mode observations of plasma waves simultaneous with the Van Allen Probes have also been completed, which simultaneous waveform data at different magnetic latitudes along the same field lines. Collaborative observations with the other satellites like THEMIS and MMS have also been carried out.

The data pipeline processing of the acquired data and data calibration are operated by each instrument team and the ERG science center. The processed data products are released from the ERG science center via a web interface. The ERG science center is managed by inter-institution collaboration between the Institute for Space-Earth Environmental Research (ISEE) at Nagoya University and ISAS. Coordination of observation planning and science data management by the ERG science center facilitates smoother and easier joint research with multiple data sets by providing a unified contact point for the complete resource.

The processed science data products after evaluation by the ERG science team are going to be open to the public. We have already released some calibrated science data, starting in August 2018. The relevant data analysis software was developed by the ERG science center and was made available as a plug-in package for SPEDAS, which is the standard data analysis software used in the solar-terrestrial space-plasma physics community. Processing for higher-level science datasets will also be released to the research community.

Over 50 scientific papers have been published in international refereed journals since the start of the Arase observations, including Nature and Nature Communication articles and 21 papers in a special issue of Geophysical Research Letters, "Initial results of the ERG (Arase) project and multi-point observations in geospace." These publications show that Arase is revealing a novel aspect of geospace, how wave-particle interactions contribute to the dynamic variation of the radiation belts. Based on this fact, the science review board found that Arase has almost completed its primary mission, even though the results are only preliminary and many scientifically important topics remain to be studied.

The extended mission has already begun, and the end of the first extended mission period is scheduled for March 2022. The extended mission covers the period from the declining phase of Solar Cycle 24 and the early phase of Solar Cycle 25 so that Arase can observe dynamical variations of the radiation belts and geospace under various solar wind conditions. The extended mission will also contribute to the completion of a survey of the radiation belts over the 11-year solar cycle period that began in 2012, by taking over the role of in-situ measurements from the Van Allen Probes mission, which is scheduled to end in 2019.



Contribution of wave-particle interactions to the radiation belts

j. Mercury Exploration with BepiColombo/MMO

Although the size of Mercury is between that of the Moon and Mars, it unexpectedly has an intrinsic magnetic field. This was discovered by the Mariner 10 spacecraft during three flybys and was confirmed by NASA's Mercury orbiter MESSENGER, which completed its mission in May 2015 as planned by deorbiting into Mercury.

BepiColombo is an ESA–JAXA joint mission to Mercury that aims to understand the process of planetary formation and evolution and to identify the similarities and differences between the magnetospheres of Mercury and Earth. The MESSENGER observations raised many new questions, and BepiColombo hopes to answer these questions.

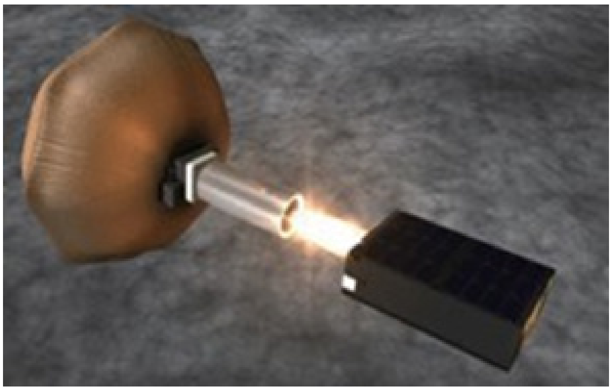
The baseline mission consists of two spacecrafts: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The two orbiters and the Mercury Transfer Module (MTM) will be combined in a stacked configuration, which is called the Mercury Cruise System (MCS). JAXA is responsible for the development and operation of the MMO, while ESA is responsible for the development and operation of the MPO, as well as the launch, cruising, and insertion of two spacecraft into their dedicated orbits. The main objectives of the MMO are to study Mercury's magnetic field and the plasma environment around Mercury, including solar wind–magnetosphere interaction, mainly by using in-situ measurements, while the main objective of the MPO is to study planet Mercury itself, mainly by using remote sensing.

After nearly 6 months of launch site operation, BepiColombo was launched on 20 October (UTC) from Guiana Space Center (CSG) by the Ariane-5 rocket. After a few days of critical operations, the initial check of the instruments lasted until December and confirmed that MMO, MPO, and MTM are working properly. The first arc of electric propulsion was successfully completed from December to March. The Mission Commissioning Result Review (MCRR) was held on 26 March and the responsibility for BepiColombo was handed over from the Project Manager to the Mission Manager at ESA.

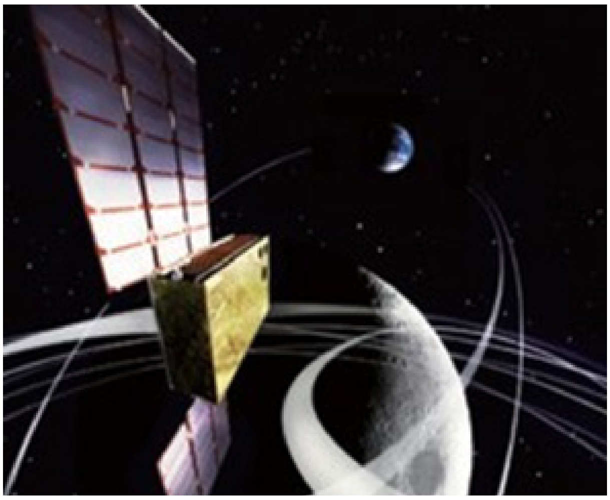
14 peer-reviewed papers related to the BepiColombo project were published in FY2018.

Ariane 5 carrying BepiColombo at the launch pad.

k. SLS CubeSats: OMOTENASHI and EQUULEUS



Artist's concept of OMOTENASHI deceleration maneuver with a solid-fuel motor at spinning attitude.



Artist's concept of EQUULEUS observation from L2.

OMOTENASH I (Outstanding MOon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor) and EQUULEUS (EQUilibriUm Lunar-Earth point 6U Spacecraft) are 6U, 14-kg CubeSats that will be launched by NASA's Space Launch System (SLS) in 2020.

OMOTENASHI demonstrates technologies for the world's smallest moon lander and observes the radiation environment. To achieve a moon landing by a CubeSat, a semi-hard landing scheme has been developed. The landing speed is controlled to approximately 50 m/s using a small solid rocket motor and gas jet propulsion units. We have also developed a shock absorption mechanism consisting of an airbag, crushable material and epoxy filler. The radiation environment will be measured by commercial portable dose meters.

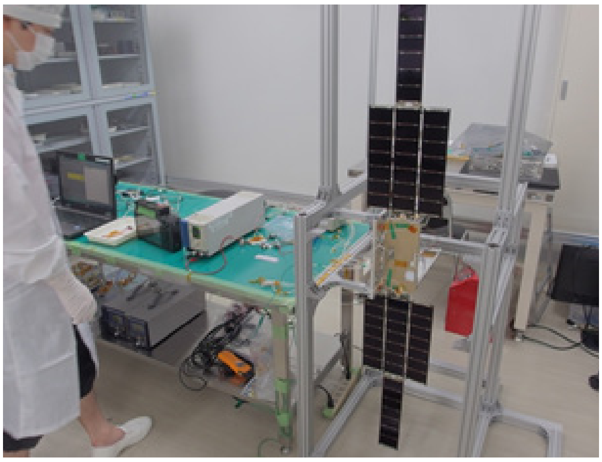
EQUULEUS has four missions. The primary, engineering mission is the demonstration of the trajectory control techniques within the Sun-Earth-Moon region by a nano-spacecraft during the flight to the Earth—Moon Lagrange point L2. A water resistojet propulsion system has been newly developed for trajectory control. The other, scientific missions are to observe Earth's plasmasphere, lunar impact flashes and the lunar dust environment. Those observations will be conducted by three instruments, namely, PHOENIX, DELPHINUS and CLOTH.

For both spacecraft, ultra-light-weight communication systems are being developed. Compatibility tests were conducted at JAXA's Usuda Deep Space Center.

Spin firing tests for the OMOTENASHI solid rocket motor and spin separation tests to measure the separation disturbance were conducted.

Manufacturing, integration and environmental testing for the flight model of EQUULEUS has started at the University of Tokyo, which will be completed to be ready for the shipment to NASA.

Small, light-weight and low-cost technologies developed for both spacecraft will contribute to future space science and human exploration. They will promote the participation of universities, industry and even individuals in future space exploration.



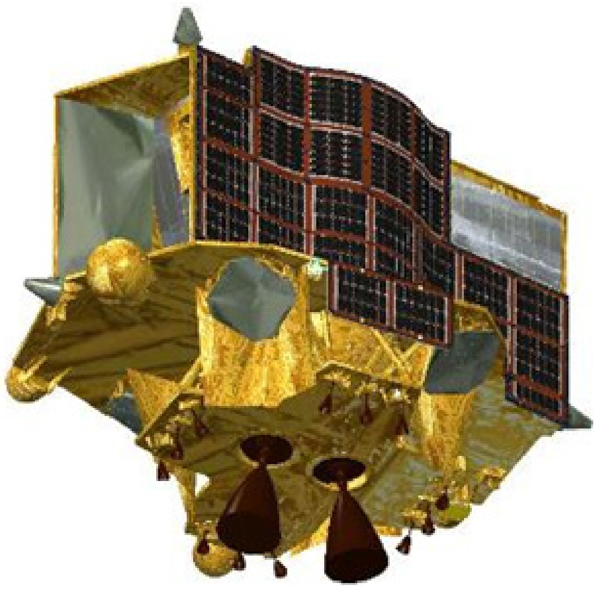
Solar array paddle functional test for the flight model of EQUULEUS

I. The Smart Lander for Investigating Moon (SLIM)

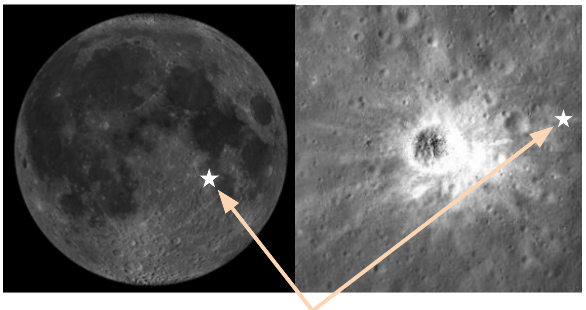
The Smart Lander for Investigating Moon (SLIM) is a project aimed at demonstrating the possibility of precise "pinpoint" landings on the lunar surface using a small and lightweight spacecraft. Pinpoint landings with accuracies of 100 m are required for future Moon explorations. Moreover, since conventional ground-based navigation systems cannot achieve this level of accuracy, it is necessary to develop an autonomous onboard navigation system. A novel image-based onboard navigation system has been developed and it will be demonstrated during the SLIM mission, together with several other technologies.

In April 2016, JAXA authorized the SLIM project and the formation of a specific project team. As continuous investigation from FY2017, suitable system configuration was discussed to adopt the situation after HITOMI (ASTRO-H) anomaly. Finally, JAXA and the team of SLIM project decided to launch the SLIM using a H-IIA rocket, together with an XRISM (X-Ray Imaging and Spectroscopy Mission) satellite. In FY2018, a preliminary design study (contemplating some modifications in response to the launcher change) and several elemental tests were conducted. The preliminary design was modified based on the results of these tests, followed by a preliminary design review. This last process included component vendors, system design, and JAXA's engineering peer reviews. Finally, at the end of FY2018, the results of the review were summarized and SLIM project was approved to start detailed design phase (Phase-C).

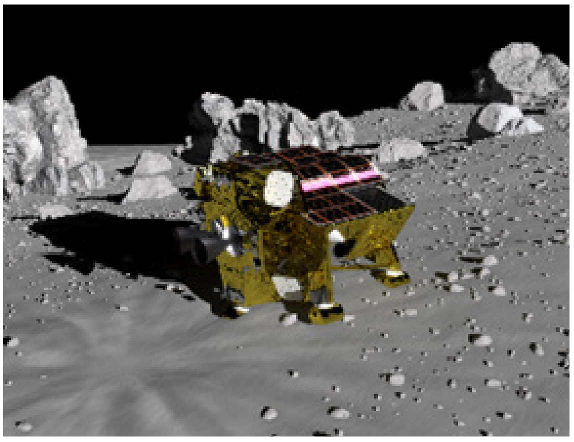
Pinpoint landing is a key technology for the next generation of lunar landers, since it will allow access to specific places on the moon that are scientifically valuable or important exploration targets. Thus, SLIM is a precursor for future national and international landing missions on the Moon, Mars, other planets and astronomical bodies.



Appearance of the SLIM spacecraft.



Location of the target landing site (13.3 degS / 25.2 degE).



Expected view of the SLIM on the landing site.

m. X-Ray Imaging and Spectroscopy Mission (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM) has been proposed in order to reach the scientific objectives targeted at the time of launching ASTRO-H (HITOMI). The XRISM will recover scientific information in the shortest time possible by focusing on one of the main science goals of HITOMI: "Resolving astrophysical problems by precise high-resolution X-ray spectroscopy". This decision was taken after evaluating the performance of the instruments aboard HITOMI, the mission's initial scientific results, and the landscape of the planned international X-ray astrophysics missions through 2020's and 2030's.

HITOMI opened the door to high-resolution spectroscopy in the X-ray universe, revealed a number of discrepancies between new observational results and prior theoretical predictions. The resolution pioneered by HITOMI is key also for the resolution of other fundamental questions: The high spectral resolution realized by the XRISM will not offer mere refinement; rather, it will enable qualitative leaps in astrophysics and plasma physics. The XRISM has therefore been assigned a broad scientific task: "Revealing material circulation and energy transfer in cosmic plasmas and elucidating the evolution of cosmic structures and objects". Four science objectives originally assigned to HITOMI will be hence pursued by XRISM. They include the investigation of the: (1) structure formation of the Universe and the evolution of clusters of galaxies; (2) circulation history of baryonic matter in the Universe; (3) transport and circulation of energy in the Universe; (4) new science with unprecedented high resolution X-ray spectroscopy. In order to achieve these scientific objectives, the XRISM will carry a 6 × 6 pixel X-ray microcalorimeter (Resolve SXS) on the focal plane of an X-ray mirror assembly, together with an aligned X-ray CCD camera (Xtend SXI) covering the same energy band and a wider field of view.

The System Definition Review (SDR) and the Project Initiation Review were held in April and June 2018, respectively. On July 1, the JAXA president started directing the mission and the XRISM project team was established. Phase B of the project started immediately after the establishment of the team. In March 2019, the integrated system Preliminary Design Review (PDR) was successfully completed and the project entered Phase C. The XRISM contemplates the collaboration of JAXA and NASA, with the contribution of ESA.

Graphic rendering of the X-ray Imaging and Spectroscopy Mission on orbit

n. Demonstration and Experiment of Space Technology for Interplanetary Voyage, Phaethon Flyby and Dust Science (DESTINY+)

In 2022, DESTINY+ will be launched into a highly elliptical orbit and start powered spaceflight for asteroid 3200 Phaethon.

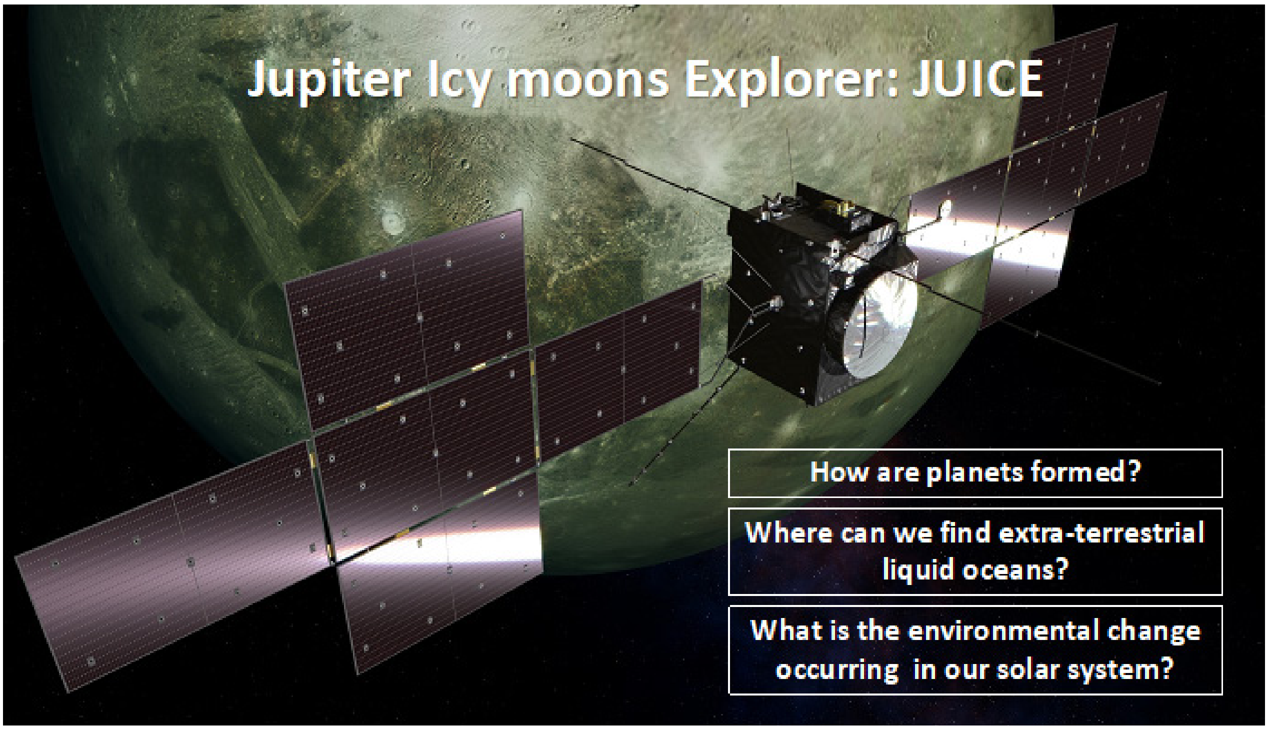
DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) is a candidate of the ISAS Epsilon-class small program. The DESTINY+ is a joint engineering and science mission. The mission has the following two engineering mission objectives; E1 Development of space transportation technology using electric propulsion and extension of the range of applications of electric propulsion and; E2 Acquisition of advanced flyby exploration technology and expansion of opportunities for small body exploration. In addition, DESTINY+ has the following two scientific mission objectives; S1 Elucidation of the situation of dust reaching Earth's surface. The physical (velocity, direction of arrival and mass distribution) and chemical properties of dust reaching Earth will be clarified and; S2 Investigation of a meteor shower parent body asteroid 3200 Phaethon as a specific source of dust coming to Earth.

DESTINY+ will be put into an elliptical orbit around Earth by an Epsilon launch vehicle, after which electric propulsion will be used to expand the orbit to reach the moon. At this point, it will escape Earth's gravitational sphere of influence via multiple lunar gravity assists, approach the asteroid Phaethon after cruising in deep space using electric propulsion and conduct a flyby observation. After the Phaethon flyby, DESTINY+ may head for a subsequent exploration object as part of an extended mission.

DESTINY+ became an ISAS pre-project after passing an ISAS project preparation review in August 2017. JAXA plans to develop scientific instruments to observe an active asteroid, Phaethon during its flyby, whereas DLR has an interest in providing the DESTINY+ Dust Analyzer (DDA), a field in which Germany has had the leading expertise in the world for decades. Following establishment of Implementation Arrangement (IA), DLR and JAXA have been conducting joint feasibility studies. An international observation campaign was conducted for Phaethon during its last close encounter with Earth in December 2017. Photometric, spectroscopic and polarimetric observations of Phaethon were successfully performed with ground-based and space telescopes. We have been conducting conceptual designs of the spacecraft system, thin-film solar array paddles, electric propulsion, advanced thermal control, orbit determination during orbit raising around the earth, orbit synthesis of all mission phases, mission and bus interface and the interface between the spacecraft and the "Epsilon" launch vehicle with a kick stage. Bread board models of reversible thermal panels and mirror pointing mechanism for telescopic camera has been developed and tested.

Related organizations for this mission include Chiba Institute of Technology Planetary Exploration Research Center (Chitech/PERC, Japan), Universität Stuttgart Institut für Raumfahrtsysteme (Uni Stuttgart/IRS, Germany) and DLR (Germany).

o. Jupiter Icy Moons Explorer (JUICE)



In 2032, JUICE will visit Ganymede, in order to answer to the questions "How are planets formed?" Where can we find extra-terrestrial liquid oceans?" What is the environmental change occurring in our solar system?"

JUICE is an ESA L-class mission to explore Jupiter's icy moons. The science objectives of JUICE are to understand (1) the emergence of habitable worlds around gas giants and (2) the Jupiter system as an archetype for gas giants. The JUICE mission was adopted in November 2014, and JUICE will be launched by an Arian-5 rocket. After 7.5 years of interplanetary transfer and Earth-Venus-Earth-Mars-Earth gravity assists, JUICE will be inserted into an orbit around Jupiter in 2030, and make observations of all three Jupiter icy moons that potentially have subsurface oceans under their icy crust. After insertion into the Ganymede orbit in 2032, JUICE will make detailed observation of the largest icy moon in the solar system.

ISAS will participate in three science instruments—Radio and Plasma Wave Investigations (RPWI), Ganymede Laser Altimeter (GALA), and Particle Environment Package/ Jovian Neutral Analyzer (PEP/JNA)—by providing hardware and two instrument groups—Jovis, Amorum ac Natorum Undique Scrutator (JANUS) and JUICE magnetometer (J-MAG)—as science co-investigators (Co-Is). JUICE is the first mission in which ISAS/JAXA is participating as a junior partner by providing part of the science instrument payload for a foreign large science mission. Considering all the data to be obtained by five instruments that Japan will participate, the Japanese team will contribute to major science objectives related to the planet Jupiter (JANUS), Jupiter's magnetosphere (PEP/JNA, RPWI, and J-MAG), and the icy moons (GALA, J-MAG, and JANUS).

JUICE-Japan became an ISAS project after passing an ISAS project transition review in December 2017. The instrument team tested Bread Board Models (BBMs), designed and fabricated engineering models (EMs) of their hardware without any major delays. Critical design review (CDR) meeting for RPWI completed in July 2018. CDR meetings for PEP/JNA and GALA are scheduled in 2019.

JUICE is a long-term mission that will continue for approximately 20 years. To make Japan's participation in JUICE successful, it is very important to plan for project continuity as the project team makeup changes over time.

Related organizations for this mission include ESA (Europe), DLR (Germany: GALA), Swedish National Space Agency (SNSA: RPWI, PEP/JNA), Institutet för Rymdfysik Uppsala (IRF Uppsala, Sweden: RPWI), IRF Kiruna (Sweden: PEP/JNA), Imperial College London (UK: J-MAG), and the National Institute for Astrophysics (INAF-OAC, Italy: JANUS).

Letter Of Agreement (LOA) between ISAS/JAXA and DLR for GALA was concluded in September 2018. LOA between ISAS/JAXA and SNSA for RPWI and PEP/JNA was concluded in November 2018.

p. Concept Study of Martian Moons eXploration (MMX) Mission

Fig.1 One possible MMX spacecraft configuration with a launch mass of 4,000 kg. It includes three main modules for sample return, exploration, and propulsion. The nominal mission duration will be 5 years.

Mars is the outermost rocky planet in the solar system, and Phobos and Deimos are its two moons. Martian Moons eXploration (MMX) is a mission under study that would be launched in JFY 2024.The primary missions are survey of the Martian moons and sample return from one of them. The goal of the mission is to reveal the origin of the Martian moons and advance our understandings of planetary-system formation and of primordial material transport crossing the boundary between the inner and outer parts of the early solar system.

Fig. 1 shows an example of the spacecraft configuration developed in our concept development.

To realize the launch in JFY 2024, research and development activities in JFY 2018 included concept development of the MMX spacecraft system and conceptual design and prototyping of novel mission-critical technologies like the sampler system (Fig. 2) and the sample-return capsule were conducted based on the achievements of activities in JFY 2016-2017.

Fig. 2 Conceptual development result: Sampler system

Joint studies of this project were conducting followed the international cooperation framework. Development of gamma-ray and neutron spectrometers was coordinated (schedule, development model, etc.) with NASA (U.S.A.) based on an LOA about feasibility studies. CNES (France) and DLR (German) issued a joint statement about the joint development of a compact rover planned to fly with the MMX in October 2018 (Fig. 3).

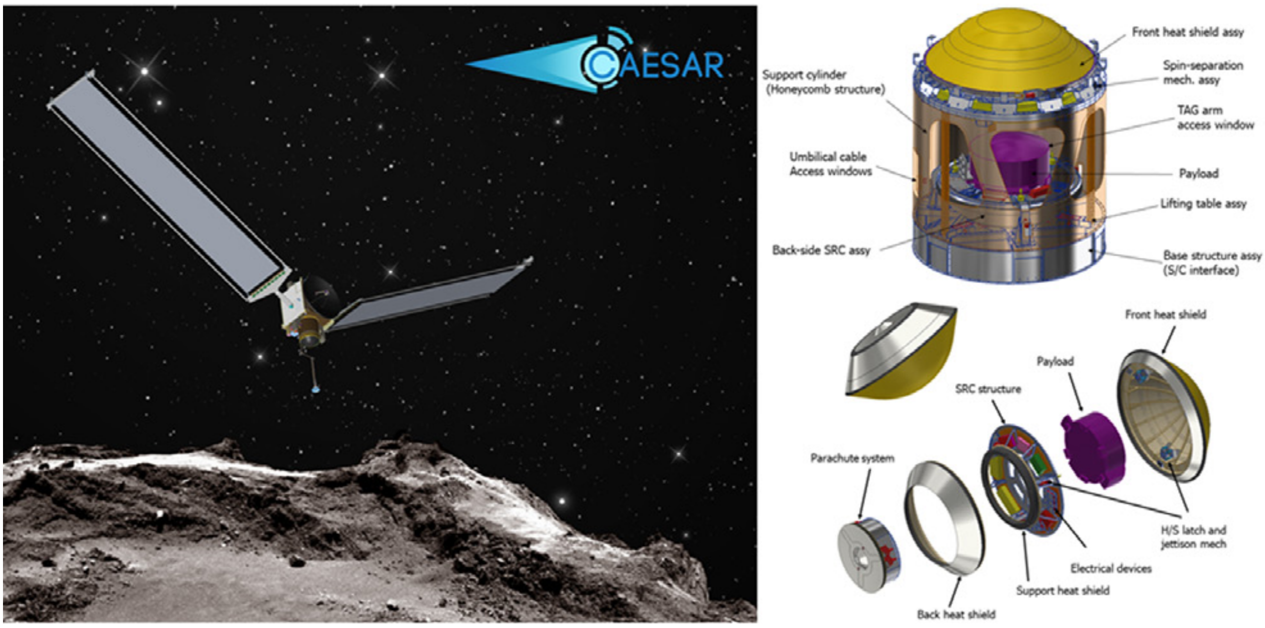
Fig. 3 Photo of Joint statement (Second from the left: Prof. Dr. Pascale Ehrenfreund Chair of Executive Board, Third from the left: Yamakawa JAXA President, First from the right: Jean-Yves LE GALL CNES President)

With regard to planetary protection category for Mars satellites, MMX activities have gotten an international agreement that is "unconstrained earth return is acceptable", therefore the impact to MMX spacecraft design was avoided.

Four peer-reviewed papers about this mission were published in FY2018. 25 peer-reviewed papers have been published in total.

In order to realize the plan, project operations and activities were performed steadily along with international cooperation.

q. Comet Astrobiology Exploration SAmple Return (CAESAR)



Artist's concept of CAESAR and Conceptual design of CAESAR Sample return capsule.

CAESAR (Comet Astrobiology Exploration SAmple Return) is a sample-return international mission to comet 67P/Churyumov-Gerasimenko, led by Prof. Steven Squyres of Cornell University and managed by NASA Goddard Space Flight Center. The CAESAR mission aims to return both nonvolatile (e.g., rock, stone) and volatile samples (e.g., ice) from comet 67P. This mission was proposed for the NASA New Frontiers Program 4 (NF-4) and selected as one of two finalist missions in December 2017. JAXA and several Japanese scientists have participated in the CAESAR mission as equal partners since 2015, contributing to both engineering and sciences aspects (i.e., the development of the Sample Return Capsule (SRC) and the related scientific planning for sample return). The SRC is an indispensable subsystem for the accomplishment of the CAESAR mission, since the mission aims at a successful sample return. If the CAESAR mission will be successful, JAXA will acquire the advanced SRC technology, which could potentially lead future explorations of the international solar system. Moreover, this technology would allow the sharing of the comet's return samples among Japanese scientists and lead to remarkable scientific advances regarding the origin of life and of the solar system.

JAXA and several Japanese scientists conceived the SRC conceptual design and the necessary activity to enhance the science value and significance for the NF-4 final selection. The results and achievements of this process were shared with the CAESAR team and the final proposal was submitted in December 2018. The activity described in the final proposal include some tests and demonstrations to mitigate the development risk of the SRC critical components and to overcome the potential weakness indicated during the first selection process.

The manufacturing trial of a large ablator block for the front heat shield was also carried out. A full-scale mock-up of the heatshield closure mechanism was developed and the function tests were carried out. The main parachute deployment test in free flight condition was conducted by dropping the parachute from an helicopter at an altitude of 600 m, above Izu-Oshima. This type of test was conducted three times: all of trials were successful and the flight data useful for the parachute system design were obtained.

The Japanese science team carried out some experimental demonstrations about the secondary alteration between rocks and ices of comet samples. The demonstration proved that sample alteration would not occur in assumed duration in CAESAR mission.

Photograph taken during the main parachute deployment test by dropping from a helicopter at Izu-Oshima

r. LiteBIRD: Lite (Light) Satellite for Studies of B-mode Polarization and Inflation from Cosmic Background Radiation Detection

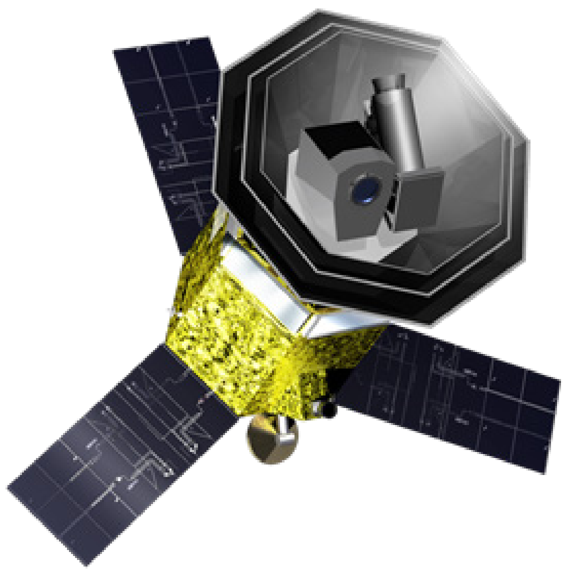
LiteBIRD is a strategic large-class mission that aims to verify inflation theory describing the expansion of the universe before the "hot big bang". According to the inflation model of cosmology, the universe experienced an extremely accelerated expansion before becoming a "fireball". The model further postulates that quantum fluctuations associated with inflation generated primordial gravitational waves. LiteBIRD aims to verify all representative inflation models through detailed analysis of primordial gravitational waves. For this purpose, an all-sky survey will be performed from Sun–Earth Lagrangian point L2 to precisely observe the spiral polarization distribution (B-mode polarization) produced by the primordial gravitational waves in the cosmic microwave background (CMB). During observations, any B-mode polarization caused by sources other than CMB needs to be carefully eliminated. For this purpose, LiteBIRD covers 34–448 GHz in 15 bands which are shared between a low-frequency telescope (LFT) and medium/high-frequency telescopes (MHFT) with overlap. The LFT adopts single reflective telescope, while the MHFT consists of two refractive telescopes. 1/f noise is reduced by using a polarization modulator with a rotating half-wave plate at ~1 Hz (LFT) and ~3 Hz (MHFT). We use transition edge sensor (TES) bolometers as detectors, which will be read with superconducting quantum interference devices. The LFT and MHFT, including detectors and optical systems, are actively cooled down to 0.1–4 K.

Following the international science review and the planning review in 2016, the mission definition phase (pre-phase A2) started in September 2016 and continued for two years. We have received the pre-phase A2 exit review in late 2018, which is continuing beyond FY2018. Various studies and developments were advanced in FY2018, especially in the cooling system, LFT & MHFT, polarization modulator (LFT), and focal plane detectors.

Regarding the cooling system, the responsibility of Japan has been modified to cover only up to the 4 K stage, with the ADRs from the US and Europe covering from the 4 K to 0.1 K stage. A pulse-tube cooler from ESA has been adopted for the shield cooler of the V-groove.

The operating temperature of the polarization modulator has been changed to 20 K. This has significantly reduced the risks and the operation frequency of the holding mechanism. A BBM of the polarization modulator was manufactured and used to test the function of the holding mechanism. Trade-off studies were performed for MHFT between the reflective and refractive optics, and two refractive telescopes were adopted for MHFT. According to the revision of the cooling chain, the number and arrangement of the detector elements were revised to maintain the required sensitivity.

LiteBIRD is based on extensive collaboration in Japan and overseas countries. Major collaborative institutes and universities in Japan include, KEK (High Energy Accelerator Research Institute), Kavli IPMU (Institute for the Physics and Mathematics of the Universe) and Okayama University. In terms of international partners, in addition to the US and Canada, European countries joined the LiteBIRD collaboration with the involvement of ESA. The US is responsible for the focal plane detectors for both the LFT and MHFT and for the ADR between 4.8-1.8 K. Canada is responsible for the room-temperature readout electronics. Europe takes responsibility for the MHFT, the ADR between 0.1-1.8 K, and the pulse-tube cooler for the shield cooler. As a result, LiteBIRD became a truly global project.



Artist's impression of LiteBIRD

s. Solar Power Sail-Craft (OKEANOS)

The solar power sail-craft (OKEANOS) is a strategic medium-sized mission that aims to demonstrate the exploration of the outer solar system and maintain Japan's leadership in solar system exploration, focusing on following items; (1) demonstrate the efficacy of the solar power sail navigation technology and of its transport payloads, necessary for landing on asteroids, and make a successful return trip from the outer planetary region; (2) demonstrate the efficacy of the exploration technology by rendezvousing with a Jupiter Trojan asteroid and deploying a lander that would collect samples and perform in-situ analysis; (3) perform scientific observations using multiple deep space instruments in both the cruising and Trojan asteroid observation environments.

Achievements:

i. In order to fit within the cost bracket for medium-sized missions (JPY 30B), the plan was revised by proposing a smaller spacecraft; however, we verified that this decision will not affect the purpose or the value of the mission.
   - The mission will be conducted in a single trip; hence, without sample return.
   - The lander will be simplified by removing the Attitude and Orbit Control System (AOCS), the propulsion, and the landing gear. The lander will orient itself after a free-fall landing by using an orienting system, similarly to the MASCOT lander on Hayabusa2. Only surface samples will be taken; hence, the underground sampler will be removed. The removal of this instrument will reduce the lander mass from 100 kg to 40 kg (see Fig. 1).
   - The mothership will be simplified as much as possible; for examples, by reducing the number of ion engines.

ii. A breadboard model of the solar power sail (having the same size of IKAROS) was developed and its performance was assessed. The results of our test indicate that this design would allow the construction of the world's lightest solar array (kW/kg class).

iii. A new sail wrapping method was developed: it minimizes the creasing of the inner-most layers related to the circumferential difference with the outer-most layers. The required stowing space was investigated experimentally and through modeling.

iv. Thin-film solar cells mounted on membranes tend to warp due to the inevitable temperature gradient. We developed a mounting method to reduce the sail membrane deformation.

v. A vision-based autonomous landing technique was developed. By combining asteroid center-of-mass and surface feature tracking, the lander will be able to land within 100 m from the target.

vi. An engineering model of the Ion thruster Power Processing Unit (IPPU) was tested, paving the way towards a flight model. The neutralizer unit was also tested: it provided an endurance of 56,700 h vs. a requirement of 24,090 h.

vii. With the aim of improving the performance of the High Resolution Mass Spectrometer (HRMS), we conducted an integration testing using a gas chromatograph. The results show that its detection performance with respect to organic compounds was substantially improved. In addition, a gas-sealing technique was devised by prototyping.

viii. OKEANOS has passed the Pre-phase A2 conclusion review (part I): the mission was considered technologically feasible.

Outcomes:

i. Ten papers were published on academic journals in FY2018. Total number of papers: 127.

ii. The solar power sail was ideated in Japan, based on previous technologies employed in the HAYABUSA, Hayabusa2, and IKAROS missions taking advantage of Japan's technical capabilities. The cruising and exploring techniques of this solar power sail will be verified, aiming to "further, freer, and more sophisticated" space explorations.

iii. Through the direct exploration of Trojan asteroids, it will be possible to investigate the most recent hypotheses regarding the formation of the solar system. Multiple observations in deep space environments will establish a new research field in space astronomy.

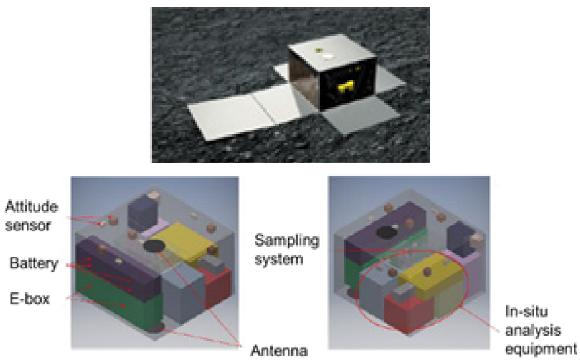
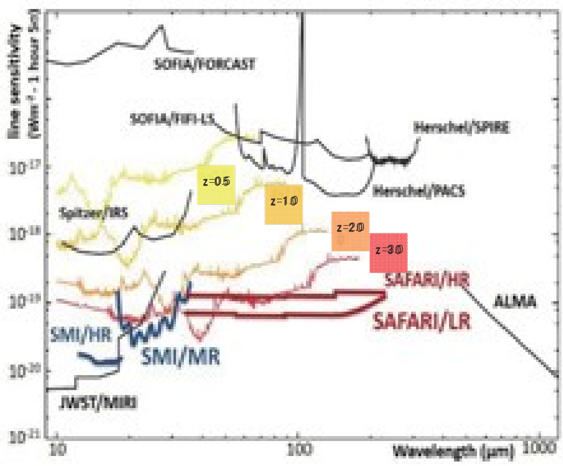


Fig. 1 Preliminary design of the lander

t. Next-generation Infrared Astronomy Mission SPICA (Space Infrared Telescope for Cosmology and Astrophysics)

The Space Infrared Telescope for Cosmology and Astrophysics (SPICA) is a next-generation infrared astronomy mission expected to reveal the history behind star-formation in the universe and the formation and evolution processes of planetary systems. SPICA will achieve these goals with its 2.5 m telescope cryogenically cooled to below 8 K (-265°C). The combination of the large aperture and low temperature is expected to enable unprecedented sensitivity at mid- and far-infrared wavelengths, which is the essential spectral range for studying the formation and revolution of galaxies, stars, planets and lives.



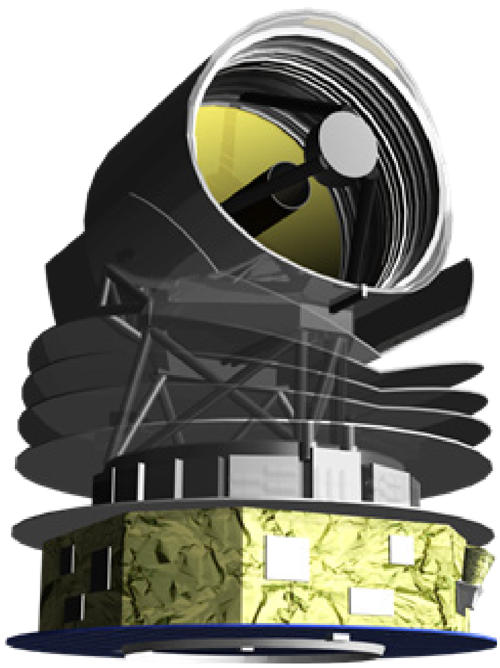
Sensitivity of SPICA instruments (SAFARI and SMI) compared with those of other missions.

SPICA is an international collaboration led by ESA.ESA is responsible for the entire satellite system, the service module and the telescope, while JAXA, as a major partner, is responsible for the integration of the payload module (PLM) with a cryogenic system and the launch operation. A series of cryocoolers, one of the key elements for the success of the SPICA mission, have been developed by JAXA, based on the technical heritage of previous JAXA-led missions, including AKARI and HITOMI. SPICA has three powerful focal-plane instruments: SPICA Far-Infrared Instrument (SAFARI), and SPICA Mid-Infrared Instrument (SMI), and SPICA Far-Infrared Polarimeter (B-BOP). SAFARI is being developed by an international consortium led by the Space Research Organization Netherlands (SRON), with the participation of 10 European countries, the USA, Canada, Taiwan and Japan. SMI is being developed by an SMI Consortium led by Nagoya University, Japan. B-BOP is led by CEA Saclay.

In May 2018, SPICA was selected as one of three candidate missions for the 5th M-class mission (M5) of the ESA Cosmic Vision among 25 proposed missions. Following the selection, The SPICA team has since been advancing intensive study on its conceptual design in collaboration between ESA and JAXA. The conceptual design activity will continue until early 2021, when final selection for M5 will be announced.

In order to enhance the feasibility of the mission, the Japanese SPICA team vigorously promoted development of the critical technologies for PLM, cryocoolers and SMI. The SPICA Science Promotion Committee has been established in September 2018 and is working actively to maximize the scientific outcome from SPICA, in a close link to ESA's Science Study Team.

SPICA is expected to play a significant role by filling the wavelength gap of the next-generation observing facilities between the near-infrared (James Webb Space Telescope [JWST] and Thirty Meter Telescope) and the submillimeter (ALMA). The synergy among the next-generation facilities is indispensable for the study of astrophysics in the coming decades.



SPICA spacecraft.

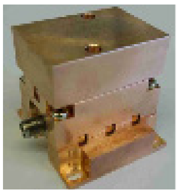
3. Others

a. GRound station for deep space Exploration And Telecommunication (GREAT)

This project has the goal of developing a new ground station with a 54-m antenna that will follow the aged 64-m antenna installed at the Usuda Deep Space Center (UDSC). Despite its smaller dimensions, the new antenna will be capable of obtaining more data from spacecraft in future deep-space activities. The new station, located about 1.5 km away in a straight line from the 64-m antenna, will begin operations with supporting Hayabusa2 and eventually BepiColombo.

The achievements of the project in JFY2018 are as follows:

1) Devices and equipment to be installed at the new station were tested at factories to verify conformance with specifications.
2) The another building for station operations and testing and the mechanical structure for the antenna, including the 54-m main reflector, were constructed.
3) To mitigate the effects of newly discovered radio interference, prototype evaluations of superconducting filters with steep attenuation characteristics were conducted successfully and the filter was cleared for use at the station.



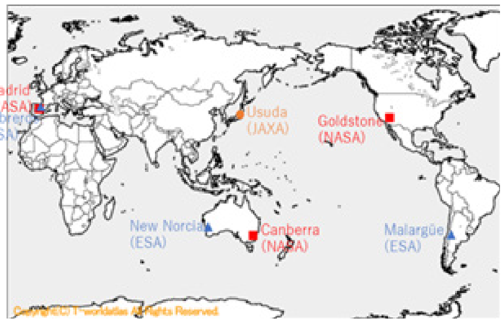
Prototype of the filter

4) The SSPA (Solid State Power Amplifier) which will reduce maintenance costs when compared with the conventional Klystron was also cleared for adoption by changing the original project plan. (Refer to photo C)

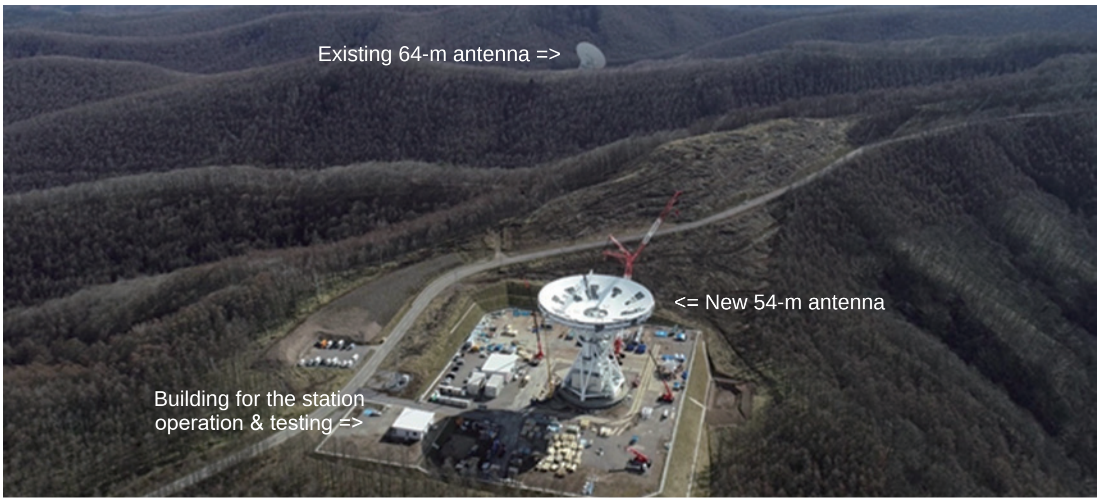
The new station will play an important role in international cooperation with NASA and ESA for deep-space activities.

Prototype of SSPA (consisting of a pair of power amplifiers)

Its geographic position is advantageous because no competing stations are present in East Asia and because its location allows combined operations with NASA and ESA stations to form a very long baseline for deep space navigation. The new station is also significant for conducting future JAXA missions and for maintaining ISAS and JAXA's position as international leaders in the exploration of the solar system. The station will also provide opportunities to take part in highly advanced overseas missions by participating in the international deep space network. In particular, the newly added Ka-band receiver is expected to enhance the station's usefulness in international collaboration.



Position of GREAT with respect to the global deep-space network.



Drone view of the site in November 2018. The 54-m parabolic antenna under construction. The building constructed this year is in the lower left. The existing 64-m antenna is behind the mountains.

b. Cryo-Chain Core Technology Program (CC-CTP)

The CC-CTP is an international project aimed at demonstrating a detector cooling system, including a cryostat and active coolers, to reach temperatures as low as 50 mK. The European CC-CTP partners are financially supported by ESA, with CNES (France) and the French Alternative Energies and Atomic Energy Commission (CEA) leading the effort.

The CC-CTP will create three cryostats. JAXA is expected to supply coolers for Cryostat #1, a concept study model; and Cryostat #3, which will be used as the ATHENA/X-IFU (X-ray integral field unit) demonstration model with microcalorimeter array. In 2017, JAXA's Joule–Thomson (JT) 4 K and 2 K coolers were combined with a French hybrid cooler which cooled down from 2 K to 50 mK. It was the first cooling chain for space use that combined Japanese and European spacecraft cooling technology. In 2018, we summarized the results and proved that this cooling chain satisfies the required cooling power for the proposed space missions ATHENA, SPICA, and LiteBIRD, which will utilize low-temperature detectors in orbit. A part of results was presented in papers and conferences. Discussions about assembly procedures, investigation, and verification the third cryostat are ongoing.

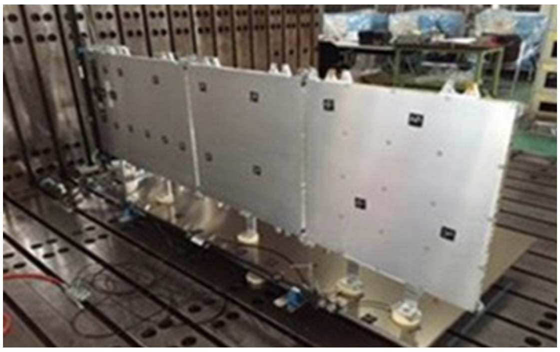
To improve the robustness of this system, we are investigating the cause of the aging effect inside cooler compressors. A test model for a two-stage stirring cooler compressor was made with frictionless flexure spring, which achieved the expected cooling performance. Active control logic to reduce mechanical disturbance is being studied in collaboration with the Research and Development Directorate. The Athena/X-IFU consortium was consolidated including the Japanese contribution to supply JT coolers. CC-CTP activity is considered part of Phase A of the study, while the X-IFU project has moved to Phase B.

c. Small Synthetic Aperture Radar for 100 kg Class Satellite

An X-band synthetic aperture radar (SAR) that can be installed on a 100-kg class satellite was developed. This was adopted as one of the ImPACT programs by the Japanese government and its final goal is to develop a SAR model with a resolution of 1m by FY2018.

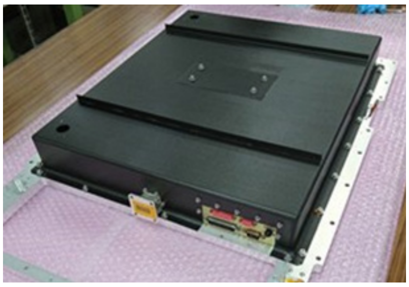
Engineering models of a SAR antenna assembly, an X-band solid state power amplifier unit for radar signal transmitting, a RF-front-end assembly and a SAR signal generating, and processing unit were manufactured, and their designs were successfully verified by each component level tests. The SAR system level test was performed in late 2018.

The 10m receiver antenna at the Usuda Deep Space Center was modified to conform to the X-band and dual circularly polarization for Gbps-order high rate downlink for the large amount of SAR observation data.



Deployable SAR Antenna Assembly Consists of Planar Slot Array Panels.

Vibration Test of SAR Antenna and Satellite Body



X-Band Solid State Power Amplifier Unit for Radar Signal Transmitting

4. R&D at Research Departments

a. Department of Space Astronomy and Astrophysics

1. Overview

The Department of Space Astronomy and Astrophysics is engaged in observational research in astrophysics, mainly from space. Our studies cover a variety of research fields, from cosmology to exoplanets, by making observations at wavelengths from radio waves to gamma rays. In FY2017, we studied data from the X-ray missions SUZAKU and ASTRO-H, data from the AKARI infrared satellite, and data from ground-based telescopes. The X-ray Imaging and Spectroscopy Mission (XRISM) was started to continue the research conducted through ASTRO-H. Members of the department have contributed significantly to the comprehensive development and studies regarding the LiteBIRD and SPICA for future missions. In September 2017, LiteBIRD began conducting its Phase A1 activity, which was completed by the middle of 2018. For SPICA, the proposal for ESA Cosmic Vision M5 was submitted in 2016, and further studies have been extensively conducted. The department has also worked on future technology developments, including lightweight X-ray and infrared telescopes, small-pixel infrared detectors, cryogenic X-ray spectrometers and their space cooling technology, X- and gamma-ray pixel detectors, analog and digital signal processing technologies, millimeter and submillimeter ultra-low-noise heterodyne receivers, and next-generation Very-Long-Baseline Interferometry (VLBI) technology. Theoretical work and investigations using ground-based facilities (i.e., ground-based telescopes) have also been widely conducted.

2. Research Activities in FY2018

2.1. High-energy astrophysics

In the area of observational research in high-energy astrophysics, the department conducted research using various X-ray and gamma-ray satellites, including SUZAKU and ASTRO-H. More than ten papers on ASTRO-H observational and technology development studies were published in 2018 despite the fact that the data obtained from ASTRO-H were extremely limited. An analysis of the SUZAKU archive data was also continued for astronomical objects, from the solar system to clusters of galaxies. We studied the metal distribution and origin of peculiar non-equilibrium plasma in supernova remnants using Chandra and NuSTAR. New tools for a Monte-Carlo simulation were also developed to enable a comparison of theoretical models with the observational data obtained from ASTRO-H.

Development studies for more sensitive observations in the future have also been carried out. For the TES microcalorimeter, laboratory experiments including its application in transmission microscopes, the analysis of rock structures, and the precise measurements of nuclear gamma-ray energy for atomic watches have been conducted. We succeeded in the development of read-out electronics using a microwave resonant circuit, which will enable the development of larger format detectors in the future. For semi-conductor sensor devices, R&D has been conducted to achieve lower background noise, a better energy resolution, a better spatial resolution, and a larger format. In the area of gamma-ray detectors, a basic study on a sensitive semi-conductor Compton camera used to detect the trajectory of electrons was conducted. For the CdTe detector used in X-ray imaging spectroscopy, which was established through the development of ASTRO-H, studies on its application to other areas, such as medical imaging or negative muon beam experiments, have been carried out.

2.2. Infrared astrophysics

In the field of infrared astrophysics, we conducted various studies using data from AKARI and other infrared satellites, as well as data from ground-based telescopes, including the Subaru Telescope and ALMA.

Using the data obtained from AKARI, various studies on galaxy formation and evolution were carried out, including a study on the evolution of the luminosity function and a search for AGN. We also combined AKARI NEP survey data with data accumulated by SCUBA2 on JCMT. A variability survey of AGN on the search and study of high-redshift low-mass black holes was conducted using Subaru HSC data.

Based on infrared spectroscopic observations taken from AKARI, we carried out systematic studies of CO absorption toward AGN. We propose that this feature is attributed to the warm molecular gas in the tori around the AGN. We also conducted a detailed analysis of Subaru high-resolution spectroscopic data on the CO absorption toward some of the bright sources observed by AKARI. We focused on a time variety study to reveal the inner structure of the tori. We also carried out follow-up observations of one of the CO absorption targets, IRAS 05189-2524, using ALMA. In addition, we studied other absorption features such as H_2O and the relation between the features and star-forming activities in ultra-luminous infrared galaxies.

Moreover, we conducted an infrared study of jets in AGN. The mid-to-far infrared emissions were discovered from a hot spot in the radio galaxy Pictor A. By comparing multi-wavelength data from the radio to optical range, it has been suggested that the infrared emissions originate from a site of recent particle acceleration within the hot spot. The very hard radio-to-infrared spectrum indicates that the so-called turbulent acceleration operates within the hot spot. Far-infrared emissions were also detected from a hot spot of the radio galaxy Cygnus A.

We conducted a CO (J = 1–0) mapping survey toward

64 Fornax-cluster galaxies using ALMA. Among them, we revealed a complex spatial distribution and velocity field of a radio galaxy, NGC1316. Our data suggest that the molecular gas of NGC1316 was injected within <~1 Gyr and is interacting with a nuclear jet.

We are constructing an AKARI/FIS catalog for nearby galaxies using the AKARI/FIS all-sky data. Photometry of the extended emissions of the nearby galaxies has almost been completed and we are currently verifying the results.

Polarimetric observational studies on star-formation regions have been extensively conducted from the near-infrared to sub-millimeter regions. Using ALMA, we observed CO isotopologues in the rho Oph A star-forming region, and revealed the selective dissociation of CO isotopologues from the UV from a massive star. Based on the results, we also discussed the spatial distribution of the ISM associated with rho Oph A.

Follow-up observations of the episodic mass-losing object WISE J180956.27-330500.2 through infrared and sub-millimeter observations and dust radiative transfer modeling are ongoing.

For studies on extra-solar planets and low-mass objects, we conducted (1) astrometric observations of M-dwarf binaries to constrain the evolutionary models of low-mass objects through a comparison with the dynamical mass, (2) the detection of icy planets beyond the snow lines using ground-based microlensing observations, (3) a comparison of a cold planet mass-ratio distribution between the planet population synthesis model based on the standard core-accretion model and the observational results from a microlensing survey, and (4) a study on the extinction toward the galactic bulge using Subaru/HSC to optimize the WFIRST microlensing survey fields.

Observational studies of the objects in our solar system were also conducted. Interplanetary dust was studied using AKARI mid-infrared spectra (5–13 μm) of zodiacal emissions. We confirmed the excess features within 9–12 μm for all spectra, which are attributed to crystalline (forsterite and enstatite) and amorphous silicates. Variations in the feature shapes among the different sky directions may imply a difference in the mineral composition of the supply sources: Jupiter-family comets, Oort cloud comets, and asteroids.

AKARI near-infrared spectra (2.5–5 μm) of asteroids were used in a study on the abundance of hydrated minerals, their evolution, and a correlation with the asteroid types. Among 66 asteroids, the absorption features of hydrated minerals of approximately 2.7 μm were detected for many different asteroids, particularly C-type asteroids, for the first time. The results suggest that C-type asteroids were heated and dehydrated.

The abundance and origin of crystalline silicates (high-temperature condensates) in comets were studied through mid-infrared observations using the Subaru telescope. We found that dust grains of Comet 17P/Holmes, which underwent a significant outburst in 2007, contain less crystalline silicates compared with grains of other comets. This suggests that Comet Holmes formed in a farther, colder region in the solar nebula than other comets.

Kilometer-sized small objects located beyond Neptune's orbit were surveyed using two small commercial telescopes with CMOS video cameras. We successfully detected a candidate stellar occultation event using a kilometer-sized Kuiper Belt Object (KBO) for the first time.

We also conducted studies to improve the calibration quality of AKARI data. A quantitative evaluation of second-order lights mixed with the long wavelength in near-infrared prism spectra was conducted for inclusion in the standard tool kit.

In parallel with the observational studies, a basic development of future infrared technology was also carried out. The development of an immersion grating for high-dispersion spectroscopy was continued with a special emphasis on the evaluation of a low-resistivity material for better availability. We also succeeded in fabricating a 32 x 32-channel far-infrared sensor by combining a Ge blocked impurity band detector with silicon support with the ROIC for FD-SOI CMOS. In 2018, we developed an array sensor controller to evaluate the far-infrared image sensor.

We also conducted a study on the Japanese contributions to the WFIRST mission, which is a NASA flagship mission after JWST. Since March 2018, the WFIRST Working Group under the Advisory Committee for space science has been restructured as the ISAS WFIRST Study Team to accelerate the activities, including providing polarimetry units as well as a mask substrate for a coronagraph instrument. We also held a workshop for Subaru-WFIRST synergistic observations. The concept definition phase of the small infrared astrometry satellite "small JASMINE" was conducted and a system study of the entire satellite was applied. As a result, the project passed its pre-phase A2 exit review in May 2019.

2.3 Fundamental physics

In relation to fundamental physics, studies on cosmic inflation based on the precise measurement of the cosmic microwave background are being conducted. For this purpose, we are also conducting studies in relation to the development of the LiteBIRD mission under collaboration with domestic institutes such as KEK and IPMU and international partners in the US, Europe, and Canada.

Gravitational waves are also a new exciting field for space astrophysics. In parallel to the contribution to the on-going ground-based facilities, feasibility studies on future space-based gravitational wave detectors have been carried out.

Theoretical studies on the interaction between matter and anti-matter have been conducted to reveal the Dipole enhancement of the protonium formation cross-section in antiproton collisions with excited hydrogen atoms.

2.4 Radio astronomy

Within the radio wavelength range, we conducted a wide variety of observational research using large radio telescopes around the world, including the Atacama Large Millimeter/sub-millimeter Array (ALMA) in Chile and the Very Long Baseline Array (VLBA) in the USA. We have also conducted advanced cooperative observations using the 64-m antenna at Usuda through the RadioAstron space VLBI project of Russia. Our observation targets are compact objects, such as active galactic nuclei (AGN), Galactic center, and maser objects.

In FY2018, we observed the circumnuclear molecular disk (CND) of the Galactic center (GC) using ALMA and found tidally disrupted molecular clouds falling to the CND.

We have also found many massive cores that will form massive stars in the GC 50 km/s molecular cloud. In AGN research, we observed a jet structure of a gamma-ray detected narrow-line Seyfert I galaxy using VLBA and found a recollimation shock area, which should be key information to better understand a relativistic jet in AGN.

Studies on star formation and inter-stellar matter evolution have also been conducted through single-dish observations of molecular clouds and OH clouds using the 45-m telescope at Nobeyama and the 64-m antenna at Usuda.

We developed a balloon-bone VLBI telescope and low-noise millimeter wave receiver for further satellite projects. Furthermore, we are participating in a construction project of the new ground-based antenna for deep space exploration, GREAT, in the context of utilizing our radio astronomy technology.

2.5 Cryogenic system for science missions

Bolometers/micro calorimeters have been proposed as extremely sensitive low-noise detectors for various fields in space astrophysics, including SPICA (infrared), LiteBIRD (microwave), and Athena (X-ray). The development of cryogenic systems, common in these projects, has been conducted in collaboration with these project teams and the JAXA Research Division. In 2016, an ESA Core-Technology Program to develop cryogenic systems to achieve 50 mK sensors in orbit was started in collaboration with ISAS. See section II.-3.-b for more details.

3. Research Topics

The following outline lists all the Department of Space Astronomy and Astrophysics research activities during FY2018.

3.1 Research in X-ray and gamma-ray regions
3.1.1 Observational research
3.1.1.1 Stellar winds from massive star based on observations by SUZAKU
3.1.1.2 Study to establish the model of X-ray emission mechanism from cataclysmic variables with strong magnetic fields and application to the SUZAKU data to estimate the white-dwarf mass.
3.1.1.3 Study of emission mechanism of X-ray binary pulsars and application to the SUZAKU data
3.1.1.4 Observational study for soft X-ray background radiation
3.1.1.5 Study to search for "dark-matter feature" in cosmic X-ray background radiation with SUZAKU
3.1.1.6 Study of hot gas plasma in clusters of galaxies by using morphology of gas distribution of clusters in collision
3.1.1.7 Study of hard X-ray transits using SUZAKU WAM
3.1.1.8 Gamma-ray and polarization study with ASTRO-H SGD instrument
3.1.1.9 Development of MONACO simulator for astrophysical radiation
3.1.1.10 Rocket experiment for hard X-ray emission from Sun (FOXSI)
3.1.1.11 Studies in high-energy gamma-ray astronomy with FERMI LAT (USA)
3.1.1.12 Studies in high-energy gamma-ray astronomy with HESS TeV gamma-ray telescope
3.1.2 Developmental research for observational technology
3.1.2.1 Development of Si mirror substrate with high-temperature plastic deformation technique
3.1.2.2 Development of high angular resolution X-ray optics
3.1.2.3 Development of TES X-ray microcalorimeter for future space missions or ground applications
3.1.2.4 Development of X-ray CCD camera with extremely low background
3.1.2.5 Development of high-precision hard X-ray imaging spectrometer
3.1.2.6 Development of Compton camera for high-sensitivity gamma-ray observations
3.2 Research in the optical and infrared wavelength range
3.2.1 Observational research
3.2.1.1 Study of galaxy formation and evolution at the peak of star-formation history in the universe using multiwavelength observations at the NEP survey region
3.2.1.2 Study of the relationship between stellar population age and molecular gas contents in galaxies
3.2.1.3 Variability survey of AGN using with Subaru HSC
3.2.1.4 Study of infrared absorption features and their relation with star-formation activity.
3.2.1.5 Study of particle acceleration at the hot spot of radio galaxies by mid- and far-infrared observations
3.2.1.6 Study of circumnuclear structure of Active Galactic

Nuclei using AKARI data
3.2.1.7 High-resolutions Infrared spectroscopic study of molecular tori in AGNs.
3.2.1.8 Infrared imaging study of nearby spiral galaxies
3.2.1.9 Optical and near-infrared study of protoclusters at high redshift
3.2.1.10 Study of galaxy evolution for WFIRST project
3.2.1.11 Molecular gas properties of member galaxies of a nearby galaxy cluster with ALMA
3.2.1.12 Construction of AKARI/FIS catalog for nearby galaxies
3.2.1.13 Study of the magnetic field structure in star-forming regions by polarimetric observations
3.2.1.14 Study of infrared circular polarization in star-forming region
3.2.1.15 Study of gas dissipation in proto-planetary disks
3.2.1.16 Infrared and radio observations of inter-stellar matter in the Galactic massive star-forming regions
3.2.1.17 Astrometry study of M-dwarf binaries to constrain mass evolution models
3.2.1.18 Study of extrasolar planets by microlensing survey
3.2.1.19 Study of icy planets population beyond snow line
3.2.1.20 Subaru precursor observations for WFIRST microlensing survey
3.2.1.21 Study of infrared diffuse emission with infrared astronomy mission MIRIS
3.2.1.22 Study of star-forming region with infrared astronomy mission MIRIS
3.2.1.23 Mid-infrared spectroscopic study for the dynamical evolution of the inter-planetary dust in the Solar System
3.2.1.24 Study of comet dust mineralogy with Subaru and AKARI mid-infrared observations
3.2.1.25 AKARI near-infrared spectroscopic study of asteroids and the abundance of hydrated minerals
3.2.1.26 Stellar occultation study for a kilometer-sized Kuiper Belt Object (KBO)
3.2.1.27 Follow-up observations of an episodic mass-losing object
3.2.2 Developmental research for observational technology
3.2.2.1 Development of far-infrared imaging sensors using Ge blocked-impurity band/fully depleted silicon on insulator CMOS chip
3.2.2.2 Development of monolithic multi-layer interferometric filter
3.2.2.3 Development of mid-infrared immersion grating
3.2.2.4 Correction of second-order light contamination and improvement of spectral calibration for AKARI spectroscopy
3.2.2.5 Development of cryocoolers for space cryogenic missions.
3.2.2.6 Material characterization at cryogenic temperature for space missions
3.2.2.7 Promoting Japanese participation in the NASA WFIRST program
3.2.2.8 System study of the small JASMINE mission
3.3 Fundamental Physics
3.3.1 Promoting LiteBIRD mission
3.3.2 Promoting Japanese participation in the ESA LISA mission
3.4 Research in the radio wavelength range
3.4.1 Observational research
3.4.1.1 Promotion of radio astronomy observation using JAXA's tracking antennas, including the 64-m antenna at Usuda
3.4.1.2 Observational study of acceleration and collimation mechanisms in radio jets of AGNs using VLBI
3.4.1.3 Observational study of molecular clouds and star formation mechanisms in the Galactic Center region using ALMA
3.4.2 Developments for Observation Technique
3.4.2.1 Development of a balloon-bone VLBI telescope
3.4.2.2 Development of low-noise millimeter wave receiver
3.4.2.3 Participation in the construct project of the new ground-based antenna for deep space exploration, GREAT.

b. Department of Solar System Sciences

1. Overview

Research activities by members of the Department of Solar System Sciences cover planetary science and interplanetary space physics, including planetary magnetospheres and the Sun. The underlying disciplines include space plasma physics, solar physics, magnetospheric and ionospheric physics, atmospheric science, planetary geology, astromaterial science, and theories governing the formation and evolution of planetary systems. Data from existing missions such as ARASE and GEOTAIL (magnetospheric physics), HINODE (solar physics), HISAKI (extreme ultraviolet spectroscopy for planetary science), AKATSUKI (Venus atmospheric dynamics) BepiColombo/MMO (Mercury magnetospheric physics), and Hayabusa2 (asteroid explorer) have been studied extensively, and samples brought back by HAYABUSA from the asteroid Itokawa have been analyzed. Missions under preparation, including MMX (Martian Moons eXploration: Phobos sample return mission) and JUICE (Jupiter Icy Moons Explorer), are also being handled by members of the department. In addition, we are engaged in basic research regarding the development of new onboard instruments for future missions and small-scale projects using sub-orbital opportunities.

2. Research Activities in FY2018

2.1 Solar physics

HINODE, which has been in orbit for 12 years, has made significant contributions to our understanding of observational solar plasma physics as well as fundamental problems including coronal heating and flare triggering mechanisms. Some of our results, which were published this year, include the origin of linear polarization in the chromospheric H alpha line observed during solar flares based on a statistical study of ground-based observations, a trigger mechanism responsible for a flare-related filament eruption leading to the most severe magnetic storm during the current solar cycle, and mechanisms for the recurrence of active-region jets.

What are the prospects of solar physics for the 2020s? In addition to new instrument developments through sounding rockets and balloon experiments, the solar physics community has made an effort to propose new solar missions for launch during the 2020s. The Next Generation Solar Physics Mission (NGSPM) Science Objectives Team (SOT) is an international advisory team supported by JAXA, NASA, and ESA created to discuss the different aspects of space missions.

Led by T. Shimizu, Project Manager of HINODE, the team has conducted studies and discussions aimed at (1) listing the high-priority objectives and tasks of science that need to be addressed in relation to next-generation solar physics, (2) listing the high-priority instruments required for high-priority science items and, (3) developing ideas for an international framework necessary to implement missions that will fly instruments. In the final report delivered to JAXA/NASA/ESA in July 2017, three of the highest priority instrument packages (a high-resolution coronal/transition-region spectroscopic telescope, high-resolution coronal imager, and large telescope for diagnosing the magnetic field and the dynamics of the chromosphere and photosphere, in order) were identified along with their scientific rationale and the recommendations for mission architectures used to fly the instruments. In 2018, discussions and information exchanges toward realizing the recommendations in the NGSPN-SOT report were conducted, including community-based science meetings and agency-based conversations.

As a conclusion, from a series of discussions within the solar physics community and the NGSPM-SOT report, the community has given its highest priority to the mission concept of flying a high-resolution coronal/transition-region spectroscopic telescope for diagnosing EUV/VUV spectral lines emitted by plasma within a seamless temperature range from the chromosphere to the transition region and corona and by super-hot plasma created through solar flares. This mission concept, called Solar-C_EUVST, was proposed to the ISAS as a candidate competitively chosen M-class mission in January 2018. The scientific objectives are to understand how fundamental processes lead to the formation of the solar atmosphere and solar wind and to understand how the solar atmosphere becomes unstable, releasing the energy that drives solar flares and eruptions, by investigating the energy and mass transfer from the solar surface to the solar corona and interplanetary space. This mission is positioned at the center of the solar research roadmap in Japan and has strong support from the US and European communities. As a result of a selection review led by the Advisory Committee for Space Science and Engineering, Solar-C_EUVST was selected in July 2018 to proceed to the next study phase. ISAS completed an international science review in December 2018, and a review for selecting a pre-project candidate in March 2019, it was concluded that Solar-C_EUVST will proceed to the mission definition phase (PrePhase A2).

In addition, a magnetic reconnection is one of the most fundamentally important processes in space plasma, and the solar corona is the best place for conducting X-ray imaging observations to help us learn more about its physical processes. Complementary metal-oxide-semiconductor (CMOS) detectors with fast readouts and low-scattering mirrors are key components that are expected to enable a new high-time resolution spectroscopic imaging mission in this direction. Indeed, we have already succeeded in prototyping a Wolter-type mirror, demonstrating an extremely high level of performance. A working group aiming to understand particle acceleration under the framework of a magnetic reconnection was established in 2017 with the participation of multiple disciplines. Studies with the working group are in progress toward the next mission proposal to the ISAS for an Epslion mission, called PhoENiX.

As a follow-up to the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) mission, a sounding rocket experiment (designated CLASP II) was prepared toward launch in April 2019. While the first CLASP mission succeeded in detecting polarization in the Lyman alpha line, which is a sign of the Hanle effect in the solar chromosphere, CLASP II is expected to detect polarization in the Mg line to obtain magnetic field information on the chromosphere. A continuous rotating polarizer, a key technology for accurate measurements of polarization, was originally developed in this department.

The development of the readout and data-recording electronics for a focal-plane X-ray CMOS pixel detector was carried out for Focusing Optics X-ray Solar Imager 3 (FOXSI-3), which is another NASA sounding rocket experiment. FOXSI-3 was launched in September 2018 and successfully delivered imaging-spectroscopic data of the soft X-ray corona using this new instrumentation.

The CLASP-2 sounding rocket experiment has been defined jointly with the SUNRISE-3 balloon-borne experiment as one of ISAS's small science programs, i.e., "small solar observations" programs, which will acquire new diagnostic capabilities of magnetic fields in the upper solar atmosphere.

A Japanese group consisting of scientists at NAOJ, ISAS, and Kyoto University are preparing a focal plane instrument, called Sunrise Chromospheric Infrared spectroPolarimeter (SCIP), for the third flight of the upgraded SUNRISE (1-m telescope) observatory on a stratospheric balloon (SUNRISE-3, scheduled in 2021). SUNRISE is dedicated to the investigation of the processes governing the physics of the lower solar atmosphere, and SCIP will measure the polarization of infrared spectral lines emerging from the chromosphere and photosphere. The studies at ISAS this year include a scientific evaluation based on an analysis of numerical simulations and the development of scanning mirror mechanisms and polarization modulator mechanisms.

2.2 Space plasma physics

The Magnetospheric Multiscale (MMS) mission is a NASA Heliophysics flagship project conducting 3D high-resolution formation flying observations of space plasma dynamics using four closely situated spacecraft. The objective of the MMS mission, launched on March 12, 2015 from the US Kennedy Space Center onboard an Atlas-V rocket, is to unveil the microphysics driving a magnetic reconnection, which is considered to be one of the most important processes in space plasma physics. Because magnetic reconnections occur frequently on the surface of the boundary of the Earth's magnetosphere, and in the Earth's magnetotail, these are the regions that the MMS spacecraft will visit to conduct unprecedented in situ observations. Members of the department participated in developing the onboard Fast Plasma Investigation (FPI) instruments, which include four dual electron spectrometers (DES) and four dual ion spectrometers (DIS) per spacecraft. The data obtained thus far have proven to be excellent and are being made available to global research communities. Collaboration between Magnetospheric Observation Satellite GEOTAIL and MMS is ongoing.

The MIO spacecraft (Mercury Magnetospheric Orbiter, MMO) is a JAXA contribution to the BepiColombo Mercury exploration program. In FY2018, we transported all spacecraft to the launch site in French Guiana. We conducted the final assembly and tests of the spacecraft, including the removal of non-flight items, and built all the spacecraft in a stacked configuration. We launched the BepiColombo spacecraft using an Arian-5 launch vehicle on October 20, 2018. After the successful launch, we conducted the initial commissioning of MIO in November 2019 and confirmed that the spacecraft and payloads are operating normally. All commissioning activities planned during the Near Earth Commissioning Phase were completed in December 2018, and the first electrical propulsion was then started. ESA's Mission Commissioning Result Review was held at the end of March 2019, and the BepiColombo mission passed the review. In parallel, the Science Working Group worked on science operations planning. We held an international Science Working Team meeting in Tokyo in March 2019 and discussed the science operations planning. The Young Scientist Working Group is at the core of such activity, and we held an international workshop in Portugal in March 2019 to study the latest science results, remaining issues, and observation requirements of BepiColombo.

SS-520-3 is a sounding rocket that will be launched from Spitsbergen, Norway. The scientific purpose of SS-520-3 is to understand the ion up-flow phenomena in the dayside polar cusp region. Although the SS-520-3 launch was scheduled between December 6 and 19, 2017, a malfunction of the timer equipment was found during the final stage of the integration test. Because the problem could not be rectified by the deadline for transport of SS-520-3 to the launch site, the launch was postponed. The timer equipment problem was completely fixed at the beginning of FY2018. However, the severely poor budgetary situation at ISAS in 2018 prevented SS-520-3 from being launched in winter of 2018–2019. Approaching the solar minimum in this solar cycle, the opportunity to satisfy the launch conditions will decrease. To overcome this situation, the SS-520-3 Payload Instrument team has decided to add a possible ion outflow over the morning side polar cap aurora as an alternative target of the experiment.

We are also participating in two sounding rocket missions (RockSat-XN and LAMP) operated by NASA, in order to reveal the relationship between the pulsating aurora and microburst precipitation of MeV-range electrons. RockSat-XN was successfully launched on January 13, 2019. LAMP will be launched in FY2020.

The results of ARASE (ERG) are described elsewhere.

2.3 Atmospheric science

The HISAKI satellite (Spectroscopic Planet Observatory for Recognition of Interaction of Atmosphere, SPRINT-A) was launched in September 2013 and has been making observations of the plasma distribution in the magnetosphere and/or ionosphere of various planets, including Jupiter and Venus, since December 2013. In 2018, HISAKI succeeded in observing Jupiter's inner magnetosphere at the time of the closest approach of NASA's Jupiter spacecraft JUNO, and Venus and Mars at their closest approach to Earth. The scientific results produced by the cooperative observation with JUNO showed HISAKI's potential importance by providing continuous observations. A collaborative investigation using the "HISAKI" data has been promoting international cooperation (since 2016) within certain international frameworks, including the Participating Scientist Program by NASA. Collaborative studies have shown the important presence of Japan in the full-scale exploration of Jupiter's magnetosphere.

The noteworthy results for 2018 include studies on the inner Jovian magnetospheric response during the period of an active eruption of the satellite Io in January 2015, and on the difference between its response during the active and quiet periods. During this eruption period, it was shown that the transport quantity and speed in the inner magnetosphere became several times greater and faster than during the quiet period. It is also clear that a sudden enhancement of the aurora took place and Io plasma torus emissions occurred more frequently (every few days). HISAKI is continuing its collaborative observations of Jupiter with JUNO at the time of JUNO's peri-Jove passage in order to study the transport of energy and materials in Jupiter's magnetosphere. HISAKI will also continue its collaborative observations of Venus with the Venus climate orbiter, AKATSUKI, in order to study the evolution of its atmosphere.

AKATSUKI, also known as the Venus Climate Orbiter and PLANET-C, was launched in 2010 from Tanegashima Space Center. It failed to be inserted into orbit around Venus in December 2010, but after 5 years of wondering around the Sun, it arrived at Venus in December 2015. The spacecraft was designed to observe the Venusian atmosphere, especially its motion, revealing the meteorological structure of Venus, which is extremely different from that of earth. The spacecraft was equipped with 5 cameras, an IR1 camera observing 1-μm infrared light, an IR2 camera observing 2-μm infrared light, an LIR camera observing 8–12-μm infrared light, a UV imager observing 283- and 365-nm UV light, and a LAC camera observing the lightning on Venus. These cameras take motion pictures of clouds and minor components at different altitudes to reveal the 3D structure of the Venusian atmospheric motion. Furthermore, an ultra-stable oscillator, which is identical to the one onboard Venus Express, was equipped for radio occultation measurements to understand the vertical structure of the Venusian atmosphere. The IR1 and IR2 cameras operated for more than 1 Earth year and other cameras are still observing Venus. The Indian Space Research Organization solicited proposals for science payloads on their Venus mission scheduled for a 2023 launch (November of 2018). Some members of the AKATSUKI Project Team proposed three instruments, namely, an ultra-stable oscillator for radio science experiments, an updated version of an IR2, and an updated version of an LIR.

The opportunity to study the Martian atmospheric escape using a Mars orbiter (Mars Aqueous-environment and Climate Orbiter, MACO) is considered one of the next 20-year objectives for Mars exploration. It is also being investigated whether the scientific requirements can be satisfied using the new technologies of the Mars landing mission in the future, such as a Martian atmospheric capture and a Mars plane. To prepare for these future missions, a fundamental optical technology is being developed to protect the high contrast vane from stray light, which is essential for close-up observations of the upper atmosphere of Mars. In parallel, within the framework of the Mars Science Sub Science Team (SST) of the MMX project, the scientific objectives for the physics of the near-Mars space and the Martin atmosphere are being discussed to provide feedback for the design of the instruments and the observation plan.

2.4 Planetary science

The Hayabusa2 mission, which is expected to return samples from the C-type asteroid 162173 Ryugu, has been conducting observations of Ryugu since July 2018. Establishment of the Curation Facility for the Hayabusa2 sample to be returned in 2020 started by building a new clean room and fabricating a set of clean chambers, including a new technology to pick up samples in a vacuum environment. The MMX project that is the Phobos sample return mission, is in preparation for a launch in 2024. Its science and instrumentation are under study, with international collaboration on a near-infrared hyperspectral imager and gamma-ray and neutron spectrometers. Japanese participation in JUICE and the Demonstration and Experiment of Space Technology for INterplanetary voYage (DESTINY^{+}) project, an M-class planetary mission driven by a dust science theme, is expected to ramp up soon. In addition, a solar powered sail mission (OKEANOS) to rendezvous with and land on a Jupiter Trojan is under intensive study for scientific objectives and its instrumentation is being enabled through international collaboration. A study on the Comet Astrobiology Exploration Sample Return (CAESAR) mission, a finalist for NASA's New Frontier mission to return samples from comet 67P/Churymov-Gerasimenko, is ongoing.

Each of these exploration missions is targeting small bodies born "outside the snowline", which refers to the distance from the sun where water becomes solid ice. We have formulated a roadmap that describes how these multiple missions are linked together and why such a systematic approach is required. Without a supply of water and other volatiles (including organic compounds) delivered by small bodies from outside the snow line, our planet would never have become habitable. However, there are still some fundamental questions remaining: When and how did this process occur? Furthermore, is it possible for habitability to be established on worlds outside the snow line?

A penetrator hard lander system, which enables us to investigate the internal structure and to make in-situ observations on the surface of the Moon and planets, is under development. State-of-the-art of communication and data processing and low-temperature durability technology have been applied to realize these Mars and small body asteroid missions. We are also developing a penetrator system for the monitoring of volcanic activities on Earth for the purpose of disaster prevention.

The SLIM project team conducted detailed analyses of the landing site candidates and selected the landing site in FY2018. Our department contributed to the data analyses for selecting the landing sites suitable for scientific interest and the technology requirements for landing. Based on the landing site selection, we also conducted detailed geological analyses of the surrounding region of the landing site, which will be useful for future data analyses. Regarding the development of a multiband camera, manufacturing of an engineering model has begun.

MMX is the third Japanese sample return mission followed by HAYABUSA and Hayabusa2. The MMX spacecraft is scheduled to be launched in 2024, orbit both Phobos and Deimos (multi-flybys), and retrieve and return >10 g of Phobos regolith back to Earth in 2029. The origins of Phobos and Deimos are still a matter of significant debate, namely, the capture of asteroids versus in-situ formation by a giant impact on Mars. In either case, MMX will provide clues about their origins and offer an opportunity to directly explore the satellite building blocks or juvenile crust/mantle components of Mars. MMX is also aimed at understanding the physical processes in the circumplanetary environment of Mars. The new knowledge of Phobos/Deimos and Mars will be further leveraged to constrain the initial conditions of the Mars-moon system and to gain vital insight regarding the sources and delivery process of water (and organics) into the inner rocky planets.

Recognizing that science and human exploration are mutually enabling, US/NASA created the Solar System Exploration Research Virtual Institute (SSERVI) to address basic and applied scientific questions fundamental to understanding the Moon, Near Earth Asteroids, the Martian moons Phobos and Deimos, and the near-space environments of these target bodies. Many space agencies and organizations such as universities in not only the US but also in other countries have participated in these activities. NASA expected JAXA/ISAS to join in these activities as an international partner and to become a node of the Japanese scientific community. In response, we proceeded to make an agreement for our participation with SSERVI.

Internationally, it has been recognized that "planetary protection" is one of the most important themes for future space exploration. At ISAS, we have started studying and working on planetary protection because we are planning a mission to a Martian satellite where lives may be able to survive. We have also been involved in considerations and/or reviews for planetary protection planning of various JAXA explorations such as MMX and OMOTENASHI.

3. Research Topics

The following outline lists all the Department of Solar System Sciences research activities during FY2018:

3.1 Solar physics
3.1.1 Solar observations: HINODE, HINODE-IRIS
3.1.2 Instrument development (photon-counting X-ray telescope, photon sensor driver, high-speed CMOS-based sensor, mechanisms), and future mission planning
3.1.3 CLASP, CLASP II
3.1.4 International balloon experiment SUNRISE-3
3.2 Space plasma physics
3.2.1 In situ and remote sensing observations: AKEBONO, GEOTAIL, REIMEI, MMS, KAGUYA, HISAKI, ARASE (ERG) and magnetosphere of outer planets
3.2.2 Sounding rocket: SS-520-3, RockSat-XN, and LAMP
3.2.3 Numerical simulations: PIC simulation for space plasma research and physics of proto-planetary disks
3.2.4 Instrument development
3.2.5 Future missions: BepiColombo (Mercury), JUICE(Jupiter), mission planning of a formation flying satellite FACTORS, satellite observation of exoplanets' atmosphere by UV, space telescope for planets by UV, and satellite observation of Martian atmospheric escape
3.3 Atmospheric science
3.3.1 Venus: AKATSUKI
3.3.2 Mars
3.3.3 Earth's lower thermosphere and ionosphere: Observation of anomalous phenomena in the Sq current focus by sounding rocket, Observational study of the ionospheric electron density irregularity, Observational study of thermal electron energy distribution in the lower ionosphere.
3.4 Planetology
3.4.1 Lunar science using KAGUYA data
3.4.2 Asteroids: curation and analysis of Itokawa samples and in preparation for Ryugu sample, Hayabusa2 to the C-type asteroid 162173 Ryugu
3.4.3 Future missions: SLIM, DESTINY+, penetrator technology, landing mission to the Moon and Mars, MMX (Phobos sample return), OKEANOS mission to Jupiter Trojan asteroid, CAESAR (comet sample return), the lunar and Mars cave

missions, HERACLES (lunar sample return)
3.4.4 Instrument development

c. Department of Interdisciplinary Space Science

1. Overview

The Department of Interdisciplinary Space Science performs research and development for onboard devices and information systems deployed with flight vehicles and space platforms (e.g., balloons, rockets, satellites, and the ISS). The department contributes to novel interdisciplinary studies in space science and peripheral fields through fundamental research in the following areas:

- Space utilization. The department aims to use the unique characteristics of space, such as microgravity and radiation, to understand phenomena that are difficult to measure and observe on the ground. The department conducts materials-science studies to yield materials with novel functions. We also study space biology—that is, the effects of the space environment on behavior, development, and evolution—and astrobiology, including the search for the precursors of life and extraterrestrial life.
- Information systems. The department is studying basic computing technologies, such as data processing, computer networking, distributed processing, and high-capacity databases, that will enable the high-speed processing, transmission, and storage of the large amounts of observation data generated by scientific satellites. We also perform space-engineering research about the visualization of space science data, monitoring for spacecraft malfunctions, numerical simulations, and data assimilation.
- Scientific balloons. The department is engaged in R&D of balloons used for space science research. This includes work on balloon operating systems and experimental systems used in scientific observations and engineering demonstrations.

2. Research Activities in FY2018

2.1 Space utilization science

In the field of materials science, phenomena that occur in extremely high temperatures are often studied using electrostatic levitation. Using an electrostatic levitator in the International Space Station, several oxide samples (e.g. Al_2O_3, Er_2O_3) whose melting temperatures are over 2,000°C have been melted successfully and their liquid-phase thermophysical properties have been measured.

In order to develop a hybrid energy conversion device that uses the thermoelectric and photovoltaic properties of InGaSb, InGaSb crystals were grown and analyzed based on the results of the Alloy Semiconductor Experiment on the ISS. The thermoelectric properties of InGaSb was improved with the optimization of Ga additions, and are so far the most impressive among any reported values of binary or ternary III-V semiconductors.

Life science activities are also underway. Last year, 5'-AMP was administered to rats at 20 °C. This experiment showed that hypothermia can be maintained for about 4 hours while body temperature is lowered to near the ambient environmental temperature. Research on muscle atrophy due to drug-induced artificial-hibernation was continued from last year, and in particular, long-term preservation of artificial hibernation was studied. In order to extend the artificial-hibernation time and maintain hypothermia for a long period, a small implantable osmotic pump was tested. This pump can continuously administer a fixed amount of drugs. The small osmotic pump installed under the skin was confirmed to continuously administer a steady dose of drugs.

Behavioral science activities were also advanced this year. Indirect gravitational stimuli and a visual signal were studied with starfish’s righting behavior. The effect of contact between tube feet and water surface had little effect on righting behavior. Righting behavior did not change by background colors, that could regulate the behavior to take action to hide from an enemy. These results suggest that righting behavior is the direct response to gravitational stimuli.

In astrobiology, the "Tanpopo" experiment, which captures cosmic dust and exposes microbes to test the Panspermia hypothesis, is almost completed in the Kibo exposure module on the ISS. Although the sample is still under analysis, the capture of cosmic dust and the survival of microbes in the test environment have been confirmed.

To explore the viability of life in extreme environments like the Moon and Mars, life science experiments are underway in the Van Allen radiation belt aboard a microsatellite, in launches of sounding rockets, and aboard a hybrid flight system of balloon and drones called ‘Barone’.

2.2 Research in information science and information technology

The department performed basic research on large- scale computation applied to spacecraft development and operations. The low memory bandwidth CPU acceleration method proposed so far was evaluated using an architecture different from that of the JAXA supercomputer. While confirming the effectiveness, we studied new issues. In the development of the hierarchical equally spaced cartesian structured grid solver, test calculations were performed on the aircraft take-off and landing configuration.

Usually, it takes several months to create a computational grid for the analysis of a real configuration with such a complex geometry, but it has been confirmed that the new method can create it in a few minutes and that analysis is also possible.

The department investigated methods of visualization and studies related to visualization. (1) We are developing methods to visualize the behavior of the asteroid probe Hayabusa2 with Super Hi-Vision quality in collaboration with NHK. The purpose of the collaboration is to assist the operations of space probes by visualizing the behavior of the probe. In conjunction with the telemetry data of Hayabusa2 and high-resolution real-time CG techniques provided by NHK, we have been able to visualize the behavior of Hayabusa2 with reality. (2) In order to visualize asteroid simulants, we developed methods of local refinement applicable to shape models of asteroids. While keeping the whole shape of the object, we can generate local fine shape models, such as the point of the touch-down. Another method to generate local shape models has made it possible to simulate artificial craters generated by the SCI (Small Carry-on Impactor) and so on. (3) We developed methods to visualize various reflection models and indirect illumination, which can be assumed in case of asteroid exploration. The methods are also applicable to other types of visualization, such as the body of the SCI.

The data archive study is also handled by this department. There are two topics, namely, long-term preservation and utilization. For the long-term preservation of the planetary data archive, the global standard: Planetary Data System version 4, PDS4, is used to prepare archives for ongoing and future missions. In addition, the ancillary data archive in SPICE format is used to support science for the Hayabusa2 mission. For the implementation, the Web Service API: Planetary Data Access Protocol, PDAP, is developed to search planetary data. The engine has been unified, and it supports HAYABUSA, Akatsuki, and SELENE (Kaguya) data. The response from the API is VOTable and is in XML format, which enables users to access the metadata using a programmatic interface. For remarkable utilization, anomaly detection is studied using engineering conversion datasets.

2.3 Research on scientific balloons

A super-pressure balloon was developed to expand the possibilities for scientific observations with balloons. This balloon can achieve long-duration flights by maintaining lift and volume against differential pressure due to solar irradiation. Since 2010, intensive efforts have been underway to cover the balloon's film with a diamond-shaped net to increase its resistance to pressure during the daytime. This balloon has the advantage of being lighter than the conventional lobed-pumpkin design. This year, the mechanical properties of the net for the balloon were studied by tensile tests. The result shows that the breaking strength of the net is 8 times higher than the required strength. However, it is 80 % of the breaking strength of the filament of the net. The reason for the degradation is considered to be the twisting of the net. From ground inflation tests of two 2,000 m^3 balloons, the relation between the radius and meridian length were measured and compared to the theoretical shape of Euler's elastica, which is the shape withstanding the differential pressure only by meridian tension. Gas leakage of the 10 m^3 balloon developed last year was tested to find small holes on the gore films primarily along the sealed lines. A new method to reduce the leakage was developed and applied to the balloon. After filling the air inside the balloon with a differential pressure of 1,000 Pa, the differential pressure was kept positive for more than 400 hours.

In space science research using balloons, detailed analyses of cosmic-ray data obtained during balloon flights over Antarctica in the Balloon-borne Experiment using a Superconducting Spectrometer were continued. The energy spectrum of antiprotons is being extended to lower energies, and hitherto undiscovered antideuterons are being searched.

In addition, the department continued the operation of CALET on the ISS to observe high-energy electrons, gamma-rays, and other components of cosmic radiation. As one of our most important achievements, by doubling the data statistics, we improved the precision of the cosmic-ray all-electron (electrons and positrons) energy spectrum and extended the energy range to 4.8 TeV. We also searched for gamma-ray counterparts of five gravitational wave events observed by the LIGO/Virgo Scientific Collaborations. The derived upper limit on the gamma-ray emission indicates that there will be a favorable opportunity to detect high-energy gamma-ray emission in further observations.

Furthermore, studies were promoted to continue development of the General Anti-Particle Spectrometer (GAPS), selected as a Small Science Program in 2017, to address the dark-matter enigma through highly sensitive observations of cosmic-ray antiparticles, including the undiscovered antideuterons.

3. Research Topics

The following outline lists all the Department of Interdisciplinary Space Science research activities during FY2018.

3.1 Space utilization science
3.1.1 Materials science
3.1.1.1 High-temperature melt and metastable phase using levitation method
3.1.1.2 Research on crystal growth
3.1.2 Life sciences
3.1.2.1 Study on artificial hibernation for interplanetary

d. Department of Space Flight Systems

1. Overview

The Department of Space Flight Systems is engaged in fundamental and applied academic research on space flight systems to contribute to space science projects. The main fields of research are systems engineering (SE) related to space exploration, space transportation engineering, and discipline engineering.

2. Research Activities in FY2018

2.1 Space navigation SE

Space navigation SE research in the Department plays a role in pioneering projects and includes applied flight dynamics, control systems theory, and transport system design for spacecraft and flight vehicles. The department is focusing on research for spacecraft, such as interplanetary probes and advanced scientific satellites, and their navigation, guidance, and control. Space flight systems, such as those for rockets, are being developed. We also perform mission planning and analysis, orbit design, and system design and testing using experimental craft and computer simulations.

2.2 Space transportation engineering

Space transportation engineering research covers a variety of areas, such as propulsion systems and aerodynamics for the propulsion and navigation of space flight vehicles. The department is involved in developing solid, liquid, and hybrid rockets for the following projects: a reusable rocket to realize future space transportation; an air- breathing space plane engine; advanced space propulsion systems, such as electric propulsion used for interplanetary transfers; and a system and its component technologies for re-entry/recovery and orbit control using the atmosphere. Furthermore, the department is evaluating and optimizing the aerodynamic characteristics of flight vehicles, in addition to fundamental research on chemical reactions, flow, heat, and electromagnetism, from perspectives of mechanical engineering, fuel engineering, chemical reaction engineering, magneto fluid dynamics, heat transfer engineering, gas dynamics, and high-speed fluid dynamics.

2.3 Discipline engineering

The department is involved in applied and fundamental research for space structures and materials for systems for various flight vehicles and other structures used on the ground, in low Earth orbit, and in geostationary orbits around planets and in deep space. We conduct investigations into structural dynamics, structure design and analysis, and mechanical environmental testing for rockets and artificial satellites. The department also works on deployment structures and mechanisms, such as extendable booms and deployable antennas. We also conduct research on the strength and workability of structural materials for spacecraft, heat-resistant materials for propulsion systems, and materials for membranes and cables. For future space structures, the department is helping to create and analyze new structures for precise shape control systems, ultra-lightweight structures (such as sails), and adaptive structures using high-performance materials.

3. Research Topics

The following outline lists all the Department of Space Flight Systems research activities during FY2018.

3.1 Epsilon rockets
3.1.1 Aerodynamics of Epsilon rockets
3.1.2 Guidance and control system for Epsilon rockets
3.1.3 Structural systems for Epsilon rockets
3.1.4 Static test firing of propulsion system for Epsilon rockets
3.2 Reusable space transportation system for frequent flights
3.2.1 Reusable rocket system
3.2.2 Reusable rocket engine and propulsion system
3.2.3 Aerodynamics and guidance and control system for reusable rockets
3.2.4 Fault-tolerant systems for reusable rockets
3.2.5 Development of cryogenic composite tank with electrocast line
3.3 Solid-fuel rockets
3.3.1 Solid propellant using high-energy materials
3.3.2 Solid propellant for a new gas generator used for auxiliary propulsion systems
3.3.3 Debris-less solid propellant
3.3.4 Solid propellant using thermoplastic materials
3.3.5 Solid propellant kneading system with artificial muscle actuators
3.3.6 Non-destructive reliability evaluation of solid rocket motor
3.4 Hybrid rockets
3.4.1 Independent control of thrust and mixture ratio in A-SOFT hybrid rocket
3.4.2 Numerical analyses of boundary layer combustion instability in axial-injection hybrid rockets
3.4.3 Safety of hybrid rockets
3.4.4 LOX vaporizing system
3.4.5 Demonstration of A-SOFT hybrid rocket engine
3.5 Technology demonstration system for space planes
3.6 Innovations for aerodynamic performance
3.7 Acoustic analysis for forecasting rocket plume noise
3.8 Problems with the aerodynamics of space transporters and other space vehicles
3.9 Thermal design, analysis, and testing of scientific satellites and new thermal control technologies for future scientific satellites
3.10 Structural systems for existing scientific satellite projects
3.10.1 Structural systems for small scientific satellites
3.10.2 Structural systems for MMO
3.10.3 Structural systems for SLIM
3.11 Structure, function, and dynamics of rockets for launching scientific satellites
3.12 Heat-resistant composite
3.12.1 Anti-environment ceramic coatings
3.12.2 Use of heat-resistant composites in various engine components
3.12.3 Weight and cost reduction of heat-resistant material used in solid rocket nozzles
3.13 Polymers and polymer matrix composites
3.13.1 Development of CFRP disks for high-speed rotation
3.13.2 High-precision composite material for large space structures
3.13.3 Carbon nanotube-reinforced composites
3.14 Strength and destruction of metallic materials
3.14.1 Creep fatigue of combustion chambers of rocket engines
3.14.2 In-situ observation of superplastic grain boundary sliding
3.14.3 Performance improvement of shape-memory alloy
3.15 Joining of ceramics and metal
3.16 In-situ observation of hypervelocity impact damage
3.17 Activities to establish international standards for materials and processes
3.18 Liquid propulsion systems
3.18.1 Combustion of bio-alcohol fuel
3.18.2 R&D of thruster that uses hydroxyl ammonium nitrate-based liquid monopropellant
3.18.3 R&D for ceramic thrusters
3.18.4 N_2O/ethanol propulsion system
3.18.5 Gas-liquid equilibrium pressure regulating system
3.18.6 Solid-gas equilibrium thruster
3.18.7 High-energy ionic liquid propellants
3.19 Electric Propulsion
3.19.1 Ion Thruster
3.19.2 DC Arcjet
3.19.3 Pulsed Plasma Thruster
3.19.4 Magneto-plasma Sail
3.19.5 Thrust Stand for micro thrusters
3.19.6 Hall Thruster
3.20 Re-entry and planetary entry
3.21 Development of re-entry vehicle with deployable flexible structure
3.22 Mars exploration airplane
3.23 Guidance system for astronomical object landing navigation
3.24 Analysis of astrodynamics (applied spacecraft flight dynamics) and deep space exploration missions
3.25 Research for Hayabusa2
3.25.1 Analysis of the orbiting, guidance, navigation, and control of Hayabusa2

3.25.2 Astrodynamics research for Hayabusa2
3.25.3 Landing dynamics of asteroid lander/rover
3.26 Operation of IKAROS
3.26.1 Observation of solar sail motion and status
3.26.2 Improvement of operation technology
3.27 Plan for exploration in the outer planetary region with solar power sail-craft
3.27.1 Planning and system design
3.27.2 Prototyping of spacecraft sails
3.27.3 Prototyping of sail deployment mechanism
3.27.4 Thin-film solar cell
3.27.5 Deployment motion and deployed form of film structure
3.27.6 Sampling
3.27.7 Rendezvous and docking
3.28 Power control system based on supply and demand conditions
3.29 Ultralightweight thin film solar array structure deployed by booms
3.30 Research and development on liquid hydrogen utilization technology

e. Department of Spacecraft Engineering

1. Overview

The Department of Spacecraft Engineering performs research on rockets, artificial satellites, planetary probes, exploration robots and spacecraft ground systems, as well as on basic technologies in the fields of electrical and electronics engineering, measurement and control engineering, and energy engineering.

In the field of electronic materials and devices, we are conducting fundamental research and development on space semiconductor devices and materials used for a range of devices. These devices include pulse radars for detecting the altitude and speed of a lunar or planetary lander, lasers and radars, communication devices, antennas, and integrated systems installed on spacecraft. We are also investigating ways to improve the performance of lithium-ion secondary cell power supply systems for spacecraft, power storage capacitors, and the use of fuel cells in spacecraft. In the fields of navigation, guidance, and control, we are developing sensors for detecting attitude, relative position, and obstacles. In addition, we are investigating high-precision attitude and alignment control technology, autonomous navigation using images, algorithms for detection and circumvention of obstacles, and guidance and control rules for landing on the Moon and planets; and are developing high-performance control actuators. Our research also encompasses intelligent and autonomous space probes and technology for the autonomous exploration of the Moon and planets using mobile robots (rovers). In the area of ground systems, we are studying high-precision orbit determination methods such as the combination of differential one-way ranging (DDOR) and optical navigation and large-scale information integration for spacecraft operation systems. Furthermore, we are researching the system architecture of small scientific satellites and cosmic energy systems, such as solar power satellites.

2. Research Activities in FY2018

2.1 Technology for power supply systems

For small missions, we developed a small SUS laminate battery with high energy density. The battery will be installed in the Smart Lander for Investigating Moon (SLIM), which was selected as the third small satellite. In addition, we developed a solar cell for future exploration of the surface of Mars. Owing to their multijunction structure, solar cells must be optimized for the solar spectrum on Mars. We improved the conversion efficiency by approximately 9% compared with solar cells for the AM0 solar spectrum. We are also conducting a project on battery designs for low temperatures and electrochemical reduction electrolysis.

We confirmed the drastic degradation of the charge/discharge cycling performance of lithium-ion secondary cells at temperatures lower than 10 °C. We further investigated the background chemistry of the degradation.

We are continuing work on an energy carrier that uses renewable energy, based on previous research on fuel cells/renewable fuel cells. We are currently attempting to apply the technology to the oxygen generator and CO_2 reduction devices for future manned operations. Furthermore, we evaluated the performance of the battery onboard the REIMEI spacecraft and determined the AC impedance trend for 13 years in orbit. Based on the collaboration contract with DLR, we transferred our REIMEI battery data to DLR and began simulations to understand the internal condition of the battery cells of REIMEI.

2.2 Communication technology

In our research on components for communications and energy transmission in space, we are developing electronic cell chips that use space-capable RF nano-electronics and prototyped system-on-chips using Si and the compound semiconductor integrated circuit called "HySIC". We developed a prototype for an active integrated antenna with a GaN Schottky barrier diode and a Si RF integrated circuit, which will be used as a component for an ultra-small phased array antenna. We also developed a GaN high-efficiency amplifier to be used in a marine radar.

For satellite and spacecraft systems, we developed an active integrated phased array antenna with a retrodirective function for the Solar Sail project, and evaluated a BBM for a docking radar to be used for sample return. We also fabricated a prototype for a compact wireless health monitoring sensor system to be used in spacecraft incorporating our high-performance small rectenna and a wireless power transmission system.

We completed the critical design of an X-band 20 kW class solid-state power amplifier (125 W output module, combining/dividing, filter) for a deep space exploration ground station at Mikasa.

2.3 Information and data processing technology

In the field of information and data processing, we are developing standard components and interfaces that can be used in various spacecraft based on standard architecture (system construction principle), and their simulation technology. For the simulation of spacecraft components, we showed that it is best to simulate state transitions using automatically generated on-board software from the Spacecraft Information Base. We developed a communication protocol called SpaceWire-R for connecting computers in spacecraft. We evaluated its interoperability and performance using an implementation developed by a European company, and hardware implementation developed by a Japanese company. This protocol is a candidate for a future JAXA design standard. In addition, we are establishing a space communications and data handling architecture as part of JAXA design standards to standardize communications and data handling methods across various spacecraft. Among the standards, the top two documents have been completed. Furthermore, we are developing a method that uses modeling technology and linguistic theory to enable the development of databases that can store spacecraft specifications.

2.4 Navigation, guidance, and control technology

We conducted research on safe landing methods; for example, the interaction between landing legs and surface soil, sloshing effect of fuel tank at touchdown, etc. We also performed research on a method for measuring slops using Shape-from-Shading technology.

We performed research on the application of a magnetic levitation mechanism by magnetic flux pinning effects to spacecraft. The aim of this research is to shut out microscopic vibration disturbances and thermal transmission. In FY2018, the vibration transmission characteristics of a proposed system with superconducting bulk material was experimentally evaluated. The results corresponded reasonably well with the numerical model, which was also proposed by our group. This indicates the effectiveness of the proposed system and the validity of the analytical model. This research will lead to the deployment of new magnetic formation flight technologies.

We are developing a motion stage for controlling the attitude of sounding rockets more accurately. It will be used onboard the S-310 series sounding rocket in the near future.

2.5 Autonomous control and robot technology

To improve the autonomy of rovers that move around to explore the surface of the Moon, we conducted a field experiment (autonomous movement and action planning). We developed technologies for environment recognition using a wide-angle high-dynamic range camera; for visual odometry in a terrain with few characteristics; for categorizing natural geography and estimating traveling power based on the robot's traveling vibrations; for path planning based on power supply level; and for estimating the absolute position based on skyline matching. We produced and verified a prototype for the image-processing board that will be installed. To improve the ground-covering ability of rovers, we compared and evaluated suspension mechanisms; measured the power supply for traveling on various types of terrain; estimated the traction force using resistive force theory; optimized and evaluated the wheel grouser shape; and fabricated a transforming wheel from a shape memory alloy. In addition, to enhance the environment recognition on the planet's surface, we conducted a movement measurement experiment using the Laser Range Imager (LRI), and improved the LRI hardware. We carried out performance verification of the laser measurement system, including topography acquisition and path planning, using a commercially available flash LIDAR.

The MINERVA-II twin rovers onboard Hayabusa2 spacecraft were deployed onto the asteroid surface in September 2018. The rovers successfully landed on the surface and conducted the world's first autonomous explorations over the surface of the small body. Numerous images taken on the surface as well as the technical status data obtained by the rovers will contribute to the scientific analysis of the target asteroid.

Subsequently, the MASCOT lander developed in Europe was ejected from Hayabusa2 during the same operation as MINERVA-II. The telemetry data from MASCOT was perfectly reconstructed at the relay component of MINERVA-II without any errors.

Small deployable probe onto the Lunar surface installable to SLIM landing mission made great progress in the payload configuration, which was transferred to the preliminary design review of the SLIM mission.

2.6 Device technology

In the field of electronic materials and devices, we performed fundamental research on semiconductor devices that will be installed in spacecraft, developed an environment-resistant device, and researched semiconductor materials. We studied the radiation tolerance of thin-BOX SOI SRAMs by heavy ion testing and simulation. We found a method to evaluate the radiation tolerance of each cell in SOI SRAMs by its electrical characteristics, and a method of estimating the radiation tolerance that depends on bias conditions.

We developed LIDARX and Flash LIDAR. LIDARX, a light pulse detection integrated circuit, is a readout circuit for avalanche photodiode (APD) output of long-distance LIDAR receivers. It measures the timing and height of the pulse output from the APD. LIDARX has been adopted as the core device of MMX's LIDAR, and the development of its EM has started. Flash LIDAR is a sensor that acquires a range image, which is used to detect obstacles during the landing process and measure the relative distance for rendezvous in orbit. In 2019, we developed the world's first distance imaging sensor using Si-MPPC. This sensor has started EM development as the core device for HTV-X mounted slave sensors.

2.7 Orbit determination

The orbit determination group determines the orbit status of operational satellites and spacecraft to prevent problems during missions. In the orbit determination for Hayabusa2, we successfully used delta differential one-way ranging (DDOR) measurements while the ion engines were firing. By using the DDOR data with OP-NAV (Optical Navigation with on-board optical telescope) data, we were able to estimate the trajectories of Hayabusa2 and its target asteroid Ryugu very precisely. This greatly contributed to the successful arrival of Hayabusa2 in Ryugu. We also participated in near-Earth object (NEO) activities led by the United Nations and continued activities for NEO observations in Asia and Japan.

2.8 Small satellite systems

We are conducting research to develop an X-band synthetic aperture radar (SAR) that can be installed in a 100 kg class satellite. This was adopted as an ImPACT program of the Japanese government and its final goal is to develop a model for an SAR with resolution of 1 m by FY2018. We developed engineering models for an antenna, a power amplifier for transmission, and an X-band high-speed transmitter for sending observed data; and verified that they achieved the desired performance. A new venture company was established in 2018 to commercialize technological products, and the company is in the process of launching the first and second demonstration SAR satellites in 2020 and 2021 with the support of JAXA.

A 2-3 Gbps high-speed downlink communication system is being developed by the ImPACT program. We applied 64APSK modulation in the X-band (8025–8400 MHz) and utilized dual circularly-polarized waves. The X-band high-speed transmitter was launched in the Rapis-1 satellite of JAXA in January 2019. In February, we received the downlink signal at the 10 m antenna, Usuda, JAXA. The signals were successfully received and demodulated at the 10 m antenna, Usuda, JAXA. We recorded a total data communication speed of 1.96 Gbps with 64APSK (RHCP) and 16APSK (LHCP) modulations. To the best of the author's knowledge, this communication speed is the world's highest in the X-band with earth observation satellites.

We have also been working on satellite architecture, components, and implementation technology while aiming to reduce the size, weight, and production time for the satellite bus; for example, efficiency enhancement of power supply units in components, and trial production of one-chip computers based on vertical assembly technique.

2.9 Navigation, guidance, and control technology

We are studying image-based navigation and landing radar for the post-SLIM era. We are investigating the improvement of performance and accuracy using deep learning networks, and have started innovative studies to apply neuromorphic processors and sensors for executing complex navigation computation under the condition of severely low resources.

2.10 Space energy systems

For space solar power satellites, we performed fundamental research on a major structure of the tethered SPS called power generation and transmission panel, and carried out a beamforming experiment for the long distance and high-accuracy wireless power transmission (WPT) system using the prototype phased array antenna system.

Carbon nanotube actuators (CNAs) have been developed to compensate for antenna deformation. Thermal vacuum test and electron irradiation test of CNAs were performed to evaluate the resistance of CNAs to space environmental factors.

We conducted experiments on microwave beams under near-field conditions as a WPT method for the drone. Also, for the WPT method, we developed an array antenna for the pilot signal that was mounted on the power-transmitting antenna surface of SPS, and evaluated the influence of antenna deformation.

We have also begun studying panels that mount antenna elements and solar arrays on the entire surface.

3. Research Topics

The following outline lists all the Department of Spacecraft Engineering research activities during FY2018.

3.1 Technology for power supply systems
3.1.1 Characteristic evaluation for a space solar cell under extreme conditions
3.1.2 Power storage device for space
3.2 Communication technology
3.2.1 Wireless sensor and high-efficiency circuit technology
3.2.2 Deep space RF communication technology for installation on satellites
3.2.3 Near-Earth communication technology for installation on satellites

3.2.4 Wireless communication technology for inside spacecraft
3.3 Information and data processing technology
3.3.1 Satellite data processing architecture
3.3.2 Application of modeling technology to satellite development
3.3.3 Software technology components for an autonomous remote system
3.4 Navigation, guidance, and control technology
3.4.1 Posture determination and control for spacecraft
3.4.2 Navigation, guidance, and control of lunar and planetary probes
3.4.3 Navigation sensor for planetary probes
3.5 Autonomous control and robot technology
3.5.1 Lunar and planetary probe robotics
3.5.2 Rover for exploration of small celestial bodies
3.6 Device technology
3.6.1 Research and development of analog integrated circuits
3.6.2 Environment-resistant electronics
3.6.3 Micromachines for space
3.7 Orbit determination
3.7.1 DDOR technology
3.7.2 Orbit determination using an open-loop receiver
3.8 Small satellite systems
3.8.1 Small scientific satellites
3.8.2 High-speed communication system for small satellites
3.8.3 Microwave synthetic aperture radar for small satellites
3.9 Space energy systems
3.9.1 Solar power satellite systems
3.9.2 Thin-film power-generating systems
3.9.3 Interaction between high power system and space environment

f. International Top Young Fellowship

Since FY2009, ISAS has offered the JAXA International Top Young Fellowship (ITYF) program as part of its initiatives to make Japan a leading member of the most advanced space science community. The program calls for the participation of young and promising researchers from across the world, and successful applicants are invited to Japan for a predetermined assignment term. It is a popular program, with the open call applicants significantly outnumbering the available places every year. Fellows invited through this program stay Japan on a three-year term, which can be extended to five years after review. The program was recognized in the FY2012 JAXA international external evaluation as "highly effective in promoting ISAS's presence and in contributing to the advancement of space science."

A total of 11 fellows have participated in the program so far, six of whom have since taken permanent posts in other institutes and universities. For FY2018, one new fellow was selected. ITYF fellows are encouraged to become involved in other projects as well as to pursue their own studies. These opportunities are expected to have a synergistic effect through interactions between the fellows and Japanese researchers at ISAS. Much as previous fellows have contributed to remarkable outcomes in the projects in which they were involved, our current fellows are not only making proactive contributions to ongoing projects, but are also actively engaged in forming future projects.

ITYF Fellows (as of March 31, 2019)

Name	Former Institute	Research Theme	Period
PERALTA, Javier	Instituto de Astrofísica de Andalucía (Spain)	Characterization of atmospheric dynamics by using "AKATSUKI" and "Venus Express"	April 2015 -
IZUMI, Kiwamu	California Institute of Technology (US)	Observational gravitational wave astronomy	September 2017-
BONARDI, Stéphane	Massachusetts Institute of Technology (US)	Self-reconfigurable modular robots for space exploration: design and control	October 2017-
QUINTERO NODA, Carlos	Solar-B Project Research Associate/ JAXA	New insights on solar polarimetry as preparation for future solar missions: Sunrise/SCIP	November 2017- March 2019

Name	Former Institute	Research Theme	Period
LAU, Ryan Masami	Caltech and Jet Propulsion Laboratory (US)	Exploring the Dusty and Dynamic Universe with SOFIA, Spitzer, JWST and Beyond	September 2018-

The following shows ITYF fellows in FY2018 and their published research:

PERALTA, Javier
Research Highlights in FY2018

The morphology of the Venus's upper clouds and their motions have been extensively studied for about 90 years. Unfortunately, the middle and lower clouds and their dynamics have not been studied with so much detail. We observed these deeper clouds with the infrared cameras IR1 and IR2 of JAXA's Akatsuki at certain near-infrared windows able to sense the albedo of the dayside middle clouds (0.9 μm) and the nightside lower cloud's opacity to Venus's deep thermal emission (1.74, 2.32 and 3.20 μm). To measure the winds, we used cloud tracking with a semi-automated technique based in template matching with FFT Phase Correlation. The observations of IR1 and IR2 reveal cloud morphologies not previously observed and, in general, completely different to those of the upper clouds. The unexpected high contrasts found for the middle clouds suggest the presence of atmospheric absorbers not considered before. Winds at the lower clouds suggest that Solar Tides might extend its influence deeper than we thought, and the discovery of decadal variations on the lower winds argues in favor of a first detection of climate change in another planet, a point to be confirmed in later studies. Results about the lower clouds were published in The Astrophysical Journal Supplement Series, while the study of the middle clouds of Venus was published in Geophysical Research Letters and the work was chosen to the front cover of the journal.

Published Research in FY2018:

- J. Peralta et al., The Astrophysical Journal Supplement Series, Vol.239, 29 (2018) doi:10.3847/1538-4365/aae844
- Peralta et al., Geophysical Research Letters, Vol.46(5), pp.2399–2407 (2019) doi:10.1029/2018GL081670
- Peralta et al., Icarus, Vol.333, pp.177–182 (2019) doi:10.1016/j.icarus.2019.05.026

IZUMI, Kiwamu
Research Highlights in FY2018

In this past year, a large fraction of my research effort was spent on the commissioning tests of the Japanese ground-based gravitational-wave detector, KAGRA, in order to bring it online as quick as possible. As the sub-lead of the main interferometer or MIF team of KAGRA, I played the main role in two critical activities; (1) test operation of the cryogenic Michelson interferometer and (2) design and implementation of a subsystem called the ALS (Arm Length Stabilization) system.

The test of the cryogenic Michelson interferometer is a major milestone in which the 3-km long Michelson interferometer, a part of the main interferometer, is interferometrically controlled with one of the end mirrors held at a cryogenic temperature of 20 K. The purpose was to assess the readiness of the various hardware utilizing the systems that were installed at the time. We successfully acquired the interferometric control and were able to operate the interferometer with most of the noise sources identified. A journal paper summarizing the results has been accepted by Class. Quantum Grav.

ALS is a system which stabilizes fluctuations in the lengths of the two 3-km long Fabry-Perot cavities with respect to the main interferometer laser. This system suppresses the fluctuations down to tens of picometers and therefore essential for achieving the resonance of the main interferometer. In this scheme, two auxiliary lasers, which are a frequency-doubled frequency-replica of the main laser, are employed such that each of them senses length fluctuations of a 3-km long optical cavity independently of the interferometric condition of the main interferometer. After the implementation, we succeeded in stabilizing the length of the one of the 3-km cavities with an achieved stability of 44 picometers in rms, successfully meeting the requirement value of 380 picometers. This marks another milestone for KAGRA towards the full operation. A journal paper for this result is in preparation.

Published Research in FY 2018:

- Y. Akiyama et al., Classical and Quantum Gravity, Vol.36(9), 095015 (2019) doi:10.1088/1361-6382/ab0fcb
- B. P. Abbott et al., Living Reviews in Relativity, Vol.21(1), 3 (2018) doi:10.1007/s41114-018-0012-9
- S. Kawamura, et al., International Journal of Modern Physics D (2018) doi:10.1142/S0218271818450013
- KAGRA collaboration, Nature Astronomy, Vol.3, 35-40 (2019) doi:10.1038/s41550-018-0658-y

BONARDI, Stéphane

Research Highlights in FY2018

This past year I have been investigating the use of compliant elements in space robots. I have developed novel control methods for such new platforms and I am currently finalizing the hardware design of a completely new robotic unit aiming at swarm colonization of extraterrestrial environments. My approach is centered around the concept of bio-inspired design, taking inspiration from social insects to build robust robots, both at the individual level but also at the colony level. My research follows two main axes:

- Hardware design: I am working on a novel magnetic based actuator that will provide fast shape changing capabilities to my robot, while having an excellent energy consumption/strength ratio. In parallel I am working on optimizing the shape of the compliant envelope of my robot to maximize its agility and impact tolerance. I am exploring the notion of robotic exoskeleton to widen the range of applications that can be carried out by my new platform.

- Control design: I am adapting some control methods that I used in the past to my new platform. I am working on finding the optimal way to generate highly dynamic motion with a restricted set of actuators. I am also collaborating with one of our PhD students on novel exploration algorithms for highly uncertain environments.

Both topics have been explored in collaboration with international colleagues from EPFL in Switzerland and MIT in the USA. We are currently hosting a master student from EPFL who is working on cave exploration strategies using the aforementioned compliant robots.

Quintero NODA, Carlos

Research Highlights in FY2018

We continued working with realistic 3D MHD simulations for understanding the capabilities of the spectral lines we will observe with the Japan-led Sunrise Chromospheric Infrared spectro-Polarimeter (SCIP). This instrument will fly onboard the stratospheric Sunrise balloon-borne telescope (Barthol et al. 2010) in 2021 and will have access to unexplored spectral regions (Quintero Noda et al. 2018) as well as to well known spectral lines (Quintero Noda et al. 2016, 2017) but with better conditions in terms of spatial resolution and signal to noise level. This requires to perform theoretical supporting studies in order to optimise the design of the instrument and to decide the observations we are going to do with it. We have been working on this during the last years, focusing on the previous year on ways to optimise the analysis of the upcoming data. In this regard, we synthesised the spectral lines using a 3D simulation (see Iijima et al. 2017), then we added the instrumental conditions expected for SCIP, e.g. noise or spatial resolution, and we proceeded to fit the observations using the numerical code presented in Socas Navarro et al. (2015). We faced some challenges at the beginning because the instrument will observe multiple spectral lines, much more than those we use to observe with present instrumentation. However, after some tests, we found an optimum configuration that will allow us to understand the properties of the solar phenomena, including their magnetic configuration, in the lower solar atmosphere for the first time. The results were presented in Quintero Noda et al. (2019), and the mentioned optimum configuration will be used as a baseline for analysing the future observations that SCIP will provide in 2021.

Published Research in FY2018:

- C. Quintero Noda et al., Monthly Notices of the Royal Astronomical Society, Vol.486(3), pp.4203-4215 (2019) doi:10.1093/mnras/stz1124
- M. Seo et al., The Astrophysical Journal, Vol.871(1), 125 (2019) doi:10.3847/1538-4357/aaf55f
- C. Quintero Noda et al., Monthly Notices of the Royal Astronomical Society, Vol.481(4), pp.5675-5686 (2018) doi:10.1093/mnras/sty2685

LAU, Ryan Masami

Research Highlights in FY2018

I started my ITYF position at ISAS in the middle of FY18 in Sept 2018, and my research highlights include planning IR observations with the upcoming James Webb Space Telescope (JWST) in our accepted Early Release Science (ERS) program that I am leading. Our JWST ERS team is composed to ~40 international researchers including several members from ISAS and University of Tokyo. My research in FY2018 focused on strengthening the international collaborations within the team and specifically focusing on encouraging involvement from Japanese researchers. In FY2018, I have been planning out a future roadmap to disseminate knowledge on JWST to domestic Japanese researchers, which includes planning a JWST proposal writing workshop at the end of FY2019. In addition to focusing on JWST, I am engaged in the different science cases that can be explored with the SPICA Mid-Infrared Instrument (SMI), which is being developed at ISAS.

Published Research in FY 2018:

- S. Tinyanont et al., The Astrophysical Journal, Vol.873(2), 127 (2019) doi:10.3847/1538-4357/ab0897

5. R&D at the Fundamental Technology for Space Science Group

a. Inter-University Research and Facility Management Group

To promote space science activities in Japan, JAXA maintains and operates the facilities that constitute the Inter-University Research System. Researchers at public and private universities are able to utilize these facilities, such as the Space Chamber Laboratory, Hypervelocity Impact Facility, and Supersonic and Subsonic Wind Tunnel Laboratory. Opportunities to use these facilities are announced annually, and the proposals are reviewed and approved by the program advisory committees as shown in the table, "Domestic Joint Research", on p.108. The Inter-University Research and Facility Management Group collaborates with researchers to maximize their scientific achievements.

b. Test and Operation Technology Group

The Test and Operation Technology Group is responsible for the development of testing technologies and the operations of the testing facilities for mechanical environmental testing, structural testing, thermal vacuum testing, anechoic chamber testing, attitude control testing, magnetic shield testing, side-jet reaction control subsystem testing, and other technical facilities, such as the clean rooms and mechanical assembly test facilities. The group also participated in the projects, the pre-projects, and the working groups (WG) of ISAS.

1. Achievements

- Support for pre-launch testing and launching of Epsilon-4.
- Support for combustion testing of N_2O/ethanol propulsion systems.
- Support for RV-X testing.
- Upgrade of the testing technologies and the operations of the test facilities.
- Support for improvement of the scientific satellite development environment.

2. Effects and Impacts

The group contributed to:

- the successful launch of Epsilon-4with Innovative Satellite Technology Demonstration-1 onboard;
- the successful launch of BepiColombo.
- the solid development of the projects with the upgraded testing technologies and the highly efficient operations of the test facilities.
- the modification of the flight environmental test building to improve the development environment of scientific satellites.

c. Advanced Machining Technology Group

JAXA has inaugurated the Advanced Machining Technology Group to improve front-load iterations of product development for planned aerospace missions and projects. The researchers and technical staff will team up to do as much in-house manufacturing as possible, from experimental jigs to flight models, to take fullest advantage of the limited funding. In addition to a new numerical control (NC) machine shop, we have integrated an existing machine shop, an electronics shop, and a space nano-electronics group, which was a part of the Department of Spacecraft Engineering, into the Advanced Machining Technology Group. The restructuring has brought synergy among these groups and has sped up the R&D process. The group participates in the development of devices incorporating nano-electronics, designs circuits, and performs top-quality machining with its NC machines. The group is making effective use of its R&D funding and will greatly contribute to the technological improvement and accumulations of JAXA.

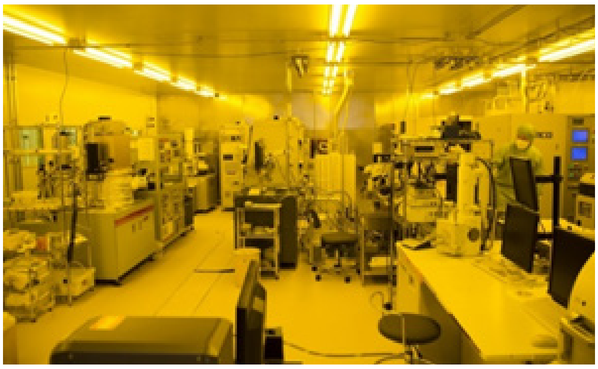
1. Achievements

- We have completed the installation of and begun using a machining center, NC composite turning centers, a wire electric discharge machine, and a contact-type three-dimensional measuring machine.
- We have introduced a brand-new large NC turning center for larger workpieces and an NC milling machine equipped with a high-speed spindle.
- We have raised the efficiency of new and old machine shops, which feature a new layout, and improved job safety with well-routed working traffic lines.
- Specialist staff who work in the nano-electronics cleanroom are completely trained in maintenance management and safety.

2. Effects and Impacts

- We have maintained the quick pace of setting up our production equipment and have begun test manufacturing components already placed on order.
- We have expanded the size of allowed workpieces with the introduction of our large NC turning center.
- We have built an environment that enables our expert staff to provide the highest quality manufacturing services.
- We will continue training our users on safety and maintaining our record of zero accidents.

New machine shop



Nano-electronics cleanroom

d. Scientific Ballooning Research and Operation Group

The Scientific Ballooning Research and Operation Group develops stratospheric balloon systems and provides flight opportunities for scientific observations and engineering demonstrations. It also studies next-generation balloon systems for use in future space science.

1. Achievements

- A scientific balloon campaign launched from Australia on February 16, 2018. Two balloon-borne experiments were carried out. The required flight profiles were realized, and the expected payload performance was achieved during these flights. The flight of one remaining experiment was abandoned due to a delay in its preparation and poor weather conditions.
- The domestic balloon campaign for FY2018 was conducted from June 18, 2018. Though the flight preparation of the planned four experiments was completed as scheduled, due to surface weather and stratospheric wind conditions, all four experiments had to be postponed.

2. Effects and Impacts

- The group intends to provide scientific ballooning flight opportunities to the space science community. In the balloon campaign in Australia we could provide balloon flights that could not be realized inside Japan, and we expect excellent scientific outcomes, though no balloon-borne experiments were possible in Japan in FY2018.
- In the balloon campaign in Australia, one turn-around flight and another steady eastward flight were completed. With these two flights, we demonstrated that we could conduct long-duration flights for > 20-hour scientific observations, which are difficult to perform inside Japan because of Japan's limited land area.
- During the balloon campaign in Australia, we established a good relationship with Australian partners, and we are now convinced to continue periodic scientific ballooning activities in cooperation with Australian partners.
- Though no flight opportunities were available in the domestic campaign, we demonstrated excellent capabilities for supporting payload preparations, which have recently become more and more complex.
- We continue all efforts to increase flight opportunities over Hokkaido, such as negotiations to expand the sea recovery area in order to relax flight trajectory restrictions and installation of an onsite weather observation system to improve the accuracy of surface weather forecasts.

e. Sounding Rocket Research and Operation Group

ISAS is operating three types of sounding rocket, the S-310, S-520 and SS-520, with space science and engineering experiments generally being conducted every year. The Sounding Rocket Research and Operation Group will contribute to design and analysis for the manufacturing and launching of the sounding rockets in the coming fiscal year and beyond. The group provides experimental opportunities with the sounding rockets for researchers, such as engineering verification tests and scientific observations.

1. Achievements

- The preliminary design, including mechanical and electrical interfaces, of the S-310-45 rocket experiment was verified in order to prepare the onboard instruments. This experiment will focus on examining a precise control strategy and the directional accuracy of multi-link structures.
- The baseline concept, including mechanical and electrical requirements of the S-520-31 rocket experiment was discussed to provide better conditions. In the experiment, a newly developed space propulsion engine will be examined in a microgravity environment. Component-level environmental tests and electrical calibration of the onboard equipment of the SS-520-3 rocket experiment were performed prior to integrated function tests. The rocket has a two-stage solid propellant design and is intended to observe the high- altitude plasma dynamics of the north polar region in Norway. This experiment has currently been postponed due to electrical problems with the avionics.
- In addition to the annual evaluation, we focused on scientific achievements and conducted experimental evaluation of the sounding rockets launched over the past 10 years.

2. Effects and Impacts

- The group has published peer-reviewed papers (in Science Advances, Chemistry of Materials, and the Journal of Crystal Growth) and published a cumulative total of 126 papers since 2003.
- A subcommittee established under the Advisory Committee for Space Science and the Advisory Committee for Space Engineering evaluated our sounding rocket activities. The subcommittee concluded that the group’s publications and other scientific results in relation to sounding rocket and balloon experiments were in line with the allocated resources.

f. Noshiro Rocket Testing Center

The Noshiro Rocket Testing Center (NTC) is one of the ISAS’s research facilities. Since 1962, different kinds of ground firing tests for solid-propellant rocket motors have been carried out in order to verify their performance prior to launch. The center has also conducted basic research on cryogenic engines and Air Turbo Ramjet engines.

In order to conduct the above verification studies, several kinds of experimental facilities have been developed. One of these is a large-scale, sea-level static firing test stand for one of the biggest, solid propellant rocket motors, the first-stage motor (M-14) for the M-V satellite launch vehicle. The maximum thrust to be tested on the stand is 450 tonf. For the purpose of testing the upper stage motors, a large-volume vacuum firing test chamber was built to achieve a low-pressure environment during solid motor firing. The second- and third-stage motors for the M-V (M-24, M-25, M-34, and M-35) together with various sizes of kick motors, such as the KM-P, KM-M, KM-V1, KM-V2, etc., were repeatedly tested in the vacuum environment. The volume of the chamber is approximately 475 m^3 with a maximum thrust capability of 150 tonf.

NTC also has cryogenic test facilities primarily for the development of liquid propellant engines and Air Turbo Ramjet engines. Recently, the center developed very highly pressurized liquid hydrogen test facilities, which supplied more than 90 MPa of pressure. Using these facilities, the center examined the characteristics of high-pressure liquid hydrogen in order to perform a risk assessment of hydrogen treatment for fuel cell vehicles and their supply stands.

1. Achievements

- Advanced rocket engines

  In order to meet the progressive requirements of future and near-future transportation systems, the center has actively tested advanced rocket engine systems with new propellants to better understand performance levels. A N_2O/ethanol liquid engine with a ceramic-based nozzle composite was developed for storable and non-toxic propulsion of small satellites. A hybrid rocket motor has also been examined to reduce safety requirements at the launch site. In the FWT experiment, inexpensive rocket motors manufactured using general purpose materials have been tested to grasp its basic performance. In 2018, a solid propellant motor with 300 kg weight was successfully examined.
- Lift-off and landing tests of reusable vehicles

  The design and development of the reusable rocket vehicle RV-X is in progress based on the technical outcomes obtained from ISAS RV-X-related studies. Currently, two flight campaigns are planned for a flight demonstration study. In the first flight test campaign, we aim to demonstrate the pump-fed capability of a deep throttling engine, attitude control characteristics using main engine gimbaling during lift-off and landing with powered flight, quick turnaround, etc. In 2018, static firing tests with a stage configuration were examined to verify the total performance of engine with LH_2/LOX tanks.

- Safety technology for liquid hydrogen utilization
  Based on the New Energy and Industrial Technology Development Organization's (NEDO) supporting research program, the actual behavior and risk assessment of very highly pressurized hydrogen were studied to improve safety regulations for fuel cell vehicles and hydrogen infrastructures, such as supply stands. Cryo-compressed hydrogen leakage diffusion was also investigated.
- The experimental apparatus was able to supply hydrogen at 90 MPa and various temperatures. Measurement criteria included hydrogen concentration distribution, blast pressure, flame length, and radiant heat. In addition, high-speed camera observation was carried out to investigate the near-field cryogenic hydrogen jet at supercritical pressure. Based on the above considerations, an extinguisher mechanism was tested in 2018.
- Liquid hydrogen loading system
  As a research program of the Cross-ministerial Strategic Innovation Promotion Program (SIP by JST), swivel joints and emergency release systems for liquid hydrogen were developed and demonstrated. In 2018, explosive phenomena were carefully observed in gases leaking from emergency release mechanisms, and further investigation of sealing materials for the swivel joints was successively conducted.
- Liquid hydrogen cooled HTC superconductors
  High Tc (HTC) superconductors, including MgB_2, have been tested with the support of the Advanced Low Carbon Technology Research and Development Program (ALCA by JST), which showed excellent properties of liquid hydrogen under temperature. The liquid hydrogen showed high latent heat and low viscosity coefficient. The center also investigated the thermal properties of a prototype generator using HTC materials.

2. Effects and Impacts

NTC has many unique facilities for experimental verification of transportation technologies and cryogenic properties. The static firing test stand has a maximum thrust capability of more than 450 tonf, and is the largest facility in Japan. The vacuum firing test chamber has a volume of more than 450 m^3, and is also the biggest facility of its kind in Japan. Moreover, the NTC has the only very highly pressurized liquid hydrogen supply facility in Japan. As a result, a large number of experimental studies have been conducted at NTC bearing fruitful results. In 2018, at least one of the NTC facilities has been in operation for more than 240 days of the year without one human accident being reported.

g. Akiruno Research Center

Akiruno Research Center aims to carry out various basic and educational experiments to develop key the components of rocket and/or satellite systems. Its unique experimental facilities support ISAS’s basic research activities and projects.

1. Achievements

- Sea-level combustion experiments on a solid propellant rocket motor with a laser ignition system were carried out in vacuum by the high-altitude testing facility (High-Altitude Testing Stand, HATS).
- A hybrid rocket combustion experiment (A-SOFT) was conducted with the liquid oxygen supply facility. The temperature-dependence of oxygen gas on the performance of the hybrid rocket was carefully examined.
- Basic chemical decomposition behavior of N_2O with catalyst decomposition system was examined by direct observation of gas temperature around the catalyst.
- To support basic research activities, reliable inspections of the experimental facilities were conducted to maintain their condition.

2. Effects and Impacts

- A-SOFT hybrid rocket combustion experiments were successfully carried out by the liquid oxygen supply facility. The temperature-dependence of oxygen gas on the performance of the hybrid rocket was carefully examined. Practical knowledge about the combustion of a SOFT hybrid rocket motor was obtained from the series of combustion experiments.
- The N_2O decomposition experiment provided basic knowledge about high-temperature gas generation behavior using different types of catalysts.
- The laser-assisted igniter was successfully tested in vacuum and practical knowledge on handling laser ignition systems was obtained. Sea-level static combustion experiments on a small-sized solid propellant rocket motor with the laser ignition system

were carried out in vacuum using HATS to demonstrate the effectiveness of the laser-assisted ignition system.

h. Science Satellite Operation and Data Archive Unit

The Science Satellite Operation and Data Archive Unit (C-SODA) is in charge of development and operation of the ground infrastructure for science spacecraft operation and data archives. C-SODA also makes space science data available to the public to enhance the scientific outcome of JAXA programs.

1. Science Satellite Operation

1.1Achievements

- C-SODA provided ground systems for ISAS scientific space missions and supported their mission operations.
- We renewed the spacecraft control room so that Hayabusa2 could perform rehearsals to prepare for approach and touch-down operations on the asteroid, Ryugu.
- A new IP-VPN network was introduced between Sagamihara, Tsukuba, Uchinoura and Usuda.
- Preparation of remote operation for ground stations at Uchinoura and Usuda was completed. Full remote operations for these stations will start in FY2018.

1.2 Effects and Impacts

- All spacecraft in orbit or transit—ARASE, Hayabusa2, HISAKI, AKATSUKI, HINODE and GEOTAIL—have been operating safely.
- The new control room supported dozens of Hayabusa2 rehearsals for the Ryugu mission.
- The new IP-VPN network resulted in a redundant network and reduced network costs.
- Remote operation of grand stations also reduced operation costs.

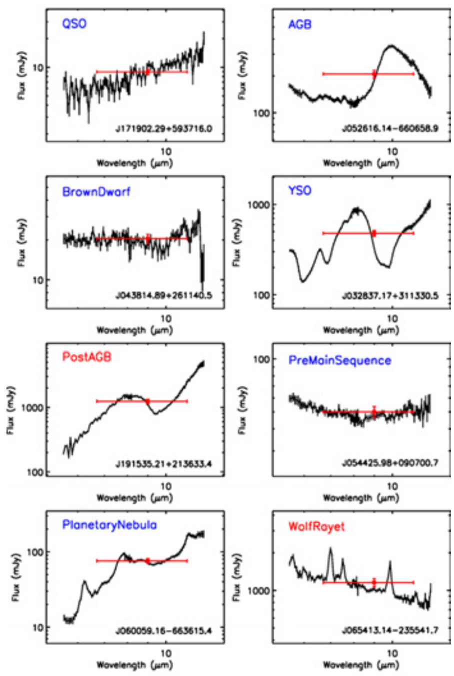
2. Accumulation and Provision of Space Science Data

2.1 Achievements

- C-SODA developed, maintained and operated the space science Data ARchive and Transmission System (DARTS) to maximize scientific outcomes from archival data for JAXA science spacecraft
- We released new datasets, including LIDAR from Hayabusa2, HITOMI, MAXI onboard ISS, AKATSUKI, and PDS3 from KAGUYA, etc.
- 10 kinds of raw telemetry data from old spacecraft were made open to public, which have been closed for more than 30 years. (Taiyo, Kyokkou, Jikiken, Ohzora, Hakucho, Temma, Hinotori, Sakigake, Suisei and Hiten, etc.)
- Following AKARI data products were newly released: Mid-infrared slitless spectroscopic catalogue (Fig.), Near-Infrared Asteroid Spectral Catalog. In addition, Far-Infrared Faint Source Catalogue, Mid-Infrared All-Sky Image Maps, Far- and Mid-Infrared Slow-scan Image Catalogues have been prepared for release.

2.2 Effects and Impacts

- In the last year, approximately 160 TB of data were downloaded by world-wide users through DARTS, totaling approximately 50 million accesses.
- Approximately 120 refereed papers using AKARI data were published in FY2018 (Approx. 1,300 papers have been published since the AKARI launch in 2006).
- DARTS maintains a large number of datasets from space science missions open to the public in a systematic manner and common data format, which helps to maximize the scientific outcome from the data, expands its scope of use and contributes to third-party verification of observation results.



Example spectra from the AKARI Mid-Infrared Slitless Spectral Catalogue. Various types of objects, from young stars to galaxies are included in the catalogue.

i. Lunar and Planetary Exploration Data Analysis Group

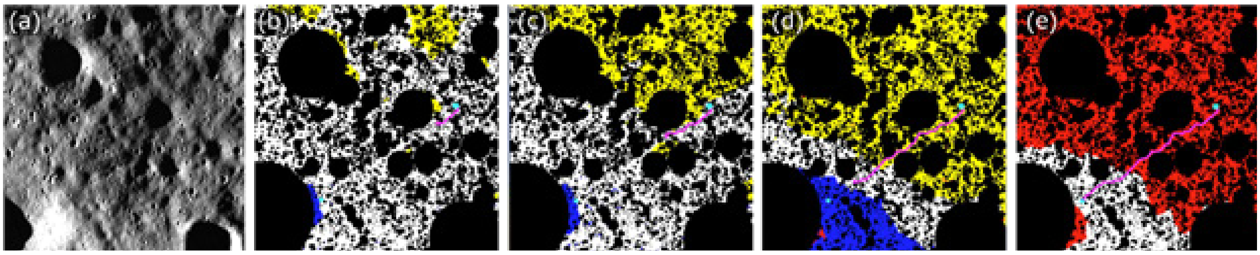
The Lunar and Planetary Exploration Data Analysis Group was established in FY2016. It aims to maximize the achievements of lunar and planetary explorations through the mission planning, strategy development, and the scientific research. This group deals with massive datasets from lunar and planetary exploration missions (including foreign missions) and achieves the higher-order data processing and analyses.

1. Achievements

- We analyzed existing remote-sensing datasets and provided support to JAXA's lunar exploration mission teams (e.g., lunar polar mission, HERACLES, the pressurized rover) for their mission-scenario studies. In the case of the polar mission, we simulated over ~10 years of the illumination and Earth visibility in lunar polar regions (at the spatial resolution of 10 m/pixel and in intervals of 3 hours) to find the landing site candidates which satisfy long sunlit and direct communication with Earth. We also developed an algorithm that can automatically find a safe route that has gentle slopes, sunshine, and Earth visibility (see figure below). An analysis tool for thermal observation data was also developed to map the variations in surface temperature to support the search for water ice in the polar regions.
- In cooperation with the National Institute of Advanced Industrial Science and Technology (AIST), the University of Aizu, and JAXA's Engineering & Design Innovative Center, we developed data-analysis techniques that use artificial intelligence. Automatic detection of impact craters and boulders from images was improved to offer sufficient accuracy for the use in landing-site studies. Automatic identification of low-albedo areas other than shadows is being developed for characterization of volcanic features on the lunar surface.
- We operated and upgraded the KAguya Data Integrated Analysis System (KADIAS), which provides WebGIS-based analysis tools that incorporate various remote-sensing datasets obtained by the Japanese lunar exploration orbiter (KAGUYA) and other foreign missions.

2. Effects and Impacts

- Analysis results provided to the lunar polar mission planning team are being used in determining the exploration strategies and the mission concept studies. Our landing-site search and the route-planning algorithm attracted the attention from various engineering communities and this has led to cooperative research with other universities.
- KADIAS lets users analyze the datasets from various lunar missions without special knowledge or large computing resources, which allows more students and young researchers do lunar science using the exploration datasets.



Snapshots of automatic route-search algorithm. (a) study area (500 m across) in a monochrome image (0.5 m/pixel), (b)-(e) high-risk regions (black: morphologic obstacle, blue: no Earth visibility, yellow: no sunlit, and red: no sunlit and Earth visibility) changing with time. Cyan dots and pink line indicate the start/goal locations and an example of derived route, respectively.

j. Astromaterials Science Research Group

The Astromaterials Science Research Group operates the curation facility at JAXA. The group acquires knowledge about planetary materials based on non-destructive and uncontaminated analysis of extraterrestrial materials.

1. Achievements

- The group performed the curatorial work of collecting, describing, and storing the samples brought back by HAYABUSA from asteroid Itokawa.
- The group published a periodical special paper online with an initial description of the Itokawa samples (i.e., sample catalog information). A total of 761 samples are included in the most-recent catalog (JAXA-SP-18-003E).
- The group made an international Announcements of Opportunity (AO) for the Itokawa samples and samples were allocated to researchers selected by an international AO committee. By the end of the last fiscal year, 60 proposals were accepted and 227 samples have been distributed.
- According to an MOU between NASA and JAXA, 35

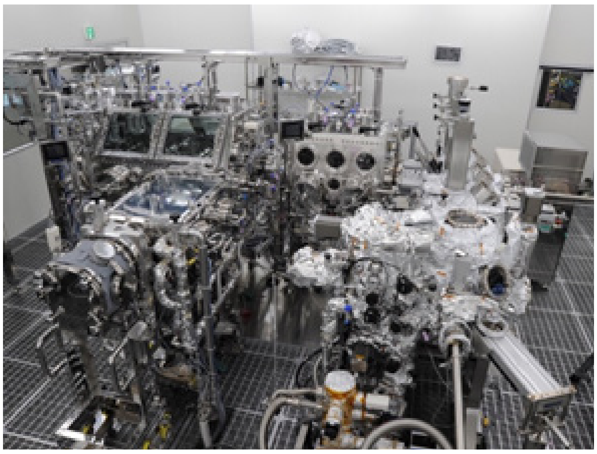
samples have been delivered to NASA so far.

- The International Symposium for Solar System Materials was held to announce the results from the international AO research on Itokawa samples. This symposium will be held annually and was attended by approximately 100 planetary science researchers from all over the world.
- In preparation for the receipt of extraterrestrial samples from future sample return missions like Hayabusa2, we have completed the construction of a new clean room and new clean chambers.
- Technical support for future sample return missions was provided through the development of sampling equipment and the examination of sample-receiving equipment.
- As for technical support for an on-site analyzer to be used in future planetary exploration missions, we began the development of a compact, high-performance mass spectrometer.
- Maintenance and operation of the group's associated facilities and equipment.
- Project researchers, postdoctoral fellows, and young researchers were hosted and they performed extraterrestrial sample analysis and other studies.

2. Effects and Impacts

The Itokawa sample analysis results thus far are summarized as follows:

- International AO#2 researcher found that Itokawa's parent body was formed about 4.6 billion years ago when the solar system was born, and it was then destroyed in a collision with another asteroid about 1.5 billion years ago (Scientific Reports 8, Article number: 11806 (2018)). Focusing on a few micrometers of phosphate minerals, which are rare in the Itokawa particles, the scientists performed precise isotope analyses of uranium (U) and lead (Pb) in particles of about 50 μm in diameter using Secondary Ion Mass Spectrometry (SIMS). The results of this study established limits on the timescale of the first samples collected from the asteroid, providing concrete figures about the absolute age of whose orbits are well known. This data will help in understanding the origins and histories of asteroids.
- International AO#4 researchers found water in the samples, representing the first-ever measurements of water contained in samples from the surface of an asteroid. The team's findings suggest that impacts by similar asteroids early in Earth's history could have delivered as much as half of our planet's ocean water (Science Advances. Vol. 5, no. 5, eaav8106 (2019))



New clean chambers installed in a new clean room for Hayabusa2 samples.

k. Deep Space Tracking Technology Group

The Deep Space Tracking Technology Group (DSTT) was established at ISAS in FY2016. This group is tasked with technical coordination among various projects and facilities within and outside ISAS that concern the tracking of deep space projects. This work was previously performed independently by individual experts. The major achievements of this group during FY2018 are as follows.

1. Support for JAXA's deep space projects

- Technical coordination for the Hayabusa2 project with NASA, providing tracking support at NASA's Deep Space Network (DSN) stations. We coordinated with DSN engineers on the usage of DSN stations during the asteroid proximity phase from 2019 to 2020 and discussed basic policies for utilizing the DSN stations during critical events.
- Technical coordination for the Hayabusa2 project with ESA, providing tracking support at ESA's ESTRACK stations. We collaborated with ESA engineers on technical aspects of the use of ESTRACK's Cebreros station in Spain and Malargue station in Argentine.
- Technical coordination with DLR for the use of Weilheim station for Hayabusa2.
- Technical coordination with NASA about JAXA's two CubeSats (OMOTENASHI and EQUULEUS), which will be launched by NASA's SLS EM-1. NASA will provide tracking support at its DSN stations. We coordinated plans for RF compatibility and SLE connection testing.

2. Support for deep space projects of international partners

- Technical coordination about NASA's EM-1 project with NASA for the provision of tracking support at JAXA's Uchinoura station. We discussed technical issues that will affect this project.

3. Study on JAXA's future deep space tracking network

- We started a study on JAXA's future deep space tracking network in collaboration with JAXA's space tracking and communications center at Tsukuba and the GREAT Project Team.
- We carried out technical studies and construction of the GREAT (54 m antenna) station (currently under development).
- We studied the replacement of the stations at Uchinoura with multi-purpose stations to be built overseas. We began preliminary studies of the possibility of building a station in Malargue, Argentina.

4. Orbit determination for JAXA's deep space projects

- We performed regular orbit determination operations for AKATSUKI and Hayabusa2.
- In the final approach phase of Hayabusa2 to Ryugu, we were able to determine the orbit of Ryugu very precisely using DDOR data in conjunction with OP-NAV (Optical Navigation with on-board optical telescope) data.
- We have continued to study issues related to the orbit determination for Mio, SLIM, and DESTINY$^+$.

III

Administration

1. History and Mission of ISAS

As a part of JAXA, ISAS cooperates with external research organizations, such as universities, to promote space science research. Space science research is defined as comprising fields of scientific research on the upper atmosphere or beyond, as well as work in related fields that facilitates this research. This integrated research approach includes physical science and engineering research conducted both in space and on the ground. Since before its integration with JAXA, ISAS has maintained and developed an inter-university research institute system. By utilizing this collaborative framework, ISAS has been developing and fostering space research and launching new space science projects, as well as conducting academic space science research as an education resource.

The roots of ISAS can be found in the Aeronautical Research Institute, which was first established at Tokyo Imperial University in 1918 and was then reorganized in 1946 as the Institute of Science and Technology at the University of Tokyo. Space Research and Development (R&D) began in 1955, with the launch of a pencil rocket by the Avionics and Supersonic Aerodynamics research group at the Institute of Industrial Science of the University of Tokyo. In 1964, ISAS was established at the University of Tokyo by integrating the Institute of Aeronautics with the sounding rocket research group in the Institute of Industrial Science. The goal of the institute was "to carry out integrated research on theory and application in the fields of space science, space engineering, and aviation."

Aeronautical space engineering and space science research was carried out mainly under the lead of ISAS, with collaboration from researchers at various organizations, such as other national, public, and private universities. This collaboration, and the intellectual freedom that it promoted, led to major achievements, such as the successful launch of Japan’s first artificial satellite, Ohsumi, by an advanced Lambda sounding rocket in 1970. The 1970s saw the development of ever more sophisticated and powerful vehicles, the Mu rockets, designed for satellite orbital insertion.

In 1981, ISAS was separated from Tokyo University and reorganized as an inter-university research institute under the Ministry of Education. Its objectives were "to carry out research on theory and application in the fields of space science and engineering, as well as serving the educational staff of national, public, and private universities engaged in research. Furthermore, it is to provide cooperation in graduate education at the request of national, public, and private universities." In 2003, JAXA was founded as an independent administrative agency by integrating three separate institutes—ISAS, the National Space Development Agency of Japan, and the National Aerospace Laboratory—to establish an organization that more efficiently and effectively performs and promotes space science research, space development, and aerospace technology R&D. The mission of ISAS under JAXA is inter-university research, facilitation of space science development, and graduate education. On April 1, 2015, JAXA’s status was redefined as a national R&D agency. To accommodate the new policy framework and implement the new emphasis on R&D, JAXA has been reorganized into seven directorates or Departments. Furthermore, in July 2018, JAXA Space Exploration Center (JSEC) was established (see the JAXA organization chart).

Following medium-term goals provided by the Minister of Education, Culture, Sports, Science and Technology, ISAS concentrates on promoting "highly original space science research with a respect for the autonomy of research participants" and "space science projects using flying objects such as satellites." The former is of an exploratory nature with research conducted by individuals or groups of researchers. A representative example of the latter is scientific satellite projects, which include satellite development, data analysis, and publication of the results.

2. Organization

As of March 31, 2019, JAXA has five Directorates, Institute of Space and Astronautical Science (ISAS), Space Exploration Innovation Hub Center, JAXA Space Exploration Center (JSEC), and other administrative departments.

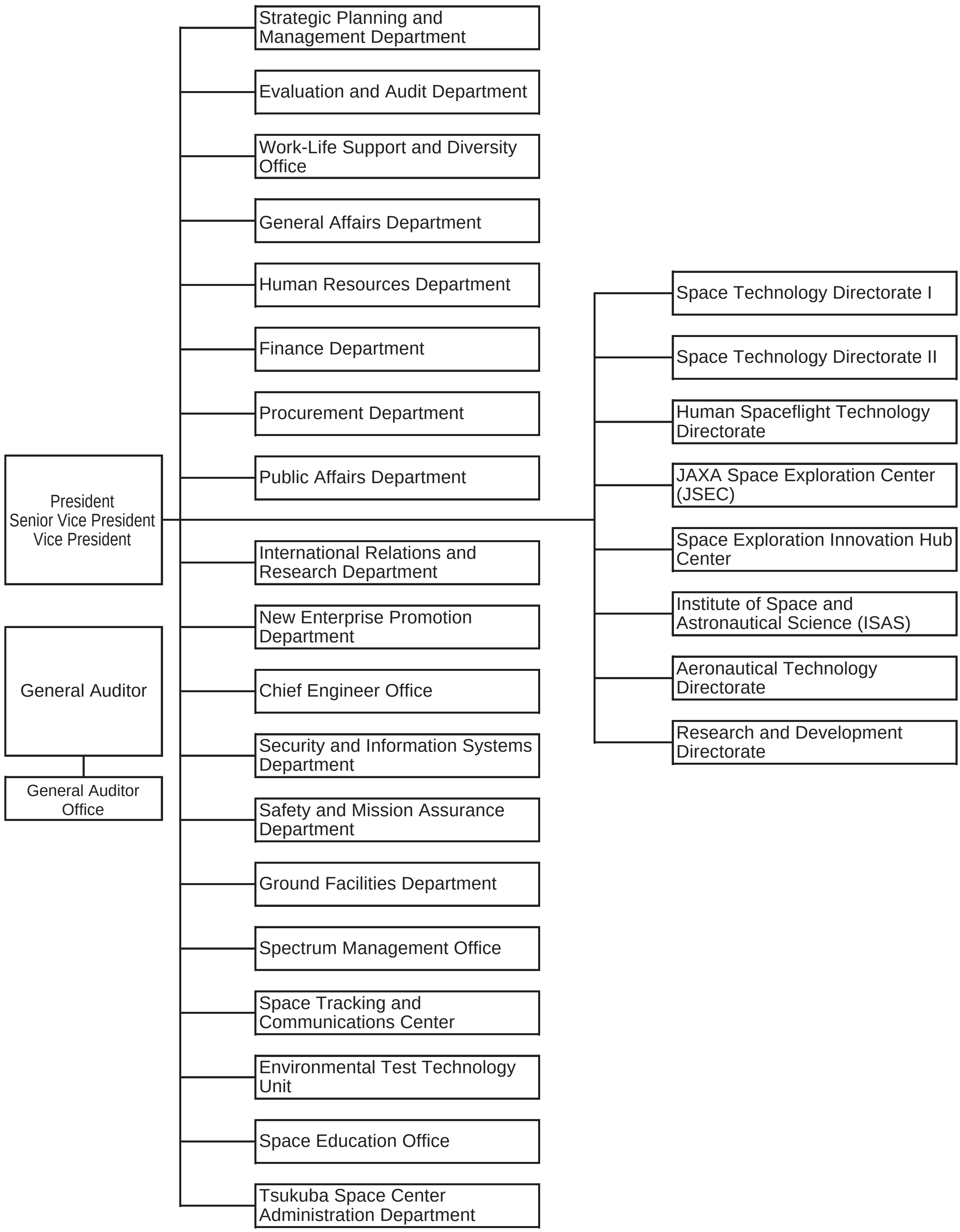
As of March 31, 2019, ISAS has five research departments:

- Space Astronomy and Astrophysics
- Solar System Sciences
- Interdisciplinary Space Science
- Space Flight Systems
- Spacecraft Engineering

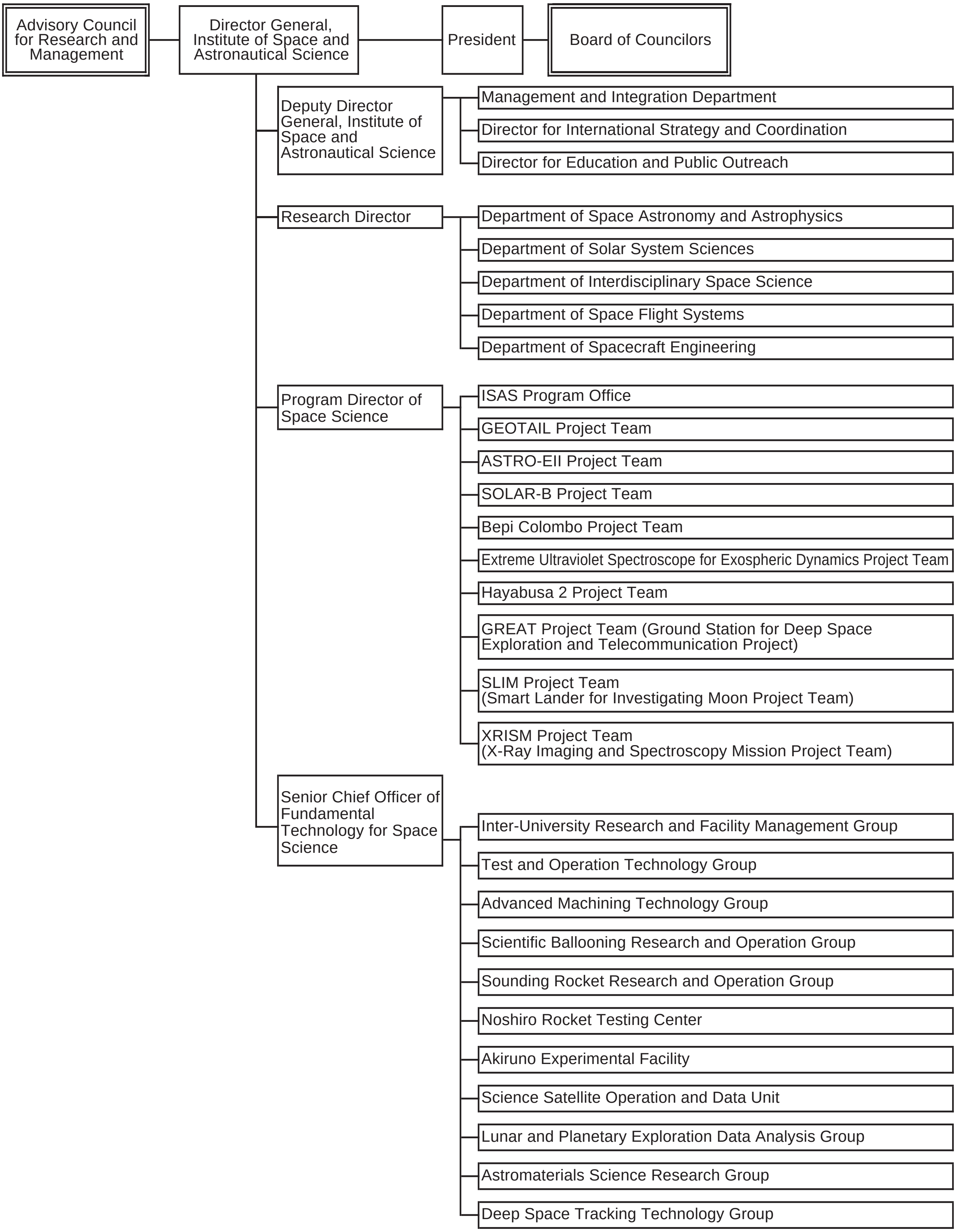
Other organizations within ISAS are the Management and Integration Department, the ISAS Program Office, the Center for Science Satellite Operation and Data Unit, 9 project teams, 8 groups, the Noshiro Rocket Testing Center, and the Akiruno Experimental Facility. In addition, the following officers and directors report to the ISAS Director General: Deputy Director General, Research Director, Program Director of Space Science, Senior Chief Officer of Fundamental Technology for Space Science, Director for International Strategy and Coordination, and Director for Education and Public Outreach (see the ISAS organization chart).

At JAXA, a Board of Councilors advises the President regarding space science and the nomination and selection of candidates for Director General of ISAS. The Advisory Council for Research and Management was established within ISAS to efficiently operate the inter-university research system.

a. JAXA Organization Chart (as of March 31, 2019)



b. ISAS Organization Chart (as of March 31, 2019)



3. Operation

The Advisory Council for Research and Management and the Board of Councilors were established to oversee the interuniversity research system and obtain advice from external scholars on ISAS business plans and other important issues regarding space science research at ISAS. The members of each council are listed below. In addition, various in-house and research committees composed of researchers from all over Japan have been established to review, for example, collaborative research plans.

a. Board of Councilors (as of March 31, 2019)

OKADA, Kiyotaka	Specially Appointed Professor, Faculty of Agriculture, Ryukoku University
KAJITA, Takaaki	Director, Institute for Cosmic Research, University of Tokyo
KAWAI, Maki	Director General, Institute for Molecular Science, National Institutes of Natural Sciences
KUSANO, Kanya	Director, Institute for Space-Earth Environmental Research, Nagoya University
GONOKAMI, Makoto (Vice-Chairman)	President, The University of Tokyo
KOBATAKE, Hidefumi	Principal, Kaetsu Ariake Junior and Senior High School, Kaetsu Gakuen Educational Association
KOMORI, Akio	President, National Institutes of Natural Sciences
TAKAYANAGI, Yuichi	Director, Tamarokuto Science Center
TAKEDA, Hiroshi	President, Kobe University
TAJIKA, Eiichi	Professor, Graduate School of Science, The University of Tokyo
CHUBACHI, Ryoji	President, National Institute of Advanced Industrial Science and Technology
HASHIMOTO, Kazuhito	President, National Institute for Material Science
HASEGAWA, Mariko (Chairman)	President, The Graduate University for Advanced Studies (SOKENDAI)
HAYASHI, Masahiko	Director, Japan Society for the Promotion of Science (JSPS) Bonn Office
FUJII, Teruo	Executive Director and Vice President, The University of Tokyo (Professor, Institute of Industrial Science, The University of Tokyo)
FUJII, Ryoichi	President, Research Organization of Information and Systems
MATSUMOTO, Hiroshi	President, RIKEN
YASUOKA, Yoshifumi	Professor Emeritus, The University of Tokyo
YAMAMOTO, Satoshi	Associate Dean, Graduate School of Science, The University of Tokyo
YOSHIDA, Kazuya	Professor, Graduate School of Engineering, Tohoku University

The term is from April 1, 2017 to March 31, 2019.

b. Advisory Council for Research and Management (as of March 31, 2019)

AOKI, Takahira	Professor, Graduate School of Engineering, The University of Tokyo
IGUCHI, Satoru	Vice-Director General, National Astronomical Observatory of Japan
KUSANO, Kanya	Director, Institute for Space-Earth Environmental Research, Nagoya University
SASOH, Akihiro	Professor, Graduate School of Engineering, Nagoya University
SUGITA, Seiji	Professor, Graduate School of Science, The University of Tokyo
NAGATA, Harunori (Vice-Chairman)	Professor, Faculty of Engineering, Hokkaido University
NAGAHARA, Hiroko	Deputy Director, Research Center for Science Systems, Japan Society for the Promotion Science
HIROSE, Akira	Professor, Graduate School of Engineering, The University of Tokyo
FUJITA, Osamu	Professor, Faculty of Engineering, Hokkaido University
YAMAMOTO, Satoshi	Associate Dean, Graduate School of Science, The University of Tokyo
WATANABE, Junichi	Vice-Director General, National Astronomical Observatory of Japan
ISAS	
INATOMI, Yuko	Director, Department of Interdisciplinary Space Science
KUBOTA, Takashi	Professor, Department of Spacecraft Engineering
SAITO, Yoshifumi	Director, Department of Solar System Sciences

SATO, Eiichi	Director, Department of Space Flight Systems
HAYAKAWA, Hajime (Chairman)	Professor, Department of Solar System Sciences
FUJIMOTO, Masaki	Deputy Director General
MITSUDA, Kazuhisa	Professor, Department of Space Astronomy and Astrophysics
MORITA, Yasuhiro	Professor, Department of Space Flight Systems
YAMADA, Takahiro	Director, Department of Spacecraft Engineering
YAMADA, Toru	Director, Department of Space Astronomy and Astrophysics

The term is from April 1, 2017 to March 31, 2019.

c. Advisory Committees

ISAS has two advisory committees, the Advisory Committee for Space Science and the Advisory Committee for Space Engineering. Its main responsibility is to oversee the conduct of academic research and related work on space science in cooperation with universities and in consultation with the ISAS Director General.

The Sounding Rocket Technical Committee, Committee for Space Biology and Microgravity Science, Committee on Scientific Ballooning, and Committee for International Space Exploration were also organized under the Advisory Committee for Space Science and the Advisory Committee for Space Engineering. The Curation Technical Committee was organized under the Advisory Committee for Space Science, while the Space Transportation System Committee was established under the Advisory Committee for Space Engineering.

1. Advisory Committee for Space Science

The Advisory Committee for Space Science formulates research plans and reviews technical issues related to space science.

1-1. Developing Missions on the Roadmap for Space Science and Exploration

To enhance mission development, the committee promoted working group (WG) activities and research group activities and urged the relevant parties to proceed with necessary research and development activities. In FY2018, the committee held a WG chief meeting, confirmed progress on mission proposals with a year-end evaluation, gave feedback about those WG activities, and supported activities around the development of new missions.

The Advisory Committee for Space Science, in collaboration with the Advisory Committee for Space Engineering, evaluated submitted plans for Concepts for Competitive Middle-class missions in FY2017, and recommended the approval of the HiZ-GUNDAM and So-lar-C_EUVST missions.

In addition, a task force working on planning space science over the next 20 years was established in FY2018. This planning will contribute to the formation of a long-term vision for space science missions. This planning includes the selection of targets for exploration, determining the appropriate size and frequency of space science missions, and the development of related technology.

1-2. Strategic R&D

For new initiatives (i.e., "pre-project"), WGs conduct R&D to address technical issues that may obstruct the path to achieving mission goals. Research proposals are considered by open application, and research funds are allocated after review. Progress reports are shared within the ISAS community.

Working group activities and status are summarized below.

<u>Ongoing Working Groups (WGs)</u>

- Strategic Large-class projects
  - > Next-generation Solar Observation Satellite (SOLAR-C) WG
- Competitive Middle-class projects
  - > Frontiers of Formation, Acceleration, Coupling, and Transport Mechanisms Observed by Outer Space Research System (FACTORS)
  - > Physics of Energetic and Non-thermal plasmas in the X-(magnetic reconnection) region (PhoENiX)
  - > Broadband X-ray High-sensitivity Imaging Spectrometer (FORCE) WG
  - > Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES-2) WG
  - > High-z Gamma-ray Bursts for Unraveling the Dark Ages Mission (HiZ-GUNDAM) WG
  - > Small Astrometry Satellite for Infrared Exploration (Japan Astrometry Satellite Mission for Infrared Exploration, or JASMINE) WG
  - > Small Projects
  - > GEOspace X-ray imager (GEO-X) WG
  - > Circumpolar Stratospheric Telescope (FUJIN) WG
  - > Klypve-EUSO working group onboard International Space Station WG
  - > LargE Area burst Polarimeter (LEAP) for ISS WG
  - > Strategic International Projects
  - > Laser Interferometer Space Antenna (LISA)
  - > Ultraviolet spectrum observation in extrasolar planets WG

> ATHENA WG

> WFIRST WG

• Equipment development Working Groups

> Life Detection Microscope (LDM) WG

Working Groups whose status changed in FY2018

> Imaging X-Ray Polarimetry Explorer (IXPE) WG was approved for Small Projects.

> JASMINE WG was approved for Pre-Phase A2.

> SOLAR-C WG was approved for Pre-Phase A1b.

> HiZ-GUNDAM WG was approved for Pre-Phase A1b.

> Wide-field Monitoring of Transient Astronomical Objects (Wide-Field Monitoring of All-sky X-ray Image, or WF-MAXI) WG was completed as WG.

> Turbulence Heating ObserveR THOR WG was completed as WG.

> Asteroid/Moon Penetrator Plan (APPROACH-2) WG was completed as WG.

> WFIRST WG was approved for study team.

Achievements and Impacts

Notable results are listed below.

• SOLAR-C WG (Solar-C_EUVST), in system review of its next phase, examined disturbance management systems in the small standard bus, and the systems related to the main mirror part of the EUVST telescope. Also, prototype development of ultra-high-precision solar sensors has been completed. In response to these results, PrePhase-A2 planning review was performed.

• HiZ-GUNDAM WG studied the establishment of satellite bus posture stability and the extraction of future tasks. They also studied directional disturbance by an orbital thermal analysis of the near-infrared telescope, while clarifying the conditions that will deteriorate imaging performance.

• Physics of Energetic and Non-thermal plasmas in the X-(magnetic reconnection) region (PhoENiX) WG is examining satellite system concepts and the development of the mission and the bus. Soft and hard X-ray mirrors and the X-ray high-speed CMOS camera are also under development. In the development of soft X-ray mirrors, the polishing and the measurement processes needed for the expansion of the effective mirror area were evaluated. The X-ray system enhancement and sensors were also tested.

1-3. Basic R&D on Onboard Equipment

The objective of basic R&D is to develop onboard equipment for space science observation and space experiments. These initiatives have an exploratory nature that requires proof-of-principle prior to acquiring external funds, such as a Grants-in-Aid for Scientific Research (KAKENHI).

Achievements and Impacts

In FY2018, 12 proposals were accepted in the areas of the high-energy astronomy (5 proposals), infrared and terahertz astronomy (3), planetary exploration (3), and solar studies (1). Each of these has proceeded in cooperation with academic researchers outside ISAS.

These proposals represent the following achievements in the development and implementation of new technology: (1) Development of a pixel detector that enables high spatial resolution for broadband X-rays; (2) Development of a precise positioning mechanism for an X-ray reflector; (3) Development of a fine metal mesh that increases X-ray photon sensitivity; (4) Achievement of high-sensitivity infrared detectors that measure the 30-60 micron band; (5) Development of a compact vacuum pump that works without needing a constant power supply; (6) Development of an evaluation method for free curved mirrors in low-temperature environments.

These achievements are basic technological developments that promote activities in space observation and space exploration, and steady progress has been made in the face of limited financial resources.

2. Advisory Committee for Space Engineering

The Advisory Committee for Space Engineering is a research committee established to formulate research plans, plan research projects and review other technical issues related to the engineering of hardware used to reach, travel in and perform experiments in space.

2-1. Strategic R&D

The objective of strategic R&D is to propose future engineering missions involving scientific satellites and spacecraft and to conduct research in element technologies for innovative scientific satellites, spacecraft and rockets.

Working Groups

• WG for Network-Type Planetary Exploration using Scattered Micro Planetary Probes with deployable Flexible Aeroshell

• Detonation Engine Kick Motor Sounding Rocket Demonstration of Putting into Orbit

• Formation Flying WG

Operations

• Engineering research using the REIMEI satellite

Studies on Basic Hardware Technologies

• Study on the inertial platform for payloads of ISAS/JAXA sounding rockets

• Development of micro ion thrusters for payloads for chemical -free satellites

• R&D on Mars airplane

• Demonstration of a super-pressure balloon for long duration flight

• Demonstration research on advanced solid propellant rocket system

• Studies on an innovative thermal control system

• Studies on frequently reusable space transportation system

• Research on innovative satellite bus technology

• Research on rover for exploration of small bodies, moons, and planets

- Research on an innovative parafoil-type vehicle for Mars exploration
- Development of an electrodeless magnetic nozzle helicon plasma thruster
- Study on highly-precise structures and materials for advanced scientific observations
- Research for Landing/Contact/Impact System on Astronomical Body Surface
- Feasibility study and demonstration of a 100kW-class laser propelled launch System
- BBM and Its Functional Tests for High Efficiency Cryo-Coolers abroad Spacecraft
- Ultralightweight thin film solar array structure deployed by booms
- Development of a next-generation hard lander: Approach to Mars and Jupiter Moons
- Development of high-performance shape memory alloy actuators through additive manufacturing
- Development of innovative heat management technology for long-term cryogenic propellant storage
- Small Satellite Attitude Control Systems using an Interplanetary Magnetic Field
- Research and development on innovation of sample return capsule for future deep space exploration
- Construction of the architecture of spacecraft onboard network and software
- Transformer Spacecraft
- Study of advanced aero-assisted reusable space transportation system
- Guidance and Navigation Technologies for Rendezvous and Landing to Far-distant Celestial Bodies

The Achievements that have been publicly released include 80 papers, 136 presentations at international academic conferences, 256 presentations at domestic academic conferences, 16 Awards, 24 invited speeches, 3 patents, 3 published books and 14 other media reports (including press releases).

Notable Achievements are listed below.

- The WG for Research and Development of Micro Planetary Probes using Deployable Flexible Aeroshell, in order to realize the planned "Shrinking Mars entry Probe with Unfolding Robe (SPUR)" aeroshell, researched basic hardware technologies by improving the heat resistance of flexible aeroshells and testing the space resistance of flexible materials.
- The research group (RG) on an innovative detonation-based propulsion system for sounding rockets and landers prepared for space demonstrations while the general design of the rotating detonation engine was established. The group also fabricated a rotating detonation engine with a plain cylinder and confirmed that the detonation propagation was stable and that the supersonic jet could be exhausted.
- The Frequently Reusable Space Transportation System RG developed composite light-weight materials and hermetic connectors for energizing sensors in cryogenic propellant tanks. The group also researched methods for constructing and verifying navigation guidance control systems using model-based design.
- The Research on Innovative Satellite Bus Technology RG has conducted several trial tests with the goal of achieving a compact and lightweight satellite bus that can be constructed quickly. They include four-layer 3D CPU modules that use Micro-electro-mechanical-systems (MEMS) packaging technology, a compact and high-efficiency power supply unit, and lightweight high-performance thrusters with ceramic-metal joints.
- The RG for Demonstration Research on Advanced Solid Propellant Rocket Systems established a new inspection procedure that combines ultrasonic inspection and γ-ray transmission tests, and they summarized this procedure in the quality assurance strategy. The group also led the study of high-energy fuels, such as ADN, and new propulsion technologies that use these fuels.
- The RG for Rover Exploration of Small Bodies, Moons, and Planets studied a small robot that will improve the frequency and exploration range of mobile surface exploration missions. The group also developed prototypes of a small probe system that uses a hopping mechanism. This technology is planned to be mounted on the Smart Lander for Investigating the Moon (SLIM) mission.
- The RG for R&D on a Mars airplane aims toward the realization of the world's first Mars airplane that will perform a wide range of movement and observation in the Martian atmosphere. The RG designed and evaluated the flight system, aerodynamic model, and navigation guidance control system for balloon-borne high-altitude flight demonstrations planned for FY2019.
- The Formation Flying (FF) WG investigated the technical requirements for the realization of a future space-borne gravitational-wave telescope and infrared interferometer, and examined the feasibility of demonstrating this technology demonstration with small spacecraft. They also updated the FF technology R&D roadmap.

2-2. Technical Committees

The Sounding Rocket Technical Committee, Committee for Space Biology and Microgravity Science, and Committee on Scientific Ballooning deliberated about application screening and research plans. Committee for International Space Exploration gave advice and recommendations to the deep-space gateway mission and the Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES) mission. Space Transportation System Committee developed a research plan for a space-transport system.

4. ISAS Program Office

a. Overview

ISAS projects and experiments are executed by relatively few teams with highly skilled members who are undertaking challenging missions. Shared support and strategic program activities that take a bottom-up approach are crucial for the reliable implementation of these projects.

The ISAS Program Office was thus established to provide interdepartmental support for various project teams while using limited human resources. The office also provides effective support to WGs in the early phases of projects.

The following are some specific activities of the ISAS Program Office:

(1) Support for projects and experiments:
- Consultation services and interfacing with related departments.
- Collaboration in planning and preparation for management reviews.
- Other activities related to project implementation and specific technical challenges.

(2) Sharing information related to projects and experiments and providing risk management services.
(3) Developing implementation methods suitable for Space Science Projects
(4) Support for the selection for Competitive Missions
(5) Secretarial services for technical reviews and evaluations of Space Science Projects
(6) Support for the Chief Engineer Office

b. Summary of Work in FY2018

1. Support for Space Science Projects

Project Support by the Program Office

WGs include many members who are not part of JAXA and have little experience in space science projects. Thus, support during the early phase of project planning is essential to minimizing problems that may arise in the development phase. Therefore, the office mainly supports the initial phases of project activities, such as clarifying scientific goals, setting mission requirements that support those goals, verifying the adequate selection of system requirements, identifying issues and risks, and developing risk-management measures.

In FY2018, we supported the LiteBIRD, OKEANOS (Solar Power Sail), SPICA, small-JASMINE, Solar-C EUVST, HiZ-GUNDAM, CAESAR-SRC, and OMOTENASHI projects.

In addition, for the DESTINY+ project, the office supported the study of the kick-stage motor in the upper stage of the Epsilon launcher to identify adequate technical requirements, and coordinated the design of interfaces between DESTINY+ and the launch vehicle.

Project Support by the SE and PM Senior Experts

The Program Office has selected experts to provide sensible support for space science projects and WGs. These experts provide advice and suggestions to improve systems engineering (SE) and project management (PM) during the technical meetings organized by each project team. The experts mainly consist of retired JAXA staff that are experienced in system development for satellites and spacecraft.

2. Issue tracking for projects and technical activities

The Program Office organized monthly progress-report meetings to monitor progress, challenges, and risks in all projects under development, and to ensure that information is shared among projects. These meetings include the Director General, Deputy Director General, Program Director, and Director of the Management and Integration Department. Various experts were also involved in these meetings and detailed discussions about technical topics were conducted from the perspective of project management.

The office also held another monthly meeting to confirm the status of projects in on-orbit operations and to coordinate technical demonstration activities at ISAS.

3. Implementation Procedures for Space Science Projects

Reflecting the project management reform of JAXA following the Astro-H incident, the Program Office developed implementation procedures for space science projects, especially for initial phases.

The reformed project management protocol has newly adopted the Concept Maturity Level (CML) as a yardstick for mission concept development in addition to the Technology Readiness Level (TRL). Implementation for Space Science Projects also uses both yardsticks.

4. Support for the selection for Competitive M-class Missions

The Program Office plays two roles in mission selection. The office supports candidates, helping them to arrange their ideas in the form of proposal materials that are compatible with the CML yardstick. Second, the office serves secretariat of the review panel.

Solar-C EUVST and HiZ-GUNDAM were selected as new candidates for M-class missions.

5. Evaluation of Space Science Projects

The Program Office serves as the secretariat for project review and evaluation meetings at ISAS, in cooperation with the Management and Integration Department. In FY2018, the office worked with project teams to prepare review materials for the following projects (project status or activity follows the project name):

- SLIM: PDR
- CAESAR-SRC: planning review prior to phase A
- OMOTENASHI: CDR
- AKATSUKI: nominal on-orbit operation completion review
- LiteBIRD: intermediate review in pre-phase A2
- OKEANOS: intermediate review in pre-phase A2
- SPICA: intermediate review in pre-phase A2

6. Support for Chief Engineer Office

The Program Office cooperated with chief engineer activities at ISAS to further increase the effectiveness of SE/PM promotion activities:

- Provision of information for Chief Engineer Office meetings.

5. Safety and Mission Assurance Officer

In July 2017, the Safety and Mission Assurance (S&MA) Officer was moved under the direction of the Senior Chief Officer of Safety and Mission Assurance in response to organizational changes in the strengthening of the independent evaluation system. The S&MA operations are to be done independently of ISAS, however the ISAS Safety Review Committee remains as an S&MA operation. The S&MA Office was involved as a jury member of the ISAS Safety Review Committee, while other S&MA members were involved in operation of the committee.

The ISAS Safety Review Committee has two roles in the safety review meeting for the research on large-scale experiments and the safety evaluation of small experiments.

In FY2017, we ensured ground safety and flight safety of solid propellant rocket with motor combustion test, and conducted parachute deployment experiment for Comet Astrobiology Exploration SAmple Return- Sample Return Capsule (CAESAR-SRC), while holding five safety review meetings at ISAS.

In addition, 25 safety review meetings were conducted in FY2018 for small-scale combustion experiments at the Noshiro Rocket Testing Center, which ensured and improved safety.

6. Budget

(in 1,000 JPY)

ISAS Budget	FY2016	FY2017	FY2018
Operating Expense Grants	16,628,159	14,082,128	11,472,233
Facility maintenance subsidy	0	2,602,531	2,048,725
Total	16,628,159	16,684,659	13,520,958

External Funds

Grant-in-aid for scientific research (KAKENHI)	340,376	309,071	308,265
"Grant-in-aid for scientific research (Accepted share of expenses)"	65,448	104,553	51,731
Funded research	989,804	744,286	868,792
Cooperative research with private sector	40,793	26,651	67,977
Earmarked donations	4,620	6,000	7,819

7. Staff (as of March 31, 2019)

Director General, Institute of Space and Astronautical Science

KUNINAKA, Hitoshi

Deputy Director General, Institute of Space and Astronautical Science

FUJIMOTO, Masaki

Director, Management and Integration Department

MIYOSHI, Hiroshi

Advisor to the Director, Management and Integration Department

IMAMURA, Hiroshi
OMI, Natsuki
YASUDA, Shin

Manager, Management and Integration Department

AOYAGI, Takashi
OHSHIO, Kazuo
TSUJI, Hiroji

Director for International Strategy and Coordination

TOUKAKU, Yoshio

Director for Education and Public Outreach

IKUTA, Chisato

Research Director

KUBOTA, Takashi

Director, Department of Space Astronomy and Astrophysics

YAMADA, Toru

Director, Department of Solar System Sciences

SAITO, Yoshifumi

Director, Department of Interdisciplinary Space Science

INATOMI, Yuko

Director, Department of Space Flight Systems

SATO, Eiichi

Director, Department of Spacecraft Engineering

YAMADA, Takahiro

Program Director of Space Science

MITSUDA, Kazuhisa

Director, ISAS Program Office

MIHO, Kazuyuki

Project Manager, GEOTAIL Project Team

SAITO, Yoshifumi

Project Manager, ASTRO-EII Project Team

ISHIDA, Manabu

Project Manager, SOLAR-B Project Team

SHIMIZU, Toshifumi

Project Manager, PLANET-C Project Team

NAKAMURA, Masato

Project Manager, Bepi Colombo Project Team

HAYAKAWA, Hajime

Project Manager, Extreme Ultraviolet Spectroscope for Exospheric Dynamics Project Team

YAMAZAKI, Atsushi

Project Manager, ERG(Exploration of energization and Radiation in Geospace) Project Team

SHINOHARA, Iku

Project Manager, Hayabusa2 Project Team

TSUDA, Yuichi

Project Manager, GREAT (Ground Station for Deep Space Exploration and Telecommunication) Project Team

NUMATA, Kenji

Project Manager, SLIM (Smart Lander for Investigating Moon) Project Team

SAKAI, Shinichiro

Project Manager, XRISM Project Team (X-Ray Imaging and Spectroscopy Mission Project Team)

MAEJIMA, Hironori

Senior Chief Officer of Fundamental Technology for Space Science

MORITA, Yasuhiro

Manager, Inter-University Research and Facility Management Group

YOSHIDA, Tetsuya

Manager, Test and Operation Technology Group

MORITA, Yasuhiro

Manager, Advanced Machining Technology Group

OKADA, Norio

Director, Scientific Ballooning Research and Operation Group

YOSHIDA, Tetsuya

Director, Sounding Rocket Research and Operation Group

HABU, Hiroto

Manager, Noshiro Rocket Testing Center

ISHII, Nobuaki

Manager, Akiruno Experimental Facility

GOTO, Ken

Director, Science Satellite Operation and Data Archive Unit

TAKESHIMA, Toshiaki

Manager, Lunar and Planetary Exploration Data Analysis Group

OOTAKE, Hisashi

Manager, Astromaterials Science Research Group

YURIMOTO, Hisayoshi

Manager, Deep Space Tracking Technology Group

YAMADA, Takahiro

Department of Space Astronomy and Astrophysics [Director: YAMADA, Toru]

Professor	Associate Professor	Assistant Professor
YAMADA, Toru	KOKUBUN, Motohide	MAEDA, Yoshitomo
MITSUDA, Kazuhisa	KII, Tsuneo	WATANABE, Shin
DOTANI, Tadayasu	KATAZA, Hirokazu	TSUJIMOTO, Masahiro
ISHIDA, Manabu	YAMAMURA, Issei	WADA, Takehiko
NAKAGAWA, Takao	KITAMURA, Yoshimi	SAKIMOTO, Kazuhiro
MATSUHARA, Hideo	MURATA, Yasuhiro	DOI, Akihiro
TSUBOI, Masato	YAMAGUCHI, Hiroya	TAMURA, Takayuki
EBISAWA, Ken		
SEKIMOTO, Yutaro		
YAMASAKI, Noriko		
TASHIRO, Makoto [S]		
SHIBAI, Hiroshi [V]		
HASUMI, Masashi [V]		
KANEDA, Hidehiro [V]		
KITAYAMA, Tetsu [V]		

Department of Solar System Sciences [Director: SAITO, Yoshifumi]

Professor	Associate Professor	Assistant Professor
SAITO, Yoshifumi	ABE, Takumi	ASAMURA, Kazushi
FUJIMOTO, Masaki	MATSUOKA, Ayako	HASEGAWA, Hiroshi
SATO, Takehiko	TAKASHIMA, Takeshi	YAMAZAKI, Atsushi
HAYAKAWA, Hajime	TANAKA, Satoshi	HARUYAMA, Junichi
NAKAMURA, Masato	OKADA, Tatsuaki	OHTAKE, Makiko
USUI,Tomohiro	ABE, Masanao	SHIRAISHI, Hiroaki
	SAKAO, Taro	HAYAKAWA, Masahiko
YURIMOTO, Hisayoshi [S]	SHIMIZU, Toshifumi	MITANI, Takefumi
KURAMOTO, Kei [S]	OZAKI, Masanobu	MURAKAMI, Go
WATANABE, Seiichiro [V]	SHINOHARA, Iku	
MIYAMOTO, Hideaki [V]	ENYA, Keigo	SUGAWARA, Haruna [S]
WATANABE, Junichi [V]	TASKER, Elizabeth	
YAMAGISHI, Akihiko [V]	IWATA, Takahiro	
MIYOSHI, Yoshizumi [V]		
	YABUTA, Hikaru [V]	
	ISHIHARA, Morio [V]	
	HORINOUCHI, Takeshi [V]	
	YOKOYAMA, Takaaki [V]	

Department of Interdisciplinary Space Science [Director: INATOMI, Yuko]

Professor	Associate Professor	Assistant Professor
INATOMI, Yuko	KUROTANI, Akemi	MIURA, Akira
ISHIKAWA, Takehiko	HASHIMOTO, Hirofumi	YAMAMOTO, Yukio
YOSHIDA, Tetsuya	TAKAKI, Ryoji	IZUTSU, Naoki
	SAITO, Yoshitaka	YANO, Hajime
ISHIOKA, Noriaki [F]	IKUTA, Chisato	
SHIGETA, Yasuteru [V]	FUKE, Hideyuki	
ISHIKAWA, Hiroshi [V]		
	SHIBUYA, Takazo [V]	

[V] Visiting, [F] Full-time, [S] Specially-appointed

Department of Space Flight Systems [Director: SATO, Eiichi]

Professor	Associate Professor	Assistant Professor
SATO, Eiichi	YAMADA, Tetsuya	MORI, Osamu
KAWAGUCHI, Junichiro	FUNAKI, Ikkoh	TAKEMAE, Toshiaki
ISHII, Nobuaki	NISHIYAMA, Kazutaka	MARU,Yusuke
MORITA, Yasuhiro	TOKUDOME, Shinichiro	SAIKI, Takanao
SHIMADA, Toru	OYAMA, Akira	KITAGAWA, Koki
HORI, Keiichi	NONAKA, Satoshi	OKUIZUMI, Nobukatsu
MINESUGI, Kenji	GOTO, Ken	TSUKIZAKI, Ryudo
OGAWA, Hiroyuki	TSUDA, Yuichi	TOBE, Hirobumi
SAWAI, Shujiro	HABU, Hiroto	SATO, Yasutaka
KAWAKATSU, Yasuhiro	TAKEUCHI, Shinsuke	
FUJITA, Kazuhisa	YAMADA, Kazuhiko	
INATANI, Yoshifumi [S]	KOBAYASHI, Hiroaki [S]	
NAGANO, Hosei [V]	TAKAO, Yoshinori [V]	
FUNAZAKI, Kenichi [V]	NONOMURA, Taku [V]	
KITAZONO, Koichi [V]	MURANAKA, Takanobu [V]	

Department of Spacecraft Engineering [Director: YAMADA, Takahiro]

Professor	Associate Professor	Assistant Professor
YAMADA, Takahiro	SONE, Yoshitsugu	MITA, Makoto
HASHIMOTO, Tatsuaki	MIZUNO, Takahide	FUKUSHIMA, Yosuke
KUBOTA, Takashi	SAKAI, Shinichiro	KOBAYASHI, Daisuke
YAMAMOTO, Zenichi	FUKUDA, Seisuke	TOYOTA, Hiroyuki
KAWASAKI, Shigeo	YOSHIKAWA, Makoto	BANDO, Nobutaka
HIROSE, Kazuyuki	TANAKA, Koji	OTSUKI, Masatsugu
	TODA, Tomoaki	TOMIKI, Atsushi
SAITO, Hirobumi [S]	YOSHIMITSU, Tetsuo	MAKI, Kenichiro
KATAOKA, Jun [V]	MATSUZAKI, Keiichi	
HIRAKO, Keiichi [V]	TAKEUCHI, Hiroshi	OZAKI, Naoya [S]
	FUNASE, Ryu [V]	
	ISHIGAMI, Genya [V]	
	YONEKURA, Yoshinori [V]	

International Top Young Fellowship (ITYF)

Department	Name
Department of Solar System Sciences	PERALTA, Javier
Department of Space Astronomy and Astrophysics	IZUMI, Kiwamu
Department of Spacecraft Engineering	BONARDI, Stéphane
Department of Solar System Sciences	NODA, Carlos

[V] Visiting, [S] Specially-appointed

8. Professors Emeriti (As of March 31, 2019)

Institute of Space and Astronautical Science (ISAS)

MORI, Daikichiro
HIRAO, Kunio
KURATANI, Kenji
NOMURA, Tamiya
ODA, Minoru
OGUCHI, Hakuro
USHIROKAWA, Akio
TAKAYANAGI, Kazuo
ITOH, Tomizo
OBAYASHI, Tatsuzo
OSHIMA, Koichi
HAYASHI, Tomonao
HORIUCHI, Ryo
NISHIMURA, Jun
MIURA, Koryo
TANAKA, Yasuo
NISHIMURA, Toshimitsu
IWAMA, Akira
AKIBA, Ryojiro
SHIMIZU, Mikio
KARASHIMA, Keiichi
OKUDA, Haruyuki
KURIKI, Kyoichi
MAKINO, Fumiyoshi
OGAWARA, Yoshiaki
KAWASHIMA, Nobuki
NAGATOMO, Makoto
NISHIDA, Atsuhiro
TSURUDA, Koichiro
HINADA, Motoki
ITIKAWA, Yukikazu
YAJIMA, Nobuyuki
HIROSAWA, Haruto
KOBAYASHI, Yasunori
MATSUO, Hiroki

Japan Aerospace Exploration Agency (JAXA)

NINOMIYA, Keiken
KOHNO, Masahiro
NAGASE, Fumiaki
MATSUMOTO, Toshio
MIZUTANI, Hitoshi
UESUGI, Kuninori
TANATSUGU, Nobuhiro
NATORI, Michihiro C.
MATOGAWA, Yasunori
NAKATANI, Ichiro
TAKANO, Tadashi
HIRABAYASHI, Hisashi
MUKAI, Toshifumi
MAEZAWA, Kiyoshi
KURIBAYASHI, Kazuhiko
NAKAJIMA, Takashi
YAMASHITA, Masamichi
TAJIMA, Michio
FUJIMURA, Akio
INOUE, Hajime
KATO, Manabu
SASAKI, Susumu
ONODA, Junjiro
YODA, Shinichi
FUJII, Kozo
KOMATSU, Keiji
MURAKAMI, Hiroshi
ABE, Takashi
HATTA, Hiroshi

9. ISAS Sagamihara Campus and Related Facilities

The Sagamihara Campus was established in April 1989 as the core ISAS facility. The campus, which is located in a quiet suburb about 40 km away from Tokyo with beautiful views of the Tanzawa Mountains, contains the Research and Administration Buildings, the Flight Environment Test Building, the Wind Tunnel Facility Building, the Research and Laboratory Building, etc., where tests are performed for basic R&D and verification of onboard instruments for launch vehicles and satellites. JAXA Space Exploration Innovation Hub Center's main office and the JAXA Space Education Center are also located on the Sagamihara Campus.

One of the functions of the Sagamihara Campus is to provide graduate education programs for the next generation of researchers and engineers. In addition, as an inter-university research institutes, researchers gather from universities across the country to perform a variety of research projects. The Sagamihara Campus also invites researchers from various countries and functions as a space research center, contributing to the progress of space science internationally.

JAXA's Facilities related to ISAS

Uchinoura Space Center
- Location:
- 1791-13 Minamikata, Kimotsuki-cho, Kimotsuki-gun, Kagoshima
- lat 31° 15′ 05″ N long 131° 04′ 34″ E
- Site: 718,662m^2
- Gross floor area: 16,117m^2

Usuda Deep Space Center
- Location:
- 1831-6 Omagari, Kamiodagiri, Saku-shi, Nagano
- lat 36° 07′ 59″ N long 138° 21′ 43″ E
- Site: 97,111m^2
- Gross floor area: 3,089m^2

Taiki Aerospace Research Field
- Location:
- In the Taiki Multi-Purpose Aerospace Park169 Bisei, Taiki-cho, Hiroo-gun, Hokkaido
- lat 42° 30′ 00″ N long 143° 26′ 30″ E Site: 90,357m^2
- Gross floor area: 4,554m^2

Tsukuba Space Center
- Location:
- 2-1-1 Sengen, Tsukuba-shi, Ibaraki

ISAS Facilities

Sagamihara Campus (ISAS)
- Location:
- 3-1-1 Yoshinodai, Chuo-ku, Sagamihara-shi, Kanagawa
- lat 35° 33′ 30″ N long 139° 23′ 43″ E
- Site: 73,001m^2
- Gross floor area: 58,733m^2

Noshiro Rocket Testing Center
- Location:
- Asanai, Noshiro-city, Akita
- lat 40° 10′ 10″ N long 139° 59′ 31″ E
- Site: 61,941m^2
- Gross floor area: 3,633m^2

Akiruno Experimental Facility
- Location:
- 1918-1 Sugao, Akiruno-shi, Tokyo
- lat 35° 45′ 14″ N long 139° 16′ 24″ E
- Site: 2,008m^2
- Gross floor area: 698m^2

IV
International Collaboration and Joint Research

1. International Collaboration

Space is a common frontier for all humanity and many of the world's countries have worked together on a variety of space science missions over the years. Japan also sees international collaboration as an important means of pursuing space science missions and the nation has long been at the forefront of diverse areas of space science on a global level.

As a national pivot point for joint-university activities, ISAS must continue to play a central role in creating excellent outer space exploration missions that win support from the space science community at home and abroad. To this end, close communication and cooperation with our international colleagues is extremely important.

International collaboration will benefit space science missions in many ways. First of all, it can provide a means to realize more significant aerospace exploration efforts while reducing costs. Rather than limiting the scope to Japan-supported missions, we believe it is far more beneficial to expand our horizons and take advantage of the superior observational equipment of other countries and to encourage others to use our facilities, in order to enhance the value of all missions.

Secondly, international collaboration will offer the space science community more opportunities, despite the tight financial conditions that limit the frequency of space science missions. Accordingly, we choose to invite international colleagues on our missions and/or send members of our community along on theirs, thereby enriching the community base, which is fundamental to realizing value in the fields of space science.

Thirdly, international collaboration encourages members of the Japanese space science community to work with a diverse range of supremely talented people, which stimulates our intelligence base and facilitates exposure to more scientific data, thus paving the way to new scientific knowledge and innovation in aerospace technologies.

Given the importance of all this, ISAS needs to further engage in strategic discussions with space agencies, research institutes and universities abroad in order to strengthen our ties with our prominent counterparts around the world.

ISAS pursued numerous international initiatives of various kinds throughout FY2018. One of the new international-collaboration initiatives for current missions is the successful launch of "BepiColombo", a joint mission by the European Space Agency (ESA) and JAXA to reach the planet Mercury. It was launched on an Ariane 5 rocket in October 2018 from Guiana Space Centre in Kourou, French Guiana. Furthermore, support activities for the asteroid sample-return mission "Hayabusa2" include various form of international collaborations. For example, upon Hayabusa2's arrival at "Ryugu" in June 2018, cooperative overseas space agencies delivered congratulatory messages. The successful landing of the MASCOT lander provided by DLR/CNES was jointly announced in October 2018, and touchdown operations in February 2019 was shared in international attention. Moreover, JAXA and the Australian government have been promoting discussion and field investigations about the Asteroid Explorer Hayabusa2 Capsule retrieval operation as one of the potential retrieving sites lies in Australia.

Other international collaborations are in development. As of October 2018, JAXA and NASA have signed Memorandum of Understanding (MOU) about the X-ray Imaging and Spectroscopy Mission (XRISM) to strengthen cooperative ties fostered during the development of ASTRO-H X-ray astronomy satellite. ESA has also collaborated with JAXA on XRISM.

Other collaborations concern missions in the study phase. Multifaceted international cooperation is being promoted with NASA, ESA, CNES, and DLR regarding the Martian Moons Exploration project (MMX). Collaboration with NASA has been formalized in Letter of Agreement (LoA) and specific collaboration items have been coordinated with ESA. Additionally, at the International Astronautical Congress (IAC) held in Bremen, Germany in October 2018, the president of JAXA announced a joint statement with the heads of CNES and DLR regarding a rover that will be carried onboard MMX. The agencies have agreed that this rover would be jointly developed by CNES and DLR. At the Planetary Protection Panel during COSPAR, ISAS facilitated a discussion about Planetary Protection Policy for sample-return missions from Martian moons.

ISAS has continued to promote international collaboration about candidates for Strategic Large-class missions. These include the Lite (Light) satellite for studies of B-mode polarization and Inflation from cosmic background Radiation Detection (LiteBIRD) with NASA and Europe (ESA, CNES etc.), and the Outsized Kite-craft for Exploration and Astronautics in the Outer Solar System (OKEANOS) with DLR.

In addition, ISAS discussed the Space Infrared Telescope for Cosmology and Astrophysics (SPICA), the next-generation infrared observation telescope satellite, which is positioned as a candidate for a strategic large-scale mission in collaboration with partners in Europe.

In studies of DESTINY$^+$, one of the candidates for competitively chosen medium-size missions, collaboration was promoted with DLR based on an Implementing Arrangement. Also, various supports have been extended to acquire necessary international collaboration on the next candidate mission for competitively chosen medium-size missions.

As for overseas missions, agreements regarding cooperative activities in the development, launch, and operation phase for the ESA-led Jupiter Icy Moons Exploration (JUICE) mission were signed with DLR and the Swedish National Space Agency, who are the recipients of the instruments provided by JAXA. Also, Japan and Europe are collaborating on studying the Advanced Telescope for High ENergy Astrophysics (ATHENA) through JAXA - CNES joint effort on the Cooling Chain Core Technology Program (CC-CTP). An agreement was signed about one of the candidates for NASA New Frontiers 4, "CAESAR" with Cornell University, the organizer of the proposals, to promote ISAS's role of providing a sample-return capsule. Lastly, WFIRST is a flagship NASA mission in astrophysics, and avenues for Japanese collaboration are under consideration.

Scientific ballooning campaigns and sounding rocket launches have also involved international collaboration. As laid out in on an Implementation Arrangement about feasibility studies for a microgravity experiment on a sounding rocket launched by DLR, Japanese researchers collaborated on a study of cosmic dust. Also, an Agreement was made with NASA about the implementation of the international CLASP-2 sounding rocket experiment.

In order to promote the above-mentioned international collaborations, inter-agency dialogues have been held, such as at the COSPAR Assembly in July 2018 in Pasadena and at IAC in October 2018 in Bremen. During the COSPAR Assembly in Pasadena, ISAS presented an exhibition to promote space science and exploration activities.

ISAS has promoted further international collaboration by staying up-to-date with the latest developments in U.S. and European space science and by presenting Japanese space-science plans at conferences such as Space Science Week hosted by the National Academies of Science and the European Space Science Committee meeting.

a. International cooperation in satellite missions at the operational stage

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
Magnetospheric Observation Satellite GEOTAIL	Jul 24,1992	GEOTAIL is a cooperative mission with NASA for research on the dynamics of the structure of the magnetosphere and participation in the International Solar-Terrestrial Physics (ISTP) project.	NASA (National Aeronautics and Space Administration, USA)	Rocket launch and approximately one-third of observation equipment.
			MPS (Max Planck Institute for Solar System Research, Germany)	Provision of the Low Energy Particle Detector (LD) for the High Energy Particle (HEP) detector.
X-ray Astronomy Satellite SUZAKU (ASTRO-EII)	Jul 10, 2005	SUZAKU makes high-sensitivity observations of various X-ray objects in broader energy bands and with better resolution than previous satellites, with the aim of elucidating the evolution of cosmic structure (largest-scale galaxy cluster collisions, gas behavior during amalgamation, exploration of areas near black holes, etc.)	NASA (USA), MIT (Massachusetts Institute of Technology USA)	Japan-US cooperative development of the X-ray Telescope (XRT), X-ray Spectrometer (XRS), etc.
			ESA (European Space Agency)	Participation of ESA researchers as scientific advisors for SUZAKU.
			ISRO (Indian Space Research Organization, India)	ISRO "ASTROSAT" satellite and cooperative observations.

Solar Observation Satellite HINODE (SOLAR-B)	Sep 23, 2006	As a globally available solar observatory, HINODE observes various explosions and heating phenomena that occur in the solar surface and corona. By capturing fluctuation phenomena of magnetic energy generated in the Sun's atmosphere, we can explore fundamental problems from cosmic plasma physics, such as the origin of the corona (the Sun's outer atmosphere), the relation between changes in the electromagnetic structure of the photosphere and dynamic corona phenomena.	NASA (USA)	Japan–US cooperative development of Solar Optical Telescope (SOT), X-ray Telescope (XRT), etc. Also, Japan–US–UK cooperative development of the Extreme-ultraviolet Imaging Spectrometer (EIS).
			STFC (Science and Technology Facilities Council, UK)	Japan–US–UK cooperative development of the Extreme-ultraviolet Imaging Spectrometer (EIS).
			ESA, NSC (Norwegian Space Centre, Norway)	HINODE scientific data received at a Norwegian facility.
Venus Climate Orbiter AKATSUKI (PLANET-C)	May 21, 2010	As the world's first mission to thoroughly investigate the mechanism of movement of Venus's atmosphere, AKATSUKI uses newly developed infrared sensors to uncover atmospheric phenomena hidden beneath the planet's clouds. This will allow us to elucidate the mechanism of Venusian atmospheric dynamics that cannot be explained by conventional meteorology (planetary-scale high-speed winds) to obtain a comprehensive understanding of weather phenomena on this planet.	NASA (USA)	Provision of the Deep Space Network (DSN) tracking for AKATSUKI, scientific support.
			ESA	Participation of ESA Venus Express team researchers in cooperative research.
			ISRO (India)	Conduct radio wave occultation observation of Venus atmosphere by communication between AKATSUKI and ISRO's DSN and JAXA's DSN.

Asteroid Explorer Hayabusa2	Dec 3, 2014	A sample return mission to the C-class asteroid "Ryugu" that will provide new knowledge about the original distribution of materials in the solar system and its evolutionary process.	NASA (USA)	Deep Space Network (DSN) tracking of Hayabusa2, control support, asteroid ground observation support, OSIRISRex sample provision, etc.
			DLR (German Aerospace Center, Germany)	Hayabusa2 tracking support, microgravity experiment support.
			ASA (Australian Space Agency), Department of Industry and Science, Australian Defense Organisation (Australia)	Permission for sample reclamation capsule landing in Australia and landing operations support.

Cooperative projects with overseas satellite missions

Gamma-ray Burst Observation Mission Swift	Nov 20, 2004	Swift is an international collaboration with the US, UK, and Italy for investigating the formation of gamma-ray bursts, the largest known explosive phenomena.	NASA (USA)	JAXA, Saitama Univ., Univ. of Tokyo to provide Burst Alert Telescope (BAT).
Magnetosphere exploration satellite constellation THEMIS(Time History of Events and Macroscale Interactions during Substorms)	Feb 17, 2007	THEMIS is a US-led mission, consisting of five magnetosphere exploration satellites and full-sky cameras. Combining these with magnetosphere observation equipment will elucidate the occurrence mechanism of "substorms", the explosive development of the aurorae.	NASA (USA), UC Berkeley (USA)	JAXA researchers participating as science personnel.
Gamma-ray Space Telescope Fermi	Jun 11, 2008	Fermi is an international mission involving the US, France, Germany, Japan, Italy and Sweden. It will perform observations of black holes, neutron stars, active galactic nuclei (AGNs), supernova remnants and gamma-ray bursts, the largest known explosive phenomena.	NASA(USA)	Hiroshima Univ. providing semiconductor sensors for the gamma-ray Large Area Telescope (LAT)
Canadian small satellite project CASSIOPE (CAScade, Smallsat and IOnospheric Polar Explorer)	Sep 29, 2013	CASSIOPE is Canada's first small satellite project. Its main goal is elucidation of atmospheric outflow mechanisms from the polar region and observations of the effects of the Sun on Earth's magnetosphere and atmosphere.	Univ. of Calgary (Canada)	JAXA providing one of eight E-POP observation devices (neutral particle analyzers).
Korean Science & Technology Satellite STSAT-3	Nov 21, 2013	STSAT-3 is used for atmospheric observations and environmental monitoring, as well as galaxy observations.	KASI (Korea Astronomy and Space Science Institute, South Korea)	JAXA providing technical assistance for telescope system development of the Multipurpose Infra-Red Imaging System (MIRIS).

Magnetospheric Multi-Scale Mission MMS	Mar 12, 2015	MMS is a NASA-led mission. It uses observations with ultra- high temporal resolution from four identically constructed satellites to elucidate magnetic reconnection and other space plasma phenomena that occur near Earth.	NASA(USA)	JAXA providing technical support for development of the MMS Dual Ion Sensor (DIS) in the Fast Plasma Instrument (FPI).
Exploration of energization and Radiation in Geospace ERG	Dec 20, 2016	This mission aims at discovering how high-energy electrons that are repeatedly created and destroyed in "space storms" resulting from solar wind disturbances are produced in the Van Allen radiation belt, and how these space storms propagate.	NASA (USA)	Cooperative observation with NASA's "Van Allen Probes."
			CSA (Canada)	Cooperative observation with CSA's "ORBITALS" satellite.
			AS (Academia Sinica, Taiwan)	Provision of the Low-Energy Particle Experiment (LEP-e).

b. International cooperation in satellite missions at the development stage

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
Mercury Exploration Mission BepiColombo	October 20,2018	This is the first in-depth cooperative mission between Japan and the ESA, using two satellites—the ESA's Mercury Planetary Orbiter "MPO" and JAXA's Mercury Magnetosphere Orbiter "MMO"—to conduct comprehensive observations of Mercury's magnetic field, magnetosphere, interior and surface, thereby revealing mysteries of Mercury's past and present.	ESA	MPO development, rocket launch, etc.
			CNES (Centre National D'études Spatiales, France)	Partial provision of the MMO- mounted Mercury Plasma Particle Experiment (MPPE) and Plasma Wave Investigation (PWI) experiments. Also, Japan–France co-development of Probing of Hermean Exosphere by Ultraviolet Spectroscopy (PHEBUS) experiment.
			IWF (Austrian Space Research Institute, Austria)	Provision of Magnetic Field Measurement (MGF) device on MMO.
			SNSA (Swedish National Space Agency, Sweden)	Provision of Energetic Neutral Atom (ENA) and Mercury Electric Field In-Situ Tool (MEFISTO) electric field measuring instrument.
			FSA (Russian Federal Space Agency, Russia)	Provision of the Mercury Sodium Atmosphere Spectral Imager (MSASI) on MMO.
			DLR (Germany)	Provision of the equipment for the ion mass analyzer on MMO.

X-ray Imaging and Spectroscopy Mission (XRISM)	FY2021 (Planned)	Following the termination of ASTRO-H (Hitomi) mission, XRISM aims to provide breakthroughs in the study of "structure formation of the universe", "history of flows of mass and energy in universe", and "the composition and evolution of celestial object" as well as to discover "unprecedented science through high resolution x-ray spectroscopy". In order to achieve these science objectives, "flows of mass and energy and evolution of celestial object in hot gas plasma" is to be elucidated through unprecedented characteristic and performance.	NASA (USA)	SXS, SXI, Mission SE, Ground SW development, Science Operation, Science
			ESA	SXS LHP Development, STT Delivery, Science
			SRON (Netherlands)	SXS FWM/E Development, Science

c. Satellite missions in preparation or under proposal (international cooperation being planned)

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
Next-Generation Infrared Astronomy Mission SPICA (pre-project)	TBD	High-sensitivity infrared observations to elucidate essential processes of the universe's history, "from the Big Bang to the birth of life".	ESA	Under discussion
			SAFARI consortium (EU, Canada)	Under discussion
Solar Physics Satellite SOLAR-C (working group)	TBD	Understanding plasma dynamics as a single system extending from the solar surface to the corona and extending to inter-planetary space to elucidate universally appearing elementary plasma processes. To that end, three tasks are performed: 1) elucidating the mechanism of chromosphere– corona and solar wind formation, 2) elucidating the expression mechanism for solar surface explosion phenomena and acquisition of knowledge for predicting its generation, and 3) elucidating the variation mechanism of solar radiation spectra that affect global climate change.	NASA (USA)	Under discussion
			ESA	Under discussion

Martian Moons eXploration (MMX) Mission (pre-project)	FY2024 (planned)	By analyzing a sample from a Mars satellite return mission and performing on-orbit observations, we will pursue an overall goal of better understanding the evolution of pre-life environments through the following scientific findings: 1) uncovering the origins of the Martian satellites, in preparation for deciphering the formation process of Mars, 2) using sample analysis to place restrictions on possibilities for Mars's formation (depending on findings related to the origin of Mars's satellites), 3) unraveling the history of Mars's environment, and 4) globally observing Mars's atmosphere and surface.	NASA (USA)	Under discussion
			CNES (France)	Under discussion
			ESA	Under discussion
			DLR (Germany)	Under discussion
Outsized Kite-craft for Exploration and Astronautics in the Outer Solar System (OKEANOS) (pre-project)	TBD	Solar power sail-craft aims at demonstration of exploration of the outer planetary region and will rendezvous with a Jupiter Trojan asteroid and deploy a lander that will land on the surface to collect samples from both surface and subsurface to perform in-situ analysis. Multiple kinds of deep space observation in the cruising environment and Trojan asteroid observation will be performed.	DLR (Germany)	Under discussion
Cosmic microwave background radiation polarization observation satellite LiteBIRD (Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection) (pre-project)	TBD	This mission aims at a thorough investigation of the inflation model of cosmology. Cosmic inflation is expected to have produced primordial gravity waves and their after-effects are predicted to have been imprinted in the cosmic microwave background polarity map as "B-mode" perturbations. This mission will perform full-sky observations free of strong foreground signals so that polarized B-mode signals due to primordial gravity waves should be strongest.	NASA (USA), ESA, etc.	Under discussion

Cooperative projects with overseas satellite missions

Jupiter Icy Moons Explorer JUICE (pre-project)	2022 (planned)	JUICE is an ESA-led mission. It will map the surfaces of Jupiter and its larger satellites (Ganymede, Callisto, and Europa) and perform interior observations to investigate the possibility of life.	ESA, DLR (Germany), SNSA, (Sweden), etc.	DLR: provide part of GALA (Ganymede Laser Altimeter) SNSA: provide part of RPWI (Radio. & Plasma Waves Investigation), and PEP/ JNA(Particle Environment Package/Jovian energetic neutral atom analyzer)
Advanced Telescope for High ENergy Astrophysics ATHENA (working group)	2028 (planned)	ATHENA is an ESA-led mission. It will observe ultrahigh-temperature matter immediately before it falls into a black hole to elucidate fundamental contributions of black holes to galaxy formation.	ESA, CNES (France), etc.	Under discussion

d. International cooperation sounding rocket experiments

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
CLASP2	April 2019 (Planned)	Aims to observe the ultraviolet light emitted by ionized magnesium atoms and detect the scattering polarization, as well as the Hanle and Zeeman effects, to quantitatively measure the vector magnetic fields in the chromosphere by launching a sounding rocket.	NASA (USA)	Provision of sounding rocket launch, onboard scientific computer and charge-coupled device (CCD) camera.
			Institut d'Astrophysique Spatiale (France)	Provision of diffraction grating.
			Instituto de Astrofísica de Canarias (Spain)	Hanle effect and Zeeman effect Model calculations

e. International cooperation scientific balloon experiments

Project	Experiment Overview	Cooperating partner	Partner responsibilities
General Anti-Particle Spectrometer GAPS	Investigating problems from cosmophysics such as the elucidation of dark matter by high-sensitivity searches for antiparticles contained in trace amounts in cosmic rays.	Columbia Univ. (USA)	Cooperative development of observational equipment, etc.,with JAXA
Japan–France atmospheric balloon joint experiment	Construction of future wide-ranging cooperative relations, starting with the development of marine reclamation technologies.	CNES (France)	Provision of information pertaining to long-term tracking of balloon systems after splashdown.
Japan-Australia balloon joint experiment	A joint balloon experiment and space science research with long-time flight and the retrieval of experimental equipment on land, which were difficult in domestic balloon experiments.	Commonwealth Scientific and Industrial Research Organisation (Australia)	Permission for experiment location and experiment support

f. Framework agreements, etc., in the space science fields with overseas universities

Partner	Description
SRON (Netherlands)	Discussions on the possibility of inter-institution cooperation with a view toward future space science research.
Stanford Univ. (USA)	Promoting coordination and cooperation between our organizations to promote cooperative research in astronomy
Yale Univ. (USA)	Promoting coordination and cooperation between our organizations for academic research in the space science fields, and considering frameworks for contributing to the development of R&D and education.
Univ. of Arizona (USA)	Carrying out cooperative research related to applied research of gamma-ray detection systems.
Univ. of Southampton (UK)	Conducting joint research on fundamental electron source (cathode) technologies for Hall thrusters and other next-generation high-power electric propulsion systems.

2. Domestic Collaboration

ISAS established and operates centers for inter-university collaboration and works to improve acceptance of academic researchers and non-Japanese researchers at the Sagamihara Campus with the aim of ensuring that the ISAS-centered space science community continuously yields results from cutting-edge research.

Regarding centers for inter-university collaboration, the ERG science center was established at the Solar-Terrestrial Environment Laboratory (STEL) in 2013, Institute for Space-Earth Environmental Research (ISEE) in collaboration with Nagoya University. The center enabled efficient data management after the launch of the ARASE satellite, such as manipulating and providing standard data files and suggesting observation plans. As the inter-university collaboration with Nagoya University has demonstrated unique capabilities, ISAS concluded agreements with Nagoya University in supporting its international inter-university collaboration and after the agreements have expired at the end of FY2017.

This preceding activity model, started in 2013, has enhanced the following two proposals for FY2015-FY2018: (1) the Center for Planetary Science at the Kobe University Graduate School of Science for the creation of future planetary science missions and personnel development and (2) the University of Tokyo, Graduate School of Science for construction of a system to promote planetary exploration using ultra-small probes.

Furthermore, selections for new affiliated universities have been made during FY2017, including (1) School of Engineering, Hokkaido University for research and development of a kick-motor for Piggy-back Space Probes, (2) Planetary Exploration Research Center at the Chiba Institute of Technology for the development of fundamental technology in planetary probes and personnel development, and (3) the Kavli Institute for the Physics and Mathematics of the Universe for hard X-ray and gamma-ray imaging.

ISAS reached separate agreements with the following organizations: Iwate University for advanced machining technology, the University of Aizu for data archiving, Saitama University for X-rays, Tokyo University for the Tokyo Atacama Observatory (TAO) Project and Space Infrared Telescope for Cosmology and Astrophysics (SPICA), the Tokyo Institute of Technology Earth-Life Science Institute for the curation of extraterrestrial life, Rikkyo University for personnel development and Okayama University for the curation of extraterrestrial materials.

3. Research by External Funds

a. KAKENHI (Grants-in-Aid for Scientific Research)

Research Categories	Number of Selected Projects	Total (in 1,000 JPY)
Scientific Research on Innovative Areas (Research in a proposed research area)	1	43,013
Scientific Research (A)	7	83,070
Scientific Research (B)	18	72,801
Scientific Research (C)	23	36,341
Challenging Exploratory Research*	1	1,212
Challenging Research (Exploratory)	2	6,110
Challenging Research (Pioneering)	1	6,630
Early-Career Scientists	2	3,640
Young Scientists (A)	1	1,040
Young Scientists (B)	7	8,142
Research Activity start-up	4	5,920
JSPS Fellow	7	9,002
Fostering Joint International Research	1	8,074
Fostering Joint International Research (B)	3	23,270
Total	78	308,265

* "Challenging Exploratory Research" has been revised and new categories "Challenging Research (Pioneering/ Exploratory)" has been established. No new invitation for applications is conducted for Challenging Exploratory Research after FY2016.

Accepted Share of expenses

Research Categories	Number of Selected Projects	Total (in 1,000 JPY)
Scientific Research on Innovative Areas (Research in a proposed research area)	7	14,016
Scientific Research (S)	7	18,850
Scientific Research (A)	5	7,410
Scientific Research (B)	13	10,270
Scientific Research (C)	4	600
Challenging Research (Exploratory)	2	455
Fostering Joint International Research (B)	1	130
Total	39	51,731

b. Funded Research

Number of Researches	Total (in 1,000 JPY)
12	868,792

c. Cooperative Research with Private Sector

Number of Researches	Total (in 1,000 JPY)
50	67,977

d. Earmarked Donations

Number of Researches	Total (in 1,000 JPY)
12	7,819

4. Domestic Joint Research

a. Open Facilities for Domestic Joint Research

Facility	Number of joint research
Space Chamber test equipment	19
Ultra-high-speed collision test equipment	24
Space radiation equipment	8
Wind tunnel laboratory	27
Planetary atmospheric entry environment simulator	15
JAXA supercomputer	25

b. Research for promoting international missions

	Number of joint research
	8

c. Joint Researchers Assigned to Specific Themes through Application by ISAS Educational Faculty

	Number of joint research
	45

V

Education and Public Outreach

1. Graduate Education

At ISAS, academic staff appointed by universities as professors, associate professors, and assistant professors provide education for students at ISAS through requests by universities for experimental and theoretical research and innovative R&D.

ISAS provides comprehensive guidance on space science and space engineering research to students, as well as direct involvement in preliminary research and large research projects that are difficult to conduct at universities. Through these means, opportunities to acquire deep knowledge and planning skills for space science projects contribute to the development of human resources by fostering personnel who will lead future space science and aerospace research, engage in R&D with space equipment manufacturers and companies utilizing space infrastructure for their clients, and organizing projects in a wide range of social fields.

ISAS staff engaged in graduate education (As of March 31, 2019)

School or Program	Professors	Associate professors	Assistant Professor	Total
The Graduate University for Advanced Studies	19	39	18	76
The Graduate School at the University of Tokyo				
School of Science	8	3	6	17
School of Engineering	10	3	12	25
Special Inter-Institutional Research Fellows*	7	11	3	21
Cooperative Graduate School*	6	5	2	13

* Includes teaching staff at the Graduate University for Advanced Studies and the Graduate School at the University of Tokyo.

The Director General of ISAS defined and established the Graduate Education Committee as an organization to promote graduate education at ISAS. This committee reviews important program elements, including basic policies and guidelines related to cooperation with graduate education, cooperation with the Graduate University for Advanced Studies (known as SOKENDAI in Japan) and the University of Tokyo, and other issues related to affiliations with graduate schools.

In FY2018, the acceptance of students was enhanced under a new ISAS cooperation system after having reviewed the past system. The new system has been divided into 2 main categories based on the acceptance purpose, and upon taking into account the differences in training content and acceptance period and so on, each of them was categorized into 2 programs: Graduate Student Education/Research Guidance Program (Cooperative Graduate School System and Commissioned Guidance Student System) and Student Training Program (Skill Acquisition Program and Internships).Conditions common to each program such as handling of expenses, insurance and damage compensation as well as handling of intellectual property were clearly defined. It was also determined that agreements will be concluded for each system to fulfill the responsibility of accepting students. To provide proper guidance to the students, qualifications for JAXA employees were established, safety of students were ensured, and responsibilities of JAXA employees who provide training and guidance were specified.

Major features of ISAS cooperation for graduate education are described below.

a. Department of Space Astronautical Science, School of Physical Sciences, SOKENDAI

SOKENDAI was established in 1988 and was the first Japanese university to offer only graduate degrees. ISAS has cooperated with SOKENDAI since 2003. ISAS established the SOKENDAI Department of Space Science in what was then the School of Mathematical and Physical Science. Academic staff from ISAS also teach at SOKENDAI, instructing students in 5-year doctoral programs and other courses.

SOKENDAI Department of Space Science Admissions in FY2018

Admission month	Admission capacity	Applicants	Accepted applicants
October	5*	4	2
April		10	9

*Of which 3 were admitted to secondary doctoral courses.

b. Interdisciplinary Studies at the University of Tokyo’s Graduate School of Science and Engineering

Interdisciplinary studies at the University of Tokyo’s Graduate School of Science and Engineering originated from acceptance of graduate students from the University of Tokyo when ISAS was the National Aerospace Laboratory of Japan. Academic staff at ISAS are university instructors in eight departments at the University of Tokyo: the departments of Physics, Astronomy, Earth and Planetary Science, and Chemistry at the Graduate School of Science and the departments of Aeronautics and Astronautics, Electrical Engineering, Materials Engineering, and Chemical System Engineering at the Graduate School of Engineering. They accept, teach, and train master’s and doctoral degree students.

c. Graduate student education/research guidance program

In the Special Inter-Institutional Research Fellows system, ISAS accepts students from national, public, and private universities throughout Japan who need advice on their university-sponsored research, and provides education and guidance on specific research themes for limited periods. These activities are part of ISAS cooperation with graduate education as an inter-university research system. The universities to which the students belong regard these activities as "education at research institutions" as defined in Japanese graduate school guidelines, and they issue credits, review dissertations, and confer degrees.

d. Cooperative Graduate School System

The Cooperative Graduate School System is based on agreements between JAXA and specific universities. In the system, JAXA staff are appointed as visiting professors by universities, and they accept, teach, and train master and doctoral students under commission.

As of March 31, 2019, ISAS was cooperating with 12 schools in 10 universities and accepts, teaches, and trains master’s and doctoral degree students.

e. Commissioned Guidance Student System

To accept individual students to whom the Cooperative Graduate School System does not apply, JAXA will, based on agreements between JAXA and specific universities, appoint staff as the universities' visiting professors who will teach graduate school students on a specific theme.

2. Public Outreach

Targeted investments in outreach have increased the visibility of JAXA among research institutions and agencies. Diversification of communication channels continued throughout the year. A series of critical operations conducted by the Hayabusa2 asteroid explorer attracted global attention. The results of each operation and the photos delivered to Earth made global headlines.

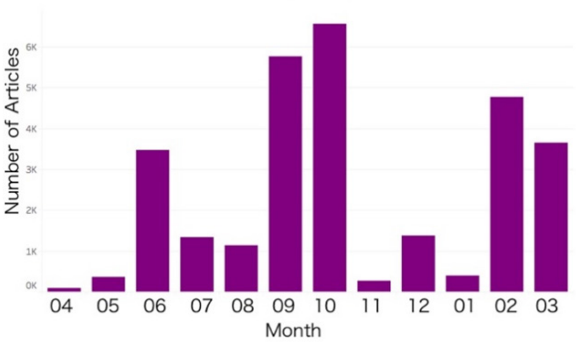
a. Press Activities

In FY2018, 48 articles were published on the ISAS’s official website. 27 of these were related to Hayabusa2, and the others covered a mix of research using ISAS experimental and analysis facilities on the ground and research using data obtained in space.

More than 29,200 articles were published by online news outlets in FY2018. This was the most press coverage that ISAS has received in 10 years. Japanese media, unsurprisingly, published the most coverage of ISAS activities. At the same time, Hayabusa2's achievements and the launch of BepiColombo, a Mercury explorer, made headlines in countries such as the United States, France, and Germany.

Number of media reports by country

Number of media reports month



ISAS/JAXA held a press conference whenever the Hayabusa2 project conducted critical operations such as the descent of the landing rover and the touchdown. ISAS/JAXA also broadcast live coverage during critical operations of Hayabusa2.

b. Exhibition and Events

ISAS’s Visitor Center, named the Space Science and Exploration Communication Hall, highlights the most important ISAS missions and scientific and engineering achievements. The Visitor Center is many guests’ first impression of ISAS. It provides visitors with an exciting experience of space science in general, along with information about ISAS-specific results, missions, experiments, and technological breakthroughs. The number of visitors peaked in August and March, since these months include the summer and spring holidays for Japanese schools.

In FY2018, the Visitor Center was also used for press conferences. More than 100 representatives of the press gathered for each press conference. An interpreters’ booth was set up in the Visitor Center for these press conferences. Bilingual streams of the conferences were broadcast via the Internet. The Internet broadcasts enabled people abroad as well as domestic audiences to tune in.

Outreach events, led by ISAS/JAXA, are held year-round to engage the public with ISAS missions and accomplishments.

ISAS invited the public to help name the Mercury Magnetospheric Orbiter of the BepiColombo project and to send messages to Mercury. More than 7,000 people responded and the project members selected "MIO" as the name of the spacecraft. The project members of "MIO" carefully installed a memory card with the received messages into the orbiter that was successfully launched in October 2018.

Souvenir photograph after naming as "MIO"

An annual special "open house" day was held at the Sagamihara Campus at the end of July, and about 6,000 people visited. Event booth locations were optimized, and smooth flow lines were planned, which alleviated the congestion that had happened in previous events. ISAS provided educational experiences that inspire and captivate visitors of all ages in a more user-friendly manner.

"Space School" events continue to captivate each new generation of learners nationwide. In the nine Space Schools hosted at ISAS in FY2018, scientists and engineers gave presentations and answered participants' questions during the half-day-long event. About 850 people joined in FY2018's "Space School at Sagamihara" and "Lectures on Space Science and a Movie," an event that commemorated the founding of ISAS.

VI
Awards

The Fourth ISAS Award Recipients

Name	Affiliation	Reason for Award	Date
TORII, Shoji	Professor Waseda Research Institute for Science and Engineering	(Special Award for Outstanding Long-term Contribution) CALET Observations of High-energy Cosmic Ray Electrons	Jan 9, 2019
NAGATA, Yasunori	Associate Professor Faculty of Engineering, Graduate School of Natural Science and Technology, Okayama University	Applications of Private Satellite Communication Networks for Spacecraft and Contributions to Overseas Balloon Experiments	Jan 9, 2019
OHTSUKA, Hirohito	Chief Engineer Rocket Technologies Division IHI Aerospace Co., Ltd.	Practical Application of a Rhumb-line Control System for Microsatellite Launch by SS-520-5 Sounding Rocket	Jan 9, 2019

Award Recipients

ISAS STAFF	Affiliation	Award	Date
SAITO, Yoshifumi NISHINO, Masaki FUJIMOTO, Masaki YAMAMOTO, Tadateru YOKOTA, Shoichiro et al.	Department of Solar System Sciences	EPS Editorial Board: EPS Excellent Paper Award 2017. "Simultaneous observation of the electron acceleration and ion deceleration over lunar magnetic anomalies (2012)."	May 2018
HABU, Hiroto et al.	Department of Space Flight Systems	Japan Explosives Society (JES): FY2017 JES Encouragement Award. "Analysis of evolved gases during the thermal decomposition of ammonium dinitramide under pressure" and "Preparation and thermal decomposition behavior of ammonium dinitramide-based energetic ionic liquid propellant."	May 2018
HABU, Hiroto et al.	Department of Space Flight Systems	Japan Explosives Society (JES): FY2018 Spring Meeting, Excellent Presentation Award.	May 2018
HASEGAWA, Hiroshi	Department of Solar System Sciences	American Geophysical Union: 2017 Editor's Citation for Excellence in Refereeing (Geophysical Research Letters).	June 4, 2018
KINOSHITA, Kyoichi ARAI, Yasutomo INATOMI, Yuko et al.	Department of Interdisciplinary Space Science	The Japan Society of Microgravity Application: JASMAC-30, Best Paper Award. "SiGe Crystal Growth by the Traveling Liquidus-Zone Method aboard the International Space Station. "(International Journal of Microgravity Science Application 33 (2016) pp. 330213 1-5)	Oct 2018
OYAMA, Akira	Department of Space Flight Systems	The Japan Society of Mechanical Engineers (JSME): Design and Systems Division, Achievement Award.	Nov 5, 2018
OYAMA, Akira	Department of Space Flight Systems	The Japan Society of Mechanical Engineers (JSME): Computational Mechanics Division, Achievement Award.	Nov 24, 2018
YOSHIKAWA, Makoto	Department of Spacecraft Engineering/ Hayabusa2 Project Team	Springer Nature: The 2018 Nature's 10.	Dec 2018

ISAS STAFF	Affiliation	Award	Date
Hayabusa2 Project Team		The Japan Society for Aeronautical and Space Sciences: Technology Award [Project]. Progress in Deep Space Navigation Technology for Small Body Rendezvous and the Arrival at Asteroid Ryugu.	Dec 2018
OYAMA, Akira et al.	Department of Space Flight Systems	The Japanese Society for Evolutionary Computation: Outstanding Paper Award. "Proposal of Simultaneous Design Optimization Benchmark Problem of Multiple Car Structures Using Response Surface Method."	Dec 9, 2018
KUNINAKA, Hitoshi	Director General, ISAS	Toray Science Foundation: FY2018 (59th) Toray Science and Technology Prize. "R&D of microwave discharge ion engines and promotion of solar system exploration."	Feb 14, 2019
SATO, Yasutaka	Department of Spacecraft Engineering	Society for Promotion of Space Science: FY2018- The 11th Space Science Encouragement Award.	Mar 8, 2019
KOBAYASHI, Daisuke HIROSE, Kazuyuki et al.	Department of Spacecraft Engineering	The Japan Society of Applied Physics: The 10th Silicon Technology Division Outstanding Paper Award. "Heavy-ion soft-errors in back-biased thin-BOX SOI SRAMs: hundredfold sensitivity due to line-type multi-cell upsets"	Mar 10, 2019
Hayabusa2 Project Team		Aviation Week: Aviation Week Network's 63rd Annual Laureate Awards, Technology & Innovation. Hayabusa2 sample-return mission.	Mar 14, 2019
Nanosatellite (SS-520 F5) Launch System Development Team		The Japan Society of Mechanical Engineers (JSME): Space Engineering Division, Space Frontier Award. "R&D of the Nanosatellite Launch System (SS-520 F5)."	Mar 29, 2019

Award Recipients

Student	Affiliation	Academic Advisor	Award	Date
KAWAUCHI, Kazuaki	Graduate School at Yokohama National University	NONAKA, Satoshi	The Japan Society for Aeronautical and Space Sciences: The 49th JSASS Annual Meeting, JSASS Excellent Presentation Awards for Students. "Supersonic Wind Tunnel Tests on Aerodynamic Characteristics of Slender Body with Asymmetric Protuberance."	Apr 2018
TAKAGI, Yuya	Graduate School at Yokohama National University	NONAKA, Satoshi	15th International Space Conference of Pacific-basin Societies (15th ISCOPS), The first prize in the Masters category."Numerical Study on Aerodynamic Improvement of Slender-bodied Reusable Rocket by Fins and Vortex Flaps."	Jul 2018
TAKAKU, Ryota	Graduate School at the University of Tokyo	NONAKA, Satoshi	Summer School (Astronomy & Astrophysics) for Young Researchers: Observation Equipment Division, Oral Award. "Development of a broadband anti-reflection coating for use in a cosmic microwave background polarization experiment."	Jul 2018
SAKAMOTO, Yuki	Graduate School at Waseda University	KOBAYASHI, Hiroaki	15th International Space Conference of Pacific-basin Societies, The first prize in the PhD category. "Thermal Fluid Characteristics of Boiling Hydrogen in a Horizontal Circular Pipe Flow."	Jul 2018
MANDO, Yuki	The Graduate University for Advanced Studies (SOKENDAI)	TANAKA, Kohji	IEEE Asia-Pacific Conference on Plasma and Terahertz Science, Outstanding Paper Award. "Study on Propagation of Plasma Induced by Hypervelocity Impact on Aluminum Plates."	Aug 2018
KAWAUCHI, Kazuaki	Graduate School at Yokohama National University	NONAKA, Satoshi	The 15th Joint Symposium between Sister Universities in Mechanical Engineering (JSSUME2018), Excellent Presentation Award. "Wind Tunnel Experiment on Slender body Aerodynamics with Asymmetric Protuberance at Mach 1.5."	Aug 2018
SEKIGUCHI, Keita	Graduate School at the University of Tokyo	SATO, Eiichi	13th International Conference on Superplasticity in Advanced Materials (ICSAM'18), Best Poster Award for Junior Researchers. "Continuous dynamic recrystallization in dual-phase titanium alloy in super plasticity"	Aug 2018
RICHARDSON, Matthew	Graduate School at the University of Tokyo	INATANI, Yoshifumi	Science for REdesigning Science, Technology and Innovation Policy (SciREX) Center, SciREX Summer Camp 2018, Bureaucrat Prize.	Aug 2018

Student	Affiliation (Cooperative graduate school)	Academic Advisor	Award	Date
RICHARDSON, Matthew	Graduate School at the University of Tokyo	INATANI, Yoshifumi	18th Australian Space Research Conference, 2nd Runner up, Best Student Presentation. "Integrated System-Level Modelling of a Reusable LH2/LOx-fed Expander-bleed Cycle Rocket Engine."	Sep 2018
RICHARDSON, Matthew	Graduate School at the University of Tokyo	INATANI, Yoshifumi	The 26th Satellite Design Contest, The Japan Society for Aeronautical and Space Sciences Award. "A SmallSat Technology Demonstrator for Space-Based Solar Power."	Oct 2018
RICHARDSON, Matthew	Graduate School at the University of Tokyo	INATANI, Yoshifumi	The 26th Satellite Design Contest, The Institute of Electronics, Information and Communication Engineers Award. "A SmallSat Technology Demonstrator for Space-Based Solar Power."	Oct 2018
ORIKASA, Isamu	Graduate School at Waseda University	INATOMI, Yuko	The Japan Society of Microgravity Application: JASMAC-30, Mohri Poster Session Outstanding Poster Award.	Oct 2018
TOMINAGA, Koji	Graduate School at Waseda University	INATOMI, Yuko	The Japan Society of Microgravity Application: JASMAC-30, Mohri Poster Session Excellent Poster Award.	Oct 2018
CELIK, Onur	The Graduate University for Advanced Studies (SOKENDAI)	KAWAKATSU, Yasuhiro	International Astronautical Congress 2018, IAF Emerging Space Leaders 2018. "High Fidelity Simulations of Ballistic Small Body Landers."	Oct 2018
CHIKAZAWA, Takuya	The Graduate University for Advanced Studies (SOKENDAI)	KAWAKATSU, Yasuhiro	The 62nd Space Sciences and Technology Conference, Student Outstanding Presentation Award. "Trajectory Design of Eclipse-Free Halo Orbits around the L2 Libration Point."	Oct 2018
MANDO, Yuki	The Graduate University for Advanced Studies (SOKENDAI)	TANAKA, Kohji	International Conference on Applied Physics and Mathematics, Best Young Research Form Award. "Basic Study on Plasma Generation Excited by Hypervelocity Impact of Space Debris."	Oct 2018
KATO, Daiba	Graduate School at the University of Tokyo	SAITO, Yoshifumi	144th Society of Geomagnetism and Earth, Planetary and Space Sciences(SGEPSS):SGEPSS Student Presentation Award (Aurora Medal). "Generation process of the secondary ion emitted from lunar surface."	Oct 2018
ARAI, Hisaaki	Graduate School at the University of Tokyo	SAKAI, Shinichiro	The Society of Instrument and Control Engineers (SICE): Control Division, FY2018 Research Encouragement Award.	Mar 8, 2019

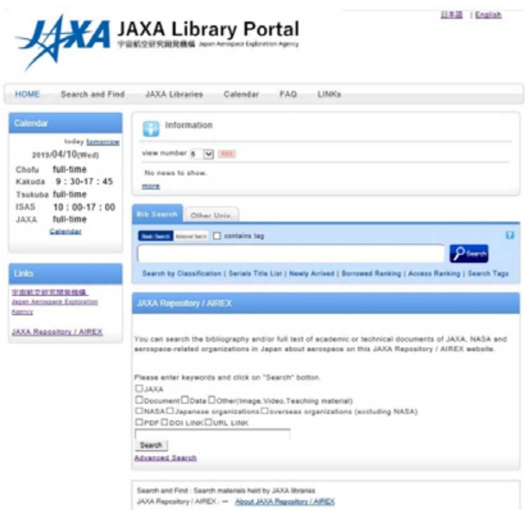
VII
ISAS Library and JAXA Repository

1. ISAS Library

The ISAS Library actively collects materials, including books, magazines, and reports, on space science and related fields, and makes them available to ISAS's many researchers. It has also served as a library of SOKENDAI parent institute since April 2003. The library makes joint purchases of e-journals and contributes to graduate education. After the establishment of JAXA on October 1, 2003, the ISAS Library created a website to share e-journals and diverse services to external users cooperating with other libraries in JAXA. JAXA Library Portal website has launched in March 1st, 2018, to fully integrate all JAXA Library websites with clearer navigation and improved information about the resources and services that users need. It works toward increasing available references and improving services, such as more convenient online search and browse functions.

ISAS Library holdings at the end of March 2019.

Category	Quantity
Total books	94,627
Foreign books	76,403
Japanese books	18,224
Total journals	1,195
Foreign journals	959
Japanese journals	236
Journals added in FY2018	168
Foreign journals	12
e-Journals	92
Domestic English journals	6
Japanese journals	58
e-Journals	about 4,100
IEL Online	180
IOP Journal	52
Elsevier Science Direct	143
Springer Journal	about 1,615
Wiley-Blackwell	about 1,400
JSTOR	about 680

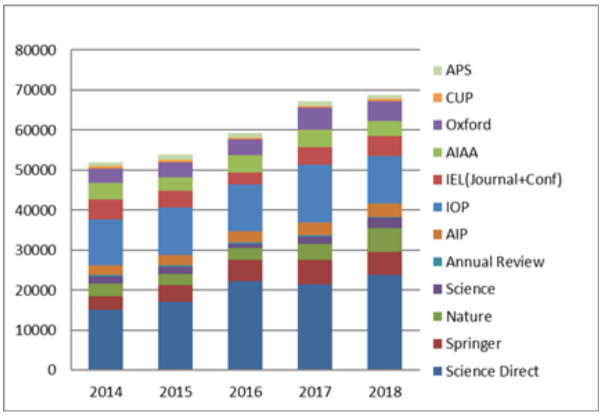


JAXA Library Portal

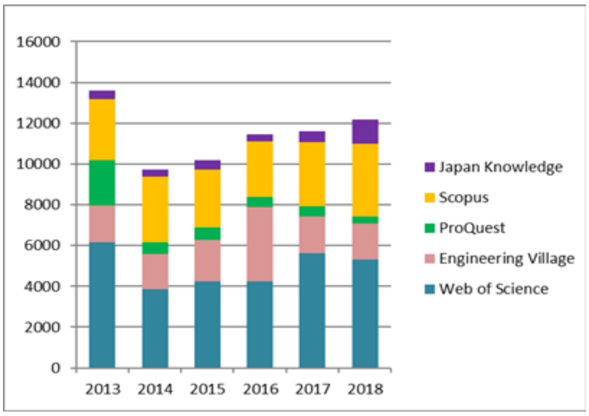
e-Books	
AGU Geophysical Monograph Series and other	598
AIAA Education Series	69
Cambridge Books Online	160
Net Library	585
Oxford Scholarship Online (Physics)	216
Springer eBOOK	about 108,000
ProQuest Ebook Central	36
Chronological Scientific Tables Premium	

Databases

- ProQuest (CSA Technology Research Database)
- Engineering Village
- Scopus
- Web of Science
- **Japan Knowledge**



Number of e-journal downloads



Number of database searches

2. JAXA Repository

https://repository.exst.jaxa.jp/

In the JAXA Repository, references, papers in journals and dissertations published mainly by JAXA staff are available for public viewing. Users can view information about references summarizing R&D results and their full text (with some exceptions).

Since the JAXA Repository was established in 2009, ISAS has added over 1,000 items each year. The repository plays an important role as a store of useful information. From 2013, the JAXA Repository has been sharing achievements presented at symposiums organized by ISAS. The launch of an online ISAS symposium application system in FY2015 contributed to the efficiency of procedures, ranging from symposium registration to publishing presentation proceedings. All the ISAS symposium proceedings held after 2003 have become available in the repository in FY2018, which has promoted the presence of the repository.

Furthermore, the JAXA Repository started assigning Digital Object Identifiers (DOIs) in FY2016 to registered papers from peer-reviewed academic journals by JAXA staff. Increasing DOI contents and preserving the accessibility of these materials will allow semi-permanent, open access to JAXA academic contents.

VIII
Publications, Presentations and Patents

Publications, Presentations and Patents

Item	Achievements
1. Publications on Web of Science	
a. Papers in prestigious academic journals by ISAS staff (April 2018- March 2019)"	1 in Nature, 5 in Science
b. Number of heavily cited papers (including ISAS staff as co-author)	56 (Jan 2008 - Dec 2018)
c. Reviewed papers published in journals	427 (Jan 2018 - Dec 2018)
2. JAXA Publications (in ISAS)	16 (Research and Development Report: 10, Research and Development Memorandum: 4, Special Publication: 2)
3. Journals, publications, etc.	
a. Published in books	8
b. Published in reviewed journals	399
4. Presentations at domestic and international meetings, etc.	Keynote speeches: 4 Invited lectures: 99 Domestic meetings: 623 International meetings: 421
5. Awards	33 (see pp. 115-120)
6. Patents	Published patent applications: 17 Patents granted: 10

http://global.jaxa.jp/

Annual Report of the
Institute of Space and Astronautical Science
2018

INSTITUTE OF SPACE AND
ASTRONAUTICAL SCIENCE,
JAPAN AEROSPACE
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