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Annual Report of the Institute of Space and Astronautical Science 2017

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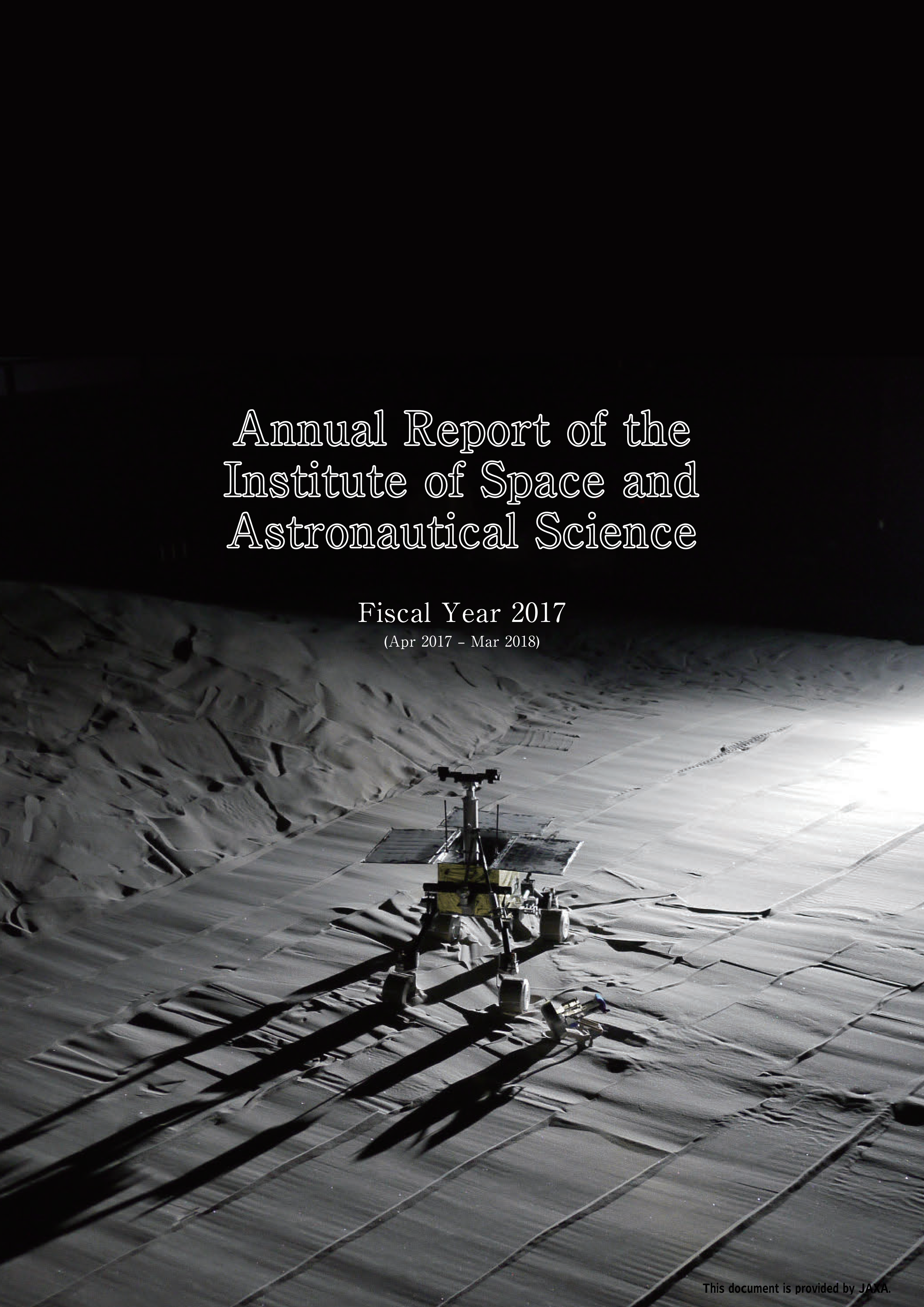


Annual Report of the Institute of Space and Astronautical Science

Fiscal Year 2017

(Apr 2017 - Mar 2018)

Message from the Director General

Hitoshi Kuninaka
Director General
Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency

The Institute for Space and Astronautical Science (ISAS) has continued to take on challenges in new domains related to aircraft, rocketry, high-altitude atmospheric observations, astronomical satellites and planetary exploration, while also revamping our organizations, members and jurisdiction. As a national research and development agency, central to our plans is to elucidate "the beginning of the universe and the structure formation from galaxies to planets" and "the origin of the solar system and life". We will attempt to explain the 13.7 billion-year history of the universe by performing observations at wavelength ranges that are absorbed by Earth's atmosphere--gamma-rays and X-rays, ultraviolet and infrared light, and radio waves, by integrating this data and in collaboration with ground telescopes. In the coming decade, we will send probes directly to other objects in our solar system, which will constitute a "JAXA Deep Space Exploration Fleet" from Mercury to Jupiter. With in situ observations and sample returns to investigate the substances that constitute them, the fleet will explore as well as elucidate the evolutionary processes that have occurred over 4.6 billion years in our solar system. While examining and reviewing the achievements of the JAXA Deep Space Exploration Fleet, we will innovate “the space engineering technology related to spacecraft and space transportation systems".

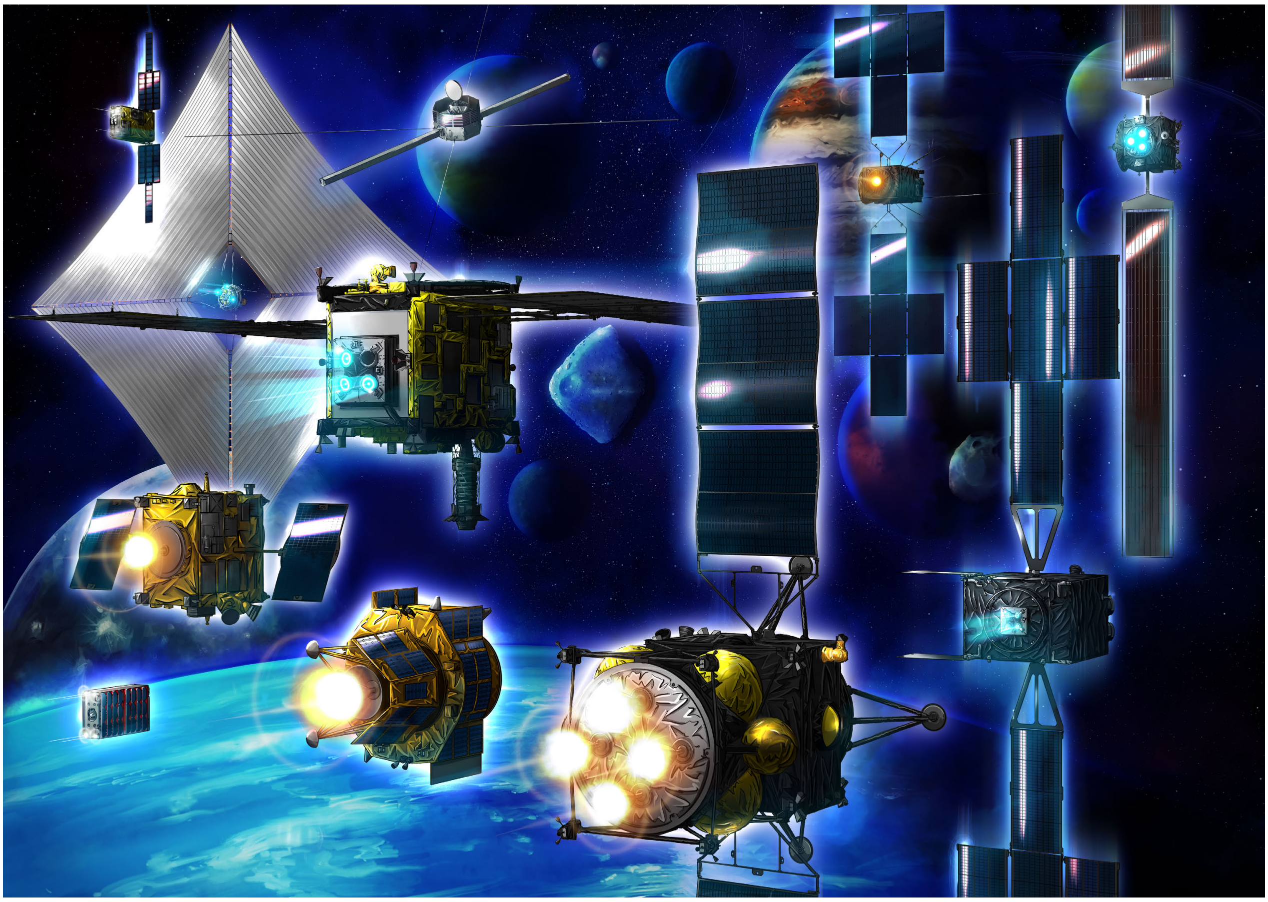
Space projects are enormous tasks and require painstaking detail. To ensure project success and maximize the scientific achievements, ISAS first and foremost acts as an inter-university research institute. Through this bottom-up process, we can consolidate ideas, knowledge skills and human resources from universities throughout Japan. In this way, ISAS encourages free and vigorous discussions that integrate science and engineering and builds consensus for mission planning. Taking ultimate responsibility, ISAS defines roles and responsibilities among participating organizations and takes the lead in system development and space mission operations to enable better performance.

International collaboration has been dramatically enhanced over the past decade. Accomplishments of ISAS have earned respect throughout the world, garnering sufficient recognition to be invited for participation in joint international projects. As these missions become increasingly large and complex and as they extend into ever-deeper regions of space, strategic provision of Japanese expertise will aid in the realization of Big Science projects that cannot be achieved through the efforts of any one country alone.

To implement our policies of making scientific results accessible to an inquiring society, ISAS actively publishes scientific data acquired through our space activities and continues to put effort into developing systems and mechanisms so that a broader array of users can access this data. Furthermore, we strive to implement ground-based engineering technologies with high affinity for social activities.

This annual report is a summary of ISAS activities in fiscal 2017, including data archiving, achievements of projects both in operation and under development, the status of future mission candidates and more exploratory research activities. We appreciate your understanding of ISAS activities and look forward to your continued guidance and encouragement.

September 2018


JAXA Deep Space Exploration Fleet

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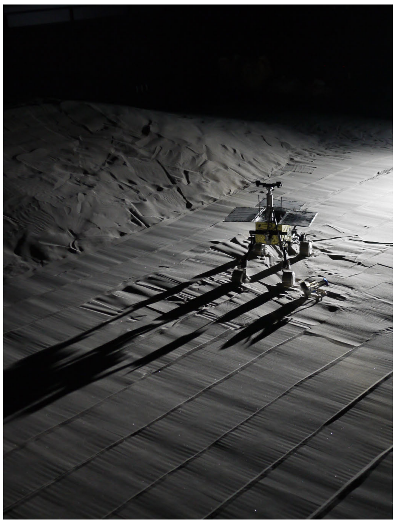
ON THE COVER

<Intelligent Lunar or Planetary Rover "Micro6" and small hopping rover "LEV">

This picture shows experiments carried out using the exploration rover "Micro6" on the exploration field at the JAXA Space Exploration facility. Micro6 is the sixth-generation test-bed rover for exploration experiments on the ground. Micro6 rover has intelligent functions, such as high mobility, AI, environment recognition, SLAM, path planning, autonomous navigation and sample collection, etc.

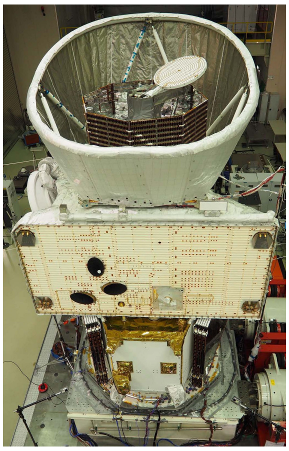
The small hopping rover "LEV" is a new type of mobile robot that is capable of moving a few meters by a hopping motion on the surface of a relatively heavy gravity body, such as the moon and Mars.
"LEV" controls direction by the rotation of one wheel and can hop on planetary regolith with energy stored in springs.



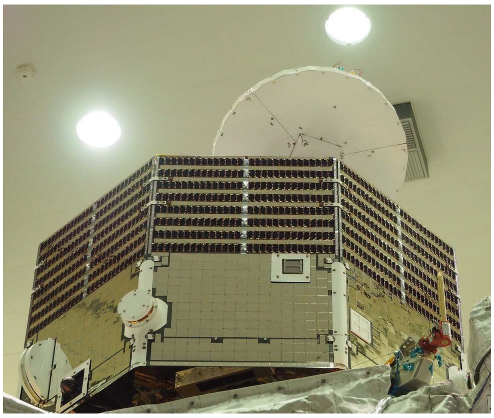
ON THE BACK COVER

<BepiColombo/MMO: Scheduled to launch in Oct 2018>

BepiColombo is the first in-depth cooperative mission between Japan and the European Space Agency (ESA), and JAXA's Mercury Magnetosphere Orbiter MMO will be launched in Oct 2018.



MMO during the environmental test performed at ESA/ESTEC. Sine vibration test for the MCS (configuration of BepiColombo during cruise). The MCS is on the shaker for lateral vibration. The bottom square part of MCS is the MTM (Electrical propulsion module). The middle rectangular part is the MPO (Mercury Planetary Orbiter). The MMO is located at the top of the MCS. The white cone surrounding the MMO is the sunshield.



MMO seen from diagonally below.

[See p. 36 for details]

I

Scientific Highlights in FY2017

1 Origin of Pulsating Aurora – Energetic Electrons Scattered by ‘Chorus’ Waves

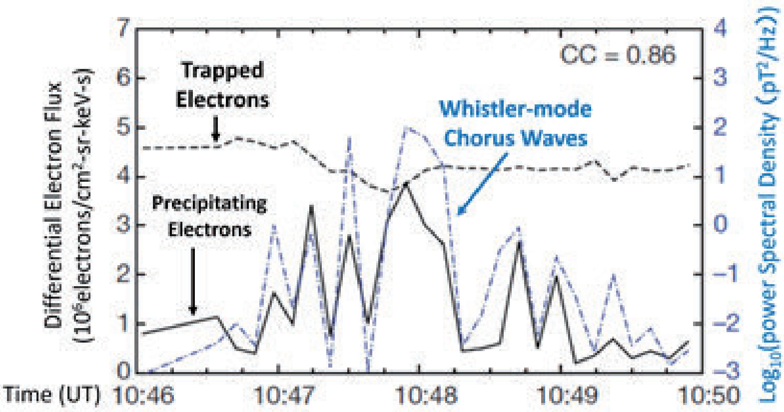
【Geospace Exploration Satellite ARASE (ERG)】

Earth’s pulsating aurorae, the quasi-periodic flickering of auroral patches with periods of a few to tens of seconds, are generated by intermittent precipitation of energetic electrons of several to tens of keV into the Earth’s upper atmosphere. A promising hypothesis to explain such precipitation is the interaction between magnetospheric electrons and a certain class of electromagnetic plasma waves called ‘whistler-mode chorus waves’.

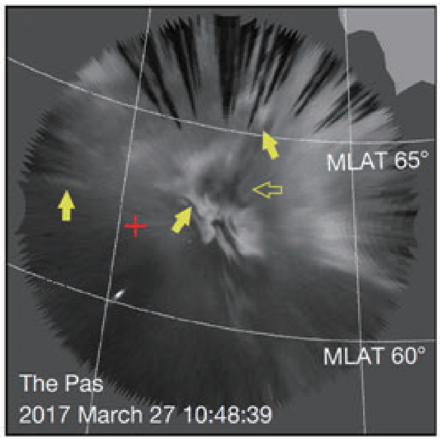
Magnetospheric electrons are usually trapped in the geomagnetic field, reaching the upper atmosphere only when they are scattered into the loss cone by the wave-particle interaction with plasma waves. However, simultaneous detection of whistler-mode chorus waves and electrons scattering into the loss cone has not been achieved. Therefore, the underlying physical prosses of pulsating aurorae has so far not been verified through observation. With the advent of the “ARASE” satellite with advanced measuring tools, we were able to identify the first clear evidence of energetic electrons being scattered by ‘whistler-mode chorus waves’ and of the resultant electron precipitation taking place.

The observations were enabled by the medium-energy electron analyzer (MEP-e) with a high angular resolution (3.5 degrees). On March 27, 2017, auroral pulsations were observed using ground-based auroral all-sky images of the THEMIS mission when a magnetic storm with auroral substorm characteristics developed. Auroral images showed On/Off pulsating auroral patches. Simultaneously, the footprints of the “ARASE” satellite passed through the wide area where the pulsating aurorae were observed. The observed precipitating electron flux within the ‘loss cone’ by MEP-e was sufficient for generating visible aurora. Our results show definitively that pulsating aurora is caused by the electromagnetic interaction between chorus waves and electrons of several to tens of keV in the near-equatorial region.

This achievement is supported by the ERG science center managed through an inter-institution collaboration between the Institute for Space-Earth Environmental Research at Nagoya University and Institute of Space and Astronautical Science (ISAS). Joint research based on satellite and ground-based observations has been made smoother and easier thanks to observation planning and the management of scientific data by the ERG science center.



Correlations between electron flux of 24.5 keV and wave power spectral density at 0.64 kHz. The solid black line shows the modulation of the precipitating electron flux and the dashed black line indicates the trapped electron flux outside the loss cone. The dash-dotted blue line shows the wave magnetic field power spectral density. The electron energy and the frequencies of the power spectral density were selected according to the resonance condition.

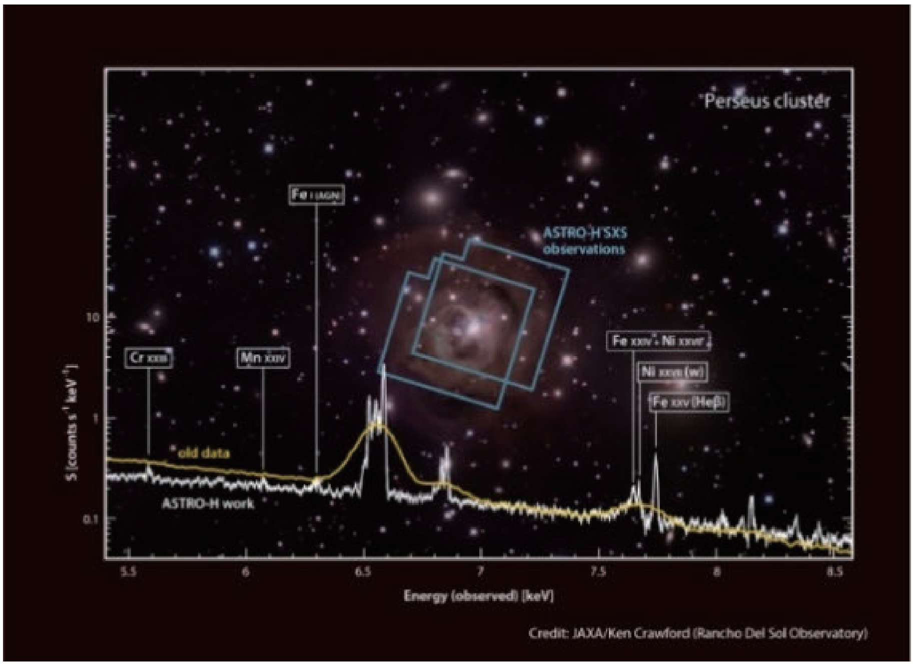


An auroral image around the footprint of “ARASE” . Distinct pulsating patches are indicated by yellow arrows. The filled and open arrows correspond to pulsations that are On and Off respectively. The red cross shows the footprint.

- S. Kasahara *et al*.. Pulsating aurora from electron scattering by chorus waves. *Nature*, Vol. 554(7692), 337-340 (2018) doi: 10.1038/nature25505
- Joint Press Release by JAXA, University of Tokyo, Nagoya University, Kanazawa University, and Tohoku University. February 15, 2018.

2 Chemical Composition of Hot Gas in the Perseus Cluster Observed by ASTRO-H

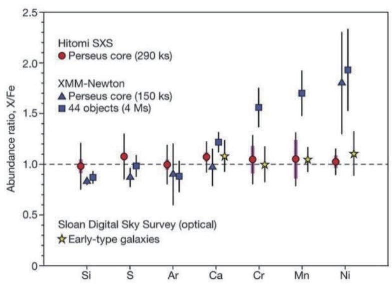
【X-ray Astronomy Satellite ASTRO-H (HITOMI)】



X-ray spectra observed by ASTRO-H SXS. The weak emission lines of chromium, manganese, iron and nickel are significantly detected.

Observations made by the Soft X-ray Spectrometer (SXS) mounted on the X-ray astronomical satellite ASTRO-H (HITOMI) show that the proportions of iron-peak elements in the Perseus cluster are nearly identical to those measured in the Sun, unlike previously believed. The study provides new insights into the mechanism of Type Ia supernova explosions, which are thought to be the major producers of the iron-peak elements. The team analyzed data from the center of the Perseus cluster observed by ASTRO-H and successfully estimated the abundances of the iron-peak elements in the hot intra-cluster gas. The unprecedented high-energy resolution of SXS, jointly developed by US National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA) and their partners in Europe, enabled the detection of weak emission lines of the various heavy elements in the X-ray spectrum. Their analysis showed that the abundance ratios of silicon, sulfur, argon, calcium, chromium, manganese, iron and nickel are all same as those of the Sun despite these abundance ratios being believed to be higher than the solar value. Since Type-Ia supernovae, occurring in the galaxy polluting the cluster hot gas are thought to be responsible for producing the majority of the iron-peak elements, including chromium, manganese, iron and nickel, the results indicate that characteristics of the explosions of Type Ia supernovae are similar, irrespective of the types of their host galaxies (spiral, elliptical or S0) with different chemical enrichment histories. This overturns previously claimed results with less significance that argued the abundance of the iron-peaked elements in the cluster hot gas was different from that of the solar neighborhood.

Comparison of the observed results with chemical synthesis models of supernovae supports that the mass of the progenitor white dwarves is comparable to the composition of those around the Chandrasekhar mass (1.4 times the solar mass) and those with sub-Chandrasekhar mass.



SXS observation results show that the relative abundance of the iron-peaked elements, considered to be produced by Type Ia supernovae explosion is similar to the Solar abundance.

- Hitomi collaboration. Solar Abundance Ratios of the Iron-Peak Elements in the Perseus Cluster. *Nature*, Vol. 551, 478-480 (2017) doi:10.1038/nature24301

3 Discovery of Equatorial Jet in Venus' Atmosphere

【Venus Climate Orbiter AKATSUKI (PLANET-C)】

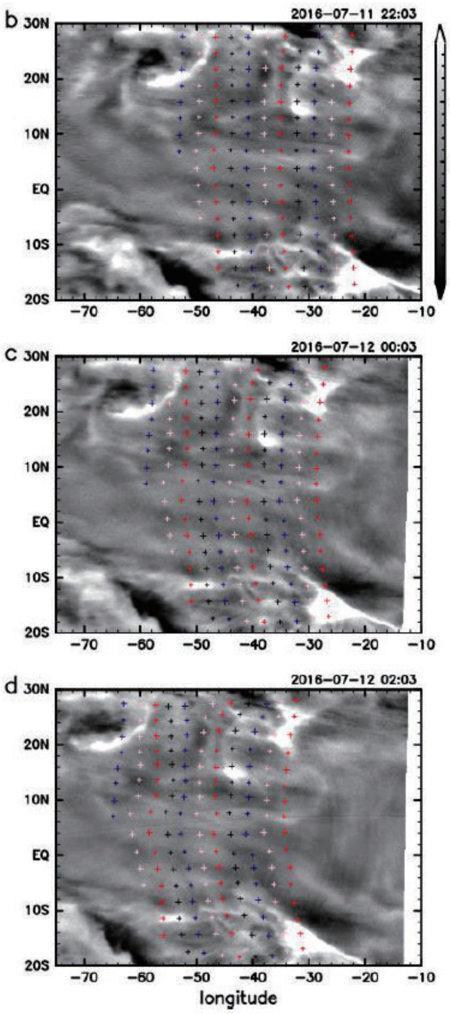
Although Venus is known as the sister planet of the earth, there are many differences in surface environment and it is remarkable that the Venusian surface is not habitable at all. To know the Venusian atmosphere is to know the condition which might have been the environment of the earth with some slight differences.

In the study of atmospheric dynamics of planets and satellites, super rotation (SR) of the Venusian atmosphere (a phenomenon where wind speed increases from the ground to the top of the clouds at an altitude of approximately 70 km and reaches 60 times faster than ground speed) is one of the most mysterious phenomena. The most important task of AKATSUKI is to explain this phenomenon and conduct precise measurement of wind velocity vectors from the orbit.

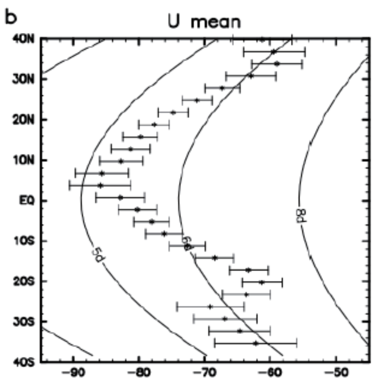
By measuring wind field with images obtained from the 2 μm camera (IR2), it was found that wind in the lower to middle cloud layer (altitude 45 - 60 km) flowed like a jet located around the equator at a specific time in 2016, causing the researchers to name it the "equatorial jet". So far, the wind velocity in this altitude range has been considered to have high horizontal uniformity and only small temporal variation. However, the existence of unexpectedly large fluctuations has been discovered for the first time based on a study using observational data from AKATSUKI.

This result was achieved with support from the three "world first scenarios", (1) Unlike conventional Venus orbiters, AKATSUKI has an equatorial orbit suitable for the observation of atmospheric motion (2) Cameras on-board AKATSUKI are optimized for the observation of atmospheric motion (3) The successful development of a cloud tracking method enabling high-precision wind velocity determination.

We do not yet have a simple mechanism to explain the equatorial jet, however the discovery of the equatorial jet is expected to provide valuable hints (because the equator is the farthest from the rotation axis, decelerating is a natural consequence of atmospheric parcels transported from higher latitudes due to conservation of angular momentum and the cause of accelerating this region is limited). By incorporating the formation of the equatorial jet into theories and numerical simulations it is expected to reveal the mystery behind the SR mechanism.



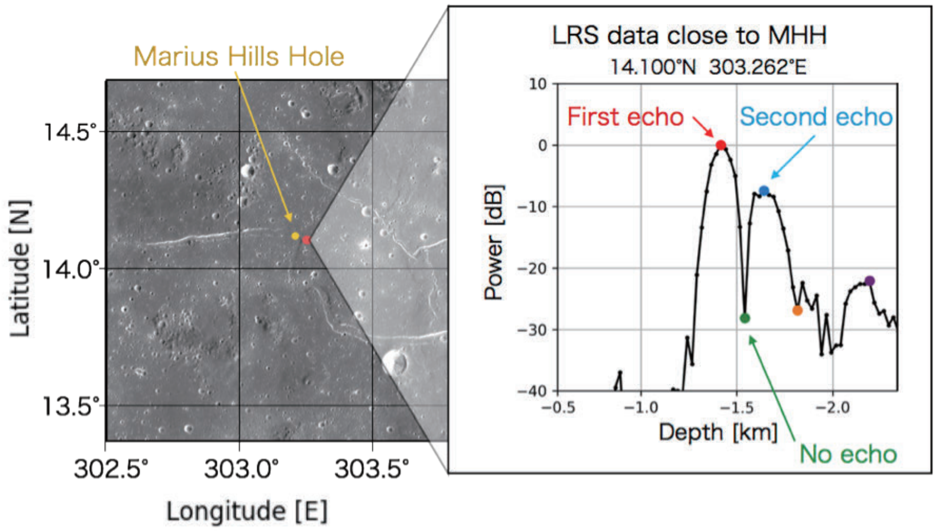
The three panels on the left are Venus night side images (IR 2, every 2 hours) acquired on July 11 - 12, 2016. Based on the wind velocity vectors obtained by analyzing the images, cloud flow and deformation are indicated with colored dots. You can see how the equator region is gradually bending toward the left (direction of super rotation). Below is a latitudinal profile of wind velocity obtained by averaging the wind velocity vectors on the latitude/longitude grid in the longitudinal direction, showing strong equatorial acceleration (jet) for the first time.



- T. Horinouchi *et al*.. Equatorial jet in the lower to middle cloud layer of Venus revealed by AKATSUKI. *Nature Geoscience*, Vol. 10, 646-651 (2017) doi:10.1038/ngeo3016
- Joint Press Release by JAXA and Hokkaido University. August 29, 2017.

4 Detection of a Huge Intact Lava Tube Underground along a Lava Flow River "rille" on the Marius Hills of the Moon

【SELenological and Engineering Explorer SELENE (KAGUYA)】



LRS data (right panel) close to Marius Hills Hole (left panel). The background of the left side panel is an image from the SELENE TC. In the right side panel, the received echo power precipitously decreased ("No echo" point indicated by the green point), prior to the second echo peak indicated by the blue point. This echo pattern implies the existence of an underlying cave, such as a lava tube.

Lunar lava tubes, or subsurface caves formed by lava flows, are important from the perspectives of both science and human exploration. If they exist, they may prove to be optimum candidate sites for future lunar bases due to stable thermal conditions and their potential to protect people and instruments from micrometeorites and cosmic ray radiation. The same stable and protected environment that would benefit future human explorers also makes them an enticing scientific target: original lava compositions, textures and even magmatic volatiles are expected to be preserved in pristine condition within these lava tubes. Careful examination of their interiors could provide unique insights concerning the evolutionary history of the Moon.

In 2009, large, deep vertical holes were discovered at Marius Hills, Mare Tranquillitatis and Mare Ingenii using lunar surface image data acquired by the high-resolution Terrain Camera (TC) onboard SELENE (KAGUYA). Later, higher resolution nadir and oblique angle observations performed by the Lunar Reconnaissance Orbiter Narrow Angle Camera confirmed that the floor of the holes extends at least several meters eastward and westward under the ceiling. The three biggest holes on the Moon are possible skylights opening into an ample space. However, whether these large spaces are subsurface lava tubes is still unknown.

In 2017, the Lunar Radar Sounder (LRS) onboard SELENE consisted of two sets of dipole antennas transmitting electromagnetic (4-6MHz) waves and receiving echoes from the Moon. We used radar echo data from the LRS to investigate the existence of underground lava tubes at Marius Hills (see the figure below).

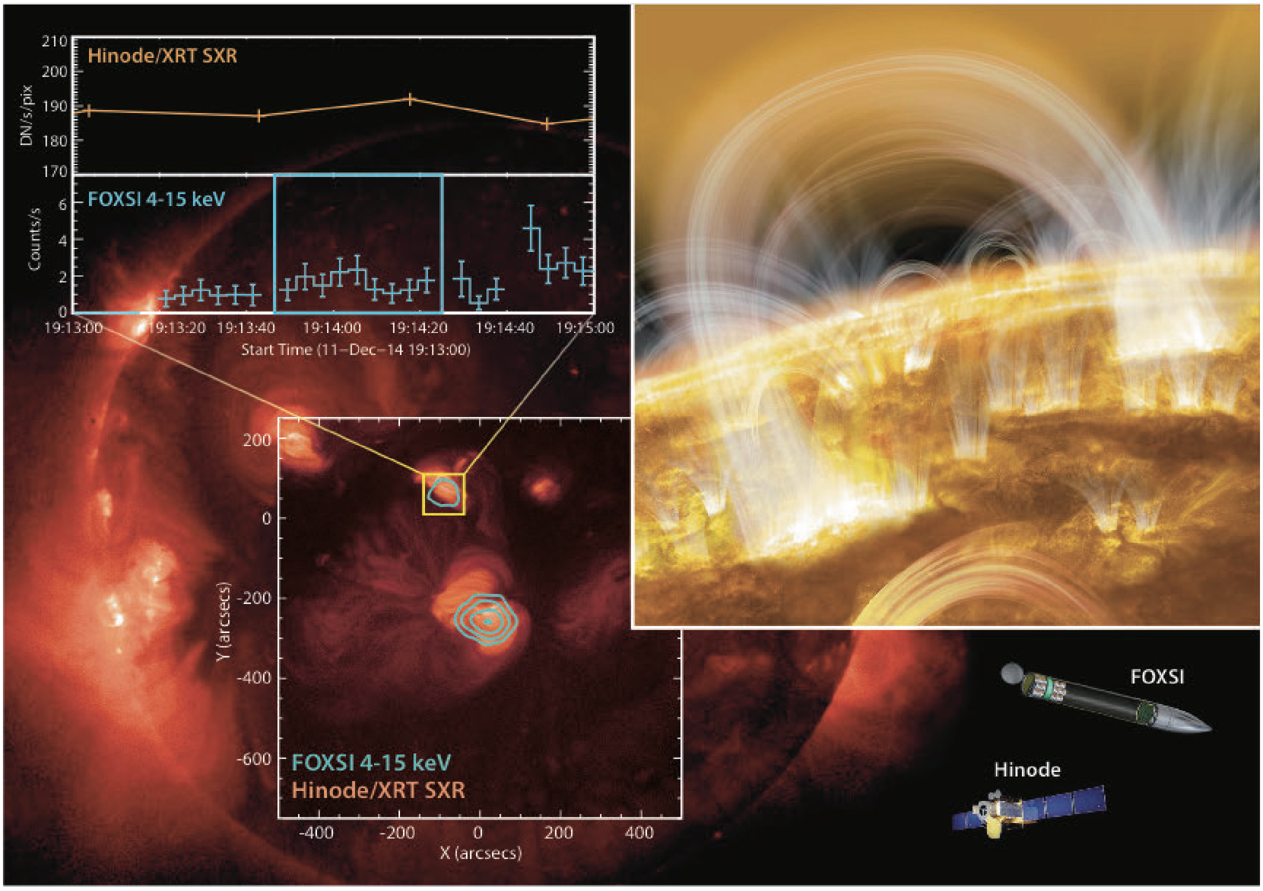
In this study, we identified candidate sites for the presence of significant intact lava tubes. These sites are intriguing from a scientific perspective and may offer potential sites for future lunar base construction around the Marius Hills Hole.

In the future, we will expand our search to other regions on the Moon where additional subsurface lava tubes may be present. We will also continue to investigate the origin and history of known candidate lava tubes using composition, topography and magnetic field data to direct future exploration of lava tubes or lunar base construction.

- T. Kaku *et al.*. Detection of Intact Lava Tubes at Marius Hills on the Moon by SELENE (Kaguya) Lunar Radar Sounder. *Geophysical Research Letters*, Vol. 44 (20), 10, 155-10, 161 (2017) doi: 10.1002/2017GL074998

5 Hidden Solar Nanoflares Revealed by a Coordinated FOXSI Sounding Rocket and HINODE Observation

【Solar Observation Satellite HINODE (SOLAR-B)】



The time variation (upper left) and image (lower left) of X-rays from an active region, from FOXSI and HINODE observations. The upper right figure shows an artist impression of an active region producing nanoflares.

A coordinated observation combining a FOXSI (Focusing Optics X-ray Solar Imager) sounding rocket experiment and the HINODE solar observatory revealed extremely hot plasma higher than 10 MK, i.e., subtle signs of nanoflares (tiny flares), in a region of the solar corona where no discernible flare activity was taking place.

The frequent occurrence of very tiny flares, so-called nanoflares, is one of several hypotheses for possible mechanisms of coronal heating. Due to lack of sensitivity, there was no observation that conclusively showed the presence of such very hot plasmas.

The second FOXSI sounding rocket for hard X-ray observation of the Sun was successfully carried out on December 2014. FOXSI was realized through a combination of a semi-conductor X-ray imaging detector of low-noise and fine pixel pitch developed in ISAS with NASA's X-ray optics. Thanks to this collaboration, FOXSI was able to observe weak hard X-ray signals (>3 keV) from very hot (exceeded 10-million Kelvin) plasmas in a region of the solar corona where no discernible flare activity was taking place.

By analyzing data from FOXSI and HINODE XRT, the researchers were able to estimate, with high accuracy, the temperature structure of the corona for the region observed.

It became clear that, albeit in small amounts, very hot (>10-million K) plasmas existed. This result strongly suggests the occurrence of nanoflares even in a region without apparent flaring activity.

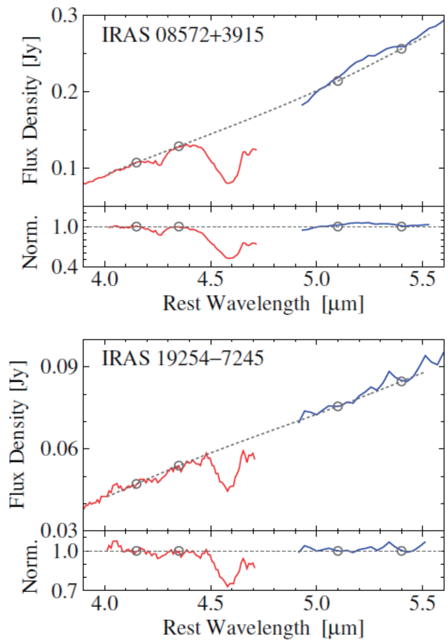
- S. Ishikawa et al.. Detection of nanoflare-heated plasma in the solar corona by the FOXSI-2 sounding rocket. *Nature Astronomy*, Vol. 1, 771-774 (2017)
doi:10.1038/s41550-017-0269-z
- Joint Press Release by JAXA and NAOJ. Oct 10, 2017.

6 Absorbing Material Around Active Galactic Nuclei Observed with AKARI (ASTRO-F)

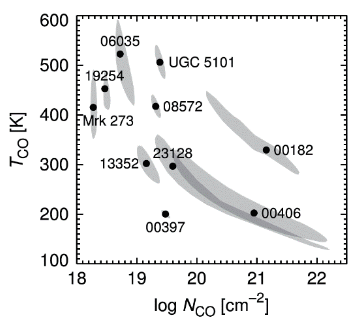
【Infrared Astronomical Satellite AKARI (ASTRO-F)】

In order to reveal the nature of the molecular torus around active galactic nuclei (AGNs), we observed the 4.7 micron carbon-monoxide (CO) absorption band spectra toward several AGNs with AKARI. We detected warm (200-500 K) gas with large column densities and attributed this component to the molecular tori that surround supermassive black holes.

The near-infrared spectra in the rest-frame wavelength range of 4.0-4.7 micron of several local AGNs observed with IRC aboard the AKARI satellite were analyzed for the CO fundamental ro-vibrational absorption band (Approx. 4.67 micron). The continuum level at the longer wavelength side, not covered by the AKARI wavelength coverage, was estimated based on spectroscopic observations conducted with the Spitzer space telescope. From a gas model fitting, the observed CO absorption band profiles were found to originate from large columns of warm gas (hydrogen column densities of $N_H > 10^{23}$ cm^{-2} and gas temperatures of 200-500 K). Such large-column-density cannot be heated to the observed temperature by ultra-violet photon heating or shock wave heating and is probably being heated by X-ray photons. This result suggests the existence of putative molecular tori around supermassive black holes and that the gas clouds in the tori are heated by X-ray radiation from the central engine of AGNs.



Infrared spectra of AGNs. Red and blue lines denote the spectra obtained with AKARI and Spitzer respectively. The CO absorption band is observed around 4.6-4.8 micron.



The CO column density and gas temperature derived using gas model fitting analysis. Each point and the accompanying shaded area show the obtained parameter values and their uncertainties respectively.

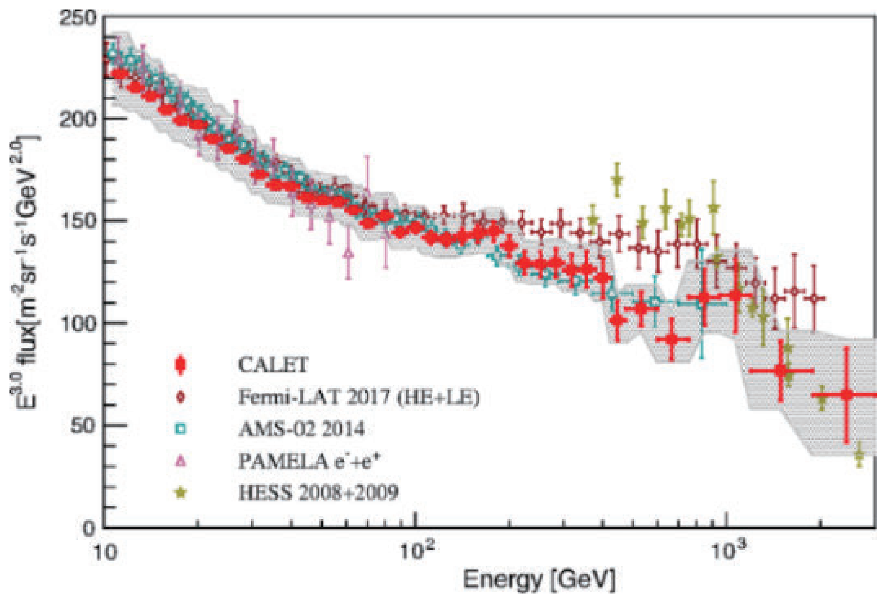
- S. Baba, T. Nakagawa, N. Isobe, & M. Shirahata. The Near-infrared CO Absorption Band as a Probe to the Innermost Part of an AGN-obscuring Material. *Astrophysical Journal*, Vol. 852(2), 83 (2018) doi:10.3847/1538-4357/aa9f25

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

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

The CALorimetric Electron Telescope (CALET) aims to reveal the acceleration and propagation mechanisms of cosmic rays to identify nearby cosmic-ray accelerators and to detect dark matter through observations of high-energy cosmic rays. The main mission instrument is a calorimeter, consisting of a charge detector and imaging and total absorption calorimeters. CALET is also equipped with a gamma-ray burst monitor. CALET was developed by an international team from Japan, the USA and Italy and was installed on Japan's external experiment module Kibo in August 2015.

Cosmic ray and gamma-ray burst data have been steadily accumulated since CALET transitioned to normal observations in January 2016. Based on the analysis of data observed over nearly 1.7 years, CALET obtained the first result of the cosmic-ray electron and positron spectrum. Nearly half a million events identified as electrons or positrons were used. The measured energy spectrum ranges in a wide kinetic energy range from 10 GeV to 3 TeV. The observed energy spectrum over 30 GeV can be fit with a single power law and is comparable to recent results from other experiments, such as the Alpha Magnetic Spectrometer (AMS) -02, the Fermi Gamma-ray Space Telescope and the Dark Matter Particle Explorer (DAMPE). In the highest energy region above 100 GeV, the obtained spectrum shows possible structures, although they are yet within the errors. CALET will accumulate more data to investigate them in more detail with increased statistics and refined data analysis.



Cosmic-ray electron and positron energy spectrum measured by CALET from 10 GeV to 3 TeV (red points). Physical Review Letters, Vol. 119, 181101.

- O. Adriani *et al*.. Energy Spectrum of Cosmic-Ray Electron and Positron from 10 GeV to 3 TeV Observed with the Calorimetric Electron Telescope on the International Space Station. *Physical Review Letters*, Vol. 119, 181101 (2017) doi:10.1103/PhysRevLett.119.181101

8 Sable Levitation of Extremely High Temperature Oxide Melt in Microgravity Established Using the ISS-ELF

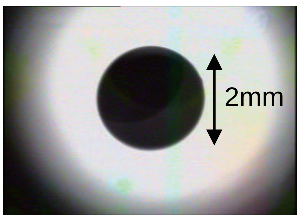
【Electrostatic Levitation Furnace Onboard the International Space Station Kibo (ISS-ELF)】

A molten erbium-oxide sample levitated in the ISS-ELF.

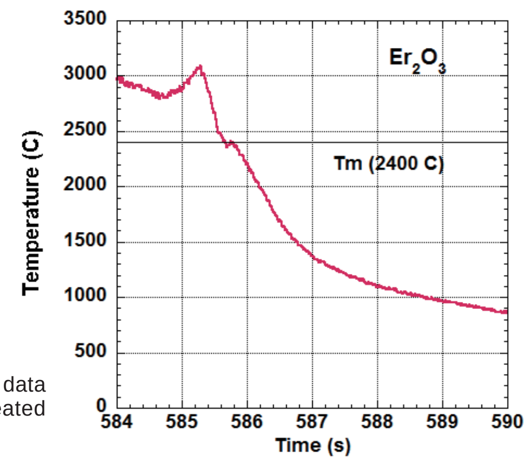
Oxide samples with melting temperatures greater than 2,000 degrees Celsius have been stably levitated and melted in the electrostatic levitation furnace onboard the International Space Station. Sample position is controlled even when the sample temperature reaches over 3,000 degrees Celsius, which is sufficient for the scientific observation of and thermophysical property measurements of extremely high temperature melts.

Due to their high melting temperature and the risk of chemical reactions between containers, oxide samples such as alumina are hard to melt with conventional method using crucibles. Therefore, research on liquid oxides is very limited. An electrostatic levitation method utilizing Coulomb force between a charged sample and surrounding electrodes has made it possible to achieve container-less processing and circumvent the above-mentioned problems. The electrostatic levitation furnace in the International Space Station (ISS-ELF) has been developed to process oxide samples under microgravity conditions.

ISS-ELF has been operational since 2016. Several oxide samples (i.e. erbium oxide) with a melting temperature above 2,000 degrees Celsius have been successfully melted in the facility. A precise and stable sample position control has been established in ISS-ELF which enables thermophysical property measurements and new functional material synthesis.



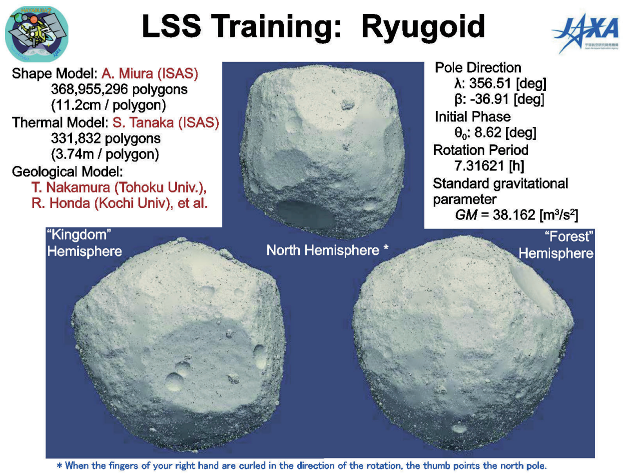
A molten melt becomes a perfect sphere due to its surface tension.



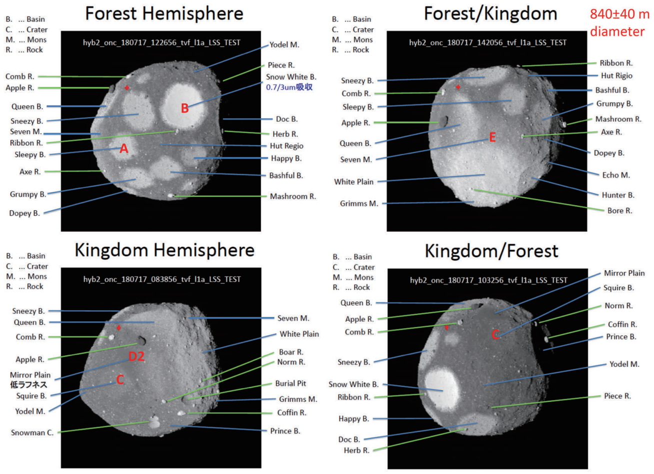
Recorded sample temperature data proves that the sample was heated over 3,000 degrees C.

- H. Tamaru *et al*.. Status of Experiments in the Electrostatic Levitation Furnace (ELF) for the ISS-KIBO. *7th International Symposium on Physical Sciences in Space* (ISPS-7) (2017)

9 Modeling and Visualization of Virtual Asteroids for Asteroid Exploration Training



Shape Model of the Asteroid Analog 'Ryugoid'



Simulated Images of Ryugoid with Notations for LSS Training (S. Watanabe et al., 2017 The Japanese Society for Planetary Science Fall Meeting, H16, September 2017)

The C-Type asteroid sample return mission, Hayabusa2 will attempt to probe the asteroid 162173 'Ryugu' from the summer of 2018 through 2019. In the period of the rendezvous with Ryugu, various critical operations are expected to be performed.

In order to increase reliability in various critical operations, Real-time Integrated Operation (RIO) training has been held since the first quarter of 2018. On the other hand, for example, in order to select landing sites for Hayabusa2 on Ryugu, scientists have to survey the asteroid in detail and consider a variety of conditions on the fly. In preparation for such occasions, we have also conducted Landing Site Selection (LSS) training.

When such training began, details of the asteroid were not yet known. Nevertheless, it was essential to simulate optical instruments on board Hayabusa2. For such simulations, precisely configured virtual asteroids and precise visualization are required.

To model the virtual asteroids that satisfy the requirements derived from the training, modeling software has been developed based on the knowledge of both scientists and engineers in related fields.

Several models with different resolutions were prepared so that suitable models can be selected for the respective training. Some of the models are provided with geological maps based on the knowledge of planetary geology or thermal maps based on supposed observation programs and thermal conditions.

In regard to visualization, in order to satisfy the requirements, including quality and latency, rendering software has been developed based on ray tracing with spectral radiance calculation. Low-latency rendering is performed using coarse shape models and simplified algorithms to calculate the radiance. Precise rendering is performed using fine shape models with approximately 400 million polygons and complex algorithms to calculate the spectroscopic radiance of the models. The software also includes algorithms to map geological attributes and thermal distributions, etc.

It has been proven that these methods satisfy ongoing training for Hayabusa2. They are also applicable to forthcoming missions in the future.

- Y. Takei, T. Takahashi, T. Yamaguchi, T. Saiki, A. Miura, H. Takeuchi, Y. Tsuda. A Hardware-in-the-loop simulator for deep space touchdown operation training of Hayabusa2. *The 68th International Astronautical Congress (IAC)*. Adelaide, Australia. September 2017.
- S. Watanabe, Y. Ishihara, S. Tanaka, T. Yamaguchi, A. Miura, Y. Yamamoto, N. Hirata, T. Morota, N. Sakatani, K. Kitazato, K. Matsumoto, H. Yabuta, Hayabusa2 LSS Data Acquisition and Analysis Team. Dry run of the landing site selection for Hayabusa2: Data acquisition and analysis. *The Japanese Society for Planetary Science Fall Meeting*, H16. Osaka, Japan. September 2017.
- H. Yabuta, N. Hirata, R. Honda, Y. Ishihara, K. Kitazato, M. Komatsu, A. Miura, K. Matsumoto, T. Morota, T. Nakamura, A. Nakato, T. Noguchi, T. Okada, N. Sakatani, S. Sugita, S. Tachibana, S. Tanaka, E. Tatsumi, S. Watanabe, T. Yamaguchi, Y. Yamamoto, LSSAA Team (Hayabusa2 Project). Hayabusa2 landing site selection (LSS) training: Summary report of scientific evaluation. *49th Lunar and Planetary Science Conference*. The Woodlands, Texas. March 2018.

10 Development of Ceramic/Metal Brazed Thruster

Improving the performance of propulsion systems is one important issue in accomplishing a wide variety of future space exploration missions. Silicon nitride (Si_3N_4) ceramic thrusters have good heat resistance and a high specific impulse. They have been successfully used in space, in the Venus Climate Orbiter AKATSUKI 500 N-class main engine. However, because of ceramic shaping process limitations, such as forming and machining, the manufacture of larger size or thinner wall thrusters is difficult. This is limiting the design freedom needed to develop larger-scale and/or lighter-weight ceramic thrusters, holding back improvements to thruster performance.

To face this challenge, we have proposed to replace the ceramic thruster's nozzle, for which high heat resistance is not required, with a metal nozzle as shown in Figure 1(a). The metallic nozzle enabled us to increase the thruster size while decreasing its weight by reducing the thickness of the walls. Titanium (Ti) was selected as the nozzle material due to its superior corrosion resistance and high specific strength. This bi-material solution triggered the need for the development of a method to connect the metallic part to the ceramic combustion chamber.

Brazing, using a silver-based filler metal was considered as a means of connecting the Ti nozzle to the ceramic combustion chamber. Nevertheless, it resulted in ceramic chamber failures near the brazed joint, due to the important residual stresses created by a mismatch of the thermal expansion coefficient between the ceramic and the brazed metal. To understand this phenomenon, finite element analysis (FEA) was conducted to study the distribution of the residual stresses for a variety of design and brazing materials as shown in Figure 1(b) and 1(c). These analyses led to the development of an innovative method that reduces residual stresses by inducing plastic deformation in a soft buffer layer composed of pure niobium (Nb), combined with a gradual transition of wall thickness as shown in Figure 1b.

A 20 N-class ceramic/metal brazed thruster was successfully produced experimentally according to the joint design shown in Figure 1b. We also conducted combustion tests to evaluate the brazed thruster joint strength (Fig.2). Neither thruster failure nor combustion gas leakage was observed during combustion where the brazed area temperature reached over 600 degrees Celsius. As a result of this new development, we can now expect improvements in thruster performance in the future.

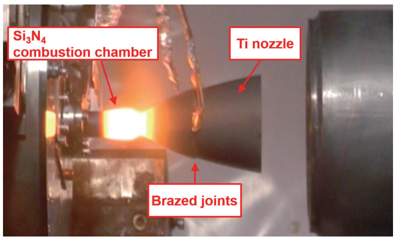


Fig.2 Image of the combustion test.

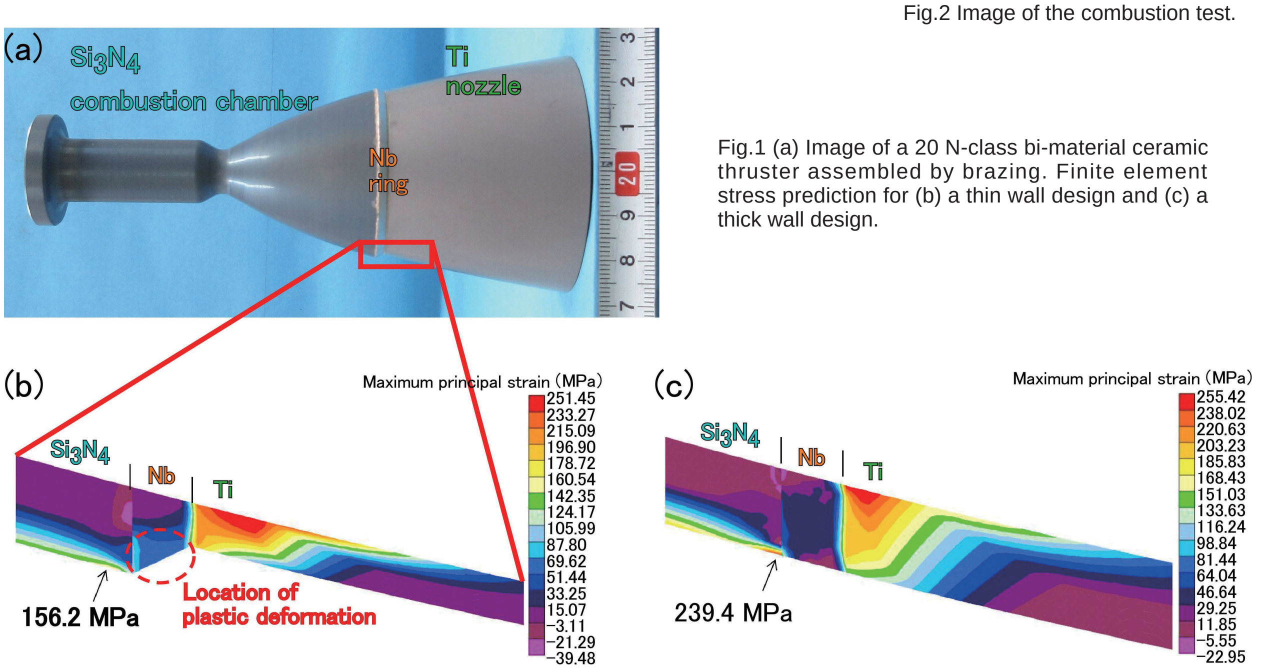


Fig.1 (a) Image of a 20 N-class bi-material ceramic thruster assembled by brazing. Finite element stress prediction for (b) a thin wall design and (c) a thick wall design.

- H. Tobe *et al.*. Evaluation of the Strength of Brazed Joints in Ceramics/Metal Thruster. *Aerospace Technology Japan*, Vol. 17, 97-103 (2018)

11 Crushable Shock Absorption for Versatile Landing Missions

【Cube-Sat Onboard SLS OMOTENASHI】

The crushable structure realizes not only chuteless landing on planetary bodies with an atmosphere, but also on airless ones by absorbing the landing shock energy, protecting the inner instrument modules against the landing shock within a prescribed deceleration level. The lunar semi-hard landing mission, OMOTENASHI, proposed by JAXA is selected for launch by NASA SLS in 2018. The present study shows the state-of-the-art technology development of the crushable shock absorption structure together with a design example for the small lunar semi-hard impact surface probe of OMOTENASHI.

Recently, target bodies of solar exploration have extended to distant heavenly bodies beyond the Mars and even to more distant ones. Because the overall mission duration tends to be longer and longer in such high-energy missions, reliability requirements for the subsystems become more severe.

The crushable structure realizes not only chuteless landing on the planetary bodies with an atmosphere, but also on airless ones by absorbing the landing shock energy, protecting the inner instrument modules against the landing impact shock within a prescribed deceleration level.

The compact probe for semi-hard impact landing forms one of the key technologies to accomplish such challenging exploration missions under small weight budget restraints. One of the important issues concerned with the semi-hard landing of compact probes is secure functional reliability of the subsystem and impact shock absorption.

In order to verify the validity of the analysis and identify other issues concerned with the crushable material, the landing impact tests are being carried out using the ballistic range at the JAXA Kakuda Space Center by impacting a small test model with onboard measurement systems onto the hard target. (Fig. 1) Measured impact data is then compared with the analytical predictions. One of the crushable materials together with the airbag subsystem have been selected for the landing shock-absorption system in the lunar semi-hard landing mission, OMOTENASHI, to be launched by NASA SLS in 2018 (Fig. 2).

Figure 3A and 3B show an example of acceleration and SRS (shock response spectrum) analysis at impact onto the target. Compared with the SRS of the half-sine wave with a frequency of 250 Hz, the norm of the deceleration exceeded it in the frequency range below 50 Hz, which is considered to be caused by the measurement offset drift around zero-G and is not essential to the spectrum analysis. The peak acceleration up to approximately 3,000 G is estimated around the frequencies from 400 to 500 Hz, which requires careful design or treatment for the onboard instruments because the resonant frequency of the instruments tends to lie in this frequency region.

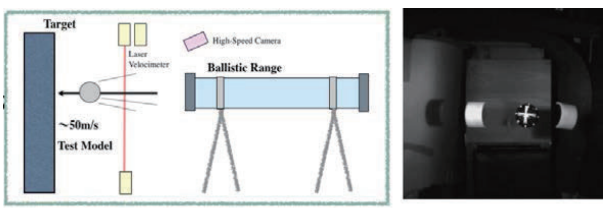


Fig.1 Schematics of impact tests at the ballistic range facility (left) and the dummy capsule just before impact taken by high-speed camera (center).

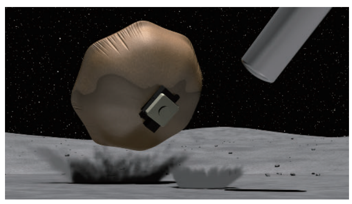


Fig.2 Artists' impression of semi-hard landing onto the lunar surface in the OMOTENASHI project.

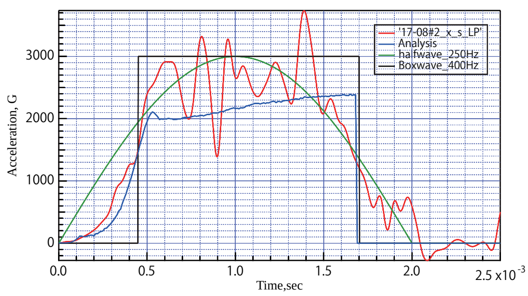


Fig.3A Impact shock acceleration (Approx. 1 ms) of the Urethane at a speed of 30 m/s onto the hard target was compared with the sine-wave and rectangular wave.

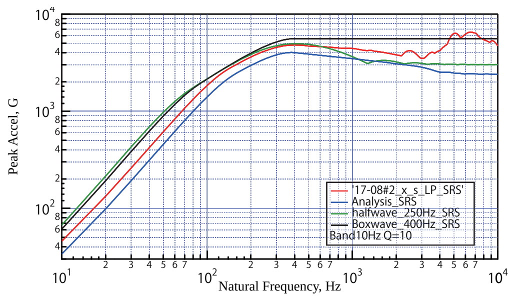
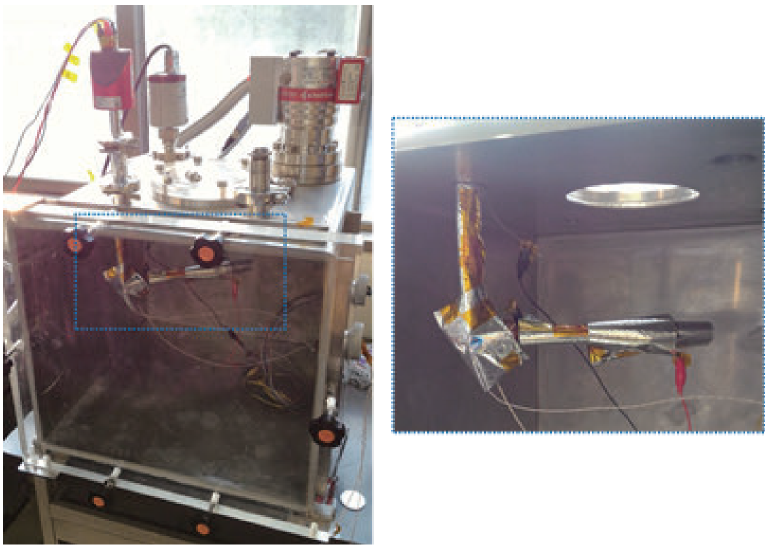


Fig.3B Impact shock response spectrum: Shock resonation is high in the higher frequency region beyond 400-500 Hz.

12 Development of Solid-gas Equilibrium Propulsion System for Small Spacecraft

A phase equilibrium propulsion system is a cold-gas jet in which the phase equilibrium state of the fuel is maintained in a tank and its vapor is ejected when a valve is opened. We proposed a solid-gas equilibrium propulsion system for use in small spacecraft as an extension of a gas-liquid equilibrium propulsion system. Compared to a gas-liquid system mounted on the IKAROS solar sail, the proposed system is less complex and has a much lower pressure, which is suitable for CubeSat-class spacecraft. Ejection experiments performed with a prototype system (see the figure below) using naphthalene revealed that the solid-gas equilibrium propulsion system enables continuous ejection (for more than twenty hours), which is not possible using a gas-liquid system. Moreover, the gas inside the fuel tank is basically maintained at the vapor pressure during ejection if a sufficient amount of fuel remains. As a result, the pressure can be controlled by temperature control and was demonstrated by heater control. During heater control, however, it takes some time for the pressure to increase, and this period of time should be properly understood before actually being used on any spacecraft.

For more accurate feedback control, we recommend measuring the temperature inside the tubes. Alternatively, the tank pressure should be fed back. Even if the pressure is increased, it is still low enough to be safe from the viewpoint of the structural strength of the tank and the piping system, which is a significant difference from the gas-liquid system and an advantage, especially in CubeSat-class spacecraft applications. The initial amount of fuel is one of the key factors because it determines the length of the solid-gas equilibrium phase and end-of-life phase. The solid-gas equilibrium phase dominates if the amount of fuel is large, however the phase may not be observed for a long time if only a small amount of fuel is prepared, especially if heater control is performed. This is an important factor in the system design. Another key factor is the viscosity of the vapor, which influences the gas flow and changes the practical throat area and must also be taken into account in system design. In addition, if a filter is inserted, the gas may choke at this point and a trade-off must be considered between the capability of holding the solid inside and the thrust level to determine the porosity size. Further studies will include other sublimable substances for fuel and evaluation of a flight model aimed at a specific space mission.



Photograph of the overall experimental setup (left) and the piping system (right).

- T. Chujo *et al*.. Development of Solid-gas Equilibrium Propulsion System for Small Spacecraft. *Acta Astronautica*, Vol. 140, 133-139 (2017) doi: 10.1016/j.actaastro.2017.07.050

13 Small Carry-on Impactor (SCI) for the Hayabusa2 Kinetic Impact Experiment

The Japanese asteroid explorer Hayabusa2 is now in operation. Hayabusa2 is the successor of HAYABUSA, which returned to earth from the asteroid Itokawa with sample materials. Data from HAYABUSA found that Itokawa is a rubble-pile body with macroporosity. However, no direct observational data on the internal structures and subsurface materials of the asteroid are available. One of the most important scientific objectives of Hayabusa2 is to investigate the chemical and physical properties of the internal materials and structures.

The small carry-on impactor (SCI) is a compact kinetic impactor and it is required to remove the asteroid surface regolith and create an artificial crater (Fig.1). After the impact experiment, the Hayabusa2 spacecraft will try to observe the resultant crater using scientific instruments and to retrieve sample materials from around the crater.

High kinetic energy (i.e. Approx. 2km/s impact speed and 2kg impact mass) is required for creating a useful crater on the asteroid. Traditional acceleration devices, such as rocket motors and thrusters can achieve such high impact speed. However, a large acceleration distance is required. This indicates that a guidance system is necessary if traditional acceleration devices are used and the weight and size of the impact system become large.

To overcome this problem, we adopted a special type of shaped charge to accelerate the impact head (Fig.2). By this means, the required period for acceleration is shorter than one millisecond, making it possible to crash into the asteroid.

The velocity, shape and flight direction error of the impact head were verified by ground flight tests. The long-range flight test of the full-size model was conducted twice (2011 and 2013). The velocity of the impact head was more than 2000 m/s and the flight direction error in each case was less than 1 deg. This confirmed that the performance requirements of the explosive part of the SCI were satisfied.

The proximity operation phase of Hayabusa2 will begin in the middle of 2018 and the impact experiment is scheduled for 2019.

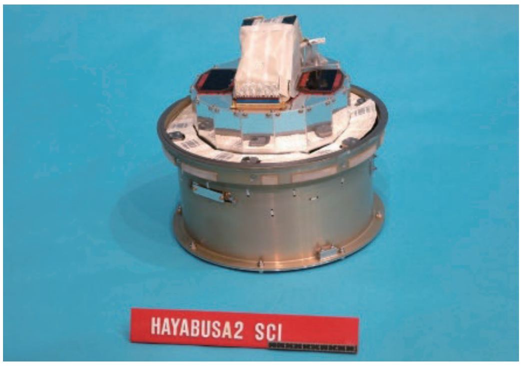


Fig.1 Small Carry-on Impactor. Weight is Approx.14kg.

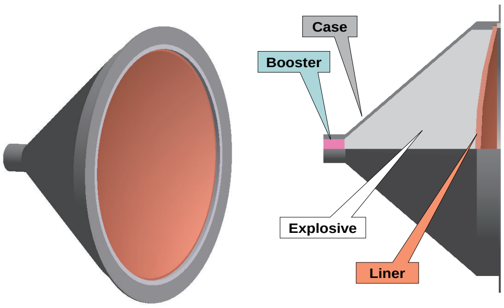


Fig.2 Developed shaped charge for Hayabusa2 impact mission. It includes 4.7 kg HMX-based polymer-bonded explosive.

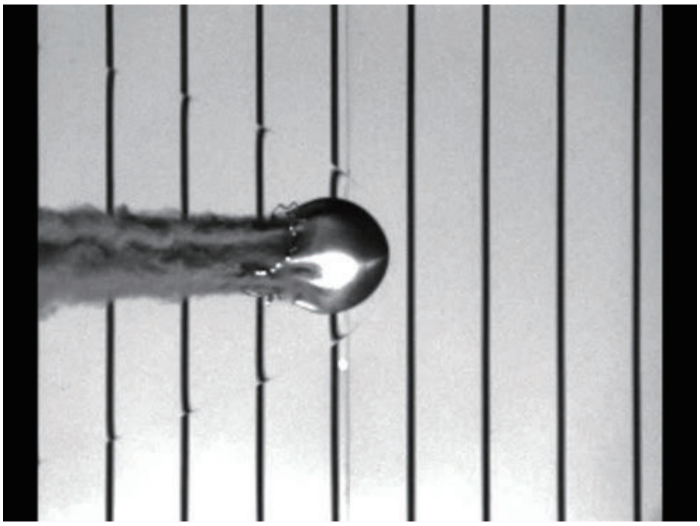


Fig.3 Shape of the formed impact head observed in the ground test. It was almost identical to the result of the computational simulation. The speed of the impact head was more than 2 km/s.

- T. Saiki *et al*.. The Small Carry-on Impactor (SCI) and the Hayabusa2 Impact Experiment. *Space Science Reviews*, Vol. 208 (1-4), 165-186 (2017) doi:10.1007/s11214-016-0297-5

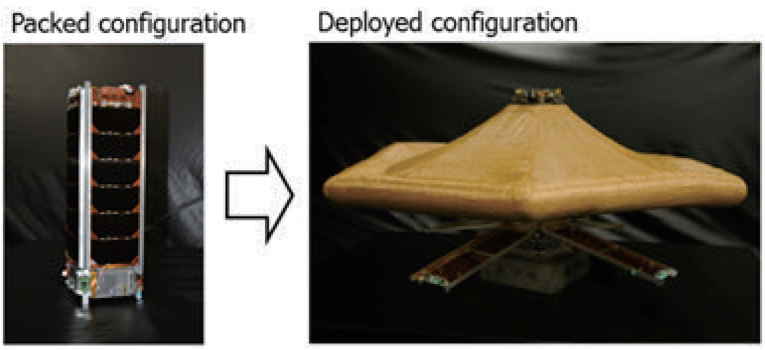
14 Development and Flight Operation of Nanosatellite "EGG"

【EGG: re-Entry satellite with Gossamer aeroshell and GPS/Iridium】

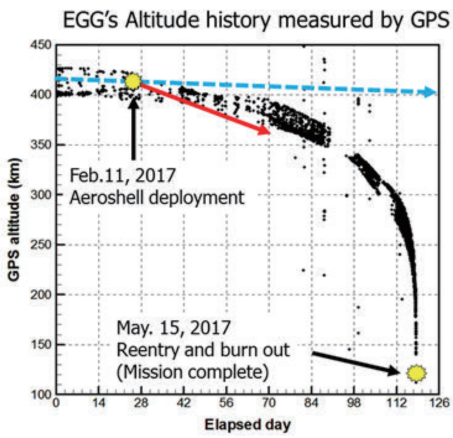
Nano-satellite "EGG (re-Entry satellite with Gossamer aeroshell and GPS/Iridium)" was developed as part of research and development into a reentry system with a deployable and membrane aeroshell. The EGG is a 3U CubeSat (11cm x 11cm x 34cm, 4kg) with a packed membrane aeroshell. This membrane aeroshell consists of an inflatable ring and a membrane flare and can be deployed by the gas injection system installed in EGG's main body. The diameter of the deployed aeroshell is 80cm.

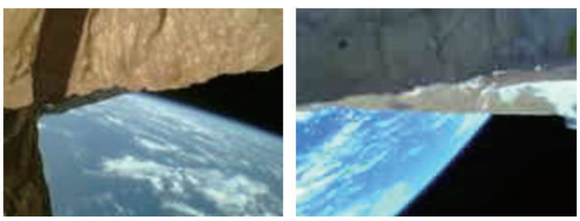
The EGG was deployed from the ISS by J-SSOD (JEM Small Satellite Orbital Deployer) in January, 2017. The aeroshell deployment sequence was conducted successfully in February. Pictures of the deployed aeroshell were captured by the onboard cameras. After deployment of the aeroshell, the EGG gradually fell in altitude due to the aerodynamic force acting on it. This trend of orbital decay can be confirmed by GPS data. After that, the altitude of the EGG continued to fall due to the aerodynamic force acting on the deployed aeroshell. Finally, the EGG reentered the atmosphere and burned out in May 2017. The EGG's mission was completed. All the flight data was acquired via Iridium satellite networks. Therefore, the EGG became the first satellite operated solely by telemetry and a command system utilizing an Iridium satellite network.

EGG projects demonstrate that this method, a nanosatellite deployed from ISS by a JSSOD system, can provide valuable opportunities for flight tests using new technologies in LEO. This achievement of technical demonstration in an EGG mission will lead to the realization of a return and recovery service from LEO and nano-probe for future planetary exploration.

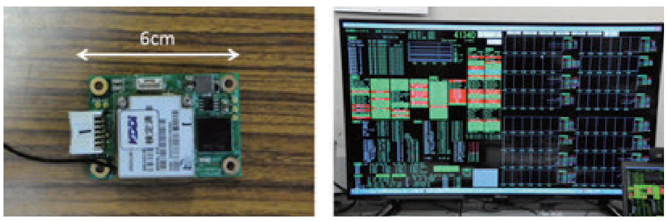


Flight model of nanosatellite "EGG"
*Packed configuration is 3U-size (11cm×11cm×34cm, 4kg)
*Deployed aeroshell has a hexagonal pyramid shape with diameter of 80cm.





Images of deployed aeroshell captured by onboard camera.
These image data is downloaded via an iridium network.



Telemetry command system without special ground station utilizing commercial satellite network (Iridium SBD service) (Left : onboard transceiver, right : Quick look system developed for EGG's operation.)

- K.Yamada *et al*.. *The 61st Space Sciences and Technology Conference*. Niigata, Japan. (2017)

15 Realization of a Quasi-Kinematic Orbit Determination method, enabling precise orbit determination of low-thrust, deep-space spacecraft without stopping continuous acceleration

Simultaneous two-dimensional Delta-DOR measurements were performed for the Hayabusa2 probe, enabling the first-ever, direct three-dimensional position measurement for low-thrust, deep-space probes.

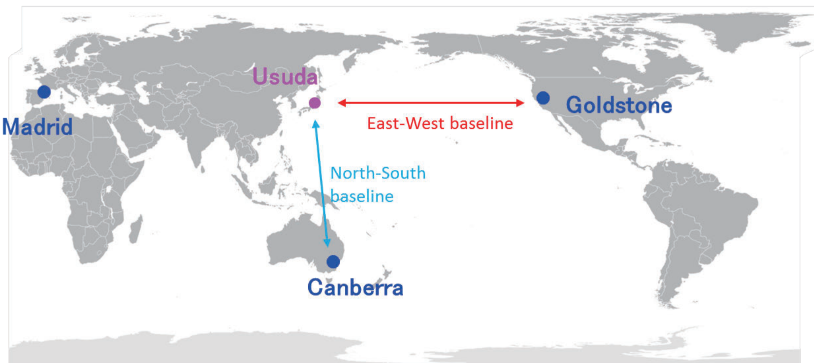
Conventionally, Doppler and ranging measurement data have been used as fundamental observables for orbit determination of deep space probes. Because the spacecraft's angular position in the plane-of-sky is determined through diurnal variation of Doppler data by the rotation of the earth in conventional methods, a minimum of a few days observing the arc is required for orbit determination. Since the inadequacy of the non-gravitational acceleration model of probes strongly couples with the Doppler measurements, conventional OD methods cannot provide precise solutions for the probes for which the contribution of non-gravitational perturbative forces are dominant, such as ion propulsion spacecraft or solar sails.

Delta Differential One-Way Ranging (Delta-DOR) is a technique that can resolve this, as the Delta-DOR data provides a direct measurement of the spacecraft's angular position relative to the baseline vector joining the two radio antennas. While measurements from two orthogonal baselines are required to determine both components of angular position, existing space agencies do not have the number of stations required to provide two orthogonal baselines simultaneously. Now that JAXA' s Delta-DOR observation system is operational for joint observations with other agencies, simultaneous two-dimensional Delta-DOR measurements have become possible.

A Quasi-Kinematic Orbit Determination Method, in which two dimensional Delta-DORs and a 2-way ranging measurement are performed during a short period of time, was applied to the Hayabusa2 probe in January 25, 2017 during its electric thrust cruising period. While the total duration of observations was only 52 minutes, three-dimensional position was instantaneously measured with an estimated posteriori position error of only 1.28 km (1-sigma). A slight variation of a few percentage in accuracy can be expected for the ion thrust model, and the expected variation in position during this short arc due to uncertainties of the ion thrust model are small enough (e.g., position change is only 17m even if 10% model error is predicted) that they can be ignored.

While Delta-DOR measurement has proven to be a useful tool for low thrust, deep space missions, like NASA' s Dawn mission in the past, such measurements had always been performed during the period the electric thrusters were not in use. Our measurements for the Hayabusa2 were the world' s first Delta-DOR based orbit determination without stopping the electric thrusters. With this new method, the dedicated coasting period for orbit determination is no longer necessary and the operation rate of the electric thrusters can be increased to almost 100%.

An advantage of this method is availability of precise position measurement independently from the precise ion thrust model. This means that this model can also be used for precise modeling of ion thrust. In fact, this method was applied in the 3rd ion engine operation period in 2018 and a small direction error of 0.2 degrees in the ion thrust model was identified using this measurement. This was fed back to the ion engine operation plan in the very last period before arrival at the target asteroid and contributed very much to the successful arrival at the asteroid.



Ground stations were used for this measurement. By using the Japanese Usuda Station in combination with the DSN facilities, two-dimensional simultaneous Delta-DOR measurement became possible for the first time.

- H. Takeuchi *et al.*. A Quasi-Kinematic Orbit Determination Method for Deep Space Probes. ISTS, 2017-d-097 (2017).

16 RF Energy Harvester for Space-by-Wireless Based on Space Nano RF Electronics Technologies

It is important that wireless technology for applications in space plays a significant role for remote microwave sensing information and observation of global warming and for satellite-earth communication such as HAYABUSA-UDSC (Usuda Deep Space Center) telemetry command and communication. Furthermore, wireless technologies using microwaves have made great progress by wireless powering to equipment in satellites. The combination of wireless communication, sensing and wireless powering technologies for applications in space enable us to realize an all-wireless system, called a Space-by-Wireless system. For this purpose, an active integrated antenna (AIA) array using a single antenna with directly connected microwave integrated circuits is necessary for the high-performance and compact communication and sensor systems.

In order to achieve this, cutting-edge fabrication technology in the field of nano RF electronics should be applied. Based on this nano RF electronics technology, we developed a highly-functional 2×2 AIA for transmission at 5.8 GHz with a GaN amplifier (Fig.1). The output power and maximum efficiency were 5 W and 70% respectively. We also developed a receiving circuit with an antenna and Si small rectifier. The efficiency and size of the Si rectifier were 21% and 1.0 mm × 0.5 mm respectively. This harvester is the smallest in the world.

The Hybrid Semiconductor Integrated Circuit (HySIC) rectifier was developed as a radio frequency (RF) energy harvester. The rectifier was manufactured based on the junction technique, which connects a GaN diode to a Si substrate under ultra-high pressure at room temperature. Over 100 mW of output power was harvested by the HySIC rectifier.

We succeeded in a wireless power transfer experiment using an AIA via an antenna and HySIC rectifier. The ability to transfer power without wires into spacecraft will help to realize small, light-weight, highly-functional and low-cost deep space craft in the future.

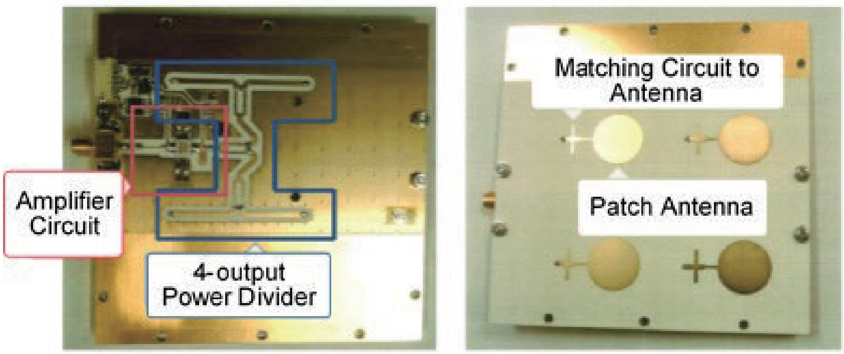


Fig.1 Active Integrated Antenna Array

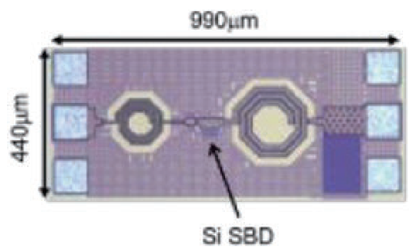


Fig.2 Full-Si Energy Harvester (the smallest in the world)

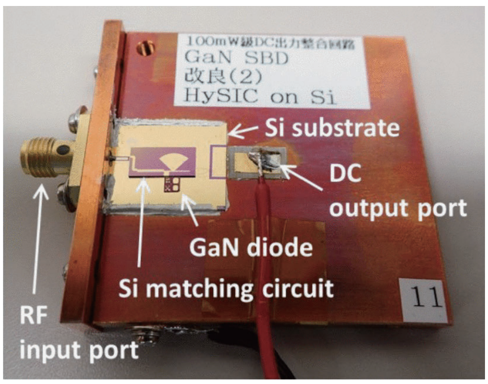


Fig.3 HySIC RF Energy Harvester

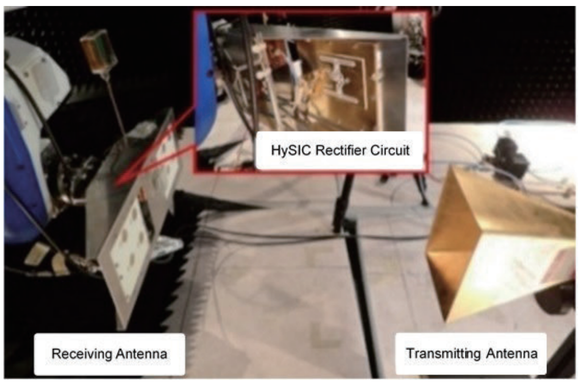
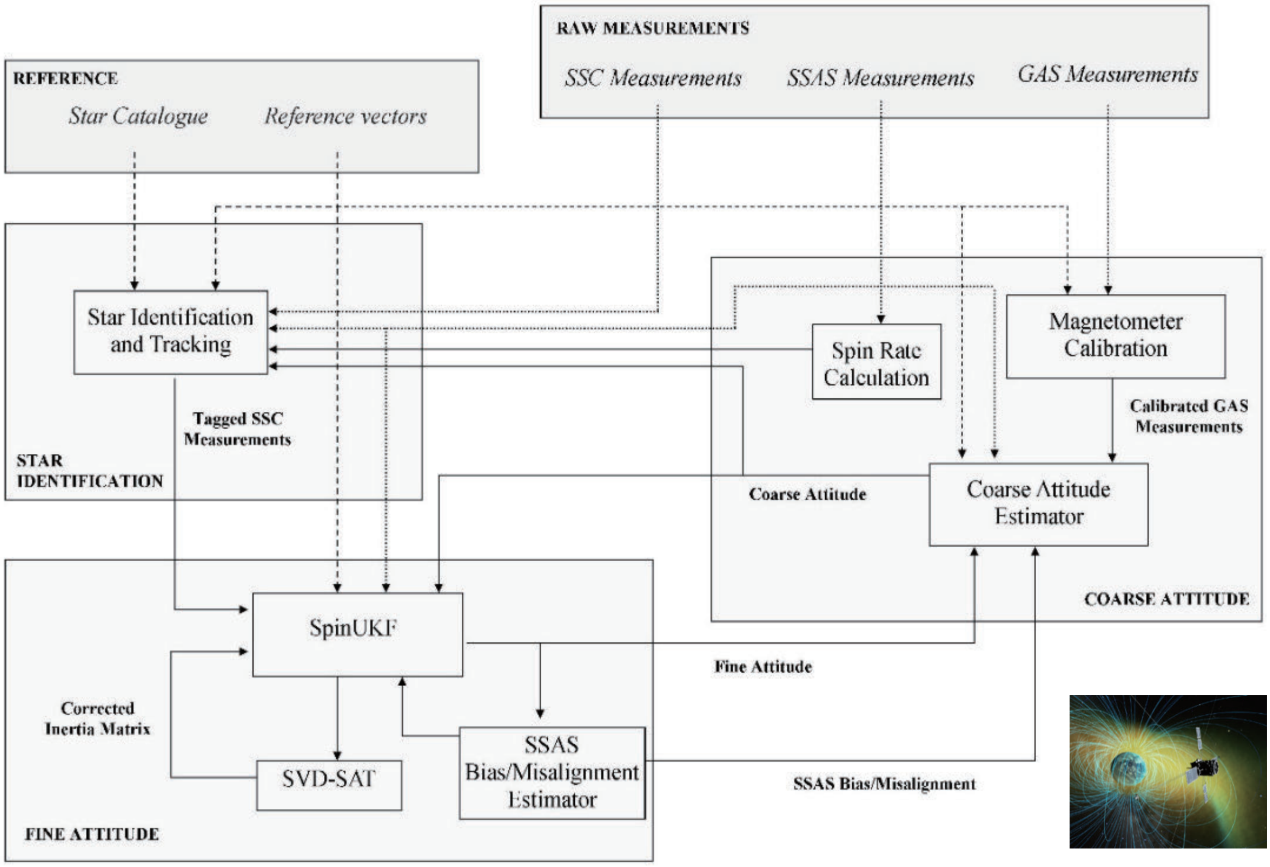


Fig.4 Experimental Set-up of Wireless Power Transmission

- R. Kishikawa *et al*.. Development of Rectifier with Gallium Nitride and Silicon for Space Use. *The transactions of the Institute of Electronics, Information and Communication Engineers C*. Vol. J100-C(12), 561-568 (2017)

17 Advanced Attitude Determination Algorithm for Spinning Satellites



On ground attitude determination system with SpinUKF for the ARASE (ERG) satellite

We have researched and developed an advanced attitude determination algorithm for spinning satellites, based on the modern approach for three-axis stabilized satellites and applied this to offline attitude determination of the ARASE satellite.

Modern and advanced attitude determination algorithms, such as several types of Kalman filters, have been studied primarily for use on three-axis stabilized satellites. However, it was difficult to apply these advanced algorithms to spinning satellites because the attitude dynamics and attitude sensor data behavior is completely different from those of three-axis stabilized satellites.

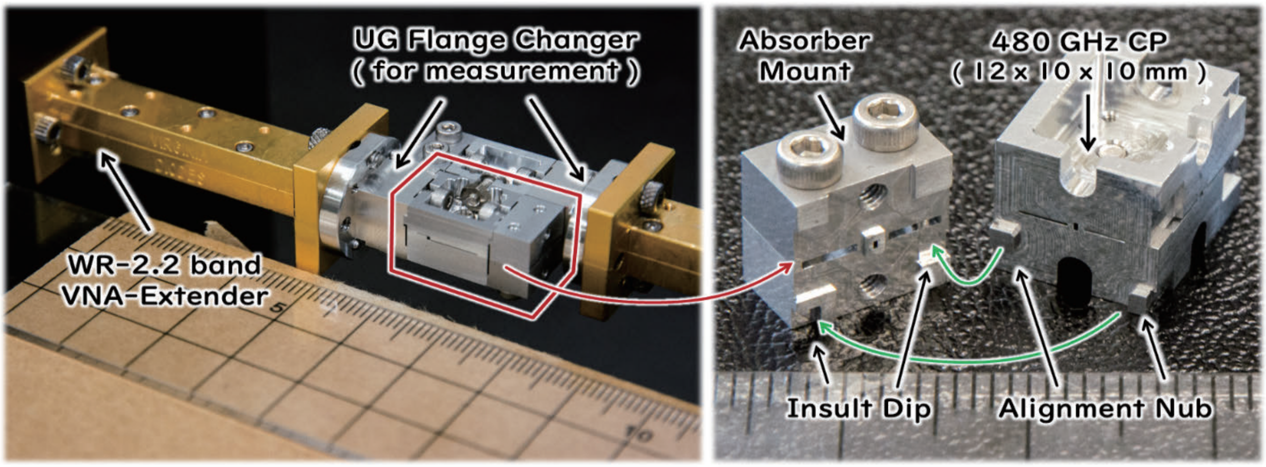
As a result, we set about studying adaptation of the UKF (Unscented Kalman Filter), one of the modern and advanced Kalman filtering algorithms for spinning satellites. Several technical key points were identified, such as representation of the attitude in the filter and smart pre-filtering on the spin-type attitude sensor data. Ultimately we proposed a UKF based novel algorithm, “SpinUKF”, specially designed for spinning satellites.

With SpinUKF, spin axis determination error can generally be reduced to be approximately 1/5, compared to the conventional TRIAD-based algorithm used for scientific spinning satellites. Time resolution of the determined attitude is also enhanced by having continuous recursive attitude estimates for the satellite rather than single-point estimates.

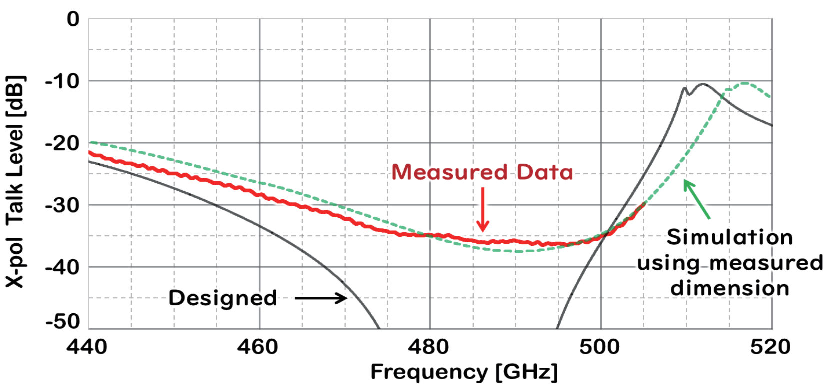
An on ground attitude determination system using SpinUKF as a core algorithm was developed and applied to the ARASE (ERG) satellite. In addition to the accurate attitude knowledge, the developed on-ground attitude determination system enables estimation of several important parameters, such as the spin-axis tilt angle and magnetometer bias error, even when using data with limited sampling time.

- H.E. Soken *et al*.. Advanced Attitude Determination Algorithm for Arase: Preliminary Mission Experience. *Advances in the Astronautical Science*, Vol. 162, 1175-1193 (2018)

18 Development of 480 GHz band Waveguide Circular Polarizer



Photographs of the developed 480 GHz Circular Polarizer (CP)



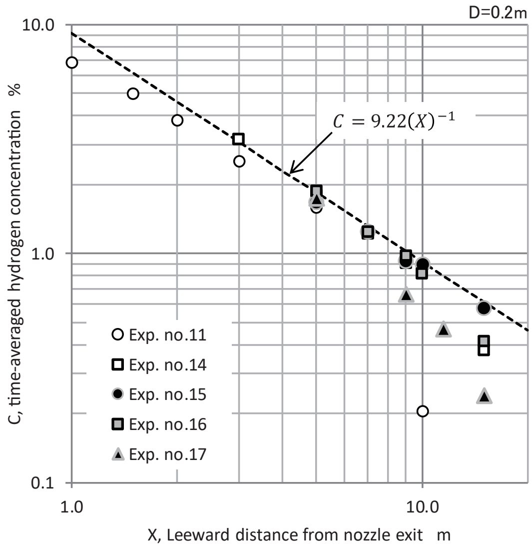
Measured and simulated X-pol Talk performance of 480 GHz CP.

We have developed a Waveguide septum type Circular Polarizer (WG-CP) in the 480 GHz band with -36 dB X-pol Talk performance, which is necessary for high-precision atmosphere / astronomical observation in the submillimeter-wave band. Owing to the development of new and high-precision fabrication techniques, we developed a WG-CP for use in wavebands approximately twice as high as the highest conventional waveband, 230 GHz band that could also be applied to higher bands, such as 630/770 GHz. WG-CP is a useful waveguide device that can realize circularly polarized wave separation with very high accuracy and very low loss, with more efficiency and a more compact design than other methods. However, due to its structural problems; it is prone to machining errors, especially on the Stepped Septum part, the conventional WG-CPs were used in up to 45 GHz band (Q-band).

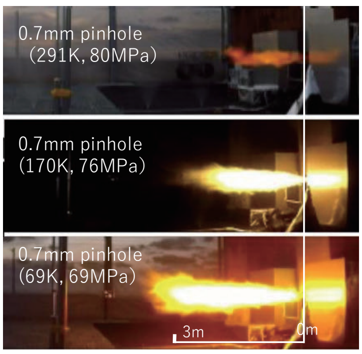
We developed a new WG-CP model with a structure more resistant to machining errors and demonstrated practical use in 230 GHz band astronomical observations [1]. We applied this new model to the 480 GHz band in order to install it into a developing 480 GHz band receiver for satellite observations of planetary atmospheres. Furthermore, to suppress dimensional machining errors, a new metal surface polishing technique, which can obtain a horizontal plane of less than 2 μm, and a very high precision connection flange able to suppress the connection position error to under 3 μm were developed as part of this work.

- Y. Hasegawa *et al*.. A new approach to suppress the effect of machining error for waveguide septum circular polarizer at 230 GHz band in radio astronomy. *Journal of Infrared, Millimeter, and Terahertz Waves*, Vol. 38, 638-652 (2017) doi: 10.1007/s10762-017-0364-3

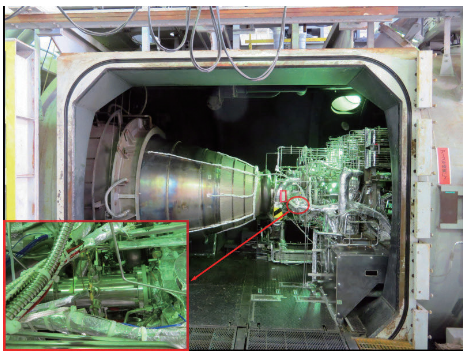
19 Research and Development on Liquid Hydrogen Utilization Technologies Through Collaboration with External Organizations



The 1% hydrogen concentration distance was necessary to extend 2 m as compared with the conventional safety standard.



Pictures of hydrogen combustion flame under various temperature conditions.



Capacitive void fraction sensor for LE-5B-3 ground tests

We are advancing research and development into liquid hydrogen utilization technology common to space transportation engineering, cryogenic and superconductivity-related technology and energy engineering through cooperation with industry and academia.

To improve safety regulations for fuel cell vehicles and hydrogen infrastructure, experiments of cryo-compressed hydrogen leakage diffusion were conducted. The experimental apparatus can supply hydrogen at 90 MPa at various temperature conditions. The objective of the experiments was to measure hydrogen concentration distribution, blast pressure, flame length and radiant heat. In addition, high speed camera observations were used to investigate the near-field of cryogenic hydrogen jets at supercritical pressure. This research was supported by the New Energy and Industrial Technology Development Organization (NEDO)'s "Research and Development on Improvement of Domestic Regulations, International Standardization and Harmonization for Fuel Cell Vehicles and Hydrogen Infrastructure".

We have developed cryogenic hermetic connectors and capacitive void fraction sensors for liquid hydrogen systems in collaboration with Kyocera Corporation and proceeded to apply them to the LE-5B-3 engine combustion test and the reusable rocket experimental vehicle (RV-X).

- H. Kobayashi. Current situation and issues of hydrogen utilization at Noshiro Rocket Testing Center (NTC). *Liquid hydrogen utilization symposium for a hydrogen-based society*. Tokyo, Japan. Nov 14, 2017.

20 Successful Launch Experiment with SS-520 F5

【Development of Nanosatellite Launch System】

SS-520 F5, the rocket for the nanosatellite was launched on February 3, 2018 and TRICOM-1R "TASUKI" was successfully injected into the low earth orbit.

Guinness World Records recognized SS-520 F5 as the smallest orbital rocket.

The remodeled sounding rocket, SS-520 F5, was launched on February 3, 2018, and the nanosatellite, TRICOM-1R "TASUKI", was also successfully injected into the low earth orbit. The aim of this rocket launch experiment was to confirm the performance of mass-produced products, which worked normally during rocket flight and in orbit. The first trial of this experiment with the SS-520 F4 in 2017 experienced problems with the power supply circuit. Based on the results of the fault analysis, the rocket system for the SS-520 F5 mainly improved the architecture of the electronics.

The remodeled sounding rocket, SS-520 F5, was launched on February 3, 2018 and the nanosatellite, TRICOM-1R "TASUKI", was also successfully injected into the low earth orbit.

The aim of this rocket launch experiment was to confirm the performance of mass-produced products, which worked normally during rocket flight and in orbit. As a result, a variety of mass-produced products for the electronics were installed in the avionics and other components.

The first trial of this experiment with SS-520 F4 in 2017 experienced problems with the power supply circuit in the rocket. Attempts to identify the cause were done through a fault tree analysis and it was believed that the electrical trouble was triggered by harness wire damage or problems with the heat resistance structure.

The primary mission of TRICOM-1R was a Store and Forward mission. The satellite communicated with the ground station by the specified low power radio wave and the data was communicated back and forth between the satellite and the station.

The results of the successful flight of F5 showed that cause of the failure in F4 was due to technical issues.

II
Status Report

1. Space Science Roadmap

a. Goals and Basic Frameworks

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

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

b. Strategic Large Missions under development

MMX (Mars's moon eXploration) is a Martian moon sample return mission. The mission is now a pre-project of JAXA and in Phase A (concept-development and project-formulation phase). International science instrument teams were formed this fiscal year. The X-ray Astronomy Recovery mission is also a pre-project of JAXA and in Phase A (project formulation phase).

Two mission candidates, LiteBIRD (Cosmic Microwave Background B-mode observation) and Solar Power Sail (Jupiter and Trojan asteroids explorer) are in the concept study phase. One of these two missions will be selected for pre-project in JFlossY2018. SPICA (Infrared Astronomy Mission) is a mission candidate led by the European Space Agency (ESA) and Japan will participate in the L-class category. This mission is also in the concept study phase at JAXA. The first down selection of the ESA M5 will be announced early next fiscal year.

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

Smart Lander for Investigating Moon (SLIM), M-class mission 1, moved to the project phase (Phase B) in FY2016. However, in order to fully utilize the launch capability of the H2 launcher for the XARM mission, the SLIM project team sought a dual launch option. The mission plan was re-considered according to this option. DESTINY$^+$, an M-class mission 2 candidate, is a flyby mission to the meteor-shower parent body, Phaethon. It will also characterize planetary dust on the way to the asteroid. This mission is currently in transition from Phase A1 to Phase A2.

Small JASMINE, one of the candidates for M-class mission 3, is an infrared astrometry mission dedicated to learning more about galactic bulge. It is currently in transition from concept investigation (Pre-Phase A1) to mission definition phase (Pre-Phase A2). An international science review was conducted by ISAS. The team is re-considering the scientific objectives of this mission based on the action items from the international review.

ISAS issued an announcement for an opportunity for mission candidates for M-class missions 3 or 4. Early next fiscal year, a maximum of three candidates will be selected for the next study (Pre-Phase A2). If there are candidates for M-class mission 3, they will compete with Small JASMINE at the end of Pre-phase A2.

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

Japan's contribution to the ESA's Cosmic-Vision L1 mission, JUICE (JUpiter ICy moons Explorer) is in Phase B as an ISAS-level project. Components for the three mission instruments are currently under development. CAESAR (Comet Astrobiology Exploration Sample Return) is a candidate for NASA's flagship mission, New Frontier 4. JAXA conducted a concept study (Pre-Phase A2) as Japan's contribution to the mission, providing a return capsule and further contributing to science studies.

e. Missions close to deployment and in operation

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

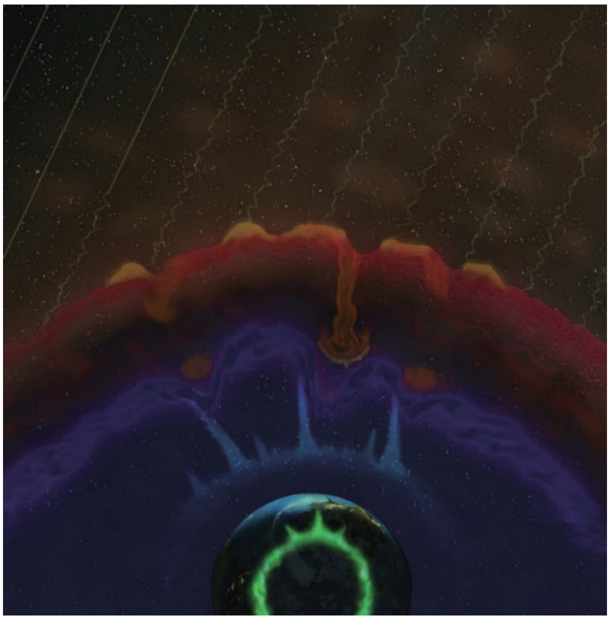
MMO (Mercury Magnetospheric Orbiter) was shipped to ESTEC and integration and tests of the BepiColombo system were carried out. Hayabusa2 performed its approach operation to the asteroid, Ryugu, successfully. The five spacecraft in orbit, the Geo-space explorer, ARASE, the planetary spectroscopy mission,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

f. Small missions conducted with matching funds with external organizations

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

2. Space Science Programs

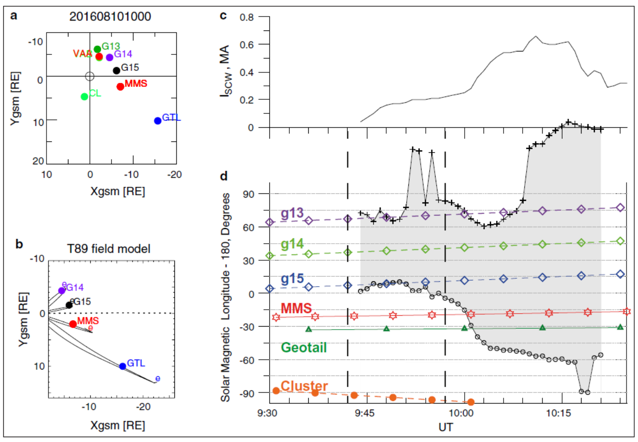
a. Earth Magnetosphere Observation with GEOTAIL



(C) E. Masongsong, H. Hietala (UCLA EPSS), D.-S. Han (Polar Research Institute of China)

Throat aurora observed near local noon for approximate radial orientations of the interplanetary magnetic field monitored by GEOTAIL [1].

Since the launch of the joint U.S.-Japan satellite GEOTAIL in 1992, it has been operating continuously for more than two solar cycles. The major purpose of GEOTAIL is to make direct observations of plasma in the Earth's magnetotail. Except for the failure of one of the two data recorders at the end of December 2012, other spacecraft systems and instruments are in good condition. The effect of the data recorder failure was minimal, with a data loss of about 10–15%, thanks to the support from NASA's Deep Space Network (DSN). One to two years after data acquisition, the data are calibrated, archived, and made available to researchers all over the world. ISAS has approved the continued operation of GEOTAIL until at least the end of March 2019.



Locations in Earth's magnetosphere of a number of satellites on 10 August 2016 [2] when GEOTAIL and MMS simultaneously observed a magnetospheric substorm (left) and temporal evolution of auroral electric current and dipolarized magnetic field region in the magnetotail (right).

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

As a result of cooperative observations with the MMS satellites, we revealed for the first time the relationship between magnetic field dipolarization in the nightside magnetosphere and temporal evolution of the magnetotail plasma sheet boundary layer during an aurora explosion that is known to occur during magnetospheric substorms [2]. The results are important for understanding how the electric current system leading to electron precipitation into the ionosphere during aurora explosion forms and spatiotemporally develops in the magnetotail.

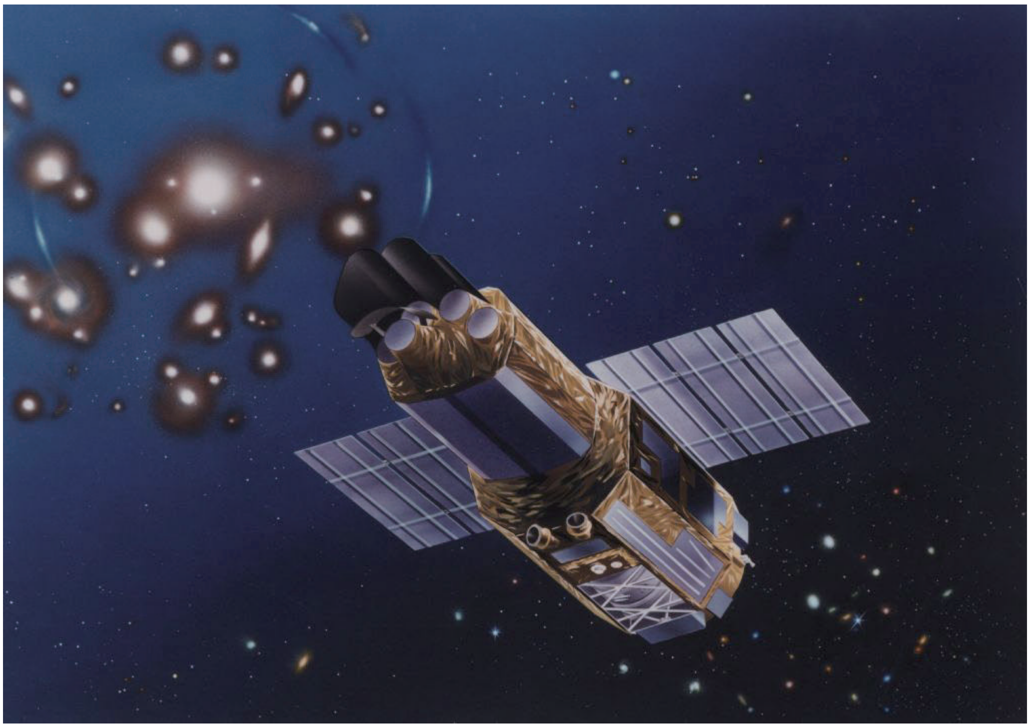
([1] Journal of Geophysical Research Space Physics, February 2017, and [2] Earth Planets and Space, September 2017).

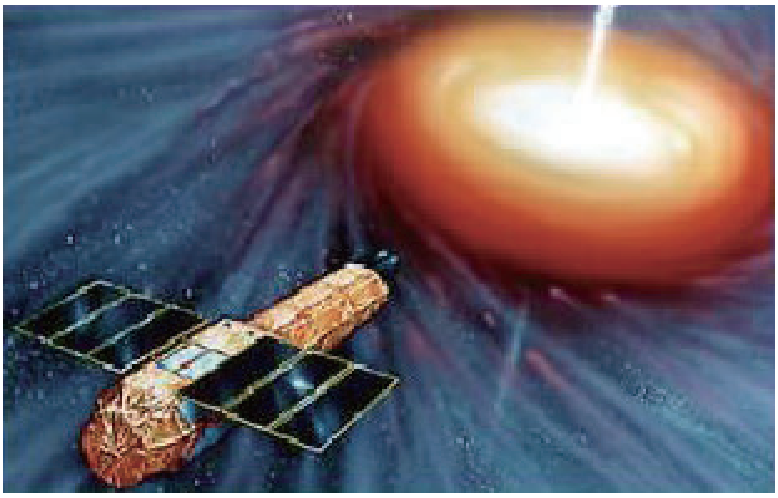
b. X-ray Astronomy with SUZAKU

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

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

In FY2017, 61 peer-reviewed papers were published related to SUZAKU. The cumulative number of peer-reviewed papers is 1008.





c. Small Satellite INDEX

A small scientific satellite, INDEX (INnovative-technology Demonstration Experiment, code name "REIMEI") is a piggy back satellite with a mass of 72kg launched in 2005. It has remained in orbit for 12 years. The scientific purpose is observation of fine structure of aurora phenomena by means of three-spectral imagers and particle energy analyzers. The engineering purpose is to demonstrate small satellite technologies. The highlights of INDEX in FY2017 are as follows.

The method of constant-current and constant-votlage is widely used to charge onboard batteries. Constant current is provided at the initial constant-current phase of charging. After the battery voltage reaches a specific voltage, its voltage is maintained by the power supply circuit to recover votlage loss due to internal battery impedance. The current of this constant-voltage phase can be approximated as an exponential decay curve. We found with ground tests that the time constants of the exponetial decay curve seem to be a decreasing function of battery capacity loss.

Figure 1. shows a tapering current during the constant-voltage control for the charge of the REIMEI onboard battery in 2005 immediately after launching, and 2015 after 60,000 charge-discharge cycles. The tapering or the slope of the charge current depends on the capacity and the time constant for the chemistry of the cells. By understanding the relationship among the parameters, we can calculate the residual capacity we obtained today.

Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR) performs 3D electro-chemical simulations of the REIMEI battery based on its initial parameters in the development phase. They include thermochemical parameters and degradation phenomena of separaters and electrolytes. We will compare the onboard charge-discharge data with the electro-chemical simulation by DLR. Figure 2. indicates the curves of battery voltage (V) and capacity per area (Ah/m^2) for the ground test and the electro-chemical simulation. Figure 2. shows good coincidence between the measurement data and the simulation. We may predict future performance of the onboard battery and its failure mode.

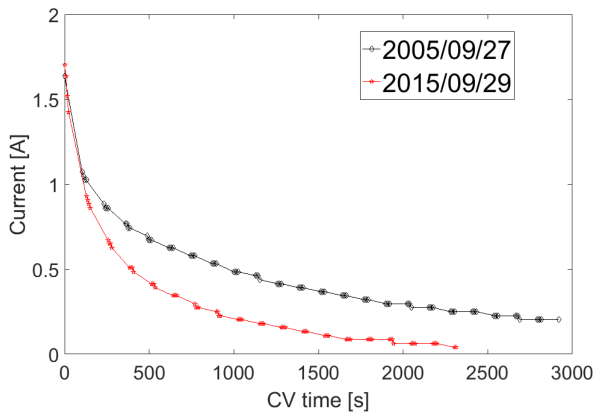
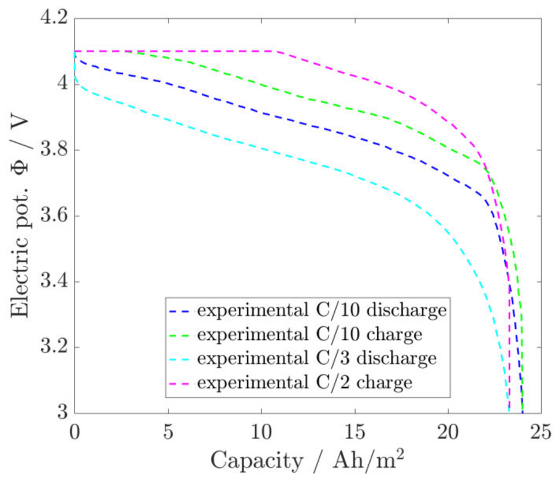


Fig.1 Decay curves of the REIMEI onboard battery in 2005 (immediately after launch) and 2015 (after 60,000 charge/discharge cycles).



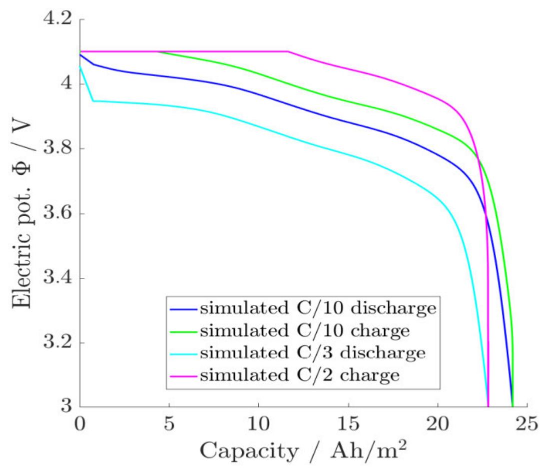


Fig.2 Battery voltage vs capacity. The top graph shows data from ISAS. The bottom graph is simulation data from DLR

d. Solar Observation with HINODE

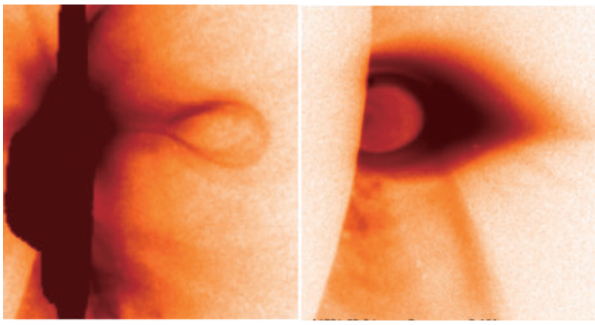
The aims of the HINODE satellite (formerly called SOLAR-B) are to better understand the space weather of the Sun-Earth system. Specifically, we are observing the solar processes of magnetic field generation; energy transfer from the photosphere, that is, the solar surface, to the corona and for the heating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

HINODE was launched in September 2006 and has been continuously operated as an on-orbit solar observatory for over 11 years. The observatory is open to the world-wide research community and 16 new observing proposals were delivered to the HINODE operation team in FY2017. In addition to closely coordinated observations with NASA's Interface Region Imaging Spectrograph (IRIS) satellite on a regular basis, coordinated observations with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile have started. Data acquired by HINODE is made fully available to the world research community immediately after observations.

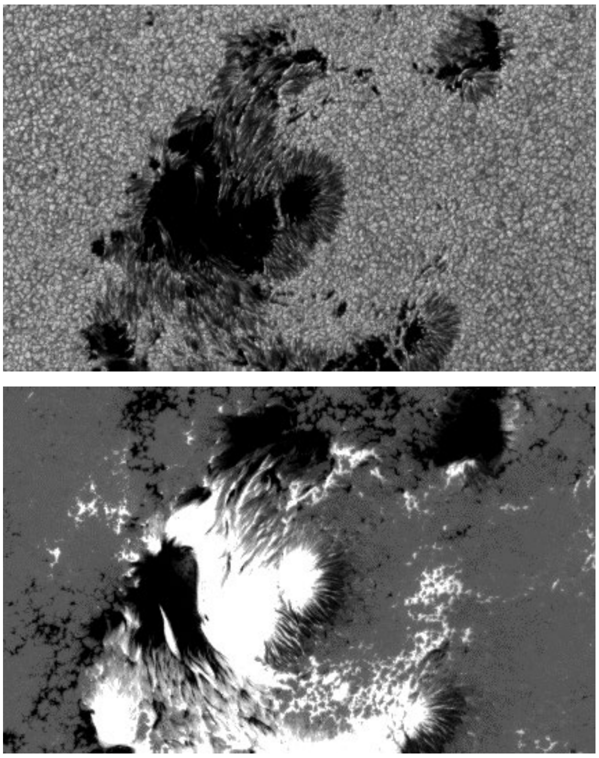
In FY2017, 76 articles were published in referred journals based on HINODE observations, resulting in a cumulative total of 1,152 referred papers to date, making it one of the most productive ISAS missions.

One of highlights in FY2017 was the successful observation of a series of large flares from September 6-10 in 2017. One of those was the largest flare in the current solar cycle. Particular attention was drawn from the public from the view point of its influence on Earth, and this was a good opportunity to create appeal for the importance of space observations, including 4 series of Web public releases to report on HINODE observations.

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



Two soft X-ray images captured during an eruption and the following development of a cusp-shaped structure of the limb flare on September 10, 2017. Soft X-ray and EUV spectroscopic data is used to investigate energy release at the reconnection site.



The continuum (top) and line-of-sight magnetogram (bottom), derived from an analysis of a spectro-polaraimeter map recorded at a time close to the occurrence of the largest flare on September 6, 2017. They are used to better understand flare triggers.

e. Venus Meteorology Observations by AKATSUKI

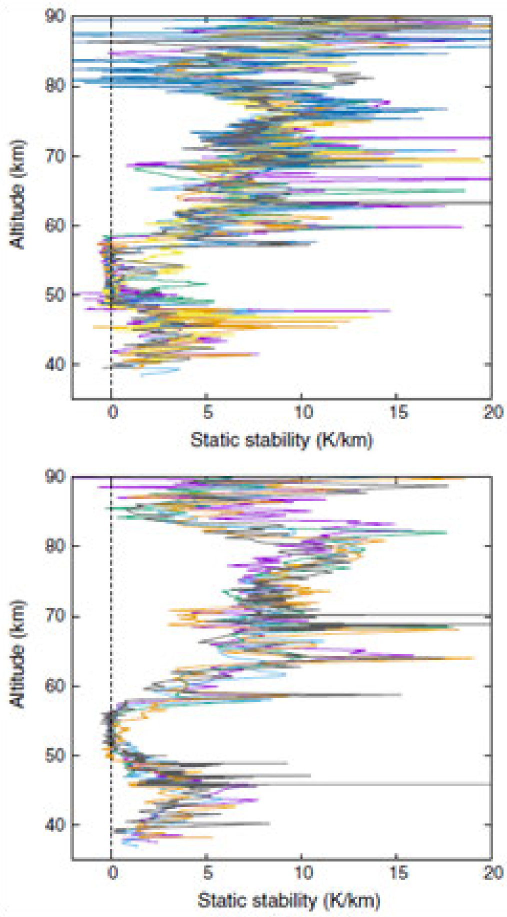
AKATSUKI, in the Venus orbit since December 2015, continued observations of the atmospheric motion of Venus. One primary objective of AKATSUKI is to understand the mechanism of super rotation, a high-speed wind blowing around Venus at 100 m/s. Unfortunately, of the five on-board cameras, IR1 and IR2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

In the summer of 2016, observations, primarily by IR2 (Venus night-side, sensitive to 50-60 km altitudes) discovered accelerated winds (reaching over 80 m/s) near the equator in the middle-to-lower cloud layer (Horinouchi et al., 2017). Near-simultaneous day-side observations by UVI (sensitive to 65-70 km altitudes) show rather normal wind profiles. Such phenomenon, named the "equatorial jet", has never been reported before (some indication existed in previous ground-based measurements although with far larger error bars) while winds in these areas were previously believed to be somewhat uniform and stable at

~60 m/s. Similar data from March 2016 did not show such acceleration near the equator, but did show wind profiles consistent with our previous observations. Therefore, the equatorial jet may be sporadic and confined to the middle- to-lower region of clouds. For more details, see page 5.

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

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



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

f. Solar Power Sail Demonstration with IKAROS

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

Achievements:

- Using the exposure experiment facility 'ExHAM' in the Japanese Experiment Module of the International Space Station, we confirmed degradation of electric properties of thin-film solar cells (Fig. 1).
- We established a mechanical model of solar sails for analysis of orbit and attitude dynamics where deflection and torsion of the membrane varies according to the spin rate – the more the spin rate increases, centrifugal force and deformation of the membrane is turned over. We confirmed that the model was consistent with actual history of the spin rate and the sun angle obtained from the flight data (Fig. 2).
- In FY2015, we established a method to detect weak signals. In FY2016, we verified the validity of orbit determination by artificial range data using weak signals. In FY2017, we evaluated attitude estimation using weak signals as an extension of our activities over the last two years. We confirmed that real-time communication was impossible with weak signals, however it could be possible to determine orbit and attitude from them by integrating them with off-line signal processing (Fig. 3).

Outcomes:

- Total number of papers: 108
- The method to obtain telemetry range data by postprocessing using open-loop record data to catch radio waved is expected to be applicable to a wide range of spacecraft operation as well as solar sails.
- IKAROS team received The Laurels for Team Achievement Award 2017 from IAA (International Academy of Astronautics).
- A student presenting the off-line signal processing for IKAROS searching operation received a student award in SCI'17.

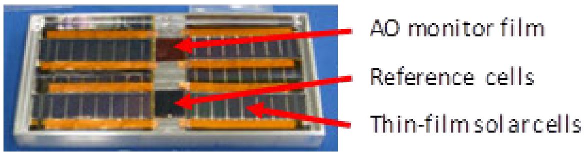


Fig.1 Exposure experiment in the Japanese Experiment Module

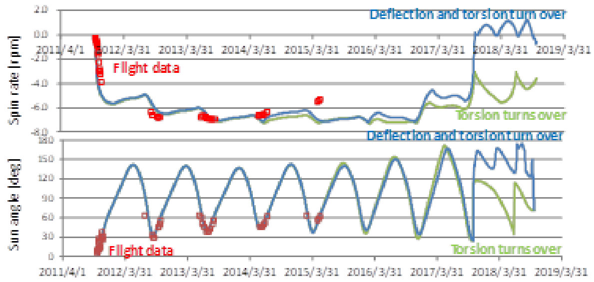


Fig.2 Mechanical model of solar sails

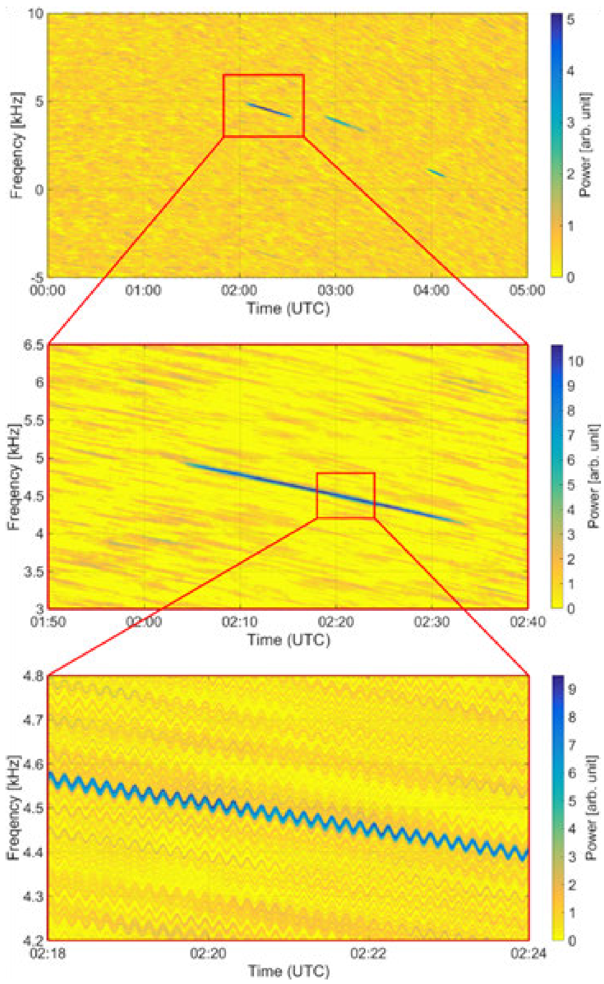


Fig.3 Orbit and attitude estimation using weak signals

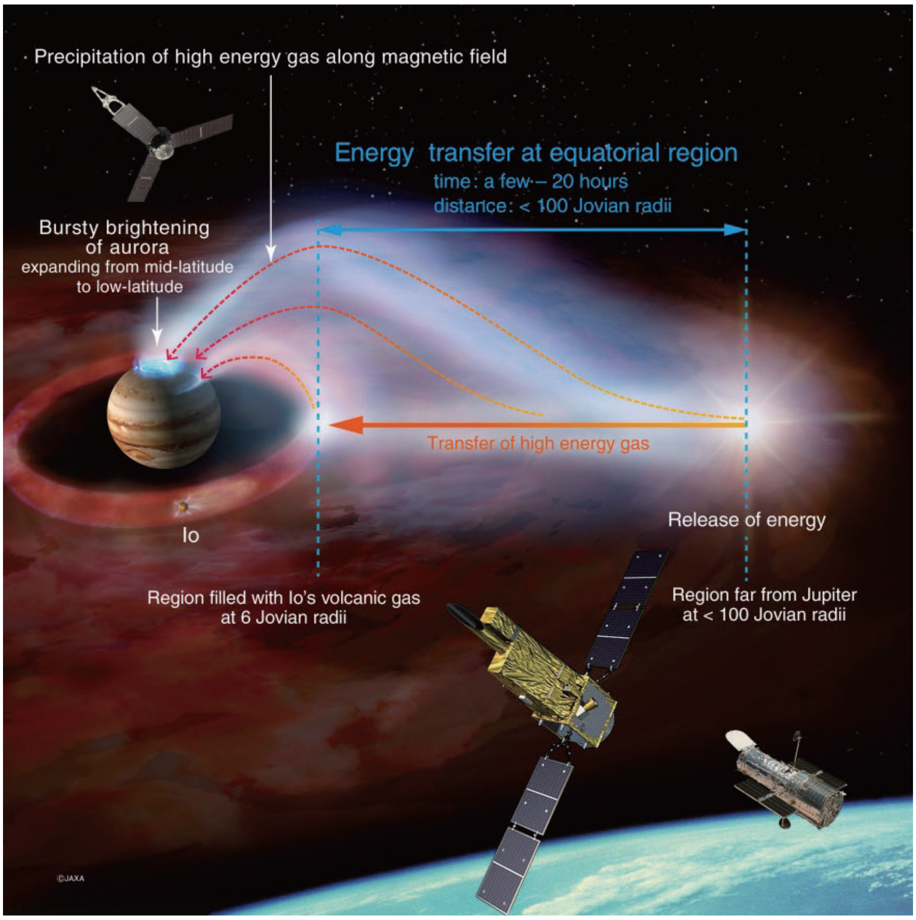
g. Extreme-ultraviolet Spectroscopic Planetary Observation with HISAKI

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

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

In this fiscal year, 8 peer-reviewed papers regarding HISAKI data were published, for a cumulative total of 29. Two articles using HISAKI observation results contributed to the special issue of GRL on the initial results of JUNO, which included the joint observation results during the interplanetary space cruising phase of the JUNO mission. HISAKI played the most important role as the producer of continuous observation data, while the other satellites are subject to limits on their observation time. Results from Venus airglow spectrum observations with high wavelength resolving power captured unconfirmed atmosphere light emissions. This became one of the more important results for basic data on Venus atmospheric chemistry.

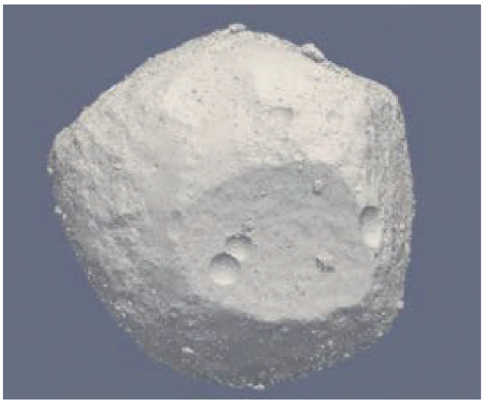
The HISAKI science team takes a principal position among scientists of Jovian magnetosphere study at the international level, including international collaboration in NASA's Participating Scientist Program (planetary scientific research program of NASA using HISAKI data), the organization of the international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



Schematic illustration of energy release and transportation process in the Jupiter magnetosphere from results of international collaborative observations.

h. Asteroid Explorer Hayabusa2

Landing Site Selection (LSS) training (left) and Real-Time Integrated Operation (RIO) training (right)



3D shape model “Ryugoid”

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

Three long-term ion engine thrusts are required before arriving at Ryugu and two have already been performed. The final long-term thrust will be performed from January to June of 2018. Test observations of planets and stars were carried out when the ion engine was not in operation. Searches were made for Earth Trojan asteroids when the spacecraft was near point L5 (L5: one of the Lagrangian points) in April 2017, however, no asteroids were found. In June or July of 2018, approximately three and half years after the launch, Hayabusa2 will arrive at Ryugu. Hayabusa2 will first make observations of Ryugu to determine a landing point. This will be followed by the release of the lander and rovers, touchdowns and the impactor experiment.

In 2017, more than one year before arriving at Ryugu, training for proximity phase operations started. There are two kinds of training; Landing Site Selection (LSS) training and Real-Time Integrated Operation (RIO) training.

LSS training started at the beginning of 2017. The purpose of this training is to verify the process for landing site selection, in particular, checking the decision making framework or criteria, tools and interface. A fictitious asteroid was made for the training, which we called "Ryugoid". Ryugoid is a 3D shape model of approximately 370 million polygons, which has various surface features such as craters, boulders, facets and dips. We also created fictitious observation data. The project members attempted to analyze the fictitious data without knowledge of Ryugu and finally selected a touchdown point to complete the training.

RIO training started in the latter half of 2017. The purpose of this training is to simulate various kinds of proximity phase operations in real time and to check the tools, procedures and operation times. There are several important proximity phase operations, such as low altitude operations, lander/rover release operations, touchdown operations and impactor operation. RIO training will continue up until the final approach phase.

The number of peer-reviewed papers related to Hayabusa2 that were published in FY2017 was 20, and cumulative number of peer-reviewed papers published to date is 96.

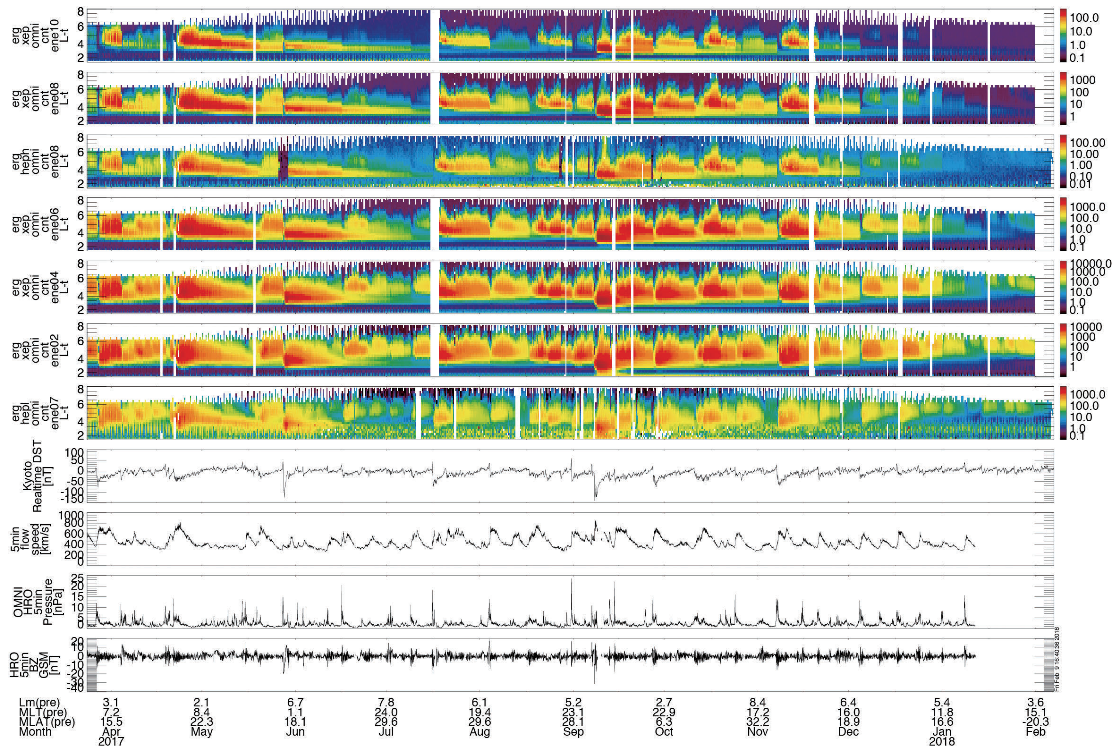
i. Geospace Exploration with ARASE

The geospace explorer ARASE (ERG) was developed as the second small science satellite of ISAS/JAXA in collaboration with universities and institutes in Japan and Taiwan. The ARASE satellite was successfully launched by the second Epsilon launch rocket on December 20, 2016, from the Uchinoura Space Center (USC) located in the southern part of Kyushu and initiated its regular scientific observation on March 24, 2017.

The Exploration of energization and Radiation in Geospace (ERG) is a science program intended to address when, where and how high-energy electrons in the Earth's radiation belts are generated and lost. Understanding the dynamic variation of the geospace is one of the most important issues in solar system science. The essential key observation of this program is using the ARASE satellite to conduct detailed in-situ measurements of particles and electromagnetic fields in the radiation belts with monitoring the global variation of geospace by the ground measurements, such as network observatories of radar facilities, aurora cameras and magnetometers. The ERG program also prepared strategic joint-observations with NASA Van Allen Probes. The ERG program challenges the scientific mysteries of the radiation belts by these organized observations. Coming scientific results from ARASE are also expected to contribute to improvements in space weather forecasting.

ARASE is designed as a spin-stabilized satellite with a rotation rate of approximately 7.5 rpm. Given its perigee altitude of approximately 400 km and apogee altitude of approximately 32,000 km, ARASE can cover all radiation belts in its orbit. The orbital period is approximately 570 minutes at an inclination of approximately 31°. The satellite system and all the onboard mission instruments are in good condition and all the mission instruments achieved their expected performance as designed. ARASE is providing us with data from comprehensive observation of the radiation belts.

The ARASE satellite has successfully captured dynamic variations in relativistic electron fluxes in the radiation belts during magnetic disturbances associated with the solar wind disturbances, including various types of magnetic storms. In particular, ARASE is observing continuous electron energy spectra from 19 eV to 20 MeV and continuous electromagnetic waveforms from DC to 20 kHz in the radiation belts, which are indispensable for better understanding the mechanisms behind dynamic variations of the radiation belts. Based on the observation results from the ARASE satellite and its related ground observations, ERG program team members are now advancing their data analysis research and preparing to publish initial scientific results in peer-reviewed international journals.



A summary plot of the ARASE observation that presents time and spatial variations of energetic electrons during the interval from March 2017 to January 2018. The top seven panels indicate electron fluxes in energy of which are 3.9, 2.5, 2.0, 1.7, 1.1, 0.7, 0.4 MeV. The vertical and horizontal axes of each panel represent the distance from the Earth and time. The electron flux intensities are color-coded. The bottom three panels show the solar wind speed, pressure and the north-south component of the solar wind magnetic field. The figure shows that variations of high energy electrons in the outer radiation belt correspond to the solar wind disturbances.

j. Mercury Exploration with BepiColombo/MMO

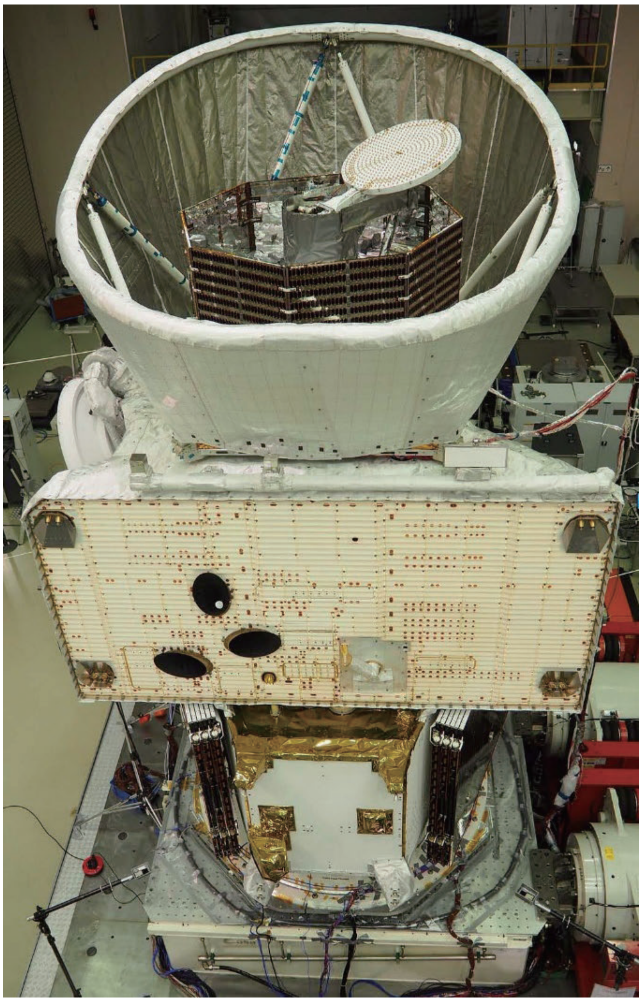
Although the size of Mercury is between that of the Moon and Mars, it unexpectedly has an intrinsic magnetic field. This was discovered by the Mariner 10 spacecraft during three flybys and was confirmed by NASA's Mercury orbiter MESSENGER, which completed its mission in May 2015 as planned by deorbiting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

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

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

The final assembly, integration and verification (AIV) test (Acoustic test, Sinusoidal vibration test, and EMC test) for the MCS at the ESA European Space Research and Technology Centre (ESTEC) was completed over May – September 2017. The MTM thermal vacuum test was completed in November, having been postponed from December 2016 due to a problem with MTM's power processing units in September 2016, which caused the launch window for BepiColombo to be shifted from April 2018 to October 2018. Each module will be transferred to the launch site (CSG) in April - May 2018 and BepiColombo will be launched by an Ariane-5 rocket in the October – November launch window. BepiColombo will arrive at Mercury in 2025.

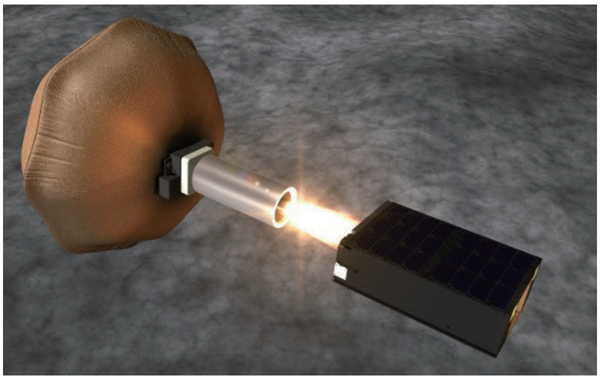
Two peer-reviewed papers related to the BepiColombo project have been published in FY2017.



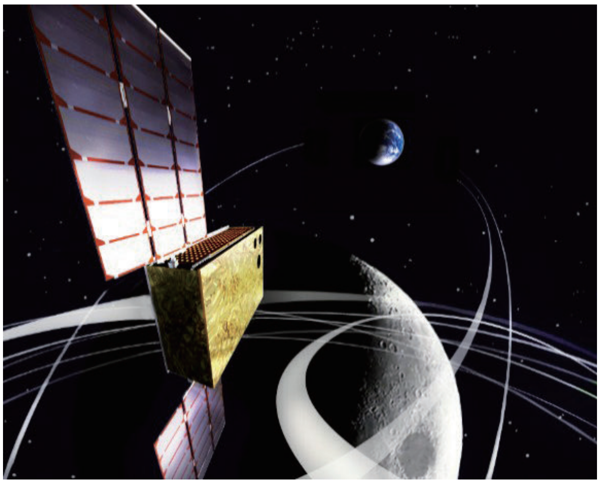
(c) ESA / JAXA

MCS (Mercury Cruise System) vibration test at ESTEC.

k. SLS CubeSats: OMOTENASHI and EQUULEUS



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



Artist's concept of EQUULEUS observation from L2.

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

OMOTENASHI demonstrates technologies for the world's smallest moon lander and observes the radiation environment. To achieve a moon landing by a CubeSat, a semi-hard landing scheme has been developed. The landing speed is controlled to approximately 30 m/s using a small solid rocket motor and gas jet propulsion units. We have also developed a shock absorption mechanism consisting of an airbag, crushable material and epoxy filler. The radiation environment will be measured by commercial portable dose meters.

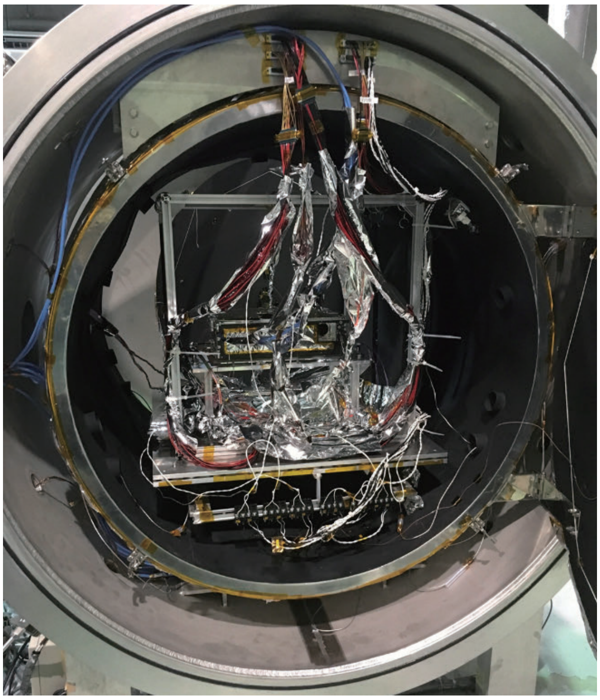
EQUULEUS has four missions. The primary, engineering mission is the demonstration of the trajectory control techniques within the Sun-Earth-Moon region by a nano-spacecraft during the flight to the Earth—Moon Lagrange point L2. A water resistojet propulsion system has been newly developed for trajectory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

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

Some impact tests for the OMOTENASHI shock absorption system were conducted at JAXA's Kakuda Space Center and Shimokita Test Center operated by the Acquisition, Technology & Logistics Agency, to ensure the shock acceleration is smaller than 3,000 G when impact velocity is less than 30 m/s. A small solid-fuel rocket motor and other instruments for OMOTENASHI were also developed and tested.

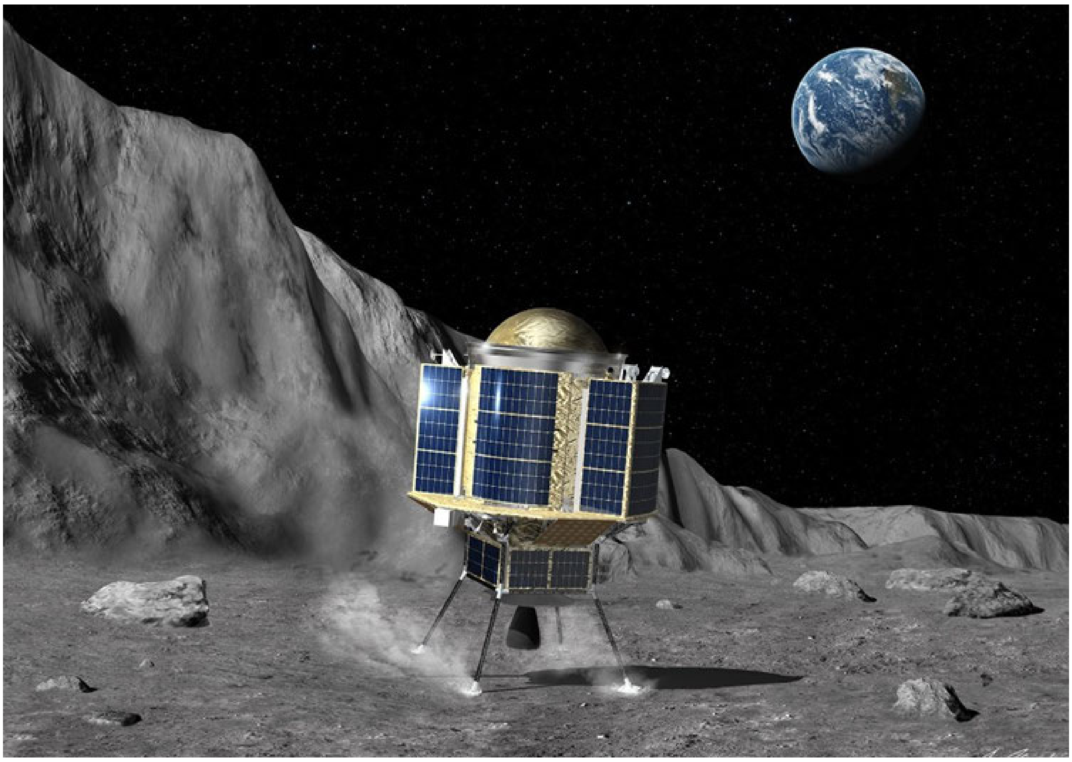
Development, integration and environmental testing for the engineering model for EQUULEUS were conducted at the University of Tokyo. The test results will be integrated into flight model development.

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



Thermal vacuum test for the engineering model for EQUULEUS

I. The Smart Lander for Investigating Moon (SLIM)

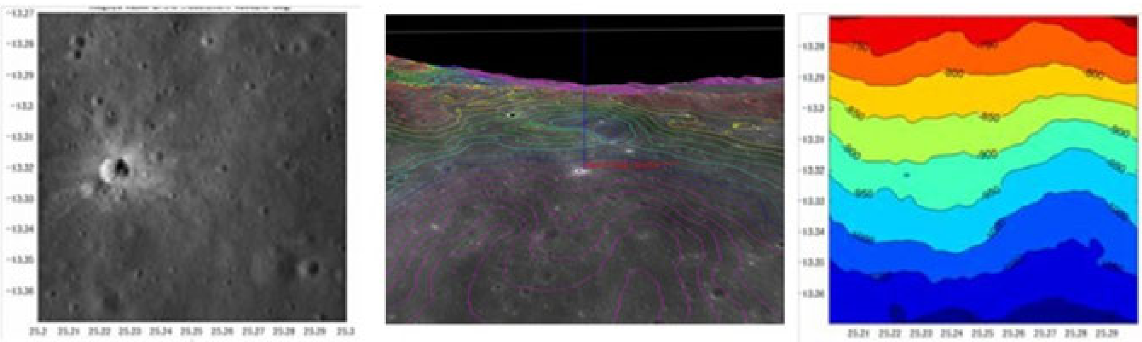


Artist's impression of the SLIM landing on the Moon.

The Smart Lander for Investigating Moon (SLIM) mission, which was authorized by JAXA along with the formation of the project team in April 2016, will demonstrate precise "pinpoint" landing technology on the lunar surface as well as several technologies for developing small, lightweight exploration spacecraft. During FY2017, the project team focused on adopting environmental changes after the HITOMI (ASTRO-H) anomaly. To minimize the project risk with limited resources, the project team and JAXA performed an extensive trade-off analysis on the launcher. Suitable spacecraft configuration, schedule and cost were investigated and evaluated for two scenarios, 1) a single launch with an Epsilon rocket, and 2) a dual launch, XARM + SLIM, with a H-IIA rocket. In the end, the project team submitted a proposal to ISAS and JAXA to change the launcher from an Epsilon rocket to a H-IIA dual launch and the proposal was authorized.

Conducting an accurate and safe landing on the target is an essential objective for the SLIM project, along with the scientific observations to be conducted after landing. Thus, the guidance, navigation, and control schemes required for such pinpoint landings were and are being studied intensely, with special attention being paid to the category of robustness. Since image based navigation systems are a key technology for pinpoint landing, numerous simulations were carried out to evaluate accuracy and robustness. The tested algorithm was used on a space-grade FPGA to check feasibility and validity.

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



View and topographical appearance of candidate landing point.

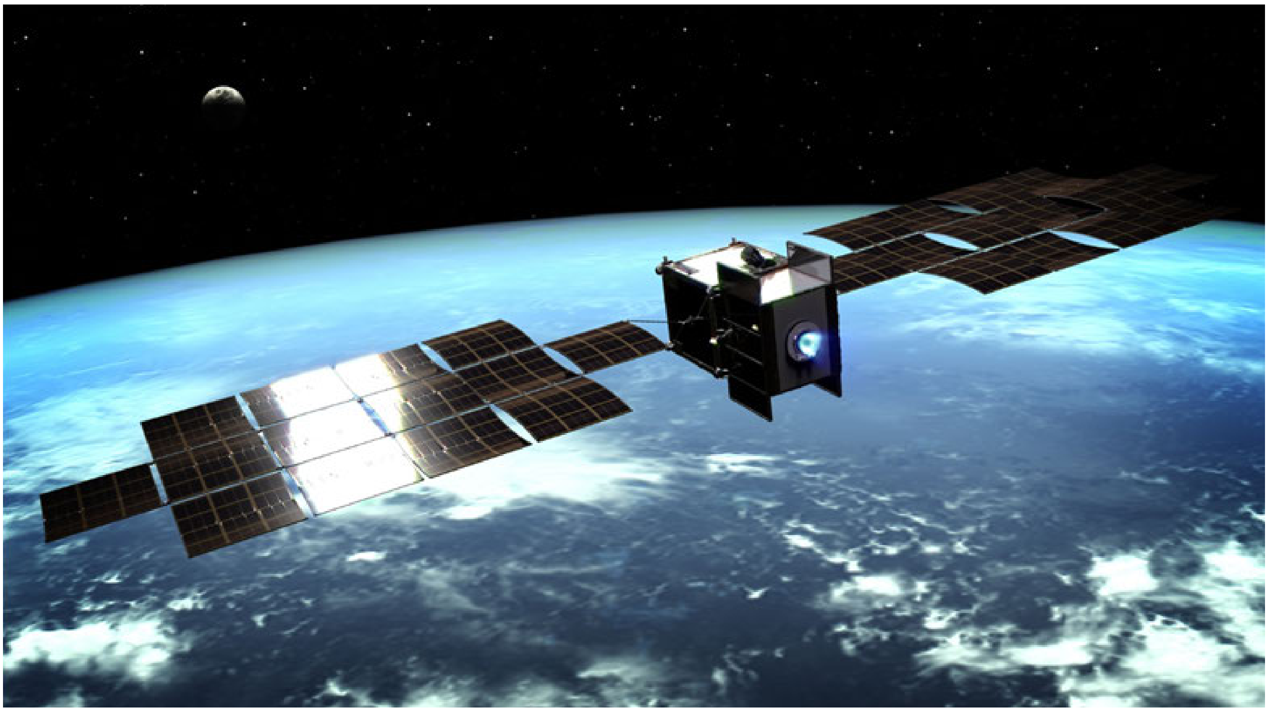
m. X-ray Astronomy Recovery Mission (XARM)

The ASTRO-H mission was designed and developed through an international collaboration between JAXA, NASA, ESA and the CSA. It was successfully launched on February 17, 2016, and then named HITOMI. During the in-orbit verification phase, the on-board observational instruments functioned as expected. The intricate coolant and refrigeration systems for soft X-ray spectrometer (SXS, a quantum micro-calorimeter) and soft X-ray imager (SXI, an X-ray CCD) also functioned as expected. However, on March 26, 2016, operations were prematurely terminated by a series of abnormal events and mishaps triggered by the attitude control system. These errors led to a fatal event: the loss of the solar panels on the HITOMI mission. The X-ray Astronomy Recovery Mission (or, XARM) is proposed to regain the key scientific advances anticipated by the international collaboration behind HITOMI. XARM will recover this science in the shortest time possible by focusing on one of the main science goals of HITOMI, “Resolving astrophysical problems by precise high-resolution X-ray spectroscopy". This decision was reached after evaluating the performance of the instruments aboard HITOMI and the mission’s initial scientific results and considering the landscape of planned international X-ray astrophysics missions through 2020 and 2030.

HITOMI opened the door to high-resolution spectroscopy in the X-ray universe. It revealed a number of discrepancies between new observational results and prior theoretical predictions. Yet, the resolution pioneered by HITOMI is also key to answering these and other fundamental questions. The high spectral resolution realized by XARM will not offer mere refinements; rather, it will enable qualitative leaps in astrophysics and plasma physics. XARM has therefore been given a broad scientific charge: “Revealing material circulation and energy transfer in cosmic plasmas and elucidating the evolution of cosmic structures and objects". To fulfill this charge, four categories of science objectives that were defined for HITOMI will also be pursued by XARM; these include (1) Structure formation of the Universe and evolution of clusters of galaxies; (2) Circulation history of baryonic matters in the Universe; (3) Transport and circulation of energy in the Universe; (4) New science with unprecedented high resolution X-ray spectroscopy. In order to achieve these scientific objectives, XARM will carry a 6 by 6 pixelized X-ray micro-calorimeter on the focal plane of an X-ray mirror assembly and an aligned X-ray CCD camera covering the same energy band and a wider field of view.

In 2017 the XARM pre-project team was initiated and has conducted the system feasibility study and the system definition activity. Based on the mission requirements and system requirements, the system specifications were drafted for the System Definition Review planned in early 2018. The XARM mission will be a joint project of JAXA and NASA with the contribution of ESA.

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



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

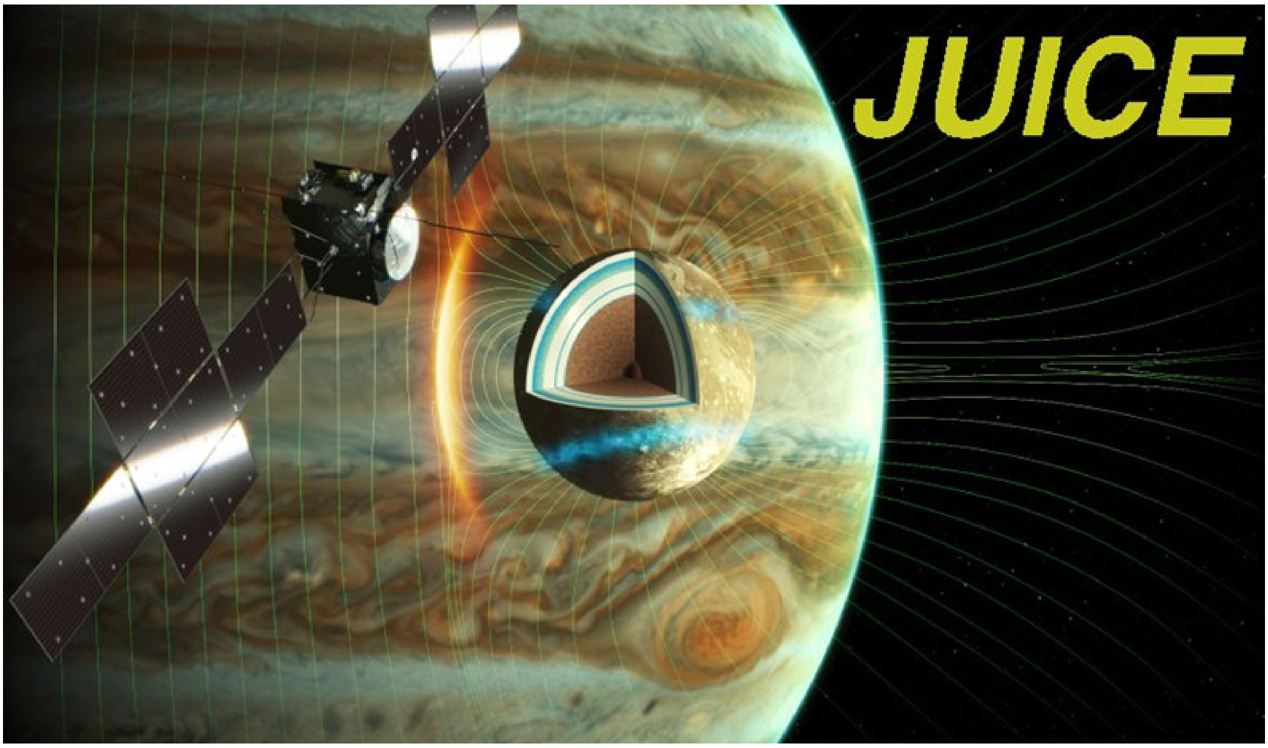
DESTINY$^+$ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) is a candidate of the ISAS Epsilon-class small program. The DESTINY$^+$ is a joint engineering and science mission. The mission has the following two engineering mission objectives;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

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

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

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

o. Jupiter Icy Moons Explorer (JUICE)



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

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

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

JUICE-Japan became an ISAS project after passing an ISAS project transition review in December 2017. A preliminary design review (PDR) was also held between December 2017 and March 2018. The instrument team tested BBMs (Bread Board Models) and designed engineering models (EMs) of their hardware without any major delays. A critical design review (CDR) is scheduled for FY2018. JUICE is a long-term mission that will continue for approximately 20 years. To make Japan's participation in JUICE successful, it is very important to plan for project continuity as the project team makeup changes over time.

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

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

Fig.1 One possible MMX spacecraft configuration with a launch mass of 3,400 kg. It has three main modules for sample return, exploration, and propulsion. Nominal mission duration is 5 years.

Mars is the outermost rocky planet in the solar system, and Phobos and Deimos are its two moons. Martian Moons eXploration (MMX) is a mission under study to be launched in the early 2020s. The mission is to survey the Martian moons and return samples from one of them. The goal of the mission is to reveal the origin of the Martian moons and advance our understanding of planetary system formation and of primordial material transport around the boundary between the inner and outer parts of the early solar system.

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

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

International collaboration is frequently discussed to realize a "world best" line-up of scientific instruments on MMX. As a result, NASA and Centre National D'études Spatiales (CNES, France) have agreed to provide onboard equipment (a neutron/gamma ray spectrometer from NASA and a near-infrared spectrometer from CNES). We will continue to steadily work toward realization of the project with international cooperation (NASA, CNES, and possibly other agencies).

Management reviews were held in December 2017, and the project phase-up was approved. Preliminary design will continue up until the end of next year.

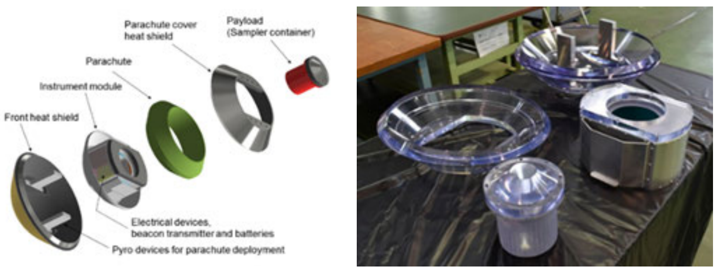


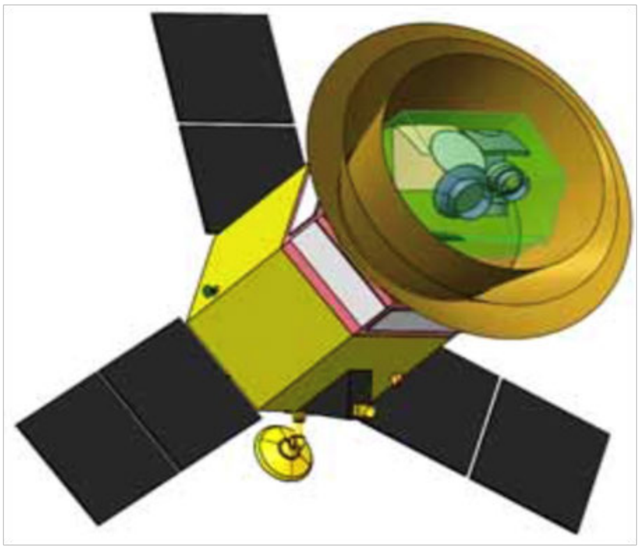
Fig. 2 (left) Conceptual figure of the sample return capsule. (right) Bread Board Model of the capsule.

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

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

Following the international science review and the planning review in 2016, the mission definition phase (pre-phase A) started in September 2016 and will continue for two years up until August 2018. In FY2017, various studies and developments were conducted to reduce technical and programmatic risks. Frequency sharing between the LFT and HFT were revised with an increased number of detectors. Scan parameters of the sky were also reoptimized. Thermal and mechanical design of the telescopes was greatly improved with the introduction of V-groove and the reduced heat-load to the cooling chain increased its feasibility. Concept design of the holding mechanism and the launch-lock for the polarization modulator was developed, and design and fabrication of the real-size bread board model for the LFT polarization modulator is ongoing. In addition to the payload module, we developed a concept design for the service module with the system companies (see figure on the left). LiteBIRD needs to achieve unprecedented accuracy to detect the B-mode polarization. We also studied a feasible method of ground tests and calibration in Japan, which is essential to its success.

LiteBIRD is based on extensive collaboration in Japan and overseas countries. Major collaborative institutes and universities in Japan include, KEK (High Energy Accelerator Research Institute), Kavli IPMU (Institute for the Physics and Mathematics of the Universe) and Okayama University. In terms of international partners, in addition to the US and Canada, European countries have recently joined the LiteBIRD collaboration with the involvement of ESA. The US is responsible for the focal plane detectors for both the LFT and HFT and Canada for the room-temperature readout electronics. Europe takes responsibility for the HFT and the sub-kelvin cooler. As a result, LiteBIRD will be a truly global project.



(C) Mitsubishi Electric Corporation (MELCO).
Artist’s impression of LiteBIRD

r. Solar Power Sail-craft (OKEANOS)

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

Achievements:

(i) We promoted development in accordance with the activity plan for Phase A1; (A) confirming feasibility of the spacecraft system and development of the key technologies; (B) maximizing the science achievement and; (C) promoting international cooperation.

(ii) (A) We investigated both Plan-A' (landing and multi-rendezvous) and Plan-B (landing and sample return) and identified feasible systems (Fig. 1). We investigated operation scenarios around a Trojan asteroid. We prepared manufacturing machines and materials for manufacturing the Bread Board Model (BBM) for the solar power sail (Fig. 2). We made progress in the interface design between the spacecraft main body and the deployment structure. We identified a strategy to mitigate curvature of the sail membrane structure and evaluated the impact on the membrane shape. We invited engineers from NASA to research better designs for the communication system. We concluded assembly of the BBM for the IPPU with a domestic manufacturer. In parallel, we estimated the mass, electric efficiency and cost of the IPPU in the event it was necessary to purchase it from overseas. We concluded laboratory experiments to confirm the function of the sampling mechanism for the surface and subsurface sampling (Fig. 3). We started development of a mass spectrograph to realize miniaturization.

(iii) (B) We held an international review for the Trojan science and received many constructive opinions and discussed a synergistic effect achieve through cooperation in the cruising observations.

(iv) (C) We constructed an international partnership with the LUCY team, Europe and the US. We received 8 proposals for observation equipment.

Outcomes:

(i) Academic journal published in FY2017: (7 papers). Total number of papers: 117.

(ii) The solar power sail is an idea originating in Japan, which has advanced technologies demonstrated in the HAYABUSA, Hayabusa2 and IKAROS missions taking advantage of Japan's technical capabilities. We will verify cruising and exploring techniques and realize "further, freer and more sophisticated" space exploration.

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

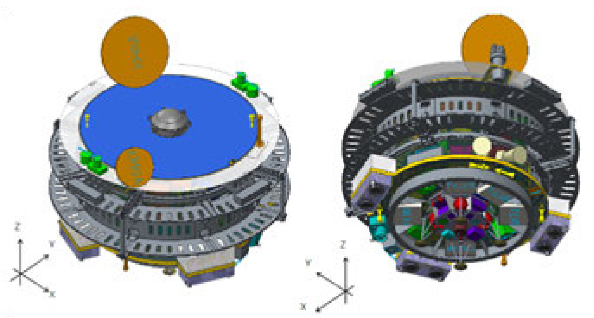


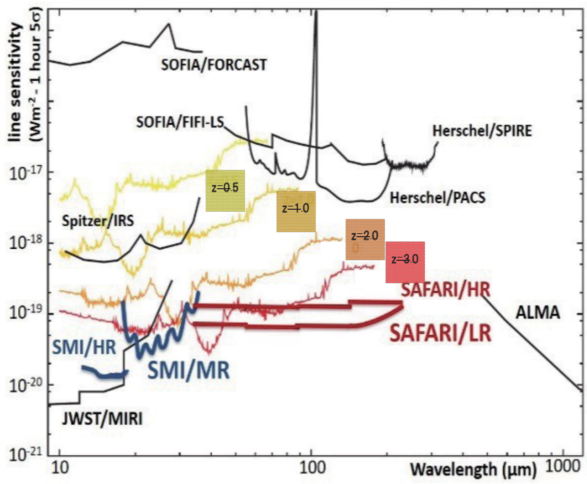
Fig.1 System design of Plan-B.

Fig.2 Preparation for manufacturing the BBM for the solar power sail.

Fig.3 Verification experiment for the surface and subsurface sampling mechanism

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

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



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

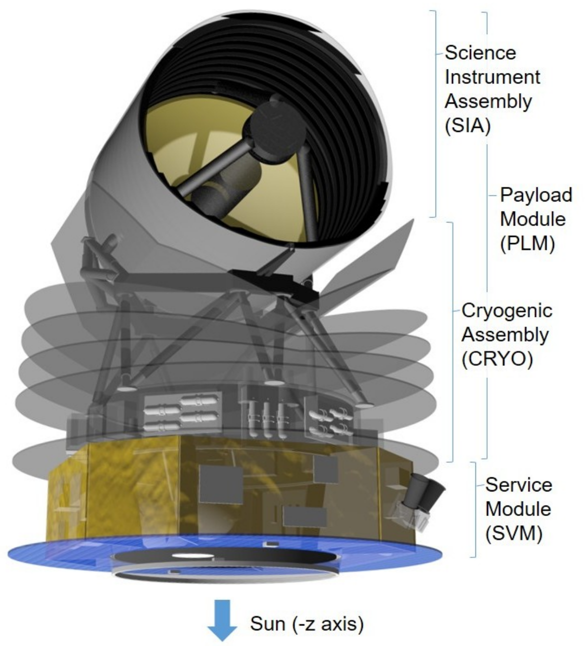
SPICA is an international collaboration led by ESA, in which ESA is responsible for the entire satellite system, the service module and the telescope while JAXA, as a major partner, is responsible for the integration of the payload module (PLM) with a cryogenic system and the launch operation. A series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

The proposal for the SPICA mission was submitted to ESA in October 2016 as a candidate for the 5th M-class mission (M5) of the ESA Cosmic Vision. ESA is expected to announce the result of the first down selection of M5 candidates in mid-2018. If selected, SPICA will go through an intensive study on its conceptual design in collaboration between ESA and JAXA.

In FY2017, the international SPICA team published six white papers summarizing SPICA's science objectives. In order to enhance the feasibility of the mission, the Japanese SPICA team vigorously promoted development of the critical technologies for PLM, cryocoolers and SMI. The SMI team progressed with the conceptual design on the basis of input from the SPICA Observational Instrument Advisory Board comprising of experts outside the team.

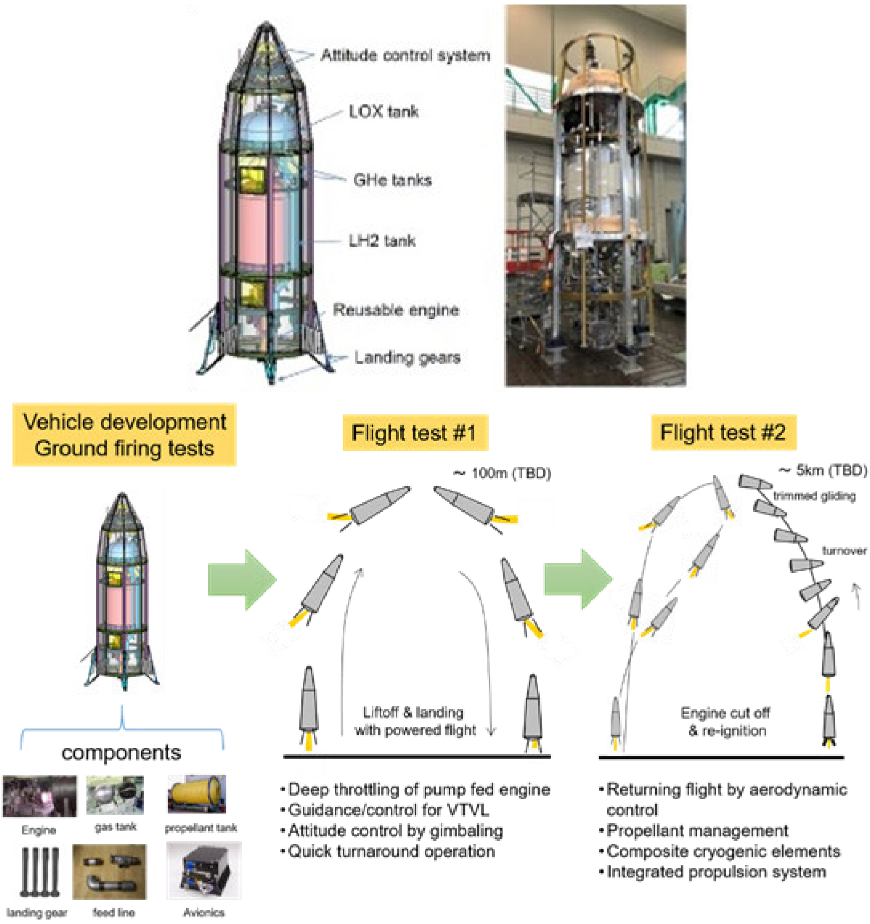
SPICA is expected to play a significant role by filling the wavelength gap of the next-generation observing facilities between the near-infrared (James Webb Space Telescope [JWST] and Thirty Meter Telescope) and the submillimeter (ALMA). The synergy among the next-generation facilities is indispensable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

SPICA spacecraft.



3. Other Programs

a. Reusable Rocket Flight Demonstration



Flight demonstrations by reusable rocket vehicle RV-X.

To make space access for scientific research much easier and increase opportunities for rocket launches, we have proposed a fully reusable sounding rocket. A reusable sounding rocket differs to the presently used expendable rockets. Some key technologies have matured sufficiently to advance the reusable sounding rocket project to Phase A. From 2010 to 2016, the following reusable vehicle technologies were verified: reusable engine development and repeated operation, reusable insulation development for the cryogenic tank, aerodynamic design and model flight demonstration for the return flight, cryogenic liquid propellant management demonstration, landing gear development and health management system construction. As a result, the subsystems required for a reusable sounding rocket were prepared for integration into a launch system.

After these technical demonstrations, a study for system-level verifications by a small flight demonstrator proceeded in FY2016. Objectives of the demonstrations are (1) system architecture study for repeated flight operation, including quick-turnaround operation and fault-tolerant design; (2) life-cycle management and frequent repeated use of a cryogenic propulsion system and its flight demonstration; (3) development of an advanced return flight method and vertical landing and flight demonstrations; and (4) demonstration of advanced technology for future reusable launch vehicles, such as increased onboard use of composites, in-flight fuel management, gaseous hydrogen/oxygen auxiliary propulsion, system health management and a high- performance engine with a long service life.

Design and development of a reusable rocket vehicle RV-X is in progress harnessing the technical outcomes obtained from ISAS RLV related studies. Two flight campaigns are planned in this flight demonstration study. In the first flight test campaign, we will demonstrate a pump fed and deep throttling engine, gimbaling attitude control for vertical landing by lift-off and landing with powered flight, a quick turnaround operation and so on. In 2017, the propulsion system tests were conducted at the Noshiro Rocket Testing Center to investigate the performance of thermal insulation for the LH2/LOX tank, etc. Three papers were published in FY2017.

b. R&D of the Nanosatellite Launch System (SS-520 F5)

The remodeled sounding rocket, SS-520 F5, was launched on February 03, 2018 and the nanosatellite, TRICOM-1R “TASUKI”, was also successfully injected into the low earth orbit. The aim of this rocket launch experiment was to confirm the performance of mass-produced products, which worked normally during rocket flight and in orbit. As a result, a variety of mass-produced products for the electronics were installed in the avionics and other components.

The first trial of this experiment with the SS-520 F4 in 2017 experienced problems with the power supply circuit in the rocket. Attempts to identify the cause were made through a fault tree analysis and it was believed that the electrical trouble was triggered by harness wire damage or problems with the heat resistance structure. Based on the results of the fault analysis, the rocket system for the SS-520 F5 mainly improved the architecture of the avionics.

A retrial of the experiment in 2018 was decided by ISAS and preparations were completed in approximately six months.

The SS-520 F5 test flight proceeded as planned. The sequence of events, including the attitude control system, called a rhumb line control system, the separation and spin operated as planned. The primary mission of TRICOM-1R was a Store and Forward mission. The satellite communicated with the ground station by the specified low power radio wave and data was communicated back and forth between the satellite and the station. The satellite also conducted earth observations using a small camera module for smart phones and the photo data was sent to the station.

The results of the successful flight of F5 showed that the cause of the failure in F4 was due to technical issues.

SS-520 F5 rocket on the launcher at Uchinoura space center

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

The GREAT antenna under development. (c) Mitsubishi Electric.

Pre-assembly of the antenna structure rotating around the azimuth axis.

Rib structures supporting panels of the main mirrors of the antenna.

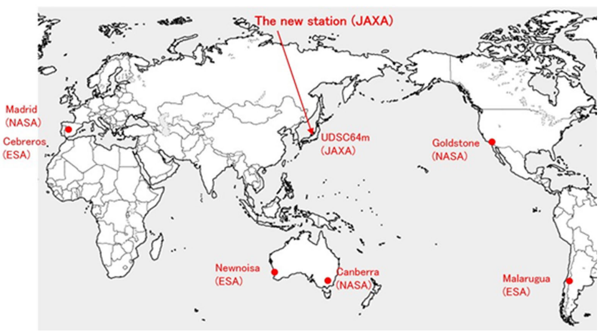
This project aims at developing a new ground station employing an antenna with a diameter of 54 m to follow our aged 64-m antenna at the Usuda Deep Space Center (UDSC). Despite its smaller dimensions, the new antenna will be capable of obtaining more data from spacecraft in our deep space activities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

We achieved the following results in FY2017.

We moved into the production phase of the antenna, low noise amplifiers and transmitter & receiver equipment following the successful completion of detailed design reviews on these sub-systems. We will proceed with our plan to start test operations of our system with Hayabusa2 in December 2019.

We also completed construction of the building for the power supply and the foundation of the antenna subsystem on the site located in the national forest area of Saku city in Nagano prefecture. This work was done through cordial coordination with the forestry agency and local governments.

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



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

Drone view of the site. The UDSC 64m antenna can also be seen behind the mountains.

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

Commercial wireless systems have taken full advantage of using solid-state technology instead of vacuum electron tubes for the purpose of low power consumption, high spectral purity and high reliability. Use of solid-state technology is a solution that contributes to easier maintenance and an appreciable reduction in the operation cost of ground stations. A new GaN solid-state power amplifier (SSPA) is under development by JAXA in 2016 for a 20-kW-class high power transmitter to go into a new 54-meter deep space ground station now under construction at Nagano prefecture. Transmitting RF characteristics was evaluated with a view to verify the performance of an extremely high power combining output. Details of the development and evaluation of the prototype are introduced in this report.

The 20-kW SSPA transmitter consists of a total number of 384 power amplifier (PA) modules and three types of n-way power combiners, a signal combination technique based on paralleled amplifier configuration. The exterior of the RF input section of a 14.7-kW X-band SSPA #1 (192 PA stacks) assembly is shown in Fig.1. The design of the SSPA adopted the use of commercially-off-the-shelf products - transistors and integrated circuits, DC-DC converter and control circuits - to save cost and time. In particular, a GaN high-electron-mobility transistor (HEMT) device was employed for PA modules to improve power consumption under limitation of the ground station power resource. The PA modules frequency range from 7,145- to 7,235-MHz was successfully prototyped with a 125-W power output and power added efficiency of over 40%. The final SSPA output of 25.1-kW yield a pair of 15.8-kW SSPA #1 and #2 assembly and 2-way waveguide combiner for this evaluation shown in Fig.2. The prototype of the SSPA transmitter is 2.35 m in width x 2.35 m in depth x 2.35 m in height, weighing 3.8 tons and power consumption of 368-kW.

The output RF characteristics were measured while varying the input level and center frequency according to required specifications of SSPA in order to judge feasibility. In January, we achieved maximum RF power output of 74.6 dBm (29-kW) at the input level of -1 dBm to satisfy the requirements. These results indicate that SSPA can be applied to ground station transmitters in the future.

Our future work will include the resolution of high power breakdown effects within microwave waveguide components, reduction of interference effects to a low noise amplifier at common feed by waveguide filter and also improving power gain and loss of SSPA through designs and experiments.

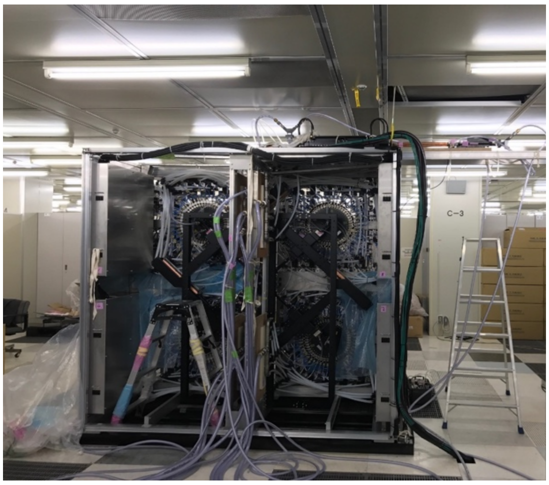


Fig.1 Exterior of input section of a 15.8-kW X-band SSPA #1 assembly.

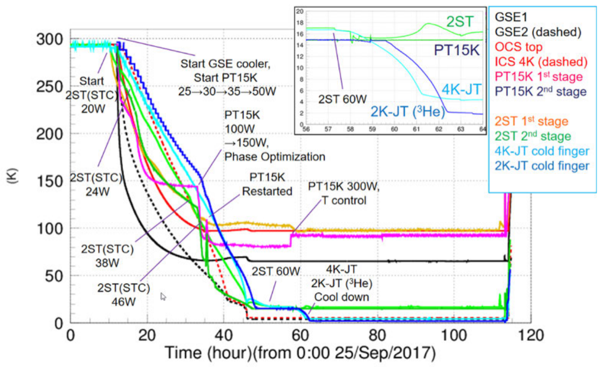
Fig.2 Pair of 15.8-kW X-band SSPA #1 and #2 output section.

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

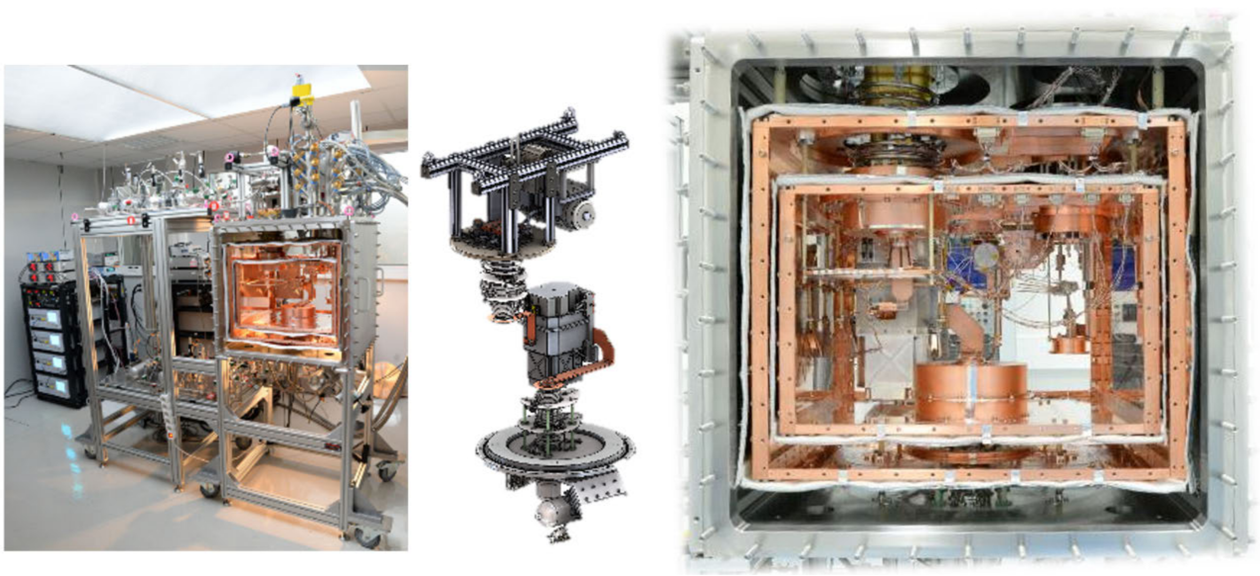
The CC-CTP is an international project aiming to demonstrate a detector cooling system, including a cryostat and active coolers, to reach temperatures as low as 50 mK. The European CC-CTP partners are financially supported by ESA, with CNES (France) and the French Atomic Energy Commission (CEA) leading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

CC-CTP will make three cryostats, and JAXA is expected to supply coolers for Cryostat #1, a concept study model, and Cryostat #3, which will be used on ATHENA. In 2016, JAXA's Joule-Thomson (JT) 4K and 2K coolers and related control electronics were transported to the CEA Grenoble premises. In 2017, post-shipment test of the 4K JT coolers were performed. 2K JT coolers were combined with a European pulse tube cooler as a precooler. The combination of Japanese and European spacecraft cooling technology was firstly confirmed at several heat loads, input power and cold-end temperatures. CEA's Hybrid coolers which will cool down from 2K to 50 mK were then installed and tested based on the Athena X-ray Integral Field Unit (X-IFU) concept, SPICA, and LiteBIRD operations. These results were sufficiently consistent with designed and expected performance and were presented at the European Cryogenics workshop.

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



Temperatures of several tests from 300 K to < 2K. Data taken at CEA (2017/9/25~).



Setup of the Cryostat 1 experiment at CEA. (Left) The cryostat with JT coolers and control electronics. (Middle) Schematics of the coolers. The hybrid coolers located at the center, 2K-JT are connected from the top and 4K-JT from the bottom. (Right) Close up of the actual cryostat. A GSE cooler is at the left-top.

f. Small Synthetic Aperture Radar for 100 kg Class Satellite

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

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

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

Deployable SAR Antenna Assembly Consists of Planar Slot Array Panels.

Vibration Test of SAR Antenna and Satellite Body

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

4. R&D at Research Departments

a. Department of Space Astronomy and Astrophysics

1. Overview

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

2. Research Activities in FY2017

2.1. High-energy astrophysics

In the area of observational research in high-energy astrophysics, the department conducted research using various X-ray and gamma-ray satellites, including SUZAKU and ASTRO-H. A review paper summarizing studies conducted over nine years was published in relation to the Wide-band All-sky Monitor (WAM) onboard SUZAKU. A study with WAM revealed that the spectral properties and the characteristic flux correlation observed for z~1 GRB are also shared with the higher redshift objects toward z~6.

More than 20 papers on ASTRO-H observational and technology development studies were published in 2017 in spite of the fact that data obtained from ASTRO-H was very limited. Among these, the results published in Nature, which brought a new insight in that the abundance of iron-peak elements in the hot gas in the Perseus cluster is similar to the solar abundance, was introduced as a research highlight. New tools for Monte-Carlo simulation in data analysis were also developed to enable comparison of theoretical models with the observational data obtained from ASTRO-H.

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

2.2. Infrared astrophysics

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

With the data obtained from AKARI, various studies of galaxy formation and evolution were carried out, including the NEP survey by SCUBA2 on JCMT, a study on anti-correlation between stellar population age and molecular gas contents in starburst galaxies and a study of the star-formation suppression mechanism for galaxies under ram pressure in the Virgo cluster. From infrared spectroscopic observations taken from AKARI, a study into molecular gas with high column density traced by CO absorption feature heated by AGN X-ray emission, a study of star-formation phenomena in the circumnuclear regions of AGN-starburst composite galaxies and a study of the substructures in molecular torus of AGN from the combination of AKARI results and Subaru high dispersion spectroscopy were conducted.

Studies of AGN were also conducted using various other methods. A study into the infrared spectra of the hot spots of radio galaxies using AKARI, WISE and Spitzer data was also carried out. A variability survey for AGN to search and study high-redshift low-mass black holes was conducted using Subaru HSC data.

Polarimetric observational studies on star-formation regions were extensively conducted. First, a unique observation to detect circular polarization was conducted to reveal the general properties of circular polarization in the high-mass star forming region as well as magnetic field structure and circumstellar structure. A study related to the origin of the homo-chirality of life was also carried out. The near-infrared and sub-mm wavelength polarimetric observations revealed the structure of the magnetic field over various scales of cluster forming regions, from the entire molecular clouds to the cores.

In relation to studies of star-forming regions, a large survey of molecular lines in the Cygnus region was also conducted using the Nobeyama 45m telescope to see the effects of UV emission due to star-formation activity on the molecules. For proto planetary disks, a study on the time scale of gas dissipation was conducted based on AKARI data. A study based on data from the Subaru Telescope, ALMA and infrared satellites to study mass-loss objects was also completed

As for studies of extra-solar planets and very low mass objects, the following studies were conducted; astrometry observations of M-dwarf binaries to constrain the evolutionary models of low-mass objects by comparison with dynamical mass, detection of icy planets beyond the snow lines using ground-based micro-lensing observations and optimization in planning the future WFIRST observations.

Studies of the objects in our solar-system were also conducted. The abundance and origin of the crystalline mineral formed under high temperature in comets was studied using mid-infrared observations from the Subaru Telescope. AKARI near-infrared spectra of asteroids were used in the study of the abundance of hydrated minerals, their evolution and correlation with the asteroid type.

We also conducted studies to improve calibration quality of AKARI data. Quantitative evaluation of the second-order lights mixed in the long wavelength in near-infrared grism spectra was obtained to collect for the effect, in order to achieve more accurate flux measurement. The variation of detector sensitivity due to the temperature change after the loss of helium coolant was also evaluated, which enables us to utilize the wider range of the observed spectra.

In parallel to the observational studies, basic development for future infrared technology was also carried out. The development of Immersion Grating for high-dispersion spectroscopy was continued in 2017, and the anti-reflection coating was improved to obtain much better efficiency of the gratings. We also succeeded in fabricating the 32x32-channel far-infrared sensor by combining the Ge BIB (Blocked Impurity Band) detector with silicon support with the ROIC for FD-SOI CMOS. In 2017, a demonstration model of the sensor was made by combining the Ge BIB detector and the ROIC using Au bump bonding. In order to test and evaluate the sensor array, we also designed the control electronics. We also made a prototype test array with a 128x128 format with infrared sensitivity based on the results of the development of the FD-SOI CMOS circuit.

We also conducted a study for the Japanese contribution to the WFIRST mission, which is the NASA flagship mission after JWST. An international workshop to discuss Subaru-WFIRST synergistic observations was held in 2017.

2.3 Fundamental physics

In relation to fundamental physics, studies into cosmic inflation based on the precise measurement of cosmic microwave background are being conducted. For this purpose, we are also conducting studies in relation to the development of the LiteBIRD mission.

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

Theoretical works in studying the interaction between matter and anti-matter were conducted to reveal Dipole enhancement of the protonium formation cross section in antiproton collisions with excited hydrogen atoms.

2.4 Radio astronomy

In the radio wavelength range, we performed a wide variety of observational research using domestic and foreign radio telescopes, such as the ALMA in Chile and the Very Long Baseline Array (VLBA) in the USA. We also advanced cooperative observations 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 FY2017, we used ALMA to search for intermediate mass black holes in the galactic central region to discover a promising candidate at the distance of 0.15pc from the galactic central black hole. In relation to Active Galactic Nuclei, studies on radio galaxies were also conducted to reveal the general properties of the jet acceleration region. These studies revealed a jet within the gamma-ray emitting region, a region 100pc from the nucleus.

In addition, research on the formation of stars and the development of inter-stellar matter was conducted through the single-dish observation of a molecular cloud and HI cloud using the 45-m telescope at Nobeyama and the 64-m antenna at Usuda.

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

2.5 Cryogenic system for science missions

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

3. Research Topics

The following outline lists all the Department of Space Astronomy and Astrophysics research activities during FY2017.

3.1 Research in X-ray and gamma-ray regions
3.1.1 Observational research
3.1.1.1 Stellar winds from massive star based on observations by SUZAKU
3.1.1.2 Study to establish the model of X-ray emission mechanism from cataclysmic variables with strong magnetic fields and application to the SUZAKU data to estimate the white-dwarf mass.
3.1.1.3 Study of emission mechanism of X-ray binary pulsars and application to the SUZAKU data
3.1.1.4 Observational study for soft X-ray background radiation
3.1.1.5 Study to search for "dark-matter feature" in cosmic X-ray background radiation with SUZAKU
3.1.1.6 Study of hot gas plasma in clusters of galaxies by using morphology of gas distribution of clusters in collision
3.1.1.7 Study of hard X-ray transits using SUZAKU WAM
3.1.1.8 Gamma-ray and polarization study with ASTRO-H SGD instrument
3.1.1.9 Development of MONACO simulator for astrophysical radiation
3.1.1.10 Rocket experiment for hard X-ray emission from Sun (FOXSI)
3.1.1.11 Studies in high-energy gamma-ray astronomy with Fermilab (USA)
3.1.1.12 Studies in high-energy gamma-ray astronomy with HESS TeV gamma-ray telescope
3.1.2 Developmental research for observational technology
3.1.2.1 Development of Si mirror substrate with high-temperature plastic deformation technique
3.1.2.2 Development of high angular resolution X-ray optics
3.1.2.3 Development of TES X-ray microcalorimeter for future space missions or ground applications
3.1.2.4 Development of X-ray CCD camera with extremely low background
3.1.2.5 Development of high-precision hard x-ray imaging spectrometer
3.1.2.6 Development of Compton camera for high-sensitivity gamma-ray observations
3.2 Research in the optical and infrared wavelength range
3.2.1 Observational research
3.2.1.2 Study of galaxy formation and evolution at the peak of star-formation history in the universe using multiwavelength observations at the NEP survey region
3.2.1.3 Study of the relationship between stellar population age and molecular gas contents in galaxies
3.2.1.4 Study of suppression of star-formation by ram pressure in clusters
3.2.1.5 Study of IR absorption feature in galaxy spectra
3.2.1.6 Study of particle acceleration at the hot spot of radio galaxies by mid- and far-infrared observations
3.2.1.7 Study of circumnuclear structure of Active Galactic Nuclei using AKARI data
3.2.1.8 Variability survey of AGN using with Subaru HSC
3.2.1.9 Infrared imaging study of nearby spiral galaxies
3.2.1.10 Optical and near-infrared study of protoclusters at high redshift
3.2.1.11 Study of galaxy evolution for WFIRST project
3.2.1.12 Study of the magnetic field structure in star-forming regions by polarimetric observations
3.2.1.13 Study of infrared circular polarization in star-forming region
3.2.1.14 Study of gas dissipation in peroto-planetary disks
3.2.1.15 Infrared and radio observations of inter-stellar matter in the Galactic massive star-forming regions
3.2.1.16 Study of young objects with mass loss
3.2.1.17 Astrometry study of M-dwarf binaries to constrain mass evolution models
3.2.1.18 Study of extrasolar planets by microlensing survey
3.2.2.19 Study of icy planets population beyond snow line
3.2.2.20 Subaru precursor observations for WFIRST microlensing survey
3.2.2.21 Study of diffuse emission with MIRIS (Korean IR instrument)
3.2.2.22 Study of star-forming region with MIRIS
3.2.2.23 Mid-infrared spectroscopic study for the dynamical evolution of the inter-planetary dust in the Solar System
3.2.2.24 Study of comet dust mineralogy with Subaru and AKARI mid-infrared observations
3.2.2 Developmental research for observational technology
3.2.2.1 Development of far-infrared imaging sensors using Ge blocked-impurity band/fully depleted silicon on insulator CMOS chip
3.2.2.2 Development of monolithic multi-layer interferometric filter
3.2.2.3 Development of mid-infrared immersion grating
3.2.2.4 Correction of second-order light contamination and improvement of spectral calibration for AKARI spectroscopy
3.2.2.5 Demonstration of cryogenic deformable mirror for wavefront correction in space-borne telescopes

3.2.2.6 Cryogenic system for space missions
3.2.2.7 Development of the instruments of CIBER-2, future rocket experiment for cosmic infrared background
3.2.3 Promoting Japanese participation in the NASA WFIRST program
3.3 Fundamental Physics
3.3.1 Experiment of precise control of interferometer using the 532nm laser
3.3.2 Theoretical study for the effects of radiation pressure in interferometer performance
3.3.3 Development of studies for large aperture long distance laser
3.4 Research in the radio wavelength range
3.4.1 Observational research
3.4.1.1 Promotion of radio astronomy observation using JAXA's tracking antennas, including 64-m antenna at Usuda
3.4.1.2 Identification of gamma-ray radiation region through VLBI observation of radiowave jets
3.4.1.3 Observation of dust clouds falling into black hole at center of galaxy using VLBI observation network
3.4.1.4 Observation of formation of stars in molecular cloud at center of galaxy using large millimeter- and submillimeter-wave radio telescope, such as ALMA
3.4.2 Developmental research for observational technology
3.4.2.1 Study of scientific goals and observation systems for radio astronomy project, where, for example, low-frequency radio astronomy, submillimeter wave astronomy and space VLBI are expected to be used
3.4.2.2 Design and development of experimental craft for balloon VLBI flight
3.4.2.3 Technological study for GREAT, new ground antenna station for deep space exploration

b. Department of Solar System Sciences

1. Overview

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

2. Research Activities in FY2017

2.1 Solar physics

HINODE, which has been in orbit for eleven years, has made significant contributions to our understanding of observational solar plasma physics as well as fundamental problems such as coronal heating and flare triggering mechanisms. A typical example, which was published this year, is the new knowledge that gas convection and turbulence in the photosphere (the solar surface) is the ultimate origin of both coronal heating and the dynamic magnetic activity of the Sun. In this case, we developed a scheme to look into fine structures of the gas dynamics in sub-arcsecond scale with a correction of HINODE telescope's imaging performance. High-resolution data collected by HINODE enabled us to visualize high-speed downflows developed at the boundary (intergranular lane) of convection cells. Such high-resolution diagnostic capabilities enable comparisons with radiative magnetohydrodynamic (MHD) simulation modeling of a convection cell, from which validation of the numerical modeling, as well as the development of a new analysis method for wave excitation within a convection cell, are expected to emerge.

But what will be the shape of solar physics in the 2020's? The solar physics community has made efforts to propose new solar missions for launch in the 2020's, in addition to new instrument developments via sounding rockets and balloon experiments. The Next Generation Solar Physics Mission (NGSPM) Science Objectives Team (SOT) is an international advisory team supported by JAXA, NASA and ESA to discuss the space mission aspect.

Led by T. Shimizu from ISAS, the team had studies and discussions aimed at; (1) listing the high-priority objectives and tasks of science that need to be addressed in relation to next-generation solar physics; (2) listing the high-priority instruments required for those high-priority science items and; (3) developing ideas for the international framework necessary to implement missions that will fly those instruments. The final report was delivered to JAXA/NASA/ESA in July 2017, in which three of the highest priority instrument packages (high resolution coronal/transition-region spectroscopic telescope, high resolution coronal imager and a large telescope for diagnosing magnetic field and dynamics at the chromosphere and photosphere, in order) have been identified and their science rationale, as well as the recommendations for mission architectures that will fly the instruments.

As a conclusion from series of discussions in the solar physics community and the NGSPM-SOT report, the community has given its highest priority to the mission concept that will fly a high-resolution coronal/transition-region spectroscopic telescope for diagnosing EUV/VUV spectral lines emitted by a seamless temperature range of plasma existing from the chromosphere to the transition region and corona and super-hot plasma created during solar flares. This mission concept, Solar-C_EUVST, was proposed to ISAS as a candidate for a competitively chosen M-class mission in January 2018. The scientific objectives are to understand how fundamental processes lead to the formation of the solar atmosphere and the solar wind and to understand how the solar atmosphere becomes unstable, releasing the energy that drives solar flares and eruptions, by investigating the energy and mass transfer from the solar surface to the solar corona and interplanetary space. This mission is now positioned at the center of the solar research roadmap in Japan and also has strong support from the US and European communities.

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

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

Development of the readout and data-recording electronics for the focal-plane X-ray CMOS pixel detector was successfully carried out for FOXSI-3 (Focusing Optics X-ray Solar Imager 3; to be launched in 2018), which is another NASA sounding rocket experiment.

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

2.2 Space plasma physics

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

One of the remarkable results is that we successfully investigated details of the solar wind-magnetosphere interaction occurring at the outer boundary of Earth’s magnetosphere, based on a combination of MMS observations and large-scale computer simulation. We have revealed that as a result of velocity shear-driven instability excited along the outer boundary, more vigorous magnetic reconnection is induced, which in turn generates micro-scale plasma tornados, leading to turbulent entry of solar wind plasma into the magnetosphere. The rate of this turbulent plasma entry is found to be one order of magnitude higher than earlier predictions. The results are important for understanding how the solar wind plasma enters the magnetosphere, causes active aurora and leads to disruptions of geosynchronous satellites.

The Mercury Magnetospheric Orbiter (MMO) is a JAXA contribution to the BepiColombo Mercury exploration program. In FY2017 all the tests of full-assembled spacecraft in ESA/ESTEC were completed and transportation of the spacecraft to the launch site was approved. While development is complete, it has been recognized that not all the collected data will be downloaded to Earth, so a certain amount of science operation planning remains to be done. Accordingly, a team composed of younger scientists has begun to review the science scenario by referring to results from the MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) project. This planning activity is also paying substantial attention to the fact that there will be opportunities for two-spacecraft observations in the planetary magnetosphere.

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

SS-520-3 is a sounding rocket which will be launched from Spitsbergen, Norway. The scientific purpose of SS-520-3 is to understand ion upflow phenomena in the dayside polar cusp region. Mechanical fit checks, electrical interface checks, and environmental tests of SS-520-3 were performed in 2017. Although the SS-520-3 launch was scheduled between December 6-19 2017, a mal-function of the timer equipment was detected during the final stage of the integration test. Since the problem could not be rectified by the deadline for transportation of SS-520-3 to the launch site, the launch was postponed until winter in FY2019 or later.

We are also participating in two sounding rocket missions (RockSat-XN and LAMP) operated by NASA, in order to reveal the relationship between the pulsating aurora and microburst precipitation of MeV-range electrons. RockSat-XN and LAMP will be launched in FY2018 and FY2019 respectively.

The results of ARASE (ERG) are described elsewhere.

2.3 Atmospheric science

“HISAKI” satellite (SPRINT-A : Spectroscopic Planet Observatory for Recognition of Interaction of Atmosphere) was launched in September 2013 and has been making observations of plasma distribution in the magnetosphere and/or ionosphere of planets, including Jupiter and Venus since December 2013. Collaborations with the Hubble Space Telescope and X-rays observation satellites, such as Chandra, XMM-Newton and SUZAKU were carried out in order to observe Jupiter’s magnetosphere from a new perspective and a unique framework in January and April 2014. The scientific results produced by the cooperative observation with NASA’s Jupiter spacecraft JUNO (since 2016) showed HISAKI’s potential to provide continuous observations. Collaborative investigation using the “HISAKI” data promotes international cooperation (since 2016) in some international frameworks, including the Participating Scientist Program by NASA, the international study team at ISSI (the International Space Science Institute) and the SAKURA program (Japan-France Integrated Action Program) run by JSPS (Japan Society for the Promotion of Science). The collaborative studies show the important presence of Japan in the full-scale Jupiter magnetosphere exploration. Two papers were published in the GRL special issue outlining JUNO’s initial results. The two papers dealt with the role of solar wind in the energy acquisition and release processes in the Jupiter magnetosphere. The results were obtained by the in-situ solar wind observation by JUNO before and after arrival in Jupiter’s orbit and ongoing observations of Jupiter by “HISAKI”. The long-term consecutive observations, one of the characteristics of “HISAKI”, enabled us to observe the Jupiter magnetosphere at the time of Io’s volcanic eruption. The observations discovered that oxygen atoms produced by sublimation of the sulphur dioxide of the volcanic ejecta forms the atmosphere of Io for approximately 100 days. The result also demonstrated that observations made by HISAKI” can study the temporal variation process in a time scale as long as 100 days. Furthermore, it is expected that the variation of Io surface material distribution can be studied further in the future. The high wavelength resolution, another characteristic of "HISAKI", enabled us to identify some emission lines of the extreme ultraviolet wavelength in the Venus atmosphere for the first time. The long-term observation, spanning approximately 20 days worked well. In comparison with Earth and Mars atmospheres, Venus’ atmosphere shows largely different physical properties in the thermosphere, such as temperature and atmospheric pressure, but at the same time, the extreme ultraviolet spectrum is similar between the Venus atmosphere and Earth and Mars atmosphere, which suggests similarities in the chemical properties. "HISAKI" continues collaborative observations of Jupiter with JUNO at the time of JUNO’s peri-Jove passage in order to study transportation of energy and material in the Jupiter magnetosphere. "HISAKI" will also continue collaborative observation of Venus with the Venus climate orbiter, AKATSUKI in order to study the evolution of Venus’ atmosphere.

The results of AKATSUKI (PLANET-C) are described elsewhere.

2.4 Planetary science

The Hayabusa2 mission, which is expected to return samples from the C-type asteroid named 162173 Ryugu, is ready for its final approach and has conducted its first light observation of Ryugu by the ONC-T camera in February 2018. A series of Landing Site Selection Process (LSSP) training have been performed for all the remote sensing data acquisition, analysis and evaluation in a short time. A series of Real-Time Integrated Operation (RIO) Training continued until the beginning of FY2018 in order to check and improve procedures and personnel performance for all the critical operations, such as touchdowns. Establishment of the Curation Facility for the Hayabusa2 sample to be returned in 2020 started in the form of building a new clean room and fabricating a set of clean chambers, including a new technology to pick samples in a vacuum environment. The Martian Moons eXploration (MMX) project, the Phobos sample return mission, is in preparation for launch in 2024. Its science and instrumentation are under study, with international collaboration on a near-infrared hyperspectral imager and a gamma-ray and neutron spectrometer. Japanese participation to the Jupiter Icy Moons Explorer (JUICE) and the Demonstration and Experiment of Space Technology for INterplanetary voYage (DESTINY$^+$) project, an M-class planetary mission driven by a dust science theme, are expected to ramp up soon. In addition, a solar power sail mission (OKEANOS) to rendezvous with and land on a Jupiter Trojan is under intensive study for the science and its enabling instrumentation with international collaboration. A study for the CAESAR mission, a finalist for NASA's New Frontier mission to return samples from comet 67P/Churymov-Gerasimenko is ongoing.

All these exploration missions are targeting small bodies born “outside the snowline”, which refers to the distance from the sun where water, ammonia, methane, carbon dioxide, carbon monoxide, etc. become cold enough to condense into solid ice grains. We have formulated a roadmap that describes how these multiple missions are linked together and why such a systematic approach is needed. The key issue is that it is these small bodies, born outside the snowline, that somehow “switched on” the habitability of Earth, which was born inside the snow line, and thus was born dry. Without a supply of water and other volatiles (including organic compounds) delivered by small bodies from outside the snow line, our planet would never have become habitable. However there are still some fundamental questions remaining: when, specifically at which stage of solar system evolution (from comet to primordial asteroid) and in what form (the small body itself or via dust), did this process occur? Furthermore, is it possible for habitability to be established on worlds outside the snow line?

A penetrator hard lander system which enables us to investigate the internal structure and to make in-situ observations on the surface of the Moon and planets is under development. We proposed an M-class mission which deploys one penetrator system on the Moon to determine the crustal thickness and the heat flow. Using this technology, we are also developing a penetrator system for Earth's monitoring of volcanic activities for the purpose of disaster prevention. For future missions, an advanced penetrator technology which can be used for lunar polar region and icy satellites is under investigation.

The SLIM project team conducted detailed analyses of landing site candidates and preliminary design of the bus systems and instruments during FY2017. Our department contributed to the data analyses for selecting landing sites suitable for the scientific interest and technology requirements for landing. Based on the results of these analyses, the SLIM project conducted landing site selection studies. To develop the Multiband Camera, preliminary designing, evaluation of a candidate detector and other studies were conducted. Based on these results, we conducted the PDR for this instrument. The biggest challenge is to develop an instrument having the required performance within the tight resources (especially mass budgets) and severe lunar surface conditions (especially thermal conditions).

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

Internationally, it is recognized that "planetary protection" is one of the most important themes for future space exploration. We, ISAS, have started studying and working on planetary protection because we are planning a mission to a Martian satellite where lives may survive. We have been involved in establishing a standard and a review board for planetary protection.

3. Research Topics

The following outline lists all the Department of Solar System Sciences research activities during fiscal year 2017:

3.1 Solar physics

3.1.1 Solar observations: HINODE, HINODE-IRIS

3.1.2 Instrument development (photon-counting X-ray telescope, photon sensor driver, high-speed CMOS-based sensor, mechanisms), and future mission planning
3.1.3 CLASP, CLASP II
3.1.4 International balloon experiment SUNRISE-3
3.2 Space plasma physics
3.2.1 In situ and remote sensing observations: AKEBONO, GEOTAIL, REIMEI, MMS, KAGUYA, HISAKI, ARASE (ERG) and magnetosphere of outer planets
3.2.2 Sounding rocket: ICI-4, SS-520-3, RockSat-XN, and LAMP
3.2.3 Numerical simulations: PIC simulation for space plasma research and physics of proto-planetary disks
3.2.4 Instrument development
3.2.5 Future missions: BepiColombo (Mercury), JUICE(Jupiter), mission planning of a formation flying satellite FACTORS, satellite observation of exoplanets' atmosphere by UV, and satellite observation of Martian atmospheric escape
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: curation and analysis of Itokawa samples and in preparation for Ryugu sample, Hayabusa2 to the C-type asteroid 162173 Ryugu
3.4.3 Future missions: SLIM, DESTINY$^+$, penetrator technology, landing mission to the Moon and Mars, MMX (Phobos sample return), OKEANOS mission to Jupiter Trojan asteroid, CAESAR, the lunar and Mars cave missions, lunar sample return (HERACLES)
3.4.4 Instrument development

c. Department of Interdisciplinary Space Science

1. Overview

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

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

2. Research Activities in FY2017

2.1 Space utilization science

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

InGaSb crystals obtained in the Alloy Semiconductor Experiment on the ISS were analyzed in detail. The dissolution of the GaSb feed crystal occurred to a greater extent along the (111)B plane than along the (111)A and (110) planes. A static model was proposed that explains the variations in the dissolution of GaSb along different planes according to their ratio between the planar atomic density and the primitive dangling bond density of a GaSb unit cell.

In life sciences, the muscle oxidation activity decreased and the mRNA of PCG - 1α also decreased in the dormouse muscle that caused muscle atrophy in the activity restricted breeding. However, it was revealed that mRNA of PCG - 1α increases with temperature dependence at low temperature. Induction of simulated hibernation using drugs in rats was investigated and skeletal muscle changes analyzed. When rats were injected with 5'-AMP and kept at 20°C, hypothermia was maintained for about 4 hours with body temperature lowered close to the environment temperature and there is a tendency to suppress muscle atrophy even in simulated hibernation.

Under light and dark conditions, righting behavior in individual starfish was recorded and analyzed in an improved experimental system, less affected by mechanical stimuli (such as contact stimulus) not involving gravitational force. The results suggested that visual information is involved in righting behavior.

An astrobiology study, the "Tanpopo" experiment, which captures cosmic dust and exposes microbes to verify the Panspermia hypothesis, is currently underway in the Kibo exposure facility. Although the sample is being analyzed, the capture of cosmic dust from the capture experiment and the survival of microbes in the test environment have been confirmed.

To explore the viability of life in extreme environments such as the Moon and Mars, life science experiments in the Van Allen radiation belt and a hybrid flight system of balloon and drones ‘Barone’ were examined.

2.2 Research in information science and information technology

The department performed basic research on large-scale computation applied to spacecraft development and operations. Further analysis of the proposed speeding-up method on low memory bandwidth CPUs was conducted. In order to understand the speeding-up mechanism and applicable conditions, we evaluated this method with real application programs and confirmed its effectiveness. We have advanced the development of a hierarchical equally spaced cartesian structured grid solver and introduced Image Point to achieve high accuracy. Verifications and validations of the solver were conducted with laminar boundary layer flows on a flat plate and two-dimensional airfoil flows.

The department investigated methods of visualization and studies related to visualization. (1) In order to study the apparent variation of the brightness of Hayabusa2 during the Earth swing-by, a furbished shape model was investigated. The model consists of several components each of which is used to simulate the reflection of the corresponding part of the spacecraft. It turned out that the model is capable of simulating the variation of brightness during the Earth swing-by. (2) To visualize an asteroid simulant, a method to generate asteroid models was investigated. In this method, a variety of scientific knowledge is taken into account, such as the distribution of boulders and craters, geological attributes and thermal distribution, etc. The generated models have sufficient quality to be used in training for asteroid exploration. (3) In combination with the models described above, visualization methods were investigated to satisfy the requirements issued by the training. The methods include, for example, precise rendering that simulates optical instruments on board the spacecraft for scientific usage and rough and quick rendering for the simulator of the spacecraft, etc.

In the field of research into the data archive, we advanced development of Planetary Data System Version 4 (PDS4), the next generation world standard data archive for planetary explorations. We implemented the PDS4 data archive of the “Hayabusa2” project using public data at the time of the Earth swing-by carried out in December 2015. It was the first implementation of the PDS4 as a domestic mission. We urged NASA to include “urn:jaxa:darts” in the PDS4 master dictionary so that JAXA can be registered as an Agency. It was officially adopted in September 2017.

2.3 Research on scientific balloons

A super-pressure balloon was developed to expand the possibilities for scientific observations with balloons. This balloon can achieve long duration flights by maintaining lift and volume against differential pressure due to solar irradiation. Since 2010, an intensive effort has been underway to cover the balloon’s film with a diamond-shaped net to increase its resistance to pressure during the daytime. It has the advantage of being lighter than the conventional lobed-pumpkin design. This year, to reduce manufacturing costs and improve reliability, a new sewing method was developed and applied to a 2,000 m^3 balloon. The balloon showed pressure resistance of 1,020 Pa, twice the required pressure for this balloon and comparable to the value before the improvement. A 7,000 m^3 balloon was developed using this method for a demonstration flight. From the viewpoint of improving reliability, we also studied stability of the heat sealer to seal the balloon film and properties of the net, including the tensile strength and weatherability.

In space science research using balloons, detailed analysis of cosmic ray data obtained during balloon flights over the Antarctic in the Balloon-borne Experiment using a Superconducting Spectrometer was continued. The energy spectra of antiprotons, and the isotope abundance of primary protons and helium were reported.

In addition, the department continued the operation of CALET on the ISS to observe high-energy electrons, gamma-rays and other components of cosmic radiation. As one of our most important achievements, we identified half a million events of cosmic-ray electrons and positrons among the early phase data and determined the energy spectrum over a wide range from 10 GeV to 3 TeV. Possible structure observed in the higher energy region above 100 GeV motivates us to further investigate the spectrum with increased statistics and refined data analysis.

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

We also worked on plans for a balloon-borne experiment for microwave background radiation observations to study the early universe based on the polarimetry of microwave background radiation to detect primordial gravitational waves, which would directly prove the theory of cosmic inflation.

3. Research Topics

The following outline lists all the Department of Interdisciplinary Space Science research activities during FY2017.

3.1 Space utilization science
3.1.1 Materials science
3.1.1.1 High-temperature melt and metastable phase using levitation method
3.1.1.2 Research on crystal growth
3.1.2 Life sciences
3.1.2.1 Study on artificial hibernation for interplanetary flight
3.1.2.2 Response behavior to gravitational force
3.1.3 Astrobiology
3.1.3.1 'Tanpopo' experiment which capture cosmic dusts and expose microbes
3.1.3.2 Study on research and development to explore the survival of life in extreme environments such as Moon and Mars
3.2 Information science and information technology
3.2.1 Data archiving
3.2.1.1 Implementation of geographic information system-compatible observation data for Moon and planets
3.2.1.2 Development of international standard protocols for sharing planetary science data
3.2.1.3 Archiving data from Viking Mars probe
3.2.1.4 Archiving data about Earth's atmosphere
3.2.1.5 Application of machine learning to lunar and planetary probe data
3.2.2 Numerical simulation
3.2.2.1 Hierarchical equally spaced Cartesian-structured grid solver
3.2.2.2 Programming models for exa-scale supercomputers
3.2.3 Software and data
3.2.3.1 Efficient tool development
3.2.3.2 Web service for multidisciplinary research
3.2.4 Visualization and sonification of space science data
3.2.4.1 Visualization and sonification
3.2.4.2 Modeling methods
3.2.4.3 Applications of visualization and sonification
3.3 Scientific balloons and space science using balloons
3.3.1 Research on super-pressure balloons covered by net
3.3.2 Space science using balloons
3.3.2.1 Cosmic ray antiparticles using exotic atoms
3.3.2.2 Cosmic ray observations using superconducting spectrometer
3.3.2.3 Observation of high-energy cosmic-ray electrons and gamma rays
3.3.2.4 Research on early universe based on polarimetry of microwave background radiation

d. Department of Space Flight Systems

1. Overview

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

2. Research Activities in FY2017

2.1 Space navigation SE

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

2.2 Space transportation engineering

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

2.3 Discipline engineering

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

3. Research Topics

The following outline lists all the Department of Space Flight Systems research activities during FY2017.

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

e. Department of Spacecraft Engineering

1. Overview

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

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

2. Research Activities in FY2017

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 are also conducting a project on battery designs for low temperatures and electrochemical reduction electrolysis. We are continuing work on an energy carrier that uses renewable energy, based on previous research into fuel cells/renewable fuel cells. Furthermore, we evaluated the performance of the battery onboard the REIMEI spacecraft and determined the AC impedance trend for 11 years in orbit.

2.2 Communication technology

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

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

We developed a prototype for a GaN solid state power amplifier at X-band to be used at the new deep space station and obtained good results.

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 standard architecture (system construction principle). We developed a communication protocol called SpaceWire-R for connecting computers in spacecraft. We performed a test to evaluate this protocol jointly with the European Space Agency (ESA). This protocol is a candidate for a future JAXA design standard. In addition, we are establishing a space communications and data handling architecture as part of JAXA design standards so that we can standardize communications and data handling methods across various spacecraft. Furthermore, we are developing a method that uses modeling technology and a linguistic theory to enable development of databases that can store spacecraft specifications.

2.4 Navigation, guidance and control technology

We conducted research on a method for controlling landing equipment semi-actively and shock absorbing mechanisms, such as airbags as technologies for enabling the safe landing of spacecraft on the moon and planets. We also performed research on a method for searching for safe landing locations with good daylight conditions.

We developed a filter for high-precision attitude determination to be used for spinning spacecraft, based on an advanced Kalman filter for attitude determination used for three-axis stabilized spacecraft. This filter was applied to the operations of the spacecraft ARASE.

We performed research on the application of a magnetic levitation mechanism by magnetic flux pinning effects to spacecraft. The aim of this research is to shut out microscopic vibration disturbances and thermal transmission. This research will lead to deployment of new magnetic formation flight technologies.

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

2.5 Autonomous control and robot technology

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

We performed operations for the MINERVA-II rovers installed in the asteroid explorer Hayabusa2 and confirmed their health status. We also updated software for relaying data from the MINERVA-II rovers and European MASCOT rover in order to augment its functionality.

We made a proposal for a small separable probe to be installed in the SLIM spacecraft and conducted system studies.

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 FY2016, 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 the landing process and to measure relative distance for rendezvous in orbit. In FY2017, we enhanced the 16 × 16 pixel circuit to 32 x 32, prototyped a distance image sensor vertically coupled with an APD array and established a method to evaluate performance, such as breakdown voltage.

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 successfully while the ion engines were firing and were able to determine a precise orbit, contributing to the successful trajectory control of Hayabusa2 using ion engines. 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 are conducting a research activity to develop an X-band synthetic aperture radar (SAR) that can be installed on a 100-kg-class satellite. This was adopted as an ImPACT program of the Japanese government and its final goal is to develop a model for an SAR with resolution of 1m by fiscal year 2018. We developed engineering models for an antenna, a power amplifier for transmission and an X-band high-speed transmitter for sending observed data and verified that they have the desired performance. The X-band high-speed transmitter will be delivered to the innovative satellite technology demonstration program of JAXA to be launched in 2018 in order to conduct in-flight validation.

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 spacecraft, SLIM.

2.9 Space energy systems

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

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

3. Research Topics

The following outline lists all the Department of Spacecraft Engineering research activities during FY2017.

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

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

A total of 15 fellows have participated in the program so far, six of whom have since taken permanent posts in other institutes and universities. For FY2017, three new fellows were selected. ITYF fellows are encouraged to become involved in other projects as well as to pursue their own studies. These opportunities are expected to have a synergistic effect through interactions between the fellows and Japanese researchers at ISAS. Much as previous fellows have contributed to remarkable outcomes in the projects in which they were involved, our current fellows are not only making proactive contributions to ongoing projects, but are also actively engaged in forming future projects.

ITYF Fellows (as of March 31, 2018)

Name	Former Institute	Research Theme	Period
PERALTA, Javier	Instituto de Astrofísica de Andalucía (Spain)	Characterization of atmospheric dynamics by using "AKATSUKI" and "Venus Express"	April 2015 -
CRITES, Sarah	University of Hawaii at Manoa (US)	Evolution of the Solar System as Revealed by Remote Sensing of Small Bodies	July 2016-
IZUMI, Kiwamu	California Institute of Technology (US)	Observational gravitational wave astronomy	September 2017-
BONARDI, Stéphane	Massachusetts Institute of Technology (US)	Self-reconfigurable modular robots for space exploration: design and control	October 2017-
QUINTERO NODA, Carlos	Solar-B Project Research Associate/ JAXA	New insights on solar polarimetry as preparation for future solar missions: Sunrise/SCIP	November 2017-

The following shows ITYF fellows in FY2017 and their published research:

PERALTA, Javier
Research Highlights in FY2017

The atmosphere of Venus exhibits a remarkable spin that, at the region of the upper clouds (65-70 km above surface), can reach velocities sixty times faster than the underlying surface as measured on dayside images. This phenomenon, called superrotation, is not satisfactorily explained yet and most of Venus's atmospheric models fail to reproduce it accurately. Interestingly, the atmospheric circulation of Venus at the superrotating upper level has not been studied on the night side, except at the polar region. In our paper "Stationary Waves and Slow Motions in the Upper Clouds of Venus" (Nature Astronomy, 1, id. 0187 [2017]) we report the first measurements of the night side global atmospheric circulation of Venus at the upper cloud level (60-70 km) by tracking the apparent motions of cloud features in thermal emission images at 3.8 and 5.0 µm, taken during 2006-2008 by the VIRTIS instrument onboard ESA's Venus Express, and in 2015 with the SpeX instrument on NASA's IRTF telescope. Our results contradict expectations of finding superrotating motions similar to the dayside, finding a wider temporal variability which affects both the motions and the morphology of clouds. Unexpectedly, the nocturnal upper clouds exhibit morphologies different to the dayside and abundant stationary features which we interpret as gravity waves and are strongly correlated with the surface elevations. These mixed results (stationary waves and episodes of weaker motions) imply new and exciting challenges for present Venus's General Circulation Models, and are expected to provide valuable insights towards explaining the atmospheric superrotation of Venus. Our work was highlighted in the section "News and Views" of Nature Astronomy ("Venus: Tickling the clouds" Nature Astronomy, 1,0198 [2017]), as well as in ESA and JAXA press sections, and in diverse media.

Published research in FY2017:

- J. Peralta et al., Geophysical Research Letters, Vol.44 (8), pp. 3907-3915 (2017) doi: 10.1002/2017GL072900
- J. Peralta et al., Icarus, Vol. 288, pp. 235-239 (2017) doi: 10.1016/j.icarus.2017.01.027
- J. Peralta et al., Nature Astronomy, Vol. 1, 0187 (2017) doi: 10.1038/s41550-017-0187
- T. Horinouchi et al., Nature Geoscience, Vol. 10, pp. 646-651 (2017) doi: 10.1038/ngeo3016
- T. Horinouchi et al., Earth, Planets and Space, Vol.70, 10 (2018) doi: 10.1186/s40623-017-0775-3
- S. Pérez-Hoyos et al., Journal of Geophysical Research: Planets, Vol. 123(1), pp.145-162 (2018) doi: 10.1002/2017JE005406
- S. S. Limaye et al., Earth, Planets and Space, vol.70, 24 (2018) doi:10.1186/s40623-018-0789-5

CRITES, Sarah
Research Highlights in FY2017

In a paper submitted to Nature Geoscience, I along with ISAS collaborators R. Ballouz and N. Baresi describe our discovery of a new mechanism that shapes the surface of Mars' moon Phobos, and can explain its two enigmatic geological units: eccentricity-driven cold flow of grains. Phobos' surface is defined by two major geologic units, the red unit (defined by a low albedo and increasing visible to infrared continuum slope) and the blue unit (defined by higher albedo and flatter spectral slope). Despite decades of observations, the origin and relationship of the two units remains ambiguous: the red unit could be formed through space weathering of the blue unit; or the two units could be compositionally distinct. Here we show that although Phobos' orbital eccentricity is small (e~0.0151), it leads to variations in the tidal force that causes mass motion whose accumulated effect over time leads to the transformation of the red space-weathered surface, exposing blue sub-surface material and explaining the spatial distribution of blue and red materials. We modeled the effect of Phobos' slight eccentricity (0.0151) and found that induced librations cause surface slopes to vary by up to 2 degrees every orbital period (7.65 hours). Coupled with simulations of Phobos' regolith, we show that this time-varying effect leads to gradual erosion. Furthermore, visible and near-IR imaging and spectroscopy from spacecraft show that blue units are correlated with high-slope regions that experience moderate-to-high variations, where our model predicts the highest erosion rates. These results demonstrate a new mechanism where spectrally immature blue material is continually refreshed by mass wasting in certain regions (analogous to the tidally-induced refreshing of asteroid surfaces), while space weathering alters the rest of the surface into red material. This new insight into geologic processes on Phobos demonstrate that with the in-situ and laboratory measurements that the Martian Moons eXploration (MMX) mission will enable, this moon may become a "Rosetta Stone" for understanding space weathering throughout the solar system. Furthermore, our work provides additional constraints on the ongoing debate of Phobos' origin: if, as our mechanism suggests, the blue unit represents pristine, endogenous Phobos material, then impact-origin scenarios that suggest Phobos is Mars-like must explain the lack of expected spectral absorption features in the blue units.

Published research in FY2017:

- T. Kaku et al., Geophysical Research Letters, Vol.44 (20), pp.10155-10161 (2017). doi:10.1002/2017GL074998

IZUMI, Kiwamu
Research Highlights in FY2017

In this past year, my research has been chiefly focused on two different items; one is an experimental effort of bringing the Japanese ground-based gravitational-wave detector, KAGRA, online as quick as possible. The other is to seek for possible collaboration with the LISA (Laser Interferometer Space Antenna) mission of ESA in the context of their detector design and operation.

KAGRA currently proceeds with its installation in multiple steps and active commissioning tests between the major installation steps with the aim of operating the full interferometer at some point in 2019 to join the global detector network. In this past year, the goal was set to operate a 3-km Michelson interferometer with either one of or both the end mirrors kept at a cryogenic temperature of 20 K. This will mark a big milestone of achieving a km-scale laser interferometric gravitational-wave detector operating at a cryogenic temperature for the first time in the history. As a sub-lead of the commissioning team there, I lead various experimental activities on site including the design of analog and digital electronics, preparation of the necessary automation software, and physically aligning the core optics to deliver the main interferometer laser light to both end mirrors with a precision of tens of micro radians. A detailed summary of the operation of the 3-km Michelson interferometer will be reported shortly in a journal paper.

As for the activity of seeking for possible collaboration with LISA, I have attended a meeting called LISA science study team meeting held at Glasgow, UK at the end of this past March. As a representative of ISAS/JAXA, I expressed our interest that we are looking for possible contributions to the LISA mission. I accordingly started collecting the technical aspects of the mission payload design and their associated software preparation to decide on what topic we may be able to assist. I will keep in contact with the LISA project throughout the fiscal year of 2018 as well to further pursue this topic.

BONARDI, Stéphane
Research Highlights in FY2017

Since I arrived at ISAS in October 2017, I have been working on developing innovative robotic solutions for planetary exploration and future space colonization. Together with my supervisor, we have chosen to divide this topic into three main parts: advanced mobility, autonomous self-adaptation, and human-robot collaboration, focusing on one aspect per year.

My current subject of research is centered around the topic of dynamic mobility of groups of Momentum Driven Robots (MDR) in complex environments. I am working on integrating and controlling compliant elements in structures made of MDR. I am using bio-inspired techniques (Central Pattern Generators, among others) and fast relearning methods to control these structures. The large number of control parameters is one of the main challenges in this approach along with the integration of the complex sensory feedbacks into the control loop. I am developing new simulation models that I will soon calibrate during hardware experiments. These models rely on real time Finite Element Analysis (FEA) to model the compliant elements and flexible components of the robotic systems. I am planning to test my approach with colleagues from the Tsukuba research center and from my previous lab at MIT using the platforms that they developed (Int-Ball and M-Blocks, respectively).

The next step of my work will focus on the autonomous adaptation of the robotic structure to the task to be performed. I have recently submitted a KAKENHI grant for fostering joint international research together with partners from EPFL (Switzerland) and MIT (USA) to explore these topics in depth. I am also restarting a collaboration I had in the past with Tohoku University (Prof. Ishiguro) on the topic of agile locomotion using bioinspired sensory feedback.

QUINTERO NODA, Carlos
Research Highlights in FY2017

This research is divided in two main topics. On the one hand, I am working with data taken with JAXA's HINODE (formerly Solar-B) satellite and ground-based telescopes for understanding how the magnetic field configuration of solar sunspots triggers different solar eruptive phenomena. This is done applying numerical codes that allow improving the observations and inferring the physical information of the solar lower atmosphere. On the other hand, I continue characterizing different regions of the solar spectrum to determine which are the most capable solar spectral lines for future missions, in particular, for the Sunrise Chromospheric Infrared spectro-Polarimeter (SCIP), an instrument led by Japan in a consortium that includes Germany and Spain as international partners. SCIP will perform observations for more than 10 days at stratospheric heights on board the Sunrise balloon-borne telescope, with a scheduled launch in 2021. The results of those studies indicate that the infrared lines at 850 nm are able to detect acoustic shocks and oscillatory plasma motions at different atmospheric layers allowing to seamlessly trace the solar phenomena in the lower-middle atmosphere. Moreover, the spectral window at 850 nm can be complemented with different spectral lines that have access to additional solar atmospheric layers, as the ones included in the infrared region at 770 nm. This spectral region, severely affected by telluric absorption, can be entirely observed for the first time thanks to the possibilities offered by the Sunrise stratospheric balloon that flies at an average altitude of 35 km. This is because, similar to satellites, we avoid most of the telluric atmospheric absorption and we can observe solar lines that otherwise are completely blocked at ground level. Thus, we have found through those publications an optimum design for understanding the solar phenomena, mainly at low atmospheric heights where we expect to find the roots of the solar eruptive events. This design will be implemented on the Sunrise/SCIP instrument, funded by the JAXA small scale project program and the Grants-in-Aid for Scientific Research (KAKENHI) program, to perform novel observations in the near future. These observations will help us to unravel some of the oldest mysteries about the Sun and to fully understand their impact in our daily life at Earth.

Published research in FY2017:

- C. Quintero Noda et al., Astronomy & Astrophysics, Vol. 610, A79 8 pp. (2018) doi:10.1051/0004-6361/201732111
- C. Quintero Noda et al., Monthly Notices of the Royal Astronomical Society, Vol. 470 (2), pp. 1453-1461 (2017) doi:10.1093/mnras/stx1344
- C. Quintero Noda et al., Monthly Notices of the Royal Astronomical Society, Vol. 472 (1), pp. 727-737 (2017) doi:10.1093/mnras/stx2022
- L. Bharti et al., Solar Physics, 293 (3), art. no. 46 (2018) doi: 10.1007/s11207-018-1265-x
- D. Orozco Suarez, et al., Astronomy & Astrophysics, Vol. 607, A102. (2017) doi:10.1051/0004-6361/201731216
- T. Oba et al., The Astrophysical Journal, Volume 849, Issue 1, article id. 7, 11 pp. (2017) doi: 10.3847/1538-4357/aa8e44

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

a. Inter-University Research and Facility Management Group

To promote space science activities in Japan, JAXA maintains and operates the facilities that constitute the Inter-University Research System. Researchers at public and private universities are able to utilize these facilities, such as the Space Chamber Laboratory, Hypervelocity Impact Facility, and Supersonic and Subsonic Wind Tunnel Laboratory.

Opportunities to use these facilities are announced annually, and the proposals are reviewed and approved by the program advisory committees as shown in the table, “Domestic Joint Research”, on p. 109. The Inter-University Research and Facility Management Group collaborates with researchers to maximize their scientific achievements.

b. Test and Operation Technology Group

The Test and Operation Technology Group is responsible for administering and maintaining the facilities for mechanical environmental testing, structural testing, thermal vacuum testing, anechoic chamber testing, attitude control testing, magnetic shield testing, side-jet reaction control subsystem testing, and other technical facilities, such as clean rooms and machine assembly test facilities. The group also supports projects, pre-projects, and working group (WG) activities.

1. Achievements

- Support for pre-launch testing and launching of Epsilon-3.
- Support for pre-launch testing for sounding rocket SS-520-3.
- Support for pre-launch testing and launching of sounding rocket SS-520-5.
- Support for combustion testing of N_2O/ethanol propulsion systems.
- Maintenance and upkeep of the mechanical environmental test facility, thermal environmental test facility, anechoic chamber and attitude control test facility, etc.

2. Effects and Impacts

- The group contributed to the successful launch of Epsilon-3 with ASNARO-2.
- The group contributed to the successful launch of sounding rocket SS-520-5 with TRICOM-1R.
- Improved maintenance and schedule management of various testing facilities enabled the group to respond promptly to the failure of pre-launch testing and contribute to the investigation of the cause of the failure and plans for mitigation measures.

c. Advanced Machining Technology Group

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

1. Achievements

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

2. Effects and Impacts

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

New Machine Shop

d. Scientific Ballooning Research and Operation Group

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

1. Achievements

- The group successfully provided two of four planned heavy balloon flight opportunities in a domestic balloon campaign. Two remaining opportunities were postponed until FY2018 due to surface weather and stratospheric wind conditions. Though the stratospheric microorganism sampling experiment failed due to malfunction of the samplers, the flight verification of the balloon using newly developed load tapes was successfully complete.
- The group completed the preparation of three balloon-borne experiments in Australia, which aim to carry out astronomical long-duration observations in the southern hemisphere. The campaign in Australia was carried out from February 16, 2018 and three balloon launches are expected between April and May 2018.

2. Effects and Impacts

- Significant efforts have been made to realize scientific balloon-borne experiments carried out by young scientists. Through these activities, we can enlarge the community able to develop balloon-borne experiments independently. Though the balloon-borne VLBI experiment was canceled due to unexpected strong surface wind conditions just before the launch, we can expect their first flight in FY2018. For the stratospheric microorganism sampling experiment, we were able to promote new research fields by new users.
- Now that the framework necessary to realize balloon-borne experiments regularly in Australia has been established, we expect to carry out cutting edge astronomical and cosmic-ray observations, which are difficult to conduct in the domestic balloon campaign.
- As we were able to demonstrate the performance of new load tape made in Japan, we will be able to fabricate our balloons more flexibly.

e. Sounding Rocket Research and Operation Group

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

1. Achievements

- The preliminary design, including mechanical and electrical interfaces, of the S-310-45 rocket experiment was verified in order to prepare the onboard instruments. This experiment will focus on examining a precise control strategy and the directional accuracy of multi-link structures.
- The baseline concept, including mechanical and electrical requirements of the S- 520- 31 rocket experiment was discussed to provide better conditions. In the experiment, a newly developed space propulsion engine will be examined in a microgravity environment.

  Component-level environmental tests and electrical calibration of the onboard equipment of the SS-520- 3 rocket experiment were performed prior to integrated function tests. The rocket has a two-stage solid propellant design and is intended to observe the high-altitude plasma dynamics of the north polar region in Norway. This experiment has currently been postponed due to electrical problems with the avionics.
- In addition to the annual evaluation, we focused on scientific achievements and conducted experimental evaluation of the sounding rockets launched over the past 10 years.

2. Effects and Impacts

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

f. Noshiro Rocket Testing Center

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

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

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

1. Achievements

- Advanced rocket engines
  In order to meet progressive requirements of future and near-future transportation systems, the center has actively tested advanced rocket engine systems with new propellants in order to better understand performance levels. A N_2O/ethanol liquid engine with a ceramic based nozzle composite was developed for storable and non-toxic propulsion of small satellites. A hybrid rocket motor has also been examined in order to reduce safety requirements at the launch site.
- Lift-off and landing tests of reusable vehicles
  The design and development of a reusable rocket vehicle, the RV-X is in progress based on the technical outcomes obtained from ISAS RV-X related studies. Currently, two flight campaigns are planned for a flight demonstration study. In the first flight test campaign, we aim to demonstrate the pump fed capability of a deep throttling engine, attitude control characteristics using main engine gimbaling during lift-off and landing with powered flight and a quick turn round, etc. In 2017, the propulsion system was tested to investigate the performance of thermal insulation for the LH_2/LOX tanks, etc.
- Safety technology for liquid hydrogen utilization
  Based on NEDO (New Energy and Industrial Technology Development Organization)'s supporting research program, actual behavior and a risk assessment of very highly pressurized hydrogen were studied in order to improve safety regulations for fuel cell vehicles and hydrogen infrastructures, such as supply stands. Cryo-compressed hydrogen leakage diffusion was also investigated. The experimental apparatus was able to supply hydrogen at 90 MPa and at various temperature conditions. Measurement criteria included hydrogen concentration distribution, blast pressure, flame length and radiant heat. In addition, high speed camera observation was carried out to investigate the near-field cryogenic hydrogen jet at supercritical pressure.
- Liquid hydrogen loading system
  As a research program of the Cross-ministerial Strategic Innovation Promotion Program (SIP by JST), swivel joints and emergency release systems for liquid hydrogen were developed and demonstrated. 400,000 reciprocating sliding operations of the swivel joints were successfully completed without mechanical leak problems in 2017. Rules and standards for loading and unloading liquid hydrogen will be established to ensure safe operation.
- Liquid Hydrogen Cooled HTC Superconductors
  High Tc (HTC) superconductors, including MgB2 have been tested with the support of the Advanced Low Carbon Technology Research and Development Program (ALCA by JST), which showed excellent properties of liquid hydrogen under temperature. The liquid hydrogen showed a high latent heat and low viscosity coefficient. The center also investigated the heat transfer characteristics of liquid hydrogen and evaluated the electro-magnetic properties of liquid hydrogen cooled superconductors under a magnetic field of approximately 7 Tesla.

2. Effects and Impacts

NTC has many unique facilities for experimental verification of transportation technologies and cryogenic properties. The static firing test stand has a maximum thrust capability of more than 450 tonf and is the largest facility in Japan. The vacuum firing test chamber has a volume of more than 450 m^3 and is also the biggest facility of its kind in Japan. NTC also has the only very high pressurized liquid hydrogen supply facility in Japan. As a result, a large number of experimental studies have been conducted at NTC bearing fruitful results. In 2017, at least one of the NTC facilities has been in operation for more than 250 days in the year without one human accident being reported.

g. Akiruno Research Center

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

1. Achievements

- A sea level combustion experiment of the solid propellant rocket motor for the OMOTENASHI project was carried out in vacuum by the high altitude testing facility (High Altitude Testing Stand).
- A liquid oxygen supply facility was installed and hybrid rocket combustion experiments (A-SOFT) conducted using this new facility.
- A basic experiment for a small thruster by chemical decomposition of N_2O was conducted at HATS. Basic chemical decomposition behavior of N_2O was examined using direct observation of gas temperature around the

catalyst.

- To support basic research activities, reliable inspections of the experimental facilities were conducted to maintain their condition.

2. Effects and Impacts

- The combustion experiments using the high altitude testing stand proved the performance of the developed solid propellant rocket motor used in the OMOTENASHI project. With the combustion test, the project passed an important milestone.
- The new liquid oxygen supply facility enables practical combustion testing of a hybrid rocket system with liquid oxygen and an A-SOFT hybrid rocket combustion experiment was successfully carried out.
- The N_2O decomposition experiment revealed basic knowledge regarding high temperature gas generation behavior using several types of catalysts.

h. Science Satellite Operation and Data Archive Unit

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

1. Science Satellite Operation

1.1 Achievements

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

1.2 Effects and Impacts

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

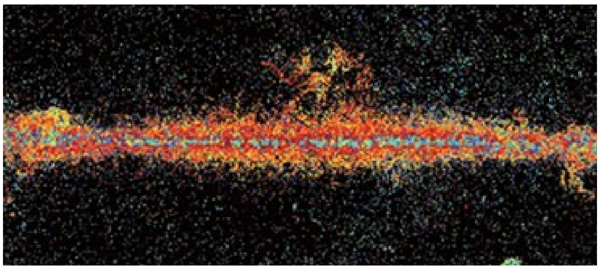
2. Accumulation and Provision of Space Science Data

2.1 Achievements

- C-SODA developed, maintained and operated the space science Data ARchive and Transmission System (DARTS) to maximize scientific outcomes from archival data for JAXA science spacecraft.
- We released new datasets, including LIDAR from Hayabusa2, HITOMI, MAXI onboard ISS, AKATSUKI, and PDS3 from KAGUYA, etc.
- 10 kinds of raw telemetry data from old spacecraft were made open to public, which have been closed for more than 30 years. (Taiyo, Kyokkou, Jikiken, Ohzora, Hakucho, Temma, Hinotori, Sakigake, Suisei and Hiten, etc.)

2.2 Effects and Impacts

- In the last year, approximately 160 TB of data were downloaded by world-wide users through DARTS, totaling approximately 50 million accesses.
- There were approximately 90,000 downloads from the server hosting the revised version of the AKARI far-infrared all-sky bright-source catalog (Fig.), the near-infrared spectral catalog and near-infrared pointed observation images. Approximately 130 refereed papers using Akari data were published in FY2016 (Approx. 1,200 papers have been published since the AKARI launch in 2006).
- DARTS maintains a large number of datasets from space science missions open to the public in a systematic manner and common data format, which helps to maximize the scientific outcome from the data, expands its scope of use and contributes to third-party verification of observation results.



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

i. Lunar and Planetary Exploration Data Analysis Group

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

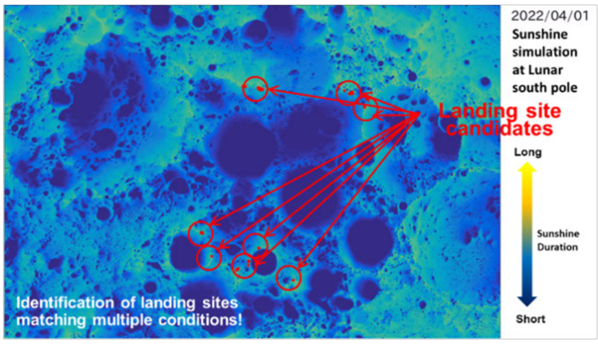
1. Achievements

- It is possible for our group and also our obligation to leverage existing exploration data sets to provide support in constructing mission scenarios and to maximizing mission outcomes. We performed data analysis around the Moon polar regions in terms of sun illumination conditions, direct communication between the Moon and Earth stations, slope of the surface and the distribution of possible water ice and geology and provided the results to the mission study team for moon polar regions.
- In cooperation with the National Institute of Advanced Industrial Science and Technology and the University of Aizu, we started development of data analysis methods using artificial intelligence and carried out some trials of extracting volcanic features and obstacle boulders.

The group operated and upgraded the function of the KAguya Data Integrated Analysis System (KADIAS) that provides the WebGIS-based analysis and download functions for observed data obtained by the Japanese lunar exploration orbiter, KAGUYA and other missions, including foreign explorations.

2. Effects and Impacts

- Information obtained from the analysis around moon polar regions, indispensable for determining exploration strategies, advanced the mission concept study of the polar landing exploration.
- The operation and upgrade of KADIAS will allow users to execute an integrated analysis using data from not only KAGUYA, but also from other lunar missions.



Landing Site Candidates in the Lunar South Pole Region

j. Astromaterials Science Research Group

The Astromaterials Science Research Group operates the curation facility at JAXA. The group acquires knowledge about planetary materials based on non-destructive and uncontaminated descriptions through the curatorial work for extraterrestrial materials.

1. Achievements

- The group performed the curatorial work of collecting, describing and storing the samples brought back from the asteroid, Itokawa by HAYABUSA.
- The group e-published a periodical special paper containing the initial description of the Itokawa samples (i.e., sample catalog information). In the recent catalog (JAXA-SP-17-005E), the total number of samples is 693.
- The group made an international AO for the Itokawa samples and samples were allocated to researchers selected by an international AO committee. By the end of the last fiscal year, 54 proposals have been accepted and 212 samples have been distributed.
- According to an MOU between NASA/JAXA, 35 samples have been delivered to NASA to date.
- An International Symposium of Solar System Materials was held to announce the results from the international AO research on Itokawa samples. This symposium is held annually and is attended by approximately 100 planetary science researchers from all over the world.
- In preparation for the receipt of extraterrestrial samples brought back in future sample return missions, such as Hayabusa2, we completed the production of a new clean room and started the production and installation of a new clean chamber.
- In terms of technical support for future sample return missions, we provided support in connection with the development of sampling equipment and examination of sample receiving equipment, etc.
- In terms of technical support for an on-site analyzer for future planetary exploration missions, we started the development of a compact, high-performance mass spectrometer.
- Achieved maintenance and operation of the group's associated facilities and equipment.
- Project researchers and postdoctoral fellows were accepted, as well as young researchers, through extraterrestrial sample analysis and other studies.

2. Effects and Impacts

From the results of Itokawa sample analysis, we expect to elucidate the history of collision events in the solar system and processes on asteroid surfaces (e.g., space weathering).

The Itokawa sample analysis results thus far can be summarized as follows:

- From the analysis of returned samples, analysis of scientific observation data acquired by the spacecraft and related research conducted based on the results of "HAYABUSA", we obtained new knowledge about "Relationship between asteroids and meteorites", "Formation history of solar system bodies" and "Exposure age of the asteroid surface”. (Geochim, Cosmochim. Acta 221, 318, Icarus 303, 22)
- As a result of international AO research into the return samples we conducted an estimation of collision destruction age of the asteroid Itokawa's parent body (GEOLOGY 45, 819). In addition, using the Atom Probe, observation of the space weathering rim of the HAYABUSA return sample was conducted, and found an excess of OH, which seems to be the origin of solar wind (LPSC abstract #1495).

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

k. Deep Space Tracking Technology Group

The Deep Space Tracking Technology Group (DSTT) was newly established in the FY2016 at ISAS. The main task of this group is to perform technical coordination among various projects and facilities within and outside ISAS concerning the tracking of deep space projects, previously performed by individual experts before this group was established. Major achievements of this group during the fiscal year 2017 are as follows.

1. Support for JAXA’s deep space projects

- Technical coordination for the Hayabusa2 project with NASA, providing tracking support at NASA’s Deep Space Network (DSN) stations. During 2017, we coordinated with the DSN engineers on the usage of DSN stations during the asteroid proximity phase from 2018 to 2019 and discussed basic policy for utilizing the DSN stations during critical events.
- Technical coordination for the Hayabusa2 project with ESA for the provision of tracking support at ESA’s ESTRACK stations. During 2017, we coordinated on technical aspects with ESA engineers to enable the use of ESTRACK’s Cebreros station in Spain during periods in which the Malargue station in Argentine (which we have been using since the launch of the spacecraft) was closed for maintenance.
- Technical coordination with NASA for JAXA’s two CubeSats (OMOTENASHI and EQUULEUS), which will be launched by NASA’s SLS EM-1, for the provision of tracking support at NASA’s DSN stations. During 2017, we presented tracking requirements to NASA and agreed on basic tracking policy with NASA.

2. Support for deep space projects of international partners

- Technical coordination for NASA’s EM-1 project with NASA for the provision of tracking support at JAXA’s Uchinoura station. During 2017, we generated a test plan for this support and performed a test at the Uchinoura station together with NASA engineers.

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

- We started a study on JAXA’s future deep space tracking network jointly with JAXA’s space tracking and communications center at Tsukuba. We developed a plan for utilizing the 54m station (currently under development) and the existing 64m station at Usuda. We also conducted a study on replacing the stations at Uchinoura with multi-purpose stations to be built overseas. We selected candidate locations and started preliminary studies.

4. Orbit determination for JAXA’s deep space projects

- We performed regular orbit determination operations for AKATSUKI and Hayabusa2.
- We also performed a study on a high-precision orbit determination technique utilizing DDOR (Delta Differential One-way Range) and applied the technique to orbit determination of Hayabusa2. We were able to verify that we can obtain very accurate trajectory solutions even during ion engine thrusts.

III
Administration

1. History and Mission of ISAS

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

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

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

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

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

2. Organization

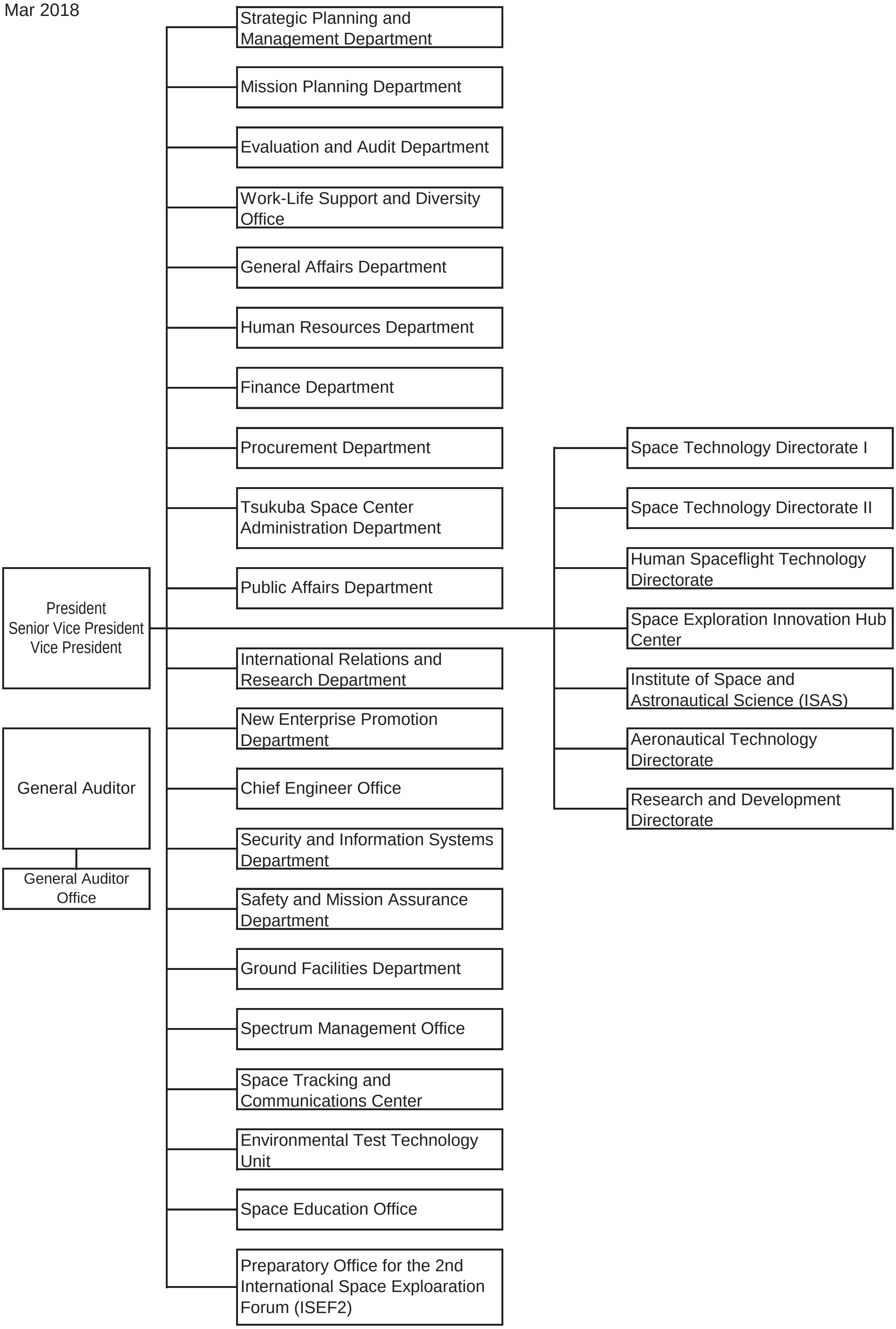
As of March 31, 2018, ISAS has five research departments:

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

Other organizations within ISAS are the Management and Integration Department, the ISAS Program Office, the Center for Science Satellite Operation and Data Unit, 10 project teams, 2 pre-project teams, 8 groups, the Noshiro Rocket Testing Center, and the Akiruno Experimental Facility. In addition, the following officers and directors report to the ISAS Director General: Deputy Director General, Research Director, Program Director of Space Science, Senior Chief Officer of Fundamental Technology for Space Science, Director for International Strategy and Coordination, and Director for Education and Public Outreach (see the ISAS organization chart).

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

JAXA Organization Chart
Mar 2018



ISAS Organization Chart
Mar 2018

- Advisory Council for Research and Management
- Director General, Institute of Space and Astronautical Science
  - President
    - Board of Councilors
  - Associate Director General
  - Deputy Director General, Institute of Space and Astronautical Science
  - Director for International Strategy and Coordination
  - Director for Education and Public Outreach
  - Director for Management and Integration Department
    - Management and Integration Department
  - Research Director
    - Department of Space Astronomy and Astrophysics
    - Department of Solar System Sciences
    - Department of Interdisciplinary Space Science
    - Department of Space Flight Systems
    - Department of Spacecraft Engineering
  - Program Director of Space Science
    - ISAS Program Office
    - GEOTAIL Project Team
    - ASTRO-EII Project Team
    - SOLAR-B Project Team
    - PLANET-C Project Team
    - Bepi Colombo Project Team
    - Extreme Ultraviolet Spectroscope for Exospheric Dynamics Project Team
    - ERG Project Team (Exploration of energization and Radiation in Geospace Project Team)
    - Hayabusa2 Project Team
    - GREAT Project Team (Ground Station for Deep Space Exploration and Telecommunication Project)
    - SLIM Project Team (Smart Lander for Investigating Moon Project Team)
    - X-ray Astronomy Recovery Mission Pre-Project Team
    - Martian Moons Exploration Pre-Project Team
  - Senior Chief Officer of Fundamental Technology for Space Science
    - Inter-University Research and Facility Management Group
    - Test and Operation Technology Group
    - Advanced Machining Technololgy Group
    - Scientific Ballooning Research and Operation Group
    - Sounding Rocket Research and Operation Group
    - Noshiro Rocket Testing Center
    - Akiruno Experimental Facility
    - Science Satellite Operation and Data Archive Unit
    - Lunar and Planetary Exploration Data Analysis Group
    - Astromaterials Science Research Group
    - Deep Space Tracking Technology Group

3. Operation

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

a. Board of Councilors (as of March 31, 2018)

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

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

b. Advisory Council for Research and Management (as of March 31, 2018)

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

KUBOTA, Takashi	Professor, Department of Spacecraft Engineering
SATO, Eiichi	Director, Department of Space Flight Systems
HAYAKAWA, Hajime	Professor, Department of Solar System Sciences
FUJIMOTO, Masaki	Research Director
MITSUDA, Kazuhisa	Professor, Department of Space Astronomy and Astrophysics
MORITA, Yasuhiro	Professor, Department of Space Flight Systems
YAMADA, Takahiro	Director, Department of Spacecraft Engineering
YAMADA, Toru	Director, Department of Space Astronomy and Astrophysics

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

c. Advisory Committees

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

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

(1) Advisory Committee for Space Science

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

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

By redefining four mission categories for space science projects—strategic large-class, competitive middle-class, strategic international, and small projects—the committee organized development phases for working group (WG) activities and provided phase execution procedures to advance mission proposals. In FY2017, the Advisory Committee for Space Science held a mission definition review jointly with the Advisory Committee for Space Engineering on submitted plans, proposed as a competitive middle-class mission, and recommended approval to ISAS with certain conditions.

(1)-2. Strategic R&D

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

Working group activities and status are summarized below.

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

- Strategic large-class projects:
  - > Next-generation Solar Observation Satellite (SOLAR-C) WG
- Competitive middle-class projects:
  - > Physics of Energetic and Non-thermal plasmas in the X-(magnetic reconnection) region (PhoENiX) WG
  - > Asteroid/Moon Penetrator Plan (APPROACH-2) 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-GUNDAM) WG
  - > Small Astrometry Satellite for Infrared Exploration (Japan Astrometry Satellite Mission for Infrared Exploration, or JASMINE) WG
- Small projects:
  - > Turbulence Heating ObserveR (THOR) WG
  - > Ultraviolet spectrum observation in extrasolar planets WG
  - > Nucleation of cosmic dust WG (Determining Unknown yet Significant Traits (DUST) WG)
  - > LargE Area burst Polarimeter (LEAP) for ISS WG
  - > Circumpolar Stratospheric Telescope (FUJIN) WG
  - > Wide-field Monitoring of Transient Astronomical Objects (Wide-Field Monitoring of All-sky X-ray Image, or WF-MAXI) WG
  - > Extreme Universe Space Observatory onboard Japanese Experiment Module (JEM-EUSO) WG
- Strategic international projects:
  - > ATHENA WG
  - > WFIRST WG
- Equipment development Working Groups:
  - > Life Detection Microscope (LDM) WG (formerly MARS 2020 Life-form Probe Microscope WG)

<u>Working Groups whose status changed in FY2017</u>

> Small Astrometry Satellite for Infrared Exploration

(Japan Astrometry Satellite Mission for Infrared Exploration, or JASMINE) WG was approved for Pre-Phase A1b.
> Exploration Project of Anti-particles from Cosmic Rays (i.e., GAPS) WG was completed as WG due to its category change to small projects
> Nucleation of cosmic dust WG was completed as WG due to its category change into small projects
> Satellite Mission for X-ray Polarimetry (PRAXyS) WG was proposed to change to Imaging X-Ray Polarimetry Explorer (IXPE) WG.

Achievements and Impacts

Notable results are listed below.

- The JASMINE WG submitted a competitive middle-class mission proposal in FY2015 and the advisory committee for space science recommended advancement to the next phase after an additional review in FY2016.
- Next-generation Solar Observation Satellite (SOLAR-C) WG submitted a competitive middle-class mission proposal for FY2017 in the form of a SOLAR-C_EUVST (Extreme UltraViolet Spectroscopic Telescope) plan, after research and development of Ultra Fine Sun Sensors (UFSS) and study of the satellite operation systems.
- Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES-2) WG carried out the development and research of novel CRFP (Caron fiber reinforced plastics) mirrors and proposed a competitive middle-class mission in FY2017 in the form of the SMILES-2 plan.
- DUST WG has been conducting research on the wide band of the floating dust infrared spectral measuring device and proposed it as a small plan. The group was proposed as a small-project mission.

Overall, in FY2017, one of the seven WGs which was active as a strategic large-class or competitive middle-class, advanced to the next phase, pre-phase A1b, of Mission review. Five of them applied for a mission proposal for a competitive middle-class project. The advisory committee for Space Science played a primary role in the creation of missions.

(1)-3. Basic R&D on Onboard Equipment

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

Achievements and Impacts

In FY2017, 12 were adopted out of 25 proposals, including improving and making prototypes for device components working at various wavelengths such as high-energy, infrared astronomy and radio waves. These proposals represent the following achievements: (1) Two-dimensional structure development of a bonded Germanium for infrared observation; (2) Development of a silicon-CdTe integrated detector with wide-band and high-accuracy resolution; (3) Development of a vacuum pump for onboard equipment; (4) Development of a metal mesh structure for solar soft X-ray observation; (5) Development of an active seismometer with penetrator; (6) Development of a next-generation X-ray observation telescope using high-temperature plastic deformation of Silicon; (7) Development of echelle grating for high-sensitivity polarization spectroscopy; (8) Development of photon counting terahertz Interferometry; (9) Development of a high-precision positioning mechanism for a reflector for X-ray observation; (10) Development of Germanium immersion grating for mid-infrared; and (11) Development of thruster technology for the control of aircraft.

(2)Advisory Committee for Space Engineering

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

(2)-1. Notable Achievements

- The Advisory Committee for Space Engineering proposed the DESTINY WG's "DESTINY^{+}" plan as a Competitive Middle-Class Mission to strengthen mission scenarios and improve the feasibility of fly-by observations. A team was organized based on the DESTINY WG for the preparation of a space science project and coordination for international cooperation and ground observation network is underway.
- The WG for Research and Development of Micro Planetary Probes using a Deployable Flexible Aeroshell proposed the "Shrinking mars entry Probe with Unfolding Robe (SPUR) aeroshell Plan" as a third Competitive Middle-Class Mission.
- The hybrid rocket research WG developed a Bread Board Model (BBM) for the Altering-intensity Swirling-Oxidizer-Flow-Type (A-SOFT) Hybrid Rocket Engine using Gaseous oxygen (GOX) and succeeded in changing axial /swirling GOX injection during combustion and in conducting thrust control and throttling by controlling valve position in combustion experiments.
- The research group (RG) on an innovative detonation-based propulsion system for sounding rockets and landers developed a rotating detonation engine for sounding rocket experiments, which achieved 107% (353 sec) of the target thrust under low back-pressure (0.6 kPa).The group also developed a Pulse Detonation

Engine (PDE), which generates the required thrust (20N).

- The Research on Innovative Satellite Bus Technology RG has conducted several trial tests and developments with the goal of achieving a compact and lightweight satellite bus and short-term construction. They include four-layer 3D CPU modules using Micro-electro-mechanical-systems (MEMS) packaging technology and lightweight high-performance thrusters with ceramic/metal joining.
- The research group for Demonstration Research on Advanced Solid Propellant Rocket System has reviewed and confirmed quality assurance methods, consisting of nondestructive tests and the process guarantee of defects found in large solid motors. The group also developed a 3D/stereo Moire camera measuring technique within one device for rocket structural tests.
- Studies on frequently reusable space transportation system RG developed a real-time simulator by acquiring the performance of the onboard sensor and its modeling, an electroforming nickel liner using foam polystyrene mold, reusable releasing mechanisms that enable the supply of liquid hydrogen and remote withdrawal before takeoff.
- A study on highly-precise structures and materials for advanced scientific observations RG evaluated the thermal deformation inhibition of the kinematic coupling for one-dimensional structures, which reduced the amount of heat deformation down to Approximately 2%. For two-dimensional structures, the RG also designed and developed the smart reflector to improve surface errors.
- The Achievements that have been publicly released include 69 papers, 197 presentations at international academic conferences, 314 presentations at domestic academic conferences, 13 invited speeches, 6 patents, 3 published books and 33 other media reports (including press releases).

(2)-2. Strategic R&D

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

<u>Working Groups</u>

- WG on sample return research in collaboration with missions of foreign space agencies
- Hybrid rocket research WG
- Research and Development of Micro Planetary Probes using Deployable Flexible Aeroshell

<u>Operations</u>

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

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

- Study on the inertial platform for payloads of ISAS/JAXA sounding rockets
- Development of micro ion thrusters for payloads for chemical -free satellites
- R&D on Mars airplane
- Demonstration of a super-pressure balloon for long duration flight
- Demonstration research on advanced solid propellant rocket system
- Studies on an innovative thermal control system
- Research on an innovative detonation-based propulsion system for sounding rockets and landers
- R&D on crushable structure for flexible landing and exploration missions
- Studies on frequently reusable space transportation system
- Research on innovative satellite bus technology
- Research on rover for exploration of small bodies, moons, and planets
- Research on an innovative parafoil-type vehicle for Mars exploration
- Development of an electrodeless magnetic nozzle helicon plasma thruster
- Study on highly-precise structures and materials for advanced scientific observations
- Research for Landing/Contact/Impact System on Astronomical Body Surface
- Feasibility study and demonstration of a 100kW-class laser propelled launch System
- BBM and Its Functional Tests for High Efficiency Cryo-Coolers abroad Spacecraft
- Ultralightweight thin film solar array structure deployed by booms
- Development of a next-generation hard lander: Approach to Mars and Jupiter Moons
- Development of high-performance shape memory alloy actuators through additive manufacturing
- Development of innovative heat management technology for long-term cryogenic propellant storage
- Small Satellite Attitude Control Systems using an Interplanetary Magnetic Field
- Evaluation of radiation resistance for onboard ceramic laser rods
- Research and development on innovation of sample return capsule for future deep space exploration

4. Management and Integration Department

In addition to managing and promoting operations of the Institute of Space and Astronautical Science, the Management and Integration Department is responsible for management of the Sagamihara campus. ISAS has intended to enhance space science research and development activities through strategic cooperation and separate agreements in specific field with universities. In addition, the department is planning and promoting comprehensive policies for development and utilization, in accordance with agreements that have been concluded inside and outside ISAS.

The Management and Integration department is engaged in the following operations of ISAS and Sagamihara Campus.

a. Strategic planning and coordination activities related to space science
b. Management and operation of ISAS
c. International cooperation
d. Inter-university research institute system
e. General affairs of Graduate Education
f. Support for space science programs
g. Activities related to the promotion of research
h. Management and administration of Sagamihara Campus
i. Supporting and promoting cooperation with universities throughout JAXA
j. General Affairs of Grant-in-Aid for scientific research at JAXA
k. Safety reviews of ground experiments and launch experiments conducted by ISAS

With the implementation of reliable operations and the improvement of the management system, notable achievements in FY2017 are as follows.

- As a result of our daily follow-up efforts to improve our safety management activities, including training and the establishment of rules and guidelines, the department has significantly reduced accidents at Sagamihara campus for FY2017 and contributed to the achievement of zero accidents involving students at the campus. Those efforts and achievements were awarded by the Director and Director General for the "Promotion of safety activities on the Sagamihara campus".
- Basic policies and procedures have been strengthened in the student acceptance system in order to ensure that the system is applied in a proper and safe environment and to contribute to the maximization of research and development activities across JAXA. In both student acceptance programs, the graduate student education/ research guidance program and the student training program, agreements and memorandums were concluded with universities to clarify roles and responsibilities, including making student insurance compulsory and the definition of staff qualifications.
- To foster young and promising researchers at ISAS, a Research Assistant acceptance system has been established, under which graduate students can experience project operations. Moreover, the tenure track model for specially-appointed assistant professor has been strengthened. This system provides project operation experience for Phd researchers, or future project managers, through small projects operations.
- The entrance hall of the research and administration building was renovated in FY2017, in order to facilitate user-friendly and efficient management. The renovation included an entrance lobby to enable researchers and visitors at Sagamihara Campus to exchange their views and foster networking among researchers and engineers and improve the information desk for students and visiting researchers.
- In order to formulate the next medium-term plan, we will cooperate with organizations or facilities outside and management and academic communities, to steadily carry out the management examination conducted by ISAS. While striving to improve the efficiency of the operations and properly incorporate project business reforms, we summarized and compiled the results of the entire space science community and future plans of space science throughout JAXA.

5. ISAS Program Office

a. Overview

ISAS projects and experiments are executed by relatively few, highly technical skilled teams undertaking challenging missions. Common support and strategic program activities utilizing a bottom-up approach are important for the reliable implementation of these projects.

The ISAS Program Office was thus established to provide cross-sectional support for various project teams with limited human resources. Also, the office provides effective support to WGs in the early phases of projects.

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

(1) Support for projects and experiments:

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

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

b. Summary of Work in FY2017

1. Support for Space Science Projects

Project Support by the Program Office

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

Generally, a staff member of the Program Office will work “hands-on” with the issues in conjunction with the WG team. In FY2017, we supported the XARM, MMX, LiteBIRD, OKEANOS (Solar Power Sail), small-JASMINE, JUICE, CAESAR-SRC and SPICA projects.

In addition, related to DESTINY$^+$, the office supported the study of the kick-stage motor in the upper stage of the Epsilon launcher to identify adequate technical requirements and also coordinated the interfaces between DESTINY$^+$ and the launcher.

Especially for the recovery from the failure of the SS-520-4 nano-launcher, the Program Office heavily assisted the project team to identify the cause and to implement the successor SS-520-5, which resulted in full success.

Project Support by the SE and PM Senior Experts

The Program Office selected some experts to perform sensible support for space science projects and WGs. They provided advice and suggestions to improve systems engineering (SE) and project management (PM) issues in the technical meetings organized by each project team. The Experts mainly consists of retired JAXA staff with experience in system development for satellites and spacecraft.

2. Tracking of issues in projects and technical activities

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

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

3. Implementation Method Suitable for Space Science Projects

Reflecting on the project management reform of JAXA based on the ASTRO-H anomaly, the Program Office arranged an implementation method appropriate for space science projects, especially in those initial phases which have a great relationship with the Advisory Committees for Space Science and Engineering.

The project management reform newly adopted CML (Concept Maturity Level) as a yardstick for mission concept growth, as well as TRL, both methods used for space science projects.

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

The Program Office had two roles for the selection. One was the support for the proposers, to arrange their ideas as proposal materials which contain appropriate aspects compatible with CML yardstick. The other was a secretariat of the Review Panel for the selection, especially to share the grade and the interpretation of CML.

5. Involvement in Evaluation of Space Science Projects

The Program Office serves as a secretariat for project review and evaluation meetings at ISAS in cooperation with the Management and Integration Department. In FY2017, we worked together with project teams to prepare review materials for the following projects (the project status or activity follows the project name):

- XARM: MDR/system requirements review/planning review prior to phase A
- JUICE: PDR, planning review prior to phase B
- SOLAR-C: planning review for extension of on-orbit

operation

- CAESAR-SRC: MDR/system requirements review/ planning review prior to phase A
- GREAT: CDR
- OMOTENASHI: CDR
- MMO: PSR
- SS-520-4: investigation of launch failure
- SS-520-5: CDR, PQR, LRR
- LiteBIRD: intermediate progress confirmation in pre-phase A
- OKEANOS: intermediate progress confirmation in pre-phase A
- SPICA: intermediate progress confirmation in pre-phase A

6. Support for Chief Engineer Office Work

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

- Provision of information to Chief Engineer Office meetings.

6. Safety and Mission Assurance Officer

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

The ISAS Safety Review Committee has two roles in the safety review meeting for the research on large-scale experiments and the safety evaluation of small experiments. In FY2017, we ensured ground safety and flight safety of the nanosatellite launch system, SS-520-5, holding nine safety review meetings at ISAS. In addition, 31 safety review meetings were conducted in FY2017 for small-scale combustion experiments at the Noshiro Rocket Testing Center, which ensured and improved safety.

7. Budget

(in 1,000 JPY)

ISAS Budget	FY2015	FY2016	FY2017
Operating Expense Grants	20,507,837	16,628,159	14,082,128
Facility maintenance subsidy	439,224	0	2,602,531
Total	20,947,061	16,628,159	16,684,659

External Funds			
Grant-in-aid for scientific research (KAKENHI)	333,148	340,376	309,071
Grant-in-aid for scientific research (Accepted share of expenses)	62,634	65,448	104,553
Funded research	619,484	989,804	744,286
Cooperative research with private sector	395,184	40,793	26,651
Earmarked donations	11,282	4,620	6,000

8. Staff (As of March 31, 2018)

Director General, Institute of Space and Astronautical Science

TSUNETA, Saku

Deputy Director General, Institute of Space and Astronautical Science

KUNINAKA, Hitoshi

Director, Management and Integration Department

SASAKI, Hiroshi

Advisor to the Director, Management and Integration Department

OMI, Natsuki
SAGE, Chiaki

Manager, Management and Integration Department

AOYAGI, Takashi
OHSHIO, Kazuo
TSUJI, Hiroji

Director for International Strategy and Coordination

TOUKAKU, Yoshio

Director for Education and Public Outreach

IKUTA, Chisato

Research Director

FUJIMOTO, Masaki

Director, Department of Space Astronomy and Astrophysics

YAMADA, Toru

Director, Department of Solar System Sciences

SAITO, Yoshifumi

Director, Department of Interdisciplinary Space Science

INATOMI, Yuko

Director, Department of Space Flight Systems

SATO, Eiichi

Director, Department of Spacecraft Engineering

YAMADA, Takahiro

Program Director of Space Science

MITSUDA, Kazuhisa

Director, ISAS Program Office

MIHO, Kazuyuki

Project Manager, GEOTAIL Project Team

SAITO, Yoshifumi

Project Manager, ASTRO-EII Project Team

ISHIDA, Manabu

Project Manager, SOLAR-B Project Team

SHIMIZU, Toshifumi

Project Manager, PLANET-C Project Team

NAKAMURA, Masato

Project Manager, Bepi Colombo Project Team

HAYAKAWA, Hajime

Project Manager, Extreme Ultraviolet Spectroscope for Exospheric Dynamics Project Team

YAMAZAKI, Atsushi

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

SHINOHARA, Iku

Project Manager, Hayabusa2 Project Team

TSUDA, Yuichi

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

NUMATA, Kenji

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

SAKAI, Shinichiro

Project Manager, X-ray Astronomy Recovery Mission Pre-Project Team

MAEJIMA, Hironori

Project Manager, Martian Moons Exploration Pre-Project Team

KAWAKATSU, Yasuhiro

Senior Chief Officer of Fundamental Technology for Space Science

MORITA, Yasuhiro

Manager, Inter-University Research and Facility Management Group

YOSHIDA, Tetsuya

Manager, Test and Operation Technology Group

SHIMOSE, Shigeru

Manager, Advanced Machining Technology Group

OKADA, Norio

Director, Scientific Ballooning Research and Operation Group

YOSHIDA, Tetsuya

Director, Sounding Rocket Research and Operation Group

HABU, Hiroto

Manager, Noshiro Rocket Testing Center

ISHII, Nobuaki

Manager, Akiruno Experimental Facility

GOTO, Ken

Director, Science Satellite Operation and Data Archive Unit

TAKESHIMA, Toshiaki

Manager, Lunar and Planetary Exploration Data Analysis Group

OOTAKE, Hisashi

Manager, Astromaterials Science Research Group

YURIMOTO, Hisayoshi

Manager, Deep Space Tracking Technology Group

YAMADA Takahiro

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

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

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

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

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

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

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

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

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

Department of Spacecraft Engineering [Director : YAMADA, Takahiro]

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

International Top Young Fellowship (ITYF)

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

[V] Visiting, [S] Specially-appointed

9. Professors Emeriti (as of March 31, 2018)

Institute of Space and Astronautical Science (ISAS)

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

Japan Aerospace Exploration Agency (JAXA)

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

10. ISAS Sagamihara Campus and Related Facilities

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

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

Time-lapse sequence at the Sagamihara Campus.

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

ISAS Facilities

Sagamihara Campus (ISAS)
- Location:
- 3-1-1 Yoshinodai, Chuo-ku, Sagamihara-shi, Kanagawa
- lat 35° 33′ 30″ N long 139° 23′ 43″ E
- Site: 73,001m^2
- Gross floor area: 57,570m^2

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

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

JAXA's Facilities related to ISAS

Uchinoura Space Center
- Location:
- 1791-13 Minamikata, Kimotsuki-cho, Kimotsuki-gun, Kagoshima
- lat 31° 15′ 05″ N long 131° 04′ 34″ E
- Site: 718,662m^2
- Gross floor area: 19,090m^2

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

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

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

IV
International Collaboration and Joint Research

1. International Collaboration

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

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

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

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

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

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

ISAS pursued numerous international initiatives of various kinds throughout fiscal FY2017. The new international collaboration initiatives for current missions include the extension of the agreement between JAXA, NASA and Hiroshima University concerning the Fermi Gamma-ray Space Telescope (FERMI) project. JAXA also extended the Letter of Agreement with NASA for The Magnetospheric Multiscale (MMS) mission. Furthermore, JAXA and the Australian Government have been promoting discussion concerning the Asteroid Explorer Hayabusa2 Capsule retrieval operation in Australia.

As for missions under development, we continued working on the joint-mission Japanese-European BepiColombo project with ESA. In relation to missions in the study phase, we had continuous discussions with NASA and ESA on X - Ray Astronomy Recovery Mission (XARM). In addition, we discussed the Space Infrared Telescope for Cosmology and Astrophysics (SPICA), the next-generation infrared observation telescope satellite, which is positioned as a candidate for a strategic large-scale mission in collaboration with partners in Europe. We also discussed Japan-Europe cooperation on the ESA-led Jupiter Icy Moons Exploration "JUICE" mission and the Advanced Telescope for High ENergy Astrophysics (ATHENA). ISAS has continued to promote international collaboration for candidates of Strategic Large-class missions, such as the Martian Moons Exploration project (MMX), Lite (Light) satellite or studies of B-mode polarization and Inflation from cosmic background Radiation Detection (LiteBIRD, and Outsized Kite-craft for Exploration and Astronautics in the Outer Solar System (OKEANOS). For DESTINY$^+$, one of the candidates for competitively chosen small size missions, we held discussions with DLR for possible collaboration.

Based on the results of these discussions, JAXA and NASA signed the agreement to conduct initial studies for XARM. The Agencies also issued a statement to encourage international science communities to participate in the XARM science team. JAXA and DLR concluded the Implementing Arrangement with DLR to conduct joint studies for possible collaboration on DESTINY$^+$.

We discussed collaboration on the Martian Moons Exploration mission (MMX), with NASA, CNES and DLR and signed the agreements respectively. Joint studies on MMX have been also discussed between JAXA and ESA.

Scientific ballooning campaigns and the launch of sounding rockets were also conducted through international collaboration. In cooperation with the balloon experiments carried out in Australia in 2017, we concluded a basic agreement with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) on the implementation of the balloon experiment in Australia. We also concluded an agreement with NASA for this campaign. In addition, we signed an implementation agreement with Minnesota University on the Focusing Optics X-ray Solar Imager (FOXSI-3) project. Furthermore, JAXA and DLR signed the Implementing Arrangement concerning feasibility studies for a microgravity experiment using a sounding rocket launched by DLR. We have concluded an agreement with NASA on the implementation of the international joint sounding rocket experiment CLASP-2.

In the field of element research, JAXA and CNES concluded the Implementing Arrangement concerning cooperative technology demonstrator activities related to the ATHENA mission (CC-CTP). JAXA also participated in collaborative research on the deterioration assessment of space batteries led by DLR and The National Institute of Advanced Industrial Science and Technology.

a. International cooperation in satellite missions at the operational stage

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
Magnetospheric Observation Satellite GEOTAIL	Jul 24,1992	GEOTAIL is a cooperative mission with NASA for research on the dynamics of the structure of the magnetosphere and participation in the International Solar-Terrestrial Physics (ISTP) project.	NASA (National Aeronautics and Space Administration, USA)	Rocket launch and approximately one-third of observation equipment.
			MPS (Max Planck Institute for Solar System Research, Germany)	Provision of the Low Energy Particle Detector (LD) for the High Energy Particle (HEP) detector.
X-ray Astronomy Satellite SUZAKU (ASTRO-EII)	Jul 10, 2005	SUZAKU makes high-sensitivity observations of various X-ray objects in broader energy bands and with better resolution than previous satellites, with the aim of elucidating the evolution of cosmic structure (largest-scale galaxy cluster collisions, gas behavior during amalgamation, exploration of areas near black holes, etc.)	NASA (USA), MIT (USA)	Japan-US cooperative development of the X-ray Telescope (XRT), X-ray Spectrometer (XRS), etc.
			ESA (European Space Agency)	Participation of ESA researchers as scientific advisors for SUZAKU.
			ISRO (Indian Space Research Organization, India)	ISRO “ASTROSAT” satellite and cooperative observations.
Solar Observation Satellite HINODE (SOLAR-B)	Sep 23, 2006	As a globally available solar observatory, HINODE observes various explosions and heating phenomena that occur in the solar surface and corona. By capturing fluctuation phenomena of magnetic energy generated in the Sun’s atmosphere, we can explore fundamental problems from cosmic plasma physics, such as the origin of the corona (the Sun’s outer atmosphere), the relation between changes in the electromagnetic structure of the photosphere and dynamic corona phenomena.	NASA (USA)	Japan–US cooperative development of Solar Optical Telescope (SOT), X-ray Telescope (XRT), etc. Also, Japan–US–UK cooperative development of the Extreme-ultraviolet Imaging Spectrometer (EIS).
			STFC (Science and Technology Facilities Council, UK)	Japan–US–UK cooperative development of the Extreme-ultraviolet Imaging Spectrometer (EIS).
			ESA (EU), NSC (Norwegian Space Centre, Norway)	HINODE scientific data received at a Norwegian facility.

Venus Climate Orbiter AKATSUKI (PLANET-C)	May 21, 2010	As the world's first mission to thoroughly investigate the mechanism of movement of Venus's atmosphere, AKATSUKI uses newly developed infrared sensors to uncover atmospheric phenomena hidden beneath the planet's clouds. This will allow us to elucidate the mechanism of Venusian atmospheric dynamics that cannot be explained by conventional meteorology (planetary-scale high-speed winds) to obtain a comprehensive understanding of weather phenomena on this planet.	NASA (USA)	Provision of the Deep Space Network (DSN) tracking for AKATSUKI, scientific support.
			ESA (EU)	Participation of ESA Venus Express team researchers in cooperative research.
			ISRO (India)	Conduct radio wave occultation observation of Venus atmosphere by communication between AKATSUKI and ISRO's DSN and JAXA's DSN.
Asteroid Explorer Hayabusa2	Dec 3, 2014	A sample return mission to the C-class asteroid "Ryugu" that will provide new knowledge about the original distribution of materials in the solar system and its evolutionary process.	NASA (USA)	Deep Space Network (DSN) tracking of Hayabusa2, control support, asteroid ground observation support, OSIRISRex sample provision, etc.
			DLR (German Aerospace Center, Germany)	Hayabusa2 tracking support, microgravity experiment support.
			Department of Industry and Science, Australian Defence Organisation (Australia)	Permission for sample reclamation capsule landing in Australia and landing operations support.

Cooperative projects with overseas satellite missions

Gamma-ray Burst Observation Mission Swift	Nov 20, 2004	Swift is an international collaboration with the US, UK, and Italy for investigating the formation of gamma-ray bursts, the largest known explosive phenomena.	NASA (USA)	JAXA, Saitama Univ., Univ. of Tokyo to provide Burst Alert Telescope (BAT).
Magnetosphere exploration satellite constellation THEMIS (Time History of Events and Macroscale Interactions during Substorms)	Feb 17, 2007	THEMIS is a US-led mission, consisting of five magnetosphere exploration satellites and full-sky cameras. Combining these with magnetosphere observation equipment will elucidate the occurrence mechanism of “substorms”, the explosive development of the aurorae.	NASA (USA), UC Berkeley (USA)	JAXA researchers participating as science personnel.
Gamma-ray Space Telescope Fermi	Jun 11, 2008	Fermi is an international mission involving the US, France, Germany, Japan, Italy and Sweden. It will perform observations of black holes, neutron stars, active galactic nuclei (AGNs), supernova remnants and gamma-ray bursts, the largest known explosive phenomena.	NASA(USA)	Hiroshima Univ. providing semiconductor sensors for the gamma-ray Large Area Telescope (LAT)
Canadian small satellite project CASSIOPE (CAScade, Smallsat and IOnospheric Polar Explorer)	Sep 29, 2013	CASSIOPE is Canada’s first small satellite project. Its main goal is elucidation of atmospheric outflow mechanisms from the polar region and observations of the effects of the Sun on Earth’s magnetosphere and atmosphere.	Univ. of Calgary (Canada)	JAXA providing one of eight E-POP observation devices (neutral particle analyzers).
Korean Science & Technology Satellite STSAT-3	Nov 21, 2013	STSAT-3 is used for atmospheric observations and environmental monitoring, as well as galaxy observations.	KASI (Korea Astronomy and Space Science Institute, South Korea)	JAXA providing technical assistance for telescope system development of the Multipurpose Infra-Red Imaging System (MIRIS).
Magnetospheric Multi-Scale Mission MMS	Mar 12, 2015	MMS is a NASA-led mission. It uses observations with ultra- high temporal resolution from four identically constructed satellites to elucidate magnetic reconnection and other space plasma phenomena that occur near Earth.	NASA(USA)	JAXA providing technical support for development of the MMS Dual Ion Sensor (DIS) in the Fast Plasma Instrument (FPI).
Exploration of energization and Radiation in Geospace ERG	Dec 20, 2016	This mission aims at discovering how high-energy electrons that are repeatedly created and destroyed in “space storms” resulting from solar wind disturbances are produced in the Van Allen radiation belt, and how these space storms propagate.	NASA (USA)	Cooperative observation with NASA’s “Van Allen Probes.”
			CSA (Canada)	Cooperative observation with CSA’s “ORBITALS” satellite.
			AS (Academia Sinica, Taiwan)	Provision of the Low-Energy Particle Experiment (LEP-e).

b. International cooperation in satellite missions at the development stage

Project	Launch	Mission Overview	Cooperating partner	Partner responsibilities
Mercury Exploration Mission BepiColombo	FY2018 (planned)	This is the first in-depth cooperative mission between Japan and the ESA, using two satellites—the ESA's Mercury Planetary Orbiter "MPO" and JAXA's Mercury Magnetosphere Orbiter "MMO"—to conduct comprehensive observations of Mercury's magnetic field, magnetosphere, interior and surface, thereby revealing mysteries of Mercury's past and present.	ESA (EU)	MPO development, rocket launch, etc.
			CNES (Centre National D'études Spatiales, France)	Partial provision of the MMO- mounted Mercury Plasma Particle Experiment (MPPE) and Plasma Wave Investigation (PWI) experiments. Also, Japan–France co-development of Probing of Hermean Exosphere by Ultraviolet Spectroscopy (PHEBUS) experiment.
			IWF (Austrian Space Research Institute, Austria)	Provision of Magnetic Field Measurement (MGF) device on MMO.
			SNSB (Swedish National Space Board, Sweden)	Provision of Energetic Neutral Atom (ENA) and Mercury Electric Field In-Situ Tool (MEFISTO) electric field measuring instrument.
			FSA (Russian Federal Space Agency, Russia)	Provision of the Mercury Sodium Atmosphere Spectral Imager (MSASI) on MMO.
			DLR (Germany)	Provision of the equipment for the ion mass analyzer on MMO.

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
Martian Moons eXploration (MMX) Mission (pre-project)	FY2024 (planned)	By analyzing a sample from a Mars satellite return mission and performing on-orbit observations, we will pursue an overall goal of better understanding the evolution of pre-life environments through the following scientific findings: 1) uncovering the origins of the Martian satellites, in preparation for deciphering the formation process of Mars, 2) using sample analysis to place restrictions on possibilities for Mars's formation (depending on findings related to the origin of Mars's satellites), 3) unraveling the history of Mars's environment, and 4) globally observing Mars's atmosphere and surface.	NASA (USA)	Under discussion
			CNES (France)	Under discussion
			ESA (EU)	Under discussion
			DLR (Germany)	Under discussion

Outsized Kite-craft for Exploration and Astronautics in the Outer Solar System (OKEANOS) (pre-project)	TBD	Solar power sail-craft aims at demonstration of exploration of the outer planetary region and will rendezvous with a Jupiter Trojan asteroid and deploy a lander that will land on the surface to collect samples from both surface and subsurface to perform in-situ analysis. Multiple kinds of deep space observation in the cruising environment and Trojan asteroid observation will be performed.	DLR (Germany)	Under discussion
Cosmic microwave background radiation polarization observation satellite LiteBIRD (Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection) (pre-project)	TBD	This mission aims at a thorough investigation of the inflation model of cosmology. Cosmic inflation is expected to have produced primordial gravity waves and their after-effects are predicted to have been imprinted in the cosmic microwave background polarity map as “B-mode” perturbations. This mission will perform full-sky observations free of strong foreground signals so that polarized B-mode signals due to primordial gravity waves should be strongest.	NASA (USA), ESA (EU), etc.	Under discussion

Cooperative projects with overseas satellite missions

Jupiter Icy Moons Explorer JUICE (pre-project)	2022 (planned)	JUICE is an ESA-led mission. It will map the surfaces of Jupiter and its larger satellites (Ganymede, Callisto, and Europa) and perform interior observations to investigate the possibility of life.	ESA (EU), DLR (Germany), SNSB, (Sweden), 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), CNES (France), etc.	Under discussion

d. International cooperation in scientific missions for space environment utilization

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

Cooperative projects with overseas satellite missions

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, China)	Cooperative analysis of returned crystals by JAXA and SICCAS (planned).
Japan–India joint life science experiment	TBD	This project will use an Indian recovery satellite (the Space Capsule Recovery Experiment [SRE2]) to perform experiments on algae grown in a microgravity environment to contribute to research on the effects of space environments on life.	ISRO (India)	JAXA providing microbial culture laboratory equipment (planned).

e. International cooperation in observational rocket experiments

Project		Experiment Overview	Cooperating partner	Partner responsibilities
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 Spectro Polarimeter 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, Brazil)	In cooperation with JAXA, flight operations and reclamation of balloon and observational equipment.
Japan–US Joint balloon experiment BESS/BESS-II (Balloon-borne Experiment with a Superconducting Spectrometer)	A joint Japan–US experiment performing cosmic particle beam observations using a balloon-mounted 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 systems after splashdown.
Japan–Indonesia tropical atmosphere cooperative research	Comprehensive research through various observations of atmospheric movement and chemical processes from the tropical troposphere layer (TTL) to the stratosphere	LAPAN (Indonesia)	Provision of appropriate facilities for observation and monitoring and obtaining permission for research within Indonesia.
Japan-Australia balloon joint experiment	A joint balloon experiment and space science research with long-time flight and the retrieval of experimental equipment on land, which were difficult in domestic balloon experiments.	Commonwealth Scientific and Industrial Research Organisation (Australia)	Permission for experiment location and experiment support

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

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

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

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

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

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

3. Research by External Funds

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

Research Categories	Number of Selected Projects	Total (in 1,000 JPY)
Scientific Research on Innovative Areas (Research in a proposed research area)	1	24,180
Scientific Research (S)	1	14,430
Scientific Research (A)	11	121,537
Scientific Research (B)	15	54,970
Scientific Research (C)	15	20,956
Challenging Exploratory Research*	4	7,354
Challenging Research (Exploratory)	1	3,640
Challenging Research (Pioneering)	1	6,110
Young Scientists (A)	2	34,710
Young Scientists (B)	11	15,794
Research Activity start-up	3	4,290
JSPS Fellows	1	1,100
Total	66	309,071

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

Accepted Share of expenses

Research Categories	Number of Selected Projects	Total (in 1,000 JPY)
Scientific Research on Innovative Areas (Research in a proposed research area)	4	29,828
Scientific Research (S)	6	59,128
Scientific Research (A)	9	9,234
Scientific Research (B)	8	5,005
Scientific Research (C)	5	903
Challenging Research (Exploratory)	2	455
Total	34	104,553

b. Funded Research

Number of Researches	Total (in 1,000 JPY)
15	744,286

c. Cooperative Research with Private Sector

Number of Researches	Total (in 1,000 JPY)
33	26,651

d. Earmarked Donations

Number of Researches	Total (in 1,000 JPY)
11	6,000

4. Domestic Joint Research

a. Open Facilities for Domestic Joint Research

Facility	Number of joint research
Space Chamber test equipment	22
Ultra-high-speed collision test equipment	25
Space radiation equipment	9
Wind tunnel laboratory	24
Planetary atmospheric entry environment simulator	14
JAXA supercomputer	27

b. Research for promoting international missions

	Number of joint research
	4

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

	Number of co-researchers
	88

V

Education and Public Outreach

1. Graduate Education

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

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

ISAS staff engaged in graduate education (as of March 31, 2018)

School or Program	Professors	Associate professors	Assistant Professor	Total
The Graduate University for Advanced Studies	18	41	18	77
The Graduate School at the University of Tokyo				
School of Science	9	3	6	18
School of Engineering	11	4	12	27
Special Inter-Institutional Research Fellows*	6	8	–	14
Cooperative Graduate School*	7	10	2	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 program elements, including basic policies and guidelines related to cooperation with graduate education, cooperation with the Graduate University for Advanced Studies (known as SOKENDAI in Japan) and the University of Tokyo, and other issues related to affiliations with graduate schools.

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

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

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

SOKENDAI Department of Space Science Admissions in FY2018

Admission month	Admission capacity	Applicants	Accepted applicants
October	5*	4	2
April		3	2

*Of which 3 were admitted to secondary doctoral courses.

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

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

c. Special Inter-Institutional Research Fellows and Technical Trainee

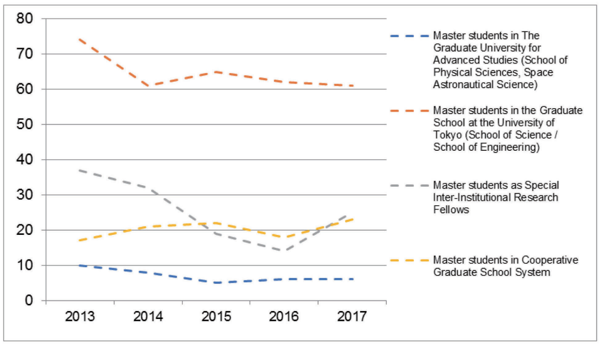
In the Special Inter-Institutional Research Fellows system, ISAS accepts students from national, public, and private universities throughout Japan who need advice on their university-sponsored research, and provides education and guidance on specific research themes for limited periods. These activities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

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

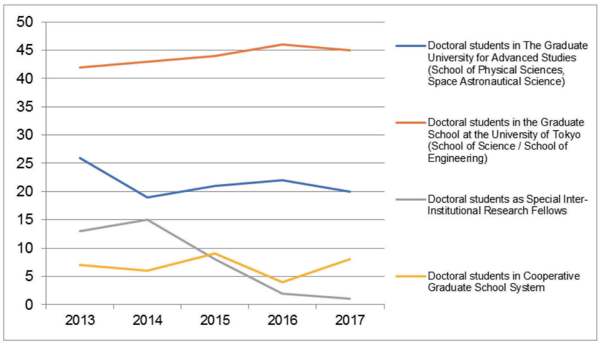
d. Cooperative Graduate School System

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

As of March 31, 2018, ISAS was cooperating with 12 schools in 10 universities and accepts, teaches, and trains master's and doctoral degree students. In some schools, we cooperate with other JAXA directorates.



Number of students receiving education for a master's degree



Number of students receiving education for a doctoral degree

e. Space Science and Technology Conference in Vietnam

The Space Science and Technology Conference was held from December 12 to 15, 2017 at Ho Chi Minh City International University, a member of the Vietnam National University (HCMIU-VNU). Six faculty staff from the Department of Space and Astronautical Science/ Graduate University for Advanced Studies (SOKENDAI) and two administrators from the school office attended the conference.

Although space science research and technology development has been stimulating interest in recent years among Southeast Asian countries, the scope of these activities is still limited to the use of data from positioning satellites, such as GPS and quasi-zenith satellites and to the production of ultra-small satellites. It is still an inconvenient situation for young researchers and scientists in Southeast Asia to be involved in research and development at the forefront. Therefore, in collaboration with HCMIU-VNU, JAXA (ISAS) held this international conference with the aim of fostering greater enthusiasm among young scientists and to further promote space science and technology across Southeast Asian countries. The Department of Space and Astronautical Science at SOKENDAI actively participated in the conference, to facilitate the future acquisition of talented international students at SOKENDAI and to prepare for the formation of a joint research center in the future. Approximately 70 participants were registered at the conference, 22 of whom were undergraduate students in Vietnam. A total of 15 participants from Japan included Professor Shinichi Nakasuka from the University of Tokyo, Associate Professor Naohiko Kohtake from Keio University, and eight faculty staff from JAXA: the Deputy Director General Hitoshi Kuninaka, Director of Space Science Kazuhisa Mitsuda, and the former Chair of Department of Space and Astronautical Science Yuko Inatomi and other faculty staff. Many scientists and researchers from institutions outside Vietnam, such as the Institute of Astronomy and Astrophysics Academia Sinica and National Space Organization in Taiwan, Korea Astronomy and Space Science Institute, as well as the Director General at the Vietnam National Space Center (VNSC) also attended the conference.

There were also discussions on how to strengthen cooperation between HCMIU, JAXA and SOKENDAI and space agencies in Asian countries. In the space utilization field, in which cooperation has already started, it was decided that issues such as disaster monitoring and air pollution will be examined. In the wake of this international conference, the Department of Physics at HCMIU and ISAS (Department of Space and Astronautical Science at SOKENDAI) reached an agreement that both institutions, in collaboration, will plan and apply for an Intensive Space Science Lecture (The Winter School of SOKENDAI/Asia) and an internship. Also, JAXA will take the initiative to hold the Asia-Pacific Regional Space Agency Forum (APRSAF) to promote continuing exploration of space science throughout Southeast Asia. Several questions and opinions

Group photo of participants at the conference at HCMIU-VNU.

were also raised by students and young researchers.

This international conference has been widely recognized in Vietnam, as evidenced by the congratulatory speech from the President of the Vietnam National University and from the Director General of the Vietnam Academy of Science and Technology delivered during the conference. Thus, the introduction of the SOKENDAI Department of Space and Astronautical Science for young scientists and the academic staff in Vietnam plays a key role in fostering a higher quality of education in the future.

2. Public Outreach

Targeted investments in outreach have contributed to the creation of space science support and increased visibility for JAXA among research institutions and agencies. Diversification of communication channels continued throughout the year. The biggest science story of the year was the detection of intact lunar lava tubes in the data from SELENE (KAGUYA) radar sounding. The success in the launch of SS-520 F5, the smallest launch vehicle in the world, was also one of the headlines.

A new visitor center, one of ISAS's significant projects, progressed well and opened in February 2018. Throughout the year, most of the public outreach effort was poured into preparation for opening the new visitor center. A working team which planned and designed exhibition contents collected items worth to show and public outreach coordinators produced new video clips explaining the history of ISAS and current progress of our missions. We utilized a big white wall of the visitor center as a 300-inch-size screen and created video clips for it. ISAS designated the visitor center as Communication Hall of Space Science and Exploration. More than 300 people come to enjoy the exhibition on each holiday and groups of students visit to learn space science by using the exhibition. We use the new facility to introduce ISAS to governmental officials and Diet members.

a. Press Activities

In FY2017, 29 press releases were issued. 14 of these were science releases, covering a mix of results of research using ISAS experimental and analysis facilities on the ground and studies based on data obtained in space. As noted above, the detection of intact lunar lava tubes in the data from SELENE (KAGUYA) radar sounding generated lots of media interest.

More than 4000 articles were published on the internet news sites in FY2017 and the number of articles was gradually increased for the past couple of years.

b. Exhibition and Events

ISAS's exhibition room at the Sagamihara Campus has spotlighted the most significant ISAS missions and science achievements. The exhibition room serves as the first impression of ISAS for many guests for a long time. To promote our outreach activities further, ISAS decided to build a new facility for exhibition and communication between researchers and the general public. After one-year construction and preparation, the new exhibition hall opened its door for everyone in February 2018. It provides visitors with an exciting experience of space science in general, along with ISAS-specific results, missions, experiments, and technological breakthroughs.

Outreach events, led by ISAS/JAXA, are held year-round to engage the public with ISAS missions and accomplishments. Annual special "open house" days were held at Sagamihara Campus for two-days at the end of August, and about 7,000 people visited. Event booth locations were optimized, and smooth flow lines were planned, thereby successfully alleviated congestion. We tried to provide educational experiences that inspire and captivate visitors of all ages in a more user-friendly way.

"Space School" events continue to captivate each

Communication Hall of Space Science and Exploration new generation of learners nationwide. In nine Space Schools hosted in FY2017, scientists and engineers made presentations and answered participants' questions during the half-day-long event. About 850 people joined in FY2017's "Space School in Sagamihara" and "Lectures on Space Science and a Movie," an event commemorating the ISAS foundation.

New exhibition room in the Communication Hall of Space Science and Exploration

VI
Awards

The Fourth ISAS Award Recipients

Name	Affiliation	Reason for Award	Date
NAGAI, Tsugunobu	Department of Earth and Planetary Sciences, School of Science, Tokyo Institute of Technology	(Special Award for Outstanding Long-term Contribution) Elucidation of "Magnetic Reconnection," a physics process driving dynamics of the earth's magnetotail.	Mar 22, 2018
Alvaro Giménez Cañete	The former Director of Science, European Space Agency (ESA)	(Special Award for Outstanding Long-term Contribution) Exceptional contribution to Euro - Japan Partnership in Space Science and Exploration	Mar 22, 2018
SATO, Akiyoshi	IHI Aerospace Co., Ltd	Establishing Quality Assurance of Solid Rocket Motor by Ultrasonic Flaw Detection Method.	Mar 22, 2018
KANO, Ryouhei	SOLAR-C Project Office, National Astronomical Observatory of Japan	Demonstration of a New Method of Retrieving Magnetic Field Information in the Solar Chromosphere and the Corona with the polarimetry via the Hanle effect.	Mar 22, 2018

Award Recipients

ISAS STAFF	Affiliation	Award	Date
NAKAMURA, Masato TODA, Tomoaki HIROSE, Chikako	Department of Solar System Sciences Department of Spacecraft Engineering Research Unit I, JAXA Research and Development Directorate	The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology: Prizes for Science and Technology (Research Category) FY2017. "Research on the Venus orbit insertion control of the Venus probe 'Akatsuki' ."	Apr 19, 2017
TOMIKI, Atsushi et al.	Department of Spacecraft Engineering	The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology: Prizes for Science and Technology (Research Category) FY2017.	Apr 19, 2017
KUNINAKA, Hitoshi	Department of Spacecraft Engineering	The Japan Society of Applied Physics: 39th JSAP Outstanding Paper Award, Award for Best Review Paper. "Physics of electron cyclotron resonance ion sources."	Sep 5, 2017
SAWADA, Hirotaka KUBOTA, Takashi et al.	Department of Spacecraft Engineering	20th International Conference on Climbing and Walking Robots and Support Technologies for Mobile Machines (CLAWAR): CLAWAR Association Best Technical Paper Award. "Development of a Flexible Propulsion Unit for a Seabed Excavation Robot."	Sep 11, 2017
MAKI, Kenichiro	Department of Spacecraft Engineering	The Institute of Electronics, Information and Communication Engineers (IEICE): IEICE Communications Society, Distinguished Service Award FY2017.	Sep 13, 2017
IKAROS Team		International Academy of Astronautics (IAA) : Laurels for Team Achievement Award 2017. "The World's First Interplanetary Solar Sailor, IKAROS."	Sep 24, 2017
TAKAHASHI, Tadayuki	Department of Space Astronomy and Astrophysics	IEEE Nuclear & Plasma Sciences Society: 2017 IEEE Glenn F. Knoll Radiation Instrumentation Outstanding Achievement Award. For contributions to the development of Cadmium Telluride semiconductor devices and their applications to high-energy space astrophysics.	Oct 5, 2017
YAMADA, Takahiro	Department of Spacecraft Engineering	Ministry of Economy, Trade and Industry: FY2017 Minister Awards, Industrial Standardization Awards.	Oct 23, 2017

ISAS STAFF	Affiliation	Award	Date
HABU, Hiroto et al.	Department of Space Flight Systems	The excellent poster award of the 6th International Symposium on Energetic Materials and their Applications. "Vapor pressure measurement of ammonium dinitramide binary mixtures using thermogravimetric analysis."	Nov 2017
TSUKIZAKI, Ryudo	Department of Space Flight Systems	NF Foundation: The 6th NF Foundation R&D Encouragement Award.	Nov 17, 2017
OTSUKI, Masatsugu et al.	Department of Spacecraft Engineering	The 18th Society of Instrument and Control Engineers -System Integration Division Annual Conference (SI2017), System Integration Award for Outstanding Presentation.	Dec 23, 2017
MIURA, Akira	Department of Interdisciplinary Space Science	Organizing Committee for the 8th International Festival of Science Visualization: The 8th International Festival of Science Visualization, Short Film Contest, Audience Choice Award. "Cycles of the Sun -- Stories of the Space Science Showcase--."	Feb 2018
TSUDA, Yuichi ONO, Go MIMASU, Yuya	Department of Space Flight Systems Research Unit I, JAXA Research and Development Directorate Hayabusa2 Project Team	The New Technology Development Foundation: The 50th Ichimura Prize in Science for Distinguished Achievement.	Mar 14, 2018
KITAMURA, Yoshimi et al.	Department of Space Astronomy and Astrophysics	The Astronomical Society of Japan (ASJ): The PASJ Excellent Paper Award FY2017. "Local Enhancement of the Surface Density in the Protoplanetary Ring Surrounding HD 142527." (M. Fukagawa et al.. PASJ: Publications of the Astronomical Society of Japan, Vol. 65(6), L14 (2013))	Mar 15, 2018
HARUYAMA, Junichi	Department of Solar System Sciences	Impress Group 25th anniversary POD (Print on Demand) Individual Publication, Temjin Award. *	Mar 20, 2018
Experiment Handrail Attachment Mechanism (ExHAM) Development / Operation Team		The Japan Society of Mechanical Engineers (JSME): Space Engineering Division, Space Frontier Award FY2017. Development/ Operation of the Experiment Handrail Attachment Mechanism (ExHAM).	Mar 30, 2018
re-Entry satellite with Gossamer aeroshell and GPS/Iridium Team (EGG-TEAM)		The Japan Society of Mechanical Engineers (JSME): Space Engineering Division, Space Award.	Mar 30, 2018

Award Recipients

Student	Affiliation (Cooperative graduate school)	Academic Advisor	Award	Date
KIKUCHI, Shota	Graduate School at The University of Tokyo	KAWAGUCHI, Junichiro	5th IAA Planetary Defense conference, Best Student Paper Award (2nd Prize). "Asteroid De-spin and Deflection Strategy Using a Solar-sail Spacecraft with Reflectivity Control Devices."	May 2017
KIKUCHI, Shota	Graduate School at The University of Tokyo	KAWAGUCHI, Junichiro	The 61st Annual Conference of the Institute of Systems, Control and Information Engineers (SCI'17), Excellent Student Presentation. "Off-line Signal Processing for the Weak-Signal Detection and the Estimation of the Orbital and Attitude Motion of a Spacecraft."	May 2017
ITOUYAMA, Noboru	Graduate School at The University of Tokyo	HABU, Hiroto	Japan Explosives Society (JES): Spring Meeting, Excellent Presentation Award.	May 2017
IWASAKI, Akihiro	The Graduate University For Advanced Studies (SOKENDAI)	GOTO, Ken	Japan Explosives Society: 2017 Spring Meeting, Special Award.	May 2017
TAKAO, Yuki	Graduate School at The University of Tokyo	KAWAGUCHI, Junichiro	The 31st International Symposium on Space Technology and Science (ISTS), Student Session Awards- JAXA President Award. "Attitude and Orbit Control of a Spinning Solar Sail by the Vibrational Input on the Sail Membrane."	Jun 2017
FUKAMI, Tomoya	Graduate School at The University of Tokyo	SAITO, Hirobumi	The Institute of Electronics, Information and Communication Engineers: FY2016 Best Paper Award. "High Speed Downlink Transmitter for Small Satellite."	Jun 1, 2017
YONEDA, Hiroki	Graduate School at The University of Tokyo	TAKAHASHI, Tadayuki	8th International Conference on New Developments in Photodetection (NDIP) 2017, Pierre Besson Prize. "Development of Si-CMOS Hybrid Detectors toward Electron Tracking Semiconductor Compton Cameras."	Jul 2017
KATO, Daiba	Graduate School at The University of Tokyo	SAITO, Yoshifumi	142nd Society of Geomagnetism and Earth, Planetary and Space Sciences(SGEPSS): Excellent Presentation Award. "Relation between the Moon originating ions and the lunar surface structure."	Oct 2017
HAN, Sooman	Graduate School at The University of Tokyo	NAKAMURA, Masato	142nd Society of Geomagnetism and Earth, Planetary and Space Sciences(SGEPSS): Excellent Presentation Award. "A study on long-term variation of Jupiter's synchrotron radiation associated with solar wind."	Oct 2017
TOGUCHI, Shintaro	Graduate School at The University of Tokyo	HIROSE, Kazuyuki	RADECS 2017, RADECS Sponsorship. "Effects of SiH Groups on ELDRS Quantified with a Combined Use of X-ray, Gamma-ray, and Electron-beam Irradiation."	Oct 3, 2017

Student	Affiliation (Cooperative graduate school)	Academic Advisor	Award	Date
MATSUKI, Yuichi	Graduate School at The University of Tokyo	SATO, Eiichi	Association of Shape Memory Alloys (ASMA) : SMA Symposium 2017, Poster Session-Best Poster Award.	Nov 2017
ITOUYAMA, Noboru	Graduate School at The University of Tokyo	HABU, Hiroto	The 6th International Symposium on Energetic Materials and their Applications (ISEM 2017), The Excellent Poster Presentation Award. "Ignition Characteristics of ADN-based ionic liquid propellant."	Nov 2017
HIGANE, Kenta	Graduate School at Tokyo Metropolitan University	SATO, Eiichi	The Japan Institute of Light Metals: Light Metal Paper Prize FY2017. "Low-temperature creep mechanism in ultrafine-grained aluminum."	Nov 4, 2017
KANAZAWA, Takaaki	Graduate School at Tokyo Metropolitan University	SATO, Eiichi	The Japan Institute of Light Metals: Light Metal Paper Prize FY2017. "Initial process of continuous dynamic recrystallization in a superplastic Al–Mg–Mn alloy."	Nov 4, 2017
IWASAKI, Akihiro	The Graduate University For Advanced Studies (SOKENDAI)	GOTO, Ken	The Society of Instrument and Control Engineers, System Integration Division: 18th International Symposium on System Integration (SI2017), Best Presentation Award.	Dec 23, 2017
KIKUCHI, Shota	Graduate School at The University of Tokyo	KAWAGUCHI, Junichiro	The 61st Space Sciences and Technology Conference, Young Researcher Award- Best Paper Award. "Stabilization of Coupled Orbit-Attitude Dynamics around Asteroids by Using Inertial Torques."	Jan 2018
TAKAHASHI, Akiyo	Graduate School at The University of Tokyo	SHIMADA, Toru	The Japan Society for Mechanical Engineers (JSME): Women of the future awards.	Mar 2018

Professor Emeritus	Award	Date
USHIROKAWA, Akio	Government of Japan: The Order of the Sacred Treasure, Gold Rays with Rosette	Aug 5, 2017
MATSUO, Hiroki	Government of Japan: The Order of the Sacred Treasure, Gold and Silver Star	Nov 7, 2017

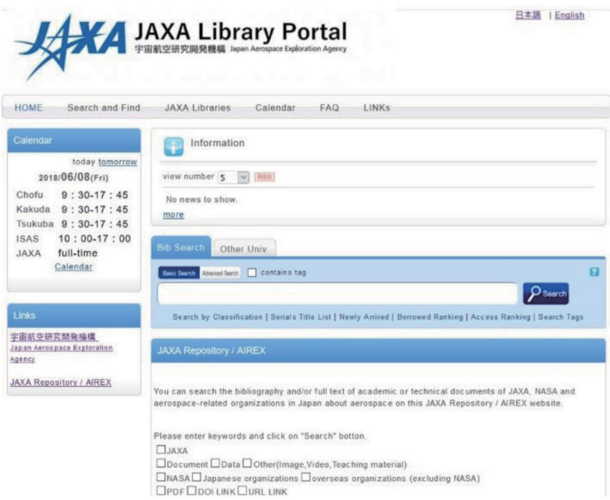
VII
ISAS Library and JAXA Repository

1. ISAS Library

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

ISAS Library holdings at the end of March 2018.

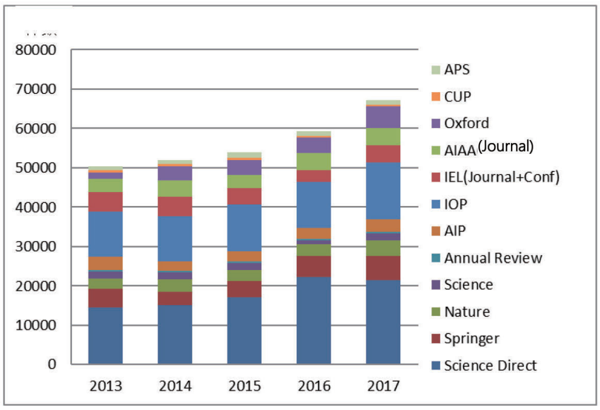
Category	Quantity
Total books	94,023
Foreign books	76,350
Japanese books	17,673
Total journals	1,195
Foreign journals	959
Japanese journals	236
Journals added in FY2017	172
Foreign journals	13
e-Journals	92
Domestic English journals	6
Japanese journals	61
e-Journals	about 4,100
IEL Online	180
IOP Journal	52
Elsevier Science Direct	143
Springer Journal	about 1,615
Wiley-Blackwell	about 1,400
JSTOR	about 680



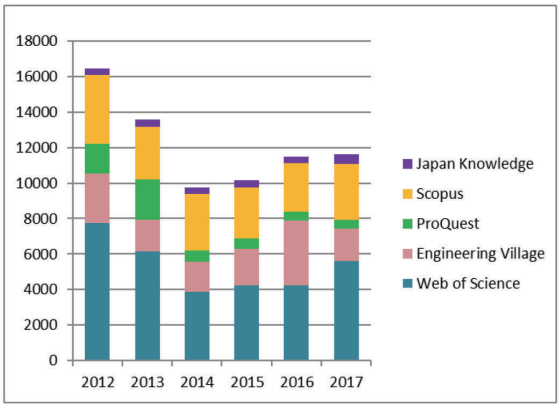
JAXA Library Portal

e-Books	
AGU Geophysical Monograph Series and other	598
AIAA Education Series	69
AIP Conference Proceedings	1,919
Cambridge Books Online	160
Net Library	585
Oxford Scholarship Online (Physics)	216
Springer eBOOK	94,600
ProQuest Ebook Central	36
Chronological Scientific Tables Premium	

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



Number of e-journal downloads



Number of database searches

2. JAXA Repository

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

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

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

The completion of adding all the ISAS symposium proceedings held after 2003 has boosted the cumulative number of the published materials held at the JAXA Repository, which has also promoted the presence of the repository. In FY2017, it was accessed over 2 million times, with increasing access to symposium presentations and materials published by JAXA.

Following modification of the system in FY2016, detailed observation data and the full text of most presentations at symposiums organized by JAXA and ISAS have also become available in the repository.

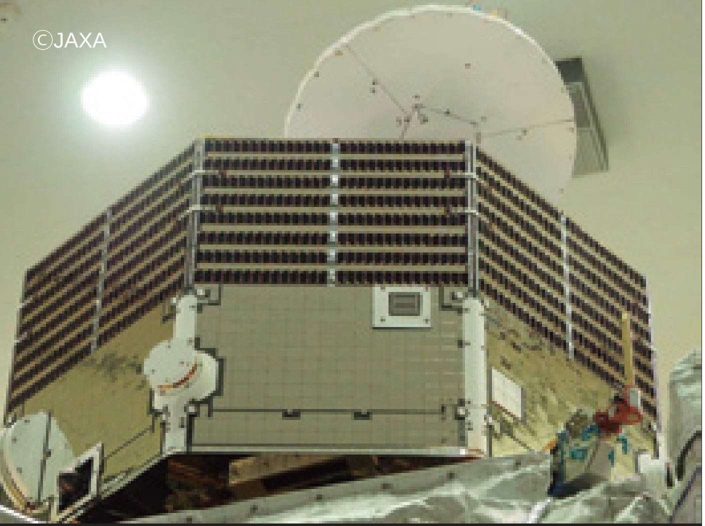
In response to these trends, the JAXA Repository started assigning Digital Object Identifiers (DOIs) in FY2016 to registered papers from peer-reviewed academic journals by JAXA staff. Increasing DOI contents and preserving the accessibility of these materials will allow semi-permanent, open access to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

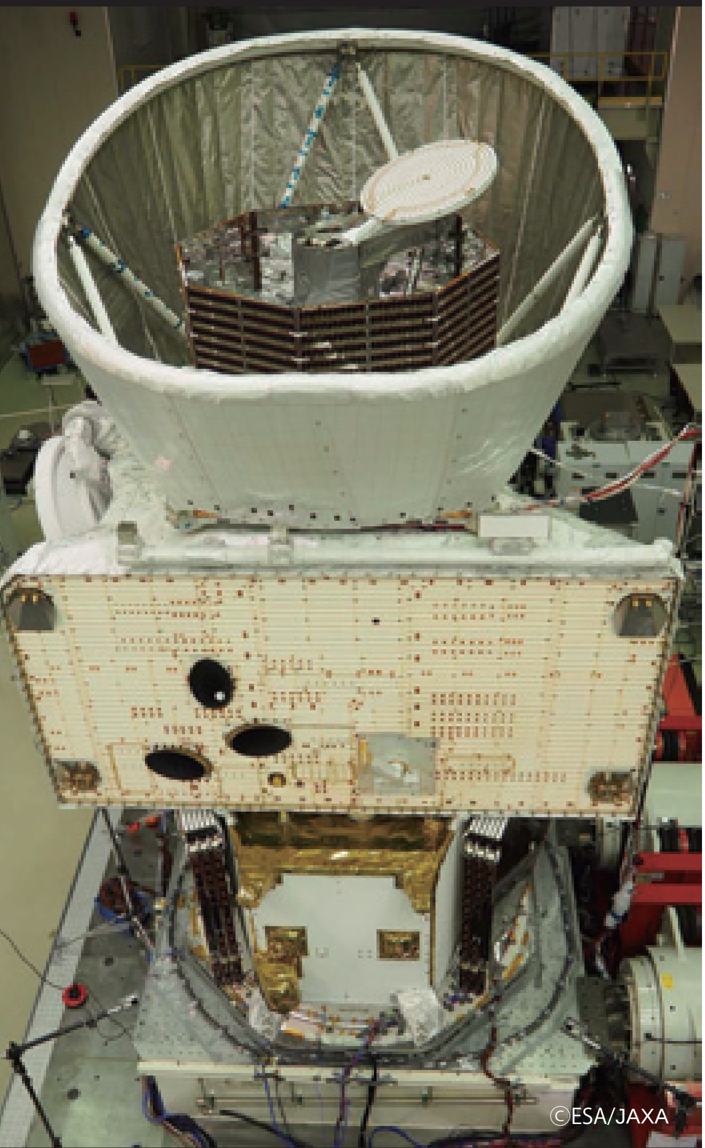
VIII

Publications, Presentations and Patents

Publications, Presentations and Patents

Item	Achievements
1. Publications on Web of Science	
a. Papers in prestigious academic journals by ISAS staff	2 in Nature
b. Number of heavily cited papers (including ISAS staff as co-author)	56 (From Jan 2007 to Dec 2017)
c. Rate of international collaboration	Average: 53% (From 2003 to 2017)
d. Reviewed papers published in journals	323 (From Jan 2017 to Dec 2017)
2. JAXA Publications (in ISAS)	6 (Research and Development Report: 3, Special Publication: 3)
3. Journals, publications, etc.	
a. Published in books	15
b. Published in reviewed journals	354
4. Presentations at domestic and international meetings, etc.	Keynote speeches: 9 Invited lectures: 76 Domestic meetings: 593 International meetings: 490
5. Awards	36 (see pp. 119-122)
6. Patents	Published patent applications: 15 Patents granted: 12





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