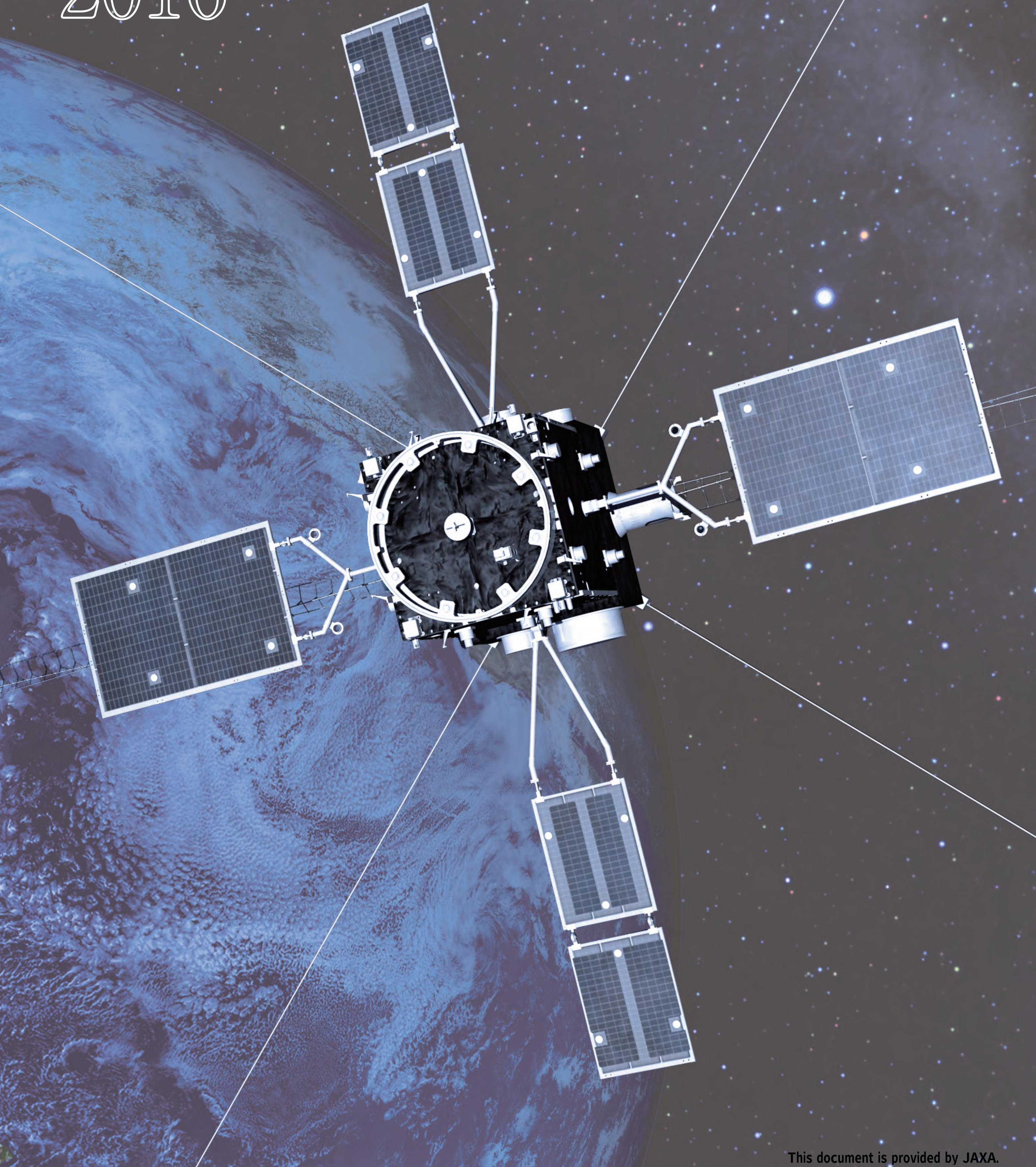
ISSN 2423-8627

Annual Report of the Institute of Space and Astronautical Science 2016



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

ISAS Library,
Management and Integration Department,
Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa
252-5210, Japan
TEL: +81-42-759-8014

Annual Report of the Institute of Space and Astronautical Science

Fiscal Year 2016
(Apr 2016 – Mar 2017)

Message from the Director General September 2017

Saku Tsuneta

Director General

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency

On April 28, 2016, the Japan Aerospace Exploration Agency (JAXA) made the difficult decision to terminate attempts to restore communication with the X-ray Astronomy Satellite ASTRO-H (also known as HITOMI), which was launched on February 17, 2016, due to the communication anomalies that occurred on March 26, 2016. Since that time, in consultation with experts inside as well as outside JAXA, the Institute of Space and Astronautical Science (ISAS) has been making every possible effort to determine what went wrong, and what can be done to prevent this from happening again in the future. Subsequently, JAXA submitted a report entitled *Hitomi Experience Report: Investigation of Anomalies Affecting the X-ray Astronomy Satellite Hitomi (ASTRO-H)* to the Space Development Committee of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The report addressed the factors related to the incident, and proposed four measures: 1) revision of ISAS project management systems, 2) clarification of the roles and responsibilities of ISAS and its subcontractors, 3) improvement of documentation and quality assurance records, and 4) thorough reviews and evaluations.

Effective implementation of these proposed measures was discussed in a panel consisting of current and former ISAS project managers, and an *Action Plan for Reforming ISAS Based on the Anomaly Experienced by Hitomi* was developed. In addition, "town hall meetings" were held to share the spirit and practice of the action plan with all ISAS employees. The plan, which was applied to launch preparations of the geospace exploration satellite ARASE, contributed to the successful and stable operation of that satellite, and will be applied to other projects such as the Smart Lander for Investigating Moon (SLIM). The plan-do-check-act (PDCA) cycle should work to further refine both current and future endeavors. Furthermore, via the activities of JAXA's Project Management Reform Committee, the action plan was incorporated and reflected in JAXA regulations applicable to all JAXA projects in July 2016, and a new series of project management reforms will be carried out in ISAS, securing the steady development and operation of spacecraft.

The ARASE satellite (formerly known as Exploration of energization and Radiation in Geospace, ERG) was launched on December 20, 2016 using an enhanced Epsilon Launch Vehicle and entered orbit as scheduled. After conducting approximately three months of critical and initial operations and confirming that all science instruments have achieved their desired performance levels, the satellite was declared to have entered into its scheduled orbit in March 2017. The successful start of the ARASE mission is a testament to the dedication and skills across JAXA.

ISAS is currently operating six satellites and space probes: ARASE, Hayabusa2, HISAKI, AKATSUKI, HINODE, and GEOTAIL. Asteroid Explorer Hayabusa2, which is currently on its planned trajectory towards the 162173 Ryugu asteroid under ion engine power, is equipped with new technologies for solar system exploration such as long-distance communication using Ka-band and uplink transfer with deep space stations, and the calibration of its onboard science equipment was completed as planned through Mars observations etc. Meanwhile, Venus Climate Orbiter AKATSUKI (PLANET-C) and extreme-ultraviolet spectroscopic planetary observatory HISAKI (SPRINT-A) have also been performing observations as planned. A total of 1,123 (as of July 2017) peer-reviewed papers from the HINODE (SOLAR-B) satellite indicate that the satellite continues to function as an international helio-physics observatory. Within the same timeframe, BepiColombo's Mercury Magnetospheric Orbiter (MMO) has successfully completed several tests at the European Space Agency (ESA).

Future ISAS missions shall be

developed through international cooperation, and the strategic Large-Class missions of ISAS are to be fully incorporated into the scientific roadmaps of other space agencies. In fiscal year 2016 (FY2016), a total of 24 bilateral meetings that included strategic dialog for that purpose in addition to the usual program dialog were held with ESA and NASA in Japan and overseas. As a result of these interactions, JAXA has coordinated with NASA and ESA regarding the next steps to be taken after the ASTRO-H mission, and began to work on an X-ray Astronomy Recovery Mission at the beginning of FY2017. This recovery mission aims to minimize the blank period in X-ray astronomy and to rebuild trust in international cooperation.

The next few years will mark a critical stage in determining science and exploration missions in the years up to the 2030s and beyond. In this context, we have been creating a grand picture of space science using the framework of "Strategic Large-Class Projects", "Competitive Middle-Class Projects", and "Missions of opportunity" in the Basic Plan on Space Policy issued by the Government of Japan. The Smart Lander for Investigating Moon (SLIM) project, which was proposed as the first Competitive Middle-Class Mission, is being developed by the project team that was established in April 2016. The Asteroid Phaethon Fly-by mission (Demonstration and Experiment of Space Technology for INterplanetary voYage, DESTINY+) was recommended as a Competitive Middle-Class Mission by the ISAS space science advisory committee, and the JAXA internal review on its feasibility is underway.

As for the Martian Moons eXploration (MMX) mission, which was selected as a Strategic Large-Class mission, the system design and prototype of a new sampling device has been developed for the launch scheduled in 2024. In addition, two missions were selected as candidates for the second Large-Class mission; the Light Satellite for the Studies of B-mode Polarization mission and the Inflation from Cosmic Background Radiation Detection (LiteBIRD) and the Solar Power Sail mission. We will carry out front-loading activities for these two missions in the period up to mid 2018, followed by JAXA's comprehensive evaluation on their scientific superiority, technical feasibility, and programmatic readiness to select the most appropriate mission. The next-generation Space Infrared Telescope for Cosmology and Astrophysics (SPICA) mission was selected as the third Large-Class mission. SPICA has become more feasible than originally proposed due to the tremendous efforts of European and Japanese researchers working together to propose the mission as a Medium-size mission opportunity in ESA's Science Programme (M5).

Missions of opportunity were outlined to promote two areas; strategic international cooperation for NASA/ESA flagship missions and miscellaneous small projects such as sub-orbital programs (sounding rockets and balloons). The former is a pathway to participate in large-scale international projects. The latter requires matching funding by external agencies in addition to JAXA funding. As for the first candidate for strategic international cooperation, JAXA has prepared to participate in the Jupiter Icy Moons Explorer (JUICE) mission led by ESA. There are currently 16 small projects being reviewed by ISAS for the latter opportunity.

A sounding rocket experiment SS520-4 was conducted at the Uchinoura Space Center (USC) on January 15, 2017 to test the sounding rocket with avionics fully employing commercial technology and to demonstrate the launch of an ultra-small satellite weighing 3 kg. Unfortunately, ignition of the second stage motor was aborted due to loss of telemetry from the booster, and the mission failed. A thorough investigation into the cause and a wide range of preventive measures are being conducted in preparation for a recovery experiment planned for FY2017.

ISAS has intended to enhance space science activities in Japan through strategic rather than ad-hoc cooperation with universities, and has chosen, through a competitive process, several affiliated universities that possess heritage and potential in the specific field of space science to complement ISAS. The ERG Science Center established at the Nagoya University's Institute for Space-Earth Environmental Research has demonstrated its unique capabilities, especially after the launch of the ARASE satellite. In addition to the Center for Planetary Science at Kobe University and the Center for Ultra-Compact Probe Development at the University of Tokyo as new partners in FY2016, selections of new affiliated universities have been made for FY2017.

With the increasing number of affiliated universities operating under JAXA-university joint funding, space science is expected to expand beyond the ISAS's inter-university research institute system (*). In addition, ISAS reached separate agreements in FY2016 with the University of Aizu in data archiving, the Institute for Planetary Materials in Okayama University in curation for extraterrestrial materials, and Iwate University in advanced machining technology.

Research activities have been conducted as planned in the

(*) The inter-university research institute system refers to how ISAS serves as a central Japanese research institution for academic study on space science by conducting joint activities in organic and diverse forms with university researchers (excerpt from the Regulations for Space Science Research via the Inter-University Research System).

Astromaterials Science Research Group, the Lunar and Planetary Exploration Data Analysis Group, the Deep Space Tracking Technology Group, and the Advanced Machining Technology Group, all of which were established inside ISAS in FY2016. In the Astromaterials Science Research Group, the architectural design of a curation facility for Hayabusa2 has been completed. In the Lunar and Planetary Exploration Data Analysis Group, landing target candidates for the SLIM mission were identified using data acquired from the lunar radar sounder SELENE to optimize scientific performance of the mission. Landing target candidates on the Martian moons and Lunar polar regions will also be studied in the Group. In the Advanced Machining Technology Group, in-house manufacturing from prototypes to flight models has started with newly-installed devices such as a five-axis machining center and large three-dimensional (3D) measuring machine. The in-house capability made available by the Group will bring better communication, shorter iteration time, lower cost and better performance from the design to manufacturing phase for researchers and technicians.

Research areas for new faculty positions have been determined, taking into account the long-term vision as indicated in the Roadmap for Space Science and the perspective of the personnel required for new projects. During the period from FY2013 to FY2016, ten employees moved to other institutes (as compared with four during the period from FY2010 to FY2012), suggesting improved mobility of faculty staff. Furthermore, over the same extended period from FY2013 to FY2016, ISAS filled 23 faculty positions (as compared with nine from FY2010 to FY2012). ISAS has also issued a call for faculty positions limited to female and non-Japanese applicants, and has hired two non-Japanese women as associate professors. Furthermore, two researchers belonging to external institutions became ISAS staff members via the cross-appointment system. In the future, ISAS intends to invite more outstanding female faculty and non-Japanese faculty members.

Moreover, a transition from faculty positions to general engineering and management positions (and vice versa) has been encouraged, as one associate professor moved to a general position while another moved from a general position to an associate professor position. With the introduction of new system for evaluating the performance of faculty members in FY2015, we are now better able to evaluate faculty members from the multiple viewpoints of not only academic research but also mentoring of students and freshman engineers, contribution to projects and contribution to administrative tasks for the overall operation of the Institute. This is obviously an ongoing effort, and therefore is subject to further improvement with the PDCA cycle, especially to cope with the aging of faculty members and low academic mobility.

Through partnerships with universities such as the Graduate University for Advanced Studies (known as SOKENDAI in Japan) and the University of Tokyo, ISAS has been very active for graduate school education through the opportunities of hands-on involvement in space science instruments and missions, and has been working to cultivate to-be researchers, technicians, and managers who will be involved in both space science and R&D for space missions. In FY2016, we assisted 18 students in acquiring their PhDs and 40 students in obtaining their Master’s degrees. In order to acquire outstanding students, we have established a scholarship program for Department of Space Astronautical Science at SOKENDAI that will start from the second semester of FY2017. The student acceptance system has been consolidated and a new management policy was enacted to ensure the graduate school education, which is one of our important missions. ISAS has also improved safety management in the campus for employees and has enhanced safety education for students to ensure that they conduct research in a safe and secure environment.

As of FY2016, there are 22 JAXA Project Research Associates (postdoctoral fellow), of which three are non-Japanese and six are JSPS (Japan Society for the Promotion of Science) fellows. The number of International Top Young Fellows (ITYF), a system under which domestic and foreign young researchers are employed with a status equivalent to associate professor for periods of up to five years, has reached a cumulative total of 12 fellows since 2010.

FY 2016 marked a pivotal year for the full-scale operation of the Basic Cooperation Plan agreed in FY 2015 between ISAS and the JAXA Research and Development Directorate. The new mentoring system for freshman engineers has enabled better interaction between them and their advisers for proper selection of research topics and more efficient on-the-job-training (OJT), and the formal presentation of their activities to ISAS senior personnel. Prompt and systematic personnel arrangements for the various needs of new-start projects are now regularly done by coordinating all ISAS demands regarding the required personnel with the Research and Development Directorate. Specifically, a great benefit has accrued to the ARASE satellite and the newly-emerging ultra-compact spacecraft missions for NASA, which require additional personnel in order to secure the implementation of the project, as explained in the action plan established after the ASTRO-H anomaly. In addition to continuing cooperation in the development of the next-generation MPU, ISAS has contributed to the development of the Hall thruster for the Engineering Test Satellite-9, reusable sounding-rock research in the Research and Development Directorate, and the acoustic sub-scale test for H3 rockets in the Space Technology Directorate I at the Noshiro Rocket Testing Center.

Through cooperation with the Space Technology Directorate I in the development of an enhanced Epsilon Launch Vehicle, which is expected to improve Japan's launch capability and expand payload capacity, the enhanced Epsilon Rocket 2 was successfully launched from USC in December 2016. The newly developed second stage motor (M-35) performed as expected, and proven high-performance and low-cost technologies will be applied to the development of H3 rockets, which is currently underway.

The GRound station for deep space Exploration and Telecommunication (GREAT) project has been developing a new ground station as a replacement for the aged antenna at the Usuda Deep Space Center (USDC), and expects to install a new antenna in a mountainous area about 1.3 km away from USDC. Following successful completion of the geological boring survey and other preparations, construction for the antenna foundation started in early 2017.

As for the X-ray Astronomy Satellite ASTRO-H HITOMI, JAXA held its first press conference immediately after the anomaly was recognized and continued to make every effort to clarify the details in press conferences held once a week until the decision was made to terminate attempts to communicate satellite in April 2016. We believe that our effort to voluntarily disclose information by sharing the reports from the press conferences online (later with English translations) was appreciated by press officials and the public.

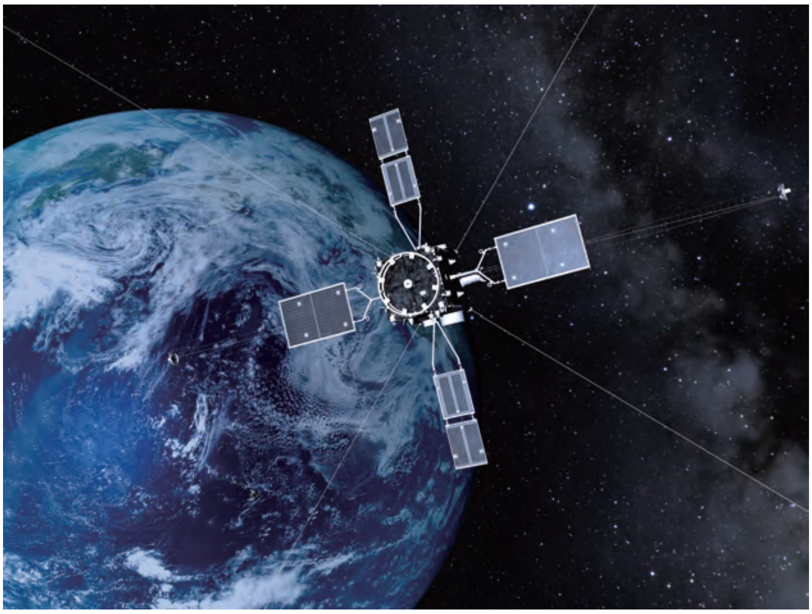
In the period after June 2016, a number of press releases were issued steadily to announce ISAS's research highlights. A notable release in FY2016 discussed the research results of particles obtained from the Itokawa asteroid. ISAS released a total of 12 other research highlights over the course of the year. In terms of public outreach efforts, ISAS released a full-scale model deployment of a solar power sail and a flight model of ARASE satellite in addition to hosting annual open house days. In addition, the Communication Hall of Space Science and Exploration was completed in the summer of 2017 and is scheduled to open with a new exhibition room during late FY 2017.

This annual report is a summary of ISAS activities in fiscal year 2016, from April 2016 to March 2017. It has been four years since I assumed the position of Director General. Through the cooperation of individuals both inside and outside our institute, I have been able to implement a large number of reforms to enhance the capability of ISAS. Nevertheless, a number of issues still need to be addressed; in particular, the implementation of the *Action Plan for Reforming ISAS Based on the Anomaly Experienced by Hitomi.* Although a certain amount of time will be required until the results of my activities is seen, I believe that these reforms will one day form the foundation for new achievements by ISAS and JAXA. I look forward to your continued support and cooperation.

September 2017

Table of Contents

ON THE COVER



Imaginary picture of the ARASE (ERG) satellite in space

The ARASE (ERG) mission has been exploring the Earth' s inner magnetosphere, in particularly, the Van Allen radiation belts with six sets of onboard particle analyzers and two sets of onboard electromagnetic field measurements since its successful launch on December 20, 2016. Science operation phase has started since March 24, 2017 after the initial critical and checkout phase successfully completed. All the mission instruments function quite well, and scientific data analysis is vigorously going under the research community. The major purpose of the ARASE mission is to study acceleration, transport, and loss processes of radiation belt particles and dynamics of the inner magnetosphere. ARASE and its coordinated ground-based multi-point measurements successfully observed several severe geospace storm events. The acquired datasets must contribute comprehensive understandings of physical mechanism of dynamically variating geospace environment.

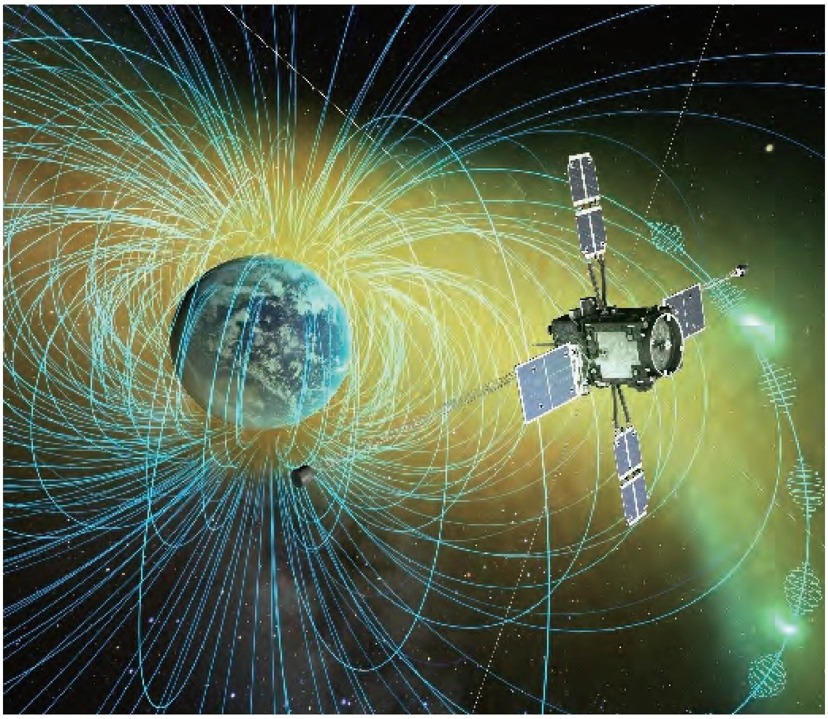
[see p. 3 and p.34]

I

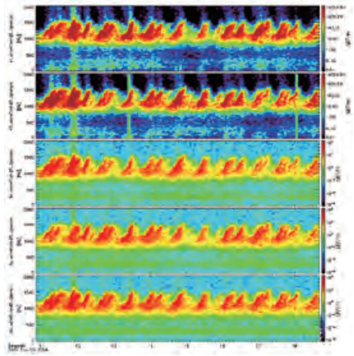
Scientific Highlights in FY2016

1 Launch of Geospace Exploration (ERG) Satellite and Beginning of ARASE Mission Operations

[Geospace Exploration Satellite ARASE (ERG)]



ARASE satellite in the Van Allen Radiation Belts.



Time variations of chorus wave power spectra observed by ARASE' s Plasma Wave Experiment during a test observation in March 2017.

The major objective of the ARASE project is to explore the acceleration, transport, and loss mechanisms of energetic electrons in the Earth's Van Allen Radiation Belts. (During mission development before launch, ARASE was known as Exploration of Energization and Radiation in Geospace [ERG].) It has long been difficult to precisely measure high-energy particles in the central region of the radiation belts because the high-energy particles themselves interfere with the measurements. The ARASE project challenges scientific mysteries of the radiation belts with nine advanced onboard science instruments, including a low-energy electron sensor provided by Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), Taiwan. Joint research activities between ARASE and NASA's two Van Allen Probes, which are concurrently exploring the radiation belt, are expected to enhance science outputs.

The ARASE satellite was launched by the second Epsilon rocket on December 20, 2016. We completed critical operations, such as perigee-up maneuvers and deployment of wire antennas and booms, during the first month (see JAXA's press release dated January 23, 2017). ARASE was inserted into an elliptical orbit with a perigee altitude of about 400 km, an apogee altitude of about 32,000 km, and an orbital inclination angle of 31° to observe the entire radiation belt. As scheduled, ARASE started regular mission operations on March 24, 2017, after we confirmed that the bus and all mission instruments were functioning properly. ARASE has been providing us with comprehensive observation data on the radiation belts since then.

Coordinated observations with international ground observation networks and cooperative observations with NASA's Van Allen Probes were scheduled for 1 month around the spring equinox. ARASE's observations will elucidate the energy exchange process of plasma waves and particles and the mechanism of dynamic variation of the radiation belts. Data from ARASE are expected to improve the accuracy of space weather forecasts.

The following list shows publications of the ERG Working Group (WG) members, including topics related to ERG preparation, such as the ground-based observations, simulations, and modeling and analysis of Van Allen Belt data.

-R. Nomura, et al. Pulsating proton aurora caused by rising tone Pc1 waves. Journal of Geophysical Research. A: Space Physics, Vol.121(2), pp. 1608-1618 (2016) doi:10.1002/2015JA021681
-M. Ozaki, et al. Fast modulations of pulsating proton aurora related to subpacket structures of Pc1 geomagnetic pulsations at subauroral latitudes. Geophysical Research Letters, Vol. 43(10), pp.7859-7866 (2016) doi: 10.1002/2016gl070008
-Peer-reviewed papers regarding ARASE by authors outside JAXA: 18

2 Discovery of a Large Stationary Gravity Wave at the Cloud-top Level of the Venus Atmosphere by Venus Explorer AKATSUKI

[Venus Climate Orbiter AKATSUKI (PLANET-C)]

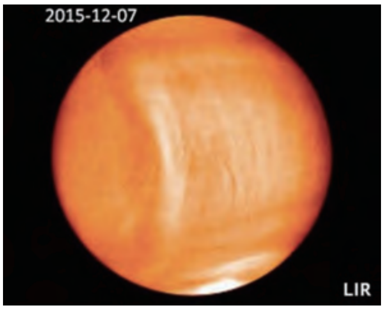


Fig. 1 10,000-km stationary gravity wave observed by LIR.

The Venus climate orbiter AKATSUKI (known as PLANET-C before launch) was successfully inserted into a Venus orbit in December 2015 after spending 5 years orbiting the sun under unexpected environmental conditions. Subsequently, five cameras and an ultra-stable oscillator for a radio occultation experiment onboard AKATSUKI finally started observation of the Venus atmosphere. The Longwave InfraRed camera (LIR), one of the cameras onboard AKATSUKI, measures both dayside and nightside horizontal distributions of the brightness temperature on the Venus disk by detecting emissions at wavelengths from 8 to 12 μm. Immediately after orbit insertion, the LIR discovered an outstanding temperature feature at an altitude of 65 km, that is, at the Venus cloud-top level. The temperature feature had an interhemispheric bow-shaped structure stretching 10,000 km across the planet (Fig. 1). The structure also appeared dimly in the 283-nm image acquired by the Ultra Violet Imager (UVI) onboard AKATSUKI, though the contrast was much weaker than that of the brightness temperature image. Over several days of observation, the bow-shaped structure remained relatively fixed in position above the highland called Aphrodite terra, although the entire upper cloud in Venus rotates much faster than the planet itself, which is known as super rotation. Remarkably, the feature arises only in the afternoon. Preliminary numerical simulations suggest that the bow-shaped structure is the result of an atmospheric gravity wave that is generated in the lower atmosphere by mountain topography and then propagated upwards (Fig. 2).

Contribution of the surface topography to the cloud-top temperature through a gravity wave has never been considered in the Venus atmosphere. Based on conventional knowledge of the Venus atmosphere, the formation and propagation of such gravity waves are improbable. Convection in the observed static, near-neutral layers between the cloud-top level and the ground can disturb gravity wave propagation. Our observation suggested that there is a layer at a critical level above the surface through which stationary gravity waves normally cannot propagate and that this layer is temporarily disrupted by spatial or temporal variability in the distribution of winds in the lower atmosphere. It suggests that winds in the deep atmosphere may be spatially or temporally more variable than previously thought.

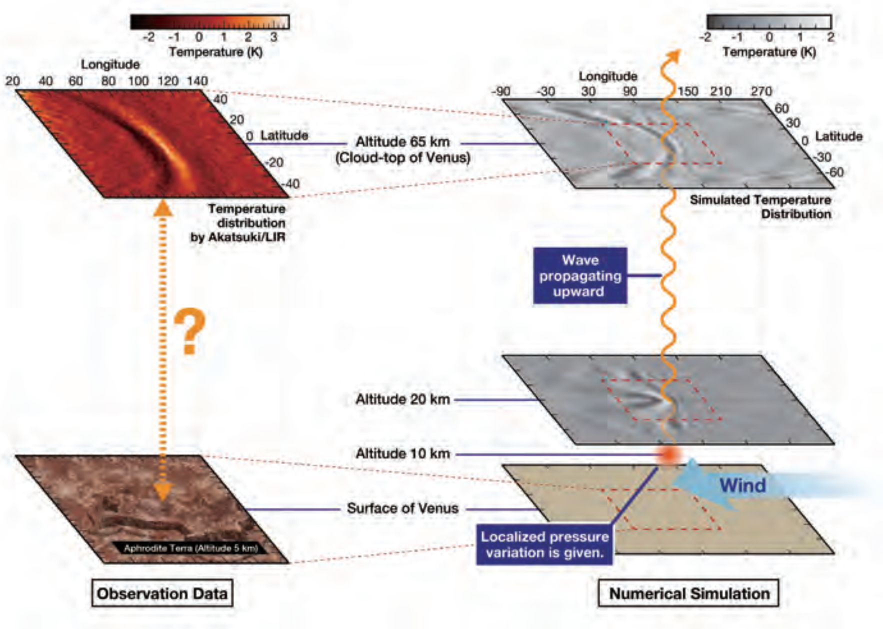


Fig. 2 Preliminary numerical simulation of the mechanism behind wave propagation in the Venusian atmosphere.

-T. Fukuhara, et al. Large Stationary Gravity Wave in the Atmosphere of Venus. Nature Geoscience, Vol.10, pp. 85-88 (2017), doi: 10.1038/ngeo2873

3 Deciphering the 4-Billion-year History of Asteroid Itokawa from Microparticles

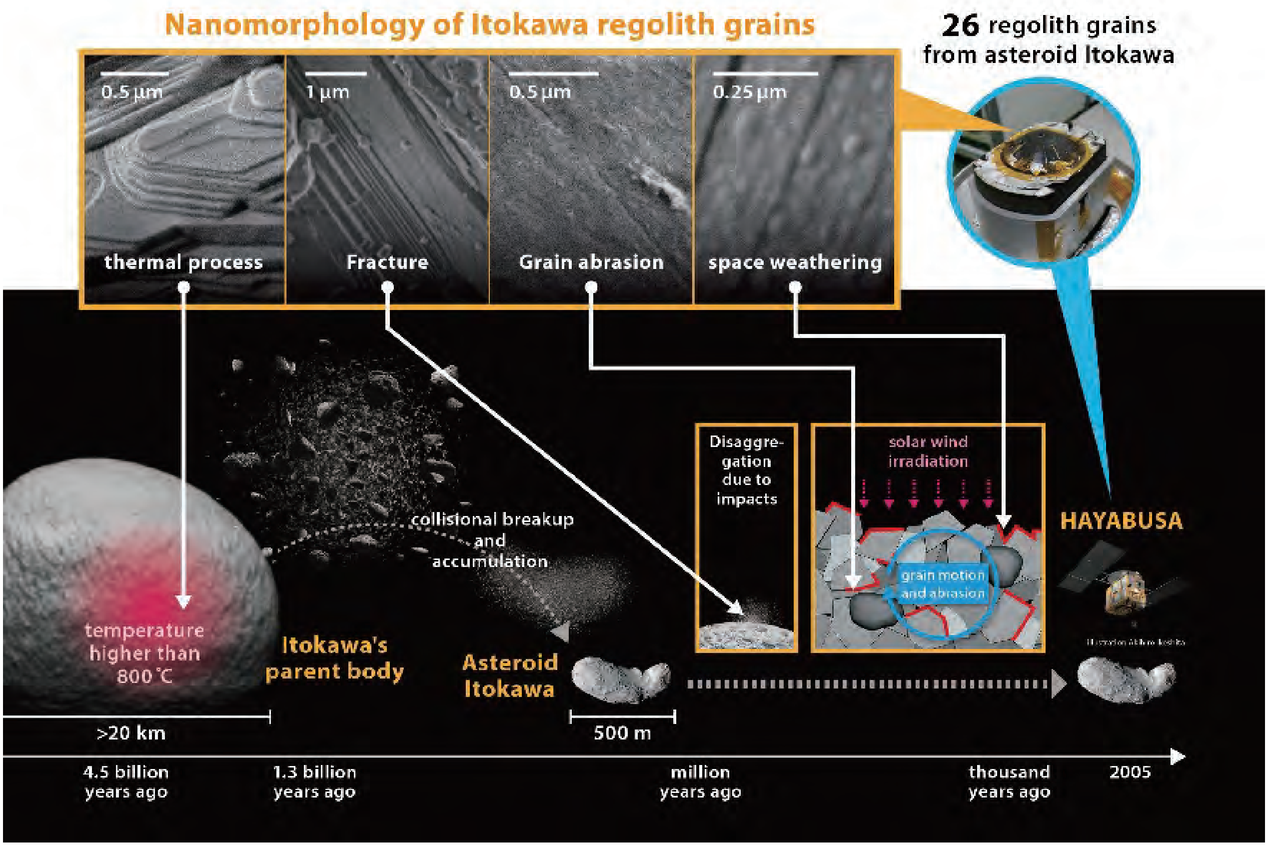
[Samples Retrieved by HAYABUSA]

Analysis of surface patterns on microparticles returned from the asteroid Itokawa by HAYABUSA (known as MUSES-C before launch) shows that the 4-billion-year history of the asteroid can be reconstructed from various features. The particles analyzed were just over 10 μm in size, and their surface patterns and marks measured were nanometers (one millionth of one millimeter). The research team observed details of the faint structure of particle surfaces using X-ray microtomography and scanning electron microscopy. The results revealed that the surface patterns, which had been thought to be of a single type, were found to have at least four varieties.

One of these variations was found to be a vestige of Itokawa's parent body. When Itokawa was born over 4 billion years ago, it was part of a parent body about 40 times bigger than Itokawa. It is believed that the parent body was destroyed once and that some of its fragments reassembled to form Itokawa, since some particles retain the pattern that was thought to have been made over 4 billion years ago during formation of the parent.

In addition, we found some patterns that were formed due to long-time exposure to solar wind or caused by friction between particles. These patterns are shaped over time scales of thousands to millions of years. In other words, observing the particle surfaces gives us clues about the asteroid’s history.

The research method we used can provide a lot of information without hurting the precious particles. Therefore, this method will be indispensable for initial analysis of extraterrestrial materials in the future.

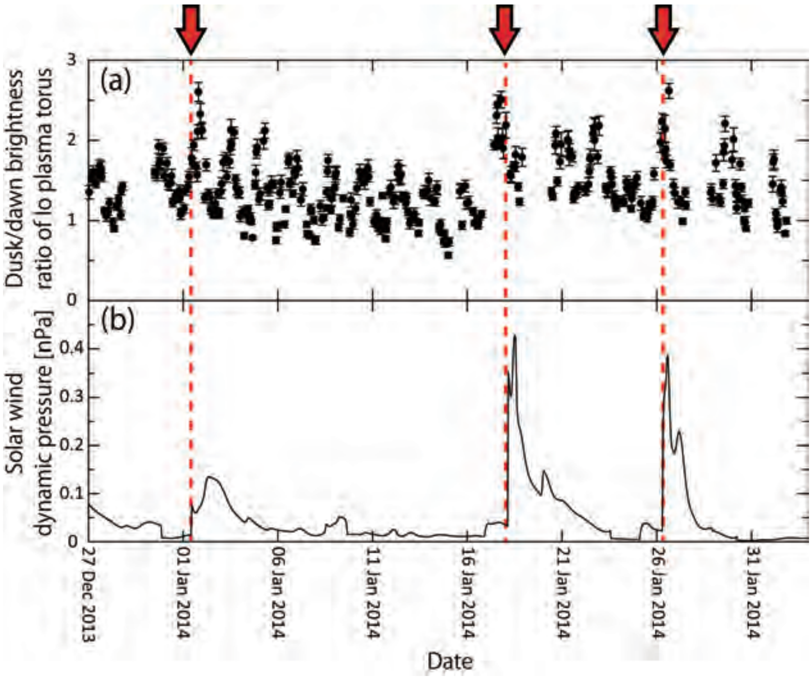


What the nanomorphology of Itokawa microparticles tells us about the asteroid's history.

-T. Matsumoto, et al. Nanomorphology of Itokawa Regolith Particles: Application to Space-weathering Processes Affecting the Itokawa Asteroid. Geochimica et Cosmochimica Acta, Vol.187, pp. 195-217 (2016) doi: 10.1016/j.gca.2016.05.011

4 New insight on the Jovian Magnetospheric Dynamics Revealed by Spectroscopic Observation Satellite HISAKI

[Extreme Ultraviolet Spectroscope for Exospheric Dynamics HISAKI (SPINT-A)]

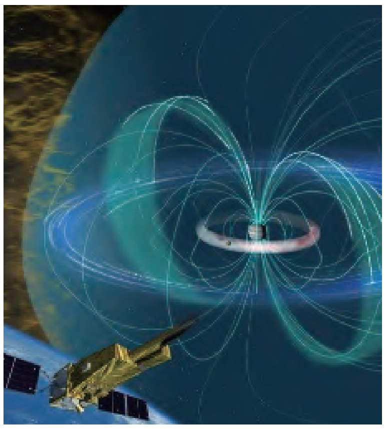


Time variation of the morning/evening IPT emission intensity ratio and numerically simulated solar wind dynamic pressure. The arrows highlight emission response to solar wind. [G.Murakami, et al., 2016, GRL]

External influences, such as solar wind fluctuations following solar flare events, were thought to be negligible deep within the massive rotating Jovian magnetosphere, because Jupiter rotates rapidly and the strongest intrinsic magnetic field of any planet, which creates a strong electromagnetic shield. In other words, the Jovian magnetosphere is very different from Earth's magnetosphere. However, HISAKI observations of the emission spectra from the Io Plasma Torus (IPT) along the orbit of Jupiter's satellite Io deep within the magnetosphere show that the influence of solar wind extends deep inside the Jovian magnetosphere. The IPT is formed from ejecta from Io's many active volcanoes.

Long-term continuous observation by HISAKI (known as SPRINT-A before launch) revealed that the emission intensity from the IPT region clearly responds to changes in the solar wind dynamic pressure. This is the first direct observational evidence that the solar wind effects can reach deep inside the Jovian magnetosphere. This result leads to a new perspective that the Jovian inner and outer magnetospheres are connected through a field-aligned current system.

In addition, continuous and simultaneous HISAKI observations of the intensities of the Jovian aurora and IPT emissions showed for the first time that the torus brightens about 12 hours after a sudden increase in aurora brightness. These results indicate that there exist multiple channels of energy transport from the outer magnetosphere to deep within the inner magnetosphere, which is similar to the structure of Earth's magnetosphere. Given the size and intensity of the Jovian magnetosphere, these results are counterintuitive and provide new insights into the Jovian magnetospheric dynamics.

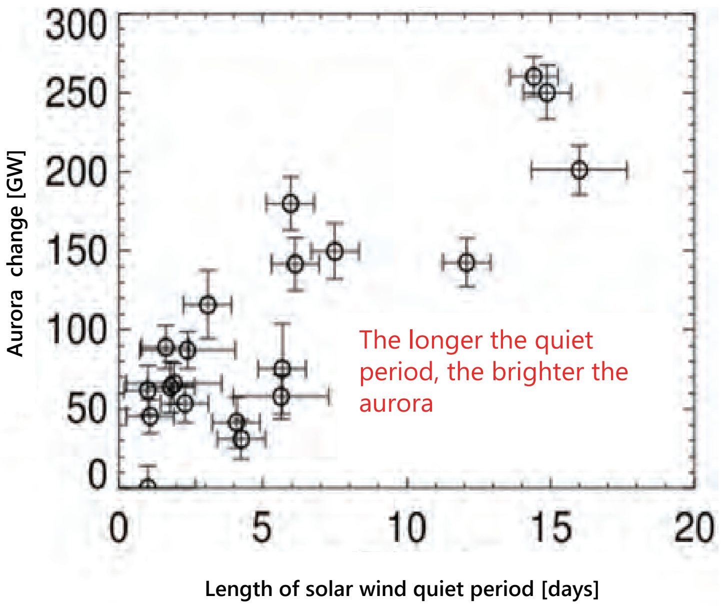


How the Jovian inner and outer magnetospheres are connected through a field-aligned current system.

-I. Yoshikawa, et al. Properties of Hot Electrons in the Jovian Inner Magnetosphere Deduced from Extended Observations of the Io Plasma Torus. Geophysical Research Letters, Vol. 43(22), pp. 11552-11557(2016) doi: 10.1002/2016GL070706
-G. Murakami, et al. Response of Jupiter's Inner Magnetosphere to the Solar Wind Derived from Extreme Ultraviolet Monitoring of the Io Plasma Torus. Geophysical Research Letters, Vol. 43(24), pp. 12308-12316 (2016) doi: 10.1002/2016GL071675 (JAXA press release, Jan 25 2017)

5 Evidence of How Jupiter's Auroras Work Revealed by Spectroscopic Observation Satellite HISAKI

[Extreme Ultraviolet Spectroscope for Exospheric Dynamics HISAKI (SPINT-A)]

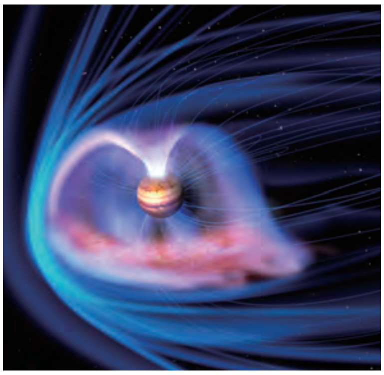


Relation between the solar wind quiet periods and the amplitudes of auroral brightening.

Although Earth's auroras are driven by solar wind fluctuations, can this mechanism alone also drive Jupiter's aurora system? In the Jovian system there is an internal source, volcanic ejecta from the Jovian satellite Io, which possibly plays an important role in the formation of Jovian auroras. The evidence for auroras being driven by an internal factor, however, had not been found previously due to a lack of continuous observation, so it was unknown whether and to what degree an internal source affects Jovian auroras. HISAKI has solved this problem by continuously observing the auroral emission intensity in Jupiter's polar regions, as well as the emission spectra of plasma around Io in the Jovian magnetosphere.

Using long-term continuous Jupiter aurora observations by HISAKI, for the first time we were able to compare time variations of the auroral emission intensities with the solar wind parameters derived using computer simulation results. When auroras are triggered by solar wind fluctuations, the amplitude of sudden increases in auroral brightness strongly depends on the duration of the solar wind quiet interval between auroral brightness peaks. The results suggest that plasma from Io builds up in the magnetosphere during solar quiet periods. Then, an increase in solar wind triggers a stronger response and produces a brighter aurora.

Thus, we have confirmed two driving sources for Jupiter's auroras: an internal factor, due to loading of plasma from Io, and an external factor, solar wind fluctuations. HISAKI data clarified that the behavior of Jupiter's auroras can be understood as an interaction between these two sources. This is an important achievement that increases our knowledge about the nature of the Jovian magnetosphere.



Artistic rendering of the Jupiter's aurora and magnetosphere.

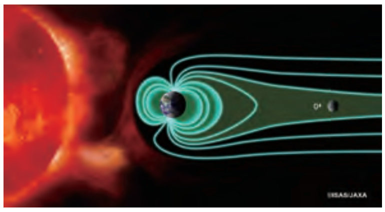
-H. Kita., et al. Characteristics of Solar Wind Control on Jovian UV Auroral Activity Deciphered by Long-term Hisaki EXCEED Observations : Evidence of Preconditions of the Magnetosphere?. Geophysical Research Letters, Vol. 43(13), pp. 6790-6798 (2016) doi: 10.1002/2016gl069481 (GRL Highlights, Sept 25 2016)

6 Earth-derived Oxygen in the Lunar Surface Measured by the Lunar Orbiting Satellite KAGUYA

[Selenological and Engineering Exlorer KAGUYA (SELENE)]

Measurement of oxygen ions by the lunar orbiting satellite KAGUYA (formerly known as SELENE) shows that oxygen ions flowing out from Earth' s upper atmosphere have sufficient energy to penetrate into the Lunar surface to a depth of tens of nanometers. Lunar surface layers are known to exhibit complicated oxygen isotope ratio variations with depth, which for many years remained puzzling. Data from KAGUYA provided a solution to this mystery.

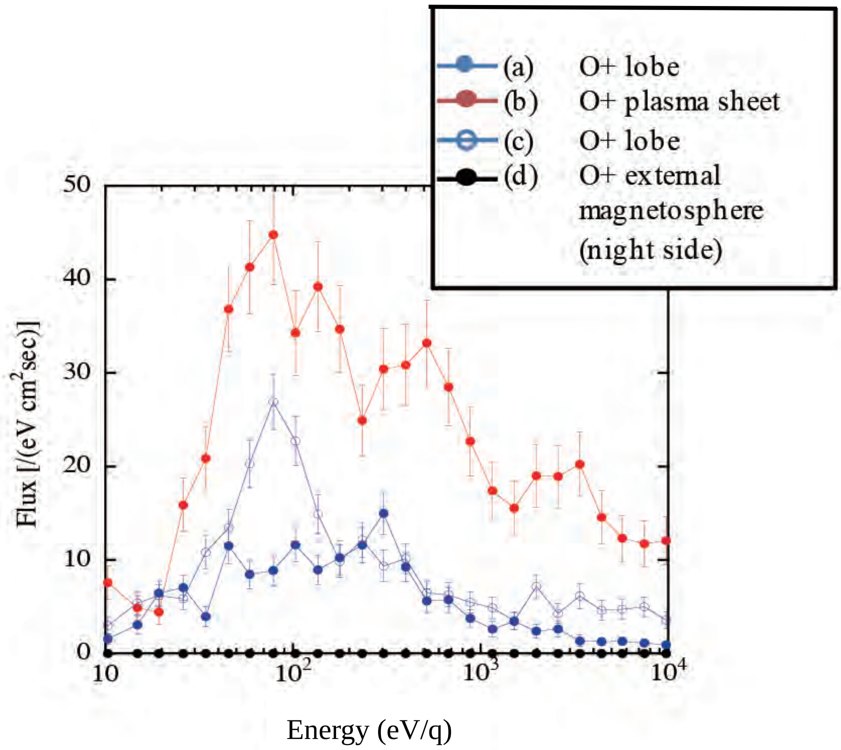
KAGUYA, orbiting 100 km above the Lunar surface, detected oxygen ions that are thought to originate from Earth' s upper atmosphere. These ions had energies sufficient to allow them to penetrate into the Lunar surface. This provided a clue toward elucidating an unresolved problem related to the complex oxygen isotopic distribution in the Lunar surface, which since the 1970s has been known to contain three major isotopic ratios. One is an "intrinsic" lunar oxygen with the same isotopic ratio as that of the Earth, which has been present in the Moon since the giant impact that formed the Earth/Moon system. The second has a large ^{16}O component coming from the solar wind, which penetrates the surface 200–2,000 nm due to its higher



Oxygen ions flowing out from the Earth.

energy (tens of keV). NASA' s Genesis mission revealed that the solar wind oxygen ions are characterized by being rich in ^{16}O with respect to any other source in the solar system. The third, with the smallest proportion of ^{16}O, has been unresolved. However, since the stratospheric ozone possesses few ^{16}O ions, the current results point to the possibility that the variant with the smallest ^{16}O component in the lunar surface may be due to Earth-derived oxygen.

The figure shows oxygen ion flux versus energy, as observed by KAGUYA near the Moon. Low-energy oxygen measured in each region (lobe, plasma sheet and external magnetosphere) are ions that originate from the Moon, and these ions are accelerated by a potential difference of 100 V or more prior to detection by KAGUYA. On the other hand, high-energy (> 1 keV) oxygen ions detected in the plasma sheet (red line) are those of Earth-origin, because ions escaping from the Earth' s atmosphere can be accelerated in the magnetosphere and are thus capable of penetrating into the lunar subsurface.

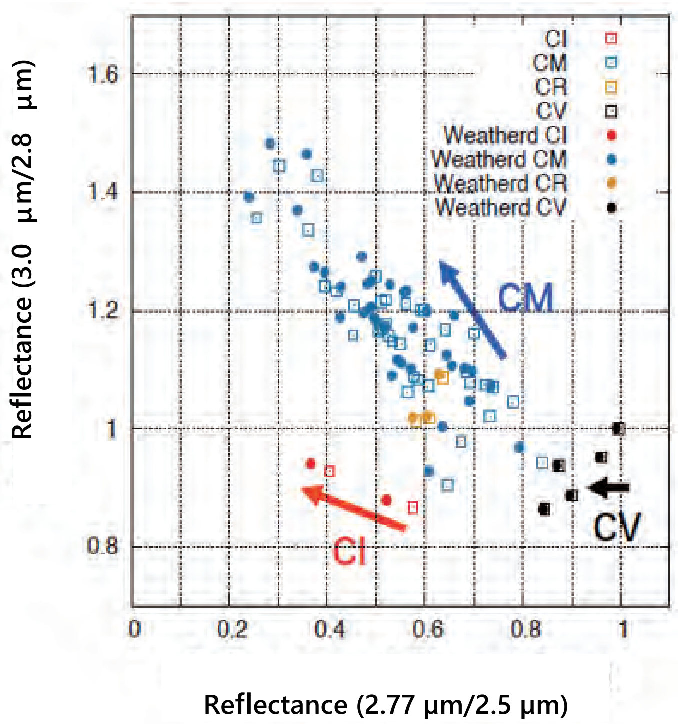


Oxygen ion flux vs. energy. Low-energy ions originate from the Moon, while high-energy ions (red line) originate from Earth.

-K. Terada, et al. Biogenic Oxygen from Earth Transported to the Moon by a Wind of Magnetospheric Ions. Nature Astronomy, Vol. 1, p. 0026 (2017) doi: 10.1038/s41550-016-0026

7 Elucidation of Space Weathering on C-type Asteroids

[Hayabusa2 Probe]



Changes in the NIR spectral features due to simulated space weathering of a C-type asteroid surrogate. The horizontal and vertical axes represent the intensity ratio between two wavelengths in the reflection spectrum. Arrows highlight the spectral shifts that occur after weathering. CI, CM, CR, and CV are various classifications of carbonaceous chondritic meteorites.

In anticipation of the rendezvous of the Hayabusa2 probe with the asteroid Ryugu in 2018, we have been working to deepen our understanding of space weathering on the surfaces of primitive asteroids. Hayabusa2 will perform imaging of the asteroid surface using a near-infrared (NIR) spectrometer, with which we hope to detect metamorphism due to space weathering. We have enough knowledge and data of space weathering in S-type asteroids, but know little about their parent C-type asteroids, a type that the asteroid Ryugu belongs to.

In Hayabusa2, identification of minerals on the asteroid surface is performed using reflectance spectral data from the NIR spectrometer, but spectral changes due to space weathering can hinder mineral identification. We have performed an experiment to estimate the changes due to the space weathering of hydrous mineral spectra expected for C-type asteroids. Space weathering affects the identification of meteorite types, but only limited change is predicted for Ryugu.

We irradiated hydrated minerals representing C-type asteroids with protons to simulate weathering by the solar wind, which allowed us to clarify changes in the form of OH/H_2O that exists in minerals. Since the characteristic absorption band of OH is at 2.77 and H_2O appears at 3.0 μm, it is possible to identify meteorite types by taking the intensity ratio at wavelengths including 2.5 μm, where the absorption characteristics of neither one appears. The form of SiOH was found to be stable even at high temperatures, implying that asteroids would have retained water in this form after migrating to the inner-part of the solar system.

Our experiments made it clear that mineral identification is possible by selecting the wavelength range properly.

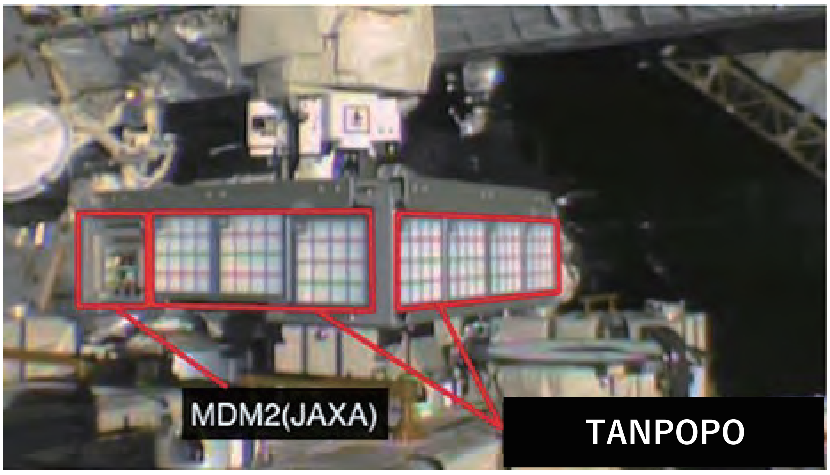
8 Overview of TANPOPO mission and Initial Analysis Results of the First Returned Exposure Samples from the Low Earth Orbit

The TANPOPO project, which is a multi-year passive astrobiology exposure and micrometeoroid capture experiment installed on the Exposed Experiment Handrail Attachment Mechanism (ExHAM) of the Japanese Experiment Module 'Kibo' Exposed Facility, is currently underway onboard the International Space Station (ISS). This mission was designed to examine the possibility of interplanetary migration of terrestrial microbes and delivery of extraterrestrial organics to the Earth.

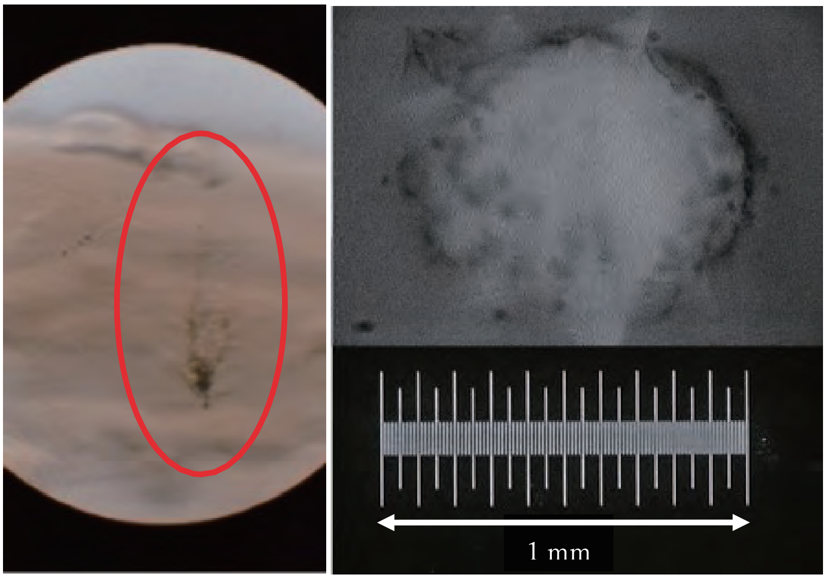
We conducted initial analyses of the first set of capture panels made of ultra-low dense, silica aerogels that was brought back to the Earth in summer 2016 after one year exposure in the low Earth orbit, and have identified 68 hypervelocity impact signatures by solid microparticles with sizes larger than 100 microns. Since Earth-orbiting particles (space debris, etc.) are unable to reach the space pointing face of the ExHAM pallet where is always pointed away from the Earth (as ensured by the low orbit and three-axis attitude control), it can be assumed that the captured particles must primarily come from comets and asteroids.

A detailed search for organic compounds within the captured micrometeoroids is currently underway. The information collected to date is being used to update direct measurements of meteoroid and orbital debris flux in the low Earth orbit for the first time in the last 20 years after Japan retrieved the Space Flyer Unit satellite in 1996.

On the exposure panels, radiation-resistant bacteria found in the stratosphere were installed inside the panels with the astronomical organic analog samples in the TANPOPO mission. The results obtained so far indicate that their survival rate was high in an aggregate form, even after one year of space exposure.



Material Degradation Monitor 2 (MDM2) and
aerogel capturing device "TANPOPO" onboard the ISS.
©JAXA/NASA

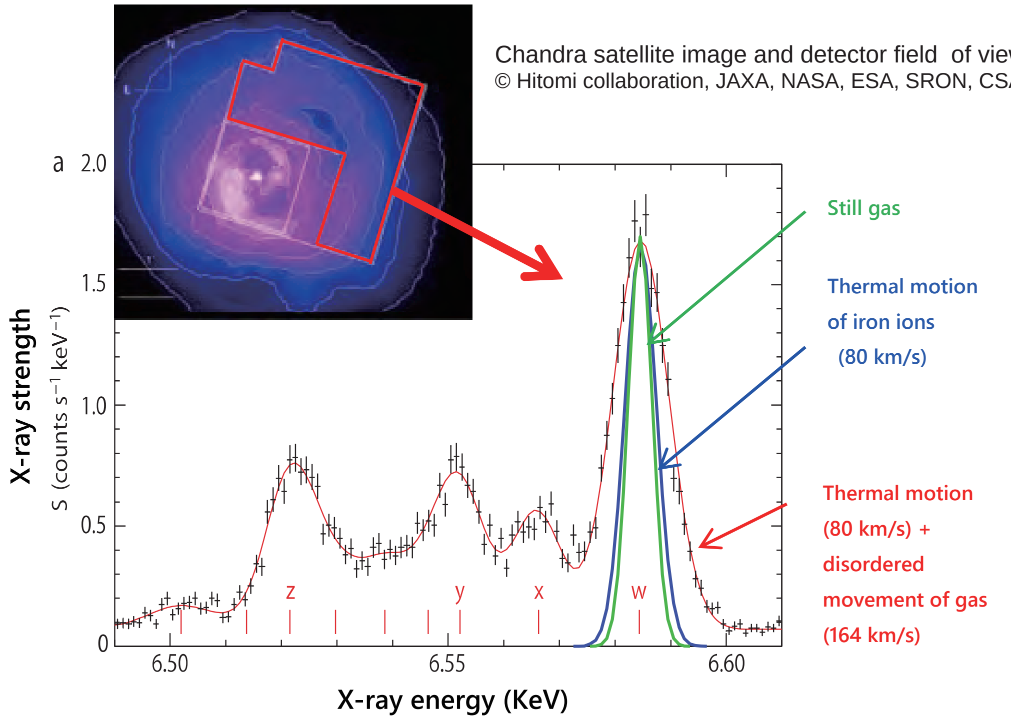


(left) A "carrot-shaped" track on the Tanpopo aerogel that captured impacting microparticle residues inside.
(right) A "bowl-shaped" impact signature on the aerogel produced possibly by a fragile but fast micrometeoroid impact.

-H. Yano, et al. "In-orbit Operation and Initial Sample Analysis and Curation Activities for the First Year Collection Samples of the TANPOPO Project", The 17th Space Science Symposium, Sagamihara, Japan. Jan 5- 6 (2017)
-A. Yamagishi, et al. "Overall of TANPOPO mission and the initial analysis results of the first return exposure sample". Space Utilization Research, Sagamihara, Japan. Jan 16-17 (2017)

9 Surprisingly Calm Hot Gas at the Center of the Perseus Cluster of Galaxies Revealed by X-ray Astronomy Satellite

[X-ray Astronomy Satellite ASTRO-H (HITOMI)]



X-ray energy spectrum of the central region of the Perseus Cluster of galaxies obtained with ASTRO-H.

Galaxy clusters are huge systems with hundreds of galaxies dominated by the gravity of dark matter, which heats the gas in these galaxies to tens of millions of degrees. At the galactic centers, massive black holes are thought to supply a large amount of energy as jets, causing severely perturbed gas movement, which prevents the hot gas from being cooled through radiation. This is a process known as active galactic nucleus feedback. ASTRO-H (known as HITOMI), the sixth Japanese X-ray astronomy satellite, was developed by a large international collaboration between agencies in Japan, USA, Canada, and Europe. In the initial operation of ASTRO-H, the onboard soft X-ray spectrometer observed the central region of the Perseus Cluster of galaxies. The spectrometer covered 0.3–12 keV at the focus of the grazing-incidence X-ray mirror and achieved an energy resolution of 4.9 eV (full-width at half-maximum), the highest ever realized above 2 keV. Although the loss of ASTRO-H prematurely terminated spectrometer operation, X-ray data of unprecedented quality was nevertheless obtained.

X-ray emissions from galaxy clusters are dominated by the optically thin thermal emission from the hot cluster gas, which includes various characteristic emission lines of highly ionized elements. The widths of characteristic lines of highly ionized iron were measured from energy spectra acquired by ASTRO-H, and the velocity of random gas motion was determined. The line-of-sight velocity dispersion was 150–200 km/s, which is unexpectedly low. Turbulent pressure support in the hot gas is estimated to be only 4% of thermodynamic pressure. A total cluster mass determined from hydrostatic equilibrium in the central region would seemingly require little correction for turbulent pressure. By measuring the velocity dispersion, important clues toward solving long-standing problems related to heating of galaxy-cluster gas by supermassive black holes were obtained. Moreover, the analysis demonstrated for the first time that turbulent motion of gas has a small influence on estimations of dark matter mass.

-Hitomi collaboration. The Quiescent Intracluster Medium in the Core of the Perseus Cluster. Nature, Vol. 535(7610), pp. 117-121 (2016) doi: 10.1038/nature18627

10 Cosmic-ray Observations with CALET on the ISS by High-precision Energy Measurements

[CALorimetric Electron Telescope (CALET) aboard the ISS Kibo]

The CALorimetric Electron Telescope (CALET) aims to reveal the acceleration and propagation mechanisms of cosmic rays, to identify nearby cosmic ray accelerators, and to detect dark matter through observations of high-energy cosmic rays. The main mission instrument is a calorimeter, consisting of a charge detector and imaging and total absorption calorimeters. CALET is also equipped with a gamma-ray burst monitor, and it measures the cosmic-ray electron spectrum over the energy range of 1 GeV to 20 TeV with a very high energy resolution of 2% above 100 GeV with the calorimeter. CALET was developed by an international team from Japan, USA, and Italy and was installed on Japan's external experiment module Kibo in August 2015 (Fig. 1). Shortly thereafter, it began to collect data.

Cosmic ray and gamma-ray burst data have been steadily accumulated since CALET transitioned to normal observations in January 2016. With the accumulated data, results have been obtained for energy spectra of electron candidates selected at 10-1,000 GeV, the charge distribution of cosmic rays (Z = 1–40), and observations of gamma-ray bursts. CALET achieved target accuracy by systematic energy calibration using onboard data, a process that is ongoing. We achieved sufficient energy precision to obtain a resolution of 2% (>100 GeV) over a 6-digit energy range (1 GeV to 1 PeV). Figure 2 shows the observed energy spectrum of all cosmic-ray events over this range obtained from Oct. 13, 2015, to Jan. 31, 2017. The results included intensive precipitation of electrons from the Van Allen Belt and have enabled us to determine the upper limit of X-rays and gamma rays in the gravitational wave event GW151226. CALET will continue to help us elucidate high-energy cosmic phenomena and search for dark matter.

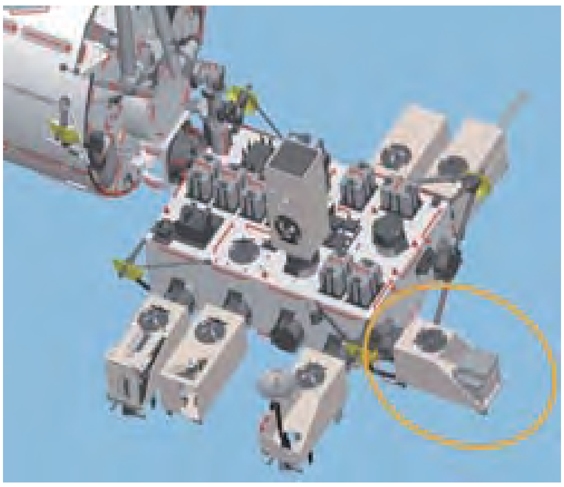


Fig. 1 CALET onboard ISS.

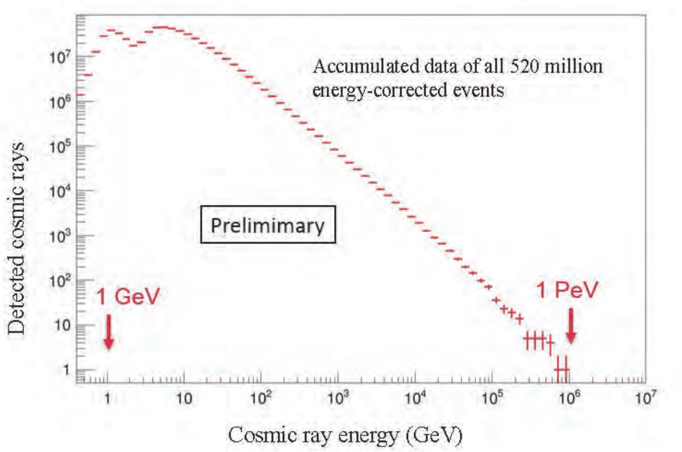
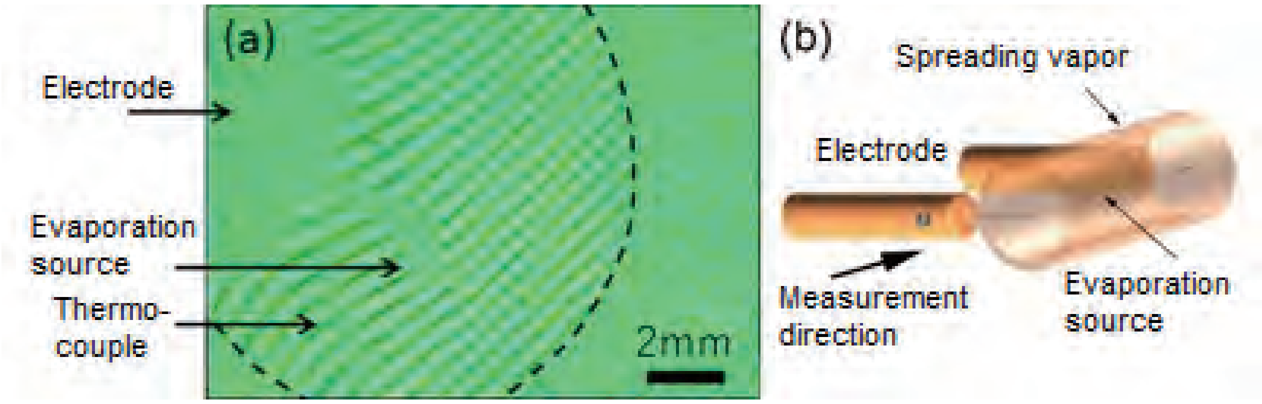


Fig. 2 Observed energy distribution of all cosmic ray events from October 13, 2015, to January 31, 2017.

- Y. Asaoka, et al. Energy calibration of CALET onboard the International Space Station. Astroparticle Physics, Vol.91, pp.1-10 (2017) doi: 10.1016/j.astropartphys.2017.03.002
- R. Kataoka, et al. Relativistic electron precipitation at International Space Station: Space weather monitoring by Calorimetric Electron Telescope. Geophysical Research Letters, vol.43(9), pp. 4119-4125 (2016) doi: 10.1002/2016GL068930
-O. Adriani, et al. CALET Upper Limits on X-Ray and Gamma-Ray Counterparts of GW151226, Astrophysical Journal Letters, Vol.829 (1), L20 (2016) doi: 10.3847/2041-8205/829/1/l20

11 Nucleation Process of Cosmic Dust Revealed by Microgravity Experiments



Example results from S-520-28 experiment: (a) interferogram showing iron vapor cooling and spreading concentrically (inside the dashed line) and forming tiny solid particles (outside the dashed line). (b) Schematic of the experimental system.

Knowledge of the composition, size, and mass of cosmic dust is the basis for clarifying both physical and chemical processes in the formation and evolution of stellar and planetary systems and the evolution of the galaxy. An interdisciplinary research team from Institute of Low Temperature Science, Hokkaido University, ISAS/JAXA, Division of Theoretical Astronomy, etc. has formed the DUST Project to develop plans for rocket-based microgravity experiments to elucidate the nucleation process and infrared spectral characteristics of space dust particles. We have a particular interest in iron dust , oxide dust such as silicates and alumina, and carbon dust in graphite and silicon carbide.

Iron in dust particles comes in various forms, such as metallic iron and iron oxide, each with different properties. Previous studies have suggested that iron is present mainly in forms other than iron oxide, iron carbide, and iron sulfide. To verify the possibility that metallic iron is present, in situ observations of gaseous iron cooling aboard an S-520-28 sounding rocket were performed, and the ease of iron aggregation, that is, the efficiency with which metallic iron forms, was investigated.

An onboard in-situ observation system composed of a nucleation chamber with a double-wavelength Mach–Zehnder-type laser interferometer and an image-recording system was adapted to conform to the size and weight limitations of the rocket. The temperature and partial pressure of evaporated iron at the nucleation was measured simultaneously by the optical system. The acquired data allowed us to prepare estimates of the sticking probability of iron atoms from the cooling rate of iron gas and other factors. The analysis results indicated a very small sticking probability of 0.002% or less. Previous ground-based experiments had estimated very different sticking probabilities from 1% to 100%.

The results of this experiment showed that it is hard for iron atoms to stick each other in interstellar space, so it is difficult for metallic iron to form. Thus, the iron in interstellar dust particles is unlikely to be present as a metal, but rather as a compound or adhered to other particles as impurities. When a star dies, it releases iron and various other elements into interstellar space, where it mixes with various types of molecules and dust that are also distributed around the dead star. Thus, a variety of molecular and chemical processes may be involved as the iron formed in a star cools, solidifies, and becomes incorporated into the interstellar medium.

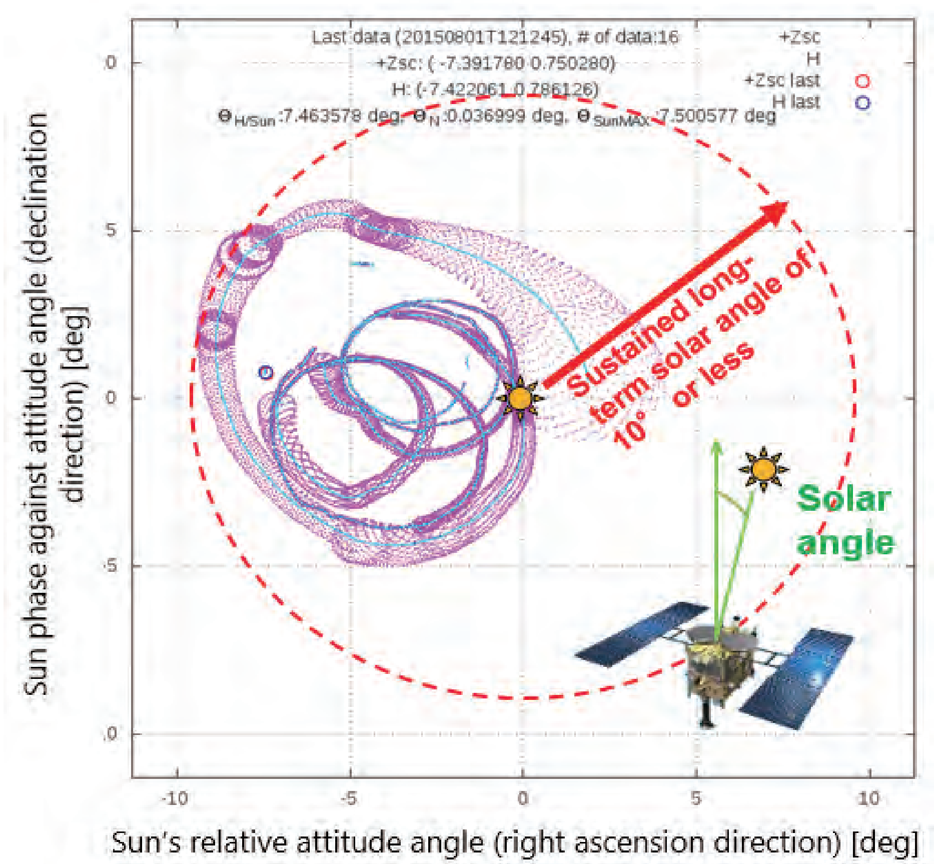
-Y. Kimura, et al. Pure iron grains are rare in the universe. Science Advances, Vol.3(1), e1601992 (2017) doi: 10.1126/sciadv.1601992

12 Realization of Zero-fuel Auto-Sun Tracking Attitude Control —an Advanced Solar Sailing Operation Technique [IKAROS and Hayabusa2 Missions]

Achievements of the Interplanetary Kite-craft Accelerated by Radiation Of the Sun (IKAROS)—the world' s first solar sail spacecraft—led to the development of theory and a technique for controlling a spacecraft's attitude without using fuel by actively utilizing disturbances caused by the solar radiation pressure exerted on the spacecraft. This was applied and demonstrated successfully in JAXA' s latest deep space explorer, Hayabusa2.

Based on the findings obtained from operating the world' s first solar power sail demonstrator, IKAROS, formulation of the motion that occurs when sunlight strikes a complexly shaped spacecraft was achieved and the attitude motion of an arbitrarily shaped spacecraft was expressed using only a few parameters.

This was applied to the flight path of Hayabusa2, demonstrating its applicability to practical operation by attaining a long-term, sun-pointing attitude using no fuel, which is impossible with conventional attitude control. This result contributes not only to solar sails but also to the design of a wider range of deep-space missions.



Auto-sun tracking of Hayabusa2 by solar sailing.

-G. Ono, et al. Generalized Attitude Model for Momentum-Biased Solar Sail Spacecraft. Journal of Guidance, Control and Dynamics, Vol. 39(7), pp. 1491-1500 (2016) doi: 10.2514/1.G001750

13 Research and Development of a High-precision, Large-scale Structural System in the X-ray Astronomy Satellite

[Achievements in the Development of X-ray Astronomy Satellite ASTRO-H (HITOMI)]

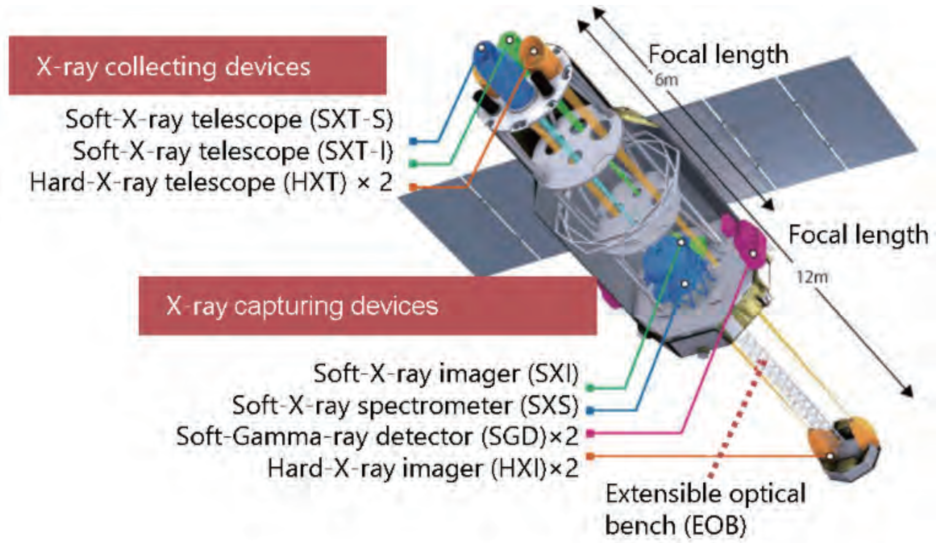


Fig. 1 Six observation devices of ASTRO-H.

ASTRO-H, launched on February 17, 2016 and was the largest scientific satellite ever built in Japan. It has a soft-X-ray telescope with a focal length of 5.6 m and a hard-X-ray telescope with a focal length of 12 m (Fig. 1). The differing focal lengths of its six observation instruments posed technical challenges for realizing high-precision alignments. In the structural system for a large satellite with a deployable structure exceeding 10 m, we achieved world-class alignment performance.

The structural systems for the telescopes consisted of a Fixed Optical Bench, Extensible Optical Bench (EOB), and connecting base plate. Because the alignment of mirrors had higher sensitivity for the observation performance than detectors, the EOB was mounted on the side of the hard-X-ray detectors. The key technologies for the high alignment performance were as follows.

First, materials with a low coefficient of thermal expansion (CTE) were selected, or materials were combined in a way to cancel out their CTEs, such as carbon fiber tubes with negative CTE and Al alloy fittings with positive CTE. Then, a highly accurate and efficient method for analysis and evaluation of thermal deformation was devised. Thus, low on-orbit thermal deformation was realized. In addition, the extensible thermal insulation blanket for the EOB played an important role in suppressing thermal deformation. Because of the thermal blanket, the temperature difference of the three longerons in the same stage of the EOB was kept to within few degrees.

We also had to develop a method for dividing and managing the alignment of systems with a large flexible structure (i.e., the EOB), which was difficult to test and verify under Earth gravity.

As a result, excellent on-orbit alignment performance was achieved (Fig. 2). The system was tested by observing the Crab Nebula with each detector. The soft X-ray spectrometer performed almost perfectly, and alignment fluctuation of the other instruments was within the requirements.

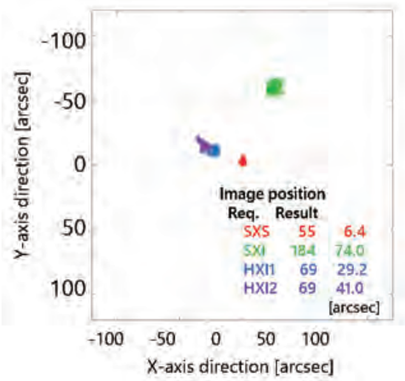
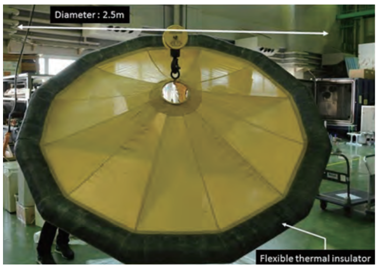


Fig. 2 ASTRO-H on-orbit alignment performance of four detectors during Crab Nebula observation.

-K. Ishimura, et.al, "Alignment performance of scientific instruments mounted on ASTRO-H (HITOMI)," The 25th Space Engineering Conference, Yamaguchi, Japan. Dec 21-22 (2016) (Presentation in Japanese).

14 Research and Development on Inflatable-type Flexible Aeroshells for Atmospheric-Entry Vehicles



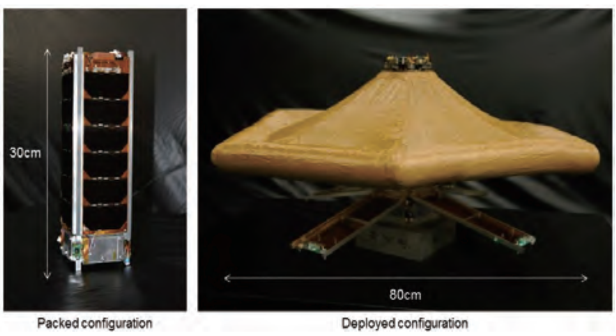
Prototype of the inflatable aeroshell supported by single inflatable ring with a diameter of 2.5 m.

In future planetary exploration, planetary probes and sample return missions will become more important. One of the critical technologies to support these missions is atmospheric entry technology. The inflatable aeroshell concept has recently received more attention as an innovative technology for atmospheric entry, and various R&D efforts have made progress in several countries. We have developed a unique inflatable aeroshell, which is a flare-type thin membrane supported by single inflatable torus. A free-flight test from an altitude of 40 km using a large scientific balloon was carried out in FY2004. An entry demonstration using a sounding rocket from an altitude of 150 km was successful in FY2012.

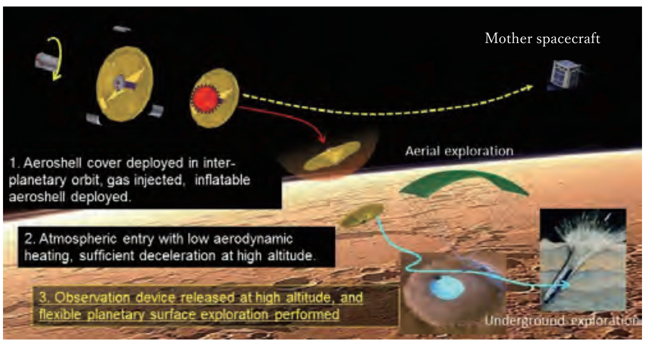
Since FY2012, we have continued to enhance the performance of inflatable aeroshell technology and to improve evaluation methods and test facilities. For example, strength tests were carried out to develop the structural strength model of an inflatable aeroshell using a full-scale model in a 6.5 m x 5.5 m low-speed wind tunnel at JAXA Chofu Aerospace Center. A 10-kW-class inductively coupled plasma heater was developed for the thermal testing of inflatable structures to investigate their durability against aerodynamic heating. Based on these tests in FY2016, a prototype model was created with sizes, materials, and manufacturing methods applicable to actual missions, such as a Mars surface survey and entry and recovery system from low Earth orbit. Gas-tightness tests, pressure resistance tests, aerodynamic structural strength tests, and heat-resistance tests confirmed that the prototype satisfied the required performance. The prototype model has a diameter of 2.5 m and a total mass of 4.7 kg.

Based on this technology, the re-Entry satellite with a Gossamer aeroshell and GPS/Iridium (EGG) nanosatellite was developed in collaboration with the University of Tokyo, Nihon University, and others. EGG features an inflatable flexible aeroshell with diameter of 0.8 m. In January 2017, EGG was deployed from the ISS and succeeded in deploying its aeroshell. After that, the orbital decay of EGG due to the aerodynamic force acting on the deployed aeroshell was observed. Finally, EGG re-entered the atmosphere and burned up in May 2017.

An inflatable aeroshell developed for atmospheric entry allows for more compact planetary explorers and has unique characteristics (such as high-efficiency deceleration) that are not found in conventional atmospheric entry vehicles, allowing application to new planetary exploration modes (such as a highly distributed exploration).



Prototype of the inflatable aeroshell supported by single inflatable ring with a diameter of 2.5 m.



Concept of Martian probe with the inflatable aeroshell.

-K. Yamada et al. The 60th Space Science and Technology Alliance Lectures, September 2016

15 Elucidation of the Roll Torque of the μ10 Microwave Ion Engine

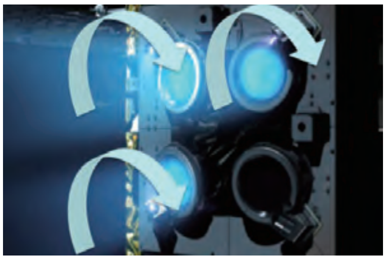


Fig. 1 Image of roll torque generated by microwave ion thruster.

Through the operation of the asteroid explorer "HAYABUSA" in space, it has been confirmed that ion thrusters cause an unexpected roll torque about the ion beam axis shown in Fig.1. Typically, the torque was on the order of 0.1-100 μN·m, which is too weak to measure using a thrust stand on ground support equipment. Though it is quite difficult to directly measure the torque, it is important to measure it to precisely control the attitude of spacecraft. While the thrusters are being operated, it is necessary to use reaction wheels to maintain the designed attitude. Once the rotation speed of the reaction wheels reaches the designed maximum or minimum speed, a cancellation maneuver must be conducted using chemical thrusters. Since the reaction wheels and chemical propellant limit the lifetime spacecraft, it is highly important to reveal the physical process of roll torque. Because of the difficulty of the torque measurement, laser-induced fluorescence (LIF) spectroscopy has been used to measure the azimuthal velocities of xenon ions shown in Fig.2.

This technique can be used to measure the azimuthal velocity by estimating the Doppler shift of the velocity functions of xenon ions. To simplify this problem, the measurement was conducted without a neutralizer cathode to avoid the possibility of the cathode affecting the trajectory of the ion beam. The measured functions were the sum of the spectra of high velocity primary ions and those of charge exchange ions. By eliminating the charge exchange ions, the azimuthal velocities were successfully measured and were found to range from -600 to +600 m/s with 10% error shown in Fig. 3. The azimuthal velocity profile was accurately reproduced by the simulated velocity profile obtained using a model including the effects of the misalignment of the accelerator grid with respect to the screen grid and the magnetic field in the discharge chamber. This is the first confirmation that the internal azimuthal velocities are conserved even after the acceleration of the grid optics. The reproduced roll torque was 0.5 μN·m about the thrust axis based on the velocity profile and ion beam density profile. This prediction agrees well with the flight data for the spacecraft.

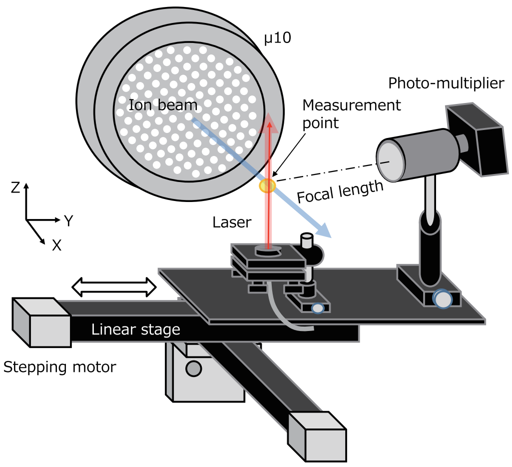


Fig. 2 Azimuthal velocity measurement of microwave ion thruster by laser-induced fluourescencespectroscopy.

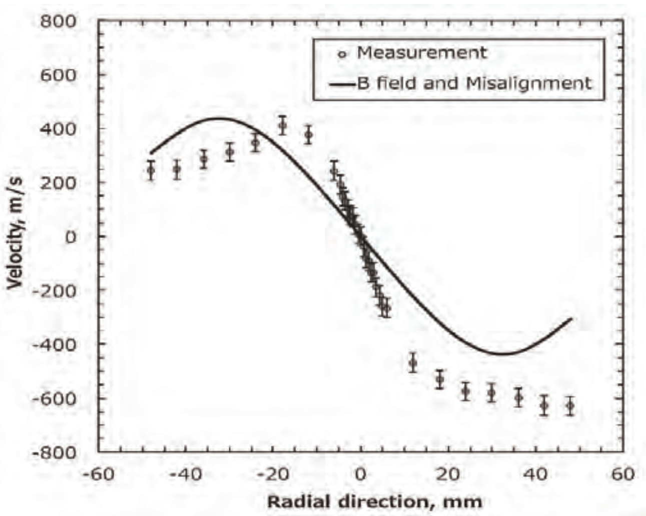


Fig. 3 Experimental and theoretical azimuthal velocity profile of the μ10 microwave ion thruster.

-R. Tsukizaki et al. Ion Velocity Measurement of the Microwave Ion thruster by Laser-induced Fluorescence Spectroscopy. Plasma Science Journal, Vol. 23(2), pp. 69-64 (2016)

16 Data Analysis on Long-life Lithium-Ion Battery of Small Satellite REIMEI

[Innovative-technology Demonstration Experiment REIMEI (INDEX)]

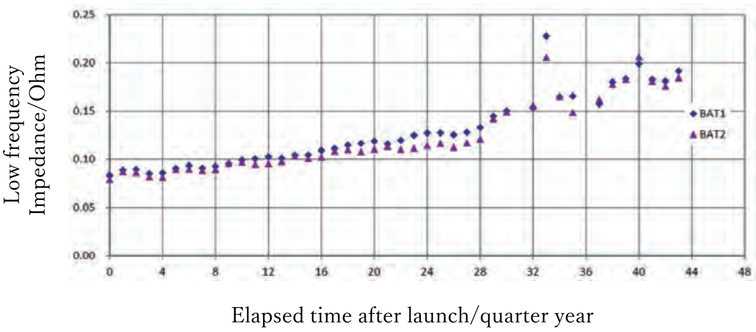


Fig. 1 History of low frequency impedance of REIMEI Lithium-ion battery (vertical axis). Horizontal axis is elapsed time after launch. Unit is a quarter year.

Recently, it has become increasingly important to reduce the risks of debris generation in low Earth orbit. However, since lithium-ion batteries have energy densities that are much higher than other battery types, they have become extremely popular for use in onboard satellite equipment since the 2000s, and thus have the potential to generate significant amounts of debris in low Earth orbits.

The small REIMEI satellite, (formerly known as INDEX) which was launched in 2005 and is still in operation, has been using lithium-ion batteries as power storage devices for more than 11 years, and those batteries had experienced more than 60,000 charge-discharge cycles as of 2016. This satellite is one of a very few in low Earth orbit that have operated lithium-ion batteries for such a long period, and we have been examining the internal state of those batteries by means of novel monitoring methods.

Specifically, we developed a novel of low frequency impedance measurement algorithm for the onboard batteries by recording its house-keeping battery data every eight seconds. The results obtained thus far show that the low frequency impedance of the batteries has gradually increased during the period since the satellite was launched (Fig. 1), and the resulting statistical data indicates that rapid voltage-decrease events have been occurring frequently at early discharge phases since 2015.

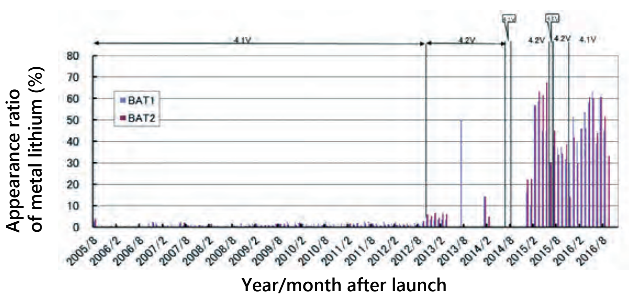


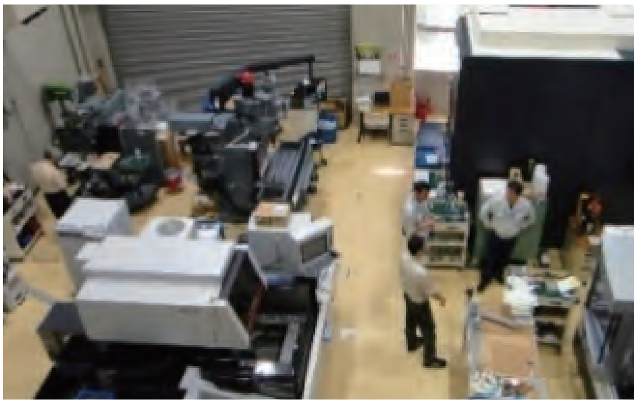
Fig. 2 Appearance ratio (%) of metal lithium phenomenon vs. Year/Month after Launch

It is considered likely that these factors result from the accumulation and dispersal of lithium within the battery because when metal lithium appears at the negative electrode, the voltage between the electrodes increases. However, when the metal lithium dissipates, the between-electrode voltage decreases to its normal value. Furthermore, since it is possible that this phenomenon can be used to profile the unique degradation patterns of lithium-ion batteries in space, we have discussed the results of our long battery life observations with members of the international community including the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German aerospace agency, and have proposed a battery health assessment method to the International Organization for Standardization (ISO).

-Y. Sone, et al. Long term operability of Li-ion battery under micro-gravity condition demonstrated by the satellite “REIMEI” . Electrochemistry, Vol.84(1), pp.12-16 (2016) doi: 10.5796/electrochemistry.84.12
-Y. Sone, et al. ” Understanding of the Internal Conditions of the Lithium-Ion Secondary Cells,” NASA Aerospace Battery Workshop, Huntsville Alabama, Nov 15-17 (2016)
-Y. Sone, et al. “Internal Impedance of the Lithium-Ion Secondary Cells Used for REIMEI Satellite After the Eleven Years Operation in Space” . ESPC 2016 – 11th European Space Power Conference, Thessaloniki, Greece. Oct 3-7 (2016)
-ISO /NP TR 20891, ‘Space systems -- Space batteries -- Guidelines for in-flight health assessment of Li-ion batteries’ , 5.3 Measurement of battery spectral impedance, 5.4 Prediction for the termination of the operation, ESPC 2016 –11th European Space Power Conference, Thessaloniki, Greece. Oct 3-7 (2016)

17 New Machine Shop Created on Sagamihara Campus

[Advanced Machining Technology Group]


New machine shop

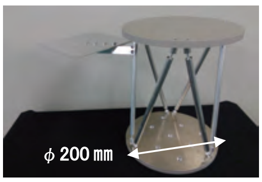

Space nanoelectronics cleanroom

A new group was established on the Sagamihara campus in FY2016, designated the Advanced Machining Technology Group. In addition to opening the door for in-house manufacturing, this group offers the capability for prototyping, will support startup of all the new JAXA mission projects, and will contribute to optimizing the products of our R&D.

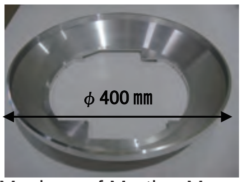
The functions of the machine shop and nanoelectronics used to be separate, but as of FY2016, these two were integrated into a single group in charge of advanced machining technologies for use in space. In addition to the conventional machine shop with its general purpose machines, a new machine shop with a newly installed 5-axis machining center, CNC turning centers, a wire-cut electric discharge machine and other equipment was created in order to realize high-quality machined products. Two specialists in manufacturing were assigned to operate the state-of-the-art machines in FY2016, and two more will be recruited in FY2017. This will provide opportunities for users unaccustomed to mechanical design or machining to develop initial concepts into final hardware designs through collaboration with technicians experienced in processes employing vacuum, low temperatures, welding, surface treatment techniques and other technologies. In addition, for the first time, we have introduced a contact-type three-dimensional measuring machine in order to verify if the tolerances of components delivered by manufacturers meet our requirements. As for equipment in the nanoelectronics field, we are operating an ISO 1 cleanroom; we also have processing systems including an ion etching apparatus, an electron beam exposure system, maskless exposure for RF devices, and a thin-film forming apparatus, and we are developing integrated circuits and other electronic devices. Through the establishment of the advanced machining technology group, JAXA has started accumulating manufacturing know-how and technical processing knowledge, and is developing techniques to contribute to the aerospace field.


Contact-type three-dimensional measuring machine

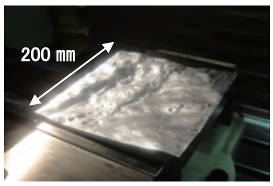
Examples of items manufactured in new machine shop



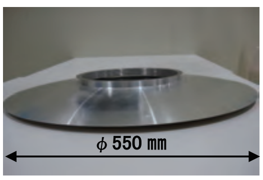
Thermal vacuum test model



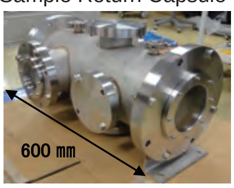
Mock up of Martian Moon Sample Return Capsule



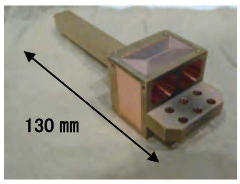
3D model of lunar surface



Re-usable rocket fuel tank cap



Vacuum chamber for experiments



Snorkel for electron microscope

II
Status Report

1. Space Science Roadmap

a. Basic Framework

1. In FY2015, ISAS redefined four space science mission classes: strategic large-class, competitive middle-class, strategic international projects, and small projects. Some projects will be developed for the three fields of astronomy/astrophysics, solar system exploration science, and space engineering, which includes satellites, spacecraft, and space transportation required for the missions in the former two fields.
   - The strategic large-class plans for space science missions are intended to achieve top scientific results internationally.
   - The competitive middle-class plans are intended to achieve frequent space science missions.
   - The strategic international project plans are intended to achieve international collaboration.
   - The small-class project plans are intended to create unique, advanced space missions.
2. For astronomy and astrophysics, projects will be implemented in various ways, including large plans, which will be strategically executed as flagship activities, and medium-size plans, which will be implemented dynamically, as well as through participation in large-scale overseas missions.
3. For solar system exploration, the initial period of about 10 years will be used to overcome engineering issues and acquire technology through highly flexible medium-size plans. This will be done as preparation for full-scale exploration through large-scale science missions beginning after 10 years. Low-cost, high-frequency space science missions will be launched using technology such as the Epsilon Launch Vehicle. Effective, efficient robotic space exploration missions are planned based on bottom-up and programmatic top-down strategies. In the programmatic strategy, space exploration missions will be planned to achieve advanced exploration with robotic landers or surface explorers on large bodies, such as for the Moon or Mars.
4. Research projects will be established, including engineering research, for developing technology to reduce the size and increase the functionality of scientific satellites and exploration spacecraft. Research will also be conducted to improve planetary exploration and deep space navigation systems and to develop new space transportation systems.

b. Strategic Large-class Space Science Missions

An announcement of opportunity (AO) was issued in FY2014 for proposals for strategic large-scale space science missions. The Advisory Committees for Space Science and Space Engineering reviewed the proposed plans and recommended three plans to the ISAS Director General. ISAS also reviewed and evaluated three recommended plans and a Martian moon exploration plan. ISAS selected the Martian moon sample return plan as a candidate for the next strategic large-scale space science mission. The conceptual design for the Martian moon sample return mission was completed and mission definition review (MDR) was conducted with participation by international experts, and the scientific merit of the proposed mission was evaluated. The conceptual designs of the other plans, LiteBIRD and Solar Power Sail, have been reviewed and Phase A1 started in FY2016. The Martian moon sample return plan was described in the revised mission work schedule in the new space basic plan (approved by Space Development and Strategy headquarters on December 8, 2015).

c. Competitive Middle-class Space Science Missions

ISAS selected the mission plans for Smart Lander for Investigating Moon (SLIM) as the first mission of the competitive middle-class plans and supported the project preparation. SLIM moved to the project phase in FY2016. SLIM is described in the revised mission work schedule in the new space basic plan. For the next competitive middle-class project, the Space Engineering and Space Science Advisory Committees conditionally conducted an MDR for the DESTINY+ mission and recommended that ISAS move it into Phase A1.

d. Small-scale Space Science Projects

The small-scale project proposals in FY2014 were evaluated and chosen by the Advisory Committees for Space Science and Space Engineering and then recommended to ISAS. ISAS set up the small project evaluation committee, reviewed the plans, and notified the working groups of the results. The first small project, the tropical troposphere stratum balloon experiment, completed the balloon experiments. A plan of providing part of the science instrument payload for ESA's L-class mission, Jupiter Icy Moons Explorer (JUICE), was reviewed as the second small project in ISAS, and the conceptual design was prepared by the team. In addition, a variety of small-scale projects were being considered to enable participation in large-scale international projects beyond FY2016.

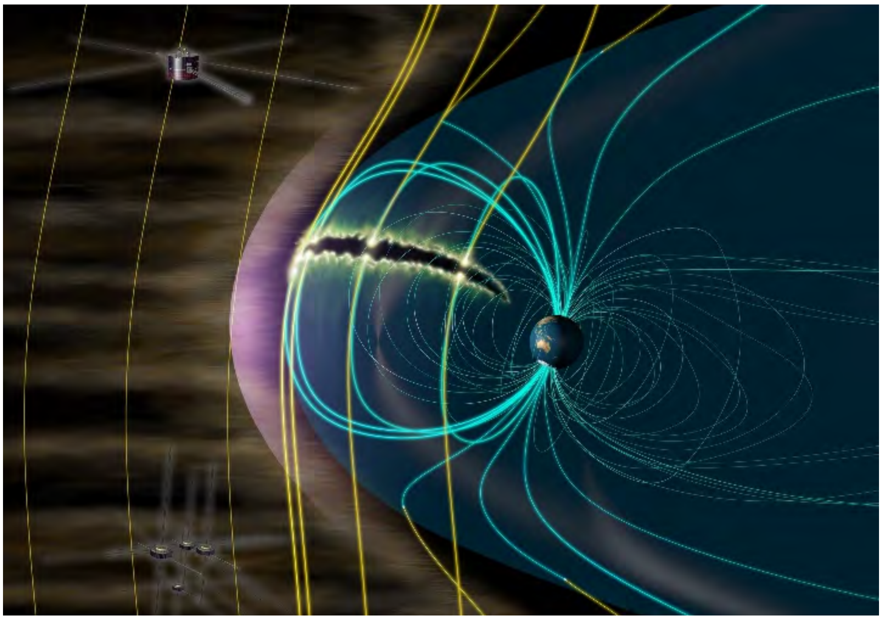
The Advisory Committees for Space Science and Space Engineering discussed how to promote the small-scale projects group in the future. ISAS outlined their policy to be able to advance in two areas of the strategic international cooperation plan and the small-class project plan by using various flight opportunities to emphasize the importance of participation in planning for overseas large-scale plans. ISAS conducted a call for small-class project plans and accepted 16 proposals for review.

e. Future Mission Strategy

In FY2014, based on a request for information about the future mission strategies and schedules of each space science and engineering community, a long-range mission plan for space science and exploration was proposed. ISAS set up a space science and exploration program examination team in FY2015, and the team developed a strategy for long-term space science based on the information from each field. The team drafted the report “The Practice Strategy of Space Science Based on the Aims, Strategies, and Progress Schedules Provided by the Community.” The strategy was discussed again in FY2016, and the report will be finalized.

2. Space Science Programs

a. Earth Magnetosphere Observation with GEOTAIL



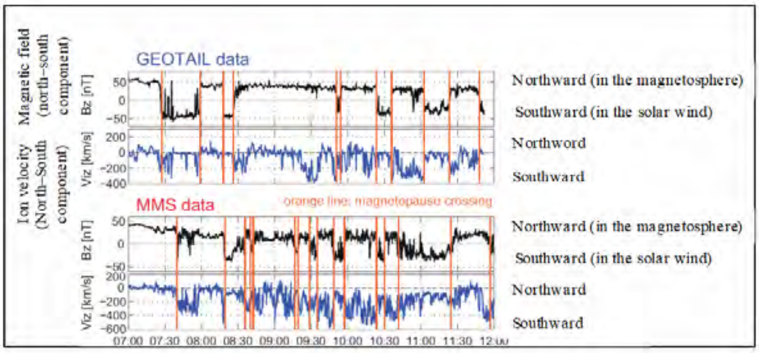
Magnetic reconnection simultaneously observed by GEOTAIL and MMS.

Since the launch of the joint U.S.-Japan satellite GEOTAIL in 1992, it has been continuously operating 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. ISAS has approved the continued operation of GEOTAIL until at least the end of March 2019.

NASA's formation flying spacecraft Magnetospheric Multiscale (MMS) was 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. The GEOTAIL–MMS collaboration will provide opportunities to make multiscale observations of plasma in space.

As a result of cooperative observations with the MMS satellite, we revealed for the first time that magnetic reconnection occurring at the boundary of Earth's magnetosphere is continuously generated for 5 hours or more over 70,000 km in the east–west direction [1], and that when the magnetic pole is tilted, the location of magnetic reconnection shifts toward the winter hemisphere [2]. These are important results for understanding how the inflow of solar wind energy into the magnetosphere changes with changes in the solar wind and planetary magnetic field.

(Geophysical Research Letters, [1] May 2016 and [2] June 2016; press conference in July 2016; published in the ISAS News, December 2016 issue).



Observation data of magnetic reconnection simultaneously obtained by GEOTAIL and MMS on October 2, 2015.

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 FY2016, 96 peer-reviewed papers were published related to SUZAKU. The cumulative number of peer-reviewed papers is 943.

c. Innovative-technology Demonstration Experiment with REIMEI

The small Innovative technology Demonstration Experiment REIMEI (formerly called INDEX), is a 72-kg piggy-back scientific satellite launched by the Japan Aerospace Exploration Agency (JAXA) in 2005. The REIMEI mission is to investigate the fine structures of aurora phenomena as well as to demonstrate small satellite technologies. The satellite has been functioning in orbit for 11 years, fulfilling its scientific objective of observing the fine structure of aurora phenomena with its three spectral imagers and particle energy analyzers. Its engineering objective involves demonstrating the feasibility of small satellite technologies.

REIMEI is equipped with lithium-ion batteries as power storage devices that have been in operation for more than 11 years, and which have experienced more than 60,000 charge-discharge cycles as of 2016. Our interesting observations regarding these long-life lithium-ion batteries are discussed on page 18. As for the satellites other engineering activities, a bread board model of an automatic satellite operation system has been developed.

As has been described elsewhere, the REIMEI satellite is one of just a few such spacecraft in low Earth orbit that have operated using lithium-ion batteries for more than 10 years. Based on observations collected to date, JAXA has discussed long-life battery operations with international agencies such as Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German aerospace agency, and has proposed a battery health assessment method to the International Organization for Standardization (ISO).

Publications: Reviewed journal papers, 1; International conference presentations, 2; Domestic conference presentations, 4; Patent submissions, 1; International standardization proposals, 1 (Additional details on p.18).

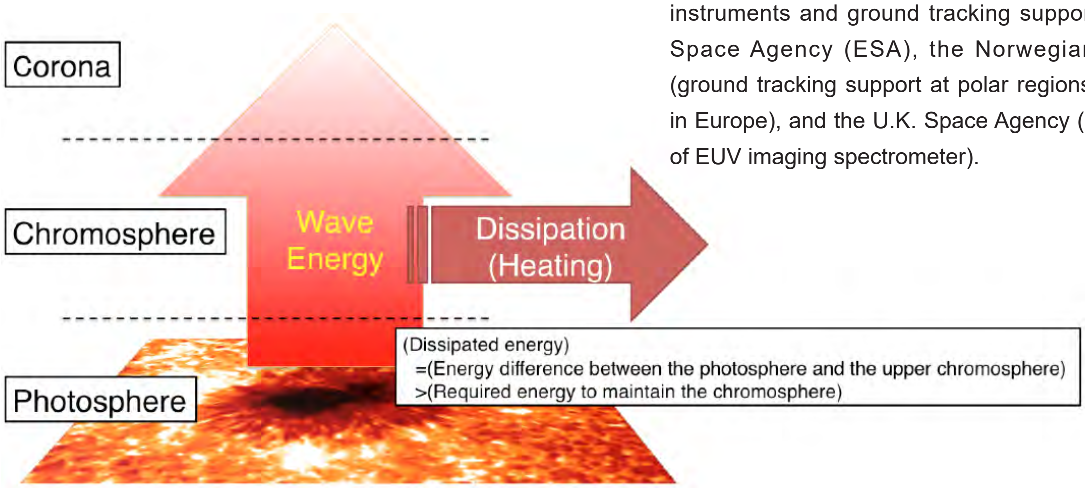
d. Solar Observation with HINODE

The aims of the HINODE satellite (formerly called SOLAR-B) are to better understand the space weather of the Sun-Earth system. Specifically, we are observing the solar processes of magnetic field generation; energy transfer from the photosphere, that is, the solar surface, to the corona and for the heating and structuring of the chromosphere and the corona; and eruptive phenomena. HINODE is a follow-on to the YOHKOH satellite, operated in 1991–2001, which revealed that the high-temperature corona is highly structured and dynamic and that rapid heating and mass acceleration are common phenomena. HINODE is designed to address the fundamental question of how magnetic fields interact with the ionized atmosphere to produce its dynamics, by accurately measuring the magnetic fields at the photosphere with simultaneous X-ray and extreme ultraviolet (EUV) measurements of coronal behavior.

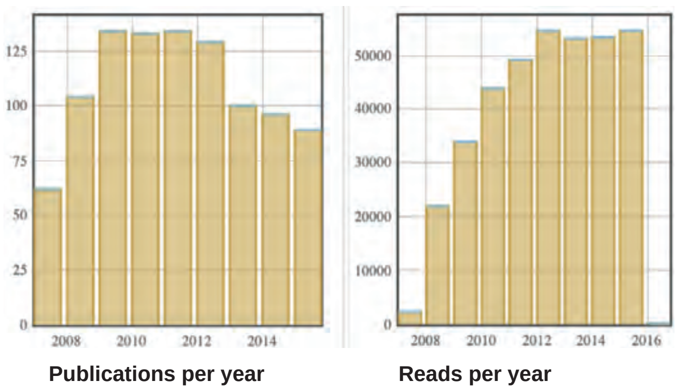
HINODE was launched in September 2006 and has been continuously operated as an on-orbit solar observatory for over 10 years. The observatory is open to the world-wide research community and 36 new observing proposals were delivered to the HINODE operation team in FY2016. Proposals were increased with the December 2016 start of solar observations by the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Data acquired by HINODE are made fully available to the world research community immediately after observations. HINODE scientific operations are also closely coordinated with Interface Region Imaging Spectrograph (IRIS), NASA's solar observation satellite.

In FY2016, 85 articles were published in referred journals based on HINODE observations, resulting in a cumulative total of 1,074 referred papers so far, which is one of the most productive ISAS missions. As part of a series of 10th anniversary events, an international symposium (HINODE-10) was held at Nagoya in September 2016 to review HINODE’s scientific achievements and to discuss future directions of solar physics research with scientists from all over the world. Public outreach and education activities were organized, including a public lecture at Nagoya (attended by 228 citizens), articles in major newspapers, a 10th anniversary HINODE highlights movie (over 50,000 views just in a couple of days after public release), and series of review articles in the *Astronomical Herald* of the Astronomical Society of Japan.

After reviewing scientific achievements and further research plans, JAXA extended the mission for 4 more years (April 2017 to March 2021). HINODE operations have been supported by NASA (operation of onboard instruments and ground tracking support), the European Space Agency (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).



Schematic drawing of the logic for estimating the energy dissipated in the Sun's upper atmosphere, as developed through HINODE-IRIS collaboration. The temperature of the upper part of the solar atmosphere (chromosphere and corona) is higher than that of the photosphere. Waves, which propagate upward along the magnetic field lines and dissipate (thermalize) the energy in the upper atmosphere, are one candidate for transporting energy to the chromosphere and corona. A research team evaluated how much energy is dissipated at the chromosphere through waves and found that the difference between the energy fluxes measured at the photosphere and the upper chromosphere is larger than the energy required to maintain the chromosphere temperature.



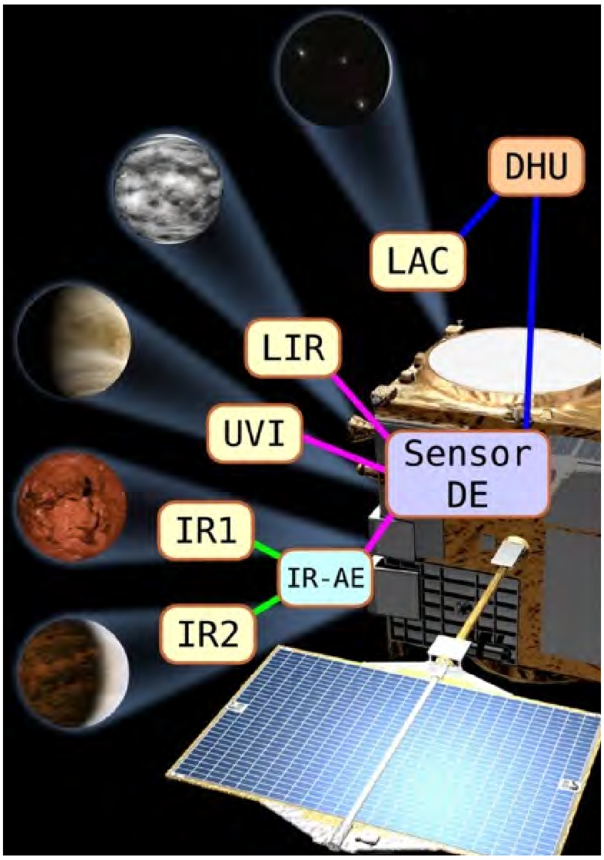
Number of peer-reviewed papers regarding HINODE-acquired data published in each year (left) and number of paper downloads (right). The statistics were recorded with support by the Astrophysics Data System funded by NASA.

e. Venus Meteorology Observations by AKATSUKI

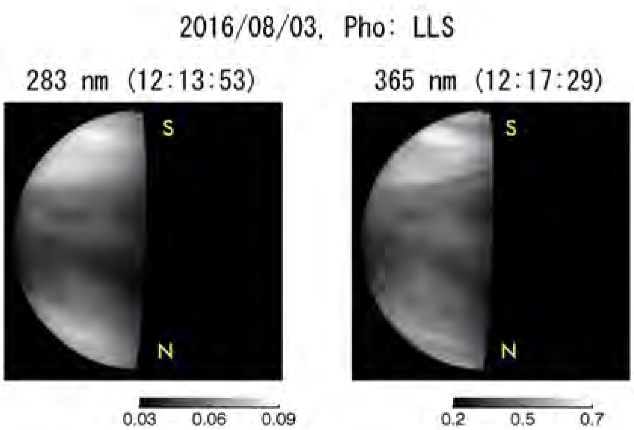
Although Venus is our twin planet, its atmospheric motion is completely different from that of Earth. In particular, we do not understand how Venus maintains so-called super rotation, which is a high-speed wind blowing around Venus at 100 m/s. AKATSUKI (formerly called PLANET-C) was launched to Venus in May 2010 to investigate the Venusian atmospheric motion. It arrived at Venus on December 7th, 2015, and started observation with five cameras that image the atmosphere at different altitudes. It is also equipped an ultra-stable oscillator for a radio occultation technique that reveals the vertical profile of the Venusian atmosphere. The spacecraft is in good health and its lifetime is limited only by the remaining fuel, which is estimated to be 300 g to 4 kg. We expect the next orbit maneuver to be in December 2018 to avoid a long umbra.

In Dec 2015, observations by the LIR discovered an arc pattern stretching approximately 10,000 km in the north-south direction. This pattern stayed at rest relative to the surface over four days, without being affected by the high-speed easterly winds of the Venusian atmosphere. The UVI detected an SO_2 distribution at 283 nm and still unknown absorber distribution at 365 nm every 2 hours at dayside. Sometimes they are well correlated but not always. In low-correlation cases, we typically observed either of the following cases: (1) dark 283 nm and bright 365 nm over afternoon side or (2) bright 283 nm and dark 365 nm over morning side. This comparison gives us a clue to understanding the SO_2 formation process and the relation between the SO_2 and its unknown absorber. Atmospheric motion at different altitudes are tracked by LIR, UVI, IR1, and IR2 cameras. By integrating these data, we will see the three-dimensional atmospheric motion on Venus.

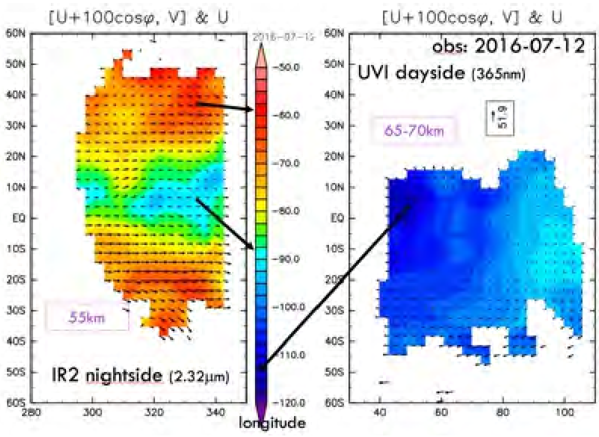
ESA's Venus Express ended its mission in 2014, before AKATSUKI arrived at Venus, but their data are compared to ours to obtain a deeper understanding Venus's atmospheric motion. Inspired by AKATSUKI, Russia restarted their Venera-D mission and two Venus probes are in final project assessment at NASA.



The five cameras onboard AKATSUKI image atmospheric motion at different altitudes

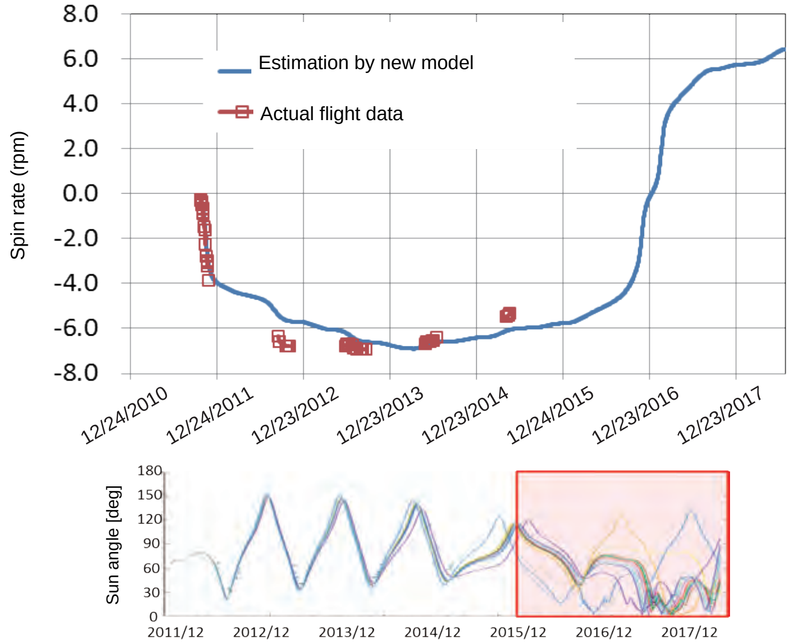


UVI detected UV reflections at 283 nm and 365 nm



Cloud tracking: "day vs. night" comparison.

f. Solar Power Sail Demonstration with IKAROS



Newly proposed attitude-trajectory analysis model considering variation of spin rate.

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.

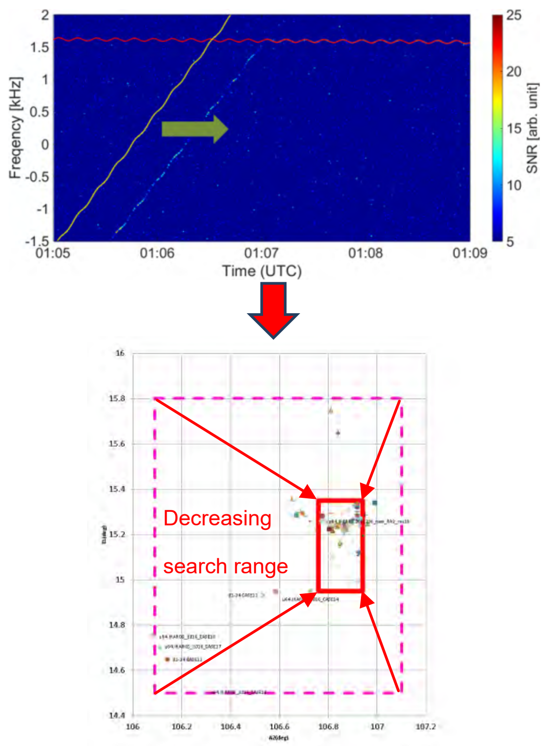
As no radiowaves from IKAROS have been received, which implies that the conventional mechanical model might no longer be correct, a new attitude-trajectory analysis model was proposed to consider the variation of spin rate and the resulting torsion angle change of the sail membrane. Running the model with actual flight data enabled estimation of the spin rate. Since 2016, the spin rate of IKAROS showed a tendency to change from negative to positive, which clarified the unique behavior of significant attitude change of spinning solar sails.

Building a method to extract artificial range data by postprocessing using open-loop record data has led to the determination of the IKAROS orbit with an estimated precision of ±1,000 km. This allowed us to narrow the search range in the actual search operation.

This method to extract artificial range data by postprocessing using open-loop record data is expected to be applicable to the operation of a wide range of deep space probes, as well as solar sails.

The International Academy of Astronautics has announced that the IKAROS team will receive the 2017 Laurels for Team Achievement Award.

In FY2016, 1 peer-reviewed paper regarding IKAROS was published, for a cumulative total of 107 peer-reviewed papers.



Extracting artificial range data and its application to decreasing the search range.

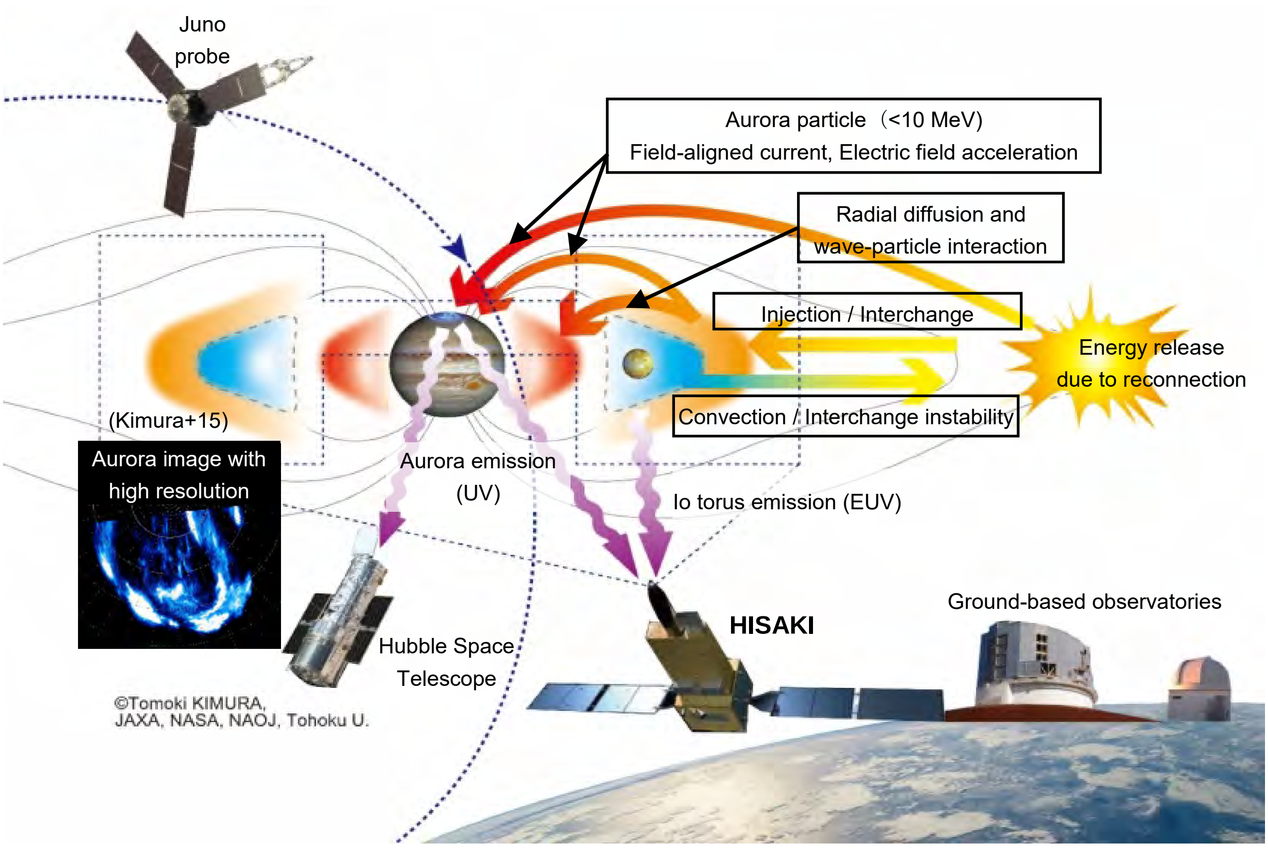
g. Extreme-ultraviolet Spectroscopic Planetary Observation with HISAKI

The extreme-ultraviolet spectroscopic planetary observatory HISAKI (formerly called SPRINT-A), which was launched on September 14, 2013, is a unique space telescope specialized for the first 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 the atmospheric evolution of the terrestrial planet.

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. In particular, the results for Jovian magnetospheric energy transport led to new perspectives, which are described in the section I-4 & I-5. A joint observation with the Hubble Space Telescope (HST) was also performed when NASA's Jupiter space probe (Juno) observed solar wind and Jovian magnetospheric plasma before and after its Jovian orbit insertion.

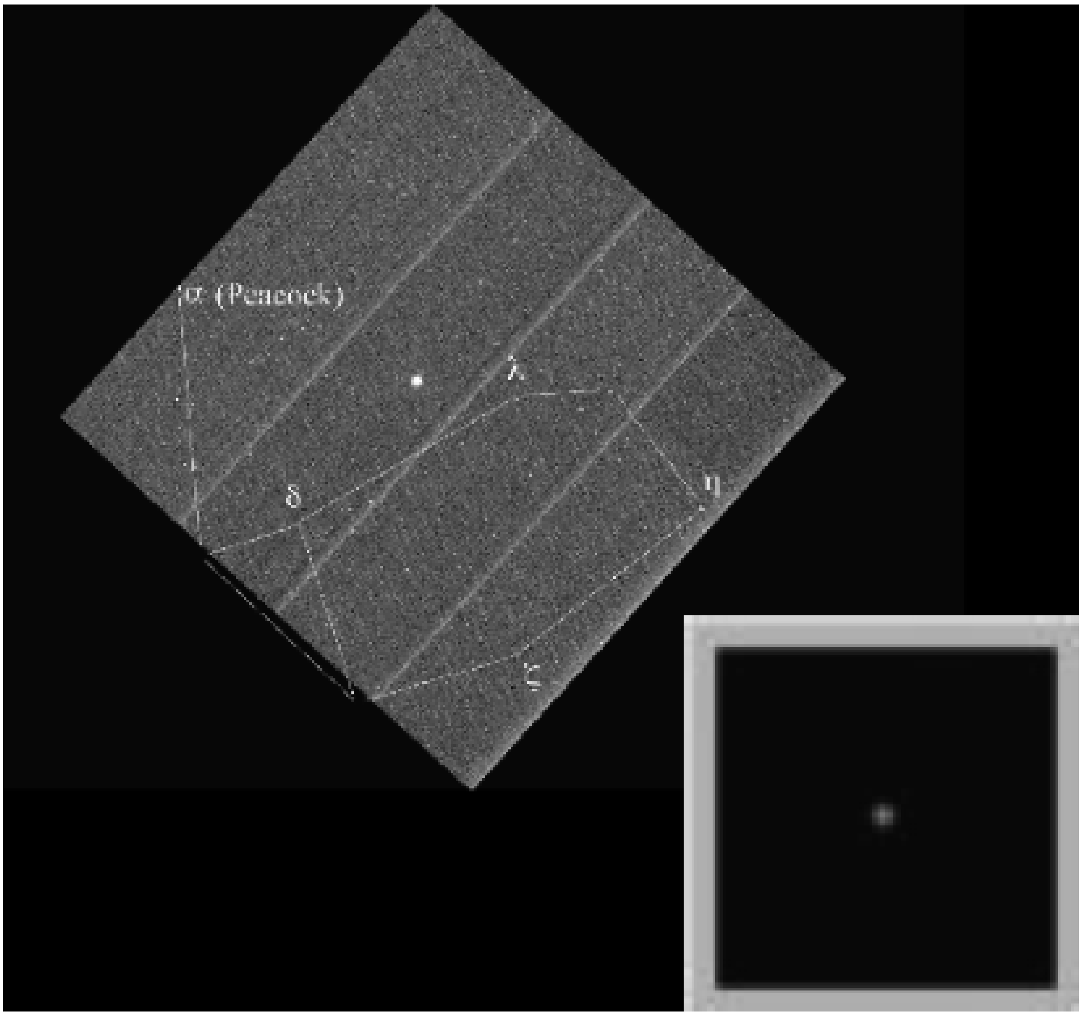
International collaborative investigation of the Jovian magnetosphere started with researchers from the USA and Europe. In FY2016, 6 peer-reviewed papers regarding HISAKI data were published, for a cumulative total of 14. Two articles using HISAKI observation results contributed to the Juno special issue of *GRL*, which included the joint observation results during the interplanetary space cruising phase of the Juno mission (under review). HISAKI played the most important role as the producer of continuous observation data, while the other satellites are subject to limits on their observation time.

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) and the organization of the international study team by the International Space Science Institute. Magnetospheric physics and aeronomy scientists, especially members of the Society of Geomagnetism and Earth, Planetary and Space Sciences in Japan, have been working with HISAKI observation results.



International collaborative observation of the Jovian magnetosphere.

h. Asteroid Explorer Hayabusa2



Mars image taken by STT (upper left) and by ONC-T (lower right)

The asteroid explorer Hayabusa2, which was launched on Dec. 3, 2014 onboard a Japan Aerospace and Exploration Agency (JAXA) H2A launch vehicle, is the follow-on mission for HAYABUSA, and the second asteroid sample return mission. The target asteroid, 162173 Ryugu, is a C-type near-Earth asteroid. Hayabusa2 successfully performed the Earth gravity assist maneuver on Dec. 3, 2015, and several engineering demonstrations and scientific observation/calibration operations have been (and are being) conducted as it continues on its interplanetary cruise toward its ultimate destination.

Throughout FY2016, the spacecraft continued normal flight powered using its μ10 ion engine as the primary propulsion system. To enhance the operationality of the asteroid proximity phase, Ka-band communications between the spacecraft and all Deep Space Network/ European Space Agency (DSN/ESA) stations has been established, and uplink transfer techniques were tested and established to ensure seamless operation over multiple stations. Both are first attempts for Japan. In addition to confirming the soundness of onboard instruments, Mars imaging using the optical navigation camera (ONC-T) and the star tracker (STT) were performed successfully. These tests were also utilized to prepare for the optical navigation operation that will be performed as part of the terminal approach to the asteroid.

In July 2016, the mission team demonstrated the spacecraft's orbital determination capability by delta-differential one-way ranging (DDOR). This was a unique measurement with few previous examples in terms of its joint implementation by three institutions—a JAXA spacecraft assisted by ESA and US National Aeronautics and Space Administration (NASA) ground stations—using the Ka communication band, and was the world's first attempt in terms of inter-organizational DDOR operation under the Consultative Committee for Space Data Systems (CCSDS) standard.

The number of peer-reviewed papers related to Hayabusa2 that were published in in FY2016 was 20, and cumulative number of peer-reviewed papers published to date is 60.

i. X-ray Astronomy with HITOMI

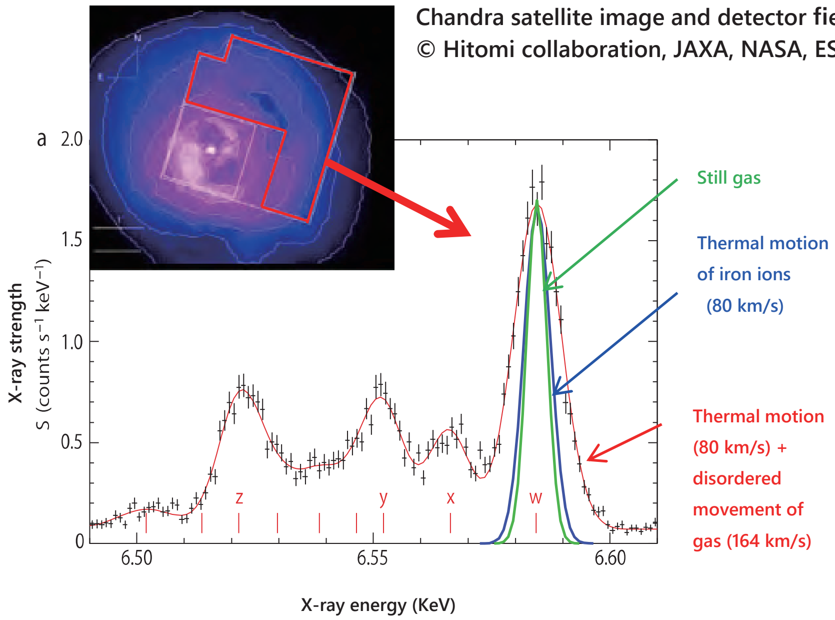
A communications malfunction occurred on ASTRO-H (also known as HITOMI) on March 26, 2016. Restoration operations were unsuccessful, so operations were abandoned on April 28, 2016. A team investigated direct and indirect factors of the anomaly and developed measures to prevent recurrence. It summarized the HITOMI anomaly in a research report delivered to the Space Development and Utilization Committee of the Ministry of Education, Culture, Sports, Science, and Technology. As a concrete execution plan for recurrence prevention measures, the “ISAS Reform Action Plan” was developed and applied to existing projects.

After analyzing and evaluating telemetry data from all subsystems based on on-orbit ASTRO-H data, a project completion review was conducted by summarizing all project activities from development through abandonment. Consequently, the “ASTRO-H Project Termination Report” was compiled to focus on extracting lessons learned from ASTRO-H and applying them to future projects. The results of the cause investigation and measures were reported to overseas institutions (e.g., NASA and ESA) to prevent recurrence and ISAS established a path toward the development of an X-ray astronomy recovery mission (XARM) with international cooperation. An agreement document with NASA has been prepared. Moreover, a pre-project preparation team for XARM has been launched, and mission definitions and project preparation tasks are being carried out based on the lessons learned from ASTRO-H.

The XARM proposal is intended to minimize the gap in X-ray astronomy caused by the loss of ASTRO-H. The proposal has restored confidence lost both domestically and overseas. By putting every effort into the launch and operation of ERG based on the action plan, we have created a template that can be applied to the operation of future satellites and probes. An implementation system under common JAXA project management rules will be useful for the development of increasingly large, complex spacecraft systems in future ISAS projects.

Initial observations of the Perseus galaxy cluster by ASTRO-H revealed that when the jet blown out of the supermassive black hole at the center of one of the galaxies in the cluster collides with high-temperature gas, the resulting perturbations are surprisingly small. This gave important clues about a long-standing problem related to the heating of galaxy-cluster gases containing a supermassive black hole.

In FY2016, 6 peer-reviewed papers were published, for a cumulative total of 65 peer-reviewed papers. An important publication from this ASTRO-H program is "The Quiescent Intracluster Medium in the Core of the Perseus Cluster," Nature, Vol. 535(7610), pp. 117-121 (2016).



X-ray energy spectrum of the central region of the Perseus galaxy cluster obtained with ASTRO-H.

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 using remote sensing.

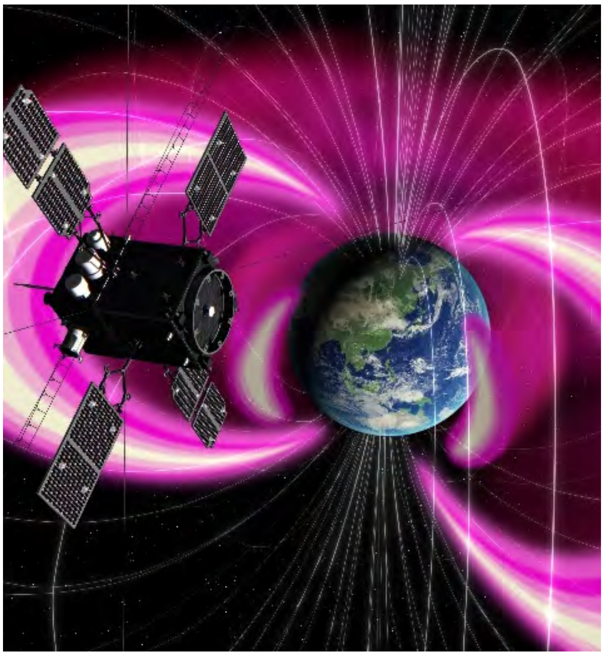
The final assembly, integration, and verification (AIV) test for the MPO at the ESA European Space Research and Technology Centre (ESTEC) has been completed, and AIV for the MTM is almost complete, except for a thermal vacuum test. The final AIV for the MMO was completed in March 2015, the MMO flight model was transported to ESTEC in April 2015, and all follow-up tasks were completed. The electrical interface test between the combined MPO and MMO was completed in February 2017. The MMO is waiting for the MCS AIV, which will begin in April 2017. Due to a problem with MTM's power processing units in September 2016, the launch window for BepiColombo has slipped from April 2018 to October 2018. It will be launched by an Ariane-5 rocket and arrive at Mercury in 2025.

Five peer-reviewed papers related to the BepiColombo project have been published. Preparation for the October 2018 launch is ongoing.

MMO sunshield integration at ESTEC. ©ESA / JAXA

k. Geospace Exploration with ARASE

The geospace explorer ARASE (formerly ERG) was developed as the second small science satellite. The purpose of the ERG project is to address when, where, and how high-energy electrons (over 1 MeV) in the Earth’s Van Allen Radiation Belts are generated and lost. Understanding the dynamic variation of the geospace is one of the most important issues in our solar system space environment. The project challenges scientific mysteries of the radiation belts with nine advanced onboard science instruments. The ARASE satellite was successfully launched by the second Epsilon launch rocket on December 20, 2016, and it is currently under the regular mission operation phase. The satellite system and all the onboard mission instruments are in good condition, and ARASE is providing us with data from comprehensive observation of the radiation belts.



ARASE satellite in the Earth's radiation belts.

Assembly-integration testing was completed in September 2016, and the post-qualification review (PQR), which includes the review of preparations and the operation plan, was also completed. After successful launch of ARASE, critical and initial operations were conducted for about 3 months. Regular mission operations started on March 24, 2017.

Prior to the PQR, JAXA carried out a comprehensive satellite loss prevention inspection based on lessons learned after the ASTRO-H anomaly. We responded to all 28 recommendations from the inspection team, which addressed comprehensiveness of test coverage, verification of installed software, quality assurance, and preparations for satellite operation, and it thereby improved operation-related preparations.

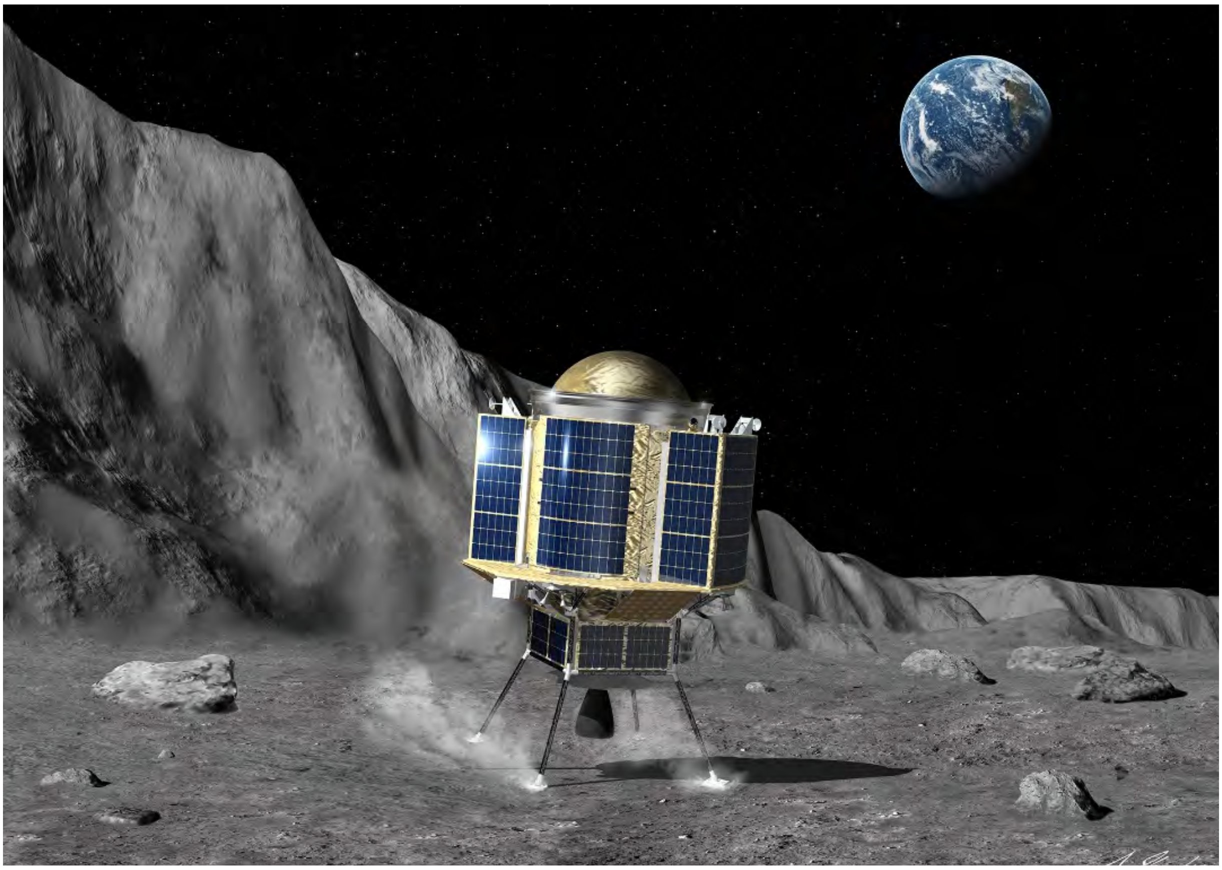
For preparing the launch operation, the ARASE tracking control unit was organized with participation from other departments of JAXA, and pre-training and rehearsals, particularly for off-normal events, were conducted.

ARASE's observations will elucidate the energy exchange process of plasma waves and particles and the mechanism of dynamic variation of the radiation belts. ARASE is expected to contribute to improvements in the accuracy of space weather forecasting.

The low-energy electron sensor was provided by ASIAA, Taiwan. A white paper for the observation strategy has been prepared jointly by ARASE and NASA's Van Allen Probes project teams. (The two Van Allen Probes are concurrently exploring the radiation belt.) Based on these interactions, it has become clear that developing joint research activities between the ARASE and NASA teams will greatly enhance the scientific output of the project.

ARASE satellite before launch.

I. The Smart Lander for Investigating Moon (SLIM)



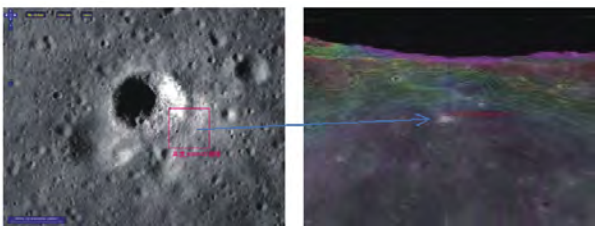
Artist's impression of the SLIM landing on the Moon.

The Smart Lander for Investigating Moon (SLIM) mission, which was authorized by JAXA along with the formation of the project team in April 2016, will demonstrate precise "pinpoint" landing technology on the lunar surface as well as several technologies for developing small, lightweight exploration spacecraft. During FY2016, the project team focused primarily on the baseline of the spacecraft configuration and the technical feasibility of the mission. Technical studies on details of development and the creation of a verification test plan were also carried out.

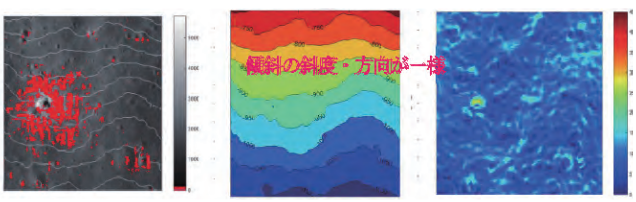
Suitable target landing positions were also discussed, and the front side of the moon was surveyed from the viewpoints of scientific benefit, landing safety and suitability for a pinpoint landing demonstration. Then, the identified candidates and their trade-offs were thoroughly investigated.

Conducting an accurate and safe landing on the target is an essential objective for the SLIM project, along with the scientific observations to be conducted after landing. Thus, the guidance, navigation, and control schemes required for such pinpoint landings were and are being studied intensely, with special attention being paid to the category of robustness. Since landing radar performance on the moon is an extremely important factor, a precise numerical simulator for the landing radar was developed and is already contributing to these studies.

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

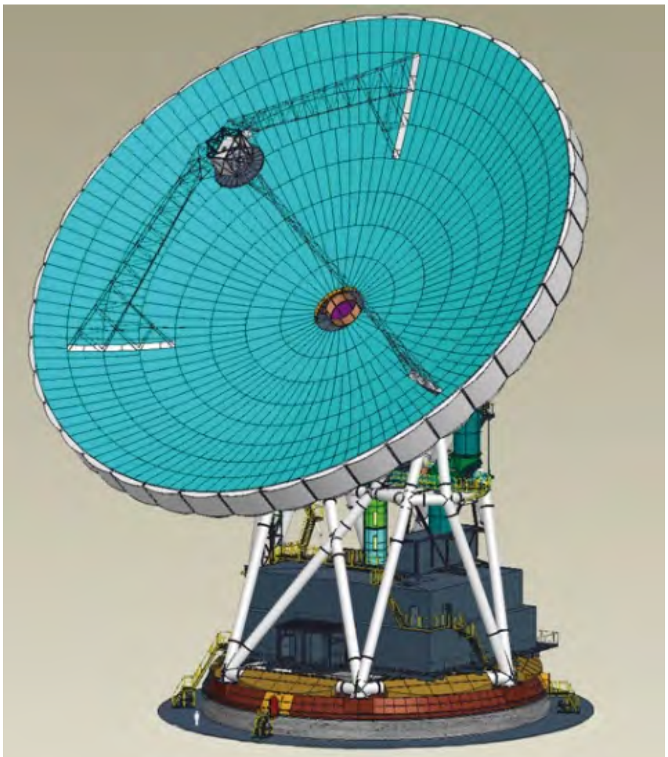


View of sample landing point candidates.



Topographical appearance of sample landing point candidates.

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



Conceptual drawing of the GREAT antenna (courtesy of Mitsubishi Electric).

This project aims at developing a new ground station employing an antenna with a diameter of 54 m to follow our aged 64-m antenna at the Usuda Deep Space Center (UDSC). Despite its smaller dimensions, the new antenna will be capable of obtaining more data from spacecraft in our future deep space activities. The new station will start its career by supporting Hayabusa2 and eventually BepiColombo.

To stay on schedule for completion by the end of FY2019, a preliminary design of the overall station system was reviewed and approved, allowing the detailed design process to begin. The important subsystems, such as antenna, transceiver equipment, and low-noise amplifiers, were independently covered in detail. Meanwhile, at the new station site, which is in a mountainous area about 1.3 km away from UDSC, we also conducted geological survey boring, followed by land development. Construction of the antenna foundation will start in FY2017.

The new station will play an important role in international cooperation with NASA and ESA in deep space activities. Its geological position is advantageous because of a lack of competing stations in East Asia and its ability to combine with NASA and ESA stations to form a very long baseline for deep space navigation. The new stations is also significant to conduct JAXA's future missions and to maintain the international leadership of ISAS/JAXA in exploration of the solar system. It also will provide opportunities to take part in highly advanced overseas missions by participating in an international deep space network. In particular, its newly added Ka-band reception function is expected to enhance international collaboration.

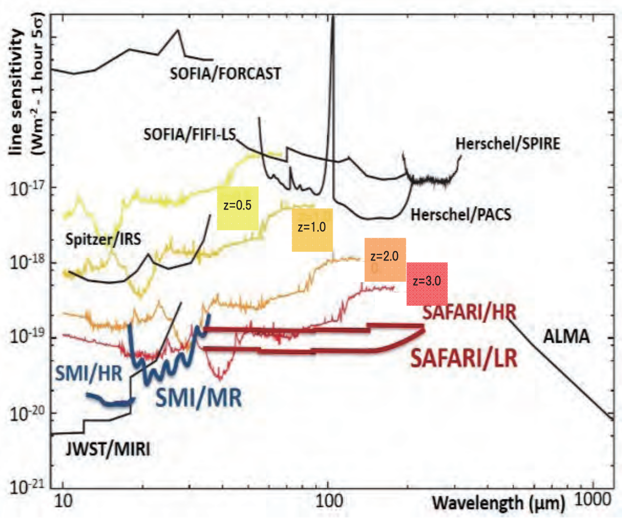
Position of GREAT with respect to the world's deep space network.

Development of the GREAT site (left); the existing 64-m antenna can be seen at the upper right corner (courtesy of Takehana-Gumi)

n. Next-generation Infrared Space Telescope for Cosmology and Astrophysics: SPICA

The Space Infrared Telescope for Cosmology and Astrophysics (SPICA) is the next-generation infrared astronomy mission satellite, which is expected to reveal the star-formation history of the universe and the formation and evolution processes of planetary systems. SPICA is being implemented with a cryogenically cooled (<8 K) 2.5-m telescope. 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 stellar evolution studies.

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

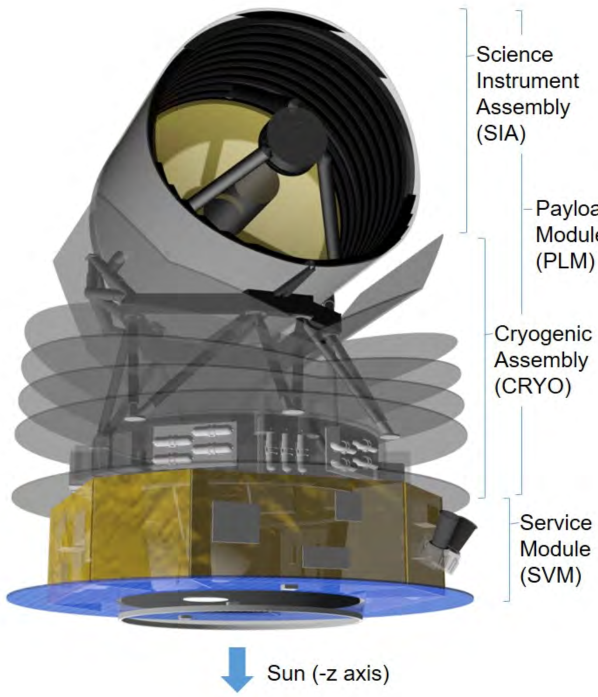


Sensitivity of SPICA instruments (SAFARI and SMI) compared with those of other missions.

In Japan, the SPICA project passed a mission definition review in FY2015 and an ISAS management review in FY2016. The Phase A activity, which focuses on the PLM and SMI designs, started in 2016. The demonstration of the cryogenic chain cooler from room temperature down to 50 mK has started under an international collaboration framework called the Cryo-Chain Core-Technology Program (CC-CTP).

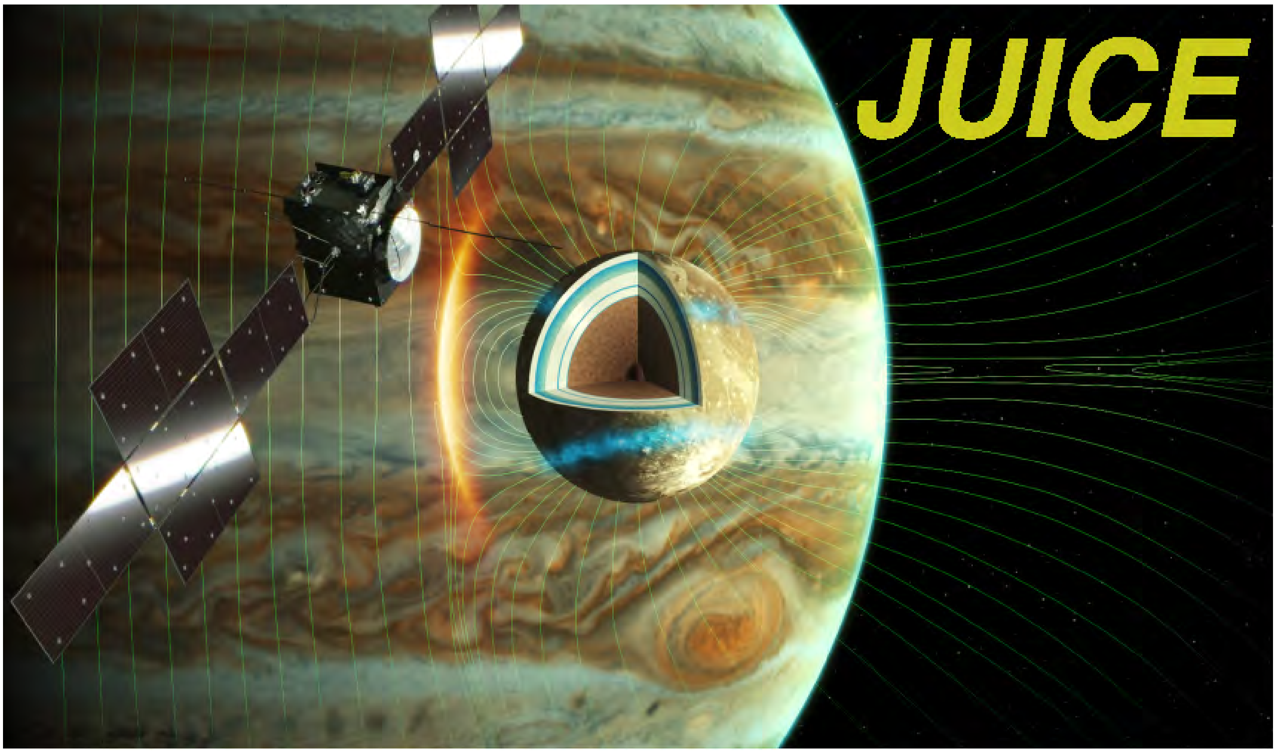
The proposal for Japan's participation in the SPICA mission was submitted to ESA in October 2016 as a candidate for the 5th M-class mission (M5) of the ESA Cosmic Vision. Proposal preparation was carried out by an international consortium led by SRON, with a large contribution from Japan. The results of the Phase A activity in Japan, the PLM and SMI conceptual designs, were incorporated into the proposal. ESA will announce the first selection of M5 candidates in 2017.

SPICA is expected to play another 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.

o. Jupiter Icy Moons Explorer (JUICE)



In 2032, JUICE will visit Ganymede, where high-energy particles in the Jupiter magnetosphere blow against Ganymede's magnetosphere.

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 pre-project after passing an ISAS project preparation review in August 2016. JUICE-Japan also passed ISAS system definition review (SDR) in November 2016. The instrument team developed bread board models (BBMs) of all key elements of their hardware and tested the BBMs without large delay. Preliminary design review (PDR) is scheduled for FY2017, and critical design review (CDR) is scheduled for FY2018. JUICE is a long-term mission that will continue for about 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), Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR, Germany: GALA), Swedish National Space Board (SNSB: 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).

p. Initial Development of Martian Moons Exploration (MMX) Mission

Fig. 1 One possible MMX spacecraft configuration with a launch mass of 3,400 kg. It has three main modules for sample return, exploration, and propulsion. Nominal mission duration is 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 to be launched in the early 2020s. The mission is to survey the Martian moons and return samples from one of them. The goal of the mission is to reveal the origin of the Martian moons and advance our understanding of planetary system formation and of primordial material transport around the boundary between the inner and outer parts of the early solar system.

Based on the mission definition, conceptual designs of the spacecraft system were developed, and the technical feasibility of the overall spacecraft system was confirmed. In addition, specifications were developed, including interface specifications between spacecraft and mission instruments—sampler system, sample return capsule, neutron and gamma-ray spectrometer, wide-angle multiband camera, near-infrared spectrometer, telescope camera, laser altimeter, dust monitor, and mass spectrum analyzer. A trade-off study was carried out among a wide range of system configurations, such as propulsion and spacecraft staging. Figure 1 shows an example of the spacecraft configuration used in our preliminary study.

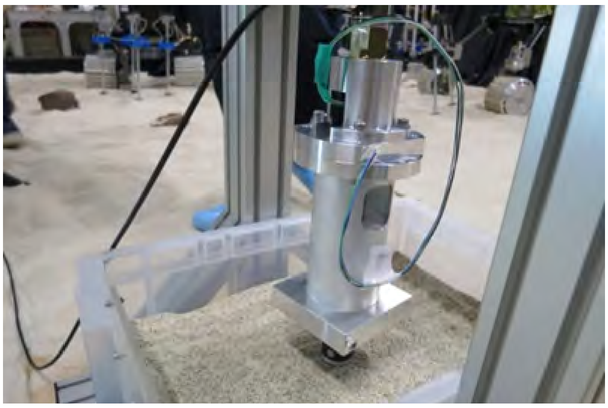


Fig. 2 Testing of BBM of the regolith sampling device using a simulated Martian moon surface.

Critical technologies have been identified from the viewpoints of mission feasibility and technology readiness level. Detailed development plans were prepared for these technologies starting from the early development phase. The critical technologies include guidance/navigation/control in proximity operation (including descent, landing, and lift-off), chemical propulsion system for Mars orbit insertion and Mars orbit escape, propulsion module separation mechanism, landing system/gear, sampling mechanism, sample return capsule, and scientific instruments. Prototyping and evaluation of elemental technologies were conducted, particularly for highly novel systems, such as the sampling device (Fig. 2), landing system, and sample return capsule.

International collaboration is frequently discussed to realize a "world best" line-up of scientific instruments on MMX. As a result, NASA and Centre National D'études Spatiales (CNES, France) have agreed to provide onboard equipment (a neutron/gamma ray spectrometer from NASA and a near-infrared spectrometer from CNES). Some optional mission instruments are under discussion (e.g., a small surface science package) with our international partners.

We will continue to steadily work toward realization of the project with international cooperation (NASA, CNES, and possibly other agencies).

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

LiteBIRD is a strategic large-class mission that aims to verify the 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) that primordial gravitational waves produced in the cosmic microwave background radiation. During observations, any B-mode polarization caused by sources other than primordial gravitational waves needs to be carefully eliminated. For this purpose, LiteBIRD will cover about 40–400 GHz, which will be divided into 15 bands with low-frequency and high-frequency telescopes. We plan to reduce the 1/f noise by using a polarization modulator with a rotating half-wave plate at about 1 Hz. We plan to use transition edge sensor (TES) bolometers combined with Si lenslets as detectors, which will be read with superconducting quantum interference devices. The low- and high-frequency telescopes, including detectors and optical systems, will be actively cooled to 0.1–4 K.

In response to a recommendation from the Advisory Committee for Space Science in FY2015, international science review was conducted in May 2016 and planning review in August 2016, which led to Phase A1 starting in September 2016. The polarization modulator was developed intensively in FY2016, and used a moth-eye structure fabricated on a sapphire plate in order to satisfy the requirements of high transmissivity (>90%) and high modulation efficiency (>98%) in a wide wavelength range. Furthermore, the heat generated by the superconducting bearing and driving system were measured with a scale model, which showed the temperature of the half-wave plate can be kept under 10 K by periodically releasing heat using the holding mechanism. Based on these results, a conceptual design of the mission instrument and satellite bus system is expected to be delivered in FY2017.

LiteBIRD will be implemented based on international collaboration with the USA and Canada. Various institutes and universities are included from Japan, such as KEK (High Energy Accelerator Research Institute), the Kavli IPMU (Institute for the Physics and Mathematics of the Universe), the National Astronomical Observatory of Japan, and Okayama University.

Artist's impression of LiteBIRD

r. Solar Power Sail-craft

Deployment test of structural model of the solar power sail and IKAROS sail (broadcasted on the Internet).

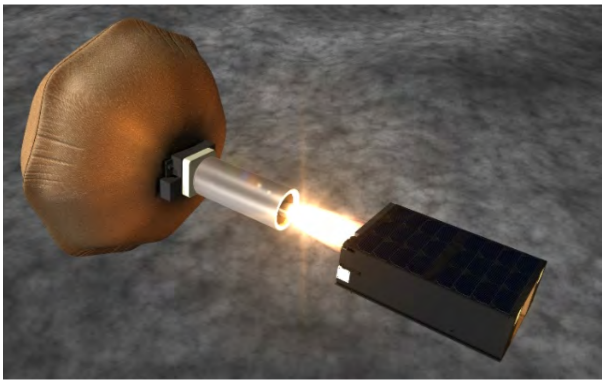
As a strategic large mission, the solar power sail-craft aims to demonstrate exploration of the outer solar system with a solar power sail spacecraft and maintain Japan's leadership in solar system exploration, focusing on following items: (1) Demonstration of navigation technology by a solar power sail and transport payloads necessary for landing on an asteroid and making a round trip to the outer planetary region. (2) Demonstration of exploration technology by rendezvousing with a Jupiter Trojan asteroid and deploying a lander to collect samples from both the surface and subsurface to perform in-situ analysis; sample return is also considered. (3) Scientific observation using multiple deep space instruments while in both the cruising and Trojan asteroid observation environments.

After ISAS project planning review, the sail-craft team transitioned the project from Pre-Phase A to Phase A1. The following studies were conducted in FY2016:

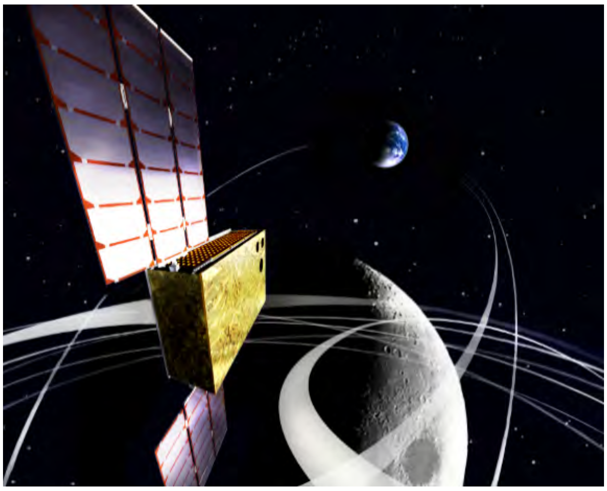
- System study. A system solution for a one-way mission was obtained.
- Solar power sail. Deployment tests using a structural model were conducted, and its accuracy was evaluated.
- Deployment structure. Sail storage and partial deployment tests using the structural model were conducted. A detailed design and weight reduction were achieved.
- Communication system. We prepared to invite NASA engineers to study our new communication systems.
- Ion engine system (IES). We started building a Bread Board Model (BBM) for development of the IES power processing unit. Endurance tests of the Engineering Model of the neutralizer are still underway.
- Observation equipment. BBMs for the surface sampler, subsurface sampler, and gas projector were made and the group formulated a strategy to realize sample collection.
- Science. For understanding solar system formation, this mission and NASA's Lucy are complimentary with each other, so maximizing cooperation is a mission objective.
- International cooperation. We jointly studied the lander with DLR (Germany). Further international cooperation for observation equipment on both the mother spacecraft and lander was proposed.

In FY2016, 4 peer-reviewed papers were published, for a cumulative total of 110 peer-reviewed papers. "Space Technology Demonstration Program for Space Exploration Missions," which includes our mission, was selected in the Japanese master plan of large research projects for FY2017. The "4th International Symposium on Solar Sailing" and International symposium "Jupiter Trojan 2016" were held.

s. SLS CubeSats: OMOTENASHI and EQUULEUS



Computer simulation of OMOTENASHI deceleration maneuver with a solid-fuel motor.



Artist's concept of EQUULEUS observation from L2.

Outstanding MOon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor (OMOTENASHI) and EQUilibriUm Lunar-Earth point 6U Spacecraft (EQUULEUS) are 6U size, 14-kg CubeSats that will be launched by NASA's Space Launch System (SLS) rocket in 2019.

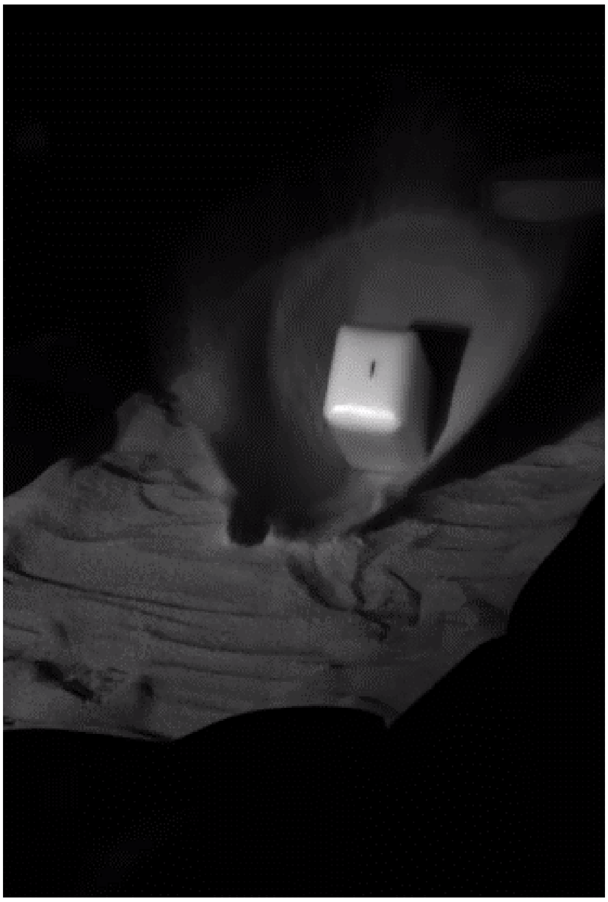
OMOTENASHI demonstrates technologies for the world's smallest moon lander and observes the radiation environment with portable dose meters. To realize moon landing by a CubeSat, a semi-hard landing scheme has been developed. The landing speed is controlled to around 30 m/s using a small solid rocket 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 Lagrangian point L2. The other, scientific missions are to observe Earth's plasmasphere, lunar impact flashes, and the lunar dust environment. For both spacecraft, an ultra-light-weight communication system is being developed.

Some impact tests for OMOTENASHI shock absorption system were conducted at the JAXA Kakuda Space Center and Japan Automobile Research Institute. The results showed that the shock acceleration to instruments on board OMOTENASHI is smaller than 3,000 G if the impact velocity is less than 30 m/s. An engineering model of a small solid-fuel rocket motor and other instruments for OMOTENASHI were also developed. Some firing tests of the solid-fuel motor were conducted.

For EQUULEUS, detailed design was completed and development, integration, and environmental testing for the engineering model of EQUULEUS were started at the University of Tokyo. The test results will be integrated into the flight model development.

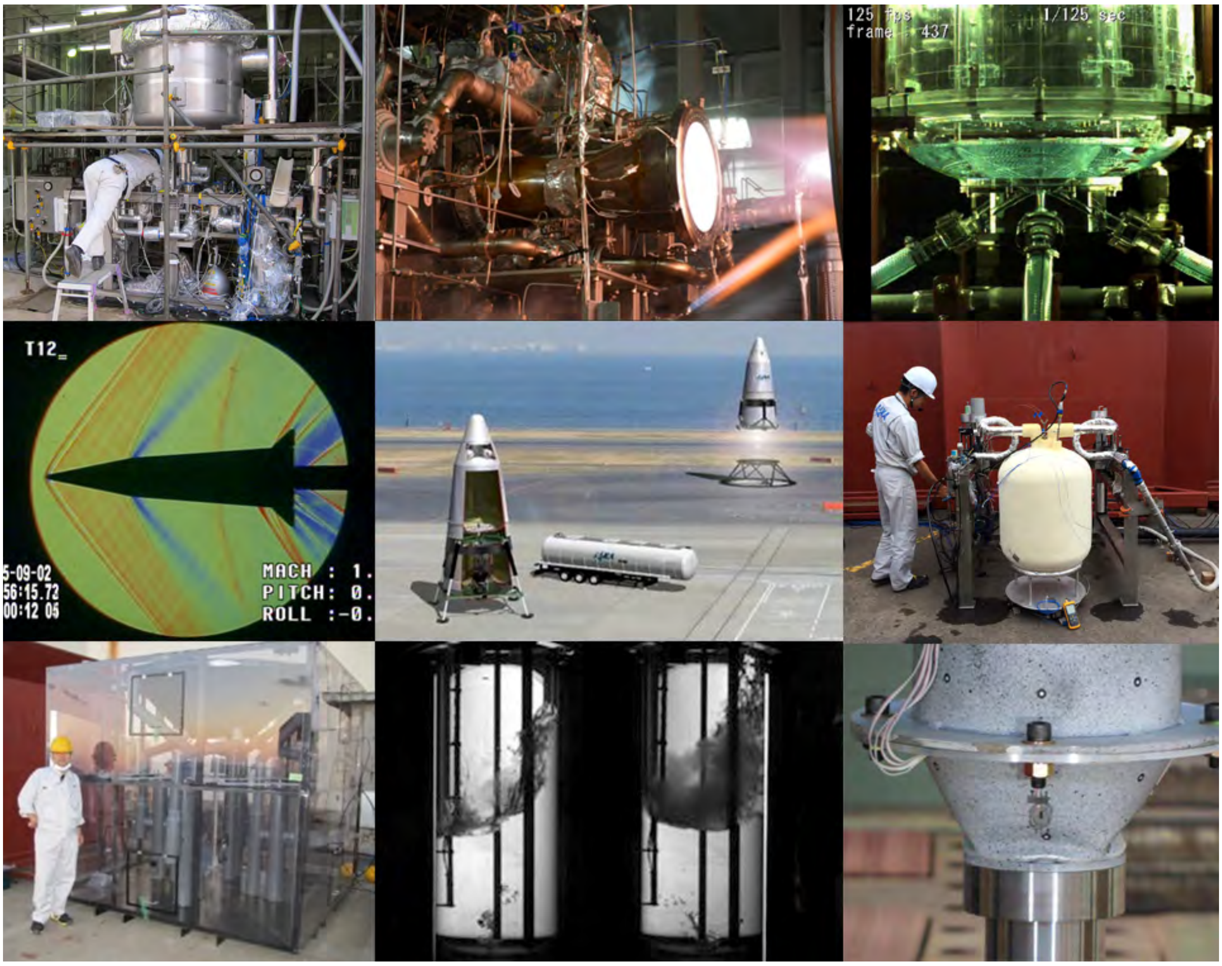
Small, light-weight, and low-cost technologies developed for both spacecraft will contribute to future space science and human exploration. They promote the participation of universities, industries, and even individuals in space exploration.



Impact testing of the OMOTENASHI shock absorption system.

3. Others

a. Reusable Sounding Rocket Technical Demonstration Project



Technical demonstrations during development of a reusable sounding rocket.

To make access to space for scientific research much easier and increase opportunities for access to rocket launches, we have proposed a fully reusable sounding rocket. Its mission definitions are (1) achieving 100 km in altitude and returning to the launch site, (2) carrying a 100-kg payload, (3) flying more than 10 times per year, (4) achieving a minimum flight duration of 1 day, and (5) operating at a cost an order of magnitude lower than that of the existing ISAS sounding rocket. A reusable sounding rocket is different from the presently used expendable rockets by being capable of repeated operations, return flights, re-ignition of the engine, vertical landing, and fault tolerance with adequate system health management. Some key technologies related to these characteristics have matured sufficiently to advance the reusable sounding rocket project to Phase A.

From 2010 to 2016, the following reusable vehicle technologies were verified: reusable engine development and repeated operation, reusable insulation development for the cryogenic tank, aerodynamic design and model flight demonstration for the return flight, cryogenic liquid propellant management demonstration, landing gear development, and health management system construction. Thus, the subsystems required for a reusable sounding rocket were prepared for integration into a launch system.

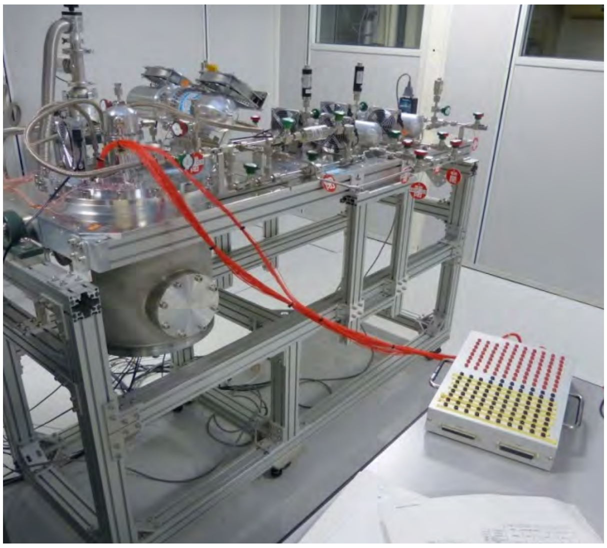
After these technical demonstrations, a study for system-level verifications by a small flight demonstrator proceeded in FY2016 as the next step. Objectives of the demonstration are (1) system architecture study for repeated flight operation, including quick-turnaround operation and fault-tolerant design; (2) life-cycle management and frequent repeated use of a cryogenic propulsion system and its flight demonstration; (3) development of advanced return flight method and vertical landing and its flight demonstration; 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 high-performance engine with long service life. Two papers were published in FY2016, for a cumulative total of five papers.

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

The CC-CTP is an international project aiming to demonstrate 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 Atomic Energy Commission (CEA) leading the effort.

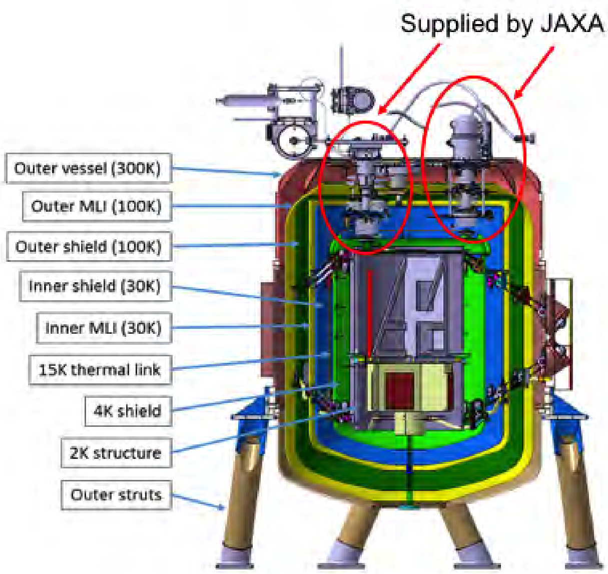
CC-CTP will make three cryostats, and JAXA is expected to supply coolers for Cryostat #1, a concept study model, and Cryostat #3, which will be used on ATHENA. In 2016, discussions with CEA and CNES were held, and thermal and mechanical interface were adjusted and drivers and monitors were prepared. After transferring design data and a mock-up, JAXA delivered a 4-K Joule-Thomson (JT) cooler with a two-stage Stirling precooler, a 2-K JT cooler, and support equipment in March 2017. They will be incorporated into Cryostat #1 by CEA after component-level post-shipment testing. The 2-K JT will be combined with a European pulse tube cooler as a precooler. Such a combination of Japanese and European spacecraft cooling technology is the first trial. They will work with sub-Kelvin coolers developed for SPICA and ATHENA.

This cooling system is intended to support the ATHENA X-ray Integral Field Unit (X-IFU) concept. Cryostat #3 will be installed in an X-ray sensor and tested as an X-IFU demonstration model in the Phase A study. This cooling system will be also useable on other missions requiring low-temperature detectors, such as SPICA and LiteBIRD. Thus, the JAXA CC-CTP team is drawn from ISAS members studying ATHENA, LiteBIRD, and SPICA, as well as the cryo-thermal group in the Research and Development Directorate.



Post-shipment testing at CEA, Grenoble, in March 2017.

2-K JT and ground support equipment (GSE) arriving at CEA, Grenoble, on March 21, 2017.



Current design of Cryostat #3.

c. Development of 20-kW-Class X-band SSPA for the Satellite Tracking Station

A new solid state power amplifier (SSPA) transmitter is under development for GREAT, the next-generation deep space exploration ground station. A GaN high-electron-mobility transistor (HEMT) device was utilized to realize a powerful X-band high-power amplifier. A limited number of GaN-HEMT devices have been developed for general-purpose space communication, but a device with the 7,145- to 7,235-MHz frequency range that is required for deep space telecommunication is not a commercial off-the-shelf product. Thus, existing commercial GaN-HEMT devices were customized to correspond to the X-band, and the prototypes were evaluated. As a result, GaN-HEMT devices with high power and efficiency were successfully prototyped with 125-W power amplifiers.

To realize total output of 20 kW, 384 amplifier modules will be combined in multiple stages. A radial power combining method was adopted, and the resulting combiner consists of a x48 combiner, x4 combiner, and x2 combiner as the final stage. The manufacture of the power combiner and the experimental evaluation of the unit was completed at the end of FY2016.

The GaN-HEMT device has a characteristic that the additive white Gaussian noise level of the whole band increases as compared with a klystron. Since this affects the X- and Ka-band receiving systems, a broadband and high attenuation waveguide filter was installed into the output circuits of the SSPA system to decrease the noise level. The filter was numerically simulated to confirm the feasibility.

The SSPA system requires comprehensive evaluation, so all the prototypes will be assembled by the second quarter of FY2017. If the new transmitter passes the evaluation, it will replace the klystron amplifier in GREAT. In addition, the SSPA can be applied to other stations in the future.

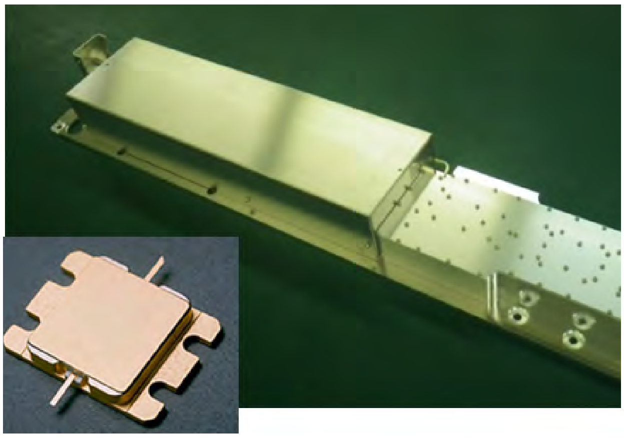


Fig. 1 Overview of GaN power amplifier

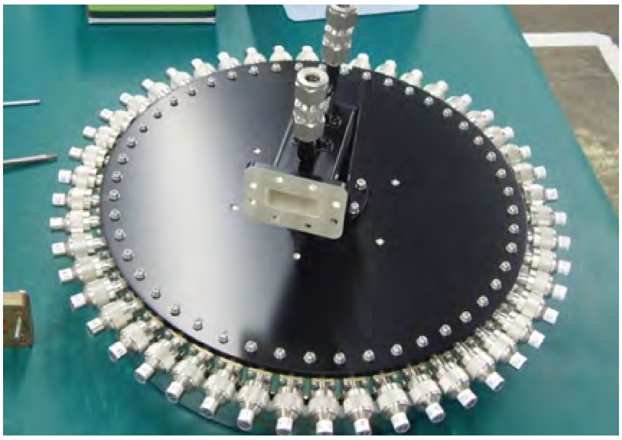


Fig. 2 Overview of 48 combiner

Fig. 3 15.8-kW output power test.

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 FY2016, we studied data from the X-ray missions SUZAKU and ASTRO-H. We also studied data from the AKARI infrared satellite. For the future missions, comprehensive development and studies were made for the LiteBIRD and SPICA missions, and members of the department contributed significantly. In September 2016, LiteBIRD started Phase A1 activity, which will last for 24 months. For SPICA, the proposal for ESA Cosmic Vision M5 has been developed and successfully submitted in collaboration with the European SPICA team. The department also worked on future technology development, including the development of 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 technology, 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) were also widely conducted.

2. Research Activities in FY2016

2.1. High-energy and Fundamental Astrophysics

As for observational research in the X- and gamma-ray regions, the department conducted research using satellites, including SUZAKU and ASTRO-H. The department investigated phenomena of various types of celestial bodies emitting X-rays, such as massive stars, cataclysmic variable stars, white dwarfs, neutron stars, pulsar wind nebulae, supernova remnants, our galactic center, active galactic nuclei, and galaxy clusters. In addition, the department studied a broad range of astrophysical phenomena, such as X-ray background radiation, which is radiation from many unresolved celestial bodies, and dark matter using that radiation. When analyzing data from these observations, it is essential to compare the data with theoretical models. The department developed new analysis methods, such as a Monte Carlo simulation tool.

On the other hand, development of technology for future missions to achieve more sensitive observations was done in various fields. Specifically, the department advanced the development of X- and gamma-ray detectors in various fields for low background, improved energy and position resolution, and large format, to improve the sensitivity. Among them, application of the Compton camera to consumer goods was promoted, such as for visualization of radioactivity in decontamination work in Fukushima.

The department also studied future missions. ATHENA is a large international X-ray observatory being developed by ESA, and it has been adopted as a Lagrangian point L2 mission by ESA's Cosmic Vision program, aiming for launch in 2028. The Japanese team plans to be in charge of a part of the cooling system (mechanical coolers) of the main mission instrument, X-IFU. The cooling system requires a long-lived, space-qualified cooler with no refrigerant. Thus, we have begun developmental research on the CC-CTP within the framework of the ESA Core Technology Program with the goal of demonstrating cryo-cooling from room temperature down to 50 mK. Two sets of JT coolers were manufactured and incorporation testing has started in France. This is a cross-mission technology development that is also needed for SPICA and LiteBIRD. To further lengthen the service life and reduce operational vibrations, a double-stage Stirling cooler has been under improvement.

The department also worked on developing the LiteBIRD mission, which will be a satellite that performs an all-sky cosmic microwave background polarization survey to detect the B-mode signal, which originated from the primordial gravitational waves emitted during the cosmic inflation era. ISAS Phase A1 activity started in September 2016.

2.2. Infrared Astrophysics

In the field of infrared astrophysics, various types of research activities were carried out using data from astronomical satellites (e.g., AKARI), rocket-borne instruments, and ground instruments. These activities can be grouped into four broad areas.

The first area is the study of infrared background radiation to explore the early universe. The Cosmic Infrared Background ExpeRiment (CIBER) is a series of sounding rocket experiments to explore the first generation of stars in the very early universe. A summary paper on the extragalactic background radiation observed with CIBER was published in 2016. This paper clearly showed the existence of excess radiation components that cannot be explained by the ensemble of known sources.

The second area is the study of galaxy evolution. On the basis of the data from the Hubble Space

Telescope(HST) and the Subaru Telescope, a series of studies of primordial galaxies in high-redshift clusters have been carried out. The AKARI all-sky data enabled us to study the effect of environments on the star-formation activity in each galaxy. A possible increase of the dust temperature in high-density regions was found, as well as a dependence of star-formation activity on types of ultra-luminous infrared galaxies. Using date taken by the Hyper Suprime-Cam (HSC) on the Subaru Telescope, it was shown that dust-obscured galaxies traced the regions with high-density dark matter.

The third area is the study of star and planetary formation processes with data from AKARI and ground-based instruments. The survey of circular polarizations using the ground-based Infrared Survey Facility telescope (South Africa) was extended, and the observations revealed the ubiquity of circular polarization in star-forming regions and suggested a special geometry to produce this phenomenon. A possible link between the homochirality seen in amino acids on Earth and the observed circular polarization was suggested. Using the AKARI all-sky data, we explored the dissipation timescale of protoplanetary disks and debris disks. We explored planets around Epsilon Eridani with the Subaru Telescope. We also checked the validity of the evolution model of low-mass stars using the mass determined from astrometry data.

The fourth category involves the study of our own solar system. Using data from the Cosmic Background Explorer (COBE), we revised the dependence of the zodiacal light on the solar-elongation angle. We also modeled the scattered and thermal spectrum from interstellar dust and showed the existence of dust particles larger than those proposed previously. We also studied ultraviolet to optical data for the sky from the HST and concluded that C-type asteroids are significant contributors to interplanetary dust formation.

The department also promoted activities to enhance the value of AKARI data. Examples include the extension of the wavelength coverage of the AKARI near-infrared data with careful analysis the effect of 2nd-order light and the improvement of the photometry of extended sources in the far-infrared all-sky data.

To enable the next generation of observation instruments, the department carried out the development of new technology for infrared observations. One notable example is the development of immersion gratings for high-resolution spectroscopy at mid-infrared wavelengths. We successfully demonstrated that CdZnTe is the right material for a mid-infrared immersion grating with very low absorption coefficient. We also continued the development of the blocked impurity band type Ge detectors for far-infrared observations. Cryogenics is another key issue for the infrared astronomy, and we participated in CC-CTP development. The final example is the development of the CIBER-2 instrument, which is a successor of the highly successful CIBER instrument. We built and tested a Bread Board Model for the telescope and used it to check the validity of the current design and identify key issues for the flight model.

In the optical and near-infrared regions, we promoted a general activity to enable Japanese participation to the NASA Wide-Field Infrared Survey Telescope (WFIRST) project, which is a NASA core mission second only to the JWST. Focusing the cosmological and exoplanet studies, we promoted the science activity as well as hardware development of the polarization instrument in the high-contrast instrument and the study of possible collaboration between WFIRST and the Subaru Telescope.

2.3. Radio astronomy

In the radio wavelength range, we performed a wide variety of observational research using domestic and foreign radio telescopes, such as the ALMA in Chile and the Very Long Baseline Array (VLBA) in the USA. We also advanced cooperative observation by using the 64-m antenna at Usuda in the VLBI observation network in Japan. One observation target is compact celestial bodies, such as active galactic nuclei, galactic centers, and celestial bodies emitting maser radiation.

In FY2016, we used ALMA to reveal the detailed dynamical structures of the “mini-spiral,” which is the ionized gas around the supermassive black hole at the core of the Milky Way. We also conducted VLIBI observations for narrow-line Seyfert-I galaxies. In addition, research on the formation of stars and the development of inter-stellar matter was conducted through the single-dish observation of a molecular cloud and HI cloud using the 45-m telescope at Nobeyama and the 64-m antenna at Usuda.

The department also developed experimental devices for the balloon VLBI and low-noise millimeter wave receiver. Furthermore, we are participating in technological discussions about the ground antenna system for deep space exploration in the context of utilizing our radio astronomy technology.

2.4. Theoretical research

The department presented an alternative method for a comprehensive understanding of shape resonances in reactive collisions. The shape resonance is an important quantum mechanical phenomenon in atomic and nuclear collision processes. The shape resonances in a certain reactive system can be arranged systematically according to a universal measure of the difference between the collision energy and the top of a potential barrier. By applying Wentzel-Krammers-Brillouin approximation as a basis, the resonance peak heights and widths were proved to be given by very simple universal formulas.

More than 10 years ago, the department proposed a three-center Coulombic over-barrier model to describe the sequential multiple electron removal from a rare gas dimer in collisions of a slow (kinetic energy of keV per nucleon) but highly charged ion. Quite recently, this model was modified to incorporate the screening effect in the projectile and in the non-active atomic site of the dimer. In the present work, the model was applied to calculate the formation cross-sections of respective ion pairs produced with the Coulomb explosion of the target dimer just after the collision. Furthermore, the department examined stereo-dynamical effects, namely the dependence on the angle between the projectile beam and the dimer axis in the laboratory. It was found that the screening effect is strong in parallel orientations but negligible in orthogonal orientations.

3. Research Topics

The following outline lists all the Department of Space Astronomy and Astrophysics research activities during FY2016.

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 Construction of model for X-ray radiation from cataclysmic variable star with strong magnetic field and its application to observation data from SUZAKU for determining mass of white dwarf
3.1.1.3 Constraints on mass radius of neutron star using X-ray burst from GRS1747-312
3.1.1.4 Constraints on radius of neutron star using gravitational redshift of Ser X-1
3.1.1.5 Study of supernova remnant CTB1 based on observations by SUZAKU
3.1.1.6 Study of accretion-disk winds and heating mechanisms of low-mass X-ray binaries
3.1.1.7 Spectral analysis using Compton shoulder
3.1.1.8 Study of super-high-velocity outflow from active galactic nucleus
3.1.1.9 Development of MONACO simulator for astrophysical radiation
3.1.1.10 Rocket experiment for hard X-ray emission from Sun
3.1.1.11 X-ray observational study of galaxies, galaxy clusters, and superclusters
3.1.1.12 Studies in high-energy gamma-ray astronomy with Fermilab (USA)
3.1.1.13 Observational study for soft X-ray background radiation
3.1.1.14 Study to search for “dark-matter feature” in cosmic X-ray background radiation with SUZAKU
3.1.1.15 Study of hot gas plasma in clusters of galaxies by using morphology of gas distribution of clusters in collision
3.1.1.16 X-ray observations of galaxies and clusters
3.1.2 Developmental research for observational technology
3.1.2.1 Development of X-ray CCD camera with greatly reduced charged particle background
3.1.2.2 Development of TES X-ray microcalorimeter for future space missions or ground applications
3.1.2.3 Development of new X-ray microcalorimeter by a new method
3.1.2.4 Development of Compton camera for high-sensitivity gamma-ray observations
3.1.2.5 Study of cooling system for X-IFU subsystem in European X-ray observatory ATHENA
3.2 Research in the infrared wavelength range
3.2.1 Observational research
3.2.1.1 Study of cosmic infrared background using rocket-borne instruments
3.2.1.2 Study of near-infrared background radiation using data from Diffuse Infrared Background Experiment (NASA)
3.2.1.3 Scattered light and thermal radiation by interstellar dust at near-infrared wavelengths
3.2.1.4 Study of UV-optical background radiation using HST data
3.2.1.5 Galaxy evolution in active era of universe revealed by multi-wavelength observation in North Ecliptic Pole region
3.2.1.6 Spatial structure around active galactic nuclei using AKARI spectroscopy
3.2.1.7 Molecular gas and environment effects in starburst galaxies
3.2.1.8 Study of environmental effects in star-forming galaxies by AKARI far-infrared observations
3.2.1.9 Star formation and active galactic nuclei as seen by AKARI
3.2.1.10 Study of protocluster at z=3.09 in SSA22 field by HST and SUBARU Telescope
3.2.1.11 Study of passive galaxies in early universe with Spitzer
3.2.1.12 Study of star-forming galaxies at z=4 with SUBARU, HST, and Spitzer
3.2.1.13 AKARI observations of nearby spiral galaxies
3.2.1.14 Study of dusty star-forming galaxies by SUBARU Telescope HSC
3.2.1.15 Star formation embedded in dust clouds using AKARI spectroscopy
3.2.1.16 Structure of zodiacal emission from AKARI all-sky maps
3.2.1.17 Observational study of episodic mass loss from red-giant stars
3.2.1.18 Study of TW Hydrae by high-resolution radio observations
3.2.1.19 Mass-loss process in red giants based on mid-infrared high-spatial observations
3.2.1.20 Study of dynamic evolution history of solar system dust by AKARI mid-infrared spectroscopy

3.2.1.21 Search for exoplanets of Epsilon Eridani by SUBARU Telescope coronagraph instrument
3.2.1.22 Evaluation of dynamical mass of late type M stars by astrometry and constraints on evolutionary models of low-mass objects
3.2.1.23 Observations to search for infrared circular polarization in star-forming regions
3.2.1.24 Study of dissipative process of protoplanetary disks and debris disks
3.2.1.25 Study of diffuse infrared radiation with Multipurpose InfraRed Imaging System (South Korea)
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 Demonstration of cryogenic deformable mirror for wavefront correction in space-borne telescopes
3.2.2.6 Cryogenic system for space missions
3.2.2.7 Development of the instruments of CIBER-2, future rocket experiment for cosmic infrared background
3.2.3 Promoting Japanese participation in the NASA WFIRST program

3.3 Research in the radio wave range
3.3.1 Observational research
3.3.1.1 Promotion of radio astronomy observation using JAXA's tracking antennas, including 64-m antenna at Usuda
3.3.1.2 Identification of gamma-ray radiation region through VLBI observation of radiowave jets
3.3.1.3 Observation of dust clouds falling into black hole at center of galaxy using VLBI observation network
3.3.1.4 Observation of formation of stars in molecular cloud at center of galaxy using large millimeter- and submillimeter-wave radio telescope, such as ALMA
3.3.2 Developmental research for observational technology
3.3.2.1 Study of scientific goals and observation systems for radio astronomy project, where, for example, low-frequency radio astronomy, submillimeter wave astronomy and space VLBI are expected to be used
3.3.2.2 Design and development of experimental craft for balloon VLBI flight
3.3.2.3 Technological study for GREAT, new ground antenna station for deep space exploration

3.4 Theoretical research
3.4.1 Theoretical research on formation of true muonium atoms
3.4.2 Theoretical research on multi-ionization process of dimer of inert gas caused by multivalent ion

b. Department of Solar System Sciences

1. Overview

Research activities by the members of the Department of Solar System Sciences cover planetary science and interplanetary space physics including planetary magnetospheres and the Sun. The underlying disciplines are 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 HINODE (solar physics), HISAKI (extreme ultraviolet spectroscopy for planetary science) and AKATSUKI (Venus atmospheric dynamics) are studied extensively, and samples brought back by HAYABUSA from the asteroid Itokawa have been analyzed. Missions being prepared, such as BepiColombo to Mercury and the Phobos sample return mission of the Martian Moons eXploration (MMX) project, are also handled by the members of the Department. In addition, we are also engaged in basic research for developing new onboard instruments for future missions and small-scale projects using sub-orbital opportunities.

2. Research activities in 2016

2.1 Solar Physics

HINODE, which has been in orbit for ten years, has made significant contributions to our understanding of observational solar plasma physics as well as fundamental problems such as coronal heating and flare triggering mechanisms. A typical example, which was published this year, is the new knowledge that gas convection and turbulence in the photosphere (the solar surface) is the ultimate origin of both coronal heating and the dynamic magnetic activity of the Sun. In this case, we developed a scheme to derive a three-dimensional (3D) structure (especially a vertical profile) of the gas dynamics. High-resolution data collected by HINODE enabled us to discern the flow dynamics within a convection cell from that at its boundary. Such high-resolution diagnostic capabilities enable comparisons with radiative magnetohydrodynamic (MHD) simulation modeling of a convection cell, from which validation of the numerical modeling, as well as the development of a new analysis method for wave excitation within a convection cell, are expected to emerge.

But what will be the shape of solar physics in the 2020’s? The solar studies scientific community must make renewed efforts to find answers to this question. The tools available now include new instrument developments via sounding rockets and balloon experiments, as well as space mission design activities aimed at the 2020’s. The Next Generation Solar Physics Mission (NGSPM) Science Objective Team (SOT) is an international body supported by the Japan Aerospace Exploration Agency (JAXA), the US National Aeronautics and Space Administration (NASA), and the European Space Agency (ESA) to discuss the space mission aspect.

Led by T. Shimizu from the Institute of Space and Astronautical Sciences (ISAS), the team has been holding discussions aimed at (1) listing the high-priority science projects that need to be performed for the next-generation solar physics, (2) listing the instruments required for those high-priority science items, and (3) developing ideas for the international decision-making framework necessary to create missions that will fly those instruments. Once complete, the results of those discussion will be placed on the table for the wider community to see. Currently, five of the highest priority instrument packages have been identified and their science rationale, as well as the recommendations for mission architectures that will fly the instruments are scheduled for publication as a report to JAXA/NASA/ESA by the summer of 2017.

Magnetic reconnection is one of the most fundamentally important process in space plasmas, and the solar corona is the best venue for performing X-ray imaging observations that will help us learn more about the physical process. Complementary metal-oxide-semiconductor (CMOS) detectors with fast read-outs 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 that shows very high performance.

As a follow-up to the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) mission, a sounding rocket experiment (which has been designated CLASP II) is being prepared. While the first CLASP mission succeeded in detecting polarization in Lyman alpha line, which is a signal of Hanle effect in the solar chromosphere, CLASP II is expected to detect polarization in the Mg line in order to obtain magnetic field information about the chromosphere. This mission is scheduled for launch in 2019.

2.2 Space Plasma Physics

The Magnetospheric Multiscale (MMS) mission is a NASA Heliophysics flagship project that performs 3D high-resolution formation flying observations of space plasma dynamics using four closely situated spacecraft. The objective of the MMS mission, which was launched on March 12, 2015 from the US Kennedy Space Center onboard an Atlas-V rocket, is to unveil the microphysics that drives magnetic reconnection, which is considered to be one of the most important processes in space plasma physics. Since magnetic reconnection occurs frequently on the surface of the boundary of the Earth’s magnetosphere, this is the region that MMS spacecraft formation visits in order to make unprecedented in situ observations. Members of the Fast Plasma Investigation (FPI) Department developed the onboard instruments, which include four dual electron spectrometers (DES) and four dual ion spectrometers (DIS) per spacecraft. The data obtained thus far has proven to be excellent, and is being made available to global research communities. A Magnetospheric Observation Satellite (GEOTAIL)-MMS collaboration is continuing, and the results obtained thus far have been published.

As mentioned above, magnetic reconnection is one of the most important processes in space plasmas, yet its triggering mechanism remains mostly unknown. Reconnection occurs when oppositely directed magnetic field lines face each other across a current sheet. Conventional wisdom states that reconnection is triggered when the current sheet thins sufficiently to become comparable to the scale of ion dynamics. In reality, this critical thickness is so small that, if this was true, it is hard for one to think of any way reconnection could be triggered in the solar corona at all.

The results obtained from our dedicated series of numerical experiments show the critical thickness can be by ~2 orders of magnitude larger when a temperature anisotropy (perpendicular temperature larger by more than a factor of 1.5 than the parallel one) is taken into account. This anisotropy emerges naturally when the current sheet is compressed and the required compression for magnetic reconnection triggering does not have to thin the current sheet all the way down to the ion scale. However, this notion is very different from the conventional wisdom mentioned above.

The Mercury Magnetospheric Orbiter (MMO) is a JAXA contribution to the BepiColombo Mercury exploration program. While its development, including various tests, has already been completed, it is recognized that not all the collected data will be downloaded to Earth, so a certain amount of science operation planning remains to be done. Accordingly, a team composed of younger scientists has begun to review the science scenario by referring to results from the MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) project. This planning activity is also paying substantial attention to the fact that there will be opportunities for two-spacecraft observations in the planetary magnetosphere.

2.3 Atmospheric Science

Since BepiColombo will make Venus flybys during its cruise to Mercury, discussion has started to consider what science can be performed when the flybys occur. An International Top Young Fellowship (ITYF) recipient, Javier Peralta, who has worked on ultraviolet (UV) and infrared (IR) images collected by MESSENGER data taken upon its Venus flyby will lead the BepiColombo discussion on the JAXA side based on his experience.

2.4 Planetary Science

The Hayabusa2 mission, which is expected to return samples from the C-type asteroid named 162173 Ryugu, is in currently underway, and the next phase of the Martian Moons eXploration (MMX) project, the Phobos sample return mission, is in preparation for launch in 2024. Japanese participation to the Jupiter Icy Moons Explorer (JUICE) and the Demonstration and Experiment of Space Technology for INterplanetary voYage (DESTINY+) project, which is an M-class planetary mission driven by a dust science theme, are expected to ramp up soon. In addition, a solar power sail mission to rendezvous with a Jupiter Trojan is under intensive study.

All these are exploration missions are targeting small bodies born “outside the snowline”, which refers to the distance from the sun where water, ammonia, methane, carbon dioxide, carbon monoxide, etc. become cold enough to condense into solid ice grains. We have formulated a roadmap that describes how these multiple missions are linked together and why such a systematic approach is needed. The key issue is that it is these small bodies, born outside the snowline, that somehow “switched on” the habitability of Earth, which was born inside the snow line, and thus was born dry.

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. But, when, specifically at which stage of solar system evolution (from comet to primordial asteroid), and in what form (the small body itself or via dust), did this process occur? Furthermore, is it possible for habitability to be established on worlds outside the snow line?

3. Research topics

The following outline lists all the Department of Solar System Sciences research activities during fiscal year 2016:

3.1 Solar physics
3.1.1 Solar observations: HINODE, HINODE-IRIS
3.1.2 Instrument development (photon-counting X-ray telescope, high-speed CMOS-based sensor, photon sensor driver), and future mission planning
3.1.3 CLASP, CLASP II
3.2 Space plasma physics
3.2.1 In situ and remote sensing observations: AKEBONO, Geotail, REIMEI, MMS, KAGUYA, HISAKI, and magnetosphere of outer planets
3.2.2 Sounding rocket: ICI-4, SS-520-3
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), Energization and Radiation in Geospace (ERG) (Earth’s inner-magnetosphere), and JUICE
3.3 Atmospheric science
3.3.1 Venus: AKATSUKI
3.3.2 Mars
3.3.3 Earth: Sounding rocket study of the ionosphere
3.4 Planetology
3.4.1 Lunar science using KAGUYA data
3.4.2 Asteroids: Itokawa samples, Hayabusa2 to the C-type asteroid 162173 Ryugu
3.4.3 Future missions: SLIM, DESTINY, penetrator technology, landing mission to the Moon and Mars, and MMX (Phobos 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 for flight vehicles and space platforms (e.g., balloons, rockets, satellites, and the ISS) and contributes to new interdisciplinary fields of space science and peripheral fields through fundamental research in the following areas:

- Space utilization science. The department aims to use the unique characteristics of space, such as its microgravity and radiation, to understand phenomena that are difficult to measure and observe on the ground and to apply our results. The department conducts materials science studies to produce materials with new functionalities. We also study space biological science—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, to 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 for visualization of space science data, spacecraft malfunction monitoring/diagnostic systems, numerical simulations, and data assimilation.
- Scientific balloons. The department is engaged in R&D for balloons used for space science research, balloon operating systems, and experimental systems for scientific observations and engineering demonstrations using balloons.

2.Research Activities in 2016

2.1 Space Utilization Science

In the field of materials science, phenomena that occur in environments with extremely high temperatures are studied using the electrostatic levitation method. We have developed methods for measuring the emissivity and heat capacity of high-temperature melts, in addition to thermophysical properties such as density, surface tension, and viscosity. The emissivity and heat capacity of two refractory metals (nickel and rhodium) has been measured. Furthermore, using the ISS electrostatic levitation furnace, a calcium aluminate sample was successfully melted.

InGaSb crystals obtained in the Alloy Semiconductor Experiment on the ISS were analyzed in detail, and the initial growth morphology for both (111)A and (111) B crystals was found to be almost flat because of the anisotropic growth kinetics. The differences of the dissolution length and growth rates were explained by attribution of different number bonds in unit cells at the crystal surfaces.

In life sciences, changes in gene expression in African Dormice skin during space flight were continuously analyzed from the viewpoint of cellular senescence, and we identified key genes for cellular senescence by oxidative stress. The mice were raised at low temperature (15°C) for 6 weeks, and genes associated with muscle atrophy that change in a temperature-dependent manner were identified. In addition, as the result of the plantar pressure analysis of the returned astronauts, it was shown that the pronation pre-flight supination motions while walking did not return even after 3 months.

The response to gravitational force (lighting behavior) in individual starfish under light and dark conditions was recorded and analyzed. The results suggested that visual information is involved in the response behavior.

In order to realize space agriculture on Mars, germination experiments under ultra-low pressure of 1/20th of normal atmospheric pressure were conducted. Most of the seeds for broccoli, radish, and common bean germinated. Cucumber germination rates varied by cucumber variety.

2.2 Research in Information Science and Information Technology

The department performed basic research on large-scale computation applied to spacecraft development and operations. We investigated a proposed method for speeding up low-memory-bandwidth CPUs. As a result, we understood the speeding-up mechanism and characteristics of SPARC64TM XIfx, which is the main CPU of the Fujitsu PRIMEHPC FX100 supercomputer. A new numerical compressible flow solver has been developed based on a hierarchical equally spaced Cartesian structured grid. A new wall model was proposed to conduct basic verifications and validations.

To provide space science data to the public, the department investigated methods of adding value to the data. The results of the study have been applied to several outreach activities: (1) the brightness of Hayabusa2 during the Earth swing-by was estimated using a computer graphics shape model, (2) methods for creating shape models of virtual asteroids and render them with virtual reality were developed, and (3) sonification methods for presenting scientific data were developed.

As for research on the data archive, high-definition movies taken by the Kaguya lunar orbiter were released. To treat the video intended for outreach as scientific data, one movie was separated into approximately 1,800 still images, auxiliary data were created from the command log and housekeeping telemetry, and the footprint was calculated from geometry information (attitude, orbit, and field of view). The images were archived in the Flexible Image Transport System format, which is the standard for astronomy. Additional labels to follow the Planetary Data System version 3 were also prepared for the planetary science field to make them available to standard tools such as NASAView and the Geospatial Data Abstraction Library. This archiving style enabled the long-term preservation of high-definition datasets to support scientific analysis in the future.

2.3 Research on Scientific Balloons

A super-pressure balloon was developed to expand the possibilities for scientific observations with balloons. This balloon can realize a long duration flight by keeping its lift and volume against differential pressure due to solar irradiation. Since 2010, an intensive effort has been underway to cover the balloon's film with a diamond-shaped net to increase its resistance to pressure during the daytime. Compared with the conventional lobed-pumpkin design, it has a merit in light weight. To improve pressure resistance and airtightness, a new sewing method was developed to fix the net onto the balloon film to avoid possible damage from sewing needles, and a new design was developed to reduce gas leakage at the top and bottom of small balloons. After investigating the mechanical properties of heat-sealed balloon film seams, a 7,000-m^3 balloon was built for launch in 2017 as a flight demonstration.

In space science research using balloons, the detailed analysis of cosmic ray data obtained during balloon flights over the Antarctic in the Balloon-borne Experiment with Superconducting Spectrometer, was continued. Papers on the energy spectra of antiprotons, the upper limit on the flux of the antihelium nuclei in primary cosmic rays, and the energy spectra for primary protons and helium were published.

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, we set stringent upper limits on the luminosities of the second gravitational wave event observed by the Laser Interferometer Gravitational-wave Observatory (USA), supporting a hypothesis that the event was a merger of two black holes.

Furthermore, studies were promoted to continue development of the General Anti-Particle Spectrometer (GAPS), which aims to address the dark-matter mystery through a highly sensitive observation of cosmic-ray antiparticles, including the undiscovered antideuterons. We also worked on plans for microwave background radiation observations using a medium-size scientific satellite (LiteBIRD) to study the early universe based on the polarimetry of microwave background radiation to detect primordial gravitational waves, which would directly prove the theory of cosmic inflation.

3. Research Topics

The following outline lists all the Department of Interdisciplinary Space Science research activities during FY2016.

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 Genetic analysis of skin of mice during space flight, hibernation, and muscle atrophy defense, and study on attitude control of astronauts returned from space
3.1.2.2 Gravity response in generation, formation, and behavior of animals
3.1.3 Astrobiology
3.2 Information science and information technology
3.2.1 Data archiving
3.2.1.1 Implementation of geographic information system-compatible observation data for Moon and planets
3.2.1.2 Development of international standard protocols for sharing planetary science data
3.2.1.3 Archiving data from Viking Mars probe
3.2.1.4 Archiving data about Earth's atmosphere
3.2.1.5 Application of machine learning to lunar and planetary probe data
3.2.2 Numerical simulation
3.2.2.1 Hierarchical equally spaced Cartesian-structured grid solver
3.2.2.2 Programming models for exa-scale supercomputers
3.2.3 Software and data
3.2.3.1 Efficient tool development
3.2.3.2 Web service for multidisciplinary research
3.2.4 Visualization and sonification of space science data
3.2.4.1 Visualization and sonification
3.2.4.2 Modeling methods
3.2.4.3 Applications of visualization and sonification
3.3 Scientific balloons and space science using balloons
3.3.1 Research on super-pressure balloons covered by net
3.3.2 Space science using balloons
3.3.2.1 Cosmic ray antiparticles using exotic atoms
3.3.2.2 Cosmic ray observations using superconducting spectrometer
3.3.2.3 Observation of high-energy cosmic-ray electrons and gamma rays
3.3.2.4 Research on early universe based on polarimetry of microwave background radiation

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 navigation, space transportation engineering, and space structure and materials engineering.

2. Research Activities in FY2016

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 Space Structure and Material 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 FY2016.

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
3.3 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
3.4 Hybrid rockets
3.4.1 Independent control of thrust and mixture ratio in hybrid rocket propulsion using variable swirling oxidizer injection
3.4.2 Mixture ratio-controlled throttle and applications in intensity-altering swirling-oxidizer-flow-type hybrid rockets
3.4.3 Numerical analyses of boundary layer combustion instability in axial-injection hybrid rockets
3.4.4 Safety of hybrid rockets
3.4.5 Oxidizer vaporizing system using boundary layer combustion
3.4.6 Conceptual study of flight tests on intensity-altering swirling-oxidizer-flow-type hybrid rockets
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

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, the department is conducting fundamental R&D related to space semiconductor devices and materials. The devices include pulsed radar for detecting the altitude and speed of a lunar or planetary lander, laser altimeters, communication devices, antennas, and integrated systems installed on spacecraft. Investigation for improving the performance of lithium-ion secondary cell power supply systems for spacecraft, power storage capacitors, and the use of fuel cells in spacecraft has been conducted. Sensors for detecting spacecraft attitude, relative position, and obstacles have been developed in the fields of navigation, guidance, and control. Investigations into 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 have been pursued with development of 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). For ground systems, the department is studying high-precision orbit determination methods, such as the combination of delta differential one-way ranging (DDOR) and optical navigation, and large-scale information integration for spacecraft operation systems. Furthermore, the system architecture for small scientific satellites and cosmic energy systems, such as solar power satellites, is under development.

2. Research Activities in FY2016

2.1 Technology for Power Supply Systems

For small missions, the department developed a small stainless steel laminated battery with a high energy density. The battery will be installed on SLIM, which was selected as the third small satellite, as well as 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. The department improved the conversion efficiency by approximately 9%, compared with solar cells for the air-mass-zero solar spectrum. Also, we have a project to design batteries for low temperatures and electrochemical reduction electrolysis. The department is continuing work on an energy carrier that uses renewable energy, based on previous research into fuel cells and renewable fuel cells. Furthermore, the department evaluated the performance of the battery onboard the REIMEI spacecraft and determined the current impedance trend for 11 years in orbit.

2.2 Communication Technology

In research on components for communications and energy transmission in space, the department continued development of electronic cell chips that use space-capable radiofrequency nano-electronics, and prototyped system-on-chips using Si and a compound semiconductor integrated circuit called “HySIC.” A prototype of an active integrated antenna with a GaN Schottky barrier diode and a Si radiofrequency integrated circuit (IC) was developed, and will be used as a component of an ultra-small phased array antenna. The group 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 retro-directive function for the solar sail project and evaluated a BBM for a docking radar to be used for sample return. The department also fabricated a prototype of a compact wireless health monitoring sensor system to be employed inside spacecraft by using our high-performance small rectenna and a wireless power transmission system.

The department developed a prototype of a GaN SPPA at X-band frequencies to be used in GREAT, the new deep space communication station, and obtained good results.

2.3 Information and Data Processing Technology

In the field of information and data processing, the department is developing standard components and interfaces based on standard architecture (system construction principle) to be used in various spacecraft. A communication method called “SpaceWire-R” for connecting computers in spacecraft is also being developed. This method has been adopted as a standard in Europe, and testing activities are being performed there. In addition, a space communications and data handling architecture was established to standardize communications and data handling methods across various spacecraft. Furthermore, the department is developing a method that uses modeling technology and linguistic theory to enable development of databases that can store spacecraft specifications.

2.4 Navigation, Guidance, and Control Technology

We continued research on semi-actively controlled landing legs to land on the Moon or a planet, and also developed a method for measuring the velocity of a spacecraft relative to the surface of a planet using images; testing yielded reasonable results.

A motion stage has been developed to control the attitude of sounding rockets more accurately. It will be used onboard an 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 on autonomous movement and action planning. Technologies are being developed for environment recognition using a wide-angle high-dynamic-range camera, visual odometry in a terrain with few characteristics, categorizing natural geography and estimating traveling power based on the robot's traveling vibrations, path planning based on the power supply level, and estimating the absolute position based on skyline matching. The department produced and verified a prototype of the image-processing board that will be installed. To improve the ground-covering ability of rovers, we compared, evaluated, and measured suspension mechanisms while 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 of the planet's surface, a movement measurement experiment using the Laser Range Imager (LRI) was conducted and the LRI hardware was improved. Performance verification of the laser measurement system was carried out, including topography acquisition and path planning, by using a commercially available flash LIDAR.

The department performed several operations for the Minerva-II rovers installed in the asteroid explorer Hayabusa2 and confirmed their health status, and conducted an experiment on the capabilities of communications and distance measurement using a balloon for verifying the operations of Minerva-II when it reaches the asteroid Ryugu.

2.6 Device Technology

In the field of electronic materials and devices, fundamental research on semiconductor devices that will be installed on spacecraft was performed, an environment-resistant device was developed, and semiconductor materials were researched. The department developed LIDARX and Flash LIDAR. LIDARX, an IC for light pulse detection, is a readout circuit for avalanche photodiode (APD) output for long-distance LIDAR receivers. It measures the timing and height of the pulse output from the APD. In FY2016, the IC was integrated into a LIDAR test bed to evaluate its distance-measuring accuracy when it is integrated into peripheral circuits and to investigate its installation on spacecraft. Flash LIDAR is a sensor that acquires a range image, and it is used to detect obstacles during the landing process and to measure the relative distance for rendezvous on orbit. In FY2016, a prototype of a small 16 × 16 pixel circuit was upgraded, and the department prototyped a distance image sensor vertically coupled with an APD array and obtained distance images using a YAG laser.

2.7 Orbit Determination

The orbit determination group determines the orbital status of operational satellites and spacecraft to prevent mission problems. For the AKATSUKI mission, analysis was conducted and operation coordination for navigating to Venus, contributing to the successful orbit insertion. In the orbit determination for Hayabusa2, DDOR measurements were used successfully while the ion engines were firing, and the orbit could be determined very precisely, contributing to the successful trajectory control of Hayabusa2 using ion engines. The department also participated in near-Earth-object activities led by the United Nations, and continued activities related to the Asia-Pacific Asteroid Observation Network.

2.8 Small Satellite Systems

The department started a research activity to develop an X-band synthetic aperture radar (SAR) that can be installed on a 100-kg-class satellite. This was adopted as an ImPACT program by the Japanese government, and its final goal is to develop a SAR model with a resolution of 1 m by FY2018. A Bread Board Model for a slot array panel antenna was developed, and it was found to function correctly according to its specifications. A power amplifier and a modulator for this project were also designed.

We have also been working on satellite architecture, components, and implementation technology aimed at reducing the size, weight, and production time for the satellite bus. We are studying image-based navigation and landing radar for the SLIM Moon landing spacecraft.

2.9 Space Energy Systems

For space solar power satellites, we produced prototypes for a phased-array antenna system and direction finder system for wireless power transmission technology and tested the microwave beam control. We established an evaluation system for finding a direction with an accuracy of approximately 0.001° based on phase and amplitude comparison using S-band microwaves.

We developed a thin-film power-generating system for a solar power sail in addition to technology for controlling and maintaining the shape of the sail by applying a coating to its surface. We also evaluated the space environment resistance of a thin-film solar cell on a polyimide film.

3. Research Topics

The following outline lists all the Department of Spacecraft Engineering research activities during FY2016.

3.1 Technology for power supply systems

3.1.1 Characteristic evaluation for 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 radiofrequency 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
3.4 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 ICs
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 SAR 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 Spacecraft power supply system using a water-cycling system

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 in 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 12 fellows (seven from the US and Europe) have participated in the program so far, five of whom have since taken permanent posts in other institutes and universities (three in Japan and two abroad). For FY2016, one new fellow was selected out of forty-seven applicants to join the two existing fellows in July. Aiming to attract stronger applicants, the recruiting structure underwent a reform to increase the number of open calls to twice a year in order to bring it into alignment with other fellowship programs abroad.

A number of ITYF registered fellows have produced significant results during their terms. For example, soon after the discovery of gravitational waves from binary black hole coalescence by the LIGO Scientific Collaboration (LSC), Dr. Yoshiyuki Inoue and his colleagues pointed out that the measured binary black hole merger rate is consistent with the rate expected from the number density of ultraluminous x-ray sources. This finding, which will help us to expose the origin of such gravitational wave emitting binary black holes, was published in Monthly Notices of the Royal Astronomical Society.

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.

The following list shows ITYF fellows in FY2016 and their published research:

ITYF Fellows (as of March 31, 2017)

Name	Former Institute	Research Theme	Period
INOUE, Yoshiyuki	Stanford University (US)	Nature of active galactic nuclei (AGN) by correlating theory and observation	February 2014 -
PERALTA, Javier	Astrophysical Institute of Andalucia (Spain)	Characterization of atmospheric dynamics by using “AKATSUKI” and “Venus Express”	April 2015 -
CRITES, Sarah	University of Hawaii at Manoa (US)	Evolution of the Solar System as Revealed by Remote Sensing of Small Bodies	July 2016-

Main research published by the fellows in FY2016:

INOUE, Yoshiyuki

The Astrophysical Journal Letters, Vol.837 (1), L15 (2017)	doi: 10.3847/2041-8213/aa61fa
Monthly Notices of the Royal Astronomical Society, Vol.461(4), pp.4329-4334 (2016)	doi: 10.1093/mnras/stw1637
The Astrophysical Journal, Vol. 828 (1), 13 (2016)	doi: 10.3847/0004-637X/828/1/13
PASJ: Publications of the Astronomical Society of Japan, Vol.68 (4), 56 (2016)	doi: 10.1093/pasj/psw052
PASJ: Publications of the Astronomical Society of Japan, Vol.68 (4), 51 (2016)	doi: 10.1093/pasj/psw049
Nature, Vol. 535 (7610), pp.117-121(2016)	doi: 10.1038/nature18627
Monthly Notices of the Royal Astronomical Society, Vol.459 (1), pp.108-120 (2016)	doi: 10.1093/mnras/stw623
The Astrophysical Journal, Vol.823 (1), 35 (2016)	doi: 10.3847/0004-637X/823/1/35

PERALTA, Javier

Geophysical Research Letters, Vol.44 (8), pp.3907-3915 (2017)	doi: 10.1002/2017GL072900
Icarus, Vol. 288, pp.235-239 (2017)	doi: 10.1016/j.icarus.2017.01.027
Icarus, Vol.285, pp.8-26 (2017)	doi: 10.1016/j.icarus.2016.12.017
The Astrophysical Journal Letters, Vol.833 (1), L7 (2016)	doi: 10.3847/2041-8205/833/1/l7
Earth, Planets and Space, Vol.68 (1), 75 (2016)	doi: 10.1186/s40623-016-0457-6

CRITES, Sarah

48th Lunar and Planetary Science Conference (3/20-24, 2017)

- Global and local distribution of troctolitic rocks using Kaguya Multiband Imager data and radiative transfer mineral mapping (#1312)
- Rock abundance as a potential discriminator of impact melt on lunar central peaks (#1359)
- Detection of lunar lava tubes by lunar radar sounder onboard SELENE (Kaguya) (#1711)
- A study of near-infrared hyperspectral imaging of Martian moons by NIRS4/MacrOmega onboard MMX spacecraft (#2318)

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. 103. 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 administering and maintaining the 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 clean rooms and machine assembly test facilities. The group also supports projects, pre-projects, and working group(WG) activities.

1. Achievements

- Support for pre-launch testing and launching of the ARASE/ERG geospace exploration satellite.
- Support for pre-launch testing and launching of Epsilon-2.
- Support for pre-launch testing, launching, and task force activities for sounding rocket SS-520-4.
- Support for combustion testing of N_2O/ethanol propulsion systems.
- Maintenance and upkeep of the mechanical environmental test facility, thermal environmental test facility, anechoic chamber, and attitude control test facility.

2. Effects and Impacts

- The group contributed to the successful launch of Epsilon-2 with ARASE/ERG.
- The group solved the problem of variability of combustion characteristics in the manufacture of low-cost solid-fuel rockets, nozzle insulation, and heat-resistant materials that can endure seconds-long combustion.
- The combustion test results with a 1,600-N thrust with vacuum specific impulse of 250 s (with nozzle opening ratio of 25) enabled us to carry out production of new igniter for engines. Improved maintenance and schedule management of various testing facilities enabled the group to respond promptly to the failure of the SS-520-4 rocket and contribute to the investigation of the cause of the failure and the plans for mitigation measures.

c. Advanced Machining Technology Group

This group has fully upgraded our machine shop and, as a common facility of JAXA, will maximize the capability of manufacturing. Thereby, the group will support the startup of new mission projects and contribute to producing various aerospace products. From laboratory prototypes to flight models, our researchers and technicians will continue to strive together to provide in-house manufacturing services to all of JAXA. In addition to the new machine shop, the conventional machine shop of the Test and Operation Technology Group, the electronics shop and the space nanoelectronics cleanroom of the Department of Spacecraft Engineering have been combined. These facilities will work on nanoelectronic device development, RF integrated circuit design, and highly accurate machining with numerical control machines. This will make for more effective use of research funding and speed the pace of research, improving technological prowess and broadening our reserve of knowledge.

1. Achievements

- The new machine shop has been upgraded to meet the requirements of high-precision numerical control machines and measuring systems, which were newly introduced.
- A five-axis machining center, CNC turning centers, a wire-cut electric discharge machine and other high-precision numerical control equipment have been installed.
- Consistency from the manufacturing stage through the product inspection stage has been improved by the construction of a constant-temperature booth housing a contact-type three-dimensional measuring machine.

2. Effects and Impacts

- We have preserved the conventional machine shop in which users can machine their own products, while establishing a sophisticated facility in which expert staff can manufacture to high standards.
- The newly installed equipment has been brought on line on schedule and has begun producing requested test pieces.

d. Scientific Ballooning Research and Operation Group

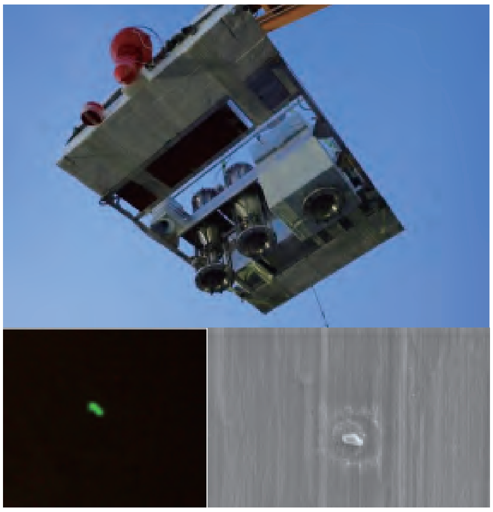
The Scientific Ballooning Research and Operation Group develops stratospheric balloon systems and provides flight opportunities for carrying out scientific observations and engineering demonstrations. It also studies next-generation balloon systems for future space science.

1. Achievements

- The group successfully carried out three of four planned experiments in two domestic balloon campaigns. The remaining experiment was postponed until FY2017 due to weather conditions and a delay in payload preparation. Ozone observations in the upper stratosphere were carried out for the first time in 3 years and compared with previous observations. In this experiment, the demonstration of a new spectroscopic device capable of measuring quantities of ozone-depleting substances, such as nitrogen dioxide, was carried out successfully.
- The group selected three astronomical observation proposals as candidates for balloon-borne experiments in Australia and began their preparation. These experiments cannot be conducted in Japan due to equipment weight and flight-time requirements.
- The group aims to carry out the next balloon campaign in Australia from March to May 2018 and has coordinated plans with Australian agencies and NASA, which owns the local facility.

2. Effects and Impacts

- In domestic activities, research teams were formed to conduct their first balloon-borne experiments, such as the Mars Aircraft High-Altitude Flight Test and the Stratospheric Microorganism Capture Experiment.
- In the experiment for capturing stratospheric microorganisms, the group successfully demonstrated the performance of a new microorganism sampler that avoids contamination from the ground, which was a problem in previous experiments. This result will allow new developments, such as observation of the altitude distribution of microorganisms.



Fluorescence micrograph (bottom left) of microorganisms captured using the stratospheric microorganism sampler (top) and an electron micrograph of the stratospheric aerosol (bottom right).

e. Sounding Rocket Research and Operation Group

To provide experimental opportunities for researchers to use sounding rockets for engineering verification tests and scientific observations, the Sounding Rocket Research and Operation Group will increase design and analysis efforts for the manufacturing and launching of sounding rockets in the coming fiscal year and beyond.

1. Achievements

- The preliminary design, including mechanical and electrical interfaces, of the S-310-45 rocket experiment was verified to prepare onboard instruments. In the experiment, a precise control strategy and the directional accuracy of multi-link structures will be examined.
- The baseline concept, including mechanical and electrical requirements, of the S-520-31 rocket experiment was discussed to provide better conditions for it. 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.
- In addition to the annual evaluation, we focused on scientific achievements and conducted experimental evaluation of the sounding rockets launched in the past 10 years.

2. Effects and Impacts

- The group published three peer-reviewed papers in 2016 (in *Science Advances, Chemistry of Materials*, and the *Journal of Crystal Growth*) and has published a cumulative total of 109 papers since 2003.
- Using the results on space dust generation related to the S-520-28 and S-520-30 flights, we produced one

book and one doctoral thesis, won three awards (the Hokkaido University Research Director's Award, the 3rd Space Science Institute Award, and the 2016 Research Encouragement Prize of the Japanese Microgravity Applied Society), and issued two press releases (to Nikkan Kogyo Shimbun newspaper and Jiji press).

- A subcommittee established under the Space Science and Engineering Committee produced an evaluation of our sounding rocket activities, which concluded that the group's publications and other scientific results related to sounding rocket and balloon experiments were appropriate to the input resources.

f. 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

1.1 Achievements

- C-SODA provided ground systems for ISAS scientific space missions and supported their mission operations.
- We built a secondary spacecraft control room so that ARASE operations could fully occupy the primary spacecraft control room during its launch, critical, and initial check-out operations.

1.2 Effects and Impacts

- All spacecraft in orbit or transit—ARASE, Hayabusa2, HISAKI, AKATSUKI, HINODE, and Geotail—have been operated safely.
- The ARASE/ERG launch, critical phase, and initial check-out operations were successful; ARASE started nominal operation smoothly and is obtaining high-quality observation data.

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 11 new datasets from DARTS to public users, including long-term data on near-Earth plasma waves measured by AKEBONO, orbital data from AKATSUKI, Extreme Ultraviolet Spectroscope for Exospheric Dynamics (EXCEED) data from HISAKI, and high-definition video data from KAGUYA.
- C-SODA produced and prepared data from the AKARI infrared astronomical satellite for public release from DARTS, including the far-infrared faint-source catalog, mid-infrared all-sky image maps, and far/mid-infrared slow-scan image data.
- High-quality lunar video data, which was obtained by a high-definition camera developed by NHK onboard KAGUYA, previously had been distributed only when requested (i.e., by media to JAXA or NHK). By making a new agreement with NHK, C-SODA has been able to publicly release all the high-definition video data online since September 2016.
- ISAS started a new program to refurbish unpublished data from old ISAS missions for release to the public. In FY2016, data from SAKIGAKE, OHZORA, and JIKIKEN were refurbished and made available to the public through DARTS.

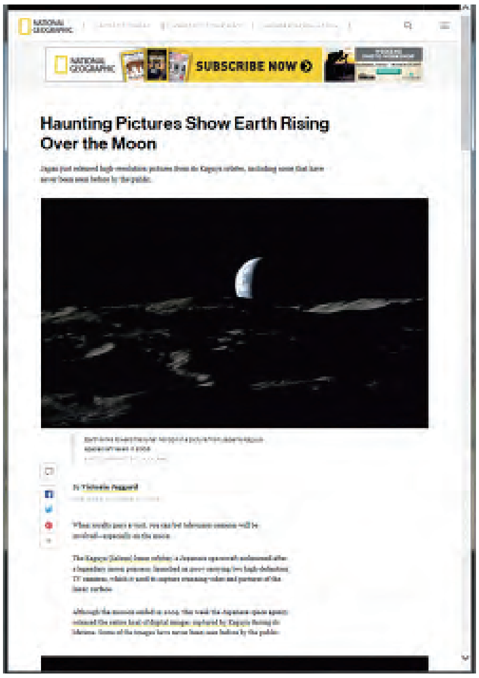


Fig. 1: National Geographic web-article dated October 11, 2016, on the release of high-definition KAGUYA data from DARTS.

2.2 Effects and Impacts

- Through DARTS, approximately 90 TB of data are downloaded by world-wide users each year. DARTS is accessed about 24 million times annually.
- Release of KAGUYA video data that covers a broad area of the Moon received an overwhelmingly positive response from all over the world. Within one day of National Geographic magazine reporting the data release on the web, DARTS was accessed about 200,000 times and 20 TB of video and images were viewed (Fig. 1).
- There were about 90,000 downloads from the server

hosting the revised version of the AKARI far-infrared all-sky bright-source catalog (Fig. 2), the near-infrared spectral catalog, and near-infrared pointed observation images. About 130 refereed papers using Akari data were published in FY2016 (about 1,200 papers have been published since the AKARI launch in 2006).

- DARTS keeps many 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 the scope of its use, and contributes to third-party verification of observation results.

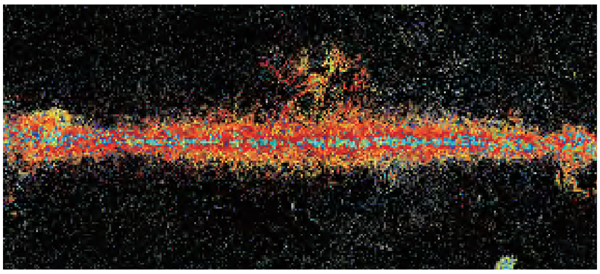


Fig. 2: Distribution of infrared sources in the galactic coordinate system of the revised AKARI far-infrared all-sky bright-source catalog. Colors represent apparent temperatures of the sources (redder colors are lower temperatures).

g. Lunar and Planetary Exploration Data Analysis Group

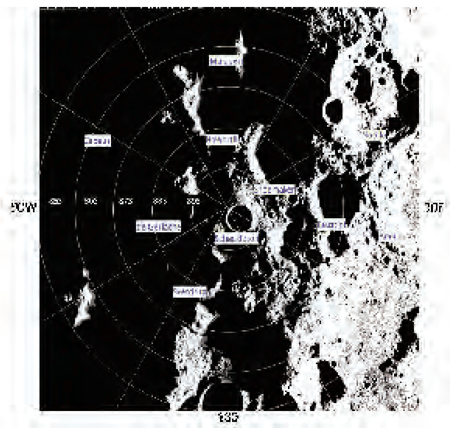
The Lunar and Planetary Exploration Data Analysis Group is a new group established in FY2016 with the aim of maximizing the results of lunar and planetary exploration through research into lunar and planetary origins, and evolution and development of strategies for planning lunar and planetary exploration. The group will also deal with the massive amounts of data from lunar and planetary exploration (including data from foreign probes) and establish systems for carrying out higher-order data processing and analysis.

1. Achievements

- The group analyzed the possible landing sites for the SLIM project in terms of geology and safe landing operation and provided the results to the mission study team.
- The group performed data analysis around the Moon polar regions in terms of sun illumination conditions, direct communication between the Moon and Earth stations, slope of the surface, and distribution of possible water ice and geology and provided the results to the mission study team for moon polar regions.
- We simulated the shape and temperature distribution of an asteroid model using hypothetical Hayabusa2 observation data.
- Geographic data around the possible landing area of the OMOTENASHI project were analyzed for landing site selection and the study of the descent trajectory.
- In cooperation with the National Institute of Advanced Industrial Science and Technology and the University of Aizu, we started development of data analysis methods using artificial intelligence and carried out some trials of extracting volcanic features and obstacle boulders.
- The group operated and upgraded the function of the KAguya Data Integrated Analysis System (KADIAS) that provides the WebGIS-based analysis and download functions for observed data obtained by the Japanese lunar exploration orbiter KAGUYA and other missions, including foreign explorations.

2. Effects and Impacts

- Our landing site analysis for the SLIM project led to a reconsideration of the landing site to expand the SLIM mission significance.
- Information obtained from the analysis around moon polar regions advanced the mission concept study of the polar landing exploration.
- The shape and thermal simulation of the hypothetical asteroid data contributed to the preparation for actual data analysis in future.
- The operation and upgrade of KADIAS will allow users to execute an integrated analysis using data from not only KAGUYA but also from other lunar missions.



Simulation of solar illumination at the south pole of the Moon (00:00, April 30, 2020).

h. Astromaterials Science Research Group

The Astromaterials Science Research Group is operating the curation facility of JAXA. Through the curatorial work for extraterrestrial materials, knowledge about planetary materials based on non-destructive and uncontaminated descriptions is acquired.

1. Achievements

- The group performed the curatorial work of collecting, describing, and storing the samples brought back from asteroid Itokawa by HAYABUSA.
- The group e-published a periodical special paper containing the initial description of the Itokawa samples (i.e., sample catalog information).
- The group made an international AO for the Itokawa samples, and samples were allocated to the researchers selected by an international AO committee.
- The group established an approval system for allocating Itokawa samples to JAXA researchers, so they can also participate in sample analysis.
- An International Symposium of Solar System Materials was held to announce the results from the international AO research on Itokawa samples. This symposium is held annually and is attended by about 100 planetary science researchers from all over the world.
- A curation facility was organized for extraterrestrial samples to be brought back by future sample return missions, including Hayabusa2.
- Maintenance and operation of the group's associated facilities and equipment were achieved.
- Project researchers and postdoctoral fellows were accepted, as well as young researchers, through extraterrestrial sample analysis and other studies.

2. Effects and Impacts

- From the results of Itokawa sample analysis, we expect to elucidate the history of collision events in the solar system and processes on asteroid surfaces (e.g., space weathering). Previous international AOs have resulted in 51 acceptances and produced 61 peer-reviewed papers (6 in FY2016).
- The Itokawa sample analysis results thus far can be summarized as follows. The initial analysis provided new knowledge on the relation between asteroids and meteorites, the formation history of small bodies in the solar system, and the age of asteroid surfaces. Investigations of asteroid formation history relied upon non-destructive measurements and estimations of small celestial body surface evolution relied upon observations of micro-collision craters. Extracts from published results are given below:
  - JAXA-centered research. We found numerous collisional micro-craters on HAYABUSA sample surfaces. From observations of number densities and crater cross-sections, we believe that many exist as secondary craters. Examining more micro-craters in the future will provide important clues regarding microscale celestial body (dust) composition and size distributions in the solar system. (Earth and Planetary Science Letters, June 2016)
  - Research resulting from AO solicitations. We analyzed the surface textures of fine particles and discovered that their history from more than 4 billion years ago to the present is engraved on their surface. (Geochimica et Cosmochimica Acta, May 2016)
- In a related activity, ISAS formed a research group for the 141st Committee for Microbeam Analysis of the Japan Society for the Promotion of Science and called for active industry participation in analyzing Itokawa samples. Industry participation is expected to promote the study of Itokawa samples and improve industrial technical prowess.

i. Deep Space Tracking Technology Group

The Deep Space Tracking Technology Group is a new group established in FY2016. The main task of this group is to perform technical coordination among various projects and facilities inside and outside ISAS concerning tracking of deep space projects, which had been performed by individual experts before this group was established. Major achievements of this group during FY2016 are described below.

1. Support for JAXA's Deep Space Projects

- The group initiated technical coordination for the Hayabusa2 project with NASA concerning tracking support at NASA's DSN stations. During FY2016, coordination for testing uplink transfer operations with the DSN, in which a spacecraft is operated continuously using two tracking stations, was performed without an interruption in the uplink when transferring operations from one station to the other. Several tests were performed using DSN's Goldstone station in California and Canberra station in Australia, and it was verified that the uplink was transferred successfully between these stations. Next, similar tests were performed using JAXA's Usuda station and DSN's Goldstone station, and again the uplink transfer was successful. Furthermore, testing of receiving telemetry at Ka-band frequencies was performed with the DSN. A preliminary test of receiving telemetry at Ka-band was performed right after launch, but the test was repeated at a deep space distance this time, and it was completed successfully. We have also started to develop protocols for coordinating the usage of DSN stations during spacecraft operations near asteroids.

- Technical coordination for tracking support from ESA's ESTRACK stations for the Hayabusa2 project is also underway. During FY2016, testing of receiving telemetry in the Ka-band was performed for the first time using ESTRACK's Malargue station in Argentina, and correct reception of telemetry at Ka-band was verified.
- We also initiated technical coordination for tracking support at NASA's DSN stations for JAXA's two CubeSats (OMOTENASHI and EQUULEUS), which will be launched by NASA's SLS EM-1. During FY2016, tracking requirements were presented to NASA and we agreed upon a basic tracking policy. A feasibility study on using tracking stations of other agencies, such as ESA, CNES (France), and DLR (Germany), has also started.

2. Support for Deep Space Projects of International Partners

The group is planning to provide tracking support from JAXA's Uchinoura station for NASA's EM-1 project. During FY2016, we developed a feasibility study on receiving three-way Doppler signals from EM-1 at Uchinoura and provided precise orbit determination data to NASA, with no major technical problems. A test plan for this support in Uchinoura and technical coordination within JAXA have been initiated.

3. Study for JAXA's Future Deep Space Tracking Network

The group initiated a study for JAXA's future deep space tracking network with JAXA's space tracking and communications center at Tsukuba. We developed a plan for utilizing the planned 54-m GREAT station, as well as the existing 64-m station at Usuda. Also, we proposed to replace the stations at Uchinoura with a multi-purpose station to be built overseas.

4. Orbit Determination for JAXA's Deep Space Projects

- The group performed regular orbit determination operations for AKATSUKI and Hayabusa2.
- Finally, we studied a high-precision orbit determination technique utilizing optical data; this technique will be used for Hayabusa2 during the asteroid proximity phase.

6. ISAS Program Office

a. Overview

Operations in ISAS are coordinated with other JAXA organizations, because ISAS projects and experiments are executed by relatively few, highly technical skilled teams who are undertaking challenging missions. Common support and strategic program activities utilizing a bottom-up approach are important for the reliable implementation of these projects. The ISAS Program Office was thus established to provide cross-sectional support for various project teams with limited human resources.

The coordination and support activities related to technical issues and improvement in the SE aspects of space science projects, which had been performed by the Systems Engineering Office until 2015, have been merged into the Program Office. The merger resulted in continuous and comprehensive support for technical and management issues in projects under development. Also, the office gives priority to providing effective support to WGs in the early phases of projects.

General support for the implementation of sounding rocket experiments and ballooning experiments was transferred to the Management and Integration Department.

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

(1) Participation and support for program strategy review, that is, the Roadmap for Space Science and Exploration.

(2) Support for projects and experiments:

- Consultation services for project activities and interfacing with related departments.
- Collaboration with planning sections and preparing for management reviews.
- Other activities related to project implementation.

(3) Operation of organizations under the ISAS Program Director and providing related support for small project teams, research project teams, intra-JAXA pre-project team activities, and other laboratories.

(4) Coordinating projects and experiments, including information sharing:

- Explaining activities to JAXA staff, reporting to external organizations, and preparing associated documents.
- Sharing information related to projects and experiments and providing risk management for project members.
- Assisting in problem-solving for projects and experiments.
- Sharing measures for resolving common issues among programs and projects.

- Continuously improving the implementation of space science programs.

b. Summary of Work in FY2016

1. Support for Space Science Projects

Project Support by the Program Office

WGs both before and after review by the Advisory Committees for Space Science and Engineering include many non-JAXA members with little experience in space science projects. Thus, support during the early phase of project planning is essential for minimizing problems in the development phase. Therefore, the office mainly supports the initial phase of WG activities, such as clarifying scientific goals, setting mission requirements supporting those goals, verifying adequate selection of system requirements, identifying issues and risks, and developing risk management measures.

Generally, a staff member of Program Office will work “hands-on” with the issues in conjunction with the WG. In FY2016, we supported the MMX, LiteBIRD, Solar Power System (SPS), Destiny+, JUICE, and SPICA WGs.

In addition, related to SLIM, the office supported the study of the kick-stage motor in the upper stage of the Epsilon launcher to identify adequate technical requirements.

Especially in the wake of the loss of the ASTRO-H spacecraft, the Program Office assisted its conceptual study of XARM as a successor.

Project Support by the SE and PM Support Team

The Program Office selected various experts to form a support team for the design of common systems for space science projects. Team members provide advice and suggestions for project teams to improve SE and project management (PM) in the development phase of projects through experiments and satellite system design meetings organized by the project team. The team mainly consists of retired JAXA staff having experience in system development for satellites and spacecraft. The team was involved in design meetings and review meetings for SLIM, ERG, and GREAT.

2. Involvement in Task Forces after Problems Occur

The Program Office was involved in the team that investigated the anomalies that ended the ASTRO-H mission from the viewpoint of SE and PM. Lessons learned from the direct and indirect causes of the failure have been applied to all ISAS projects.

3. Tracking of issues in projects and technical activities

The Program Office has organized monthly progress report meetings to monitor progress, issues, and risks in all projects under development on a timely basis, and to ensure that information is shared among projects. Its members include the Director General, Deputy Director General, Program Director, and Director of the Management and Integration Department. Various experts were involved in these meetings and detailed discussions about technical topics were conducted from a PM perspective.

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

4. Involvement in Evaluation of Space Science Projects

The Program Office serves as a secretariat for project review meetings at ISAS in cooperation with the Management and Integration Department. In FY2016, we worked together with project teams to prepare review materials for the following projects (the project status or activity follows the project name):

- ERG: Review at development completion, technical confirmation of its on-orbit operation
- ASTRO-H: Review at project completion
- XARM: MDR, system requirements review, planning review prior to phase A
- GREAT: PDR
- JUICE: SDR
- SS-520-4: CDR, PQR, investigation of launch failure
- LiteBIRD: Planning review in pre-phase A
- SPS: Planning review in pre-phase A

5. Implementation Methods Suitable for Science Projects

For the formulation of implementation methods appropriate for space science projects, the Program Office has made plans to review and renovate ISAS SE/PM reference documents.

6. Support for Chief Engineer Office Work

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

- Information provision to the Chief Engineer Office meetings.

Support activities for the space science and exploration SE/PM inspection team.

7. Safety and Mission Assurance Officer

The Safety and Mission Assurance (S&MA) Officer coordinates overall S&MA (including quality assurance) for space science projects. Specific examples are the following:

- Setting of standards, requirements, and guidelines relating to S&MA.
- Evaluation and coordination related to S&MA for each project (serves as a person in charge of S&MA implementation for some projects).
- Sharing of common information among projects, including new standards and problems.
- Organization of the ISAS Safety Review Committee and Quality & Reliability Review Committee.
- Application of JAXA-wide S&MA policy and technology, collaborating with S&MA Officers in the Safety and Mission Assurance Department and other Directorates.

Major achievements in FY2016 are discussed below.

a. S&MA for Space Science Projects

- ERG: The S&MA team took part in the ARASE/ERG final check activities, launch site operations, and onboard commissioning. At the final check, the S&MA Officer verified anomaly disposition and configuration control together with the JAXA Safety and Mission Assurance Department in terms of system and observation equipment. The officer also directed project and manufacturers to be more appropriate control. The S&MA Officer organized a quality control team within the tracking control team, the first time such a team was used in a space science project.
- The quality control team contributed to successful launch operations and onboard commissioning; the established quality control methods succeeded during the steady operation phase.
- ASTRO-H: The S&MA Officer joined in ASTRO-H accident investigation activities and contributed to the cause investigation, for example, by performing a fault tree analysis (FTA). The officer also verified the background investigation and countermeasures and coordinated S&MA improvement efforts after the investigation.
- BepiColombo/MMO: The S&MA Officer joined in system testing at ESTEC and maintained quality records. The officer participated in a major nonconformance review board, provided S&MA inputs, and responded to safety comments from the launch authority (CNES).
- SLIM: The S&MA team identified critical equipment and potential “loss of satellite” failure modes by performing a FTA. The S&MA Officer provided the FTA results to the SLIM project team for consideration of these critical issues during the preliminary design phase.
- SS-520-4 rocket: The S&MA team participated in the development and operation of SS-520-4, which was based on a sounding rocket with a third stage and small satellite. The S&MA Officer coordinated the project team and industrial suppliers to implement safety logic to comply with standard rocket safety requirements. The JAXA safety review board and a government safety committee approved SS-520-4, but it failed at launch, possibly due to an instrument short circuit. The S&MA Officer contributed to a cause investigation, re-occurrence testing, and countermeasure establishment.
- OMOTENASHI: This project requires application of safety requirements for space shuttle payloads. The S&MA Officer supported safety analysis and evaluation activities together with the Safety and Mission Assurance Department.

b. System Safety

Space science project teams adopt methods for system safety and take a steady approach to ensure safety. They adopt similar methods not only for development of satellites but for ground-based experiments, including scientific ballooning, sounding rocket experiments, and combustion experiments. The S&MA Officer was involved in all safety reviews to provide advice and coordinate with project teams and related departments as needed.

c. Update of Design Standards for Space Science Satellites

There are four design standards, including electronics, structure and mechanism, thermal, and environment, applicable to space science satellite documentation. Each space science project refers to the standards and establishes their own design standards. However, these standards have not been updated since their initial issue. Several points in the original design standards were found to not match the current state-of-the-art in satellite design.

To address the outdated documents, the S&MA Officer began updating the electronics design standard for space science satellites. JAXA owns the satellite electronics standard, and the S&MA Officer plans to update all content according to current space science satellite design. The S&MA Officer organized a team from ISAS subject matter experts with experience in space science projects to form a working group for the JAXA satellite electronics design standard, and started the update process. The S&MA Officer plans to publish revision A of the electronics standard in 2017 and address the other design standards one by one.

d. Organization of Quality & Reliability Review Committee

The Quality & Reliability Review Committee is a body for coordination and discussion related to S&MA, including establishment of standards for safety, reliability, and quality assurance in ISAS and sharing of information related to reliability and quality such as malfunctions. The S&MA Officer chairs the committee. As in the previous year, meetings were held once every 2 months in FY2016. Various information was shared relating to reliability and quality in the meetings. In addition, the S&MA Officer and committee members followed up on project-specific recommendations to ensure implementation.

e. Improvement of Clean Room Control

The S&MA Officer identified many improvement opportunities for clean room control at the spacecraft environment testing facility and drafted improvement plans. Several ISAS sections and users are involved in clean room control, so the S&MA Officer shared the issues and coordinated improvement measures with them. Responsibilities of the person in charge of clean room control were clarified, and an improvement plan was established. Each section implemented their part of the improvement plan.

f. Planetary Protection

Planetary protection establishes spacecraft cleanliness levels and operating boundaries to prevent contamination and disruption of planets, moons, and other space bodies that have potential for life, pre-life conditions, or other sensitive qualities. The S&MA Officer implements the planetary protection program together with solar system research divisions. The S&MA Officer established a “tiger team” to study the JAXA planetary protection standard and review panel. S&MA Officer will establish the ISAS planetary protection standard and JAXA planetary protection review panel in FY2017.

III
Organization

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 was reorganized into seven directorates or departments(see the JAXA organization chart).

Following mid-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 and Operation

a. Organization

As of April 1, 2016, ISAS has five research departments:

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

Other organizations within ISAS are the Management and Integration Department, the ISAS Program Office, the S&MA Officer, the Center for Science Satellite Operation and Data Unit, 11 project teams, 8 working groups (WGs), the Noshiro Rocket Testing Center, and the Akiruno Research Center. 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.

b. Operation

The Advisory Council for Research and Management and the Board of Councilors were established to oversee the inter-university 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.

Councilors (as of March 31, 2017)

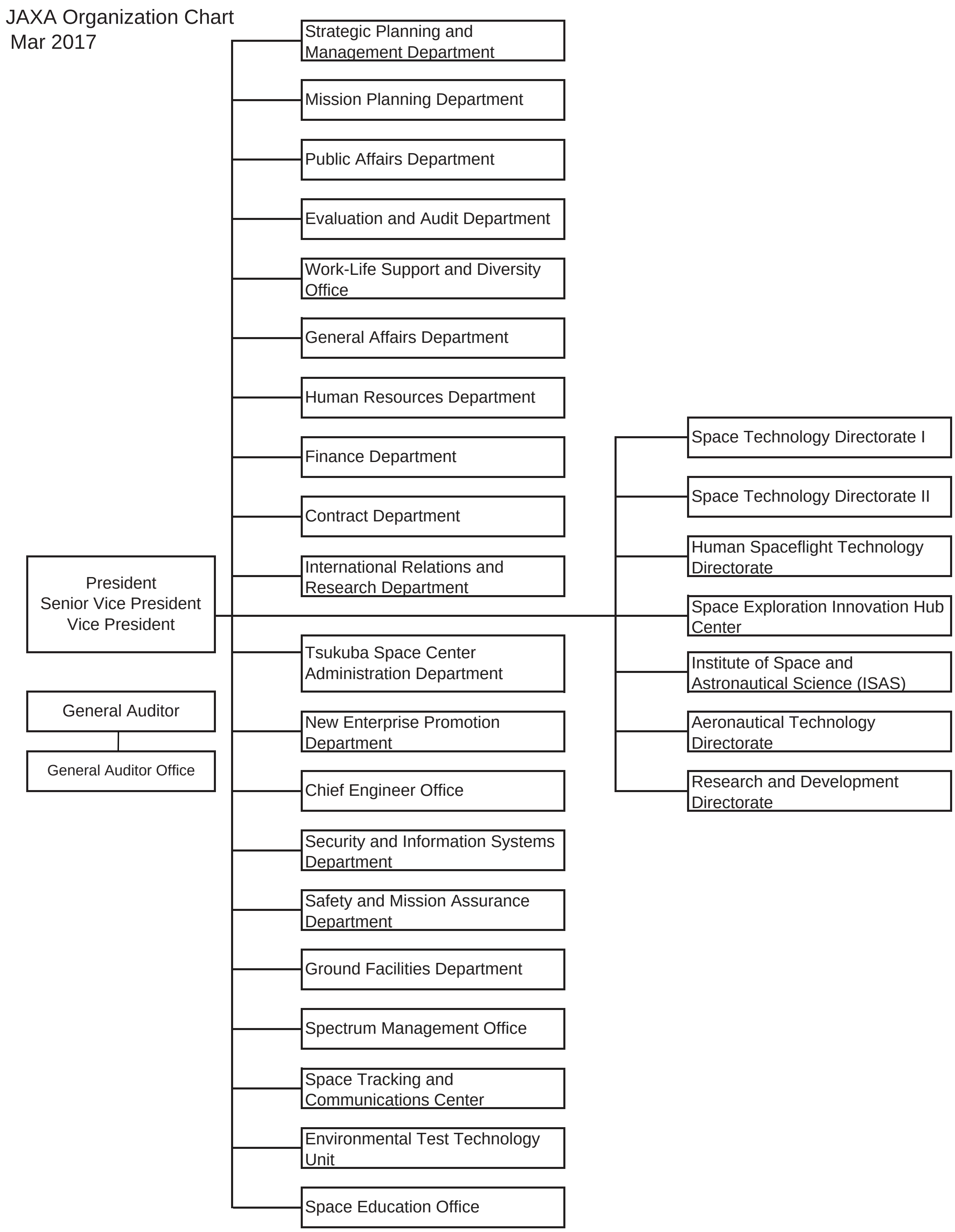
AOKI, Setsuko	Professor, Keio University
OKADA, Kiyotaka	Specially Appointed Professor, Faculty of Agriculture, Ryukoku University
OKADA, Yasunobu	President, The Graduate University for Advanced Studies (SOKENDAI)
OKAMURA, Sadanori	Professor, Faculty of Science and Engineering, Hosei University
KAWAI, Maki	Director General, Institute for Molecular Science, National Institutes of Natural Sciences
KITAGAWA, Genshiro	President, Research Organization of Information and Systems
(Chairman) KONO, Michikata	Professor Emeritus, The University of Tokyo
GONOKAMI, Makoto	President, The University of Tokyo
KOBATAKE, Hidefumi	Principal, Kaetsu Ariake Junior and Senior High School, Kaetsu Gakuen Educational Association
SATO, Katsuhiko	Director, Research Center for Science Systems, Japan Society for the Promotion of Science
TAKEDA, Hiroshi	President, Kobe University
TSUCHIYA, Kazuo	Professor Emeritus, Kyoto University
NAGAHARA, Hiroko	Professor, Graduate School of Science, The University of Tokyo
HAYASHI, Masahiko	Director General, National Astronomical Observatory of Japan, National Institutes of Natural Science
FUJII, Ryoichi	President Nomination Committee, Research Organization of Information and Systems
MATSUMOTO, Hiroshi	President, RIKEN
(Vice-Chairman) MIYAMA, Shoken	Specially Appointed Professor, Hiroshima University
MUROYAMA, Tetsuya	Commentator, Japan Broadcasting Corporation (NHK)
YASAKA, Tetsuo	Professor Emeritus, Kyushu University
YASUOKA, Yoshifumi	Director, Center for Environmental Remote Sensing, Chiba University

(Note) The term is from April 1, 2015 to March 31, 2017.

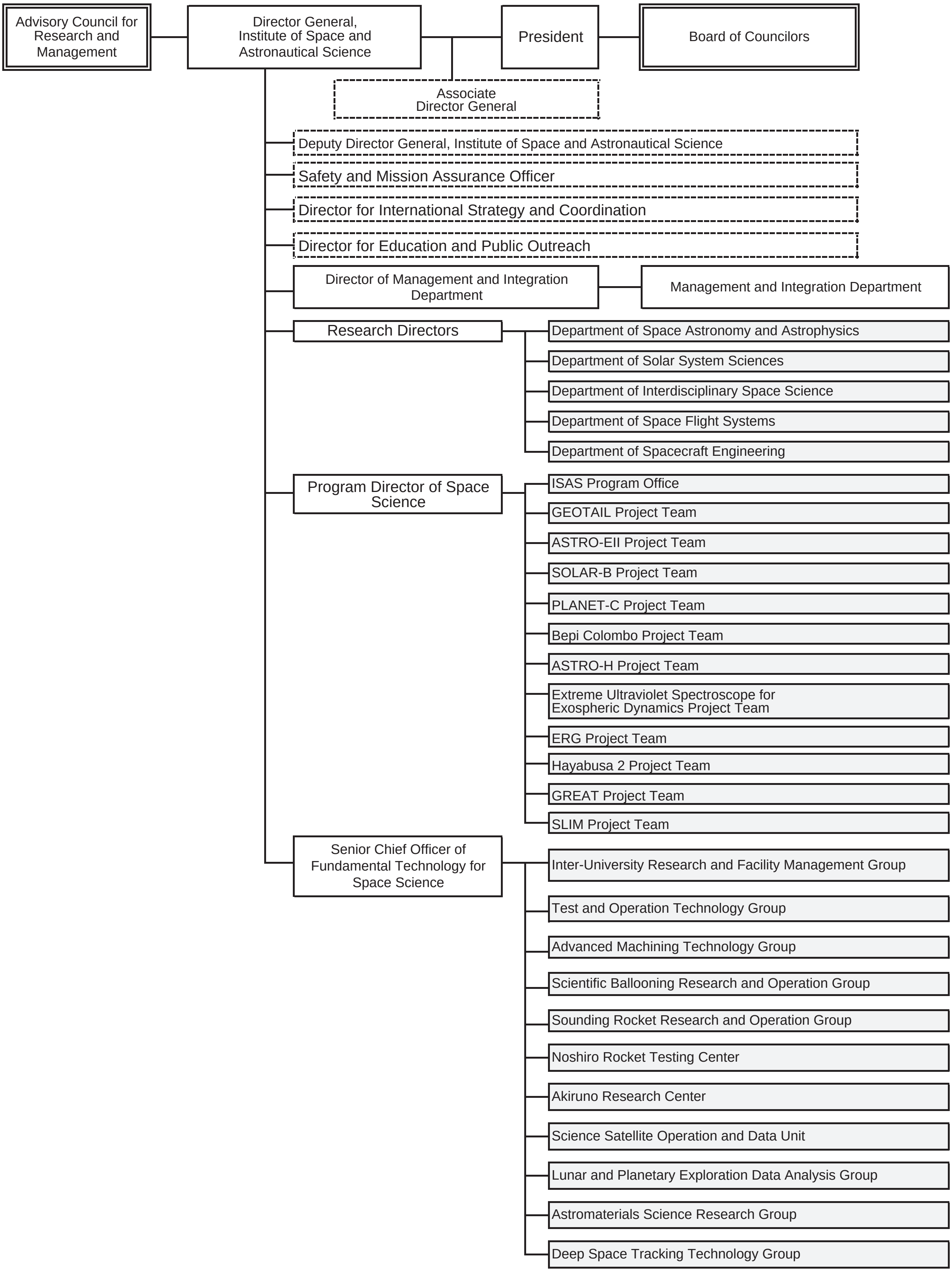
Members of Advisory Council for Research and Management (as of March 31, 2017)

ISHIHARA, Akihiko	Professor, Graduate School of Human and Environmental Studies, Kyoto University
KOBAYASHI, Hideyuki	Vice-Director General, National Astronomical Observatory of Japan, National Institutes of Natural Sciences
SAWADA, Keisuke	Professor, Graduate School of Engineering, Tohoku University
TAKEDA, Nobuo	Vice President, The University of Tokyo
NAKASUKA, Shinichi	Professor, Graduate School of Engineering, The University of Tokyo
NAGAHARA, Hiroko	Professor, Graduate School of Science, The University of Tokyo
(Vice-Chairman) FUJII, Ryoichi	President Nomination Committee, Research Organization of Information and Systems
HORI, Yoichi	Professor, Graduate School of Frontier Sciences, The University of Tokyo
MAKISHIMA, Kazuo	Group Director, Global Research Cluster, RIKEN
YAMAMOTO, Satoshi	Professor, Graduate School of Science, The University of Tokyo
WATANABE, Sei-ichiro	Professor, Graduate School of Environmental Studies, Nagoya University
[ISAS]	
ISHIOKA, Noriaki	Director, Department of Interdisciplinary Space Science
(Chairman)	
INATANI, Yoshifumi	Deputy Director General
KUBOTA, Takashi	Professor, Department of Spacecraft Engineering
SATO, Eiichi	Director, Department of Space Flight Systems
TAKAHASHI, Tadayuki	Professor, Department of Space Astronomy and Astrophysics
DOTANI, Tadayasu	Director, Department of Space Astronomy and Astrophysics
FUJIMOTO, Masaki	Director, Department of Solar System Sciences
MITSUDA, Kazuhisa	Research Director
MORITA, Yasuhiro	Professor, Department of Space Flight Systems
YAMADA, Takahiro	Director, Department of Spacecraft Engineering

(Note) The term is from April 1, 2015 to March 31, 2017.


JAXA Organization Chart
Mar 2017
President
Senior Vice President
Vice President
General Auditor
General Auditor Office
Strategic Planning and Management Department
Mission Planning Department
Public Affairs Department
Evaluation and Audit Department
Work-Life Support and Diversity Office
General Affairs Department
Human Resources Department
Finance Department
Contract Department
International Relations and Research Department
Tsukuba Space Center Administration Department
New Enterprise Promotion Department
Chief Engineer Office
Security and Information Systems Department
Safety and Mission Assurance Department
Ground Facilities Department
Spectrum Management Office
Space Tracking and Communications Center
Environmental Test Technology Unit
Space Education Office
Space Technology Directorate I
Space Technology Directorate II
Human Spaceflight Technology Directorate
Space Exploration Innovation Hub Center
Institute of Space and Astronautical Science (ISAS)
Aeronautical Technology Directorate
Research and Development Directorate

ISAS Organization Chart
Mar 2017



c. Staff (as of March 31, 2017)

Director General, Institute of Space and Astronautical Science
TSUNETA, Saku

Deputy Director General, Institute of Space and Astronautical Science
INATANI, Yoshifumi

Management and Integration Department Director
SASAKI, Hiroshi

Management and Integration Department
Advisor to the Director **OMI, Natsuki**
SAKAMOTO, Yasutoshi
SAGE, Chiaki

Manager for Management and Integration Department
AOYAGI, Takashi
MIHO, Kazuyuki
TSUJI, Hiroji

Director for International Strategy and Coordination
YAMADA, Toru

Director for Education and Public Outreach
IKUTA, Chisato

Research Director
MITSUDA, Kazuhisa

Department of Space Astronomy and Astrophysics Director
DOTANI, Tadayasu

Department of Solar System Sciences Director
FUJIMOTO, Masaki

Department of Interdisciplinary Space Science Director
ISHIOKA, Noriaki

Department of Space Flight Systems Director
SATO, Eiichi

Department of Spacecraft Engineering Director
YAMADA, Takahiro

Safety and Mission Assurance Officer
KOBAYASHI, Ryoji

Program Director of Space Science
KUBOTA, Takashi

ISAS Program Office Director
MAEJIMA, Hironori

GEOTAIL Project Team Project Manager
SAITO, Yoshifumi

ASTRO-EII Project Team Project Manager
ISHIDA, Manabu

SOLAR-B Project Team Project Manager
SHIMIZU, Toshifumi

PLANET-C Project Team Project Manager
NAKAMURA, Masato

Bepi Colombo Project Team Project Manager
HAYAKAWA, Hajime

ASTRO-H Project Team Project Manager
KUBOTA, Takashi

Extreme Ultraviolet Spectroscope for Exospheric Dynamics Project Team Project Manager
YAMAZAKI, Atsushi

ERG Project Team (Exploration of Energization and Radiation in Geospace) Project Manager
SHINOHARA, Iku

Hayabusa2 Project Team Project Manager
TSUDA, Yuichi

GREAT Project Team Project Manager
NUMATA, Kenji

SLIM Project Team Project Manager
SAKAI, Shinichiro

Senior Chief Officer of Fundamental Technology for Space Science
HIROSE, Kazuyuki

Inter-University Research and Facility Management Group Manager
YOSHIDA, Tetsuya

Test and Operation Technology Group Manager
SHIMOSE, Shigeru

Advanced Machining Technology Group Manager
OKADA, Norio

Scientific Ballooning Research and Operation Group Director
YOSHIDA, Tetsuya

Sounding Rocket Research and Operation Group Director
ISHII, Nobuaki

Noshiro Rocket Testing Center Manager
ISHII, Nobuaki

Akiruno Experiment Lab Manager
HABU, Hiroto

Science Satellite Operation and Data Archive Unit Director
TAKESHIMA, Toshiaki

Lunar and Planetary Exploration Data Analysis Group Manager
OOTAKE, Hisashi

Astromaterials Science Research Group Manager
YURIMOTO, Hisayoshi

Deep Space Tracking Technology Group Manager
YAMADA Takahiro

Department of Space Astronomy and Astrophysics [Director : DOTANI, Tadayasu]

Professor	Associate Professor	Assistant Professor
MITSUDA, Kazuhisa	YAMASAKI, Noriko	MAEDA, Yoshitomo
DOTANI, Tadayasu	KOKUBUN, Motohide	WATANABE, Shin
TAKAHASHI, Tadayuki	KII, Tsuneo	TAKEI, Yoh
ISHIDA, Manabu	KATAZA, Hirokazu	TSUJIMOTO, Masahiro
NAKAGAWA, Takao	YAMAMURA, Issei	WADA, Takehiko
MATSUHARA, Hideo	KAWADA, Mitsunobu	SAKIMOTO, Kazuhiro
TSUBOI, Masato	IWATA, Takahiro	DOI, Akihiro
EBISAWA, Ken	KITAMURA, Yoshimi	TAMURA, Takayuki
YAMADA, Toru	MURATA, Yasuhiro	ICHIMURA, Atsushi [F]
TAKADA, Masahiro[V]	SIMONESCU, Aurora	
OHASHI, Takaya [V]	NAKANISHI, Hiroyuki [V]	
SHIBAI, Hiroshi [V]		
HASUMI, Masashi[V]		
MATSUURA, Shuji[V]		
TASHIRO, Makoto[V]		

Department of Solar System Sciences [Director: FUJIMOTO, Masaki]

Professor	Associate Professor	Assistant Professor
FUJIMOTO, Masaki	ABE, Takumi	ASAMURA, Kazushi
SATO, Takehiko	SAITO, Yoshifumi	YOKOTA, Shoichiro
HAYAKAWA, Hajime	MATSUOKA, Ayako	HASEGAWA, Hiroshi
NAKAMURA, Masato	TAKASHIMA, Takeshi	YAMAZAKI, Atsushi
YURIMOTO, Hisayoshi [S]	TANAKA, Satoshi	HARUYAMA, Junichi
WATANABE, Sei-ichiro [V]	OKADA, Tatsuaki	OHTAKE, Makiko
KURAMOTO, Kei [V]	ABE, Masanao	SHIRAISHI, Hiroaki
YOSHIKAWA, Ichiro [V]	SAKAO, Taro	HAYAKAWA, Masahiko
WATANABE, Tetsuya [V]	SHIMIZU, Toshifumi	MITANI, Takefumi
NAKAMURA, Tomoki[V]	OZAKI, Masanobu	
	SHINOHARA, Iku	
	ENYA, Keigo	
	TASKER, Elizabeth	
	MIYOSHI, Yoshizumi [V]	
	TAKAGI, Masahiro [V]	
	KITAZATO, Kohei [V]	

Department of Interdisciplinary Space Science [Director : ISHIOKA, Noriaki]

Professor	Associate Professor	Assistant Professor
ISHIOKA, Noriaki	KUROTANI, Akemi	MIURA, Akira
ISHIKAWA, Takehiko	HASHIMOTO, Hirofumi	YAMAMOTO, Yukio
YOSHIDA, Tetsuya	TAKAKI, Ryoji	IZUTSU, Naoki
INATOMI, Yuko	SAITO, Yoshitaka	FUKE, Hideyuki
ISHIKAWA, Hiroshi [V]	IKUTA, Chisato	YANO, Hajime
OKANO, Yasunori [V]	TAKANO, Yoshinori [V]	
HONMA, Masamitsu [V]		

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

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

Professor	Associate Professor	Assistant Professor
SATO, Eiichi	SAWAI, Shujiro	MORI, Osamu
INATANI, Yoshifumi	YAMADA, Tetsuya	TAKEMAE, Toshiaki
KAWAGUCHI, Junichiro	KAWAKATSU, Yasuhiro	MARU,Yusuke
ISHII, Nobuaki	FUNAKI, Ikkoh	SAIKI, Takanao
MORITA, Yasuhiro	NISHIYAMA, Kazutaka	YAMADA, Kazuhiko
KUNINAKA, Hitoshi	TOKUDOME, Shinichiro	KITAGAWA, Koki
SHIMADA, Toru	OYAMA, Akira	OKUIZUMI, Nobukatsu
HORI, Keiichi	NONAKA, Satoshi	TSUKIZAKI, Ryudo
MINESUGI, Kenji	GOTO, Ken	TOBE, Hirobumi
OGAWA, Hiroyuki	ISHIMURA, Kosei	
NAKAGAWA, Ichiro [V]	TSUDA, Yuichi	
FUJII, Kozo [V]	HABU, Hiroto	
YONEYAMA, Satoshi [V]	TAKEUCHI, Shinsuke	
FUNAZAKI, Kenichi [V]	NARUO, Yoshihiro [S]	
	KOBAYASHI, Hiroaki [S]	
	YOKOTA, Shigeru [V]	
	TANAKA, Hiroaki [V]	
	MORI, Koichi [V]	
	HIGUCHI, Takehiro [V]	
	MATSUI, Makoto [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
SAITO, Hirobumi	YOSHIKAWA, Makoto	BANDO, Nobutaka
KAWASAKI, Shigeo	TANAKA, Koji	OTSUKI, Masatsugu
HIROSE, Kazuyuki	TODA, Tomoaki	TOMIKI, Atsushi
HONJO, Kazuhiko [V]	YOSHIMITSU, Tetsuo	MAKI, Kenichiro
KASUU, Makoto [V]	MATSUZAKI, Keiichi	
SAKAKIBARA, Naoki [V]	TAKEUCHI, Hiroshi	
	OZAKI, Shingo [V]	
	MITA, Yoshiro [V]	
	FUNASE, Ryu [V]	

International Top Young Fellowship (ITYF)

Department	Name
Department of Space Astronomy and Astrophysics	INOUE, Yoshiyuki
Department of Solar System Sciences	PERALTA, Javier
Department of Solar System Sciences	CRITES, Sarah

[V] Visiting , [S] Specially-appointed

3. 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.

Aerial view of the Sagamihara Campus.

Main buildings at the Sagamihara Campus and beautiful views of the Tanzawa Mountains.

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: 73,001m²

Gross floor area : 57,570m²

Noshiro Rocket Testing Center

Location:

Asanai, Noshiro-city, Akita

lat. 40° 10′ 10″ N.

long. 139° 59′ 31″ E.

Site : 61,941m²

Gross floor area : 3,633m²

Akiruno Research Center

Location:

1918-1 Sugao, Akiruno-shi, Tokyo

lat. 35° 45′ 14″ N.

long. 139° 16′ 24″ E.

Site : 2,008m²

Gross floor area: 698m²

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: 718,662m²

Gross floor area : 19,090m²

Usuda Deep Space Center

Location:

1831-6 Omagari, Kamiodagiri, Saku-shi, Nagano

lat. 36° 07′ 59″ N.

long. 138° 21′ 43″ E.

Site: 97,111m²

Gross floor area: 3,089m²

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: 90,357m²

Gross floor area: 4,554m²

Tsukuba Space Center

Location:

2-1-1 Sengen, Tsukuba-shi, Ibaraki

Sagamihara Campus (ISAS)

4. Advisory Committees

ISAS has two advisory committees, the Advisory Committee for Space Science and the Advisory Committee for Space Engineering, whose 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, Advisory Committee for Space Biology and Microgravity Science, and Committee on Scientific Ballooning were also organized under the Advisory Committee for Space Science and the Advisory Committee for Space Engineering, while the Curation Technical Committee was established under the Advisory Committee for Space Science.

a. Advisory Committee for Space Science

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

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

By redefining four mission categories for space science projects—strategic large-class, competitive middle-class, strategic international, and small projects—the committee organized development phases for WG activities and provided phase execution procedures to advance mission proposals. In FY2016, the Advisory Committee for Space Science held a mission definition review jointly with the Advisory Committee for Space Engineering on the DESTINY+ plan, proposed as a competitive middle-class mission, and recommended approval to ISAS with certain conditions.

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.

Ongoing Working Groups

- Strategic large-class projects:
  - o ATHENA X-ray satellite WG
  - o Next-generation Solar Observation Satellite (SOLAR-C) WG
- Competitive middle-class projects:
  - o Asteroid/Moon Penetrator Plan (APPROACH-2) WG
  - o Broadband X-ray High-sensitivity Imaging Spectrometer (FORCE) WG
  - o Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES-2) WG
  - o High-z Gamma-ray Bursts for Unraveling the Dark Ages Mission (HiZ-GUNDUM) WG
  - o Small Astrometry Satellite for Infrared Exploration (Japan Astrometry Satellite Mission for Infrared Exploration, or JASMINE) WG
- Strategic international projects and small projects:
  - o Turbulence Heating ObserveR (THOR) WG
  - o Ultraviolet spectrum observation in extrasolar planets WG
  - o Nucleation of cosmic dust WG
  - o LargE Area burst Polarimeter (LEAP) for ISS WG
  - o WFIRST WG
  - o Circumpolar Stratospheric Telescope (FUJIN) WG
  - o Wide-field Monitoring of Transient Astronomical Objects (Wide-Field Monitoring of All-sky X-ray Image, or WF-MAXI) WG
  - o Exploration Project of Anti-particles from Cosmic Rays (i.e., GAPS) WG
  - o Extreme Universe Space Observatory onboard Japanese Experiment Module (JEM-EUSO) WG
  - o MARS 2020 Life-form Probe Microscope WG

Working Groups Advancing to Next Phase in FY2016

LiteBIRD was approved for Phase A1 starting in September 2016. It is an international collaboration with US and Canada. The LiteBIRD WG transitioned to a pre-project planning team.

Working Groups Completed in FY2016

- Ultra-wide and Deep Survey Satellite (Wide-field Imaging Surveyor for High-redshift, or WISH) WG
- Exploration and Study of Martian Atmospheric Escape WG
- Small Gravitational Wave Observation Satellite (DECIGO Path Finder, or DPF) WG
- Dark Baryon-exploring Satellite (Diffuse Intergalactic Oxygen Surveyor, or DIOS) WG
- Satellite Mission for X-ray Polarimetry (PRAXyS) WG

Achievements and Impacts

Notable results are listed below.

- The JASMINE WG developed a robust and insulated detector box that requires a low-temperature infrared detector (170 K) to be installed in a way that isolates it from vibrations. The WG tested the prototype of the carburetor and heat pipe in a simulated environment and achieved the performance targets. The JASMINE detector is expected to be used for many missions in the future.

- The GAPS WG developed the manufacturing technology for a lithium-drift type silicon semiconductor detector. Although it is potentially cheaper and achieves higher resolution, it is thicker and larger than detectors made with high-purity silicon and germanium, but it does not yet benefit from mass production. In the FY2016 study, the GAPS WG made a prototype with the goal of fully renovating the manufacturing method and improving the defect rate while reducing costs. The WG submitted a small-project mission proposal in FY2016.
- The SOLAR-C WG planned to participate in the International Balloon Solar Observation Plan, SUNRISE-3, so it improved the accuracy of the wavelength plate rotation drive mechanism, which is key in polarization spectroscopy for magnetic field measurements of the chromosphere layer region as a spin-off result. The WG submitted a small-project mission proposal in FY2016.
- To provide a correction lens to the space-line observation plan of Russia, the JEM-EUSO WG made a prototype using a production technique unique in Japan. The WG submitted a small-project mission proposal in FY2016.
- The LiteBIRD WG, which submitted a mission proposal in FY2015, proceeded to Phase A1 activities as an ISAS pre-project preparatory team.

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).

In FY2016, all nine proposals were adopted in the areas of gravity waves (1 proposal), high-energy astronomy (4), infrared astronomy (1), outer planets and planetary exploration (2), and solar sphere (1). These proposals represent the following achievements: (1) development of technology enabling high-sensitivity measurement of a required thruster's small force noise, as required for the realization of gravitational wave observation in spacecraft; (2) fabrication of a scintillation camera using a new detector array to advance MeV gamma-ray astronomy; (3) development of an element for high-dispersion observation in the intermediate infrared region, which may bring about a breakthrough in astrochemistry; and (4) fabrication of a system that enables low-cost EUV spectroscopy by using a complementary metal-oxide-semiconductor (CMOS).

b. 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 engineering of hardware used to reach, travel in, and perform experiments in space.

1. Notable Achievements

- The Advisory Committee for Space Engineering proposed the DESTINY WG's “DESTINY+” plan as a competitive medium-scale mission to strengthen mission scenarios and improve the feasibility of fly-by observations. After the MDR, the Advisory Committees for Space Science and Space Engineering recommended advancement to Phase A1 as a medium-scale mission candidate.
- The WG for R&D on an innovative atmospheric-entry system using membrane aeroshell developed an expandable flexible aeroshell that can be applied to small earth-feedback machines and a Martian lander. The EGG microsatellite was launched and operated by the ISS for demonstration in orbit.
- The hybrid rocket research WG demonstrated the superiority of a unique boundary-layer-combustion hybrid rocket by numerical computations and trial tests, and then proposed a plan-of-flight demonstration as a small-scale mission.
- The research group for studies on a frequently reusable space transportation system has conducted research on a reusable system's intelligence, weight reduction, altitude compensating nozzle, and integrated propulsion systems, and has identified key technical issues for application to an experimental machine system.
- The research group for demonstration research on advanced solid propellant rocket system succeeded in the development of the N_2O/ethanol two-component ignition system aimed at advancing the Epsilon rocket, achieved altitude performance using an upper-stage propulsion system by performing an engine-mounted igniter and vacuum combustion test, and conducted research on non-destructive testing techniques for solid propellant mixtures and laser ignition of highly energetic, ammonium dinitramide-based ionic liquids.
- The research group for a large high-precision telescope mount developed a prototype of a large-scale low-thermal-expansion CFRP honeycomb core, controlled a 4-m-class deployable truss in movement increments on the order of arcseconds, and developed and tested a shape-adjustment smart actuator model for a smart optical bench.
- In research on a detonation-based propulsion system, a rotational detonation system for flight experiments was developed that achieved 180% of the planned thrust under low back-pressure (895 N) and 91% (299 s) of the

planned specific impulse (330 s under high vacuum). In addition, visualization of the detonation wave in a rotational detonation disk was achieved for the first time by the Schlieren method.

- An effective result was obtained with fewer resources by using a spacecraft that had completed a mission, such as a trend-analysis on the lithium-ion battery mounted on the REIMEI satellite, which had been on orbit for 11 years.

The Achievements that have been publicly released include 62 papers, 114 presentations at international academic conferences, 292 presentations at domestic academic conferences, 11 invited speeches, 7 patents, 3 published books, and 9 other media reports (including press releases). Nine awards were received for strategic R&D work.

2. 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.

<u>Working Groups</u>

- Demonstration and Experiment of Space Technology for INterplanetary voYage (DESTINY) WG
- WG on sample return research in collaboration with missions of foreign space agencies
- Hybrid rocket research WG
- WG for R&D on the innovative atmospheric-entry system using membrane aeroshell

<u>Operations</u>

- Engineering research using the REIMEI satellite
- IKAROS operation
- PRoximate Object Close flYby with Optical Navigation (PROCYON) operation

<u>Studies on Basic Hardware Technologies</u>

- Studies on landing dynamics
- Demonstration research on advanced solid propellant rocket system
- R&D on Mars airplane
- Research on innovative satellite bus technology
- Research on an innovative detonation-based propulsion system for sounding rockets and landers
- Research on a large high-precision telescope mount
- Studies on an innovative thermal control system
- Research on an innovative parafoil-type vehicle for Mars exploration
- Studies on an aerial launch platform
- R&D on crushable structure for flexible landing and exploration missions
- Studies on frequently reusable space transportation system
- Study on the inertial platform for payloads of ISAS/JAXA sounding rockets
- Observation of phase transition phenomena in superfluid helium in microgravity environment
- Research on rover for exploration of small bodies, moons, and planets
- Development of micro ion thrusters for payloads for chemical -free satellites
- Demonstration of a super-pressure balloon for long-duration flight

5. Professors Emeriti (As of March 31, 2017)

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, Nobuhi
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

IV
Budget

Budget

(in ￥1,000)

ISAS Budget	FY2014	FY2015	FY2016
Operating Expense Grants	19,539,665	2,050,783	16,628,159
Facility maintenance subsidy	83,904	439,224	0
Total	19,623,569	20,947,061	16,628,159

External Funds

Grant-in-aid for scientific research (KAKENHI)	505,675	3,331,148	340,376
Grant-in-aid for scientific research (Accepted share of expenses)	49,205	62,634	65,448
Funded research	428,613	619,484	989,804
Cooperative research with private sector	47,139	395,184	40,793
Earmarked donations	15,769	11,282	4,620

V
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 fiscal FY2016. The new international collaboration initiatives for current missions include a cooperative agreement with the Indian Space Research Organization (ISRO) on radio occultation observation using the Venus Climate Orbiter AKATSUKI, and the cooperation of the American and European space agencies in the investigation into the failure of the X-Ray Astronomy Satellite ASTRO-H, the mission of which was terminated on April 28, 2016. We have provided our international counterparts with periodic updates on ASTRO-H-related investigations.

As for missions under development, we continued working on the joint-mission Japanese-European BepiColombo project with the European Space Agency (ESA), and there is also a mission under consideration (in parallel with the investigation into the cause of the ASTRO-H satellite incident) to launch the X-ray Astronomy Recovery Mission. A number of discussions have been held with our international partners to make arrangements for this. For example, in cooperation with the US National Aeronautics and Space Administration (NASA), which provided ASTRO-H's soft X-ray spectrometer, we jointly reviewed and summarized the lessons learned from the incident, and both parties collaborated closely to develop a new mission in parallel with the recovery mission. ISAS has also deliberated with our European collaborators on Space Infrared Telescope for Cosmology and Astrophysics (SPICA), the next-generation infrared observation telescope satellite, which is another prospective strategic large-scale mission, in addition to other ESA-led projects, such as the Jupiter Icy Moons Exploration (JUICE) project and the Advanced Telescope for High ENergy Astrophysics (ATHENA) X-ray astronomy satellite.

Our efforts to deliberate on and arrange international collaboration and joint development have also extended to ISAS's other prospective strategic large-scale missions, such as the Martian Moons eXploration project (MMX), the Lite (Light) Satellite for the Studies of B-mode Polarization, and Inflation from Cosmic Background Radiation Detection (LiteBIRD) project, as well as the Jupiter Trojan Asteroid Exploration project that will use a solar power sail orbiter.

ISAS has also pursued international collaboration in our scientific ballooning and sounding rocket projects, and have signed an agreement for the former on the exchange of technology and information on scientific balloons with the Centre National D'études Spatiales (CNES), the French government space agency.

We have also been proactive in ongoing discussions with other international agencies aimed at facilitating the collaboration necessary to pursue the aforementioned projects. In June 2016, the ISAS Director General traveled to Washington D.C. to meet with G. Yoder, NASA's Deputy Associate Administrator for the Science Mission Directorate, and P. Hertz, NASA's Astrophysics Director. The main subject of discussion was the ASTRO-H satellite.

Back in Tokyo, the ISAS Director General met with Board member G. Gruppe of the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German aerospace center, in the JAXA Tokyo office, where they discussed future collaboration through the MMX and other projects. In July, a meeting on the MMX project was held in Tokyo between

J. Y. Le Gall, President of CNES, and the ISAS Director General, and in August the Director General and other members of ISAS paid a visit to the US Goddard Space Flight Center where they discussed the ASTRO-H and its recovery mission with Hertz and his NASA colleagues.

That same month, a meeting was held at ISAS between the Director General and F. Favata, Head of the ESA Programme Coordination Office, where the main topic was also the HITOMI satellite. Other meetings with NASA officials were held in Washington D.C. and the Goddard Space Flight Center in September, during which the ISAS Director General held discussions with Yoder, Hertz, and others about alternatives to the ASTRO-H project.

In October, the ISAS Director General met with DLR Board Member H. Dittus in the Tokyo office on the subject of MMX collaboration, and in December, the Director General and other ISAS officials visited the US Jet Propulsion Laboratory (JPL) and NASA headquarters to discuss future collaboration with JPL administration officers as well as with T. Zurbuchen, NASA's Associate Administrator for the Science Mission Directorate.

In February 2017, the Director General and other ISAS members held separate meetings at the ESA with A. Giménez Cañete, Director of Science, and D. Parker, Director of Human Spaceflight and Robotic Exploration, as well as at CNES with President J. Y. Le Gall and L. Suchet, Director General of CNES. Those meetings were held to exchange opinions about future collaboration, primarily with the MMX project and the X-ray Astronomy Recovery Mission. Upon returning to Tokyo, the Director General met with DLR Board Member Dittus in the JAXA Tokyo office to talk about future collaboration through the MMX, the second Demonstration and Experiment of Space Technology for INterplanetary voYage (DESTINY) mission named "DESTINY+", and other projects.

a. International cooperation in satellite missions at the operational stage

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
Magnetosphere 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 resolutions 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 (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)	ISRO "ASTROSAT" satellite and cooperative observations. (Under discussion)

Solar Physics Satellite HINODE (SOLAR-B)	Sep23,2006	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 (EU), NSC (Norwegian Space Centre)	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 (EU)	Participation of ESA Venus Express team researchers in cooperative research.
			ISRO (Indian Space Research Organization)	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 “1999 JU3” 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 (GER)	Hayabusa2 tracking support, microgravity experiment support.
			Department of Industry and Science, Australian Defence Organisation	Permission for sample reclamation capsule landing in Australia and landing operations support.
X-ray Astronomy Satellite ASTRO-H	Feb 17, 2015 (Operations discontinued on Apr 28, 2015)	A joint Japan–US–EU scientific satellite mission, with the goal of performing highest sensitivity X-ray observations of high-energy phenomena such as supernovae, the surroundings of black holes, and galaxy clusters rich in high temperature plasma to explore the structure and evolution of the cosmos.	NASA (USA)	Provision of the X-ray Micro-Calorimeter Sensor, Soft X-ray Telescope, etc.
			Stanford Univ. (USA)	Technical assistance for developing the Soft-Gamma ray Detector (SGD).
			ESA (EU)	Provision of high-voltage power supply devices, etc., for observation equipment.
			SRON (Netherlands Institute for Space Research)	Provision of filter wheels, etc., for the X-ray Micro-Calorimeter.
			DIAS (Dublin Institute for Advanced Studies, Ireland)	Participation of DIAS researchers as ASTRO-H scientific advisors.
			CSA (Canada)	Provision of Canadian Alignment Measurement System (CAMS) for the Hard X-ray Telescope (HXT)
			APC/CEA/IRFU (France)	Technical support for development of the Hard X-ray Detector.

Cooperative projects with overseas satellite missions

Project	Launch	Mission overview	Leading organization	Responsibilities
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)	Nov 21, 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	Sep 29, 2013	STSAT-3 is used for atmospheric observations and environmental monitoring, as well as galaxy observations.	KASI (Korea Astronomy and Space Science Institute)	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	FY2018 (planned)	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 (EU)	MPO development, rocket launch, etc.
			CNES (National Centre for Space Studies, 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)	Provision of Magnetic Field Measurement (MGF) device on MMO.
			SNSB (Swedish National Space Board)	Provision of Energetic Neutral Atom (ENA), and Mercury Electric Field In-Situ Tool (MEFISTO) electric field measuring instrument.
			FSA (Russian Federal Space Agency)	Provision of the Mercury Sodium Atmosphere Spectral Imager (MSASI) on MMO.
			DLR (German Aerospace Center)	Provision of the equipment for the ion mass analyzer on MMO.

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

Project	Launch	Mission overview	Cooperating 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 (EU)	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 (EU)	Under discussion
Mars Moon eXploration (MMX)Mission (internal pre-production preparation team)	TBD	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 (EU)	Under discussion
			DLR (Germany)	Under discussion

Solar Power Sail-craft (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
			CNES (France)	Under discussion
			NASA (USA)	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)	Under discussion

Cooperative projects with overseas satellite missions

Jupiter Icy Moon 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 (EU), DLR (Germany), etc.	Under discussion
Advanced Telescope for High ENergy Astrophys- ics 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 (EU)	Under discussion

d. International cooperation in scientific missions for space environment utilization

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
JEM-mounted Monitor of All-Sky X-ray imager MAXI	Jul 2009	MAXI will use the Exposed Facility of the Japanese Experiment Module (JEM) “Kibo” on the International Space Station to constantly monitor X-ray objects in non-atmospheric space, thereby capturing impossible-to-predict celestial objects.	Swift Satellite Team (USA, UK, etc.)	Co-observation with Swift satellite.
JEM-mounted Superconducting Submillimeter-Wave Limb-Emission Sounder JEM/SMILES	Sep 2009	JEM/SMILES will use the Exposed Facility of the Japanese Experiment Module (JEM) “Kibo” on the International Space Station to perform high-sensitivity measurements of trace molecules in the stratosphere, thereby elucidating their global-scale distribution and variation.	NASA (USA), NCAR (National Center for Atmospheric Research (USA)	Provision of meteorological analysis data (NASA), provision of chemical transport model calculation data (NCAR).

Cooperative projects with overseas satellite missions

Project	Launch	Mission overview	Leading organization	Responsibilities
Ground-based joint research relating to materials science	Apr 2015	This is a joint analysis project for mixed-crystal semiconductors formed in microgravity environments and returned to Earth via a Chinese recovery satellite.	SICCAS (Shanghai Institute of Ceramics, Chinese Academy of Sciences)	Cooperative analysis of returned crystals by JAXA and SICCAS (planned).
Japan–India joint life science experiment	TBD	This project will use an Indian recovery satellite (the Space Capsule Recovery Experiment [SRE2]) to perform experiments on algae grown in a microgravity environment to contribute to research on the effects of space environments on life.	ISRO (India)	JAXA providing microbial culture laboratory equipment (planned).

e. International cooperation in observational rocket experiments

Project	Experiment Overview	Cooperating partner	Responsibilities
Norwegian sounding rocket experiment ICI-4	In situ observations of regions of plasma disturbance and simultaneous acquisition and analysis of the obtained data, aimed at comprehensively understanding plasma density disturbance phenomena that occur in dayside cusp regions.	Univ. of Oslo (Norway)	JAXA providing electron density disturbance measuring instrument and the Low Energy Particle Electron Spectrum Analyzer
Chromospheric Lyman-Alpha SpectroPolarim-eter CLASP	A device for polarization spectroscopy of Lyman α-lines (vacuum ultraviolet region hydrogen-emitted spectral lines with a bright-line wavelength of 121.6 nm) emitted from the solar chromosphere and transition layers (the thin layer between the chromosphere and the corona), launched into space via a sounding rocket.	NASA (USA)	Provision of sounding rocket launch, onboard scientific computer, and charge-coupled device (CCD) camera.
		CNES (France)	Provision of diffraction grating.
		Univ. of Oslo (Norway)	Chromosphere atmospheric structure model calculation.
		Instituto de Astrofísica de Canarias (Spain)	Hanle effect model calcula-tions.

f. International cooperation in atmospheric balloon experiments

Project	Experiment Overview	Cooperating partner	Partner responsibilities
Japan–Brazil joint balloon experiment	In situ observations of regions of plasma disturbance and simultaneous acquisition and analysis of the obtained data, aimed at comprehensively understanding plasma density disturbance phenomena that occur in dayside cusp regions.	INPE (Brazilian National Institute for Space Research)	Flight operations and reclamation of balloon and observational equipment.
Japan–US Joint balloon experiment BESS/BESS-II (Balloon-borne Experiment with a Superconducting Spectrometer)	A joint Japan–US experiment performing cosmic particle beam observations using a balloon-mounted superconductingspectrometer to explore elementary particle phenomena in the early universe through precise observations of cosmic ray antiparticles.	NASA (USA)	Operation of balloon experiments, scientific equipment upgrades, etc.
Japan–India joint balloon experiment	An Indian large-diameter 1-m balloon-borne telescope equipped with a high-sensitivity JAXA Fabry–Pérot spectrometer to conduct far-infrared observations of the spectral mappings of star-forming regions.	Tata Institute of Fundamental Research (India)	Operation of balloon experiments, etc.

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 wideranging cooperative relations, starting with the development of marine reclamation technologies.	CNES (France)	Provision of information pertaining to long-term tracking of balloon system after splashdown.
Japan–Indonesia tropical atmosphere cooperative research	Comprehensive research through various observations of atmospheric movement and chemical processes from the tropical troposphere layer (TTL) to the stratosphere	LAPAN (Indonesia)	Provision of appropriate facilities for observation and monitoring and obtaining permission for research within Indonesia.
Japan-Australia balloon joint experiment	A joint ballon experiment and space science research with long-time flight and the retrieve 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

g. 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

Aiming for the ISAS-centered space science community to continuously yield achievements from cutting-edge research, 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.

Regarding centers for inter-university collaboration, the ERG science center at the Solar-Terrestrial Environment Laboratory, which was established in 2013 in collaboration with Nagoya University, enabled efficient data management in FY2016. ISAS has contributed to the establishment of a new center for inter-university collaboration through a strategy for cooperative solar system exploration. In FY2015, proposals were selected from (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) from the University of Tokyo Graduate School of Science for construction of a system to promote planetary exploration using ultra-small probes. Activities have been initiated based on the selected proposals. ISAS also cooperates with the University of Aizu in data analysis, Okayama University in curation, and Iwate University in advanced machining technology.

To bring more academic and non-Japanese researchers into the inter-university research system, and to make the campus a core of space science research, ISAS has been making effort to improve an application system for researchers, such as travel expenses, overnight accommodations, and a support system for the daily lives of non-Japanese researchers.

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)	2	74,620
Scientific Research (S)	1	21,320
Scientific Research (A)	9	72,410
Scientific Research (B)	18	92,062
Scientific Research (C)	17	26,490
Challenging Exploratory Research	8	15,835
Young Scientists (A)	1	5,590
Young Scientists (B)	15	22,270
Research Activity start-up	4	5,200
JSPS Fellows	4	4,580
Total	79	340,377

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)	4	18,915
Scientific Research (S)	3	33,670
Scientific Research (A)	11	9,295
Scientific Research (B)	8	3,185
Scientific Research (C)	3	383
Total	29	65,448

b. Funded Research

Number of Researches	Total (in 1,000 JPY)
20	989,804

c. Cooperative Research with Private Sector

Number of Researches	Total (in 1,000 JPY)
31	40,793

d. Earmarked Donations

Number of Researches	Total (in 1,000 JPY)
8	4,620

4. Domestic Joint Research

a. Open Facilities for Domestic Joint Research

	Number of joint research
Space Chamber test equipment	19
Ultra-high-speed collision test equipment	28
Space radiation equipment	8
Wind tunnel laboratory	26
Planetary atmospheric entry environment simulator	11
JAXA supercomputer	30

b. Research for promoting international missions

	Number of joint research
	4

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

	Number of joint research
	46

VI
Education and Public Outreach

1. Graduate Education

At ISAS, educational staff appointed by universities as professors, associate professors, and research associates 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, 2017)

School or Program	Professors	Associate professors	Research associates	Total
The Graduate University for Advanced Studies	15	40	20	75
The Graduate School at the University of Tokyo				
School of Science/	7	5	8	20
School of Engineering	11	4	11	26
Special Inter-Institutional Research Fellows*	7	5	–	12
Cooperative Graduate School*	7	11	2	20

* 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.

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. Educational staff from ISAS also teach at SOKENDAI, instructing students in 5-year doctoral programs and other courses.

SOKENDAI Department of Space Science Admissions in FY2016

Admission month	Admission capacity	Applicants	Accepted applicants
October	5	2	1
April		12	5*

*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. Educational 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. Special Inter-Institutional Research Fellows and Technical Trainee

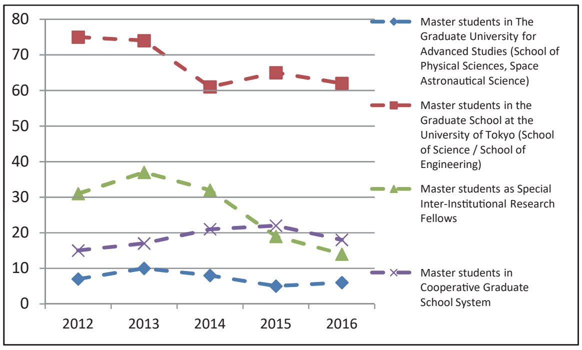
In the Special Inter-Institutional Research Fellows system, ISAS accepts students from national, public, and private universities throughout Japan who need advice on their university-sponsored research, and provides education and guidance on specific research themes for limited periods. These activities 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.

JAXA also accepts technical trainees in all directorates to prepare researchers and engineers who are not on a graduate education track. These activities are coordinated by the Management and Integration Department. When a technical trainee system was started in the former National Aerospace Laboratory of Japan, the target was researchers and engineers in private companies, related institutions, and universities. JAXA redefined this program for training students at the request of universities. ISAS too accepts and trains students from both Japanese and foreign universities by request.

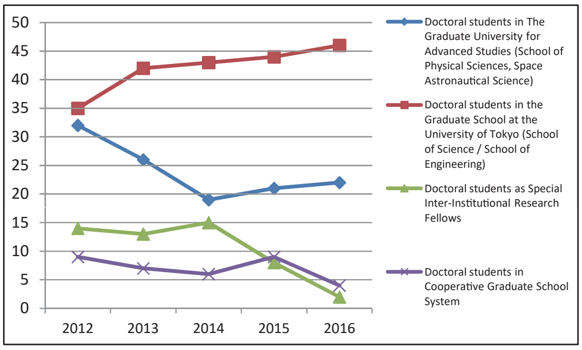
d. Cooperative Graduate School System

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

As of March 31, 2017, ISAS was cooperating with 11 schools in 10 universities and accepts, teaches, and trains master's and doctoral degree students. In some schools, we cooperate with other JAXA directorates.



Number of students receiving education for a master's degree



Number of students receiving education for a doctoral degree

2. Public Outreach

Targeted investments in outreach have contributed to the creation of space science support and increased visibility for JAXA among research institutions and agencies. Diversification of communication channels continued throughout the year and among the highlights were the promotion campaign for the ARASE geospace exploration satellite, the public demonstration of solar power sail unfolding, and the release of the high-definition video images taken by KAGUYA. The biggest science story of the year was the unlocking of the history of the asteroid Itokawa by analysis of samples returned to Earth. A new visitor center, one of ISAS's major projects, progressed well towards its opening in February 2018.

During the first quarter of FY2016, most of the public outreach effort was poured into fulfilling JAXA's responsibility for explaining the loss of the X-ray astronomy satellite ASTRO-H. JAXA held an emergency press briefing after the incident occurred and explained the latest findings on the causes of the loss at weekly press briefings. Press briefing handouts and related documents were published on our website so that everyone who was interested could read it. This was very difficult time for both JAXA and the domestic space science community, but our speedy releases of detailed information helped to minimize public misgivings about JAXA and Japanese space science.

a. Press Activities

In FY2016, 46 press releases were issued. Twelve of these were science releases, covering a mix of results of research using ISAS experimental and analysis facilities on the ground and studies based on data obtained in space. As noted above, the analysis of particles from the Itokawa asteroid generated lots of media interest. Several news items were related to the launch of the ARASE geospace exploration satellite. The carefully planned communication campaign around the lift-off included the "Let's send a message to ERG" campaign, the spacecraft display at both the Sagamihara Campus and the Uchinoura Space Center as a part of a dedicated press briefing, and online live streaming of the lift-off.

The media requested formal interviews 75 times during FY2016. This number does not include interviews given by public information officers while answering telephones, or requests to write essays and articles for magazines and newspapers.

b. Web Development

The design code for the ISAS public web pages was rewritten from scratch, to make the site more visually appealing. This new design was implemented using responsive technologies to ensure that the site is user-friendly regardless of the type of devices used (e.g., PCs vs. smartphones). The layout and content of the pages were adjusted accordingly.

c. Exhibition and Events

ISAS's exhibition room at the Sagamihara Campus has spotlighted the biggest ISAS missions and science achievements. The exhibition room serves as the first impression of ISAS for many guests, whether school children, space enthusiasts or Japan's policymakers. In FY2016, approximately 58,000 people visited to view exhibits of the innovative work being done by ISAS researchers. The frequency of guided tours was increased to three days per week in 2015. Students hired as part-time employees have held Q&A sessions on Saturdays, Sundays, and holidays since 2010; these have been very successful and have produced a high level of visitor satisfaction.

Outreach events, led by ISAS/JAXA, are held year-round to engage the public with ISAS missions and accomplishments. Annual special “open house” days were held at Sagamihara Campus on the last Friday and Saturday in July, and about 17,000 people visited. Event booth locations were optimized and smooth flow lines were planned, thereby successfully alleviated congestion.

To provide educational experiences that inspire and captivate visitors of all ages in more user-friendly way, construction has already started on a new building for the Sagamihara visitor center. The new visitor center will open in early 2018.

“Space School” events continue to captivate each new generation of learners nationwide. In nine Space Schools hosted in FY2016, scientists and engineers made presentations and answered participants’ questions during the half-day-long event. Over 800 people joined in FY2016’s “Lectures on Space Science and a Movie,” an event commemorating the ISAS foundation, and attendance was the biggest ever.

VII
Awards

The Third ISAS Award Recipients

Name	Affiliation	Reason for Award	Date
KIMURA, Yuki	Institute of Low Temperature Science, Hokkaido University	Study on nucleation of cosmic dust in a microgravity environment using S-520 observation rockets	Jan 5, 2017
KASAHARA, Yoshiya	Integrated Media Platform Center (Radio Science), Kanazawa University	Data Analysis of Magnetospheric Plasma Wave Phenomena by Very Low-Frequency Plasma Wave Observation Apparatus Onboard Magnetospheric Observation Satellite Akebono	Jan 5, 2017
KELLEY, Richard L.	NASA Goddard Space Flight Center	Exceptional contribution in the successful development and in-orbit operation of the Soft X-ray Spectrometer (SXS) aboard ASTRO-H HITOMI	Feb 16, 2017

Award Recipients

ISAS STAFF	Affiliation	Award	Date
MATSUMOTO, Kotaro HABU, Hiroto	Department of Space Flight Systems	Japan Explosives Society(JES): 2016 Spring Meeting, Excellent Presentation Award.	May 27, 2016
OTSUKI, Masatsugu KUBOTA, Takashi *et al.*	Department of Spacecraft Engineering	The Japan Society of Mechanical Engineers (JSME): ROBOMECH2016, Best Presentation Award. “A Study on Monocular Visual Odometry using Parabolic Motion Constraints”.	June 2016
ABE, Takumi	Department of Solar System Sciences	Japan Society for the Promotion of Science (JSPS): Research Fellowship for Young Scientists- Review Committee Specialist Award for FY2015.	August 2016
INATOMI, Yuko	Department of Space Flight Systems	Japan Society for the Promotion of Science (JSPS): KAKENHI,Review Committee Award for FY2016.	Sep 30, 2016
KAMATA, Yukio	Test and Operation Technology Group	Radio Engineering and Electronics Association: The 30th Award.	Nov 9, 2016
SHIMIZU, Toshifumi *et al.*	Department of Solar System Sciences	DAIWA Anglo-Japanese Foundation: Daiwa Adrian Prize 2016. British team & Japanese team for their joint collaboration in “understanding magnetic energy release at all scales in the solar atmosphere”.	Nov 15, 2016
OKAZAKI, Shun OGAWA, Hiroyuki *et al.*	Department of Space Flight Systems	The Japan Society of Mechanical Engineers (JSME): JSME Medal for Outstanding Paper FY2016. “Study on Internal Flow Characteristics of Multiple Evaporators Loop Heat Pipe (Visualization in Evaporators and Condenser under Microgravity)”.	2016
KOBAYASHI, Daisuke HIROSE, Kazuyuki *et al.*	Department of Spacecraft Engineering	2016 IEEE Nuclear and Space Radiation Effects Conference Outstanding Paper Award."Signature of Heavy-Ion-Induced Upsets in Deca-Nanometer-Scale Magnetic Tunnel Junctions".	2016

Award Recipients

ISAS STAFF	Affiliation	Award	Date
TAKEI, Yoh IWATA, Naoko NATSUKARI, Chikara ISHIMURA, Kosei and SXS-vibration-response team	Department of Space Astronomy and Astrophysics	The Japan Society for Aeronautical and Space Sciences: Technology Award. “Vibration Isolation technique for achieving world highest energy resolution performance of Soft X-ray Spectrometer (SXS) on-board ASTRO-H satellite.”	January 2017
SHIMADA, Toru	Department of Space Flight Systems	AIAA Associate Fellow, The American Institute of Aeronautics and Astronautics.	January 2017
MIURA, Akira	Department of Interdisciplinary Space Science	Organizing Committee for the International Festival of Science Visualization: The 7th International Festival of Science Visualization, The Short Film Competition, Grand Prize. “Magnetospheric Showcase-A Story of the Space Science Showcase.“	March 2017
MIURA, Akira	Department of Interdisciplinary Space Science	Organizing Committee for the International Festival of Science Visualization: The 7th International Festival of Science Visualization, The Short Film Competition, Audience Choice Award. “Magnetospheric Showcase- A Story of the Space Science Showcase.“	March 2017
The International team for CLASP project (SAKAO, Taro et al.)		National Astronomical Observatory of Japan (NAOJ): Director General Prize FY2016, Field of Research and Education. “The success of CALSP experiment”	Mar 7, 2017
ASTRO-H "HITOMI" alignment team	Department of Space Astronomy and Astrophysics	The Japan Society of Mechanical Engineers (JSME): Space Engineering Division, Space Frontier Award. ”Alignment performance of scientific instruments mounted on ASTRO-H (HITOMI).”	Mar 31, 201

Award Recipients

Student	Affiliation	Academic Advisor	Award	Date
NAKAUCHI, Yuiko	Graduate School at Aoyama Gakuin University	GOTO, Ken	9th International Conference on High Temperature Ceramic Matrix Composites and Global Forum on Advanced Materials and Technologies for Sustainable Development 2016: Student Poster Award. "Strength Degration of Carbon Fiber in C/SiC Fiber Bundle Composites."	Jun 30, 2016
SAKAMOTO, Yumika	Graduate School at Tokai University	ABE, Takumi	Japan Geoscience Union Meeting 2016, Student Outstanding Presentation Award. "A Study on electron temperature distribution inside the sporadic E layer."	July 2016
OKI, Yusuke	Graduate School at The University of Tokyo	KAWAGUCHI, Junichiro	The Institute of Electorical Engineers of Japan:2016 IEE-Japan Industry Applications Society Conference, Prize of Outstanding Technical Paper 2016. “Study on Substation Power Peak Cut with Decentralized Control.”	July 2016
MASUDA, Hiroshi *et al.*	Graduate School at The University of Tokyo	SATO, Eiichi	Atomic Energy Society of Japan (AESJ): Materials Science and Technology Division,The Best Poster Award.	Jul 5, 2016
OZAWA, Kohei	Graduate School at The University of Tokyo	SHIMADA, Toru	AIAA Hybrid Rockets Best Student Paper “Flight Performance Simulations of Vertical Launched Sounding Rockets Using Altering-Intensity Swirling-Oxidizer-Flow-Type Hybrid Motors”.	Jul 27, 2016
MASHIMO, Taiki	Graduate School at The University of Tokyo	HASHIMOTO, Tatsuaki	The 60th Space Sciences and Technology Conference, Student Session, Presentation Award. "Study on Velocity Estimation from Blurred Image for Lunar/Planetary Landing."	September 2016
MURAMATSU, Haruka	Graduate School at The University of Tokyo	MITSUDA, Kazuhisa	Applied Superconductivity Conference 2016, Best Student Paper in Electronics 3rd Place.	September 2016
MASUDA, Hiroshi	Graduate School at The University of Tokyo	SATO, Eiichi	EusoSPF 2016, Best Presentation Award: "Two-dimensional grain boundary sliding and dislocation characteristics in ODS ferritic steel"	September 2016
OSADA, Takuma	Graduate School at Waseda University	INATOMI, Yuko	The Japan Society of Microgravity Application: 11th Asian Microgravity Symposium-2016, Mohri Poster session Excellent Poster Award. "Investigation of Necessary Conditions for Ground-Based Measurement of Soret Coefficients."	Oct 27, 2016

Award Recipients

Student	Affiliation	Academic Advisor	Award	Date
TOMARU, Momoko	Graduate School at Waseda University	INATOMI, Yuko	The Japan Society of Microgravity Application: 11th Asian Microgravity Symposium-2016, Mohri Poster session Excellent Poster Award. "Error Reduction for Soret Coefficient in Soret-Facet Mission: Measurement of Coefficients on Refractive Indices of Salol/Tert-butyl Alcohol Mixtures by Interferometer."	Oct 27, 2016
HOSHI, Yasuto	Graduate School at The University of Tokyo	SAITO, Yoshifumi	140th Society of Geomagnetism and Earth, Planetary and Space Sciences: Excellent Presentation Award. "Location of magnetic reconnection lines at the low-latitude dayside magnetopause estimated from 8 years of THEMIS observations."	November 2016
HASEGAWA, Ryo	Graduate School at The University of Tokyo	FUJIMOTO, Masaki	140th Society of Geomagnetism and Earth, Planetary and Space Sciences. Excellent Presentation Award: "Dust Enrichment process by streaming instability in the dust layer of a protoplanetary disk"	November 2016
YONEDA, Hiroki	Graduate School at The University of Tokyo	TAKAHASHI, Tadayuki	Graduate School of Science, The University of Tokyo: Research Award.	March 2017
KANAZAWA, Takaaki	Graduate School at Tokyo Metropolitan University	SATO, Eiichi	The Japan Institute of Light Metals: Light Metal Promising Graduate Award FY2016. “Initial process of continuous dynamic recrystallization in a superplastic Al–Mg–Mn alloy.”	March 2017
DEGUCHI, Masaya	Graduate School at The University of Tokyo	SATO, Eiichi	The Japan Institute of Metals and Materials: The Metals Best Poster Award	Mar 15, 2017
KANAZAWA, Takaaki	Graduate School at Tokyo Metropolitan University	SATO, Eiichi	Tokyo Metropolitan University: Dept. of Mechanical Engineering, School of Science and Engineering, Master Thesis Best Presentation Award.	Mar 20, 2017

VIII
ISAS Library and Repository

1. ISAS Library

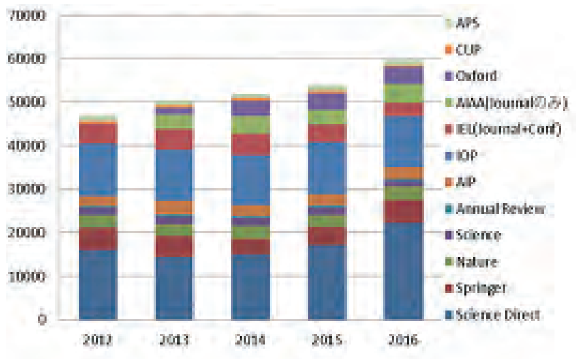
The ISAS Library actively collects materials, including books, magazines, and reports, on space science and related fields, and makes them available to ISAS's many researchers. It has also served as a library of SOKENDAI parent institute since April 2003. The library makes joint purchases of e-journals 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 various services to external users cooperating with other libraries in JAXA. 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 2017.

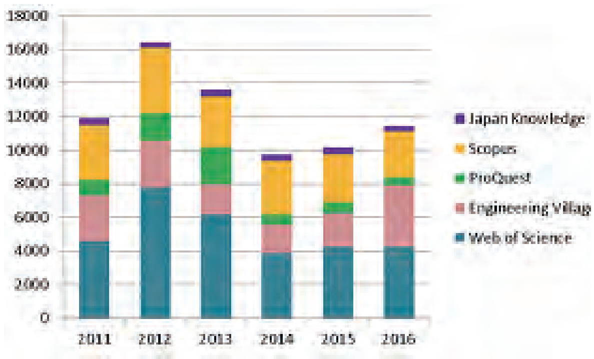
Category	Quantity
Total books	93,620
Foreign books	76,420
Japanese books	17,200
Books added in FY2016	
Foreign books	82 (61 books, 21 bound magazines)
Japanese books	350 (283 books, 67 bound magazines)
Total journals	1,194
Foreign journals	959
Japanese journals	235
Journals added in FY2016	180
Foreign journals	15
e-Journals	97
Domestic English journals	6
Japanese journals	61
e-Journals	about 4,100
IEL Online	180
IOP Journal	53
Elsevier Science Direct	143
Springer Journal	about 1,615
Wiley-Blackwell	about 1,400
JSTOR	about 680

e-Books	
AGU Geophysical Monograph Series and other	598
AIAA Education Series	69
AIP Conference Proceedings	1,639
Cambridge Books Online	160
Net Library	585
Oxford Scholarship Online (Physics)	216
Springer eBOOK	92,000
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

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).

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

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. Now, the full text of most presentations at symposiums organized by JAXA and ISAS is available in the repository, which is used as online proceedings. The symposium bibliographic information also includes detailed observation data, providing another publication venue for JAXA's achievements.

In FY2016, the JAXA Repository was accessed over 1 million times, with increasing access to materials published by JAXA and symposium presentations. In response to these trends, the JAXA Repository started assigning digital object identifiers (DOIs) to registered papers from peer-reviewed academic journals by JAXA staff. This semi-permanent access to materials allows open access of JAXA academic contents.

The repository also continues to register papers from peer-reviewed academic journals and to accept request registrations every year, which allows an increase of the amount of available text data of papers from academic journals.

IX

Publications, Presentations and Patents

Publications, Presentations and Patents

The academic research achievement by ISAS researchers in FY2016 are shown below.

Summary of Publications

Item	Achievements
1. Publications on Web of Science	
a. Papers in prestigious academic journals by ISAS staff	1 in Science*, 1 in Nature**
b. Papers in prestigious academic journals on ISAS satellites	1 in Science***
c. Number of heavily cited papers (including ISAS staff as co-author)	57
d. Rate of international collaboration	Average of research fields: 53% (from April 2003 to March 2017)
e. Reviewed papers published in journals	345
2. JAXA Publications (in ISAS)	12 (Research and Development Report:7, Research and Development Memorandum: 3, Special Publication: 2)
3. Journals, publications, etc.	
a. Published in a book	9
b. Published in reviewed journals	379
4. Presentations at domestic and international meetings, etc.	Keynote speeches: 13 Invited lectures: 64 Domestic meetings: 530 International meetings: 411
5. Awards	33(see pp.113-116)
6. Patents	Published patent applications: 19 Patents granted: 8

*J.L. Burch , et al. Electron-scale measurements of magnetic reconnection in space. Science, Vol.352(6290), aaf2939 (2016) doi: 10.1126/science.aaf2939

**Hitomi Collaboration. The quiescent intracluster medium in the core of the Perseus cluster. Nature, Vol.535(7610) 117-21(2016) doi: 10.1038/nature18627

*** A. Colaprete, (NASA Ames Res Ctr, USA) et al. How surface composition and meteoroid impacts mediate sodium and potassium in the lunar exosphere. Science. Vol. 351(6270), aad2380(2016) doi: 10.1126/science.aad2380.

http://global.jaxa.jp/

Annual Report of the
Institute of Space and Astronautical Science
2016

INSTITUTE OF SPACE AND
ASTRONAUTICAL SCIENCE,
JAPAN AEROSPACE
EXPLORATION AGENCY

Printed on Recycled Paper