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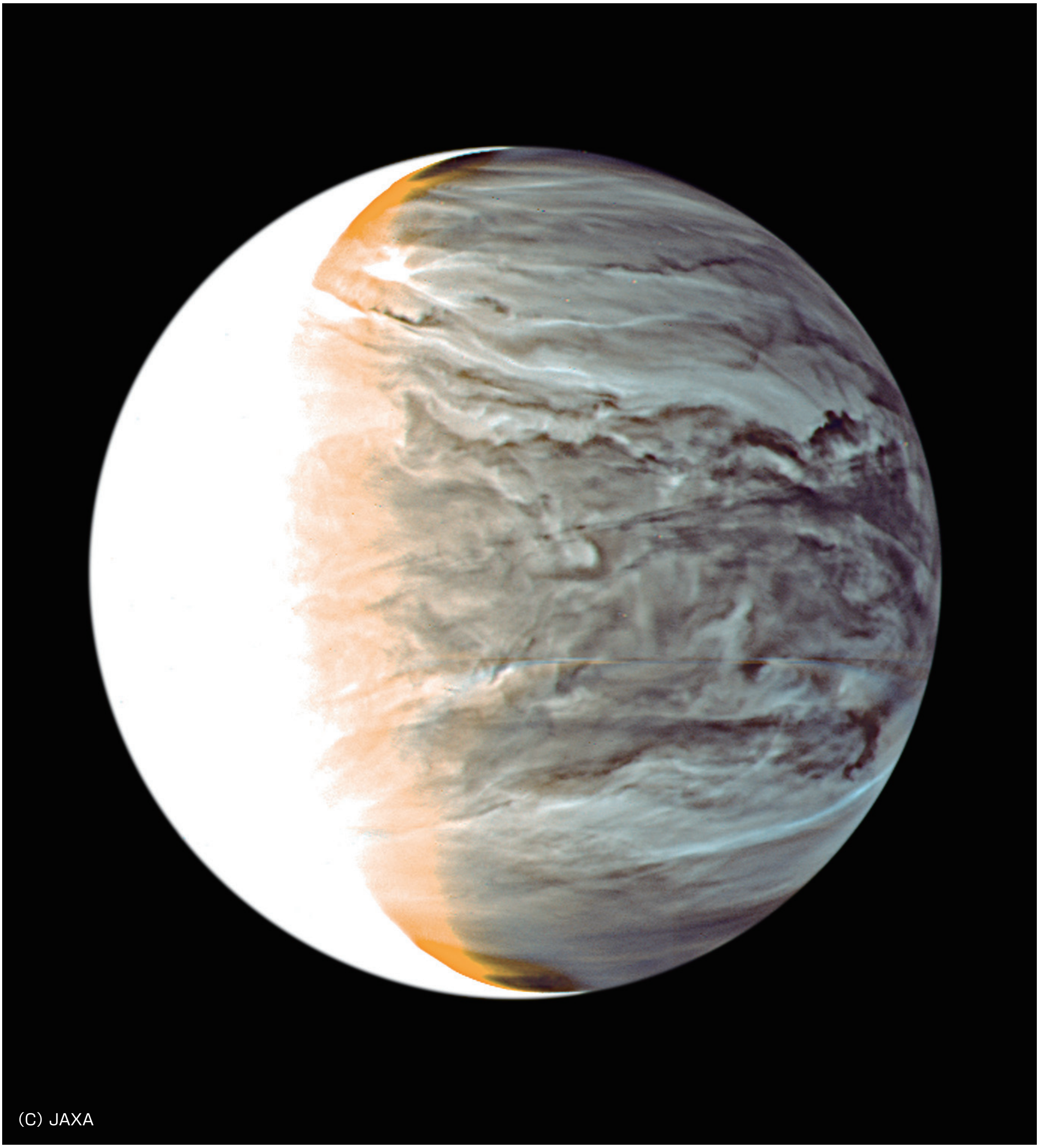
Annual Report of the Institute of Space and Astronautical Science 2015



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Annual Report of the
Institute of Space and Astronautical Science

2015

Message from the Director General

June 2016

Saku Tsuneta

Director General

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency

On March 26, 2016, we discovered communication anomalies with the X-ray Astronomy Satellite ASTRO-H “HITOMI“, which was launched on February 17, 2016. JAXA has made every effort to clarify the details of this anomaly, to confirm the status of the satellite, and to restore satellite functions. Unfortunately, we determined that functional recovery would not be possible, and made the difficult decision to abandon operation of the ASTRO-H on April 28. Having to abandon the satellite without making any full-scale observations was extremely regrettable to everyone at overseas and domestic research institutions and universities who spent many years developing ASTRO-H, as well as to researchers throughout the world who were planning to use the observational results from ASTRO-H for their studies. We also apologize for failing to meet the expectations of Japanese citizens and government in the arena of astronautical science and exploration. The burden of responsibility lies heavily on the Institute of Space and Astronautical Science (ISAS). As Director General, I fully recognize my own personal responsibility, and will ensure that our organization makes every possible effort to analyze what went wrong and what can be done to prevent this from happening in the future.

On June 14, JAXA submitted a report entitled “Hitomi Experience Report: Investigation of Anomalies Affecting the X-ray Astronomy Satellite “Hitomi” (ASTRO-H)” to the MEXT’s Committee of Space Development. The report proposed four measures to address the factors of the incident: 1) revision of ISAS project management systems, 2) clarification of roles and responsibilities of ISAS and corporations, 3) documentation of ISAS project duties and quality assurance records, and 4) thorough review and evaluation. In order to realize effective implementation of these measures, discussions at our Institute are being led by staff with experience as project managers and we are establishing an “Action Plan for Reforming the Institute of Space and Astronautical Science Based on the Anomaly Experienced by Hitomi.” The Action Plan will be applied to other projects such as SLIM (Smart Lander for Investigating Moon) and a PDCA cycle will be established in order to further refine both current and future endeavors. (Efforts to clarify factors in the anomalies affecting “HITOMI“ were taken from the end of 2015 until 2016. Accordingly, this message refers to conditions as of June 30, 2016.)

The ISAS is currently operating six satellites and space probes: “Hayabusa2“, “HISAKI“, “AKATSUKI“, “HINODE“, “SUZAKU“, and “GEOTAIL“. In particular, although the Venus Climate Orbiter “AKATSUKI“ was not able to enter into an orbit of Venus in late 2010, it succeeded in entering orbit on December 7, 2015. “AKATSUKI“ is sending detailed images of Venus, and there are great expectations for future research results. This marks the first time that a Japanese space probe has entered into orbit around a planet other than the Earth. The Asteroid Explorer “Hayabusa2“ succeeded in making a swing-by of Earth on December 3, 2015, and it is currently heading for its target asteroid Ryugu. The recent swing-by utilized Delta-DOR technology to achieve orbital control approximately 10 times greater than with conventional technology. This increases Japan's ability to freely conduct deep space exploration. During its initial functional confirmation phase, "HITOMI" achieved stable operation of prescribed sensors at a temperature of 50 mK and succeeded in observing the Perseus Cluster with extremely high energy resolution. The total number of peer review papers for the solar observation satellite "HINODE" has reached 1,024 as of June 2016, and the satellite continues to function as an international astronomical observatory.

The BepiColombo/MMO for exploration of Mercury has been transferred to the European Space Agency (ESA). The launch of BepiColombo by the ESA has been postponed until 2018 for reasons attributable to Europe. The satellite is now scheduled to enter an orbit around Mercury in 2024. The flight model for the Exploration of energization and Radiation in Geospace (ERG) is undergoing testing in preparation for its launch in 2016. Furthermore, in addition to testing for two sounding rockets and two tests in Japan for scientific balloons, we held our first-ever scientific balloon test in Australia in May 2015. The test in Australia realized a long flight duration and collection of the balloon on the ground. Moving forward, we plan to periodically conduct balloon testing in Australia as complementary flights to testing in Japan. This is also an important development in regards to how project managers and other JAXA staff are expected to have experience as PI (principal investigators) in testing for sounding rockets and scientific balloons.

The next few years are a critical stage in determining the orientation of the astronautical missions until the 2030s. In this context, the new "Basic Plan on Space Policy: Implementation Schedule" has been revised (December 8, 2015; Strategic Headquarters for Space Policy). Mars Moon eXploration (MMX) has been proposed as the first satellite of the strategically-implemented Large-size plan, and we are currently establishing a system for international cooperation while obtaining approval from research councils, management committees, and the Astronomy and Astrophysics Sub-Committee of the Physics Committee at the Science Council of Japan. The goal of the mission is to collect samples which will settle the debate on the composition of the Mars moons, to obtain new knowledge regarding the process in which planets are formed and the transportation of matter in the solar system, and to obtain new knowledge regarding the transitions and evolution of Mars by using the merits of the moons orbiting Mars. Furthermore, the Smart Lander for Investigating Moon (SLIM) is being developed as the first satellite of the competitively-chosen Midium-sized focused missions. The goal of this project is to demonstrate technology for pin-point landings on gravity celestial bodies and to realize significant reductions in the weight of lunar probe system technology. Moreover, in regards to initiatives for 2016 and beyond for the missions opportunities, the plan states that Japan will actively move forward with deliberations concerning participation in large-scale international projects such as the Jupiter Icy Moons Explorer (JUICE).

These missions are developed through international cooperation. The strategically-implemented Large-sized missions of ISAS are fully incorporated into the scientific roadmaps of international space institutions. Accordingly, in addition to administrative meetings with overseas space institutions, we have held a total of six bilateral meetings in Japan and overseas, with the participants mainly from NASA and ESA. These meetings give priority to fostering strategic dialog.

While existing as a division of the Japan Aerospace Exploration Agency (JAXA), the Institute of Space and Astronautical Science is also operated as an inter-university research institute system (*1). With the goal of strategically enhancing the comprehensive level of space science in Japan through cooperation with universities, ISAS has started centralization with universities which possess outstanding potential and records of performance in certain fields of space science (requires operation through JAXA capital and a university matching

(*1) 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).

fund). In addition to the ERG Science Center at the Nagoya University Institute for Space-Earth Environmental Research, which was added as an affiliated university center in 2013, we have now selected the Kobe University Center for Planetary Science and the Center for Ultra-Compact Probe Development in the University of Tokyo as new partners. Kobe University is working to develop exploratory missions and to cultivate personnel in the long-term through consideration of missions, while the University of Tokyo is creating systems to realize high-frequency exploration on a low budget.

In order to respond to the growing field of space science, we have newly established the Astromaterials Science Research Group which conducts R&D for technology used in analyzing astromaterials and conducts research based on analysis of samples, the Lunar and Planetary Exploration Data Analysis Group which promotes advanced processing and utilization of lunar exploration data, the Deep Space Tracking Technology Group which supports projects related to deep space tracking, and the Advanced Machining Technology Group which conducts machining/precision machining technology and precision measurement technology required for spacecraft. Furthermore, we merged the Systems Engineering Office and the ISAS Program Office in order to strengthen seamless support for all stages from project preparation to completion, with particular focus on supporting the difficult transition from a working group to pre-project. In conjunction, we also improved the method for internal review of projects. We are working to establish non-Japanese examiners as normal members of review committees, and have already had non-Japanese scholars participate in review for the Space Infrared Telescope for Cosmology and Astrophysics (SPICA) and Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection (LiteBIRD). Moreover, we have revised the scope of jurisdiction for Program Directors and for Senior Chief Officers of Fundamental Technology for Space Science, and have restructured the organization of the Management and Integration Department.

As yet another initiative, we have clarified the previously unclear goals for each of the five research departments at ISAS. As a result, the research departments are expected to serve as a platform for bringing together educational faculty, postdoctoral researchers, and graduate students at ISAS, as well as including researchers in related fields from outside our institute. The departments will facilitate cooperation between these professionals and the Advisory Comittee for Space Science and Engineering in order to create new projects. In addition to fulfilling a leading role in academic research and development of personnel, the members and directors of the departments are expected to provide leadership in organizing researchers from Japan and overseas in order to create new fields and projects.

The evaluation system and human resources system for educational faculty are of vital importance for the invigoration of a research institute. Our newly-established system for evaluating the performance of educational faculty enables faculty to actively engage in project promotion and graduate education in addition to their academic research. Academic research, project research, and instruction of graduate students and general engineers are inherently part of the same whole. The lifecycle of each researcher contains a period for focusing exclusively on research projects, a period for reaping the academic results of their research, and a period for creating new projects. Accordingly, we have abolished evaluation which separated conventional academic research from all other areas, and have instituted an integrated evaluation method.

Human resources for faculty are administered using a long-term vision which is based on our institute's orientation as defined in the Roadmap for Space Science and from the perspective of personnel required for new projects in the future. From 2013 to 2015, six employees transferred out of our institute (four from 2010 to 2012). During the same period, we recruited sixteen faculty positions even while reducing personnel expenses (there was recruitment for nine positions from 2010 to 2012). We also recruited for faculty positions limited to female and non-Japanese applicants, and 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, we plan to hire more outstanding female faculty and non-Japanese faculty. Additionally, we are promoting the transition from faculty positions to general positions, and one associate professor transitioned to a general position through the new system. Through a system for specially-appointed professors, we are also encouraging movement from general positions to faculty positions in order to execute special missions. Moreover, we have also conducted movement between research departments (four employees) and promotion which spans multiple departments (two employees). Although these efforts for detailed improvement of human resources are gradually producing results, there is still the need for continuous reform in order to address the aging of faculty and to expand interaction of personnel. Moving forward, we will review an initiative to assign general employees to positions previously filled by educational faculty, thus creating an environment which allows faculty to concentrate on academic research and projects.

Through partnerships with universities such as The Graduate University for Advanced Studies (Sokendai) and the University of Tokyo, we are implementing graduate school education through actual development of flying objects, and are working to cultivate successors who will be involved in space development and R&D for space science. In 2015, we assisted 12 students in acquiring their PhD and 51 students in obtaining their master's degree. There were 30 researchers conducting research as JAXA Project Research Associates, and of which 26 were Japanese (inclusding 8 female) and 4 were non-Japanese (including 1 famale). 5 researchers (no female) were conducting research as Research Associates at the Japan Society for the Promotion of Science. We also hired 1 International Top Young Fellow, making a total of 5 fellows at ISAS. The total amount of external fund acquired was 1.36 billion yen, a major increase over the previous year despite a reduction in the amount of Grants-in-Aid for Scientific Research (KAKENHI).

2015 marked a further increase in cooperation between ISAS and other departments at JAXA. ISAS and the Research and Development Directorate agreed to a Basic Cooperation Plan in order to promote cooperation in projects and exchange of personnel. This agreement has enabled systematic deployment of staff with specialized skills to space science projects and systematic training of young (first to fifth year employees) general staff through actual space science projects to instill them with specialized skills. ISAS staff participates in projects of the Research and Development Directorate including research on electric propulsion systems for fully-electrical satellites, SOI-ASIC development, and research on highly-integrated semiconductor components for use in outer space. Furthermore, based on technology demonstrated by "HITOMI", we have started joint development with the National Centre for Space Studies, France (CNES) and the Research and Development Directorate for space freezers required for LiteBIRD, SPICA, and the large-scale X-ray observatory mission Athena at ESA. This project is positioned as the first phase of technological development through programming defined in the new Basic Plan on Space Policy. We are also continuing to cooperate with the Space Technology Directorate I to develop a enhanced Epsilon Launch Vehicle. A combustion test for the second stage motor (M-35) was successfully performed at the Noshiro Rocket Center. Another joint project being advanced by ISAS through cooperation with the Space Tracking and Communications Center is development of a deep space antenna to serve as a successor of the Usuda Deep Space Center. Although this project was made difficult by the contradiction of high-level required specifications and a strict budget, a definite plan has been formulated through the hard work of the development team. In addition to being used in Japanese deep space exploration missions such as "Hayabusa2", "BepiColombo", and the prospective mission for collecting samples from a Mars moon, this antenna is also expected to support missions by NASA and ESA.

In terms of public relations and public outreach, we issued ten press releases to convey significant research results to the general public. This is double the number of press releases issued in 2013. A wide range of research fields are covered in the press releases, from observational/theoretical research results in planetary science to results of observation for distant areas of the universe. All in all, it was a highly successful year for the institute in terms of press releases. We are also utilizing this opportunity to have even more people become interested in space science and have conducted PR activities for research which supports the foundation of space science. Specific examples include open application of names for the target asteroid of "Hayabusa2", the Earth swing-by of "Hayabusa2", and the entry of "AKATSUKI" into orbit around Venus. Moreover, we are continuing our efforts to improve the content of media such as comprehensive pamphlets and annual reports. We are also preparing English-language versions of these publications.

2015 also marked the full-scale start of the construction plan for the Space Science Exploration Exchange Building (provisional name). This facility will be constructed adjacent to the Space Exploration Test Building of the Space Exploration Innovation Hub Center (hereinafter referred to as the “Exploration Hub”) and is scheduled to be developed as an exchange facility for the Exploration Hub. The facility aims to deepen the relationship between space science and society, and to create further innovation in industry. To achieve this goal, the facility will introduce technological developments, academic research results, and future-oriented activities, and will provide opportunities for exchange among ISAS staff and external parties. Currently, the facility is scheduled to open in the second half of fiscal 2017. Land preparation is scheduled to be completed in the first half of fiscal 2016, and construction of the building will then proceed.

This annual report is a summary of ISAS activities in 2015. It has been three years since I assumed the position of Director General. During that time, through the cooperation of individuals both inside and outside our institute, I have been able to implement a large number of reforms which will elicit the capability of ISAS. During the process of implementing these reforms, I engaged in repeated deliberation with ISAS staff at internal town meetings and institute-wide meetings. Nevertheless, a number of issues still need to be addressed; in particular, the implementation of the “Action Plan for Reforming the Institute of Space and Astronautical Science Based on the Anomaly Experienced by Hitomi.” Although a certain amount of time will be required until results will be seen, I believe that these reforms will one day form the foundation for new achievements by the ISAS and JAXA. I look forward to your continued support and cooperation.

June 2016

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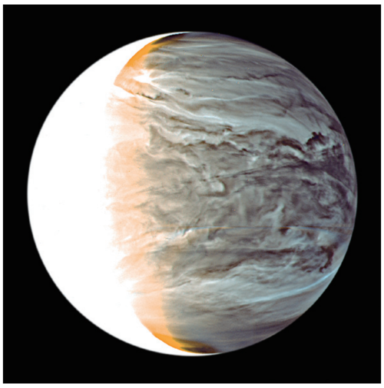
Explanation of Images on Cover / Back Cover

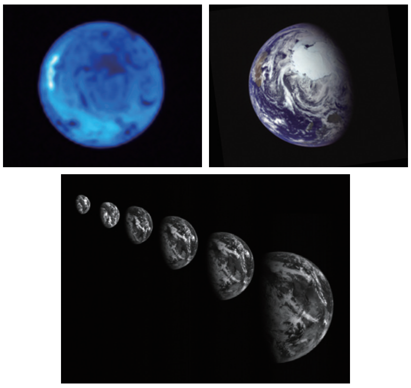
Pseudo coloration for the complex nighttime surface of Venus. Rendered from images of 1.735 um and 2.26 um wavelengths taken from the IR2 camera mounted on the Venus Climate Orbiter "AKATSUKI". (March 25, 2016) (Cover Image)



The image was created by using red for 1.735 um, blue for 2.26 um, and green for averages of the two colors. The brightness of Venus' daytime surface is a strong 1.735 um and a large amount of light extends over the nighttime surface. This creates the orange color which can be seen at the border between the daytime and nighttime surfaces. The nighttime surface of Venus seen at these wavelengths is illuminated by thermal radiation from the hot lower atmosphere, and the clouds at an altitude of about 50 km appear as a silhouette. The subtle contrasts in color gradation which appear in this pseudo coloration are thought to depict differences such as varying sizes of cloud particles.

Image of the Earth photographed by "Hayabusa2" during an Earth swing-by. (Back Cover Image)

At 7:08.07 (Japan time) at night on December 3, 2015, Hayabusa2 successfully performed an Earth swing-by operation, passing over the Pacific Ocean at a height of 3,090 km. According to plan, the swing-by was used to increase Hayabusa2's inertial velocity relative to the solar system by approximately 1.6 km/s and to change its course by approximately 80º relative to the Earth. During the swing-by, the satellite used its sensors to observe the Earth and Moon.



Top left: Photograph taken using mid-infrared camera (December 4)

Top right: Pseudo color image rendered using ONC-T (Optical Navigation Camera-Telescope) (December 4Bottom: Series of photographs taken using ONC-W2 (Optical Navigation Camera-Wide Angle 2) (December 3)

I. Scientific Highlights in FY 2015

1 Venus Orbit Insertion to observe atmospheric circulation

[Venus Climate Orbiter "AKATSUKI" (PLANET-C)]

Engineering highlights

1. Venus orbit insertion revenge 1 (VOI-R1) was successfully achieved on December 7, 2015, using four reaction control system thrusters at the top panel of the spacecraft, instead of using orbital maneuver engine which was destroyed at the VOI trial in December 2010 (Figure 1).
2. The trajectory design strategies were highly reliable for solving dynamical problems with difficult boundary conditions.
3. The precise orbit determination technology evaluated the closest approach position accurately from the encounter planet.
4. The thermal design method secured the spacecraft components against severe solar heating.
5. The solar array paddles produced stable electric power under unexpected high temperatures of more than 160 °C.

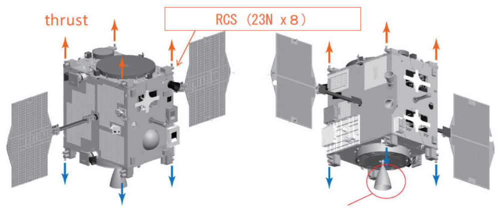


Figure 1 Four attitude control thrusters (23 N) on the top panel of spacecraft were used in VOI-R1 on December 7, 2015.

Scientific highlights

Scientific instruments on board AKATSUKI revealed new information about the atmosphere of Venus.

1. LIR discovered a large bow-shaped feature in the thermal map at the cloud top of Venus (Figure 2, images taken on 7 December 2015). The feature was observed until December 11 and appeared to rotate with the same speed as the surface (~1.6 m/s), rather than at the speed of the background atmospheric super-rotation (~100 m/s).
2. UVI imaged Venus at 283 nm in the SO_2 absorption band and 365 nm in the unknown absorber band (Figure 2). We are investigating the interrelation of dynamics and chemistry in the upper atmosphere by comparing these images.
3. IR1 visualized the surface topography of Venus, as imaged at 1.01 μm on the night-side of the disk (Figure 2). Details of Aphrodite (3 to 5 km elevation) were captured. IR1 also captured small-scale structures in the cloud layer, which are clues to the cloud formation process.
4. IR2 acquired impressive 2.26 μm images of the night-side disk of Venus, in which waves and turbulences of various scales were visualized (Figure 3). On the day-side disk, 2.02 μm images of reflected sunlight indicated the co-existence of super-rotating cloud features and topographically fixed features.
5. RS obtained vertical profiles of the atmospheric temperature by a radio occultation technique (Figure 4). The profiles show significant temporal and spatial variation, the cause of which will be studied by combining RS and camera data.

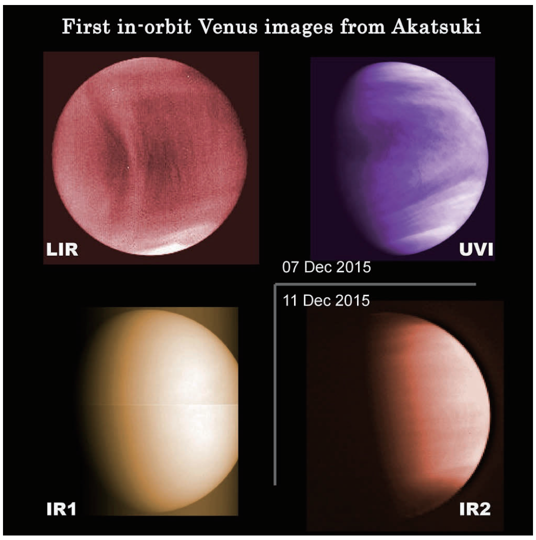


Figure 2 First in-orbit Venus images from the four on-board cameras (LIR, UVI, and IR1 on December 7, and IR2 on December 11 after the sensor had cooled).

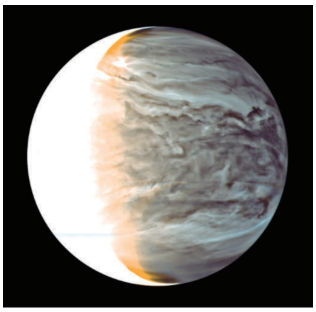


Figure 3 Impressive view of the night-side of Venus imaged with IR2 (25 March 2016). Two images (1.735 and 2.26 μm) were high-pass filtered and combined to produce this false color image.

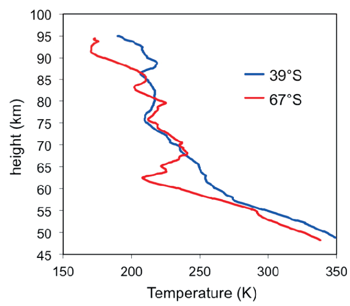


Figure 4 Example result of the radio occultation experiment. The vertical profile of atmospheric temperature is acquired for the entrance and exit of the spacecraft, indicating latitudinal variations of atmospheric temperature.

2 Earth swing-by of Hayabusa2

[Asteroid Explorer “Hayabusa2”]

On 3 December 2015, just one year after launch, Hayabusa2 returned and performed its Earth swing-by. An Earth swing-by, also known as an Earth gravity assist, is a technique for changing the speed and direction of spacecraft by using the Earth's gravitational force. The increase in speed of Hayabusa2 from the Earth swing-by is equivalent to the total acceleration of the ion engine for one year.

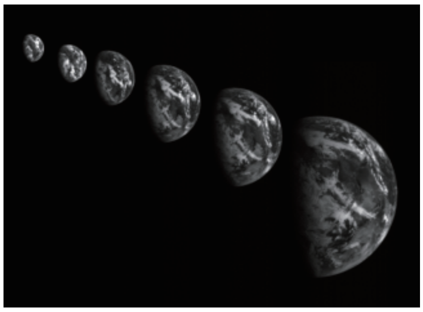


Figure 1 Images of the Earth taken by ONC-W as Hayabusa2 was approaching the Earth swing-by.

Precise orbit determination is crucial for performing the Earth swing-by. Hayabusa2 is the first JAXA spacecraft to be equipped with full delta differential one-way range (DDOR) capability. This technology enables us to determine the orbit of the spacecraft 10 times more precisely than by the conventional range-Doppler method. This DDOR technology was demonstrated before the Earth swing-by.

When Hayabusa2 approached the Earth and Moon, observations were carried out by the onboard instruments. For example, the optical navigation camera, wide-angle (ONC-W) took images of the Earth during approach (Figure 1). The telescopic optical navigation camera (ONC-T) took color images of Antarctica and the surrounding region (Figure 2). The thermal infrared imager (TIR) took thermal images of the Earth (Figure 3), and the near-infrared spectrometer (NIRS3) obtained spectral data from the Earth and Moon. These data will serve as references for future observations of the asteroid Ryugu. In addition, an optical link experiment was performed with the LIDAR laser altimeter. LIDAR on Hayabusa2 detected laser light from a satellite laser ranging ground station at a distance of 6.7 million km.

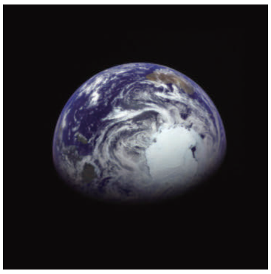


Figure 2 Image of the southern hemisphere of Earth taken by ONC-T just after the Earth swing-by.

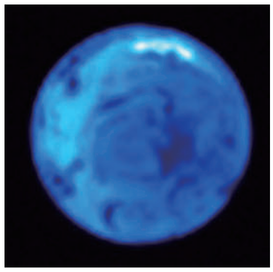


Figure 3 Image of the southern hemisphere of Earth taken by TIR around the same time as the image in Figure 2.

After the Earth swing-by, long-term ion engine operation was used from March to May 2016, putting Hayabusa2 on the planned trajectory toward Ryugu. We are looking forward to arriving at Ryugu in 2018 and gathering exciting data.

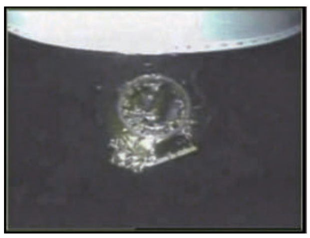
3 Launch of Hitomi and Achievements by the soft X-ray spectrometer (SXS) onboard X-ray astronomy satellite Hitomi (ASTRO-H)

[X-ray astronomy “HITOMI” (ASTRO-H)]

X-ray astronomy satellite Hitomi (ASTRO-H) was launched at 17:45:00 on Feb. 17, 2016 (JST), and separation from the rocket and opening of the solar array wings were verified. Results of the orbital calculation also confirmed that the satellite was injected into the intended orbit. *(JAXA press release, Feb. 17–18, 2016)* The soft x-ray detector (SXS) was cooled and initial functions such as the extension of the extended optical bench (EOB) were verified as planned after the launch, thus confirming the expected performance for creating scientific achievements.

H-ⅡA rocket 30 launch

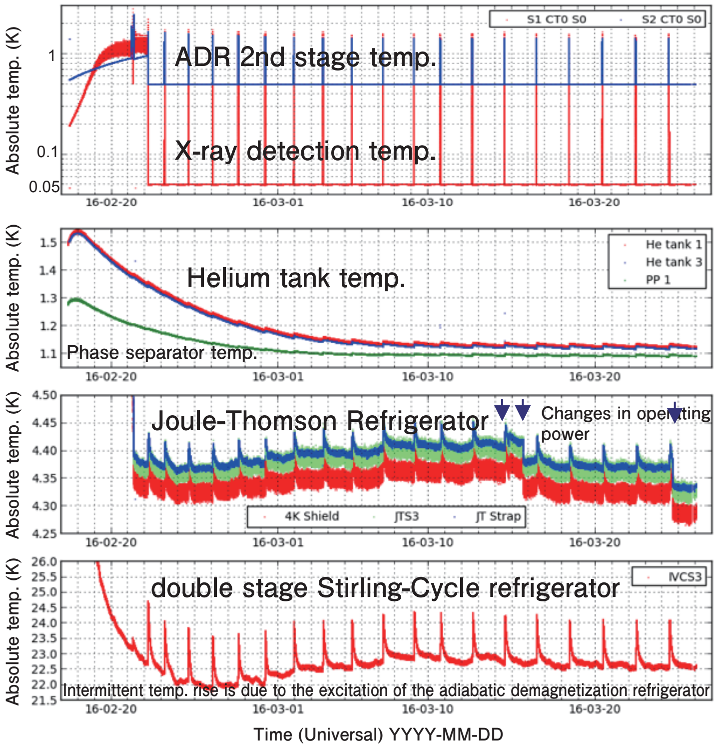
However, an operational abnormality was detected during the verification phase for initial functions on March 26, and radio signal from the satellite could not be received. As a result of a JAXA-wide effort to identify the problem, understand the state of the satellite, and do everything to recover the satellite functions, we were able to determine the mechanism that triggered the “attitude abnormality” from a “normal state of the satellite” and led to the “separation o f bodies“; it was concluded that functional recovery of the satellite could not be expected, and therefore, efforts should concentrate on investigating the cause *(JAXA press release, April 28, 2016)*.



ASTRO-H after separation

Time history of the cooling system in orbit

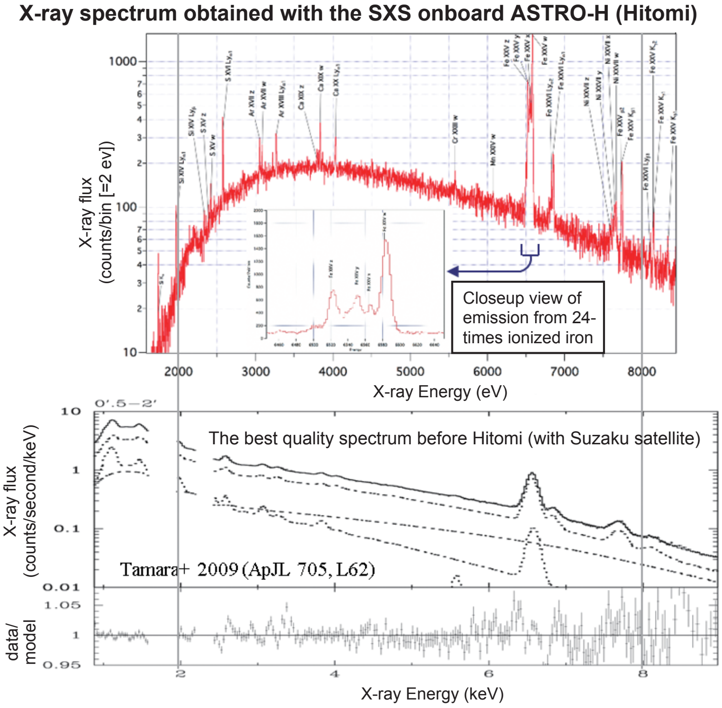
- Adiabatic demagnetization refrigerator (ADR) was first excited on Feb. 22; the detecter temperature reached 50 mK. The ADR was recycled approx. once every 2 days and maintained at 50 mK up to March 26.
- From the temperature difference between the helium tank and phase separator, the evaporation rate of helium was estimated to be approx. 35 μg/s, and heat input into helium was estimated at approx. 730 μW (nominal design value is 750 μW).
- Taking the gradual degradation of the mechanical-refrigerator performance and the amount of helium filled in pre-launch operation into account, liquid helium lifetime was estimated to be 4.2 years (requirement is > 3 years, nominal design value is 3.5 years).



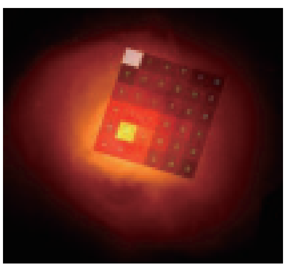
Observation results of Perseus cluster of galaxies (critical phase, initial verification phase)

- An energy resolution equivalent to that of the ground tests (4.9 eV half width half maximum at 5.9 keV) was confirmed, and the fine structure of emission lines that could not be resolved by the energy resolution of past instruments (~120 eV FWHM) was directly observed successfully for the first time.
- From the results, line-of-sight velocity dispersion of high-temperature plasma at the central region of the galaxy cluster was determined to be 164± 12 km/s. This discovery indicates for the first time that kinetic energy does not contribute significantly to the dynamic equilibrium of the plasma in galaxy clusters (paper being published early July).

X-ray spectrum obtained with the SXS onboard ASTRO-H (Hitomi)



Note: the gate valve at the X-ray entrance on SXS was closed. The X-ray below 3 keV is attenuated by the beryllium window on the gate valve.



35 pixel image by the SXS onboard Hitomi
- Superimposed over the X-ray image by the U.S. satellite Chandra. Both show X-ray intensity in pseudo-color.
- SXS field of view covering the Perseus cluster core region extending by 60 kilo persec
- Pixel on the top-lefti not used.

4 SUZAKU satellite reveals the average chemical composition of our Universe on the largest scales to be the same as that of our Sun

[X-ray Astronomy "SUZAKU" (ASTRO-EⅡ)]

All the chemical elements that are heavier than carbon, like the oxygen we breathe and the silicon that makes up the sand on the beach, were produced inside stars through nuclear fusion and released by stellar explosions called supernovae. By measuring the chemical composition of the Universe, scientists are trying reconstruct the history of how, when, and where each of the chemical elements vital for the evolution of life were produced.

Generally, there are two ways that a supernova explosion can happen, and the proportions of chemical elements that are produced depend on the supernova type. Lighter elements, like oxygen and magnesium, originate mainly from the explosions of massive stars, more than ten times the size of our Sun, at the end of their lifetimes. These are known as core-collapse supernovae. Smaller stars usually end their life cycles as white dwarves, a small fraction of which can explode as a thermonuclear or type Ia supernova if they accrete matter from a companion star, causing the white dwarf to become unstable to the pull of its own gravity. Heavier atoms, like iron and nickel, mostly come from this latter type of supernova. To produce the chemical composition of our Solar System, for instance, we need roughly one thermonuclear supernova for every five core-collapse supernova explosions. JAXA research fellow Aurora Simionescu wanted to find out whether the average chemical composition of the Universe was similar to that of our Solar System, or whether our local neighborhood was a special place.

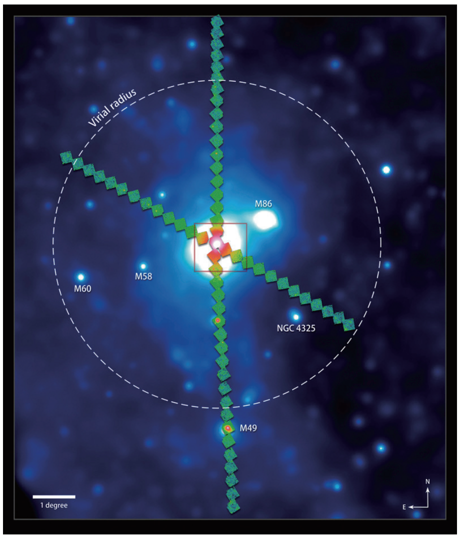


Figure 1 Suzaku mapped iron, magnesium, silicon and sulfur in four directions all across the Virgo galaxy cluster for the first time. The northern arm of the survey (top) extends as far as 5 million light-years from the cluster's centre. The dashed circle shows what astronomers call the virial radius, the boundary where gas from the surrounding large-scale structure is just falling into the cluster. Some prominent member galaxies of the cluster are labeled as well. The background image is part of the short-exposure all-sky X-ray survey acquired by the German ROSAT satellite. Credits: A. Simionescu (JAXA) and Hans Boehringer (MPE)

Perhaps counterintuitively, the answer to this question is best found not by looking at the stars themselves, but by looking at intergalactic space. This is because most of the normal matter in the universe, and thus also most of the metals, are currently not contained in stars, and are in a hot, diffuse gas that fills the space between galaxies. The gas is so hot that it radiates X-ray light. The brightest X-rays come from so-called clusters of galaxies, the places in the Universe where galaxies are packed closest together.

"I've found this idea fascinating ever since the first year of my PhD: X-raying the chemical content of our Universe", says Simionescu. But back then, almost 10 years ago, it was hard to obtain reliable measurements of the metal abundances, except for in the very densest, brightest parts of the intergalactic medium, due to a lack of X-ray photons and high background noise. So, we could only probe the chemical composition of the central part of a galaxy cluster, only one-thousandth of the typical volume.

JAXA's SUZAKU X-ray satellite dedicated a large amount of its observation time to addressing this problem, collecting data over many weeks. The first such deep observations, targeting the brightest system, the Perseus Cluster, allowed remarkably detailed measurements of the iron abundance in the intra-cluster medium on large scales. However, information about chemical elements predominantly produced by core-collapse supernovae was still missing.

For these measurements, observations of a galaxy cluster with a lower average temperature were needed, where the emission from lighter elements would be stronger than in the Perseus Cluster. SUZAKU spent about two weeks looking at the Virgo Cluster, the nearest and second-brightest cluster in the X-ray sky, which has such a suitably low temperature. With this new data set, Simionescu and her colleagues at JAXA and Stanford University detected not just iron, but for the first time also magnesium, silicon, and sulfur all the way to the edge of the galaxy cluster. Their results are reported in a study published recently in the Astrophysical Journal.

"What we found was that the ratios between the abundances of iron, silicon, sulfur, and magnesium, are constant throughout the entire volume of the Virgo Cluster, and indeed roughly consistent with the composition of our own Sun and most of the stars in our Galaxy", explains Dr. Norbert Werner from Stanford University, a co-author of the article.

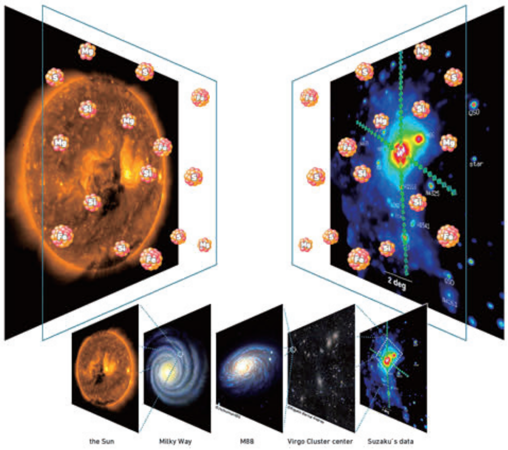


Figure 2 Suzaku reveals that the chemical composition, in terms of the relative abundances between Si, S, Mg, and Fe, remains the same over a very broad range of spatial scales: from the size of the Solar System (Pluto is 7.4 light-hours away) up to the entire volume of the Virgo Cluster that is ten million light years across. The same chemical make-up that allowed life to develop in our small corner of the Universe is found, wherever you look.

Galaxy clusters cover such a large volume that the content of each object is believed to be representative of the rest of the Universe. The new SUZAKU finding means that the chemical elements in the cosmos are very well mixed, with a chemical composition that remains the same from scales of the solar radius (hundreds of thousands of kilometers) to the size of a cluster of galaxies (several million light years). Although there may still be a few special places in the Universe that retain a different chemical make-up, on average, the bulk of the Universe has a very similar composition to our local neighborhood: the same raw soup of elements that is necessary for life like ours is found wherever you look.

"The SUZAKU satellite has opened a brand new window on the Universe and shown us that wherever you look, over vast scales, the mix of chemical elements is essentially the same" said Steven Allen, Professor of Physics at Stanford University and co-author of the study. "It's a beautifully simple result, and another step in understanding how the Universe around us came to be."

5 HINODE and IRIS reveal that magnetically driven resonance helps heat the Sun's atmosphere

An international research team from Japan, the US, and Europe combined high-resolution observations from the HINODE (SOLAR-B) mission and NASA's IRIS mission, together with state-of-the-art numerical simulations and modeling from the National Astronomical Observatory of Japan's supercomputer. In the combined data, researchers detected and identified the observational signatures of resonant absorption, which is an important mechanism for the conversion of wave energy into heat in the solar corona. The result was published in The Astrophysical Journal in August 2015.

The solar corona consists of a hot gas at approximately 1 million °C; the surface of the Sun is only 6000 °C. The mechanism that maintains the high temperature of the corona is not known, and this is referred to as the coronal heating problem. It is one of the most intriguing mysteries in astronomy.

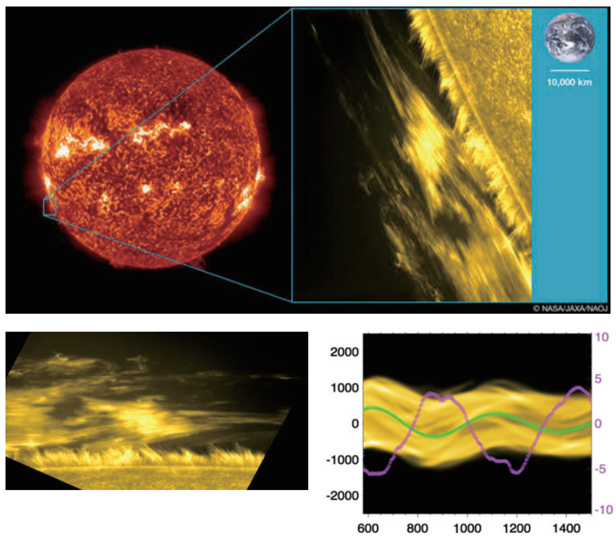


Figure 1 (Top) Solar surface image from the NASA solar observation satellite SDO. (Bottom) Solar prominence captured by HINODE. The image shows that the prominence is a thin strand-like structure. Prominence vibration in the green region was observed simultaneously by Hinode and IRIS and used to identify the wave dissipation. © NASA/JAXA/NAOJ

Resonant absorption is a process where two different types of magnetically driven waves resonate, strengthening one of them. In particular, this research examined Alfvénic waves, which can propagate through a prominence (a filamentary structure of cool, dense gas floating in the corona). For the first time, researchers could directly observe resonant absorption between transverse waves and torsional waves that produces a turbulent flow that heats the prominence. HINODE observed the transverse motion and IRIS observed the torsional motion (Figure 1).

These observations would not have been possible with HINODE alone, and thus joint observations from HINODE and IRIS were crucial in investigating the wave behaviors in detail. The study showed that it is possible to investigate the wave heating process observationally, and future research will contribute to solving the coronal heating problem.

6 New zodiacal emission model based on the AKARI all-sky survey data

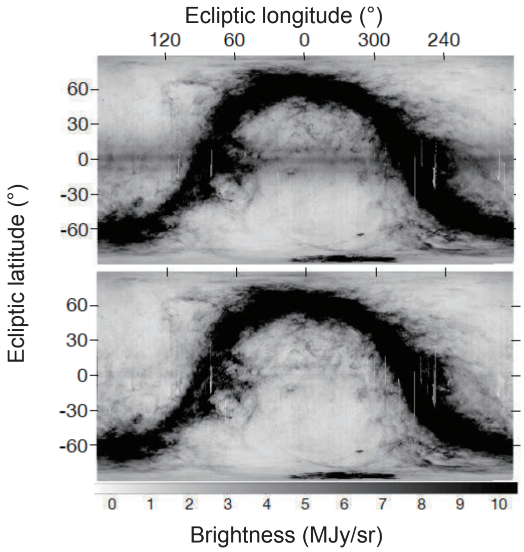
[Infrared Astronomy “AKARI” (ASTRO-F)]

Based on the all-sky far-infrared image map by AKARI published in December 2014, a spatial distribution model was developed for the zodiacal emission, which is infrared radiation produced by dust in the solar system. The spatial resolution of AKARI is several times higher than for past observations, and fine structures in the emission components were successfully reproduced.

Zodiacal emission is a major radiation source from the sky in the mid- to far-infrared wavelengths. The emission consists of a smooth component from the dust distributed over the solar-system and of fine structures from asteroidal dust bands and the circumsolar ring. These fine structures were discovered by the IRAS all-sky survey in 1983. However, IRAS's spatial resolution (3–5 arcmin in the far-infrared) and short observation period (10 months) prevented detailed modeling. The new model based on the AKARI data with the higher spatial resolution (1.0–1.5 arcmin) and longer observation period (16 months) has improved the zodiacal emission model greatly and reproduced these fine structures accurately.

The revised zodiacal emission model is not only useful for studies of solar-system dust, but is also important for investigating galactic and extra-galactic infrared radiation. Precise removal of the foreground strong component from zodiacal emission is crucial for detailed observations of the infrared radiation behind it. With the revised model, we can reduce the residual of the subtracted zodiacal emission to one tenth of the previous level; therefore, we will be able to obtain infrared observations that are more accurate.

The results have been published in *Publications of Astronomical Society of Japan*, Volume 68, article id. 35 (2016).

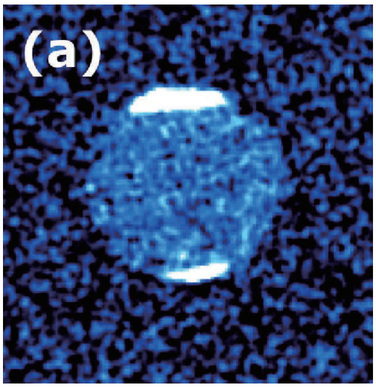


(Upper) Far-infrared all-sky infrared map by AKARI, currently available to the public. Parallel stripes near the center represent the zodiacal emission.
(Lower) Image after subtracting the zodiacal emission component model constructed in this study. The background infrared radiation can be seen clearly.

7 Understanding the space environment around Jupiter's magnetosphere

[Extreme Ultraviolet Spectroscope for Exospheric Dynamics “HISAKI” (SPRINT-A)]

The X-ray aurora in the polar region of Jupiter is emitted by ions entering Jupiter’s atmosphere. The ions have energies three orders of magnitude greater than those of the plasma seen at the poles on Earth. The physical mechanism that creates such high-energy ions in Jupiter’s magnetosphere was unknown. Simultaneous observations by large X-ray telescopes (XMM-Newton, ESA and Chandra, NASA) and JAXA telescope HISAKI (SPRINT-A) were conducted to understand the emission mechanism of the Jovian polar X-ray aurora (Figure 1). Long-term continuous observations by HISAKI have allowed the solar wind dependence to be studies. The simultaneous observations show that the intensity of the X-ray aurora is correlated with the solar wind velocity, and that a process at the boundary layer of Jupiter’s magnetosphere results in the X-ray emissions. The results support the hypothesis that the boundary layer of the Jovian magnetosphere is a strong accelerator of energetic particles and advance our understanding of the generation of non-thermal plasma (Journal of Geophysical Research, paper accepted February 2016). Our understanding of Jovian magnetospheric dynamics will be developed further with new data from the NASA Jupiter explorer, JUNO. Joint observations with other space telescopes and JUNO are being planned.



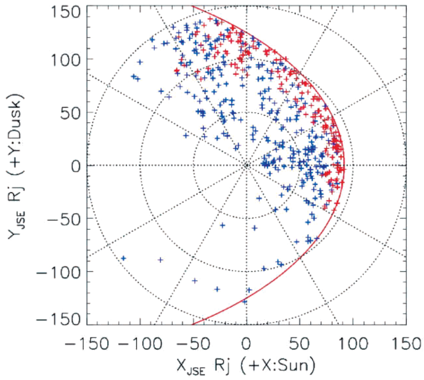


Figure 1 (Left) X-ray aurora observed by satellite Chandra. (Right) Origins of the X-ray aurora emission in the magnetosphere (red and blue crosses). The Jovian magnetospheric boundary (red line) is also shown (Kimura et al., 2016). The origins of the X-ray aurora are close to the boundary layer. The characteristics and the dependence on the solar wind velocity show that X-ray-emitting energetic ions are produced in the boundary layer.

8 Strengthening industry and mission competitiveness

[Hall thruster R&D]

All-electric propulsion refers to a spacecraft system where orbital transfer delta-v from the launch orbit to geostationary orbit (GEO) and delta-v for North–South station keeping (NSSK) both provided by electric propulsion. This system can drastically reduce the weight of a satellite, particularly the propellant weight for orbital transfer, which will reduce the cost per payload hugely. In typical cases, the cost per payload for an all-electric propulsion satellite is expected to be half of that of a conventional satellite based on chemical propulsion. The first all-electric propulsion satellite bus, Boeing's 702SP, flew successfully with an ion engine system, that features high specific impulse (Isp) and a corresponding high payload ratio. However, the drawback is the long trip time for orbital transfer, which typically takes half a year. To enable quick orbital transfer, a Hall thruster with a moderate Isp can provide a better system, which is why western companies are developing Hall thrusters. These thrusters depend on a selected Isp, but the high thrust-to-power ratio and low dry weight of Hall thrusters enable quick orbital transfer, possibly in less than three months if the optimum Isp is selected.

For quick orbital transfer from a launch orbit to GEO, a Hall thruster system with a higher thrust-to-power ratio is required. The most popular operational Isp range of Hall thrusters is 1500–2000 s, with a typical thrust-to-power ratio of 60 mN/kW. However, a thruster with a higher thrust-to-power ratio and a lower Isp will deliver spacecraft more quickly and efficiently because higher thrust, and hence higher acceleration, is possible. Vice versa, for NSSK, a higher Isp of 2500–3000 s is preferable to minimize propellant consumption for a typical geosynchronous satellite lifetime of 15–20 years. Based on these requirements, a Hall thruster capable of a high-thrust mode for quick orbital transfer and high-Isp operation for NSSK is ideal. We are focusing our research and development on bimodal Hall thrusters. So far, breadboard models (BBM) of 2–4 kW and 6 kW Hall thrusters have been designed and tested by JAXA, IHI AEROSPACE, IHI, and Tokyo Metropolitan University. Low-power models, such as BBM1 (left in Figure 1), are intended to replace ion thrusters for NSSK, or main propulsion systems for small and medium class deep space explorers. In contrast, higher-power models, like BBM2 (right in Figure 1), will have both a high-thrust mode (up to 480 mN and 1300s or higher) for quick orbit raising from geostationary transfer orbit to geostationary earth orbit, and a high-Isp mode (120 mN and 2500s (goal)) for efficient NSSK operation after insertion into geostationary orbit. Several tests on BBM2 have been conducted at powers up to 6.9 kW and a thrust value of up to 473 mN was obtained for a xenon mass flow rate of 30 mg/s. For a reduced flow rate and a higher acceleration voltage, an Isp of 2300s was obtained. Bimodal operation that can switch between high-thrust mode and high-Isp mode will create an ideal thruster system useful for geosynchronous satellites and space exploration.

(Asian Joint Conference on Propulsion and Power, March 2016).

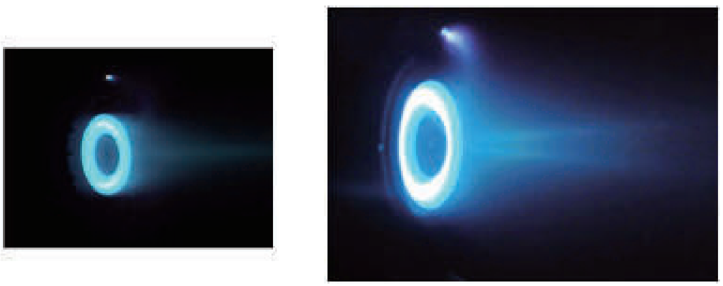


Figure 1. Breadboard model thrusters (left) BBM1 operating at 2 kW and (right) BBM2 operating at 6 kW.

9 First measurement of the electron structure of molten boron with an electrostatic levitation furnace

Boron is a technologically important material because of its high hardness, low density, and high melting point. Some theoretical studies suggest that boron could acquire a metallic character on melting, similar to silicon and germanium. Although transport experiments on liquid boron have indicated the survival of semiconducting behavior, the question of whether liquid boron is a metal or not was controversial and unsolved because handling liquid boron is difficult due to its high melting temperature and its chemical reaction with crucibles.

The electronic properties of molten boron were measured by using an electrostatic levitation method (Figure 1), developed for microgravity experiments in space, combined with the third-generation synchrotron radiation facility SPring-8. The bonding characteristics of liquid boron at 2500 K were studied by high-resolution Compton scattering. Excellent agreement was found between the measurements and the corresponding Car-Parrinello molecular dynamics simulations. In contrast to silicon, boron had a similar range of movement (itinerant range) in the liquid and the solid (Figure 2). This indicated that boron retains its semiconductor properties and does not become a metal, despite previous predictions.

Our results obtained will improve our understanding of the physical properties of molten boron, which could lead to the development of new materials.

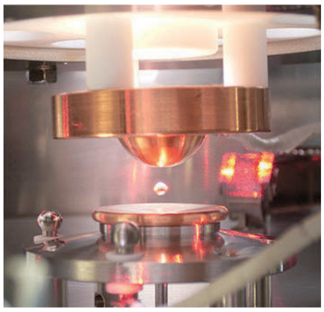


Figure 1 Electrostatic levitation furnace.

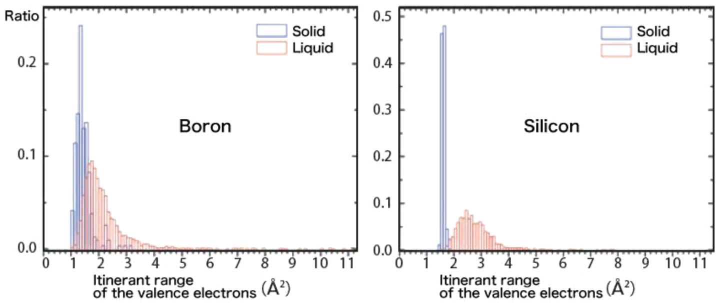
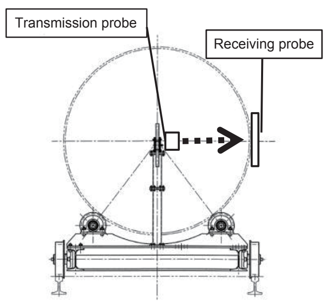


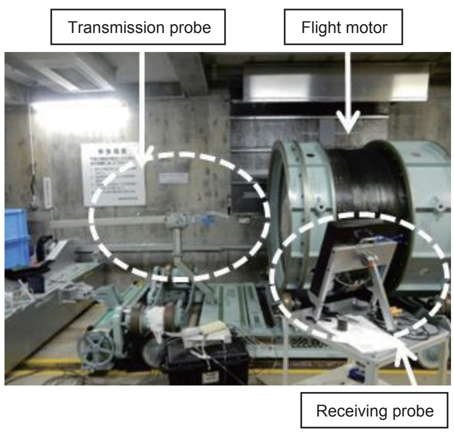
Figure 2 Experimental itinerant range of the valence electrons for (left) boron and (right) silicon.

10 Development of new inspection technology for the epsilon flight motor

[Epsilon Rocket Research]

A solid rocket motor cannot be verified with the flight motor itself; therefore, quality assurance has previously been performed with a radiation test that requires large facilities and multiple inspection processes. Quality assurance of a three-stage flight motor was conducted by using a new ultrasonic flaw detection method that could potentially replace conventional radiation tests. Our ultrasonic test combines several new technologies for detecting flaws through poor transmission of ultrasonic waves. The new testing method no longer requires maintenance and renewal of large facilities and it reduces the testing time by two-thirds *(Symposium on Advanced Materials and Nondestructive Measurement for the Establishment of a Safe and Secure Society, March 2016)*. We are planning to apply this new quality assurance approach to all the second and third-stage motors in the Epsilon rocket.





(Upper) Schematic view and (Lower) testing setup of ultrasonic tests for Epsilon flight moter

11 Achieving the fastest speed for high-speed telemetry transmission with a small satellite

Recently, Earth observation satellites have been able to take images with resolutions of several tens of centimeters. However, there are technical difficulties in transmitting the image data to Earth stations, because available radio frequency bands for high-speed data downlinks are limited. Thus, developing communication technologies for high-speed data links under the constraints of the radio frequency bandwidth is important.

We have developed a frequency bandwidth-efficient 64APSK modulation technology for Earth observation satellites that is 1.5–2 times more efficient than conventional technologies. Together with Prof. Nakasuka's group at the University of Tokyo, we applied these technologies to the small satellite, HODOYOSHI #4, which has a mass of 64 kg. The 3.8 m antenna station at Sagamihara campus, Institute of Space and Astronautical Science (ISAS), Japan, received 505 Mbit/s data with 64APSK modulation and demodulated and decoded the data without error. This communication speed is the highest achieved for a small satellite.

Each state (symbol) can express 6 bit of information in 64APSK modulation (Figure 1). In this demonstration of 505 Mbit/s data transmission, only 125 MHz radio frequency bandwidth was of the full bandwidth allocation of 375MHz for the X band (8025–8400 MHz) Earth observation data link. It is possible to have three 125 MHz bands in the full band, with right-hand and left-hand circular polarization channels for each of the three bands. Over these six channels, Earth observation satellites could transfer as much as 3000 Mbit/s in the X band.

At present, several IT companies are proposing plans to launch hundreds of small satellites for Earth imaging or recording movies with short intervals. It is expected that these projects will face difficulties in transmitting large amounts of observation data over the limited radio frequency bandwidth. Our high-speed communication technology may contribute greatly to these new types of Earth observation mission.

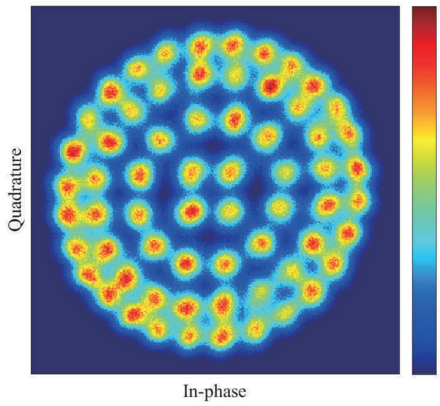


Figure 1 Constellation plot of 64 APSK modulation signals from HODOYOSHI #4 satellite. Sixty-four APSK modulation signals from HODOYOSHI #4 satellite to the 3.8 m antenna Earth station, Sagamihara, ISAS, are plotted in the plane of in-phase axis and quadrature axis. The color scale shows the event frequency of appearance, where red indicates more frequent events. The transmitted signals are decoded and recovered by error-correction codes

12 Development of a reusable system with minimized fuel consumption [Reusable sounding-rocket research]

The rocket Falcon 9, developed by an American private company, consumes a large amount of propellant because it is decelerated and guided toward the landing point by using main engine thrust. We designed a return landing approach that minimizes fuel consumption for developing reusable sounding rockets (Figure 1). The consumption of propellants during the return flight was compared with an optimized control simulation, and the results showed that fuel consumption can be minimized during returning flights by maximizing the use of aerodynamics to achieve sufficient deceleration *(2015 Symposium for Space Flight Dynamics, December 2015)*.

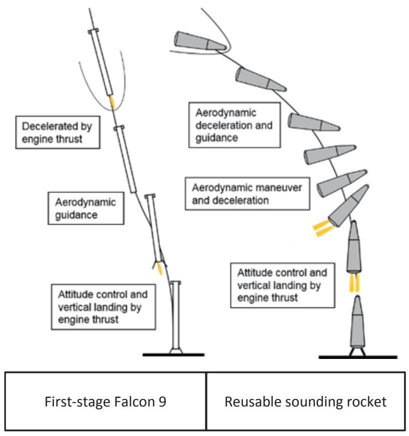


Figure 1 Deceleration of reusable sounding rocket during return flight

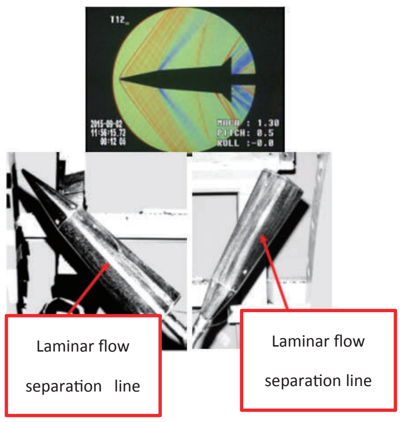


Figure 2 Aerodynamic wind tunnel tests

13 Microgravity crystal growth of semiconductors on the Kibo module

$In_xGa_{1-x}Sb$ is an important material that has tunable properties in the infrared (IR) region and is suitable for IR-device applications. Because the quality of crystals depends on the growth conditions, the growth of alloy semiconductors can be examined better under microgravity conditions (μG) where convection is suppressed. In the present study, we investigated the dissolution and growth of $In_xGa_{1-x}Sb$ alloy semiconductors via a sandwiched structure of GaSb(seed)/InSb/GaSb(feed) under normal and μG conditions. $In_xGa_{1-x}Sb$ crystals were grown by using a gradient heating furnace on the Kibo module aboard the International Space Station under μG, and a similar experiment was conducted under terrestrial conditions (1G) by using the same growth method. The crystals were cut along the growth direction and their growth properties were studied. The In composition and growth rate of the crystals were calculated.

The μG results showed that large crystals may be produced at an accelerated growth rate if convection is damped during crystal growth. The acceleration of crystal growth cannot be explained by the conventional assumption that crystal growth speed decreases under μG because the materials are transported by diffusion alone. Compared with 1G (right in Figure 1), the composition of the crystals grown under gG was more uniform, leading to improved quality with fewer defects (left in Figure 1) and accelerated crystal growth. These findings provide valuable hints at new avenues of research that could spur the development of new growth technology for the production of high-quality bulk semiconductor crystals for IR elements, which is difficult in under 1G.

We propose the following explanation of the difference of the growth rates. Under μG, the solutes dissolved at the seed interface could not move to the feed interface owing to the absence of convection, and thus the solution at the seed interface became locally supersaturated. Therefore, the growth under μG started earlier than that under 1G. Moreover, the dissolved solutes from the feed interface diffused quickly toward the seed interfaces because of the density gradient between the solute and solvent. Therefore, the growth rate was high under μG compared with 1G. In contrast, convection was dominant under 1G, which reduced the solute accumulation near the seed interface. The seed dissolution stopped once the crystal started to grow from the seed interface. Thus, the initiation of the growth was delayed and the growth rate was low compared with μG.

Reference: Y. Inatomi *et al*., "Growth of $In_xGa_{1-x}Sb$ alloy semiconductor at the International Space Station (ISS) and comparison with terrestrial experiments", *npj Microgravity* 1 (2015) 15011.

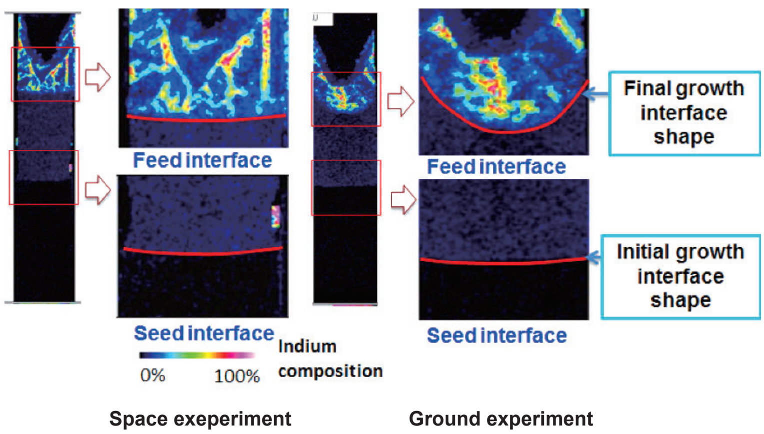


Figure 1 Electron probe microanalysis mapping of In distribution in (left) μG and (right) 1G samples.

14 REIMEI satellite reveals the origin of main and internal modulations of pulsating aurora

[Innovation Technology Demonstration Experiment “REIMEI” (INDEX)]

The origin of the main and internal modulation of the pulsating aurora (PsA) is revealed by the interactions between the lower-band Chorus waves and plasma sheet electrons, based on simultaneous observations of precipitating electrons and auroral emissions in the magnetic footprint of the REIMEI satellite. *(JAXA press release Sep 28, Journal of Geophysical Research Sep, 2015)*

The PsA appears as irregular patches of luminosity with quasi-periodic (2–20 s or longer, main) temporal fluctuations. The luminosity variations of the PsA are characterized by a series of rapid on-off switching caused by the intermittent precipitation of electrons with energies of several to tens of kiloelectron volts. In addition to quasi-periodic on-off switching, fast modulations embedded in the pulsation on-time, called quasi-3 Hz (internal) modulations, are observed.

The REIMEI satellite can observe the fine structures of auroral emissions and the corresponding precipitating auroral particles simultaneously. By using this unique feature, the REIMEI satellite has revealed the fine structure of the energy spectra of precipitating electrons corresponding to the PsA, where each of main and internal modulations have their own components in the energy spectra, including energy-time dispersions (Figure 1). Moreover, the stable precipitations around 1 keV are associated with the PsA.

Furthermore, we have reproduced these energy spectra with numerical simulations. In this simulation, Chorus waves (plasma waves) are generated around the geomagnetic equator and propagate along the geomagnetic field line, where ambient electrons are scattered when a resonance condition is fulfilled. Some of the scattered electrons precipitate into the ionosphere and excite auroral emissions. Figure 2 shows the measured and simulated spectra, which are similar. The fine structure of the precipitating electrons that cause PsA is a manifestation of Chorus frequency spectrum, namely the lower and upper Chorus waves. Thus, we have explained the generation mechanisms of the main and internal modulations of PsA.

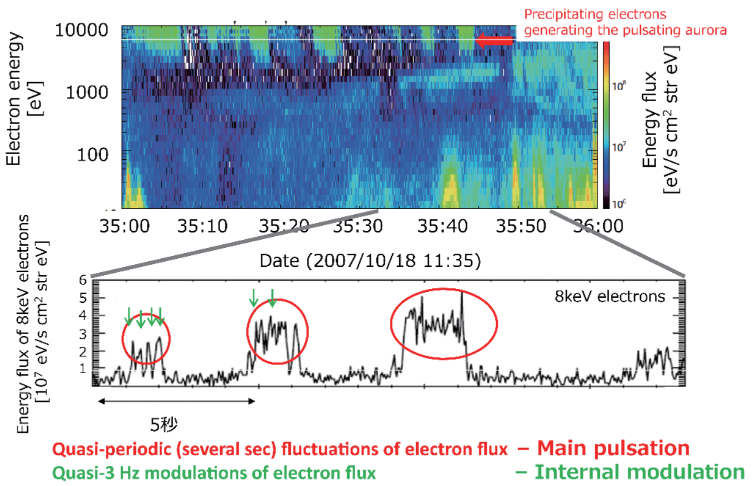


Figure 1 (Upper panel) Precipitating electron energy spectra observed during the pulsating aurora. (Bottom panel) Energy flux of 8 keV electrons. Signatures of the main and internal modulations are clearly visible.

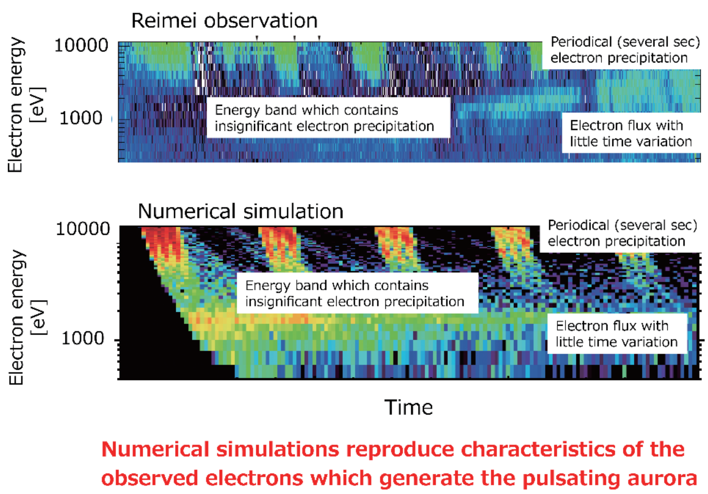


Figure 2 (Upper panel) Precipitating electron energy spectra observed during the pulsating aurora. (Bottom panel) Electron spectra reproduced by the numerical simulations, which consider Chorus waves and related electron scattering.

Ⅱ. Status Report

1. Space Science Roadmap

1.1 Roadmap for Space Science and Exploration

1.1.1 Basic framework

1. Space science projects at ISAS are divided into strategic large size plans, competitively chosen medium size plans, and small projects. Some projects will be promoted for the three fields of astronomy/astrophysics, solar system exploration science, and for space engineering, which includes satellites, spacecraft, and space transportation required for the missions in the previous two fields.
   - The strategic large size plans for space science missions are intended to achieve top scientific results internationally.
   - The competitively chosen medium size plans are intended to achieve frequent space science missions.
   - The small-scale project plans are intended to create unique, advanced space missions including international collaboration.
2. For astronomy and astrophysics, actions will be implemented in various ways, including large size 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 ten years will 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 by using technology such as Epsilon Launch Vehicles. 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 big bodies such as the moon or Mars.
4. Research projects will be established including engineering research, such as developing technology to reduce the size and increase the functionality of scientific satellites and exploration spacecraft, and for planetary exploration, deep space navigation systems, and new space transportation systems.

1.1.2 Strategic Large Size Space Science Missions

Announcement of Opportunity was issued in FY 2014 for proposals for strategic large size space science missions. The Advisory Committees for Space Science/Engineering reviewed the proposed plans and recommended three plans to the director general of the Institute of Space and Astronautical Science (ISAS). 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 size space science mission. The conceptual design for the Martian Moon sample return mission was completed and mission design review was conducted by reviewers, including 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 will start in FY 2016. The Martian Moon sample return plan was described in the revised mission work schedule in the new space basic plan. (December 8, 2015: approved by Space Development and Strategy headquarters)

1.1.3 Competitively-chosen Medium Size Space Science Missions

ISAS selected the mission plans for Smart Lander for Investigating Moon (SLIM) as the first mission of the competitively-chosen medium size plans and supported the project preparation. SLIM will move to the project phase in FY 2016. SLIM is described in the revised mission work schedule in the new space basic plan.

1.1.4 Small-scale space science projects

The small-scale project proposals in FY 2014 were evaluated and chosen by the Advisory Committees for Space Science/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. The plan for the second small project, the Jupiter ice satellite exploration plan (JUICE), was reviewed and the conceptual design was prepared by the team. In addition, a variety of small-scale projects were being considered to enable participation in largescale international projects such as JUICE beyond FY2016.

The Advisory Committees for Space Science/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-scale plan by using various flight opportunities to emphasize the importance of participation in planning for overseas large-scale plans. The decision will be made through detailed discussions in FY 2016.

1.1.5 Future mission strategy

In FY 2014, based on a request for information (RFI) about the future mission strategies and schedules of each space science and engineering communities, a long-term mission plan for space science and exploration was proposed. ISAS set up the space science and exploration program examination team in FY 2015, and the team constructed 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 will be discussed again in FY 2016, and the report will be finalized.

2. Space Science Programs

a. Aurora Observation: "AKEBONO" (EXOS-D)

The AKEBONO satellite was launched in 1989 and has been operating for 26 years and two months. Initially, the main objective of the AKEBONO project was to observe the aurora and investigate the acceleration mechanism of the aurora electrons. The long-period data from AKEBONO enabled us to examine the statistical characteristics of the aurora and its dependence on the season.

After the degradation of the instruments for observing the aurora image (ATV), magnetic field (MGF), electric field (EFD), and aurora particles (LEP and SMS), which were essential for investigating the aurora, the main objective changed to studying the inner magnetosphere, namely, the radiation belt and plasmasphere. The features and dynamics of the plasmasphere were studied by the electron temperature detector. The enhancement or dissipation of the radiation particles and the related wave activities were studied by the data from the radiation monitor (RDM) and wave instruments (PWS and VLF). These three instruments remained operational until the satellite operation was terminated. Statistical analysis revealed the long-period variation of the inner magnetosphere over two solar cycles, which could not have been achieved by other projects.

It was decided that AKEBONO should be terminated because of the degradation of the satellite power system (solar panels and battery), the reduction of the observation region caused by the change in the orbit, and the degradation of the majority of the scientific instruments. The transmitter onboard AKEBONO was permanently switched off on 23 April 2015.

Final AKEBONO operation on 23 April 2015

b. Earth's Magnetosphere Observation: "GEOTAIL"

The joint US-Japanese satellite GEOTAIL was launched in 1992 and it has been continuously operated for more than two solar cycles. The main purpose of GEOTAIL is to make direct observations of the plasma in the Earth's magnetotail. Most of the scientific instruments on GEOTAIL are still in good condition, except for the instruments that finished operation due to long-term degradation. Apart from the failure of one of the two data recorders that occurred at the end of December 2012, the other spacecraft systems are in good condition. The effect of the data recorder failure was minimized (data loss of 10% to 15%) by support from NASA's Deep Space Network (DSN). The data after calibration (1-2 years after data acquisition) are archived and are available to researchers worldwide. Recently, ISAS approved the continued operation of GEOTAIL, at least to the end of March 2019, provided that NASA's DSN operation support continues.

NASA's formation flying spacecraft MMS were launched on 12 March 2015. Japanese researchers from the GEOTAIL project have been deeply involved in the MMS project, designing, fabricating, and performing initial tests on 16 FPI-DIS sensors in Japan. All the 16 FPI-DIS sensors have been fully operational since September 2015. GEOTAIL operation time in Japan has been increased to allow collaboration with MMS since July 2015 (Figure 1). The GEOTAIL-MMS collaboration will provide opportunities to make multi-scale observations of space plasma.

Achievements:

1. A joint observation project was initiated with NASA's MMS spacecraft to understand the magnetic reconnection. Simultaneous observations of the magnetic reconnection in

the magnetopause were obtained (Figure 2).

2. A continuous observation dataset for Earth's magnetosphere has been acquired for more than two solar cycles (approximately 22 years). Data have been received both in Japan and in the US, and the observation data have been made available to researchers worldwide.
3. Number of peer-reviewed papers in 2015: 30; cumulative number of peer-review papers: 1150.
4. Ion and electron acceleration and heating in the magnetic reconnection region have been clarified by using the data obtained near the magnetic neutral line. The length of the magnetic neutral line was estimated. This is a valuable achievement based on the long-term observation data obtained by GEOTAIL (Figure 2) *(Journal of Geophysical Research, October 2015)*.

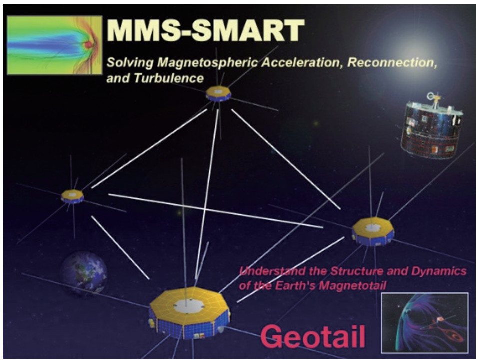


Figure 1 Geotail-MMS collaboration

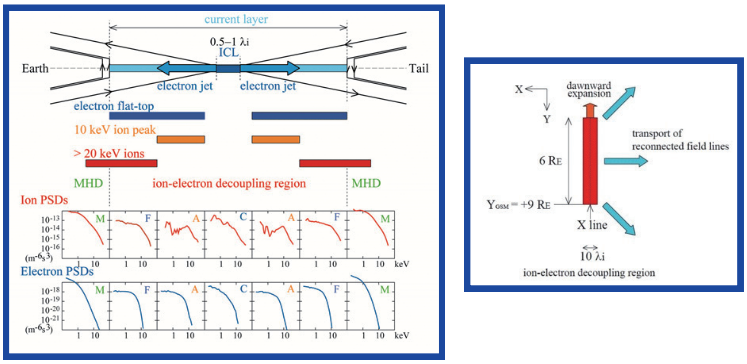


Figure 2 Structure of the magnetic reconnection region. PSD: phase space density.

c. X-ray Astronomy: "SUZAKU" (ASTRO-EⅡ)

Achievements:

Despite the 10th international announcement for observation proposals, communication with the satellite has only been intermittent since June 2015. Recovery operations were performed, but a decision was made to end the science observations based on the communications, battery, and attitude control (26 August 2015). The operation will be completed in the near future. Thirty-three observations were recorded for the accepted international proposals over 2 months up to the end of May 2016.

Impacts:

1. Number of peer-reviewed papers for 2015: 65; cumulative number of peer-reviewed papers: 828 (up to the end of September 2015).
2. SUZAKU observed the Perseus galaxy cluster for a long time. These observations revealed that the average chemical composition of our universe on the largest scales is the same as that of our sun. See the Scientific Achievement section for more detail.

d. Innovation Technology Demonstration Experiment: "REIMEI" (INDEX)

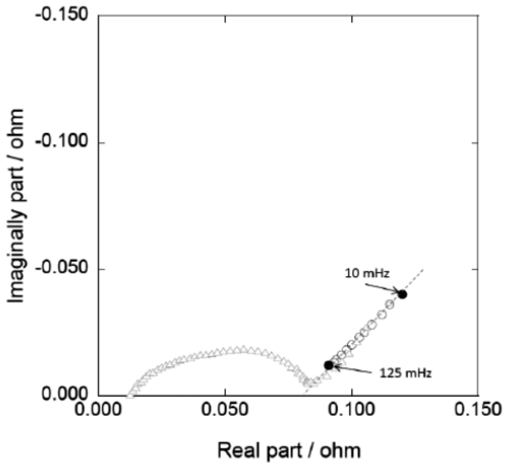
The small scientific satellite, Innovative technology Demonstration Experiment (INDEX; code name REIMEI) is a 72 kg piggy-back satellite that was launched in 2005. The satellite has been functioning in orbit for 10 years, fulfilling its scientific objective of observing the fine structure of aurora phenomena with its three spectral imagers and particle energy analyzers. Its engineering objective was to demonstrate the feasibility of small satellite technologies. The highlights of INDEX in 2015 are as follows.

Scientific Achievements:

The ISAS INDEX team and Nagoya University team analyzed the INDEX aurora observations and performed computer simulations based on the aurora observation data. The simultaneous observations of precipitating electrons and auroral emissions in the magnetic footprint of the REIMEI satellite show that the origin of the main and internal modulation of the pulsating aurora arises from interactions between the lower-band Chorus waves and plasma sheet electrons *(JAXA press release September 28; Journal of Geophysical Research September 2015)*. The details are presented in the Significant Research Achievements.

Engineering Achievements:

We proposed a new method for estimating the internal status of on-board batteries and demonstrated this method with INDEX's lithium-ion battery, which has undergone more than 60,000 charge-discharge cycles. We define a step response battery voltage waveform as when the discharge current increases stepwise. The real HK data for battery voltage is expressed as a convolutional form of the step response function and the time history of the discharge current. We use an appropriate equivalent circuit for the battery, and then we perform a least-squares error estimation for the circuit parameters. The figure shows the Nyquist plot of the on-board lithium-ion battery of the REIMEI satellite. This method can be a useful tool for estimating the internal status of on-board batteries.



Nyquist plot of the on-board lithium-ion battery of the REIMEI satellite.
○ Results calculated from in-orbit data.
△ Estimation based on ground test.

e. Solar Observation: "HINODE" (SOLAR-B)

HINODE (SOLAR-B) launched on 23 September 2006 Japan local time, and has been observing the Sun in the visible light, extreme UV, and soft X-ray wavelength bands. Through precise measurements of magnetic fields at the solar surface and imaging and spectroscopic measurements of the hot plasma in the solar corona, HINODE has been capturing various types of dynamics and heating in the solar atmosphere and helping researchers to investigate the physical mechanisms deeply coupled with magnetic fields. As an orbital observatory open to the world, HINODE has continued its observations in coordination with NASA's IRIS satellite, and 22 observation proposals were accepted from the international community in 2015. The solar activity cycle reached a maximum in 2014-2015, and the observation target of the highest priority has been given to solar flares, which are the most energetic explosions in the solar system and also affect the solar-terrestrial environment.

Achievements:

1. As an example of remarkable results, researchers detected and identified the observational signatures of resonant absorption, which is an important mechanism for the conversion of wave energy into heat in the solar corona. These results were acquired by combining high-resolution observations from the HINODE Solar Optical Telescope and IRIS with supercomputer numerical simulations and modeling. The results provide useful information for understanding the coronal heating problem.
2. By making the observational data from HINODE open to the public, the program's contribution to scientific achievements remains high. For example, the discovery of a new formation mechanism for X-ray jets using the X-Ray Telescope (US) (Nature, July 2015) and identification of a possible low-speed solar wind source using the EUV Imaging Spectrometer (US) (Nature Comm., January 2015).

Impacts:

1. Number of peer-reviewed papers published in 2015: 90; cumulative number of peer-reviewed papers published in journals: 981 as of December 2015.

f. Venus Meteorology: "AKATSUKI" (PLANET-C)

Achievements:

1. Three-step fine corrections of the trajectory were performed in July 2015, which confirmed the feasibility of using the attitude control system thrusters for the orbit insertion in December 2015.
2. On 7 December 7 2015, the attitude control thrusters fired for about 20 min, adequately decelerating the spacecraft so that it began orbiting Venus. The orbit was tuned further on December 20 to ensure stable operation for a longer period.
3. All the subsystems (thermal, mechanical, electrical, telecommunication, attitude-orbital control, scientific instruments) were confirmed healthy in orbit, so the science mission (data acquisition) began in early 2016.
4. AKATSUKI failed to enter orbit around Venus due to a malfunction of its propulsion system in December 2010. However, it retried the maneuver and entered an elliptic orbit around Venus in December 2015. It became the Japanese first spacecraft captured in a planetary gravitational field.

Impacts:

2015 in peer-reviewed papers numbered 1. The cumulative number of peer-reviewed papers is 18.
2. For the first time in space exploration, a "failed" spacecraft successfully entered an orbit around a planet on a second attempt, 5 years later. Furthermore, the main engine was no longer usable and the spacecraft experienced perihelion nine times, during which solar heating was 30% more than anticipated. The orbit insertion in December 2015 was made possible by 5 years of careful operations and tens of thousands of trajectory simulations by the team. These will be valuable assets for future missions.
3. Our success was noted in the administrative policy speech by Prime Minister Abe at the deliberative assembly. The achievement also received a Gold Medal Prize (special award) from the Yomiuri Techno-Forum.

g. Solar Power Sail Demonstrator: IKAROS

Search operation was conducted for the Solar Power Sail Demonstrator (IKAROS) by using open-loop tracking data.

Achievements:

1. We re-established communication with IKAROS, which was rebooted after hibernation mode, on 23 April 23 2015. This was the fourth instance of signal acquisition, however, we used a different method from the three previous times. Re-acquisition was achieved by post-processing open-loop tracking data recorded.
2. We detected a signal and also estimating the spinning motion of the spacecraft, allowing us to acquire the range rate data and beacon data, even under difficult communication conditions. Furthermore, we may be able to obtain range data and telemetry data from weak signals from the spinning spacecraft stored by the open-loop recorder.

Impacts:

1. Number of peer-reviewed papers in 2015: 4; cumulative number of peer-reviewed papers: 106.
2. Searching by using open-loop tracking data can be applied to spacecraft with an unknown attitude, in addition to spinning spacecraft such as IKAROS. This method provides flexibility and redundancy in spacecraft operations.

h. Extreme ultraviolet spectroscope for Exospheric Dynamics: "HISAKI" (SPRINT-A)

Operation of the extreme-ultraviolet spectroscopic planet observatory (SPRINT-A) and planetary remote sensing from earth orbit.

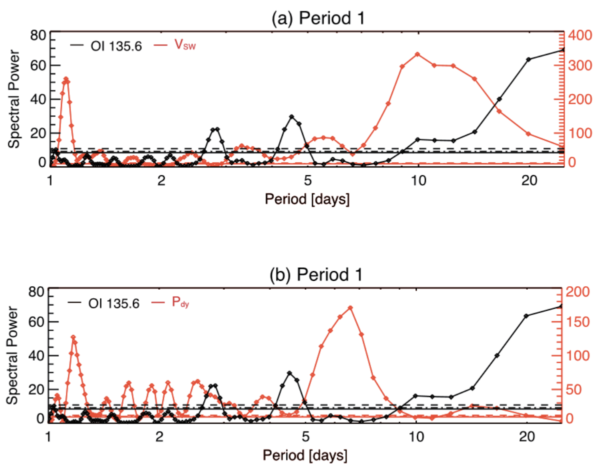
The extreme-ultraviolet spectroscopic planet observatory HISAKI (SPRINT-A), which was launched on 14 September, 2013, is the first space telescope for planetary observations from Earth orbit. It has an instrument for measuring the extreme ultraviolet spectrum to understand energy transportation in Jupiter's magnetosphere and the atmospheric evolution of the terrestrial planet. The instrument has the highest time resolution and longest observation duration.

Achievements:

1. The longest-term planetary observations of Jupiter and Venus were obtained.
2. A joint observation was performed with X-ray space telescopes (Chandra, XMM-Newton, and SUZAKU).
3. Observations of astronomical bodies, such as galaxy clusters and remains of a supernova, were also performed during periods in which planetary observation was not feasible.

Impacts:

1. Number of peer-reviewed papers in 2015: 5; cumulative number of peer-reviewed papers: 14.
2. The observations from this project have attracted attention from the scientists all over the world, and special SPRINT-A sessions and special subcommittees have been organized at domestic and international conferences and symposiums (e.g., The Society of Geomagnetism and Earth, Planetary and Space Sciences).
3. Periodical variations in Venus ionospheric emissions in the morning sector were captured for the first time by the long-term observations. The results showed that the period was



Difference in periodic variations in Venus's ionosphere (black) and solar wind variations (red). Spectrum power shows the strength of the variation for a given period (Masunaga et al., 2015).

independent from the solar wind variation cycle, which has important implications for the physical relationship between the ionosphere and kinetic transportation in the lower-layer neutral atmosphere in the environment of Venus *(Journal of Geophysical Research, December 2015)*.

i. Asteroid Explorer: “Hayabusa2”

The asteroid explorer Hayabusa2 was launched on 3 December 2014 by the Japanese H2A launch vehicle. Hayabusa2 is the follow-on mission for HAYABUSA, and it is the second asteroid sample return mission. The target asteroid is asteroid 162173 Ryugu, which is a C-type near-Earth asteroid. After the launch, the initial check confirmed that all the instruments were working normally and stably.

Hayabusa2 has Ka band and X band communication systems. This is the first time that a Japanese deep space spacecraft has had Ka band communication. Hayabusa2 is also the first JAXA spacecraft equipped with full delta differential one-way range (DDOR) capability. This DDOR technology was demonstrated before the Earth swing-by.

On 3 December 2015, Hayabusa2 completed the Earth swing-by. After the Earth swing-by, the spacecraft was in a normal state and was on the exact planned trajectory (Figure 1). Just before and after the Earth swing-by, observations of the Earth and the Moon were performed with the onboard instruments, such as the optical navigation camera (ONC), thermal infrared imager (TIR), and near-infrared spectrometer (NIRS3). The laser altimeter (LIDAR) was used to perform a laser link experiment between the explorer and the Earth (Figure 2).

Hayabusa2 is equipped with four 10 mN ion engines to navigate the round-trip journey between the asteroid and the Earth. After the Earth swing-by, the long-term ion engine operated from March to May 2016 and Hayabusa2 was put on the trajectory towards Ryugu as planned.

Hayabusa2 also demonstrates new engineering technologies for interplanetary flight. Solar Sail Mode attitude control is one such technology, where the attitude is maintained by the solar radiation pressure (SRP) exerted on the surface of the spacecraft, instead of using thrusters and reaction wheels. A total of 192 days of zero-fuel, SRP-assisted attitude control was achieved with this new technique.

Impacts:

1. Number of peer-reviewed papers in 2015: 12; cumulative number of peer-reviewed papers: 40.

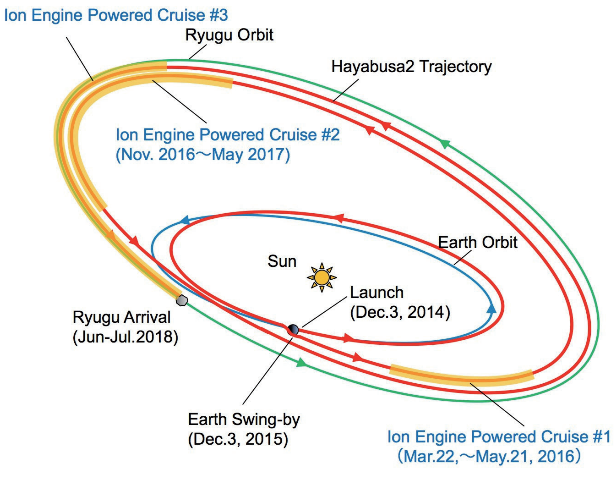


Figure 1 Schematic trajectory of Hayabusa2 from launch to the asteroid arrival

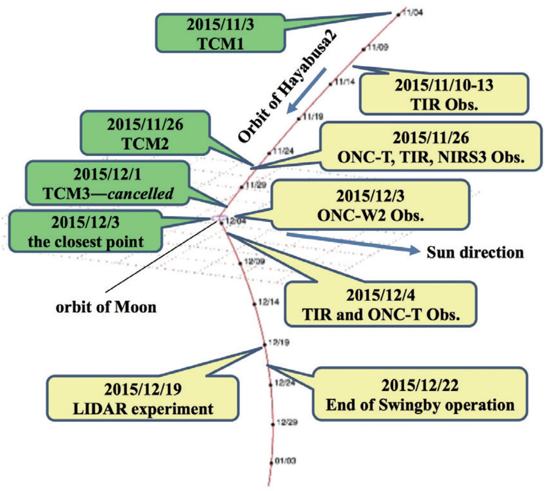


Figure 2 Operations before and after the Earth swing-by. TCM: trajectory correction maneuver.

j. X-ray Astronomy: “HITOMI” (ASTRO-H)

The flight model for the X-ray astronomy satellite ASTRO-H was produced and comprehensive testing and launch planning were conducted.

Achievements:

1. The project continued to perform comprehensive tests, including heat vacuum tests and oscillation tests, to confirm the performance of the equipment.
2. On 17 February, 2016, H-IIA rocket F30 was launched and named “HITOMI.” Important sequences were operated as expected after the launch, including the cooling of a soft

X-ray detector (SXS) and extension of the extended optical bench (EOB). SXS was cooled to 50 mK, and it was confirmed that the performance of the energy resolution was meeting the required level.

3. During the initial function verification phase on March 26, an abnormality in satellite operation occurred in which radio waves from the satellite could not be received. An emergency headquarter site was setup with the President of JAXA as the head to understand the whole picture, grasp the state of the satellite, and assert a company-wide effort to recover the satellite functions. Technical evaluation by JAXA revealed that an “attitude abnormality” occurred while the satellite was in a “normal state“; this was identified as the mechanism leading to the ”separation of bodies,” and it was concluded that functional recovery could not be expected. Thus, current work is focused on identifying the root cause *(JAXA press release, 28 April, 2016)*.

Impacts:

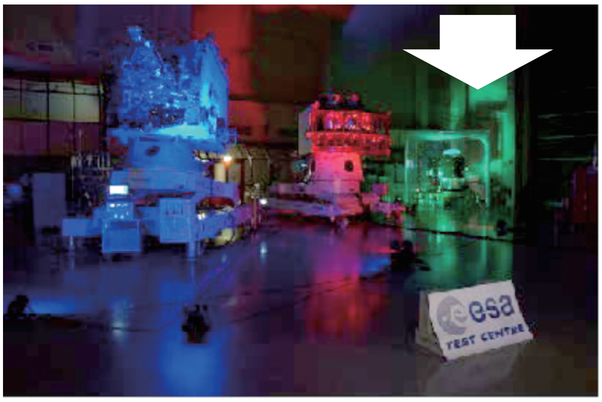
1. Number of peer-reviewed papers in 2015: 126; cumulative number of peer-reviewed papers: 680 (since 2009).

k. Mercury Exploration: MMO/BepiColombo

Mercury is the closest planet to the Sun. The size of Mercury is between that of the Moon and Mars; however, Mercury has an intrinsic magnetic field, which was discovered by the Mariner 10 spacecraft during three flybys and was confirmed by NASA’s Mercury orbiter MESSENGER. MESSENGER deorbited into Mercury as planned on May 2015 and completed its mission.

BepiColombo is a European Space Agency (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 spacecraft: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The two orbiters and Mercury Transfer Module (MTM) are combined in a stack configuration. The stack is called the Mercury Cruise System. JAXA is responsible for the development and operation of the MMO, whereas 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, whereas the main objective of the MPO is to study Mercury itself. The BepiColombo modules (MPO and MTM) built by ESA are undergoing the final assembly, integration, and verification (AIV) test at ESA/European Space Research and Technology Centre (ESTEC). The final AIV for the MMO was completed in March 2015 and the MMO flight model was transported to ESA/ESTEC in April 2015. Follow-up tasks were completed between April and June, and the transfer process to ESA was completed. Preparations for combined tests with ESA’s modules were also completed. The MMO is waiting for the stack level AIV which is expected to start in January 2017. BepiColombo will be launched by an Ariane-5 rocket in 2018 and will arrive at Mercury in 2024.



(Left) Loading the MMO for transfer at the Sagamihara campus.
(Right) Public viewing after arrival at ESA. From left to right: MPO, MTM (electrical propulsion module), and MMO.

l. Exploration of energization and Radiation in Geospace (ERG)

The flight model for the Energization and Radiation in Geospace (ERG) exploration satellite was fabricated and tested.

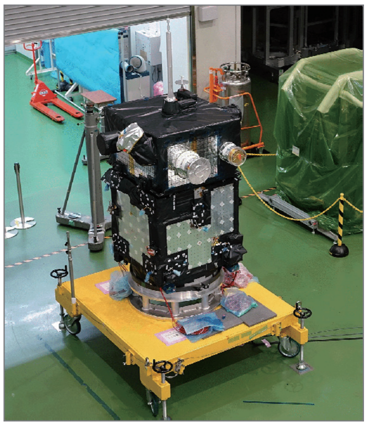
Achievements:

1. We performed flight tests for the 2016 launch. April-June: primary integration test, September-February: individual environment and calibration tests for bus and mission components; February-present: FM comprehensive test.
2. A processing program for the wave-particle interaction analyzer was developed, and verification of its functions was completed for the core component of the processing algorithm through comprehensive electric tests of the mission component.
3. The data analysis research environment has been improved, and data have been used more frequently as many researchers around the world now have access to it for studies with coordinated ground observations.

Impacts:

1. Number of peer-reviewed papers in 2015: 19 (as of February 2016); cumulative number of ERG-related peer-reviewed papers: 39 (2006 to February 2016). The majority of the papers discuss the ground observation network development for ERG, the coordination with Van Allen Probes satellites, and the development of the data analysis environment.

We aim to identify energy exchange processes between plasma waves and particle energy, identify the high-energy mechanisms in the Van Allen radiation belt, and improve the precision of space weather predictions by the wave-particle interaction analyzer on the ERG satellite.



Alignment measurements of ERG after the integration of mission and bus components

m. Smart Lander for Investigating Moon (SLIM)

The Smart Lander for Investigating Moon (SLIM) mission will demonstrate precise “pinpoint” landing technology on the lunar surface and several technologies for developing small, lightweight exploration spacecraft.

Achievements:

The plan was assessed by JAXA to evaluate the aim of the mission, and the validity of the development plan and project plan. The risk identification and mitigation plans were assessed in detail, and the validity of the phase-A plan was confirmed. Based on the authorized phase-A plan, investigation of the system baseline and several fundamental tests were performed. The main engine firing test was one of these fundamental tests, and confirmed that the design meets the basic requirements. The project plan was revised based on the phase-A study and reviewed by JAXA. Finally, the Phase-B study was authorized as a JAXA project.

Impacts:

Pinpoint landing technology is a key technology for the next generation lunar landers. It will allow access to specific places on the moon that are scientifically valuable or important as exploration targets.

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

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

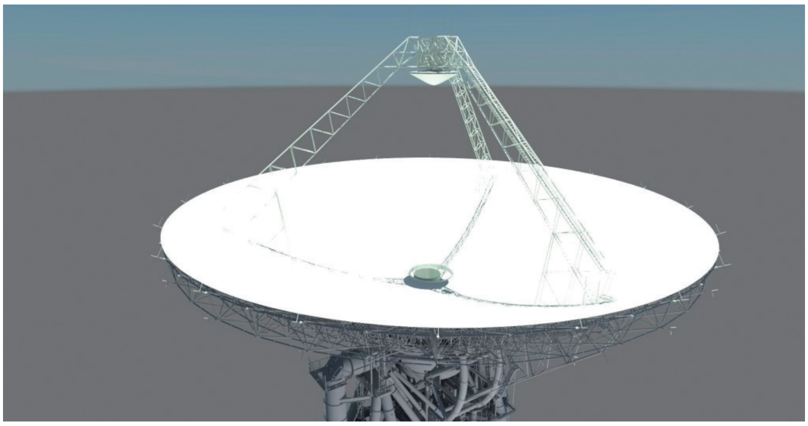
We started the GRound station for deep space Exploration And Telecommunication (GREAT) project.

Achievements:

1. Although JAXA has an antenna 64 m in diameter in Saku City, Nagano prefecture, that has been used for our deep space missions for more than 30 years, it is reaching the end of its operational life.
2. After defining the mission and the system requirements, the GREAT project was approved on November 1, 2015 to begin the development of a new ground station for JAXA (Figure 1). The basic aims of the project are as follows.
   - To be able to transmit and receive with the X-band and receive with the Ka-band
   - To use parts of the existing 64 m station as effectively as possible.
   - To be completed by the end of Japanese fiscal year 2019.
3. The new station will be located at about 1.5 km from the 64 m station as the crow flies.

Impacts:

1. To enable continuous flexible and autonomous operation for our deep space missions.
2. To contribute to future international deep space missions through the geographic location of Japan.



Artist's image of the GREAT project antenna.

o. The next-generation infrared space telescope: SPICA

Space Infrared Telescope for Cosmology and Astrophysics (SPICA) is a next-generation infrared astronomy mission that aims to reveal the process that enriched the universe with metal and dust and led it to the formation of habitable worlds by observing (1) metal and dust enrichment through galaxy evolution and (2) planetary system formation of habitable systems.

Achievements:

1. With the original scientific goals upheld, the SPICA plan was renewed to increase its feasibility as follows.
   * Scientific aims and objectives have been made clearer and more precise.
   * The technical feasibility has been increased by the reduction in diameter from 3 to 2.5 m.
   * The expected performance has been improved by using a powerful cutting-edge detector.
2. The new SPICA plan was evaluated by the International Science Evaluation Advisory Board in July 2015. The expected achievements from the SPICA plan were verified as being competitive and offering high value until the late 2020s.
3. Researchers both in Japan and Europe have agreed to submit a proposal for the new SPICA plan for the Cosmic Vision M-class mission (M5).
4. The new SPICA plan was submitted to Space Science Communities to be reviewed, and was approved in JAXA Mission Definition Review.
5. Technical investigations, mainly on the SPICA payload module under development by Japan were performed, and

SPICA International Science Evaluation Advisory Board held in Paris in July 2015.

practical solutions were found. The technical development of SPICA has been advancing.

Impacts:

1. Number of peer-reviewed papers in 2016: 15; cumulative number of peer-reviewed papers: 109
2. On 16 March 2016, the special session "Astronomy with new SPICA" was held in the 2016 annual spring meeting of the Astronomical Society of Japan. There were more than 250 participants who were very interested in the SPICA mission, and the session was a success.

3. R&D at Research Departments

a. Department of Space Astronomy and Astrophysics

1. Overview

Our department is engaged in observational research in astrophysics, mainly using observations from space; next-generation observation equipment and technology; the study and launch of new space missions; and the theoretical study of atomic and molecular processes related to astrophysics. Observations are conducted over a wide range of wavelengths, including radio waves, submillimeter waves, infrared, X-rays, and gamma rays. We are also conducting complementary research with ground observation equipment, including that for visible light. Our main targets include galaxy clusters, active galactic nuclei, galaxies, stars, star-forming regions and protostars, supernova remnants, interstellar matter, extrasolar planets, and cosmic background radiation.

We are advancing research and development of next-generation observation equipment, such as lightweight X-ray or infrared telescopes, small-pixel infrared detectors, cryogenic X-ray spectrometers and their space cooling technology, coronagraphs, X-ray or 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.

2. Research activities in 2015

We observed various phenomena in space by using a wide range of wavelengths, from radio waves to gamma rays. We also developed new observation equipment for future missions, improved existing detectors, and reviewed missions. Furthermore, we conducted theoretical studies, mainly on atomic and molecular processes.

2.1. High-energy astrophysics

For observational research in the X-ray and gamma ray regions, we performed research using gamma ray satellites and X-ray astronomy satellites, including SUZAKU. We investigated phenomena at various levels of a variety of celestial bodies that emit 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, we carried out a broad range of astrophysical research on, for example, X-ray background radiation, which is radiation from many unresolved celestial bodies, and on dark matter using that radiation. When analyzing the data from these observations, it was essential to compare the data with a theoretical model. We developed new analysis methods such as a Monte Carlo simulation tool.

2.2. Infrared astrophysics

In the infrared wavelength regime, we carried out research based on various data gathered by AKARI and other space infrared missions, rocket-borne instruments, and ground-based telescopes. Multi-wavelength data from distant galaxies in the North Ecliptic Pole (NEP) region revealed the evolution of the mid-infrared luminosity function of galaxies up to $z \sim 2$ more precisely than previous studies. Because of the very wide field coverage of the Hyper Supreme-Cam on the Subaru telescope, our survey in the NEP region detected many dusty ultra-luminous active galactic nuclei. The rocket-borne mission CIBER measured the absolute intensity of the near-infrared diffuse galactic light. Analysis of the Cosmic Background Explorer data concluded that the ratio of diffuse galactic light at 1-2 μm to far-infrared radiation increased toward the low galactic latitude regions. A study of galaxies in the cluster RXJ0152.7-1357, located about 7 billion light years away, with AKARI data found that there were starburst galaxies outside of the cluster, further than 3 million light years from the center, and that the inner conditions of the cluster member galaxies were the same as those of the non-member galaxies. Using the AKARI Far-Infrared All-Sky Survey Maps, the distribution of the zodiacal emission was reconstructed with the highest resolution ever, and resulted in a new zodiacal emission model.

2.3. Radio astronomy

For the radio wave range, we performed a wide range of observational research using domestic and foreign radio telescopes such as the Atacama Large Millimeter Array (ALMA) and the Very Long Baseline Array (VLBA). 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 2015, we measured the radio core position shift of a nearby radio galaxy from the multi-frequency imaging with VLBA and determined the fine structure of the jet base. Using

ALMA, we obtained dust continuum images of the Galactic Center with unprecedented high dynamic ranges, and we found a close correlation between the dust emission peaks and the OB stars in the region. In addition, we advanced research on the formation of stars and the development of interstellar matter 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.

2.4. Theoretical research

We investigated the formation processes of true muonium atoms theoretically. True muonium atoms are the Coulomb binding system composed of a muon and an antimuon, which are leptons and are much heavier than electrons. Therefore, true muonium is an exotic hydrogen-like atom, expected to be most appropriate for testing the quantum electrodynamics theory. Producing true muonium atoms effectively is an area of considerable interest.

In collisions of slow, highly charged ions with a molecule, a number of electrons are removed from the molecule and a Coulomb explosion occurs. Recently, this type of collision process has been investigated by triple coincidence measurements of the scattered ion and the dissociated ion pair. We developed a mechanical model that describes the dynamics of the multi-ionization process, where the target is a two-atom molecule, to forecast or interpret experimental results. Recently, we theoretically analyzed the experimental results obtained at the Grand Accélérateur National d’Ions Lourds in France, for a dimer of an inert gas. We succeeded in explaining the distribution of each valence of the ions. Furthermore, we found that the electron involved in the formation of the quasi-molecule during the collision process plays an important role by partially shielding the charge of each ion.

2.5. Technology development

For observational research in the X-ray and gamma ray regions, we engaged in developmental research in various fields to increase the sensitivity of observations. We reduced the background in X-ray and gamma ray detectors, increased the energy and positional resolution, and developed a larger detector format. Some of these results have been adopted in consumer products, such as the Compton camera, which was used to visualize radioactive contamination during the decontamination work at Fukushima. We also reviewed multiple current and future missions.

Athena is a large international X-ray observatory based on international collaboration with Europe. It has been selected as an L2 mission for the European Space Agency Cosmic Vision missions, with a target launch data in 2028. Japan is expected to supply part of the X-IFU cooling system (mechanical coolers), which is the main mission instrument in Athena. Development of the mechanical coolers will focus on longer life and smaller disturbance. We measured the performance and disturbance of the double-stage Stirling cooler, the ball bearing of which was replaced with a leaf spring.

We have also achieved technical developments in infrared astronomy. An immersion grating for high-dispersion spectroscopy achieved a diffraction efficiency close to the theoretical estimate. We established basic technology for blocked impurity band (BIB) germanium far-infrared image sensors. A binary mask coronagraph for future high-contrast observations was created. Cryogenics for high-sensitivity infrared observations has been investigated.

We have also planned future missions. LiteBIRD is a future mission that aims to verify the cosmic inflation hypothesis through the observations of B-mode polarization of the cosmic microwave background. The advisory committee for space science in 2015 recommended the mission to Institute of Space and Astronautical Science (ISAS) as a candidate strategic large class mission, and was approved to undergo the next ISAS review. In the US, the international partner for LiteBIRD, LiteBIRD was selected for the Mission of Opportunity and the phase A study was started. Because of this progress, we brought forward studies of mission instruments and the satellite bus system.

For the radio wave range, we reviewed the scientific goals and the observation systems related to, for example, low-frequency radio astronomy, submillimeter astronomy, and space VLBI, considering future satellite missions. We also developed experimental devices for the balloon VLBI and low-noise millimeter wave receiver. Furthermore, we are participating in the technological discussion about the ground antenna system for deep space exploration in the context of utilizing the radio astronomy technology of the research departments.

3. Research topics

3.1 Research in X-ray and gamma ray regions

3.1.1 Observational research

3.1.1.1 Stellar winds from a massive star based on observations by SUZAKU

3.1.1.2 Construction of a model for X-ray radiation from a cataclysmic variable star with a strong magnetic field and its application to the observation data from SUZAKU for determining the mass of a white dwarf

3.1.1.3 Constraints on the mass radius of a neutron star by using the X-ray burst from GRS1747-312

3.1.1.4 Evolutional history of the supernova remnant Cassiopeia A based on observations by SUZAKU

3.1.1.5 A supernova remnant that looks bright owing to the emission of GeV gamma rays based on observations by SUZAKU

3.1.1.6 Activeness of the central core of a galaxy based on observations by SUZAKU

3.1.1.7 Constraints on the radiation mechanism of the jets in active galactic nuclei by modeling the gamma ray

variation over a short period
3.1.1.8 Observational study of origin of soft X-ray background radiation with SUZAKU
3.1.1.9 Search for dark matter indicators from X-ray background radiation with SUZAKU
3.1.1.10 Plasma physics in a cluster of galaxies using the gaseous form of a merging galaxy cluster
3.1.1.11 X-ray observational study of galaxies, galaxy clusters, and superclusters
3.1.2 Development research for observation technology
3.1.2.1 Development of an X-ray CCD camera with greatly reduced charged particle background
3.1.2.2 Development of a TES X-ray microcalorimeter for future space missions or ground applications
3.1.2.3 Development of new X-ray microcalorimeter
3.1.2.4 Development of a Compton camera for high-sensitivity gamma ray observations
3.1.2.5 Research on an X-ray and gamma ray image detector using a cadmium telluride semiconductor
3.1.2.6 Study of a system design for the small satellite mission DIOS
3.1.2.7 Study of a cooling system for the European X-ray observatory Athena X-IFU subsystem
3.1.2.8 Research on the observation system to be installed on LiteBIRD
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 DIRBE data
3.2.1.3 Scattered light and thermal radiation by interstellar dust in near-infrared wavelengths
3.2.1.4 GOALS: Merger and star-formation efficiency in luminous infrared galaxies
3.2.1.5 Star formation galaxies at z ~ 4 observed by broad-band millimeter spectrometer Z-Spec
3.2.1.6 Galaxy evolution in the active era of the universe revealed by multi-wavelength observation in the North Ecliptic Pole region
3.2.1.7 Spatial structure around active galactic nuclei using AKARI spectroscopy
3.2.1.8 Molecular gas and environment effects in starburst galaxies
3.2.1.9 Study of environmental effects in star forming galaxies by AKARI far-infrared observations
3.2.1.10 Star-formation and active galactic nuclei as seen by AKARI
3.2.1.11 AKARI observations of nearby spiral galaxies
3.2.1.12 Study of diffuse radiation using the infrared satellite MIRIS
3.2.1.13 Estimating attenuation by galactic dust using AKARI-SDSS-GALEX data
3.2.1.14 AKARI study of PAH intensity and environment effect in RX J0152.7-1357
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 Spectroscopic studies of brown dwarf atmospheres
3.2.1.18 Observational study of episodic mass-loss from red-giant stars
3.2.1.19 Fine structure of Herbig Ae stars
3.2.1.20 Mass-loss process in red-giants based on mid-infrared high-spatial observations
3.2.2 Development of observational technology
3.2.2.1 Development of GeBIB/FD-SOI CMOS far-infrared imaging sensors
3.2.2.2 Development of far-infrared CSIP detectors
3.2.2.3 Development of monolithic multi-layer interferometric filter
3.2.2.4 Development of free-standing binary pupil mask coronagraphs
3.2.2.5 Development of mid-infrared immersion grating
3.2.2.6 Correction of second-order light contamination and improvement of spectral calibration for AKARI spectroscopy
3.2.2.7 Demonstration of cryogenic deformable mirror for wavefront correction in space-borne telescopes
3.2.2.8 Development of millimeter-wave half-wave plates for polarimetry observations of cosmic microwave background
3.2.2.9 Cryogenic system for space missions
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 antennae including the 64 m antenna at Usuda
3.3.1.2 Identification of gamma ray radiation region through VLBI monitor observation of radio wave jets
3.3.1.3 Monitor observation of dust clouds falling into a black hole at the center of the Galaxy using the VLBI observation network in Japan
3.3.1.4 Observational research of the formation of stars in a molecular cloud at the center of the galaxy, using a large millimeter- and submillimeter-wave radio telescope such as ALMA
3.3.2 Development research for observation technology
3.3.2.1 Study of the scientific goals and observation systems for the 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 an experimental craft for the balloon VLBI flight

3.3.2.3 Technological study of the antenna system for the new ground station for deep space exploration
3.4 Theoretical research
3.4.1.1 Theoretical research on the formation of true muonium atoms
3.4.1.2 Theoretical research on the multi-ionization process of a dimer of an inert gas caused by a 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, and the formation and evolution of planetary systems. Data from missions such as HINODE (solar physics) and HISAKI (extreme ultraviolet spectroscopy for planetary science) are studied extensively, and samples brought back by HAYABUSA from the asteroid Itokawa have been analyzed. Missions being prepared, such as BepiColombo to Mercury, are also handled by the members of the Department. In addition, we are also engaged in basic research for developing new on-board instruments for future missions and small-scale projects using sub-orbital opportunities.

2. Research activities in 2015

2.1 Solar Physics

To understand the heating mechanism of the solar atmosphere, energy input by the waves propagating upward from a sunspot into the solar corona has been analyzed. Data from HINODE and IRIS (NASA) have been studied. HINODE enabled us to reveal that the oscillations inside sunspots arise from vertically propagating slow-mode waves. Simultaneous IRIS observations at higher altitudes show saw-tooth waves with shorter periods, consistent with acoustic cutoff theory in the stratified layer. These allow us to estimate the amount of energy deposited into the chromosphere just above the sunspot. The estimated energy of 10^7 erg/cm^2/s is enough to maintain the high temperature of the chromosphere; however, the wave alone is not enough to heat the corona that is situated above it and has a higher temperature.

The NASA sounding rocket Chromospheric Lyman-alpha SpectroPolarimeter (CLASP) was launched in September 2015. It has hardware heritage from HINODE and will gather high-resolution spectroscopic polarization measurements. The key technology in CLASP is the motor that rotates a wave plate at a precise fixed rate.

2.2 Space Plasma Physics

The Magnetospheric Multiscale (MMS) mission is a NASA Heliophysics flagship mission that performs three-dimensional formation flying observations of space plasma dynamics with four spacecraft. The mission was launched on March 12, 2015 from the Kennedy Space Center by an Atlas-V rocket. The objective of MMS is to unveil the microphysics that drives magnetic reconnection, one of the most important processes in space plasma physics. Magnetic reconnection occurs frequently on the surface of the boundary of the Earth's magnetosphere, and thus this is the region that MMS visits to make unprecedented in situ observations with the spacecraft formation. Members of the department are in charge of the instrument that detects ions, FPI-DIS. The instrument is installed on all the four MMS spacecraft. The initial check-out of the instruments that were developed and fabricated was completed in September 2015. In recognition of the contribution, NASA awarded our members with a Group Achievement Award in June 2015. Data is also being processed to provide research opportunities to the Japanese scientific community. A Geotail-MMS collaboration is continuing and the results are as follows. (1) Under a southward interplanetary magnetic field, the reconnection line shifts more than two Earth radii toward the winter hemisphere from the magnetic equator. (2) Magnetic islands form and disappear into a reconnection jet during a quasi-steady reconnection event.

As a follow-up to a project initiated by an ex-International Top Young Fellowship (ITYF) recipient, Adam Masters, the survey of the Cassini observations of Saturn's bow shock continues. This year, we measured the properties of shock front reformation at high Mach numbers and the correlation between the detection of relativistic electrons at shock fronts and high Mach numbers. Unlike bow shocks detected around Earth, Saturn's bow shock can reach very high Mach numbers, reaching the range expected in a supernova remnant. Thus, this study bridges detailed observations in the heliosphere and exotic targets studied in high-energy astrophysics.

2.3 Atmospheric Science

An ITYF recipient, Javier Peralta, worked with the team members to develop a scheme to analyze cloud images of Venus taken by AKATSUKI. He also analyzed the UV and IR imagery data taken by the European Space Agency (ESA) Venus Express and NASA MESSENGER to find cloud motion in the Venusian atmosphere that was previously unknown. He is taking the lead in coordinating the ground telescope observations with AKATSUKI.

2.4 Planetary Science

Smart Lander for Investigating Moon (SLIM) is a small-scale lunar landing technology demonstration mission. The science payload for the mission was selected by the members of the department. Of the 20 proposals submitted, five were selected and listed in order of priority, and the list was handed over to the SLIM team for an accommodation study. Therefore, the department contributed to maximizing the output from the SLIM mission.

MMX is a mission to return samples from Phobos and has the following top three objectives: (1) to reveal the origin of Phobos; (2) to understand transport across the snow line during the formation phase of the solar system; and (3) to contribute to our understanding of the evolution of the Martian surface environment. The study team was established in 2015 to fix the mission objective and the mission requirements, corresponding system requirements, and the mission concept. The launch of MMX is planned for 2022. Members of the department are playing key roles in the scientific aspects of the mission study and in coordinating international collaboration.

JUICE is an ESA mission to study the Jovian system and the icy moons Ganymede, Calisto, and Europa. There will be three hardware contributions and two science contributions to the mission from JAXA. Members of the department are the core members of the JAXA-JUICE team and have contributed to phasing up.

3. Research topics

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 (NASA sounding rocket)
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), ERG (Earth's inner-magnetosphere), and JUICE (icy moons of Jupiter)
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 Ryugu
3.4.3 Future missions: SLIM (small lunar lander), DESTINY (asteroid flyby), 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

We research and develop on-board devices and information systems for flying objects (e.g., balloons, rockets, satellites, the International Space Station) and we contribute to new interdisciplinary fields of space science and peripheral fields through fundamental research in the following areas.

1. Space utilization science: we aim to use the unique environment 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. We are conducting materials science studies to produce materials with new functionalities, and we are investigating fundamental fluid science, such as plasma physics, related to these materials. We also study space biological science, in which we investigate the effect of the space environment on behavior, development and evolution, and astrobiology, including searching for the precursors of life and extraterrestrial life.
2. Information systems: we are studying basic technologies, such as data processing, computer networks, distributed processing technology and high-capacity databases, to enable the high-speed processing, transmission, and storage of the large amounts of observation data obtained by scientific satellites. We also conduct observational research based on the analysis of space plasma, solar, and astronomical data obtained mainly by artificial satellites. Our theoretical research is based on the visualization of data, numerical simulation of plasma in celestial bodies, and modeling of the data obtained by satellites. We are also involved in space engineering research for spacecraft malfunction monitoring/diagnostic systems, numerical simulations, and data assimilation.
3. Scientific balloons: we are engaged in the research and development of balloons used for space science research, their operating systems, and experimental systems for scientific observations and engineering demonstrations using balloons.

2. Research activities in 2015

2.1 Space utilization science

For the field of materials science, we research phenomena that occur in very high- or low-temperature environments by using the electrostatic levitation method. We measure thermophysical properties, such as density, surface tension, and viscosity, and we have also established a method to measure the emissivity and heat capacity of high-temperature melts. We measured these properties for molten niobium, which has a melting point around 2500 °C. Furthermore, the electrostatic levitation furnace for the International Space Station (ISS) has been launched together with the samples, which will be processed in FY 2016. We also conducted crystal growth experiments on the semiconductor InGaSb under a strong magnetic field and on a centrifuge to compare those results with that of the Alloy Semiconductor experiment on the ISS. We found that, under terrestrial conditions, the growth rate of InGaSb was damped because buoyancy convection prevented diffusive transport of GaSb to the growth surface in the InGaSb melt.

In our research on dust plasma, we studied the ion temperature in plasma, the particle temperature in Coulomb crystals, and a new small plasma chamber. We showed that the ion temperature is very close to room temperature. In contrast, the particle temperature is approximately 10 times higher than room temperature, and we obtained new results suggesting there is a reduced void region in Coulomb crystals.

In our life science research, the gene expression changes related to cell aging in the skin of space flight mice were analyzed over time. One of the causes of cell senescence was the arrest of the cell cycle by oxidative stress. We showed that in hibernating animals, muscle atrophy was prevented by increasing the activity of oxidative enzymes. We also measured the plantar pressures of astronauts after returning to the earth, and we found that long-term stays in space affected the pronation and supination movements of steps during walking. Furthermore, righting behavior and negative phototaxis in starfish were recorded and analyzed to understand the relationship between two reaction behaviors to gravitational force and another stimulus applied simultaneously.

To recognize sterilization above 80 °C during the Tanpopo mission, a mechanical thermometer based on a bimetallic strip coil was developed and attached to the Tanpopo exposure panel. The Tanpopo exposure panel was launched in orbit and an exposure experiment was started on the Japanese Experiment Module - Exposed Facility on the ISS. A maximum temperature of 26.4 ± 5 °C was obtained from nine thermometer readings, confirming that no high-temperature sterilization occurred.

2.2 Research in information science and information technology

The seismic events on the Moon are divided into many categories. We classified the events by machine learning instead of by traditional manual classification. We tried several algorithms using the manual classification as the validation set. A neural network algorithm provided better results. We found that the manual classification could be used for cross-validation of the support vector machine. In addition, a possible new sub-group in the classification was suggested by this validation process.

As a part of the data archiving study, the seismic data from the Viking Lander 2 mission were released in the last year. The purpose of the previous study was to recover its original information. In 2015 we found that there were many failures in the original archives, and the failures could be categorized into four core failures. We plan to process and categorize the data to make the data available for scientific analysis.

We conducted basic research on using large-scale supercomputer computations to develop spacecraft. A method for speeding up low-memory bandwidth CPUs was proposed. We also modeled a self-induced oscillating heat pipe and applied a data assimilation method to satellite thermal analysis.

To provide space science data to the public, we investigated methods of adding value to the data. The results of the study have been applied to several outreach activities.

* We confirmed that estimating the trajectory of HAYABUSA around the first touchdown on Itokawa was appropriate.
* We integrated ray-tracing functions into the visualization tool of the space probe data, which enabled precise rendering of shadows in real time.
* We studied of methods for data selection, format conversion, and coordinate conversion to present space science data to the public. The results have been published in a visual format.

2.3 Research on scientific balloons

We have developed a super-pressure balloon, which will allow the long flight operations required for future scientific balloon experiments. In research on a super-pressure balloon covered with a net, we investigated how to design a balloon leaving some margin on the film without losing deployment stability through ground inflation tests of a 5000 m^3 balloon and a 10 m^3 balloon. Based on the results of this study, a ground inflation test of a 2000 m^3 balloon with a new design revealed that the balloon has a burst pressure of 1000 Pa, which satisfies the required differential pressure for the small balloon. In space science research using balloons, we continued the detailed analysis of cosmic ray data, obtained during balloon flights over the Antarctic in a cosmic ray observation experiment using a superconducting spectrometer (BESS), and we derived the energy spectra for protons and helium from primary cosmic rays, which comprises the fundamental data for cosmic ray physics. In addition, the CALorimetric Electron Telescope apparatus was launched and installed on the ISS in 2015, and then scientific observations were started to identify dark matter and reveal the origin of the high-energy electrons, protons, and nuclei that come from space by observing the direction and the energy of cosmic rays, such as high-energy electrons and gamma rays. Furthermore, we promoted the following studies to projects: high-sensitivity observations of antiparticles in cosmic rays using exotic atoms with the General Anti-Particle Spectrometer (GAPS), which aims to study dark matter based on high-sensitivity exploration of antiparticle components, such as deuterons, which are thought to be rare; and planned microwave background radiation observations using a small 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 space inflation.

2.4 Astrophysics research

Using JAXA's SUZAKU satellite and the European Space Agency's XMM-Newton satellite archival data, we are studying properties of various cosmic X-ray sources. In particular, we are investigating a universal model explaining X-ray spectral variations in Seyfert galaxies. In addition, a project to create a SUZAKU source catalog has begun, including sources serendipitously in the field of view of primary targets.

3. Research topics

3.1 Space utilization science
3.1.1 Materials science
3.1.1.1 High-temperature melt and metastable phase using the levitation method
3.1.1.2 Research on crystal growth
3.1.2 Dust plasma
3.1.3 Life sciences
3.1.3.1 Genetic analysis of the skin of space flight mice, hibernation, and muscle atrophy defense, and study on the attitude control of astronauts returned from space
3.1.3.2 Gravity response in the generation, formation and behavior of animals
3.1.3.3 Astrobiology
3.2 Information science and information technology
3.2.1 Data archiving
3.2.1.1 Implementation of GIS-compatible observation data for the Moon and planets
3.2.1.2 Development of international standard protocols for sharing planetary science data
3.2.1.3 Archiving data from the Mars probe
3.2.1.4 Archiving data on the Earth's atmosphere
3.2.2 Numerical simulation
3.2.2.1 Data assimilation method for satellite development
3.2.2.2 Programing models for an EFLOPS computer
3.2.2.3 Numerical simulation for a self-induced oscillating heat pipe
3.2.3 Software and data
3.2.3.1 Efficient tool development
3.2.3.2 Development of a web service for multidisciplinary research
3.2.4 Interdisciplinary research related to space science
3.2.4.1 X-ray binary systems
3.2.4.2 X-ray time variation in an active galactic nucleus
3.2.4.3 Dynamics of plasma in a galaxy cluster, based on X-ray observation
3.2.4.4 Impact of a solar eclipse on the chemistry of the atmosphere
3.3 Scientific balloons and space science using balloons
3.3.1 Scientific balloons
3.3.1.1 Research on super-pressure balloons covered by a 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 a superconducting spectrometer
3.3.2.3 Observation of high-energy cosmic-ray electrons and gamma rays
3.3.2.4 Research on the early universe, based on the 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 system engineering related to space navigation, space transportation engineering, and space structure and materials engineering.

2. Research activities in 2015

2.1 Space navigation system engineering

Our space navigation system engineering research plays a role in pioneering projects and includes applied flight dynamics, control systems theory, and transport system design for spacecraft and flying objects. We are focusing on research for spacecraft, such as interplanetary probes and advanced scientific satellites, and their navigation, guidance, and control. We also develop space flight systems such as those for rockets. We perform planning and mission analysis, orbit design, system design, and testing using experimental craft and computer simulations.

2.2 Space transportation engineering

Our space transportation engineering research covers a variety of areas such as propulsion systems and aerodynamics for the propulsion and navigation of flying objects and for probes that fly through the atmosphere into space, and return from space. We are 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 navigation; and a system and its component technologies for re-entry/recovery and orbit control using the atmosphere. Furthermore, we are evaluating and optimizing the aerodynamic characteristics of flying objects, in addition to fundamental research on chemical reactions, flow, heat, and electromagnetism, from perspectives including mechanical engineering, fuel engineering, chemical reaction engineering, magneto fluid dynamics, heat transfer engineering, gas dynamics, and high-speed fluid dynamics.

2.3 Space structures and material engineering

We are involved in applied and fundamental research for space structures and materials for systems for various flying objects and structures used on the ground, in low Earth orbits, and in geostationary orbits on planets and in deep space. We investigate the structural dynamics, structure design and analysis, and the mechanical environmental testing for rockets and artificial satellites. We also work on deployment structures and mechanisms as for extendable booms and deployable antennas. Furthermore, we research 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, we are helping to create and analyze new structures for precise shape control systems, ultra-lightweight structures, such as sails, and for adaptive structures using high-performance materials.

3. Research topics

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 system for Epsilon rockets
3.1.4 Static firing test 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 a propulsion system
3.2.3 Aerodynamics and a guidance and control system for a reusable rocket
3.2.4 Fault tolerant system for a reusable rocket
3.3 Solid rockets
3.3.1 Solid propellant using high-energy material
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 a thermoplastic material
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 altering-intensity swirling-oxidizer-flow-type hybrid rockets
3.4.3 Numerical analyses of boundary layer combustion instability in axial-injection hybrid rockets
3.4.2 Safety of hybrid rockets
3.4.3 Oxidizer vaporizing system using boundary layer combustion
3.4.4 Conceptual study on flight tests on altering-intensity 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, for example, space transporters
3.9 Thermal design, analysis, and testing of scientific satellites and new thermal control technologies for future scientific satellites
3.10 Structural systems for existing scientific satellite projects
3.10.1 Structural system for small scientific satellites
3.10.2 Structural system for Hayabusa2
3.10.3 Structural system for MMO
3.10.4 Structural system for ASTRO-H
3.11 Development of an environmental testing method
3.12 Vibration control for flexible structures
3.13 Structure, function, and dynamics of rockets for launching scientific satellites
3.14 Large, high-precision optical bench and related technologies
3.15 Heat-resistant composites
3.15.1 Anti-environment ceramic coatings
3.15.2 Use of heat-resistant composites in various engine components
3.15.3 Weight and cost reduction of heat-resistant material used in solid rocket nozzles
3.15.4 Degradation characteristics of the CFRP for the ablator
3.16 Polymers and polymer matrix composites
3.16.1 Development of CFRP disk for high-speed rotation
3.16.2 Development of simple non-destructive technology for CFRP
3.16.3 High-precision composite material for large space structures
3.16.4 Carbon nanotube-reinforced composites
3.17 Strength and destruction of metallic materials
3.17.1 Low-temperature creep of metals and alloys
3.17.2 Creep fatigue in the copper alloy used in the combustion chamber of rocket engines
3.17.3 Development of low-temperature superplastic titanium alloy and in situ observation of grain boundary sliding
3.17.4 Development of high-temperature shape-memory alloy in the Zi-Ni-Zr-Pd system
3.18 In situ observation of hypervelocity impact damage in a

e. Department of Spacecraft Engineering

1. Overview

The Department of Spacecraft Engineering researches spacecraft, such as rockets, artificial satellites, planetary probes, and exploration robots, and spacecraft ground systems and engineering technology in the fields of electrical and electronics engineering, measurement and control engineering, applied physics, and energy engineering.

In the field of electronic materials and devices, we are conducting fundamental research and development of spacecraft semiconductor devices and semiconducting materials for the devices. The devices include pulse radar for detecting the altitude and speed of a lunar or planetary lander, lasers and radars, communication devices, antennas, GPS receivers for space, and integrated systems installed on spacecraft. We are investigating improving the performance of a lithium-ion secondary cell power supply system for spacecraft, a power storage capacitor, and the use of fuel cells in spacecraft. In the fields of navigation, guidance, and control, we are developing a sensor for detecting attitude, relative position, and obstacles. We are investigating high-precision attitude and alignment control technology, autonomous navigation using images, algorithms for detection and circumvention of obstacles, and guidance and control rules for landing on the Moon or planets. We are also developing high-performance control actuators. Our research also encompasses intelligent and autonomous space probes and technology for the autonomous exploration of the Moon and planets using mobile robots (rovers). For ground systems, we are studying high-precision orbit estimation methods, such as the combination of differential very-long-baseline interferometry and optical navigation, and large-scale information integration for spacecraft operation systems. Furthermore, we are researching the system architecture of small scientific satellites and cosmic energy systems such as solar power satellites.

2. Research activities in 2015

2.1 Technology for power supply systems

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

2.2 Communication technology

In our research on components for information communication energy transmission in space, we continued to develop and evaluate a high-power, high-efficiency X-band GaN device to be installed on spacecraft, and an ultra-low-noise amplifying integrated circuit for radio astronomy and X-ray detection using GaAs. We have investigated a proposal for an electronic cell chip that uses space-capable RF nano electronics and we have started prototyping a system-on-chip using the Si and compound semiconductor integrated circuit “HySIC.” We fabricated a prototype compact RF energy harvester with a GaN Schottky barrier diode and a Si RF integrated circuit rectifier circuit.

For satellite and spacecraft systems, we developed an active integrated phased array antenna with a retrodirective function for deep space communication satellites and wireless power transmission technology for rovers. We also fabricated a prototype RF sensor and a compact wireless health monitoring sensor system for inside spacecraft by using our high-performance small rectenna, microwave power transmission, and a wireless power transmission health monitoring sensor system that uses energy harvesting.

We conducted functional testing and performance measurements in deep space for the communication system that was flown on PROCYON, which is a deep space CubeSat we developed with the University of Tokyo.

2.3 Information and data processing technology

In the field of information and data processing, we are developing standard components and interfaces that can be used on various spacecraft, based on standardized architecture (constitutive principle). We tested a communication method called SpaceWire-R for connecting computers in spacecraft. This method will be adopted as the standard in Europe. In addition, we are establishing a space communications and data handling architecture so that we can standardize communications and data handling methods across various spacecraft. Furthermore, we are developing a method that uses modeling technology and language theory to establish a database for spacecraft specifications.

2.4 Navigation, guidance, and control technology

Landing legs are required for the safe landing of probes on the Moon or planets. We have demonstrated that landing legs with semi-active control have superior anti-tumbling characteristics compared with conventional passive legs made of aluminum honeycomb material.

2.5 Autonomous control and robot technology

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

We performed several operations for the MINERVA-II rovers installed in the asteroid explorer Hayabusa2 and confirmed their health status. Preparations based on the ground model were made for the surface exploration of the asteroid by the rovers scheduled in 2018-2019.

2.6 Device technology

In the field of electronic materials and devices, we performed fundamental research on semiconductor devices that will be installed on spacecraft, developed an environment-resistant device, and researched semiconductor materials. We conducted development of LIDARX and Flash LIDAR. LIDARX, a light pulse detection integrated circuit (IC), 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 FY 2015, we integrated the IC into the LIDAR test bed (the laser range-finder used for evaluation) 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 landing process and to measure relative distance for rendezvous in orbit. In FY 2015, we upgraded a prototype of a small 16 × 16 pixel circuit, 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 orbit status of operational satellites and spacecraft to prevent problems with missions. For the AKATSUKI mission, we conducted analysis and operation coordination for navigating to Venus, contributing to the successful orbit insertion. In the orbit determination for Hayabusa2, we used delta differential one-way ranging (DDOR) measurements. We determined the orbit very precisely and contributed to the successful Earth swing-by of Hayabusa2. We installed a signal transmission device on PROCYON for improving DDOR accuracy and conducted a joint observation with NASA's Jet Propulsion Laboratory. We 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

We have developed technology for high-speed transmission of observation data obtained by small satellites. In FY 2015 we installed a high-speed transmitter that we developed for the 50-kg-class small satellite HODOYOSHI 4, and established a downlink communication with the X-band 64APSK modulation method at 505 Mbps via the 3.8 m antenna at Sagamihara. This is the first demonstration of 64APSK modulation from a low-Earth orbit satellite. We are also researching an X-band synthetic aperture radar (SAR) that will be installed on a 100-kg-class satellite. We started developing a small SAR system with 1 m ground resolution as an ImPACT program.

We have also been working on satellite architecture, components, and implementation technology, while aiming to reduce the size, weight, and production time for the satellite bus. We are studying image-based navigation and landing radar for the experimental Moon landing craft, SLIM. We developed a new method to evaluate satellite battery deterioration and life based on estimating the alternating-current impedance.

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

3.1 Technology for power supply systems
3.1.1 Characteristic evaluation for a space solar cell under extreme conditions
3.1.2 Power storage device for space
3.2 Communication technology
3.2.1 Wireless sensor and high-efficiency circuit technology
3.2.2 Deep space RF communication technology for installation on satellites
3.2.3 Near-Earth communication technology for installation on satellites
3.2.4 Wireless communication technology for inside spacecraft
3.3 Information and data processing technology
3.3.1 Satellite data processing architecture
3.3.2 Application of modeling technology to satellite development
3.3.3 Software technology components for an autonomous remote system
3.4 Navigation, guidance, and control technology
3.4.1 Posture determination and control for spacecraft
3.4.2 Navigation, guidance, and control of lunar and planetary probes
3.4.3 Navigation sensor for planetary probes
3.5 Autonomous control and robot technology
3.5.1 Lunar and planetary probe robotics
3.5.2 Rover for exploration of small celestial bodies
3.6 Device technology
3.6.1 Research and development of analog integrated circuits
3.6.2 Environment-resistant electronics
3.6.3 Micromachines for space
3.7 Orbit determination
3.7.1 DDOR technology
3.7.2 Orbit determination using an open-loop receiver
3.8 Small satellite systems
3.8.1 Small scientific satellites
3.8.2 High-speed communication system for small satellites
3.8.3 Microwave synthetic aperture radar for small satellites
3.9 Space energy systems
3.9.1 Solar power satellite systems
3.9.2 Thin-film power-generating systems
3.9.3 Spacecraft power supply system using a water-cycling system

f. International Top Young Fellowship

In FY 2009, the International Top Young Fellowship (ITYF) was established to make Japan a hub for world-class space science. Through an international application process, this system invites top young researchers from all over the world and employs them in fixed-term positions. The competition for selection is fierce because there are dozens more applications than there are positions. In principle, researchers are employed for three years, and the term may be extended to a maximum of five years based on evaluation results. One researcher was selected from 70 candidates and was employed in FY 2015, and now five fellows are registered.

The ITYF fellows have produced significant results during their terms. For example, Dr. Aurora Simionescu and her colleagues at JAXA and Stanford University observed the chemical composition in the hot gas of a galaxy cluster to reveal the average chemical composition of the Universe. JAXA's SUZAKU X-ray satellite dedicated a large amount of observation time to this project, collecting data over many weeks. A large-area observation of the Virgo Cluster proved that the chemical elements are distributed uniformly throughout the entire volume of the galaxy cluster, in relative proportions roughly consistent with the composition of our own Sun. Their results were reported in a study published in Astrophysical Journal Letters in October 2015.

The ITYF system was evaluated as highly effective in an international external evaluation for ISAS in Fall 2012 because it "significantly contributes to enhancing the recognition of ISAS and developing space science." Five years after the system was started, most researchers have produced the results expected of them according to an internal review of the ITYF system conducted by ISAS. However, it was highlighted that the interaction with researchers at ISAS was insufficient. Therefore, to improve the system, we took the following action in FY 2015.

1. An action plan based on the plan-do-check-act model will be introduced to maximize the interaction of the researchers with ISAS staff.
2. A review meeting (plan/result evaluation) for the year will be convened. Governance will be established to maximize the results produced by the organization as a whole.
3. During the application process, new fellows will be informed directly of the aims of the organization.

ITYF Fellows (as of March 31, 2016)

Name	Former Institute	Research Theme	Period
CAMPAGNOLA, Stefano	NASA Jet Propulsion Laboratory (US)	Research on advanced mission and orbit planning methods	March 2012 –
SIMIONESCU, Aurora	Stanford University (US)	Physical processes associated with large structure formation, extending from the center of galaxy clusters to their perimeter and beyond	June 2013 –
INOUE, Yoshiyuki	Stanford University (US)	Nature of active galactic nuclei by correlating theory and observation	February 2014 –
LEE, Shiu-Hang	RIKEN (Japan)	Modeling of the supernova remnant shock wave for elucidation of the origin of galactic cosmic rays	April 2014 –
PERALTA, Javier	Astrophysical Institute of Andalucía (Spain)	Characterization of atmospheric dynamics by using "AKATSUKI" and "Venus Express"	April 2015 –

Main research published by the fellows in FY 2015:

Astronomy & Astrophysics, Vol. 585, A53 (2015)
The Astrophysical Journal Letters, Vol. 811(2), L25 (2015)
The Astrophysical Journal Letters, Vol. 816(1), L15 (2016)
The Astrophysical Journal, Vol. 806(1), 71 (2015)
The Astrophysical Journal, Vol. 818(2), 187 (2016)
IEEE Aerospace and Electronic Systems Magazine, Vol. 30(7), 6–17 (2015)

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

a. Inter-University Research and Facility Management Group

In order to promote space science activities in Japan, JAXA maintains and operates the facilities that function as Inter-University Research System. The researchers of public and private universities are able to utilize the facilities, such as Space Chamber Laboratory, the Hypervelocity Impact Facility, the Supersonic and Subsonic Wind Tunnel Laboratory, etc. Announcement of opportunity to use these facilities is called once a year, and the proposals are reviewed and approved by the program advisory committees as shown in Table "Domestic Joint Reserach" on P.71. The Inter-University Research and Facility Management Group collaborates with researchers to maximize their scientific achievements.

b. Test and Operation Technology Group

1. Project support

Our expertise have been provided to the projects, the pre-projects, and the working groups.

(1) The engine, propellant, stand, supply, and measurement system of an advanced propulsion system were designed, evaluated , and analyzed. Countermeasures against freezing of the coolant supply system used in a ground combustion test of the Epsilon M-35 motor are developed. During the test, propulsion capability at an accuracy within ±0.47% was detected.

(2) Test methods for acquiring frequency characteristics of the horizontal bearing in a vibration testing machine were summarized, and interface jigs for the test was manufactured.

(3) The group has participated in balloon experiments in Australia and developed equipment including balloon launchers, helium gas filling equipment, balloon control equipment, load tape, and large exhaust valves.

(4) The group has provided support for the development and evaluation of a rocket and satellite system with various testing devices, primarily at the mechanical environmental test facility, thermal environmental test facility, anechoic chamber, attitude control test facility, and Akiruno research center. The accuracy of shared measurement equipment was maintained and controlled. A star simulator that contributes to performance testing of a JAXA strategic component, a small star scanner.

(5) The group has operated the onboard radar for sounding rockets and ground equipment. A command decoder and a command converter for sounding rockets were developed.

(6) A flight demonstration for a conformal compact antenna (CCA) was conducted. The CCA does not stick out from the rocket surface.

(7) The group has planned upgrades and designed, manufactured, and operated telecommunication equipment (call-for-command, ITV, broadcasting, etc.) used for rocket testing and satellite development.

(8) R&D for vibration control using piezoelectric elements was conducted.

2. Major support for R&D

- R&D on a flying object system using the N_2O / ethanol propulsion system and injection element
- Research on measurements of the airframe of flying objects
- Development of a method for sine sweep vibration testing
- R&D on a charger for pressurizing propulsion system with an air-breathing engine
- R&D on a second stage motor for Epsilon rocket
- R&D on an ultra compact satellite launch rocket

c. Science Satellite Operation and Data Archive Unit

Science Satellite Operation and Data Archive Unit has operated and developed science and engineering databases for science satellites and permanent space-science data storage, and worked to make the data easier to use. Also, the unit continued creating AKARI and KAGUYA (SELENE) data products.

Achievements:

1. Provided the operational environment for ISAS missions, supported operations, and archived and provided accumulated data to maximize science mission outcomes, including those of AKARI, KAGUYA, SUZAKU, HINODE, AKEBONO, AKATSUKI, and HAYABUSA.
2. Updated the Far-infrared All-sky Point Source Catalogue and the Near-infrared Spectral Catalogue with AKARI observation data, and publicly released nearinfrared image data.
3. Publicly released Kibo onboard experiment data, Viking 2 landing ship seismometer data, HAYABUSA sample initial

data, and AKATSUKI trajectory data.

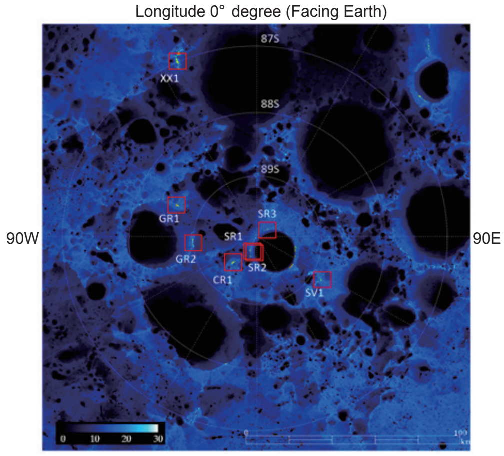
4. Analyzed the distribution of sun-illuminated areas from KAGUYA data to evaluate candidate landing sites in lunar polar regions, which have attracted international attention as a target for future landing missions.

Impacts:

1. We analyzed the composition of ice in the envelopes of protostars (newborn stars) in the Large Magellanic Cloud (LM) using data obtained by AKARI and the Very Large Telescope (VLT) of the European Southern Observatory in Chile. We found that methanol is less abundant in the LMC than in similar objects in the Milky Way galaxy. This suggests that the synthesis of organic matter differs by environment *(Astronomy & Astrophysics, Jan. 2016)*.
2. The public release of AKARI data will increase the value of AKARI observations by promoting data access and extending data use. It also helps the AKARI team through third-party validation.
3. Public data from AKARI are used by many researchers, particularly the Far-infrared All-Sky Survey maps and near- and mid-infrared image data released last year.
   a. Analysis of over 70 million spectrum data points observed by the KAGUYA lunar orbiter revealed that high-calcium pyroxene material is abundant at depths greater than 10 km. This revealed important information on the substance distribution and movement immediately after the moon's origin. It also furthered understanding of the origin and evolution of the moon and planets *(Journal of Geophysical Research: Planets, 2015)*.
   b. Analysis of daylight conditions in the lunar polar region from KAGUYA observations provided essential information for the development of international space exploration scenarios and the joint Japan–U.S. Resource Prospector mission.

Shining Large Magellanic Cloud over the southern night sky
© ESA/Hubble

Longitude 0° degree (Facing Earth)



Daylight distribution data for the south pole region of the moon from KAGUYA observation. The color represents the continuous daylight hours (black: 0 days; white: >30 days). Seven red squares represent the exploration candidate locations with optimal daylight conditions.

d. Astromaterials Science Research Group

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

1. Project support

(1) Continuing to collect, describe and storage curatorial workof the returned samples brought back from asteroid Itokawa by Hayabusa project.

(2) Publishing web a periodical special paper regarding the initial description of the sample (sample catalog information)

(3) Carrying out international AO for Itokawa (Hayabusa returned) sample, and allocated the samples to the researchers selected by AO committee.

(4) Hosting the international symposium (Symposium of solar system materials) for the announcement of the obtained results from the international AO research. About 100 worldwide researchers from the relational planetary science field are attending this symposium every year.

(5) Preparation of curation facility for the extraterrestrial

samples to be brought back in a future sample return mission including Hayabusa2.
(6) Maintenance and operation of the associated facilities and equipment.
(7) Accepting a project researcher and postdoctoral fellows. We train the young researcher through such extraterrestrial sample analysis studies.

e. Disciplinary Engineering Group

Disciplinary Engineering Group was restructured our organization in October 2015, based on the Basic Cooperation Plan between ISAS and the Research and Development Directorate. Staff previously assigned to the Disciplinary Engineering Group are now in the Research and Development Directorate. The new system enables participation in both space science projects and in R&D and projects throughout JAXA.

The following is a list of results and achievements produced by each group.

1) Navigation, Guidance and Control Group

1. Introduction

The Navigation, Guidance and Control Group provides technical support relating to orbit analysis, navigation, guidance, and control for various ongoing and future high-priority space science missions, especially plans for lunar and planetary exploration. We are involved in projects, pre-projects, and working groups, identifying hidden technical issues and initiating specific research.

2. Project support

(1) We provided support for the launch of the Venus orbiter AKATSUKI and its interplanetary operation. We also planned for calculation and control of a precise trajectory for Venus orbit insertion. Furthermore, we analyzed a long-term trajectory for the next rendezvous with Venus.
(2) We conducted system validation for BepiColombo, ASTRO-H, SPICA, Hayabusa2, small satellites (common bus, first and second assemblies), FFAST, Small-JASMINE, DESTINY, demonstration equipment of small solar sails, and international manned spacecraft. We also performed trajectory analysis; trajectory determination; guidance control; and validation of attitude, trajectory control, and propulsion subsystems.
(3) We analyzed launch trajectories, safety evaluations, and airframe system validations for space transport systems, including single-use and reusable sounding rockets and the Epsilon rocket.
(4) We developed and validated an attitude control system for experimental balloons.

3. Fundamental technology research and element technology development

(1) Development and performance evaluations of small star scanners
(2) Development and performance evaluations of tip-tilt mirrors for high-precision pointing
(3) Analysis of micro disturbances in satellite structures and experimental verification of the transfer characteristics of such disturbances
(4) Analysis and performance evaluation of subsystems in next-generation propulsion systems, including GH_2/GOX integrated propulsion systems, HAN-based propulsion systems, and ethanol-based propulsion systems
(5) Research on relative navigation technology for GPS-combined navigation, formation flight, etc.
(6) Research on high-precision calculations of spacecraft trajectory for deep space exploration and development of DDOR technology
(7) Concept verifications of movement systems, exploratory rovers, and walking robots for lunar and planetary exploration, including trade-off studies and walking simulations

4. Maintenance and management of research equipment

To conduct efficient R&D, we maintained and managed ground testing devices and trajectory analysis servers used for the performance evaluation of sensors in attitude control systems and guidance and control devices, ground testing devices for propulsion systems, and launch control systems for small flying objects.

2) Propulsion Group

1. Introduction

The Propulsion Group is involved in various projects, pre-projects, and working groups, and provides expertise in propulsion systems, analysis, and experimental technology. Our department covers a wide area, including R&D on chemical and electric satellite propulsion systems for orbit and attitude control of satellites, main propulsion systems and sub propulsion systems used for launch and attitude control of rockets, and basic research on various engines for future reusable transport systems and hybrid rockets. Because chemical and electric propulsion systems for satellites and sounding rockets are deeply related to space science missions, we contribute to all phases of propulsion system development, including initial evaluations, device development, launch-site tasks, ground operations, and orbital operations.

2. Project support

- We continued monitoring propulsion systems in satellites located in orbit including SUZAKU (ASTRO-EII), HINODE (SOLAR-B), AKATSUKI (PLANET-C), IKAROS, and SDS-4, and were involved in their operation.
- We developed electric and chemical propulsion for Hayabusa2 and a gas jet for PROCYON, and took part in their orbital operations.
- For satellites under development—including MMO (BepiColombo), ASTRO-H, and ERG—we continued to develop propulsion system devices.
- We evaluated propulsion systems required for small scientific satellite projects (SLIM, DESTINY) and SPICA, and demonstrated technologies for Mars surface exploration.
- We demonstrated technologies for reusable sounding rockets through engine combustion tests at the Kakuda Space Center, and demonstrated the reusability of the LOX/LH_2 rocket engine over 100 flights.
- We developed a solid propulsion system and conducted second-stage solid-motor static firing tests of the Enhanced Epsilon launch vehicle at the Noshiro Rocket Testing Center.
- We developed gas jets for sounding rockets and took part in launch site operations.

3. JAXA-wide collaboration

We improved the reliability of propulsion systems aboard scientific satellites and probes, collecting basic data that may prevent problems. Specific studies resulted in new findings regarding the influence evaluation of propellant permeate, the influence evaluation of long-term propellant storage, evaluations of oxidant (MON-3) behavior in rocket equipment environments, and cleaning methods. We also conducted JAXA-wide collaboration regarding electrical propulsion, ceramic thrusters, low-toxicity propulsion systems, propulsion systems for reusable sounding rockets, N_2O / ethanol propulsion systems, Epsilon launch vehicles RCS & PBS, and equipment for the Epsilon launch vehicle at the Uchinoura Space Center (hydrazine, high pressure gas, etc.)

4. Involvement in working groups

We were involved in working groups related to solar sails, demonstrations of advanced solid rocket systems, hybrid rocket research, spaceplane technology demonstrations, a smart lander for lunar exploration, and demonstration of space technologies for interplanetary missions.

5. Research for future missions

We took part in the following research for future missions:

(1) Research related to low toxicity propulsion systems, including R&D on a HAN-based monopropellant thruster and research on N_2O / ethanol propulsion systems

(2) Research related to satellite propulsion systems, including two-propellant propulsion systems with integrated fuel cells, long-term reliability of heat-resistant composites, gas-liquid equilibrium thrusters, and development of an oxidant-resistant diaphragm.

(3) Research related to improved reliability of solid rockets and solid propellants with high performance and low environmental load

3) Thermal Systems and Fluid Dynamics Group

1. Introduction

The Thermal Systems and Fluid Dynamics Group provides expert knowledge and skills, including analytical and experimental technology that contributes to projects, pre-projects, and working groups. We aim to improve our knowledge and expertise through these activities. We also develop expertise in thermal systems and fluid dynamics that are required for future science missions. In October 2015, our activities were transferred to the Department of Space Flight Systems and Research Unit II of the Research and Development Directorate.

2. Project involvement

Through our involvement in projects, pre-projects, and working groups, we contributed to solving various problems in design, development, testing, and evaluation. Specific projects include AKATSUKI, Hayabusa2, BepiColombo/MMO, HISAKI, ERG, HITOMI (ASTRO-H), SPICA, the Epsilon Launch Vehicle, the Reusable Sounding Rocket, GAPS, Mars aircraft, SLIM, DESTINY, PROCYON, Solar sails, SOLAR-C, Small-JASMINE, and JUICE.

3. Maintenance and improvement of expertise

Research related to maintenance and improvement of expertise includes the following.

- Research on loop heat pipes
- Research on oscillating (pulsating) heat pipes
- Research on a next-generation multi-function deployable radiator
- Research on the characteristics of multilayer insulation during evacuation
- Evaluation of thermal control materials
- Research on evacuation of satellite structures in rocket fairings
- Research on satellite outgassing and molecular contamination
- Research on advanced heat pipes
- Research on heat switches
- Research on thermal storage devices
- Research to enhance the functionality of Smart Radiation Devices (SRD)
- Research on radiation control devices with MEMS
- Research on multilayer-controlled thermal control materi-

als (Controlled Optical Surface Film: COSF)
- Research on insulation for Mars surface exploration
- Research on hybrid thermophotovoltaic energy conversion devices for space
- Research on emissivity of space thermal control (protection) materials at high temperatures
- Research on evaluation and estimation of the degradation of thermal control materials used for scientific satellites
- Development of advanced insulation for cryogenic satellites
- Development of a cryogenic high-emissivity radiator material
- Development of silver-evaporated PEI
- Development of a single-phase pumped loop system
- Development of a multi-phase pumped loop system
- Research on in-orbit characteristics of thermal control material by an ExHAM experiment

4. Collaboration with DE

We collaborated with the Aerospace Research and Development Directorate and Thermal Systems Group for Projects and the Thermal Systems Design Standard Committee (WG6, WG6T, WG6R, and WG17).

5. Inspection of technical infrastructure

- We maintained and inspected thermal and fluid dynamics analysis software.
- We maintained and inspected an arc-heating wind tunnel and established an environment to improve its usability for users both inside and outside JAXA.
- We maintained and inspected measurement devices with thermo-optic characteristics and provided them to project teams.
- We maintained and inspected ammonia-filling equipment to develop two-phase flow devices for use in space.

4) Structures, Mechanics and Materials Group

1. Introduction

Our group provides expert knowledge in Structures, Mechanics and Materials and related fields and expert skill including analysis and experimental technology to contribute to projects, pre-projects, and systematic R&D. One of our main tasks is long-term planning for maintenance and upgrades of various rocket launchers. We conduct R&D on technology in thermal systems and fluid dynamics required for or achieves future science missions, collaborating with parties inside and outside of JAXA.

2. Involvement in projects

We are involved in under-development projects (Hayabusa2, ASTRO-H, ERG, BepiColombo, the Epsilon rocket, reusable sounding rockets, pre-project SPICA, and laboratories for scientific ballooning and sounding rockets) to provide expertise as a department responsible for structural systems. We are also involved in working groups (advanced solid rocket system, SLIM, DESTINY, mid-size electric solar sail, airplane for mars exploration, FRV, etc.) as the department responsible for structural systems.

3. Fundamental technology research

(1) R&D on the precise design of large structural systems for space (strategic R&D by the Advisory Committee for Space Engineering)
(2) Research on vibration control for spacecraft

5) Electronic Devices and Space Power Systems Group

1. Introduction

We provided expert knowledge in Electronic Devices and Space Power Systems to contribute to projects, pre-projects, and working groups, and conducted R&D on fundamental technologies. We improved our expertise and developed human resources through these activities.

2. Support for projects, pre-projects, and WGs

We provided the following support as an expert on electronic parts and devices and as the department responsible for power subsystems:
- APL control for MMO, ASTRO-H, and ERG / Review for NSPAR.
- Radiation test and tolerance evaluation for PROCYON
- Operation of HISAKI, HINODE, and AKATSUKI and management of their power systems
- Development of power system devices for MMO, ERG, and ASTRO-H
- Involvement in trial launch and initial operations of ASTRO-H
- Development of power systems that satisfy requirements specific to each working group, including SLIM, DESTINY, demonstrations of technologies for Mars surface exploration projects, and electric solar sails.

3. List of fundamental works regarding electronic devices

- Preparation of a summary of reliability assurance programs for scientific satellite parts (distributed in ISAS)
- Development of guidelines when using consumer products for space equipment
- Involvement in a task force for measures against part malfunctions
- Provision of parts information to related project teams
- Review in JAXA committees
- Activities in committees outside JAXA
- Reliability analysis of electronic and electro-mechanical

parts
- Hearing about electronic and electro-mechanical parts to system manufacturers
- Development of a next-generation MPU.
- Feasibility study of a chip-scale atomic clock for space applications

4. List of fundamental works regarding space power systems
- Development of a SUS-laminated Li-ion rechargeable battery
- Development of a digital electrical power-control circuit using a balance charger / discharger integrated with a balance circuit
- Development of photovoltaic cells optimized for Mars surface exploration
- Demonstration system for elemental technology for a next-generation small-satellite power system (Next-generation Small Satellite Instrument for EPS: NESSIE)
- A study of acquisition of primary AM0 reference cells using balloons
- Feasibility study of COTS secondary batteries for space applications
- Feasibility study of perovskite solar cells for space applications

6) Telecommunications and Data Handling Group

The Telecommunications and Data Handling Group, DE, Sagamihara focuses on research useful for projects and support for the development of promising wireless communication technologies. We also apply our expertise to human resource development.

In an advanced study of kW-class GaN SSPA for developing the 34m/20m tracking radar at USC, we developed a 20kW GaN SSPA for the advanced UDSC. We were responsible for the communication subsystem of PROCYON and took part in its operation as a radio operator. Our works included development of a flight-data analysis tool and evaluation of actual operation results related to telecommunication components. We succeeded in the first space application of a low-cost and ultimately downsized X-band deep-space telecommunication system appropriate for a 50 kg-class deep-space probe. We also conducted ground tests related to long-term operation of the GaN HEMT used in the PROCYON mission.

We assisted development of consumer rockets for avionics. Specifically, we created guidelines, conducted arrangements and evaluations of consumer products, established redundant systems with Ethernet-based networks, and developed demonstration components for sounding rockets. We introduced technologies from commercial companies and advanced their development, and developed general-purpose communication devices for Reusable Sounding Rockets and the fourth kick-stage for Epsilon.

We also developed the first system for microwave wireless power transmission and energy harvesting for a spacecraft health monitoring system using RVT. Specifically, we fabricated a compact 8-channnel sensor node applicable to thermal and acceleration sensors, just one-third the size of comparable state-of-the-art sensors. This study has attracted the attention of engineers working in this field.

5. ISAS Program Office

1. About the ISAS Program Office

Developments in ISAS are conducted in coordination with JAXA integration, because ISAS projects and experiments consist of relatively few, highly skilled teams and involve 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 ISAS Program Office carries out cross-sectional support of projects and experiments, including management support, responses to Councils, and experiment coordination with external organizations. The following are some specific examples:
- Coordination of program strategies and technical strategies
- Program plan arrangement and coordination with external organizations
- Reporting within and outside of JAXA, and support for reporting and plan management
- Serving as a liaison office for projects and experiments
- Dealing with common cross-program issues

(1) Activities regarding program strategy
- Participation and support for review of the Roadmap for Space Science and Exploration.
- Arrangements for facility maintenance requirements and coordination with related directorates, such as arrangements for earth station maintenance, future planning, and information sharing among the Transportation Directorate and Epsilon Launch Vehicle project team.

(2) Support for projects and experiments
- Council Office in ISAS
- Consultation services for project activities and interfacing with related departments

- Other activities related to project implementation
- Coordination of project budgets, project support by collaborating with planning sections, and preparation for management reviews

(3) Operation of organization under PD and related support for small project teams, research project teams, intra-JAXA pre-project team activities, and other laboratories

(4) Arrangements for projects and experiments, including information sharing
- Explanations to JAXA staff, arrangements for reporting to external organizations, and document preparation
- Information sharing related to projects and experiments, and risk management from the standpoint of project members
- Aid in solving problems in projects and experiments
- Measures for common issues among programs and project-specific issues
- Coordination of test and operation facilities
- Improvement in implementation of space science programs

2. Summary of works in the last year

We supported the implementation of sounding rocket experiments and ballooning experiments (working as the general affairs section for various experiments, handling overseas communication, etc.) through collaboration with the Management and Integration Department. While we worked to solve problems in space science projects and experiments, the need for support to solve both program-specific issues and issues common among programs grew. We thus attached importance to specific support as well as cross-sectional activity, and various consultation services became a large part of our activities. As an example, we lead the planning for renovation of the environmental laboratory building at the Sagamihara campus.

We served as a secretariat for project screening, such as technology confirmation meetings for MMX MDR/SRR, GREAT MDR/SRR, ASTRO-H development completion screening, JUICE ΔSRR, and the insertion of AKATSUKI into orbit around Venus.

We participated in formulating implementation policy for the action plan in response to recommendations by the Task Force for Improvement in Implementation of Space Science Programs.

As the secretariat of teams preparing for construction of the successor facility to the Usuda Deep Space Center, we were involved in RFP execution and selection support based on a summary of requests from the prior year. We also supported activities to establish a project and transferred duties to the GREAT Project Office.

In conjunction with the separation of the ISS Science Project Group from ISAS and its subsequent merger with the Human Spaceflight Technology Directorate, we served as an intermediary for tasks and assigned duties. In particular, we developed and assigned duties associated with operation of MAXI and provided technological support for CALET.

6. Systems Engineering Office

1. Introduction

The Systems Engineering Office works on projects under development or review and carries out activities including coordination and support related to technical issues, improvement in systems engineering (SE) skills, and setting of strategy for activities and technology development aiming to improve SE in space science programs and projects.

2. Activities in 2015

2.1 Activities to prevent problems in projects

2.1.1 Support for projects under development

(1) Tracking of issues in projects under development

The Systems Engineering Office has organized monthly Progress Report Meetings of Space Science Projects since 2013 for management to monitor progress, issues, and risk in under-development projects on a timely basis, and so that information can be shared among projects. This meeting is organized based on suggestions by the Task Force for Improvement in Implementation of Space Science Programs. Its members include the Director General, Deputy Director General, Program Director, and Director of the Management and Integration Department. In 2015, we held twelve meetings, including a written report issued in February in conjunction with the launch of ASTRO-H. Various experts were involved in these meetings and detailed discussions about technical topics were conducted considering viewpoints from project management. Furthermore, we revised the implementation guidelines to further increase the usefulness of the report content.

(2) Implementation method of projects suitable for science satellites

Based on recommendations by the Task Force (TF), we were involved in the formulation of implementation methods appropriate for the Space Science Program. During this process, we reviewed ISAS SE / project management (PM) reference literature. We also cooperated in the creation of ISAS normative documents as implemented by the Safety and Mission Assurance Officer.

(3) Situation monitoring and information sharing with SE matrix and SE/ Program Office regular meetings

Continuing from last year, we facilitated the timely sharing of information by holding weekly SE / Program Office (PO) meetings consisting of the Systems Engineering Office, SE staff from each project or experiment, C-SODA (concurrently serving as a member of the Systems Engineering Office), and the PO. The scope included BepiColombo/MMO, ASTRO-H, SPRINT-A, ERG, PROCYON, Hayabusa2, ISS science, SPICA (pre-project), reusable sounding rockets (led by the Directorate), C-SODA ground system, PLANET-C (under initial operation), PROCYON (under operation), sounding rockets, and scientific ballooning.

Based on the results of information sharing, we implemented project support and surveys as necessary, and shared information with ISAS directors.

(4) Project support by the SE & PM support team

Continuing from last year, a Support Team for Design of Common System for Space Science Projects consisting of experts was formed in the Systems Engineering Office. Team members provided advice and suggestions for the project team to improve SE 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 BepiColombo, ASTRO-H, ERG, and JUICE.

(5) Involvement in review and evaluation of space science projects

The Systems Engineering Office also cooperated with the PO and Management and Integration Department to function as a secretariat for review meetings at ISAS. The Systems Engineering Office cooperated with project teams to support review and evaluation of the following space science projects:

- AKATSUKI: Technology confirmation meeting in regards to Venus orbit insertion
- AKEBONO: Review at completion of late-stage use
- PROCYON: Review at project completion
- ASTRO-H: Follow-up for SXS CDR, review at development completion
- SLIM: SDR, review of ISAS plan
- MMX: MDR, SRR
- SPICA: MDR, SRR
- Successor facility to the Usuda Deep Space Center (GREAT): Review of ISAS plan
- JUICE: Review of ISAS plan
- Auxin transportation aboard ISS: CDR
- Solid combustion aboard ISS: PDR

In regard to open applications for new projects implemented by the Advisory Council for Science and Engineering, we responded to council requests by conducting a survey to support technological evaluations. We also implement similar technology evaluation support activities at the request of ISAS.

2.1.2 Support for projects under review

Working groups (WGs) under the Advisory Committees for Space Science and Engineering review future space science projects.

WGs include many non-JAXA members with little experience in space science projects. Incorporating the viewpoints of SE from the early phase of project planning is thus essential to minimize problems in the development phase. Therefore, the Systems Engineering Office mainly supports the initial phase of WG reviews, such as clarifying scientific goals, setting mission requirements supporting those goals, adequate selection of system requirements, and listing of issues and risks and measures against them.

(1) Support for review by WG

Generally, support is provided in response to requests from a WG. This year, we supported the LiteBIRD, SOLAR-C, JUICE and MMX WGs. We also aided in system reviews by some manufacturers.

In addition, we supported preparation for management review for forming a JAXA project from SLIM that was solicited by a public call for space science missions aboard an Epsilon-class satellite in 2013, and served as a bridge to the project office.

(2) Maintenance and updating of the website

In 2015, we continued to operate and manage the ISAS external website to provide timely information about support for WG provided by the Systems Engineering Office and SE information. On this website, we introduce how the Systems Engineering Office supports the success and initial design of missions in space science projects. We updated the site to provide open JAXA documents useful for WG activities. The Systems Engineering Office also wrote documents useful for WG activities and published them on the site.

2.2 Involvement in task force after problem occurs in projects

We participated in several ISAS-organized task forces (TF) on projects with issues to coordinate and solve technical issues in under-development projects. Specific TFs include an event response team on the HISAKI SC2 reset, a TF on SPICA, a TF on SPICA expansion, and ASTRO-H. We also participated in activities selected by the Director General, including surveying and analyzing technological items, and were involved in the team for Investigation of Anomalies Affecting the X-ray Astronomy Satellite “HITOMI” (ASTRO-H).

2.3 Support for Chief Engineer Office (CEO) works

We cooperated with CE activities at ISAS to further increase the effectiveness of SE promotion activities that influence not only the Committee on Earth Observation (CEO) but all of JAXA.

(1) Information provision to the CEO meeting

We participated in the CEO meeting and provided information on matters such as SE/PM cases at ISAS.

(2) Support activities for space science and exploration SE/PM maintenance team

We supported the activities of the maintenance team on the Sagamihara campus by conducting investigations and evaluations and by handling administrative paperwork.

(3) General affairs support for CE activities at ISAS

7. Safety and Mission Assurance Officer

The Safety and Mission Assurance (S&MA) Officer coordinates S&MA (system safety, mission assurance, and quality assurance) of overall space science projects. The following are some specific examples.

(1) Setting standards, requirements, and guidelines related to S&MA
(2) Evaluation and arrangements related to S&MA in each project (working as a person-in-charge of S&MA implementation in some projects)
(3) Sharing common information among projects including new standards and problems
(4) Organization of the ISAS Safety Review Committee and Quality and Reliability Review Committee
(5) Application of JAXA-wide S&MA policy and technologies collaborating with S&MA Officers in the Safety and Mission Assurance Department and other Directorates

Major achievements in 2015 are described below.

1. Quality assurance of BepiColombo/MMO, ASTRO-H, and ERG

We took part in a task force on launch-site problems and tasks, observed experiments, and reviewed quality records to perform quality assurance of scientific satellites and planetary orbiters, including ASTRO-H.

Regarding ASTRO-H, we organized a Quality Team to assure the quality of launch-site tasks, collaborating with the Safety and Mission Assurance Department, and took part in those tasks. As a result, we succeeded in launching ASTRO-H as planned with no launch-related problems.

For BepiColombo/MMO, we took part in the handover of MMO to ESA and system testing at ESTEC/ESA as the party in charge of S&MA implementation. We took part in major task forces for problems, provided advice, and performed coordination from the viewpoint of S&MA. We also handled safety coordination with Launch Authority and summarized quality records contributing to the completion of MMO development.

2. Implementation of the action plan for task force suggestions

The Task Force Report on Improvement in Implementation of Space Science Program was published in December 2012. However, the Action Plan based on the report was inadequate. ISAS thus reviewed the Action Plan in 2014. The S&MA Officer took part in the projects described above, and experienced the actual situation of space science projects. Based on these experiences, we identified areas for improvement in space science projects from the viewpoint of S&MA, and applied these in the Action Plan for Task Force Suggestions. Specific examples are as follows:

(1) Application of S&MA standards to space science projects

We applied S&MA standards to space science projects to improve their S&MA.

(2) Assigning S&MA to project members

We assigned responsibility for S&MA to a member in each project. This person monitors safety, reliability, and quality assurance, and acts as a counterbalance in the project. Through this, we aim to establish a system for timely evaluation of S&MA. The S&MA Officer focuses on items common among projects and supports project teams.

The above activities were included in the Action Plan for Task Force Suggestions, and were established as ISAS policy in 2014.

To implement the action plan, the S&MA Officer drafted the S&MA Control Standards Regarding Reliability, Quality, Configuration Control, and Software Product Assurance, and coordinated with space science projects, members with project manager experience, and manufacturers. As a result, the S&MA Officer established these control standards and applied them to SLIM projects. The S&MA Officer plans to apply these to all space science projects in future.

The SLIM project team plans to assign a person in charge of S&MA within the project team. The S&MA Officer prepared a technical document to clarify the roles and responsibilities of those responsible for S&MA in project teams.

3. Efforts for system safety

Space science project teams adopt and apply methods to ensure system safety. They adopt similar methods not only for development of satellites but also for ground experiments, including scientific ballooning, sounding rocket experiments, and combustion experiments. S&MA Officers were involved in all safety reviews as reviewers and officers in the ISAS Safety Review Committee to provide advice and coordinate with project teams and related departments as needed.

Despite this, there was an accident during an experiment at the Akiruno testing facility. The S&MA Officer took part in an accident resolution board and helped to identify root causes and background factors and to establish preventive measures. Previously, the Akiruno testing facility also held its own safety review, but the S&MA Officer combined the reviews of the

Akiruno testing facility and the ISAS Safety Review Committee.

4. Update of design standards for space science satellites

There are four design standards applicable to space science satellites, including those for electronics, structures and mechanisms, thermal characteristics, and environment. These were issued long ago, however, and had not been updated. Space science projects therefore referenced these documents and established their own design standards. We found several points in the original design standards that did not conform to changes in satellite design due to technological progress.

From recognition of these problems, the S&MA Officer began updating electronics design standards for space science satellites. JAXA owns the satellite electronics standard, so the S&MA Officer planned to establish a new standard based on updated JAXA standards but considering technological progress and current satellite design. The S&MA Officer organized a team of ISAS knowledgeable persons with experience in space science projects and representing the working group in charge of JAXA satellite standards to begin updating the electronics design standards. The S&MA Officer plans to publish revision A of the new standard in 2016 and tackle other design standards one-by-one.

5. Implementation of mandatory inspection point (MIP) and key inspection point (KIP) method

MIP/KIP is a method of quality assurance that involves inspection of circuit boards and device assemblies at their manufacturing sites. In space science projects, MIP/KIP had not been performed for all devices. The S&MA Officer employed staff for hardware inspections, who inspected the actual BepiColombo/MMO, ERG, and ASTRO-H satellites.

For issues related to manufacturing processes and configuration management, we surveyed the actual conditions at manufacturing sites and discussed specific measures with project teams and manufacturers.

6. Organization of Quality & Reliability Review Committee

The Quality & Reliability Review Committee is a meeting for coordination and discussion of S&MA, including establishment of standards for safety, reliability, and quality assurance in ISAS. It is also for sharing information related to reliability and quality such as malfunctions. The S&MA Officer manages this meeting as its chair. As was done last year, in 2015 we held this meeting once a month. In this meeting, we share information related to reliability and quality. In addition, the S&MA Officer and members follow up on project issues to ensure implementation.

7. Improved clean room control

The S&MA Officer identified many improvement points for clean room control at spacecraft environment testing facilities, and drafted preventive plans. Several ISAS sections and users are involved in clean room control, so the S&MA Officer shared the identified issues and coordinated preventive measures with the users. As a result, the person in charge of clean room control was clarified, and improvement plans were established. Each section implemented their improvement plans.

8. ISS Science Project Group

The ISS Science Project Group performs research on International Space Station (ISS) equipment, suborbital vehicles, and related items. This involves pursuit of the following efforts for scientific research, particularly by using the microgravity environment of the ISS.

- Sample development for fluid science, combustion science, crystal growth science, and plant physiology, and flight analysis work at the ISS's Japan Experiment Module (JEM) onboard laboratory
- Science observations, observation data processing, and data-based research on the JEM using onboard laboratory platform equipment including the omnidirectional X-ray monitor (MAXI), earth ultra-altitude atmosphere image observation (IMAP) instrument, and a sprite and thunder discharge high-speed light-imaging sensor (GLIMS)

Achievements

1) Promoted space missions for experiments in fluid science, crystal growth science, and plant physiology, and collected earth and space observations (four cases of developed samples, six cases involving operations and analysis, and seven cases of post-flight analysis).
2) Group combustion equipment was prepared for the launch of the H-Transfer Vehicle (HTV5), which launched successfully on August 2015.
3) The latter phase of IMAP/GLIMS operations for the overboard platform consolidated mission continued. The mission ended with the disposal of HTV5.

Impacts

1) We published five peer-reviewed papers between April and September 2015, for a cumulative number of 735 papers.
2) Quality and speediness of reporting by the ground processing system was improved through research. Data for physical experiments from the onboard laboratory were organized to promote data use by researchers.

9. Sounding Rocket Research and Operation Group

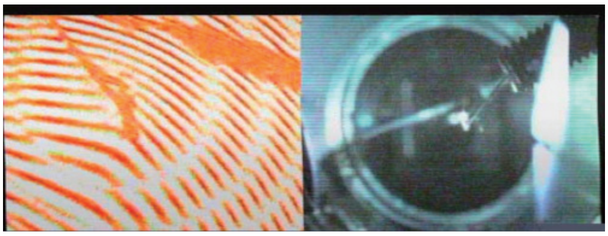
In order to provide opportunities for researchers to use sounding rockets for experiments and observations, there will be increased design and analysis efforts for the manufacturing and launching of sounding rockets in the coming fiscal year and beyond.

Achievements

1. Successful launch of two sounding rockets (S-520-30 and S-310-44)
2. An experiment by S-520-30 documented the nucleation of oxides (alumina and silica). Slow diffusion of oxidized aluminum vapors generated by microgravity in a concentric circle was observed.
3. The sounding rocket "S-310-44" was launched to investigate anomalous electron heating in the ionospheric Sq current focus at a 100 km altitude. The observations indicate that high electron temperatures were significantly associated with strong electron density perturbations, a high energy tail in the electron energy distribution, and a lower hybrid wave, all of which are essential for the generation mechanism of electron heating.
4. Progress was made in preparation for the launch of SS-520-3.

Impacts

1. We published four peer-reviewed papers in 2015, for a cumulative number of 106 papers since 2003.
2. In experiments aboard S-520-30, we performed nucleation experiments with carbon-based materials made possible by successes in nucleation experiments with oxides. This advances our understanding of the nucleation process of space dust from the general evolution of substances, from organic molecules related to the origin of life to the formation of planetoids.
3. In experiments aboard S-310-44, we clearly demonstrated and observed a plasma heating phenomenon that occurs in the mid-longitude ionosphere. This furthered understanding of how the mechanism that causes the high-temperature layer in plasma to sometimes occurs in lower part of the ionosphere.



Generation of space dust (microparticles) from oxidized Al vapor in an experiment aboard S-520-30. Changes in the interference stripes in the left image show the temperature and concentration at the point of generation. On the left is a two-wavelength interference stripe image, and on the right is a visible light image.

10. Scientific Ballooning Research and Operation Group

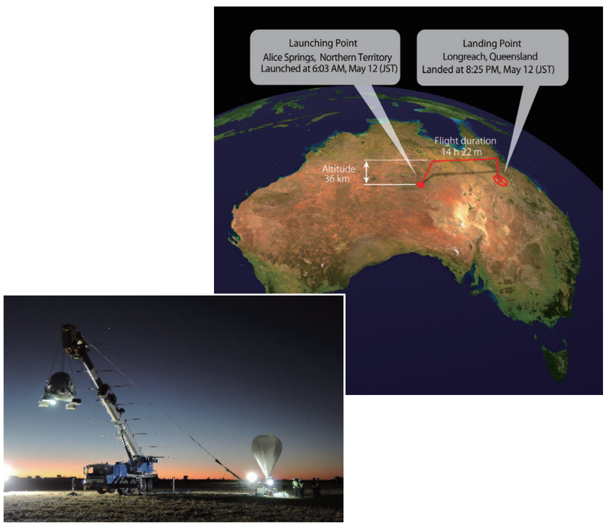
The Scientific Ballooning Research and Operation Group develops stratospheric balloon system and provides flight opportunities to carry out scientific observations and engineering demonstrations. It also studies next-generation balloon system for future space science.

Achievements

1. On May 2015, JAXA conducted their first balloon-borne experiment in Australia, where we can realize balloon-borne experiments with long flight duration and a ground recovery. In the successful flight, a cosmic gamma-ray imaging observation was carried out for 11.5 hours.
2. JAXA continues to establish an agreement with Australian government which enables JAXA to carry out scientific ballooning in Australia periodically, which is complementary to domestic campaigns.
3. Two balloon-borne experiments out of three scheduled were carried out successfully in Japan. The remaining one was postponed by 2016 or later due to delay of the payload preparation.

Impacts

1. By establishing a new framework for JAXA's stratospheric balloon campaigns in Australia, balloon-borne experiments with a long flight duration and a ground recovery can be carried out, which are difficult to be realized in Japan. The cutting-edge observations in astronomy and cosmic-ray



Launch of a balloon in Australia and its flight trajectory physics are encouraged, which require high statistics and high sensitivity studies.

2. Cryogenic stratospheric air sampling experiment was conducted in Japan for the first time in three years. This enabled to provide essential data to study atmospheric science topics such as variations in greenhouse gas and atmospheric circulation.
3. A set of safety documents were prepared to show explicit guidelines on the designs of balloon system to help scientists to build their payload properly.

11. Reusable Sounding Rocket Testing Project

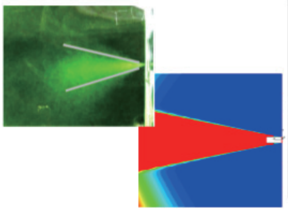
The Reusable Sounding Rocket Testing Project conducts research on reusable sounding rockets to drive technology demonstration efforts such as engine reuse and return flight methods.

Achievements

1. We improved the technical validation and system design of a reusable sounding rocket with the following requirements: an operational interval of less than 24 hours, 100 potential reuses, a payload of 100 kg, and capable of reaching altitudes of over 100 km.
   - We developed a new hydrogen detection sensor that detects hydrogen leakage under anoxic conditions (as in outer space) and validated a technology for detecting engine malfunctions by segmenting the bottom of the rocket body and the engine.
   - We assessed the feasibility of using an insulator material that can be reused at least thirty times by evaluating insulator degradation in repeated filling of a propellant tank.
   - By conducting a system falling experiment with landing legs, we assessed shock absorption and body system requirements for shock loads to meet the necessary requirements.

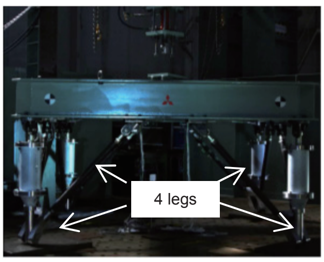
Impacts

1. We published one peer-reviewed paper in 2015, for a cumulative number of five papers.
2. We presented progress toward system technology validation and control of the reusable engine at the 66th International Space Conference (IAC). By invitation, we also made two presentations on the reusable sounding rocket concept and plan.



Ground tests and analyses of GH2 leak

Reusable insulation tests by LH2 supplied into a scale tank



Drop tests for verification of landing gears performance

Figure. R&D of reusable sounding rocket

Ⅲ. Organization

1. History of ISAS

The Institute of Space and Astronautical Science (ISAS), a member of the Japan Aerospace Exploration Agency (JAXA), cooperates with external research organizations such as universities to promote space science research. Space science research is defined as comprising fields of scientific research in the upper atmosphere or beyond and work that allows research activities in related fields. This is an integrated research field that 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. We not only carry out space science projects within that framework and in decision-making of the Institute, but also by fostering research and supporting space science projects. We also conduct academic space science research as an institute equivalent to those of universities and other facilities.

Space development in Japan began with the 1955 launch of a pencil rocket by the Avionics and Supersonic Aerodynamics (AVSA) research group, which was established at the Institute of Industrial Science of the University of Tokyo. In 1964, the first incarnation of ISAS was established by integrating the Institute of Aeronautics (first established as the Aeronautical Research Institute at Tokyo Imperial University in 1918, then reorganized in 1946 into the Institute of Science and Technology at the University of Tokyo) with a department related to sounding rockets at the Institute of Industrial Science. The goal of ISAS was to carry out “integrated research on theory and application in the fields of space science, space engineering, and aviation.”

Since then, research and development in aeronautical space engineering and science research has been carried out mainly under the lead of the ISAS with cooperation from researchers at various organizations such as national, public, and private universities. Research and development is integrated to maximize researcher freedom, thereby achieving major results such as the 1970 launch of Japan’s first artificial satellite, “OHSUMI.” From developments in space science and engineering research, which were mainly led by ISAS, in 1981 the Institute was reorganized into ISAS as an inter-university research institute under the Ministry of Education. The objectives of ISAS were defined as carrying 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 formerly independent institutes (ISAS, the National Space Development Agency of Japan, and the National Aerospace Laboratory) to establish an organization that more efficiently and effectively promotes research and development in space science, space development, and aerospace technology. ISAS was transferred to JAXA to perform main functions of inter-university research, facilitating space science development, and graduate education.

On April 1, 2015, JAXA’s status was redefined as a “national research and development agency.” For reasons such as the introduction of “research & development” to the existing “projects” pillar to accommodate its policy framework, JAXA was reorganized into seven departments (Space Technology Directorates I & II, the Human Spaceflight Technology Directorate, ISAS, the Aeronautical Technology Directorate, the Research & Development Directorate, and the Space Exploration Innovation Hub Center).

ISAS is expected to play a central role in space science development and graduate education. Following mid-term goals provided by the Minister of Education, Culture, Sports, Science and Technology, ISAS concentrates on promoting “highly original space science research that respects the autonomy of researchers” 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 includes satellite development, data analysis, and publication of the results.

As of April 1, 2015, ISAS is composed of five research departments: the Department of Space Astronomy and Astrophysics, the Department of Solar System Science, the Department of Interdisciplinary Space Science, the Department of Space Flight Systems, and the Department of Spacecraft Engineering.

2. Organization and Operation

a. Organization

In addition to ISAS, JAXA contains five directorates, one innovation hub, and other common departments (see JAXA Organization Chart).

The ISAS is composed of five research departments, the Management and Integration Department, the ISAS Program Office, the Systems Engineering Office, the Safety and Mission Assurance Officer, the Center for Science Satellite Operation and Data Archive, eleven project teams, five groups, and the Noshiro Rocket Testing Center. In addition, the Deputy Director General, the Research Director, the Program Director of Space Science, the Senior Chief Officer of Space Science and Disciplinary Engineering, the Director for International Strategy and Coordination, and the Director for Education and Public Outreach are assigned under the Director General (see ISAS Organization Chart).

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

b. Operation

The Advisory Council for Research and Management and the Board of Councilors were established to take over the inter-university research system at the former ISAS and to obtain advice from external scholars on business plans and other important issues regarding space science research. 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, 2016)

AOKI, Setsuko	Professor, Keio University
OKADA, Kiyotaka	Director, Center for Novel Science Initiatives, National Institutes of Natural Sciences (NINS)
OKADA, Yasunobu	President, The Graduate University for Advanced Studies (SOKENDAI)
OKAMURA, Sadanori	Professor, Department of Advanced Sciences, Faculty of Science and Engineering, Hosei University
KAWAI, Maki	Special Advisor to the President, RIKEN
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	President, National Institute of Technology
SATO, Katsuhiko	President, National Institutes of Natural Sciences (NINS)
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
FUJII, Ryoichi	Professor, Solar-Terrestrial Environment Laboratory, Nagoya University
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	External Auditor, Research Organization of Information and Systems

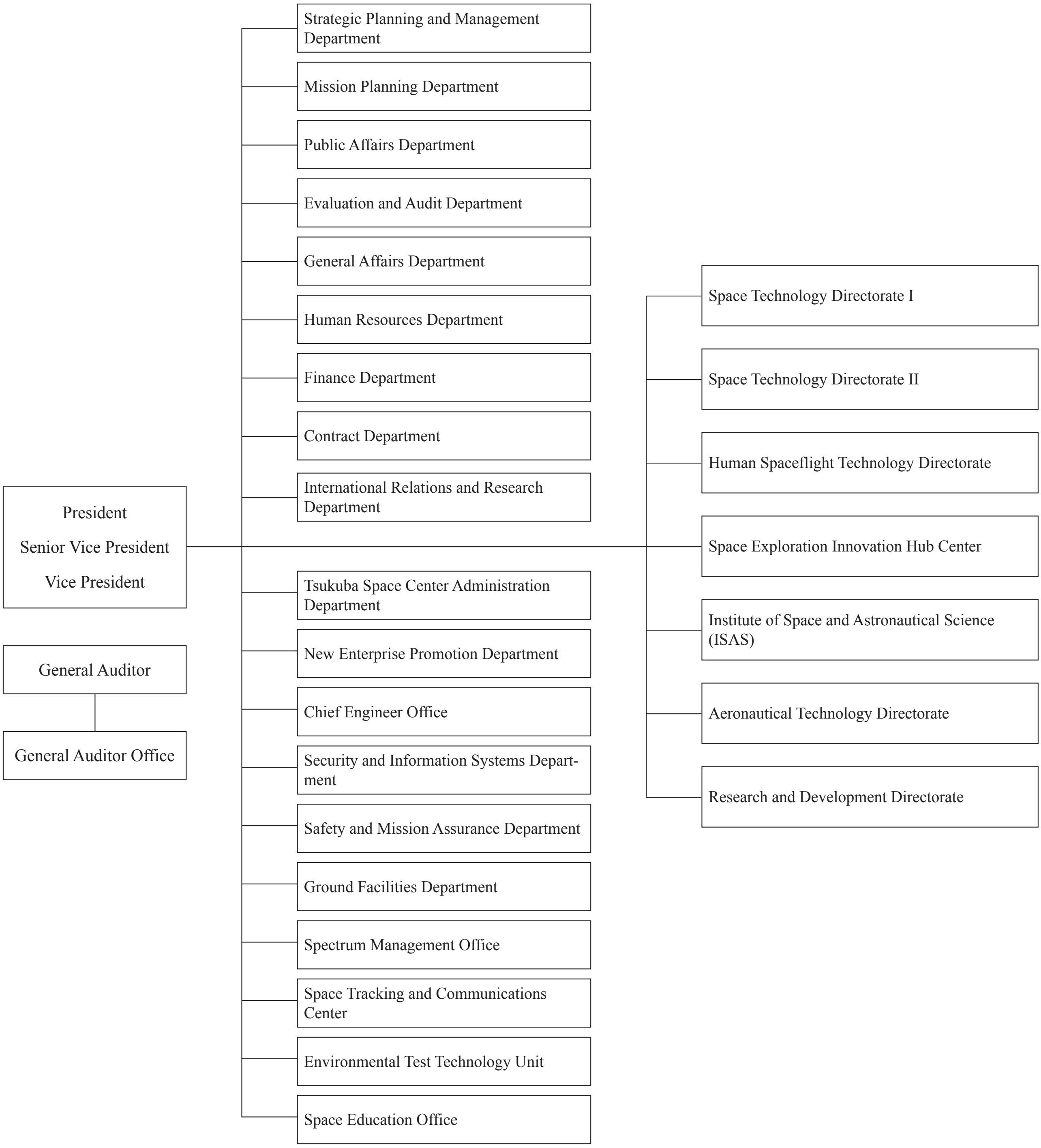
(Note) The term is from April 1, 2015 to March 31, 2017.

Members of Advisory Council for Research and Management (as of 31 March, 2016)

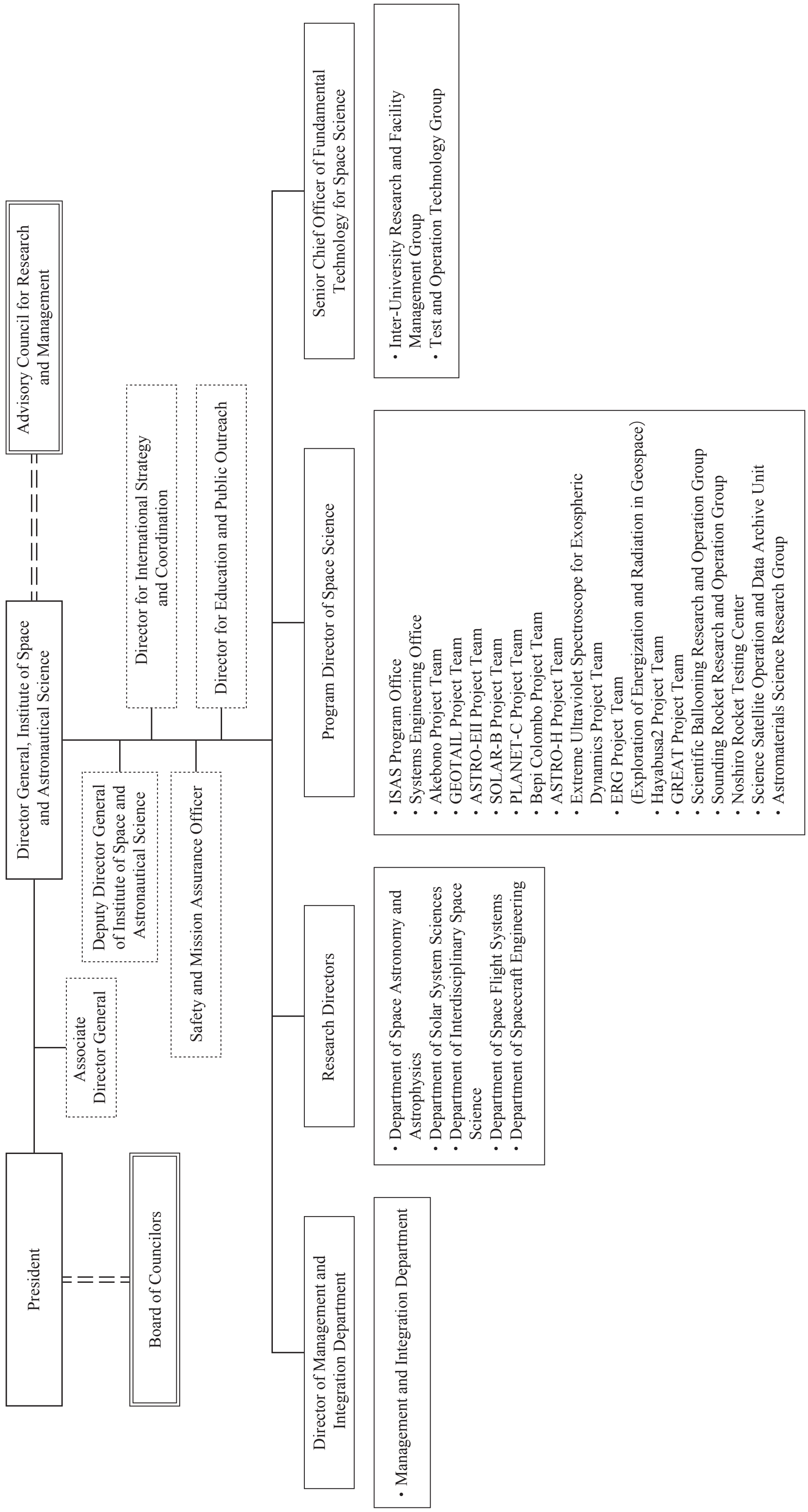
ISHIHARA, Akihiko	Professor, Graduate School of Human and Environmental Studies, Kyoto University
KOBAYASHI, Hideyuki	Vice-Director General, National Astronomical Observatory of Japan
SAWADA, Keisuke	Professor, Graduate School of Engineering, Tohoku University
TAKEDA, Nobuo	Vice President, The University 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	Professor, Solar-Terrestrial Environment Laboratory, Nagoya University
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



ISAS Organization Chart



c. Staff (as of March 31, 2016)

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

Associate Director General
FUKAI, Hiroshi

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

Research Director
MITSUDA, Kazuhisa

Safety and Mission Assurance Officer
KOBAYASHI, Ryoji

Director for International Strategy and Coordination
FUJIMOTO, Masaki

Director for Education and Public Outreach
INATANI, Yoshifumi

Management and Integration Department
Director SASAKI, Hiroshi

Management and Integration Department
Advisor to the Director
KANAZAWA, Yukihiro
OIKAWA, Masakatsu
YAMADA, Shuji

Manager for Management and Integration Department
KOSAKA, Akira
AOYAGI, Takashi

Management and Integration Department
Inter-University Research Coordination Division
Manager TSUJI, Hiroji

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

Program Director of Space Science
KUBOTA, Takashi

ISAS Program Office
Director KII, Tsuneo

Systems Engineering Office
Director KII, Tsuneo

Akebono Project Team
Project Manager MATSUOKA, Ayako

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 TAKAHASHI, Tadayuki

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

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

Science Satellite Operation and Data Archive Unit
Director TAKESHIMA, Toshiaki

Astromaterials Science Research Group
Manager YURIMOTO, Hisayoshi

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 MOCHIHARA, Yoshitaka

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

Professor	Associate Professor	Assistant Professor
MITSUDA, Kazuhisa	YAMASAKI, Noriko	MAEDA, Yoshitomo
TAKAHASHI, Tadayuki	KOKUBUN, Motohide	WATANABE, Shin
DOTANI, Tadayasu	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	ICHIMURA, Atsushi
EBISAWA, Ken	KITAMURA, Yoshimi	DOI, Akihiro
YAMADA, Toru	MURATA, Yasuhiro	TAMURA, Takayuki
TAKADA, Hiroaki [V]	FUJIMOTO, Ryuichi [V]	
KANEDA, Hidehiro [V]	NAKANISHI, Hiroyuki [V]	
OHASHI, Takaya [V]		
SHIBAI, Hiroshi [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
WATANABE, Sei-ichiro [V]	TANAKA, Satoshi	KASAHARA, Satoshi
KURAMOTO, Kiyoshi [V]	OKADA, Tatsuaki	HARUYAMA, Junichi
NAKAMURA, Eizo [V]	ABE, Masanao	OHTAKE, Makiko
YOSHIKAWA, Ichiro [V]	SAKAO, Taro	SHIRAISHI, Hiroaki
WATANABE, Tetsuya [V]	IMAMURA, Takeshi	HAYAKAWA, Masahiko
	SHIMIZU, Toshifumi	MITANI, Takefumi
	OZAKI, Masanobu	KOBAYASHI, Naoki
	SHINOHARA, Iku	
	ENYA, Keigo	
	TACHIBANA, Shogo [V]	
	MIYOSHI, Yoshizumi [V]	
	TAKAGI, Masahiro [V]	

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

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

[V] Visiting Professor/Associate Professor, [F] Full-time Teacher

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

Professor	Associate Professor	Assistant Professor
INATANI, Yoshifumi	OGAWA, Hiroyuki	NARUO, Yoshihiro
KAWAGUCHI, Junichiro	SAWAI, Shujiro	MORI, Osamu
ISHII, Nobuaki	YAMADA, Tetsuya	TAKEMAE, Toshiaki
MORITA, Yasuhiro	KAWAKATSU, Yasuhiro	MARU, Yusuke
KUNINAKA, Hitoshi	FUNAKI, Ikkoh	SAIKI, Takanao
SHIMADA, Toru	NISHIYAMA, Kazutaka	YAMADA, Kazuhiko
HORI, Keiichi	TOKUDOME, Shinichiro	KITAGAWA, Koki
SATO, Eiichi	OYAMA, Akira	NONOMURA, Taku
MINESUGI, Kenji	NONAKA, Satoshi	OKUIZUMI, Nobukatsu
HATTA, Hiroshi [F]	GOTO, Ken	TAKEUCHI, Shinsuke
NAKAGAWA, Ichiro [V]	ISHIMURA, Kosei	TSUKIZAKI, Ryudo
FUJII, Kozo [V]	TSUDA, Yuichi	TOBE, Hirobumi
	HABU, Hiroto	
	HYAKUTAKE, Toru [V]	
	FUNASE, Ryu [V]	
	KAWAI, Nobuaki [V]	
	YOKOTA, Shigeru [V]	
	TANAKA, Hiroaki [V]	
	MORI, Koichi [V]	
	HIGUCHI, Takehiro [V]	

Department of Spacecraft Engineering [Director : YAMADA, Takahiro]

Professor	Associate Professor	Assistant Professor
HASHIMOTO, Tatsuaki	SONE, Yoshitsugu	MITA, Makoto
KUBOTA, Takashi	MIZUNO, Takahide	FUKUSHIMA, Yosuke
YAMAMOTO, Zenichi	SAKAI, Shinichiro	KOBAYASHI, Daisuke
SAITO, Hirobumi	FUKUDA, Seisuke	TOYOTA, Hiroyuki
YAMADA, Takahiro	YOSHIKAWA, Makoto	BANDO, Nobutaka
KAWASAKI, Shigeo	TANAKA, Koji	OTSUKI, Masatsugu
HIROSE, Kazuyuki	TODA, Tomoaki	TAKEUCHI, Hiroshi
IKEDA, Hirokazu [F]	YOSHIMITSU, Tetsuo	TOMIKI, Atsushi
UMEDA, Minoru [V]	MATSUZAKI, Keiichi	MAKI, Kenichiro
HIROKAWA, Jiro [V]	OZAKI, Shingo [V]	
HONJO, Kazuhiko [V]		
KASUU, Makoto [V]		
SAKAKIBARA, Naoki [V]		

[V] Visiting Professor/Associate Professor, [F] Full-time Teacher

International Top Young Fellowship (ITYF)

Department	Name
Department of Space Astronomy and Astrophysics	SIMIONESCU, Aurora
Department of Space Astronomy and Astrophysics	INOUE, Yoshiyuki
Department of Space Astronomy and Astrophysics	LEE, Shiu-Hang
Department of Solar System Sciences	JAVIER, Peralta
Department of Space Flight Systems	CAMPAGNOLA, Stefano

3. Sagamihara Campus and Other Facilities

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/Building

Site : 73,001m²

Gross floor area : 56,239m²

Noshiro Rocket Testing Center

Location

Asanai, Noshiro-city, Akita

lat. 40° 10′ 10″ N.

long. 139° 59′ 31″ E.

Site/Building

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/Building

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/Building

Site : 712,922m²

Gross floor area : 19,072m²

Usuda Deep Space Center

Location

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

lat. 36° 07′ 59″ N.

long. 138° 21′ 43″ E.

Site/Building

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/Building

Site : 90,357m²

Gross floor area : 4,554m²

Tsukuba Space Center

Location

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

4. Advisory Committees

The Institute of Space and Astronautical Science (ISAS) established the Advisory Committee for Space Science and the Advisory Committee for Space Engineering to perform research, to review the implementation of academic research on space science performed in cooperation with universities, and for other related work in response to inquiries by the ISAS Director General. Also, the Technical Committee for Space Program reviews special technical matters and to conduct research.

The Sounding Rocket Technical Committee, Advisory Committee for Space Biology and Microgravity Science, and Committee on Scientific Ballooning were established 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 is a research committee that formulates research plans and reviews other technical items in relation to space science.

1) Strategic R&D

Objective: Working groups (WGs) in the project preparation stage conduct R&D to address technical issues that obstruct the path to mission goals. Research proposals considered by open application, and research funds are allocated after review. Progress reports are shared with the community.

Working Groups:

- Exploration and Study of Martian Atmospheric Escape WG
- Ultra-wide and Deep Survey Satellite (Wide-field Imaging Surveyor for High-redshift: WISH) WG
- ATHENA WG
- Next-generation Solar Observation Satellite (SOLAR-C) WG
- High-precision Measurement Plan for Polarization from Cosmic Background (Light Satellite for the Studies of B-mode Polarization and Inflation from Cosmic Background Radiation Detection: LiteBIRD) WG
- Asteroid/Moon Penetrator Plan (APPROACH2) WG
- Broadband X-ray High-sensitivity Imaging Spectrometer (FORCE) WG
- Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES-2) WG
- High-z Gamma-ray Bursts for Unraveling the Dark Ages Mission (HiZ-GUNDUM) WG
- Small Gravitational Wave Observation Satellite (DECIGO Path Finder: DPF) WG
- Dark Baryon-exploring Satellite (Diffuse Intergalactic Oxygen Surveyor: DIOS) WG
- Small Astrometry Satellite for Infrared Exploration (Japan Astrometry Satellite Mission for Infrared Exploration: JASMINE) WG
- WFIRST WG
- FUJIN WG
- Wide-field Monitoring of Transient Astronomical Objects (Wide-Field Monitoring of All-sky X-ray Image: WF-MAXI) WG
- Satellite Mission for X-ray Polarimetry (PRAXyS) WG (formerly GEMS)
- Exploration Project of Anti-particles from Cosmic Rays (General Anti-particle Spectrometer: GAPS) WG
- Jupiter Icy Moon Explorer (JUICE) WG
- JEM-EUSO WG
- MARS 2020 Life-form Probe Microscope WG

Working groups (WG) completed or restructured in 2015:

- Formation Flight All-Sky Telescope (FFAST) WG
- High-sensitivity Gamma-ray Telescope (Compton Telescope for Astro and Solar Terrestrial: CAST) WG
- MARS2020 Martian Electromagnetic/Sound Wave Observation WG
- The Extrasolar Terrestrial Planets Exploration (JTPF) WG and WFIRST-AFTA WG were restructured into the WFIRST WG.

Achievements and Impacts

Notable results are listed below.

1. Conducted low-temperature optics tests of the primary mirror support assembly for the WISH project.
2. Reduced telescope diameter from 1.4 m to 1 m and investigated feasible data transmission protocols for the solar observation satellite Solar-C.
3. Investigated technology for operating ultra-sensitive microwave sensors in low-temperature conditions and proposed a mission for LiteBIRD, a satellite for microwave-background radiation polarimetry. Also made progress in terms of front-loading like optical system designs and side-lobe assessments.
4. Investigated the feasibility of a small-scale plan for embarking on a Martian atmosphere dissipation mission, in addition to the existing mid-sized plan.
5. Analyzed the feasibility of using alignment changes and mirror surface precision fluctuations on the small

satellite JASMINE for positional astronomy applications.

6. Defined an EM development project for refrigerator systems in trans-mission activity (CC-CTP), and made progress in terms of life extension and disturbance reduction in EM development for the two-stage Stirling refrigerator used in ESA's large X-ray astronomy satellite Athena.
7. Developed a highly efficient polarimetry device designed for extrasolar planet research by NASA's WFIRST-AFTA satellite.
8. Prototyped a gas electron amplification foil for X-ray polarimetry project PRAXyS, a mission jointly proposed by NASA and GSFC.
9. Validated identification principles for cells, organic matter, and minerals with constant measurement of fluorescence decay time that will be collected by the life probe microscope scheduled for installation onboard a Mars rover.

2) Basic R&D on onboard equipment

Objective: To conduct seminal research for onboard equipment that will form the core of ideas for creative space science missions. Research proposals are being accepted from research group members, and research funds are allocated following a review. Progress reports are shared with the community.

Achievements and Impacts: Notable results are listed below.

1. Conducted model calculations to grasp physical phenomena causing issues that need to be addressed to utilize observations of antiparticles in cosmic rays (GAPS), and prepared for the development of a test model for scaling self-excited oscillatory heat pipes and multi-layered piping required for GAPS following a balloon experiment.
2. Fit an analog portion of the wave observer used for observing the electromagnetic spectrum in space onto a chip, and assessed the performance of the miniaturized system.
3. Developed a linear variable filter (LVF) for near- and mid-infrared radiation to enable spectroscopic observations of infrared space background radiation with limited resources.
4. Conducted a laser plasma spectroscopic experiment for the vacuum ultraviolet region to enable "on-site" K-Ar dating for LIBS, which identifies element compositions with spectroscopic analyses of samples volatilized by a laser.
5. Prototyped a long-life extreme ultraviolet light detector that is intended for celestial observations in space. Superior durability against radiation was achieved by placing an amplifier sensitive to extreme ultraviolet radiation in front of the CMOS image sensor.

These activities are meant to benefit future missions. Thus far these accomplishments have been publically released through over 45 presentations at academic conferences, 5 papers, and 2 reports.

b. Advisory Committee for Space Engineering

The Advisory Committee for Space Engineering is a research committee that was established to formulate research plans, plan research projects, and review other technical items related to the space engineering field.

Strategic R&D

Objective: To conduct research in element technologies (scientific satellites and rockets) for engineering missions and innovated in scientific satellites, rockets, and space transport systems.

Working groups:

- Solar sail WG (strategic R&D)
- Comprehensive R&D to initiate a demonstration mission for technology suitable for Mars surface exploration WG
- Demonstration and experiment of space technology for interplanetary voyage mission (DESTINY) research WG
- Solar-system sample-return exploration capitalizing on overseas mission WG
- Hybrid rocket research WG
- R&D on the Innovative Atmospheric-entry System using Membrane Aeroshell WG
- Research on formation flying technology WG

Operation:

- Engineering research using REIMEI satellite
- IKAROS operation

Studies on element technologies:

- Research on autonomous mobile exploration technology for lunar and planetary surfaces
- Research on asteroid exploration rover
- Studies on landing dynamics
- Demonstration research on advanced solid propellant rocket system
- R&D on Mars-capable airplane
- Technical research on innovative satellite buses
- Research on innovative miniaturization of the polarimetric Synthetic Aperture Radar (SAR)
- Research on a detonation-based innovative 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 the Mars exploration
- Studies on an aerial launch platform / system
- R&D on crushable structure for flexible landing and exploration missions
- Development of Geiger-mode distance-imaging sensor
- Studies on frequent reusable space transportation system

Achievements and Impacts

The achievements that have been publicly released include 62 papers, 172 presentations at international academic conferences, 302 presentations at domestic academic conferences, 9 invited speeches, 5 patents, 1 published book, and 30 other media reports (including press releases). Nine awards were received for this work.

Major results are listed below.

1. The solar sail WG made progress in refining the plan for the validation mission and in conducting R&D for the technical elements needed for outer planet domain exploration by solar-powered sail explorers. As a consequence, this work is now ready for transition to the next phase (phase A1).
2. The deep space probe technology WG proposed a joint engineering and science mission, Destiny+, that will conduct an advanced fly-by probe of the primitive bodies of the solar system (the source of meteor showers) through coordination between a high-performance, electric propulsion spacecraft equipped with compact avionics (capable of multi-orbital transitions between planets and around gravitational celestial bodies with twice the navigational capacity of HAYABUSA) and a microprobe that can separate from and be collected by the spacecraft.
3. The WG for innovative miniaturization of the polarimetric SAR succeeded in reaching milestones for the development of SAR that can be mounted onto a satellite capable of a 100 kg piggyback launch. This technology has been selected for the Japanese Cabinet's ImPACT project. A validation model is planned for development in 2015–2018. Additionally, the WG also validated high-speed communications (at 505 Mbps) by using 64 APSK modulation with the satellite HODOYOSHI 4. This is the first such achievement by an Earth orbiter.
4. The R&D WG for advanced atmosphere entry probes with flexible structures has coordinated with universities and JAXA to build on the unique idea of an expandable probe and has developed a flexible aeroshell with a 0.8 m diameter. Successful pre-validation tests were made by using a wind-measuring balloon, and results showed great potential for atmosphere entry missions during micro-planetary explorations.
5. The advanced solid rocket system technology WG established an ultrasonic testing method for the Epsilon 2 three-stage motor, which will enable future improvements in Epsilon rockets by assuring quality while reducing testing times. Ultrasonic tests and radiation tests (γ-ray) were conducted on a two-stage combustion motor, thus opening the possibility for applications in contingency management and next-phase solid rocket boosters. As a part of the research for low-cost synthesis methods for obtaining raw materials consisting of high-energy substances, the group verified that substitute alcohol is suitable for the synthesis of ammonium dinitramide; this technology has the potential to reduce the time required for synthesis by 70% and the cost of raw materials by 15%.
6. The hybrid rocket WG identified the mission requirements, system requirements, development team structure, risks, and project plans for its own A-SOFT boundary-layer combustion hybrid rocket.
7. Achievements were effectively realized with fewer resources by improving the degradation properties of lithium ion batteries in the space environment, as used on the satellite REIMEI, by capitalizing on the kinetic properties of the solar sail, by improving operating techniques during the long-term operation of IKAROS, and by reusing space probes that had finished their missions.

c. Technical Committee for Space Science Program

This committee accepts proposals for activities designated for open application, has committee members from inside and outside the institute conduct review of documentation and presentations, and selects themes for further support. In 2015, 26 applications were received and 18 themes were selected.

3.1. Application requirements

(1) Technical activities not eligible for strategic R&D grants or application to competitive funding under the jurisdiction of the Japanese government (Grant-in-Aid for Scientific Research (KAKENHI), etc.), but that possess high developmental factors, are required for the realization of the Space Science Program, and have the potential for horizontal application exceeding the bounds of a single mission.

(2) Activities that are required horizontally for space science

projects currently under development.

(3) Activities that target R&D for horizontal problem-solving of technical issues in space science projects, and activities that target R&D for horizontal fundamental technology in space science projects (standardization, formation of programs, etc.).

(4) Activities that contribute to the maintenance or improvement of Disciplinary Engineering group technology at ISAS.

3.2. List of selected themes

(1) Development of radiowave permeable controlled optical surface film
(2) Evaluation of outgassing
(3) Evaluation of thermal control materials
(4) Demonstration of heat pump mounting methods/evaluation testing methods
(5) Highly functional heat pipes, mechanical heat switches, and thermal storage devices
(6) Evaluation of low-cost network using Ethernet bus
(7) Research on omni-directional stable communication systems using MIMO
(8) Review of aptitude for chip-scale atomic clock (CSAC) in spacecraft
(9) Evaluation of resistance to space environments for carbon nanotube capacitor, to determine aptitude for use in space
(10) Review of methods for installing SUS-laminated Li-ion batteries in spacecraft
(11) Review of suitability of Perovskite solar cells for spacecraft
(12) Evaluation of suitability of high-performance automotive secondary batteries for spacecraft
(13) R&D on integrated digital control power sources in small satellites and probes
(14) A-SPADE: environment to support design of deep space exploratory missions
(15) Contribution to international standardization of DDOR technology
(16) Clarification and application of the attenuation mechanism caused by contact friction of fiber bundles
(17) Research on methods to reduce interference in antenna pattern synthesis
(18) Development of cleaning method for tools used to handle samples of planetary material

3.3. Year-end evaluation

At the end of 2015, we requested reporting of results for the selected research themes listed above. The reports were reviewed by the Technical Committee for Space Science Program. For all themes, it was confirmed that activities have been performed according to plan. Furthermore, a decision was made to revise the position of the Technical Committee for Space Science Program in 2016 so as to reflect the restructuring of the DE organization on October 1.

5. Professors Emeriti

Institute of Space and Astronautical science (ISAS)	Japan Aerospace Exploration Agency (JAXA)
USHIROKAWA, Akio	NINOMIYA, Keiken
TAKAYANAGI, Kazuo	KOHNO, Masahiro
OSHIMA, Koichi	NAGASE, Fumiaki
HAYASHI, Tomonao	MATSUMOTO, Toshio
HORIUCHI, Ryo	MIZUTANI, Hitoshi
NISHIMURA, Jun	UESUGI, Kuninori
MIURA, Koryo	TANATSUGU, Nobuhiro
TANAKA, Yasuo	NATORI, Michihiro C.
NISHIMURA, Toshimitsu	MATOGAWA, Yasunori
AKIBA, Ryojiro	NAKATANI, Ichiro
SHIMIZU, Mikio	TAKANO, Tadashi
OKUDA, Haruyuki	HIRABAYASHI, Hisashi
KURIKI, Kyoichi	MUKAI, Toshifumi
MAKINO, Fumiyoshi	MAEZAWA, Kiyoshi
OGAWARA, Yoshiaki	KURIBAYASHI, Kazuhiko
KAWASHIMA, Nobuki	NAKAJIMA, Takashi
NISHIDA, Atsuhiro	YAMASHITA, Masamichi
TSURUDA, Koichiro	TAJIMA, Michio
HINADA, Motoki	FUJIMURA, Akio
ITIKAWA, Yukikazu	INOUE, Hajime
YAJIMA, Nobuyuki	KATO, Manabu
HIROSAWA, Haruto	SASAKI, Susumu
KOBAYASHI, Yasunori	ONODA, Junjiro
MATSUO, Hiroki	YODA, Shinichi
	FUJII, Kozo
	KOMATSU, Keiji
	MURAKAMI, Hiroshi
	ABE, Takashi
	HATTA, Hiroshi

Ⅳ. Budget

(Unit: ¥1,000)

	FY 2013	FY 2014	FY 2015
Budget (ISAS)	14,563,065	19,623,569	20,947,061
Operating expense grants	14,333,551	19,539,665	20,507,837
Facility maintenance subsidy	229,514	83,904	439,224
External Funds			
Grant-in-aid for scientific research (KAKENHI)	451,100	505,675	333,148
Grant-in-aid for scientific research (Accepted share of expenses)	69,050	49,205	62,634
Funded research	362,360	428,613	619,484
Cooperative research with private sector	26,839	47,139	395,184
Earmarked donations	9,500	15,769	11,282

Ⅴ. International Collaboration and Joint Research

1. International Collaboration

Reflecting that space is the common frontier of humanity, space science missions are almost always conducted as multinational collaborations. In Japan, too, international cooperation has an important meaning in the field of space missions. Currently and so far, Japan leads worldwide space sciences in a variety of fields such as X-ray astrophysics, space plasma physics, solar physics, as well as solar system science, and as an inter-university research institute in Japan, ISAS should continuously play significant roles and should take responsibility in future space missions, which have to satisfy the needs of scientific community in the world with considering global trends in the future. To develop world-leading space missions, strategic partnership with international partners and relationship with scientific communities are crucially important, and to strengthen partnership with partners, strategic dialogue among space agencies, research institutes, universities in the world with ISAS is continued.

Currently going on solar system exploration missions are mostly conducted with international partners. Asteroid sample return mission Hayabusa2 is going to deliver the DLR landing package MASCOT to its target asteroid 1999 JU3, and scientists from the United States and Japan plan to share asteroid specimens from sample return missions Hayabusa2 and US mission OSIRIS-REx under an agreement signed by NASA and JAXA. AKATSUKI, Venus climate orbiter, will be operated with NASA and scientists from US and European countries are going to study data from the spacecraft. Support by NASA's deep space network (DSN) is essentially important to continuously track interplanetary spacecraft in particular critical phases such as insertion into a planet and asteroid touch down. Along with Usuda deep space center at JAXA, DSN, the largest and most sensitive scientific telecommunications system in the world, tracks Japanese interplanetary spacecraft and receives/uploads telemetry data and command for Hayabusa2 and AKATSUKI.

X-ray astronomy satellite ASTRO-H launched on Feb.17 2016 was built by an international collaboration led by JAXA with over 70 contributing institutions in Japan, US, Canada, and Europe. For example, the High-Resolution Soft X-Ray Spectrometer (SXS) by NASA, and the filter-wheel and calibration source for the spectrometer by the Netherlands Institute for Space Research (SRON). On the other hand, ISAS found that communication with HITOMI failed from the start of its operation originally scheduled at 16:40, Saturday March 26. Although ISAS had made every effort to confirm the status of ASTRO-H and to regain its functions, based on our rigorous technical investigation, ISAS declared the shutdown of HITOMI on April 28, before achieving regular operations for science.

There are two scientific satellites that are being developed with international partners. 1) Cooperative measurement by Exploration of energization and Radiation in Geospace (ERG) satellite with US Van Allen Probes provides opportunities not only for multi-point characterization of inner magnetosphere dynamics, but will provide important complimentary measurements from higher magnetic latitudes. 2) BepiColombo, mercury explorer, is a joint mission between ESA and JAXA. JAXA is responsible for the development and operation of Mercury Magnetospheric Orbiter (MMO), while ESA is responsible for the development and operation of Mercury Planetary Orbiter (MPO) as well as the launch, transport, and the insertion of two spacecraft into their dedicated orbits. Following the above three mission to be launched in 2018 or later, to start new and future space science programs, strategic L-class space missions SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is jointly studied with european partners. Furthermore Martian Moons eXplorer (MMX) and Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection (LiteBird) as strategic L-class space missions are under consideration for international cooperation. And some missions-of-opportunity contributions are being planned for ESA-led Jupiter Icy Moon Explore (JUICE) and participation into a new, large X-ray observatory called ATHENA (Advanced Telescope for High ENergy Astrophysics), ESA-led large class mission, is discussed.

In addition to space missions, by floating balloons or launching sounding rockets in Antarctica or the equatorial belt, for example, we can conduct observations impossible in the Japan area. In addition, by gathering together mutual technologies and experiences, more fruitful observations can be conducted. Chromospheric Lyman-Alpha SpectroPolarimeter (CLASP) scientific sounding rocket experiment in collaboration between Japan, US and Spain, was launched from the White Sands Missile Range in Sep. 2015. International partnership is also important in balloon experiment. International Scientific Ballooning has been conducted as long duration flights, and on May 2015, observations by Gamma-ray Telescopes was carried out on Alice Springs situated in the geographic center of Australia.

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 Organisation)	ISRO "ASTROSAT" satellite and cooperative observations. (Under discussion)
Solar Physics Satellite "HINODE" (SOLAR-B)	Sep 9, 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.

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
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, OSIRIS-Rex 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 lost 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.
(Below, cooperative projects with overseas satellite missions)				
Gamma-ray Burst Observation Mission “Swift”	Nov 20, 2004	Swift is an international collaboration with the US, UK, and Italy for investigating the formation of gamma-ray bursts, the largest known explosive phenomena.	NASA (USA)	JAXA, Saitama Univ., Univ. of Tokyo to provide Burst Alert Telescope (BAT).
Magnetosphere exploration satellite constellation “THEMIS” (Time History of Events and Macroscale Interactions during Substorms)	Feb 17, 2007	THEMIS is a US-led mission, consisting of five magnetosphere exploration satellites and full-sky cameras. Combining these with magnetosphere observation equipment will elucidate the occurrence mechanism of “substorms,” the explosive development of the aurorae.	NASA (USA), UC Berkeley (USA)	JAXA researchers participating as science personnel.

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
Gamma-ray Space Telescope "Fermi"	Jun 11, 2008	Fermi is an international mission involving the US, France, Germany, Japan, Italy, and Sweden. It will perform observations of black holes, neutron stars, active galactic nuclei (AGNs), supernova remnants, and gamma-ray bursts, the largest known explosive phenomena.	NASA (USA)	Hiroshima Univ. providing semiconductor sensors for the gamma-ray Large Area Telescope (LAT)
Canadian small satellite project "CASSIOPE" (CAScade, Smallsat and IOnospheric Polar Explorer)	Sep 29, 2013	CASSIOPE is Canada's first small satellite project. Its main goal is elucidation of atmospheric outflow mechanisms from the polar region and observations of the effects of the Sun on Earth's magnetosphere and atmosphere.	Univ. of Calgary (Canada)	JAXA providing one of eight E-POP observation devices (neutral particle analyzers).
Korean Science & Technology Satellite "STSAT-3"	Nov 21, 2013	STSAT-3 is used for atmospheric observations and environmental monitoring, as well as galaxy observations.	KASI (Korea Astronomy and Space Science Institute)	JAXA providing technical assistance for telescope system development of the Multi-purpose 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).

b. International cooperation in satellite missions at the development stage

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
Exploration of energization and Radiation in Geospace "ERG"	Fiscal 2016 (planned)	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).

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
Mercury Exploration Mission "BepiColombo"	Fiscal 2016 (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	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

Project	Launch	Mission overview	Cooperating partner	Partner responsibilities
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
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)	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
(Below, cooperative projects with overseas satellite missions)				
Jupiter Icy Moon Explorer "JUICE" (working group)	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 Astrophysics "ATHENA" (working group)	2028 (planned)	ATHENA is an ESA-led mission. It will observe ultrahigh-temperature matter immediately before it falls into a black hole to elucidate fundamental contributions of black holes to galaxy formation.	ESA (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).
(Below, cooperative projects with overseas satellite missions)				
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	2016 or later	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	Launch	Experiment overview	Cooperating partner	Partner responsibilities
Upper atmosphere observation experiment “WIND-II”	Jan 2012	The thermosphere is considered the boundary between Earth and space. This study will investigate the causes of disturbances recently revealed by radar observations and energy exchange between the neutral atmosphere and the ionosphere from the ionospheric F layer down to the E layer.	Univ. of Calgary (Canada)	Provision of Imaging and Rapid-Scanning Ion Mass Spectrometer (IRM).
			Clemson Univ. (USA)	Cooperative ground observations.
(Below, cooperative projects with overseas missions)				

Project	Launch	Experiment overview	Cooperating partner	Partner responsibilities
Daytime lower thermosphere wind Japan-US joint sounding rocket experiment "Daytime Dynamo"	Jul 2011, Jul 2013	These are upper-atmosphere observation experiments conducted using NASA sounding rockets. They simultaneously perform direct observations of ionospheric plasma and take daytime wind-speed measurements to elucidate the mechanisms of sporadic E-layer production.	NASA (USA)	JAXA provision of lithium injection system and technical support.
Norwegian sounding rocket experiment "ICI-3"	Nov 2011	Observations of disturbances in reversed-flow channels occurring in large-scale plasma flows.	Univ. of Oslo (Norway)	JAXA providing electron density disturbance measuring instrument and the Low Energy Particle Electron Spectrum Analyzer
The Focusing Optics X-ray Solar Imager "FOXSI/FOXSI2"	Nov 2012, Dec 2014	Proof-of-concept for direct high-sensitivity imaging of hard X-ray solar spectroscopic observations for high-sensitivity observations of small-scale solar flares.	UC Berkeley Space Sciences Laboratory (USA)	JAXA providing dual silicon strip detector (DSSD) and dual cadmium strip detector (CdTe DSD).
Norwegian sounding rocket experiment "ICI-4"	Feb 2015	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 SpectroPolarimeter "CLASP"	Sep 2015	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 calculations.

f. International cooperation in atmospheric balloon experiments

Project	Experiment overview	Cooperating partner	Partner responsibilities
Japan–Brazil joint balloon experiment	A joint balloon experiment for hard X-ray imaging and far-infrared interferometer observations and next-generation balloon flight performance tests.	INPE (Brazilian National Institute for Space Research)	In cooperation with JAXA, flight operations and reclamation of balloon and observational equipment.

Project	Experiment overview	Cooperating partner	Partner responsibilities
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 superconducting spectrometer 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 wide-ranging 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.

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 leading-edge research, we operated and established centers for inter-university collaboration and worked to improve acceptance of academic researchers and non-Japanese researchers at the Sagamihara campus.

Regarding centers for inter-university collaboration, we conducted research with two recruited researchers at the ERG science center at the Solar–Terrestrial Environment Laboratory, which was established in 2013 in collaboration with Nagoya University. Research there improved the environment for satellite data analysis. We contributed to the establishment of a new center for inter-university collaboration through a strategy for solar system exploration with cooperation between science.

In 2015, proposals were selected from 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 from the University of Tokyo Graduate School of Science for construction of a system to promote planetary exploration using ultra-small probes. Activities were started based on the selected proposals.

To bring more academic and non-Japanese researchers into the inter-university research system, we investigated other institutions with established Users Office systems, aiming to improve usability so that these researchers can make full use of the Sagamihara campus, and to make the campus a core of space science research. Based on this investigation, we created an improvement action plan, including an application system for travel expenses and overnight accommodations and a support system for the daily lives of non-Japanese researchers. The User Office leads these activities and implements them to promote further improvements.

3. Research by External Funds

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

Research Categories	Number of Selected Projects	Total (thousand yen)
Scientific Research on Innovative Areas (Research in a proposed research area)	3	63,960
Scientific Research (S)	1	15,990
Scientific Research (A)	9	86,970
Scientific Research (B)	16	69,524
Scientific Research (C)	18	29,175
Challenging Exploratory Research	11	19,481
Young Scientists (A)	4	22,490
Young Scientists (B)	13	17,160
Research Activity start-up	2	2,470
JSPS Fellows	6	5,928
Total	83	333,148

Accepted share of expenses

Research Categories	Number of Selected Projects	Total (thousand yen)
Scientific Research on Innovative Areas (Research in a proposed research area)	4	19,695
Scientific Research (S)	3	12,220
Scientific Research (A)	15	23,335
Scientific Research (B)	15	7,059
Scientific Research (C)	1	130
Challenging Exploratory Research	2	195
Total	40	62,634

b. Funded Research

Number of Researches	Total (thousand yen)
30	619,484

c. Cooperative Research with Private Sector

Number of Researches	Total (thousand yen)
24	395,184

d. Earmarked Donations

Number of Donations	Total (thousand yen)
17	11,282

4. Domestic Joint Research

Open facilities for domestic joint research	Number of joint research
Space chamber test equipment	20
Ultra-high-speed collision test equipment	26
Space radiation equipment	6
Wind tunnel laboratory	26
Planetary atmospheric entry environment simulator	13
JAXA supercomputer	14

	Number of joint research
Research for promoting international missions	2

	Number of joint researchers
Joint researchers assigned to specific themes through application by ISAS educational faculty	57

Ⅵ. Education and Public Outreach

1. Graduate School

At the Institute of Space and Astronautical Science (ISAS), educational staffs appointed as professors, associate professors, and research associates provide education for students accepted through requests by universities for experimental and theoretical research and innovative R&D. Staffs who engaged in graduate education are listed in Table1.

ISAS provides comprehensive guidance on space science and space engineering research to students. We also provides direct involvement in large research projects and their preliminary research that are difficult to conduct in common universities. Through these means, we provide opportunities to acquire deep knowledge and planning skills for space science projects, contribute to human resource development to foster personnel who will lead future space science and aerospace research, engage in R&D with space equipment manufacturers and companies utilizing space infrastructure their clients, and instill students with various skills for organizing projects in a wide range of social fields.

Table 1. Staff engaged in graduate education (as of March 31, 2016)

	ISAS			
	Professors	Associate professors	Research associates	Total
The Graduate University for Advanced Studies	15	40	33	78
The Graduate School at the University of Tokyo School of Science/ School of Engineering	7/11	6/3	9/13	22/27
Special Inter-Institutional Research Fellows	8(*8)	8(*8)	–	16 (*16)
Cooperative Graduate School	7(*7)	12(*11)	1(*1)	20 (*19)

* 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 items, including basic policies and guidelines related to cooperation with graduate education, cooperation with the Graduate University for Advanced Studies (SOKENDAI) and the University of Tokyo, and other issues related to affiliated graduate schools.

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

1. Introduction

1.1 Department of Space Astronautical Science, School of Physical Sciences, the Graduate University for Advanced Studies (SOKENDAI)

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

SOKENDAI Department of Space Science Admission in 2015

Admission capacity	Applicants	Passing applicants
5	3 (October admission)	2 (October admission)
(of which 3 were admitted to secondary doctoral courses)	8 (April admission)	5 (April admission)

1.2 The Graduate School at the University of Tokyo, School of Science and Engineering (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 involved 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) as instructors at the University of Tokyo. They accept, teach, and train master's and doctoral degree students.

1.3 Special Inter-institutional Research Fellows and Technical Trainee

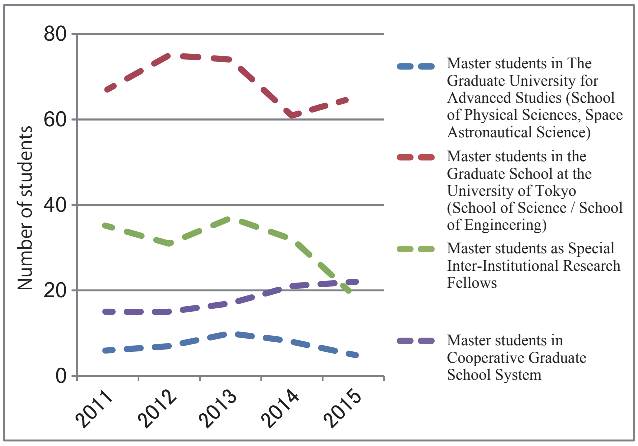
In the Special Inter-institutional Research Fellows system, ISAS accepts students from national, public, and private universities throughout Japan who need advice on their research under commission from their universities, and provides education and guidance on specific research themes for limited periods. These activities are part of ISAS cooperation for 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 the Graduate School guideline in Japan, and issue credits, review dissertations, and confer degrees.

JAXA also accepts technical trainees in all Directorates to produce researchers and engineers who are not a target for graduate education. 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 of Japanese and foreign universities by request.

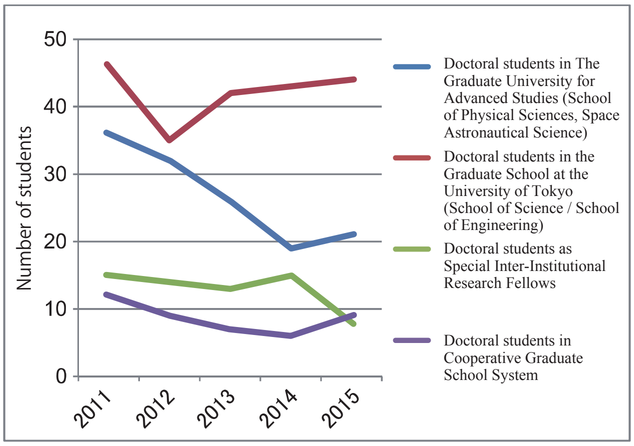
1.4 Cooperative Graduate School System

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

ISAS cooperates with nine schools in eight universities and accepts, teaches, and trains master's and doctoral degree students. In some schools, we cooperate with other Directorates (as of 31 March, 2016).



Number of students receiving education for a master's degree



Number of students receiving education for a doctoral degree

2. Public Outreach

Introduction

Our education and public outreach (E/PO) prioritizes opportunities for people who are not familiar with space science. Major activities include facility tours and cooperation with local communities and science museums. Since 2014, we have also promoted E/PO activities such as introducing our achievements in space science and ISAS duties.

1. Press activities

We notify the press of achievements and results of experiments through press releases. For these announcements, we hold press conferences and use our website in cooperation with the PR Department. In 2014, we sent out several press releases and announcements per month, and put airframes on public view twice. This year in particular, we held press briefings prior to the Earth swing-by of the asteroid explorer "Hayabusa2" and orbital insertion of the Venus Climate Orbiter "AKATSUKI," and set up a press center on the Sagamihara Campus on those days. We also held conferences to help the press understand basic space science and to announce academic achievements.

2. Expanding tours

We expanded our exhibit room and outdoor tours, and improved guided and self-guided tours on special open days.

We provided guided tours including tours of our exhibit room to increase public participation. As a result, 65,281 visitors participated in guided and self-guided tours in 2015, a much higher turnout than in 2010 (58,648), despite increased interest in that year due to the return of "HAYABUSA." This increase in the number of visitors has steadily increased; 12,984 visitors participated in guided tours, an order of magnitude higher than pre-2007 attendance (about 2,000 visitors per year).

We employed students as part-time employees and have held Q&A sessions on Saturdays, Sundays, and holidays since 2010. These sessions were successful and provided a high level of visitor satisfaction. They also help students acquire knowledge and provide educational experiences. The "Rocket Launch Sound" sessions held on Saturdays, Sundays, and holidays gained great popularity, with some visitors participating repeatedly.

Annual special open days were held at Sagamihara Campus on the last Friday and Saturday in July, and about 13,560 people visited. We optimized event booth locations and planned smooth flow lines, thereby successfully reducing crowding for many visitors.

The Noshiro Rocket Testing Center held special open days that started in 2013, during which 600 people visited for two days. In normal open days, about 1,200 people visited in 2016.

We are thus responding to the rapidly growing needs from visitors, and are planning construction of a new exhibition hall to expand opportunities for introducing our various achievements in space science R&D.

3. Cooperation with the local community

We held many joint events with Sagamihara City and the National Museum of Modern Art, Tokyo, including stargazing sessions at local festivals and seminars in public halls. We also conducted seminars at schools and joint tours with museums to attract people who are unfamiliar with space science. We appeared on the city's community FM radio station as a regular, and perform E/PO activities at local sports centers. We also collaborated with Kanagawa Prefecture in events sponsored by the Kanagawa Committee for Youth Education, including a Science Festival for Children at three sites and a robot festival.

4. Collaboration with other organizations

We actively dispatch lecturers upon request from science museums, public halls, and schools. ISAS dispatched 66 lecturers in 2014 (excluding cases where ISAS staff are involved in educational activities led by the PR Department, the Lunar and Planetary Exploration Program Group, or the Space Education Center).

We support special exhibitions held in museums and department stores throughout Japan, and lend models and panels for exhibitions by request. We are also involved in planning some events.

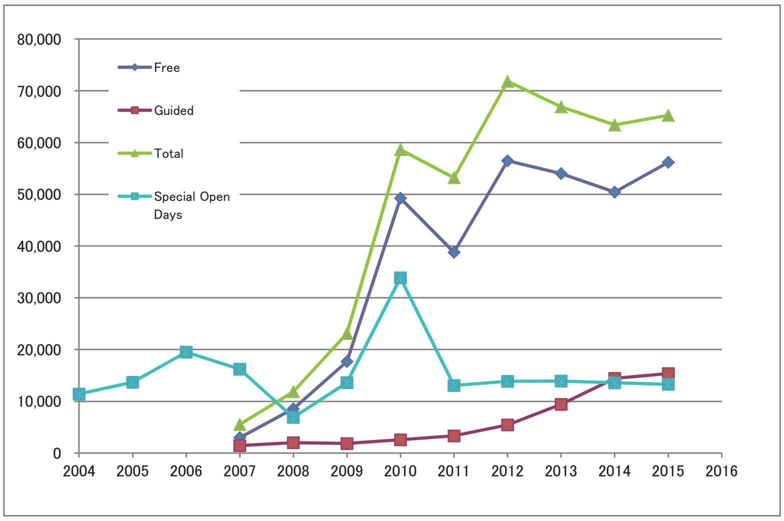
We cooperated with the Japan Science Museum Committee to assist exhibitions related to space science at science museums, including six sets of panel exhibition tours (held at 23 sites and 230,000 visitors in total).

We organized "Space School" events at ten sites including Sagamihara and Tokyo, in which 3,000 people (mainly children and their parents) participated.

5. Other

We published the PR magazine "ISAS news" each month, and we updated our website based on the content of those magazines and press releases.

In addition, we maintained an official Twitter account (@ISAS_JAXA). We had 11,473 followers at the end of 2010. This has steadily increased, reaching about 60,000 followers at the end of 2016.



Number of visitors to the Sagamihara campus

Ⅶ. Awards

The Second ISAS Award

Name	Affiliation	Reason for Award	Date
SUEMATSU, Yoshinori	National Astronomical Observatory of Japan	Development of the Solar Optical Telescope of SOLAR-B	2016.1.6
ANDO, Makoto	Tokyo Institute of Technology	Development of the honeycomb-structured Radial Line Slot Antennas for ultra-long-distance communication installed on the asteroid explorer “Hayabusa 2” and the Venus Climate Orbiter “Akatsuki”	2016.1.6
HIROKAWA, Jiro			

Staff

Name	Affiliation	Award	Date
KAWASAKI, Shigeo	Department of Spacecraft Engineering	IEEE MTT-S Wireless Power Transfer Conference 2015, The 3rd Prize Award of Student Paper Competition, “Backscatter radio coverage enhancements using improved WPT signal waveform”	2015.5
HASEGAWA, Naoki MIYACHI, Akihira MATSUNOSHITA, Makoto KAWASAKI, Shigeo	Department of Spacecraft Engineering	2015 Thailand-Japan Microwave (TJMW2015), The Best Presentation Award, “Dual-band dual-pole antenna for compatibility of MPT with communication”	2015.8
INATANI, Yoshifumi	Department of Space Flight Systems	Fluid Science Research Award 2015, Fluid Science Foundation	2015.8
SAITO, Hirobumi	Department of Spacecraft Engineering	The Institute of Electronics, Information and Communication Engineers (IEICE), Communication Society: Outstanding Contributions Award 2015	2015.9
MIURA, Akira	Department of Interdisciplinary Space Science	International Festival of Scientific Visualization 2015, The Short Film Competition, Judges Special Award, “A Variety of Lights from the Universe”, Organizing Committee for The 6th International Festival of Scientific Visualization 2015	2015.10
MIURA, Akira	Department of Interdisciplinary Space Science	International Festival of Scientific Visualization 2015, The Short Film Competition, Audience Choice Award, “A Variety of Lights from the Universe”, Organizing Committee for The 6th International Festival of Scientific Visualization 2015	2015.10
ITO, Takahiro	Research Unit I (Test and Operation Technology Group)	59th Space Sciences and Technology Conference, JSASS Young Researcher Award, The Japan Society for Aeronautical and Space Sciences	2015.10
OTSUKI, Masatsugu	Department of Spacecraft Engineering	The 16th SICE System Integration Division Annual Conference (SI2015), Best Presentation Award, The Society of Instrument and Control Engineers	2015.12
USUI, Fumihiko HASEGAWA, Sunao KATAZA, Hirokazu TAKITA, Satoshi UENO, Munetaka MATSUHARA, Hideo	Department of Space Astronomy and Astrophysics	The PASJ Excellent Paper Award 2015, “Asteroid Catalog Using AKARI: AKARI/IRC Mid-Infrared Asteroid Survey”	2016.3
Akatsuki Project Team (NAKAMURA, Masato)	Akatsuki Project Team	Yomiuri Techno Forum, 22nd Gold Medal Prize (Special award)	2016.3
Akatsuki Project Team	Akatsuki Project Team	The Japan Society of Mechanical Engineers (JSME), Space Engineering Division, Space Award	2016

Student

Name	Academic Advisor	Affiliation	Award	Date
IWASAKI, Akihiro	OGAWA, Hiroyuki	The Graduate University for Advanced Studies (SOKENDAI)	Japan Explosives Society (JES), 2015 Spring Meeting, Excellent Presentation Award	2015.5
OISHI, Takahiro	SAITO, Yoshifumi	Graduate School at The University of Tokyo	JpGU2015, Space and Planetary Sciences Section, Outstanding Presentation Award	2015.5

Name	Academic Advisor	Affiliation	Award	Date
AKATSUKA, Kosuke	KAWAGUCHI, Junichiro	Graduate School at The University of Tokyo	30th International Symposium on Space Technology and Science (ISTS): JSASS President Award「Nonholonomic Behaviour of Biased-Momentum Asymmetric Spacecraft in Sun-Tracking Motion Using Solar Radiation Pressure」	2015.7
KIKUCHI, Shota	KAWAGUCHI, Junichiro	Graduate School at The University of Tokyo	30th International Symposium on Space Technology and Science (ISTS): General Chairperson Award「Stabilization Strategy of Delta-V Assisted Periodic Orbits around Asteroids Based on an Augmented Monodromy Matrix」	2015.7
AOYAGI, Yuki KONISHI, Shingo	INATANI, Yoshifumi	Graduate School at The University of Tokyo	30th International Symposium on Space Technology and Science (ISTS): The 8th Spacecraft Control System Design Contest "Student Category First Prize"	2015.7
ABE, Yoshiaki	OYAMA, Akira	Graduate School at The University of Tokyo	The 47th Fluid Dynamics Conference/The 33rd Aerospace Numerical Simulation Symposium, Excellent Presentation Award	2015.7
SATO, Ayane	INATANI, Yoshifumi	Graduate School at Tokyo University of Agriculture and Technology (Special Inter-Institutional Research Fellow)	The 47th Fluid Dynamics Conference/The 33rd Aerospace Numerical Simulation Symposium, Excellent Presentation Award	2015.7
KIKUCHI, Takahiro	MITSUDA, Kazuhisa	Graduate School at The University of Tokyo	The 6th ASTRO-H International Summer School: Silver Winner「Heliospherical Solar Wind Charge Exchange emission observed with ASTRO-H SXS 」	2015.8
MASUDA, Hiroshi	SATO, Eiichi	Graduate School at The University of Tokyo	12th International Conference on Superplasticity in Advanced Materials (ICSAM2015): Best Poster Award「Two-Dimensional Observation of the Core-Mantle Model for Superplastic Flow in an ODS Ferritic Steel」	2015.9
DEGUCHI, Masaya	SATO, Eiichi	Graduate School at The University of Tokyo	The Japan Institute of Metals and Materials, 2015 Fall Annual (157th) Meeting, The Metals Best Poster Award	2015.9
AKATSUKA, Kosuke	KAWAGUCHI, Junichiro	Graduate School at The University of Tokyo	The Japan Society for Aeronautical and Space Sciences,59th Space Sciences and Technology Conference, JSASS Best Paper Award for Students Session	2015.10
SHIBATA, Takuma	SAKAI, Shinichiro	The Graduate University for Advanced Studies (SOKENDAI)	The Japan Society for Aeronautical and Space Sciences,59th Space Sciences and Technology Conference, JSASS Excellent Presentation Award for Students Session	2015.10
HIGANE, Kenta	SATO, Eiichi	Graduate School at Tokyo Metropolitan University	The Japan Institute of Light Metals Best Poster Award in The 129th Conference on Japan Institute of Light Metals	2015.11
KATO, Daiba	SAITO, Yoshifumi	Graduate School at The University of Tokyo	The 138th SGEPSS Fall Meeting, SGEPSS Student Presentation Award (Aurora Medal)	2015.11
IWASAKI, Akihiro	OGAWA, Hiroyuki	The Graduate University for Advanced Studies (SOKENDAI)	Japan Explosives Society (JES), 2015 Fall Meeting, Excellent Presentation Award	2015.12
ITOUYAMA, Noboru	HORI, Keiichi	Graduate School at The University of Tokyo	Japan Explosives Society (JES), 2015 Fall Meeting, Excellent Presentation Award	2015.12
IDE, Yuichiro	TOKUDOME, Shinichiro	The Graduate University for Advanced Studies (SOKENDAI)	Japan Explosives Society (JES), 2015 Fall Meeting, Excellent Presentation Award	2015.12
DEGUCHI, Masaya	SATO, Eiichi	Graduate School at The University of Tokyo	The Japan Institute of Metals and Materials, 2016 Spring Annual (158th) Meeting, The Metals Best Poster Award	2016.3

Name	Academic Advisor	Affiliation	Award	Date
DEGUCHI, Masaya	SATO, Eiichi	Graduate School at The University of Tokyo	The Japanese Society for Non-Destructive Inspection, Poster Award	2016.3
KANOH, Ryuichi	SHIMIZU, Toshifumi	Graduate School at The University of Tokyo	The 45th Summer school in Astrophysics, Oral Award	2015.7
KANOH, Ryuichi	SHIMIZU, Toshifumi	Graduate School at The University of Tokyo	The University of Tokyo, Graduate School of Science Research Award	2016.3
TANAKA, Kohei	FUKUDA, Seisuke	The Graduate University for Advanced Studies (SOKENDAI)	Excellent Paper Award of The Electrochemical Society of Japan「The First lithium-ion Battery with Ionic Liquid Electrolyte Demonstrated in Extreme Environment of Space」	2016.3

Professor Emeritus

NISHIMURA, Jun	IUPAP (International Union of Pure and Applied Physics) 2015 O'Ceallaigh Medal	2015.5

Ⅷ. ISAS Library and Repository

1. Library

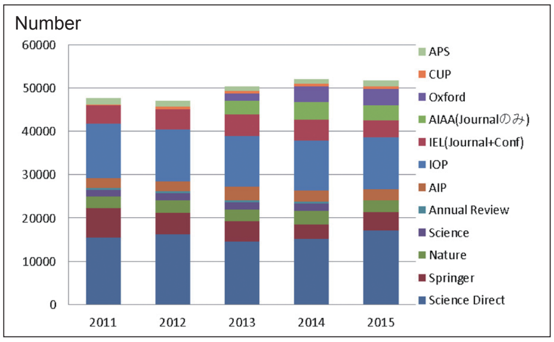
The Institute of Space and Astronautical Science (ISAS) library actively collects materials, including books, magazines, and reports in space science and related fields, and provides them to many researchers. It has also served as a library of SOKENDAI parent institutes since April 2003. The library makes joint purchases of e-journals and contributes to graduate education. Since the establishment of JAXA on October 1, 2003, it has served as the ISAS library. We created a website, and started to share e-journals and offer various services to external users cooperating with other libraries in JAXA. It works toward increasing available references and improving services to users.

The number of books and journals available at the end of March 2016 are shown below.

Number of books	93,190 (details of added books)
Foreign books	76,340 (50 books, 32 bound magazines)
Japanese books	16,850 (385 books, 71 bound magazines)

Number of journals	1,193
Foreign journals	959
Japanese journals	234

Journals added in 2015	203
Foreign journals	16
e-Journals	119
Domestic English journals	6
Japanese journals	62
e-Journals	about 4,300
IEL Online	174
IOP Journal	53
Elsevier Science Direct	165
Springer Journal	about 1,630
Wiley-Blackwell	about 1,400
JSTOR	about 680
Other	



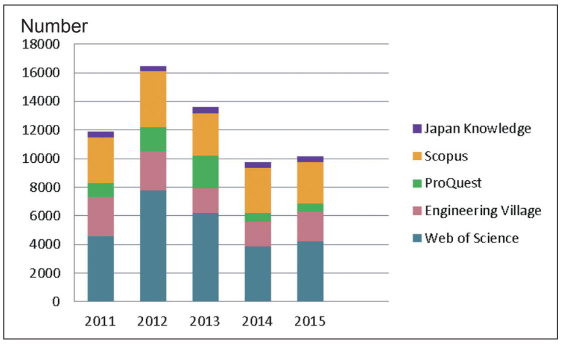
Number of downloads of e-journals (by year)

e-book

AGU Geophysical Monograph Series and other	598
AIAA Education Series	69
AIP Conference Proceedings	1,639
Net Library	579
Oxford Scholarship Online (Physics)	216
Springer eBOOK	53,612
Chronological Scientific Tables Premium	

Database

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



Number of searching database (by year)

2. JAXA Repository

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

In April 2015, we conducted system migration for the Repository and started operation at the site listed below.
https://Repository.exst.jaxa.jp/dspace/

Since the JAXA Repository was established in 2009, ISAS has registered over 1,000 items each year to increase the number of resources. The Repository plays an important role as a store of useful information.

JAXA Repository / AIREX

From 2013, the Repository has been used to share achievements presented at symposiums organized by ISAS. Now, the full text of most presentations at symposiums organized by ISAS is available in the Repository, and the Repository is used as online proceedings.

From last year, registration to the Repository and receipt for posting data have been performed online using a symposium system capable of providing online guidance for the holding of symposiums and registration of participants. This resulted in increased registration for data of symposiums held by ISAS and increased usage.

Access to the JAXA Repository in 2015 increased three-fold compared to the previous year. Furthermore, statistical results show frequent access to materials published by JAXA. This indicates increased interest in the research results of JAXA.

In response to these trends, we created the “JAXA Publications” and “Symposiums/Research Society” pages in 2015. This has increased the convenience of the JAXA Repository and made it possible to further advertise our research results.

We also continue to register papers from peer-reviewed academic journals and to accept request registrations every year. In the future, we will work toward increasing the amount of available text data, including papers from academic journals (based on copyright policy of academic societies, the copyrighted versions or publishing company versions will be registered), and to improve the convenience of search and browse functions.

Ⅸ. Publications, Presentations and Patents

The academic research achievement by ISAS researchers in FY 2015 are shown below.

Summary of Publications

Item	Achievements
1. Publications on Web of Science	
1) Papers in prestigious academic journals using ISAS satellites	1 in Nature
2) Number of heavily cited papers (Co-author includes ISAS staff)	51
3) Rate of international collaboration	Average of research fields: 52% (from 2003 to March 2016)
4) Reviewed papers published in journals (2015)	298
2. JAXA Publications (in ISAS)	10 (RR:3, RM:4, SP:3)
3. Journals, publications, etc.	
a. Published in a book	9
b. Published in reviewed journals	316
4. Presentations at domestic and international meetings, etc.	Keynote speeches: 15 Invited lectures: 77 Domestic meetings: 566 International meetings: 468
5. Awards	p.75
6. Patents	Published patent applications: 16 Patents granted: 14