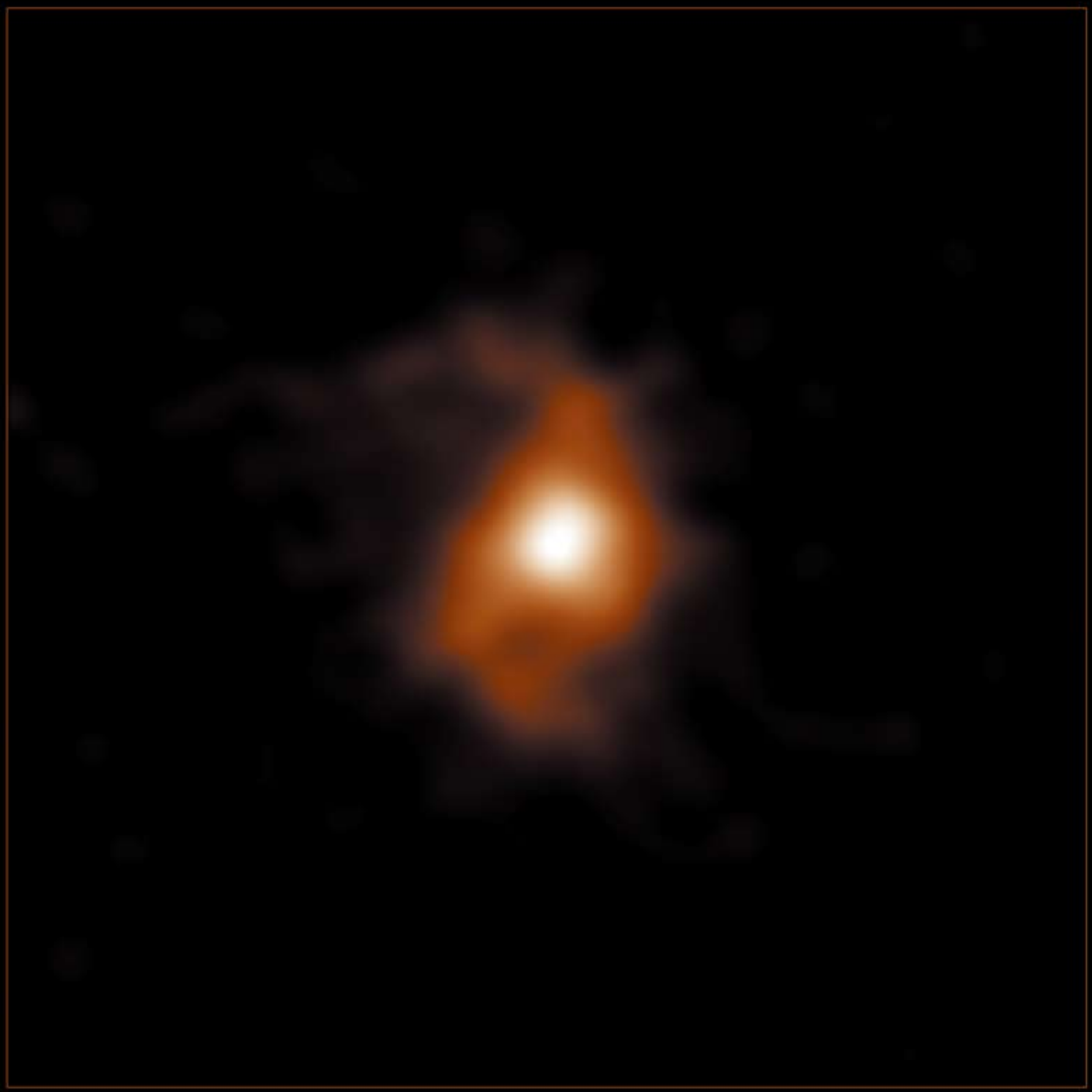
PRINT ISSN 1346-1192
ONLINE ISSN 2436-7214

# Annual Report of the National Astronomical Observatory of Japan

Volume 24 Fiscal 2021



## Cover Caption

The image shows the intensity map of the ionised carbon in the galaxy BRI 1335-0417 at 12.4 billion years ago taken by Atacama Large Millimeter/submillimeter Array (ALMA). Spiral arms are seen on both sides of the compact and bright region in the galactic centre. Further analysis of the gas motion indicates the presence of a compact mass structure and rotating disk structure in the galaxy.

Credit: ALMA (ESO/NAOJ/NRAO), T.Tsukui & S.Iguchi

## Postscript


Publisher National Institutes of Natural Sciences
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# Annual Report of the National Astronomical Observatory of Japan

## Volume 24, Fiscal 2021

# PREFACE

**Saku TSUNETA**
**Director General of NAOJ**

Fiscal Year 2021, like Fiscal Year 2020, felt a large impact from the novel coronavirus. The National Astronomical Observatory of Japan (NAOJ) has mindfully continued our efforts while ensuring the safety of our employees and neighbors through the continuation of the dual work style of telework and commuting, and by holding events for the public and research conferences online.

The big news in the astronomy world was the successful launch of the James Webb Space Telescope (JWST) in December 2021, after long years of work by the American National Aeronautics and Space Administration (NASA), the European Space Agency, and others. Like the epoch-defining Hubble Space Telescope launched 30 years earlier, JWST is expected to show us never before seen facets of the Universe. Also, the National Academies of Sciences, Engineering, and Medicine's Decadal Survey on Astronomy and Astrophysics 2020 (Astro2020) which sets the tone for the coming decade of astronomy and space science research was released. In it the US-ELT, including the Thirty Meter Telescope TMT with participation by Japan, was the top priority for a frontier ground-based observatory. These activities are outside of Japan, but some of JWST's planned observations are based on results from ALMA and the Subaru Telescope operated by NAOJ, and the high evaluation of US-ELT in the Decadal Survey is surely due in part to Japan's steady advancement of the preparation for the telescope structure and production of mirror substrates. Astronomy is no longer a field that can be pursued within a single country. Particularly in times of world instability like the present, we have high expectations for the advancement of international collaboration to solve many of the mysteries of the Universe based on peace and humanity's intellectual curiosity.

Looking at NAOJ's activities, there were many research results published in 2021. The Seimei Telescope at Kyoto University's Okayama Observatory, for which the Subaru Telescope Okayama Branch administrates the open-use, was the first to observe the eruption of a supermassive gas filament as the result of a "super flare," a giant explosive phenomenon, on the surface of a Sun-like star. This offers hints to the effects the young Sun had on the early Earth, helping to answer questions about how the environment for early life evolved.

Approximately 100 free-floating planets were found from Subaru Telescope observations of a young stellar association near the constellation Ophiuchus. It is thought that planets which originally formed around stars were ejected from their planetary systems at some point. This result too provides hints about how the Solar System evolved into its current configuration.

Big news came out of the ALMA archive in the form of the discovery of a galaxy with spiral morphology 12.4 billion years ago. This result will help to solve the mystery of how spiral galaxies like our home Milky Way Galaxy are formed. The fact that this result was obtained from the archived data without making new observations shows the importance of a well-maintained data archive. In other ALMA results, many kinds of organic molecules were detected in the extreme outer edge of the Galaxy, where the environment from the beginning of the formation of the Milky Way Galaxy has been preserved up to the present day; and the spatial distribution of molecules with deuterium around the site of planet formation was mapped. Deuterium is the key to searching for the origins of the water on Earth. As the detections of different materials in different environments increase, they bring us closer to understanding the origins of the Solar System and life.

The release of "Uchuu" the world's largest virtual Universe courtesy of the supercomputer "ATERUI II" can safely be called an important contribution to the world astronomy community. In Uchuu, the dark matter which controls the Universe is represented by 2.1 trillion particles. Through calculations of dark matter mutual gravitational interactions, galaxies of various sizes are depicted in detail throughout a huge space 9.6 billion light-years across. Comparing this data to large-scale survey programs from the Subaru Telescope and other facilities will advance our understanding of the evolution of galaxies and the large-scale structure of the Universe.

This fiscal year, the Industry Liaison Office launched in 2020 opened a website and established various procedures for collaboration with industry, strengthening our ties to the wider society. As a matter of fact, collaboration with industry is gradually developing. In September 2021, we entered an agreement with the space start-up corporation ALE for the development of a small microwave sounder for private meteorological satellites. Also, a comprehensive cooperation agreement was concluded with IWATE NIPPO CO., LTD. (a news media company) aiming to establish a support venture for next-generation researchers centered on Mizusawa VLBI Observatory, where both companies will employ the researchers as "two-fisted scientists and journalists." This is an example of a new approach based on cooperation between a research institute and media, an innovative approach as a means of securing talent for the advancement of science.

Here I would like to summarize the status of NAOJ's various projects in FY 2021. At the Subaru Telescope, using the supplemental budget which has been received almost every year since FY 2018, preventative maintenance in response to the aging of the facility has been undertaken, including repairs to the mechanical parts of the dome, and complete replacement of the dome air-conditioning system and the uninterruptible power supply units. As part of the facility update, open-use observations

have switched almost entirely to remote observations. (Remote observation system is scheduled to be completed in 2022.) This is expected to lead to more efficient open-use observations and multi-messenger and gravitational wave astronomy.

The Subaru Strategic Program using the ultra-wide field of view prime focus camera Hyper Suprime-Cam (HSC) which started in March 2014 concluded successfully at the end of calendar year 2021 after observing for a total of 330 nights over the course of 8 years. The third public data release occurred in August 2021. Analysis of the weak gravitational lensing in the first 3 years of data enabled a high spatial resolution map of dark matter across about 500 square degrees.

The wide-field, multi-object spectrograph PFS (Prime Focus Spectrograph) is conducting test observations to assess the technical performance of the instrument. Aiming to be ready for open-use observations in FY 2024, planning of the observation procedure and data analysis tool development are ongoing. There were test observations with the prototype laser guide star system of the ground layer adaptive optics (GLAO) system which is necessary for the wide-field, high-resolution infrared observational instrument ULTIMATE. ULTIMATE together with HSC and PFS will form the core instrument suite of Subaru Telescope 2.0. It will enable hitherto impossible wide-field, high-resolution observations in the infrared wavelength range.

The infrared Doppler instrument (IRD), which searches for terrestrial planets, started Subaru Strategic Program observations in February 2019. In FY 2021, intensive observations were performed for 35 nights to search for terrestrial planets around nearby M type stars. Measurements of atomic abundances in the atmospheres of M type stars were published. A line-of-sight velocity measurement precision of 2 m per second has been stability achieved. The combination of the extreme adaptive optics system SCExAO and the near infrared high-contrast integral field spectrograph CHARIS produced observations looking for protoplanets in the circumstellar disk around young stars. The development, maintenance, and operation of these instruments are proceeding through collaboration between Subaru Telescope and the Astrobiology Center of the National Institutes of Natural Sciences.

ALMA was forced to suspend observations for approximately 1 year starting in March 2020 due to the COVID-19 pandemic, but has been able to incrementally return to normal operations. Cycle 8, the 9th ALMA open-use observation cycle, started from October 2021. There were 1,735 observation proposals for Cycle 8 submitted from all over the world; this is a record for the number of observation proposals. The number of scientific papers published based on ALMA data reached 2,752 during the ten-and-a-half-years ending with FY 2021. Japan continued to have the second largest share of published papers after the United States.

In instrument development, tangible results are coming out of the collaboration in East Asia centered on NAOJ. First, August 2021 saw the successful first light of the Band 1 receivers (bandwidth 35–50 GHz) for which the development was led by the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan. NAOJ is responsible for the design and manufacturing of the corrugated horns, one of the vital components for the Band 1 receivers. The 3D metal printer in the Advanced Technology Center (ATC) has been busy mass-producing the horns. In February 2022, the new spectrometer, for which development was led by the Korea Astronomy and Space Science Institute, saw first-light on the Atacama Compact Array (ACA, Morita Array). On the other hand, preparation is also underway for the start of the ALMA 2.0 project aiming to drastically improve the performance specs of the ALMA array, including the design of high-performance parts for the Band 8 receivers (385–500 GHz).

TMT is a project to build an extremely large telescope with a 30 m diameter being advanced through collaboration between 5 countries: Japan, the United States, Canada, India, and China. Onsite construction is currently on hold due to protests, but the TMT International Observatory (TIO) Project Manager, who oversees the entire project, has moved to Hilo, Hawai`i and together with NAOJ employees, first and foremost the Director of NAOJ TMT, is engaging in a direct dialog with local individuals and groups who have been opposed to TMT. They are also participating in after-school tutoring programs at local schools and other programs. In these ways they are working to build trust with the people in the local area, including the Native Hawaiian community. As each country continues to make progress on its workshare, in Japan preparations continue for manufacturing the main body structure of the telescope. In ATC the detailed design for the Infrared Imaging Spectrograph (IRIS) and the conceptual design for the Wide Field Optical Spectrograph (WFOS) are proceeding favorably. The development of the science operations plan for after the telescope is completed is being led by the United States, and there is active discussion within the Japanese community as well.

In the Division of Science, multi-wavelength observations and theoretical research are blending together organically. Fruits of this combination include research combining ALMA observations of rotating jets with MHD models to understand the growth of young stars; and research tying multi-wavelength observations to theoretical predictions of electron capture supernovae to further our understanding of the overall picture of stellar evolution.

At KAGRA, the Large-scale Cryogenic Gravitational Wave Telescope, led by the Institute for Cosmic Ray Research of the University of Tokyo with the participation of NAOJ and the High Energy Accelerator Research Organization KEK, the upgrades of the ultra-low-frequency vibration isolators, and other components for which NAOJ is responsible, have been completed and the restart and adjustment of the main interferometer have commenced. The goal is to detect gravitational waves as part of the next coordinated international observing run O4 scheduled to start from March 2023. Also collaborative research between NAOJ and KASI has found a potential solution to the birefringence problem in the sapphire mirrors which has been a source of much anxiety in KAGRA. Preparations are underway to install new mirrors before the O5 coordinated international observing run. Also the prospect of introducing frequency-dependent squeezing technology in KAGRA is being examined, now that the proof-of-concept experiments using the interferometric gravitational wave antenna TAMA300 have successfully demonstrated the techniques.

In March 2022, the 40th anniversary ceremony was held for Nobeyama Radio Observatory. Open-use observations with the Nobeyama 45-m Radio Telescope ended in FY 2021. But based on discussion about the operation of the telescope after that, a

policy of charging for observation time has been implemented. The renewal of the focal-plane instrument has enabled results such as the completion of the Nobeyama Mapping Survey. Also in FY 2021, Mizusawa VLBI Observatory ended VERA astrometry observations. It plans to shift its research activities to focus on the East Asian VLBI Network (EAVN). EAVN has been producing results, such as determining the structure of jets right after ejection from around a black hole.

Operation of the 188-cm reflector telescope at the Okayama Branch of the Subaru Telescope is being led by the Tokyo Institute of Technology. The total number of visitors has surpassed 2 million since the facility first opened to the public in 1960. In cooperation with Asakuchi City, programs including star-gazing parties with the Okayama 188-cm Reflector Telescope have been implemented. In recognition of these activities and its scientific discoveries to date, the Okayama Branch received the 2021 Okayama prefecture tourism industry award. Ishigakijima Astronomical Observatory is a unique observatory operated in collaboration with the local government. In addition to observations of Solar System objects and research on explosive phenomena, the 105-cm aperture Murikabushi Telescope is continuing observations of the SpaceX Starlink satellites as part of research into light-pollution reduction techniques. The number of visitors to the facility has passed 150,000 since it opened in 2006. To improve the safety and security of the visitors, the facility plans to change to charged admission starting from FY 2022.

After being selected as the 4th JAXA Small Satellite in FY 2020, the Solar-C (EUVST) satellite to conduct high resolution spectroscopy of the Sun at extreme ultraviolet wavelengths has been preparing for the mission definition review. The CLASP sounding-rocket telescope experiments, which with participation by NASA and others have blazed trails in high-sensitivity polarization observations in the ultraviolet regime, executed their third flight in October 2021. Data analysis was performed to determine the 3D structure of the magnetic fields from the photosphere to the chromosphere. SUNRISE-3 is a balloon experiment to perform high-resolution polarization observations with a 1-m aperture optical telescope. NAOJ is developing the near-infrared spectro-polarimeter SCIP for it. Testing at the Max Plank Institute for Solar System Research has concluded, and preparations are underway for a flight in 2022. At NAOJ development is underway for a high-speed CMOS camera for soft X-rays and an X-ray collimator for the NASA FOXSI-4 sounding rocket experiment.

Thailand has become a new member of the East Asian Observatory (EAO), joining Japan, China, the Republic of Korea, and Taiwan. Board meetings were held regularly for the stable operation of the James Clerk Maxwell Telescope (JCMT), EAO's primary responsibility.

In ATC, development continued for a space-grade version of the InGaAs infrared sensors. This sensor will be installed in the infrared astrometry satellite JASMINE. Making best use of ATC's expertise with superconducting devices, development work has started for the super-low-power-consumption, low-noise microwave amplifiers needed for superconducting quantum computing as part of JST's Moonshot research and development program. Also, in order to strengthen ATC's development procedures, it was reorganized into a matrix organization structure.

In the Astronomy Data Center, users' meetings were held to solicit opinions from the wider community for the renewal of the large-scale archive and multi-wavelength data analysis system. The optical-infrared archive SMOKA has started to accept the giant data from Tomo-eGozen at the University of Tokyo's Kiso Observatory and TriCCS on Kyoto University's Seimei Telescope. We expect future use of this data to aid the development of time domain astronomy.

In the Public Relations Center, efforts to share astronomy results with the public have been strengthened. Making the best use of the internet and video streaming services, it has been making efforts in public information and outreach activities including the FUREAI (Friendly) Astronomy program which expanded to include remote lectures for overseas schools starting from FY 2020; the broadcast of the May 26, 2021 total lunar eclipse which, including the archive, accumulated over 2 million views; and the online regular stargazing parties and online open house which have enabled participation by a wider range of people beyond just those who can come to campus.

The "Results of Evaluation of the Current State of Research" at the end of the 4 year period published in 2021 found that in terms of both research activities and research results NAOJ is of "particularly high quality." [1] The reason for the former was cited as the establishment of the Division of Science to achieve research results transcending the boundary between theory and observation; and the reason for the latter was cited as the large-scale statistical research enabled by HSC on the Subaru Telescope, advancing our understanding on the origin of super-massive black holes and the birth and evolution of stars and the Universe.

The 2,944 papers published during 2017~2021 by members of NAOJ have had an international collaboration rate of 80.4 %; also, 16.4 % of the papers have made it into the Top10 % of papers published worldwide in terms of citations and 3.5 % have made it into the Top1 % (according to InCites as of August 2022). While as of August 2022, Japanese members account for only 5.5 % of the total members of the International Astronomical Union (approximately one quarter the number of United States members), Japan achieved a 9.5 % world share in the number of papers published in astronomy during 2021 with 1,707 papers. This is Japan's highest world share among the 22 fields of study, surpassing physics (7.0 %). As of April 1, 2022, women account for 10.5 % of NAOJ researchers (including Research and Academic Staff and specially appointed teachers) up from 8.9 % in the previous fiscal year.

The Office of International Relations opened its new homepage, providing information on living in Japan, accommodations, immigration procedures for foreign nationals, and an overview of the area around campus; as well as references for NAOJ researchers who will serve as hosts.

This concludes my overview of NAOJ's activities in FY 2020. More details can be found in the full report. I look forward to your continued cooperation and support.

(Note 1): The four-year period covered 2016-2019. Evaluation was performed in FY 2020 and the results were released in FY 2021.

# I Scientific Highlights

(April 2021 – March 2022)

# Neutrinos Transport and Signal in Core-collapse Supernova

NAGAKURA, Hiroki
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I have worked on the theory of core-collapse supernova (CCSN) by using large-scale numerical simulations. In the last year, I have paid a special attention to neutrino dynamics during the development of explosion. In [1], we proposed a new strategy to estimate proto-neutron star (PNS) mass and radius from neutrino signals in real observations. We analyzed theoretical models of neutrino signal obtained by a series of multi-dimensional CCSN simulations. We found some robust correlations between PNS properties (such as mass and radius) and neutrino signal. We evaluated the correlation and provided useful fitting formulae for which the PNS mass and radius are retrieved from the total number of neutrino events at each terrestrial neutrino detector. As shown in Fig. 1, we demonstrated that PNS mass can be retrieved only from neutrino signal within ~ 10 % errors. For PNS radii (see Fig. 2), the error is much smaller than the case with PNS mass, which is within percents.

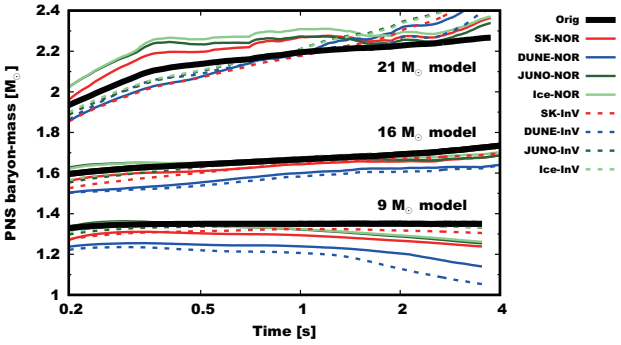


**Figure 1**: The PNS mass as a function of time for three different progenitor models: 9-, 16-, and 21 solar masses. The black line represents the PNS mass obtained from our CCSN simulations, and other colored-lines represent the retrieved PNS mass from our newly proposed method. The line type distinguishes neutrino oscillation models. The figure is taken from [1].

In [2,3], we have tacked one of the formidable issues on CCSN theory: collective neutrino oscillations. In [2], we developed a new neutrino transport code that can handle any types of neutrino oscillations, transport, and neutrino matter interactions in a self-consistent manner. We adopt a Monte-Carlo approach in our code; the design and implementation of the code is described in detail. We also carried out a suites of code tests that include fast-pairwise collective neutrino oscillation (or fast flavor conversion, FFC) with momentum-exchanged neutrino scatterings. We present rigorous demonstrations of the code performance for a broad range of neutrino oscillation problems.

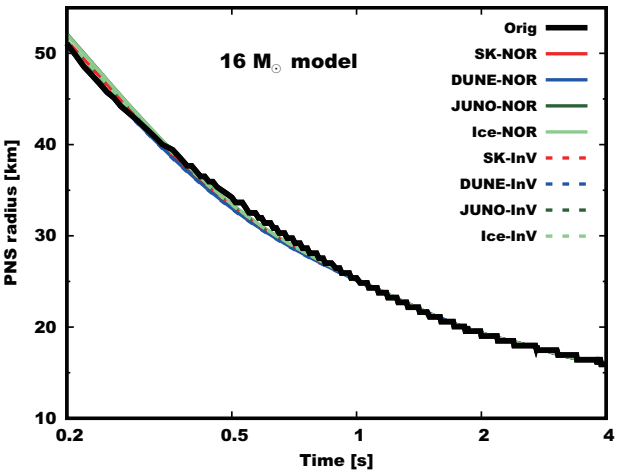


**Figure 2**: Same as Fig. 1 but for PNS radius. We only display the case with 16 solar mass model. The figure is taken from [1].

In [3], we studied a possibility of FFC in CCSN core, paying particular attention to roles of stellar rotation. We carried out two-dimensional CCSN simulations with full Boltzmann neutrino transport. It should be noted that the multi-angle treatment in neutrino transport plays a crucial role to analyze the occurrence of FFC. We found that stellar rotation facilitates the occurrence of FFC around the equatorial region. This is mainly due to the expansion of low-electron-fraction region, which enhances the disparity of neutrino absorption between electron-type and their anti-partners. This study motivates further investigation of FFC in CCSN environment.

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# Search for Rare Objects with Subaru Telescope × Anomaly Detection

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Astronomy has made great strides through the discovery of unexpected and unknown physical phenomena and species, such as the Nobel Prize-winning discovery of giant exoplanets by Mayor and Queloz [1], and the recent discovery of fast radio bursts by Lorimer et al. [2]. The ultimate goal of this project is to consciously and thoroughly search for rare phenomena and astronomical sources in the universe, including unknown events that may bring innovations from astronomical big data, by utilizing machine learning. This report introduces our initial results from the search for low-redshift rare objects using a deep anomaly detection based on convolutional neural networks (CNN), as the first series of our project [3].

There are two ways to rare object searches: (1) science-driven methods that use known information of specific rare objects as training data, and (2) data-driven methods that find anomalies by analyzing the overall data structure without any priors. The former approach has been adopted in most of previous work such as surveys of the most distant galaxy and black hole. However, the data-driven approach has not been used due to its inefficiency, requiring a huge amount of data to understand the whole structure, and the lack of proper methods.

Nowadays, the rapidly developing machine learning and legacy surveys with large telescopes, such as the Subaru Hyper Suprime-Cam (HSC) strategic survey, enabled the practical application of data-driven searches. This work attempted to detect rare objects with outlier features in the multi-band data (*grizy*) from Subaru HSC over ~800 deg$^2$ using deep anomaly detection, which has a wide range of applications from industrial use to medical diagnosis. The deep anomaly detection consists of an encoder and a decoder that perform complex nonlinear transformations, each of which is optimized to compress and reconstruct unlabeled training data. For the optimized model, if an object has an outlier that deviate from the general data, it is detected as a high anomaly score since the model cannot reproduce it well (Figure 1).

As the first series of the project, this study focused on evaluating the performance of our anomaly detection in extracting which components of galaxy images as anomalies from bright galaxies at $z$ = 0.05–0.2 identified by the Sloan Digital Sky Survey. The results show

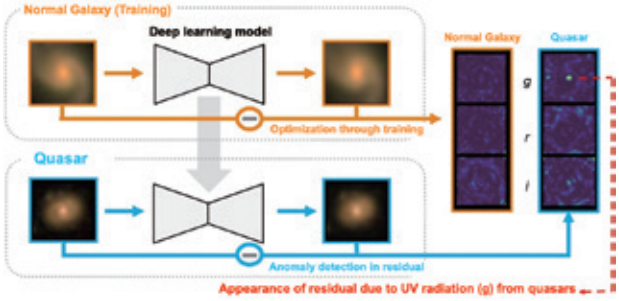


**Figure 1**: Schematic illustration of deep anomaly detection [4]. When the optimized model read an image of a rare object like a quasar, its peculiar component (in the case of a quasar, a strong UV radiation) can be detected.

**Figure 2**: Anomaly galaxy samples detected by the anomaly detection. They show blue or purple components by strong UV radiation or star formation.

that the optimized model preferentially detect objects with peculiar spectra as anomalies, especially extreme emission line galaxies (XELGs) with strong emission lines affecting broad-band photometry. This is mainly due to the fact that XELGs have distinctive features clear to the human eye (Figure 2) and are moderately abundant in the universe. Particularly, the recovery rates of XELGs in the g-band and quasars were 90 % and 70 %, which demonstrate that anomaly detection can be used to find rare objects with high probability without prior information. In the future, we plan to apply a more advanced model to all the data and put it to practical use,

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# A Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS). IV. Rapidly Growing (Super)Massive Black Holes in Extremely Radio-loud Galaxies

ICHIKAWA, Kohei[1], YAMASHITA, Takuji[2], TOBA, Yoshiki[3], NAGAO, Tohru[4], INAYOSHI, Kohei[5], CHARISI, Maria[6], HE, Wanqiu[2], WAGNER, Alexander[7], AKIYAMA, Masayuki[1], BOVONPRATCH, Vijarnwannaluk[1], CHEN, Xiaoyang[2], KAJISAWA, Ken[4], KAWAMURO, Taiki[2], LEE, Chien-Hsiu[8], MATSUOKA, Yoshiki[4], SCHRAMM, Malte[2], SUH, Hyewon[2], TANAKA, Masayuki[2], UCHIYAMA, Hisakazu[2], UEDA, Yoshihiro[3], PFLUGRADT, Janek[1], FUKUCHI, Hikaru[1]

1: Tohoku University, 2: NAOJ, 3: Kyoto University, 4: Ehime University, 5: Kavli Institute of Astronomy and Astrophysics, 6: California Institute of Technology, 7: Tsukuba University, 8: National Optical-Infrared Astronomy Research Laboratory

Local radio galaxies have been primary targets for investigating the effect of supermassive black holes (SMBHs) on the host galaxies because powerful radio galaxies or radio-loud active galactic nuclei (AGNs) mainly reside in massive galaxies whose star formation is quenched, with the presence of strong jets dispersing the interstellar medium.

However, the situation may be different at $z > 1$. Using radio AGNs selected from the Very Large Array (VLA)-COSMOS 3 GHz large project, researchers demonstrated that SMBH accretion in radio-bright AGNs becomes more radiatively efficient ($\lambda_{\rm Edd} > 10^{-2}$) at $z > 1$. They reside in star-forming galaxies, which contain plenty of cold gas. This picture of radio AGNs is completely different from those seen in the local universe in the same radio luminosity range. Still, the survey volume of VLA-COSMOS surveys is small so they may be missing a rare, but radio-bright population. The FIRST survey is the best tool for exploring such a radio-bright end since it covers half the sky with the VLA at 1.4 GHz. However, cross matching the VLA/FIRST sources with the SDSS survey catalog identified optical counterparts in only 30 % of the radio sources.

A recent Subaru/Hyper Suprime-Cam (HSC) strategic survey shed light on such a situation. We have conducted a search for optically faint radio galaxies (RGs) using the Subaru HSC survey catalog and the VLA/FIRST radio continuum catalog, and we have found a large number of RGs at $z \sim 1$ and covering > 60 % of the FIRST radio sources. The project is called the Wide and deep Exploration of Radio Galaxies with Subaru/HSC (WERGS; [1]).

In this study, we have investigated the properties of these unique optically faint RGs and found the two key results. One is that their starformation rate is high, they are likely in the star-forming or starburst phase reaching a specific star formation rate of sSFR = SFR/$M_\odot \sim 10^{-8}\,{\rm yr}^{-1}$, suggesting that some of our RGs might be in a rapid stellar-mass assembly phase with mass-doubling times of ~100 Myr. Besides, their stellar mass is relatively small, including the low-mass galaxies with $M_\odot < 10^{10}\,M_\odot$.

The second result is that infrared detected RGs are in a rapid BH accretion phase with high specific black hole accretion rate (sBHAR) with the expected Eddington ratio $\langle \log \lambda_{\rm Edd} \rangle \approx -0.4$ and some RGs may be experiencing a super-Eddington phase, which is shown in Figure 1. Actually, our RGs tend to show high jet power as well. This paints a different picture of radio galaxies compared to conventionally known local radio galaxies with low $\lambda_{\rm Edd}$. The RGs in this study represent a population of unique radio galaxies characterized by both high $\lambda_{\rm Edd}$ and high radio power.

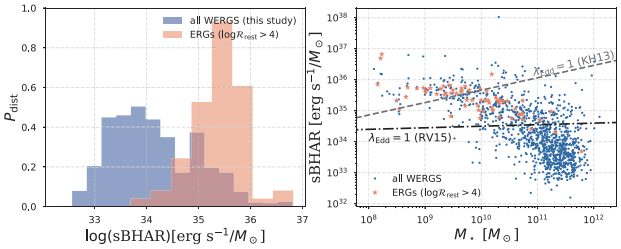


**Figure 1**: sBHAR properties for RGs in this study. The colors and symbols are orange for radio-bright RGs (ERGs) and cyan for other RGs (NRGs). (Left) The distribution of sBHAR. (Right) The relation between sBHAR and $M_\star$. The two straight lines are the expected Eddington limits $\lambda_{\rm Edd} = 1$ using Equation by [3] (gray dashed line) and using the one by [4] (black dotted–dashed line).

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# Development of a Galactic Model Optimized for the Galactic Bulge

KOSHIMOTO, Naoki[1/2], BABA, Junichi[3], BENNETT, David P.[1/2]

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Gravitational microlensing toward the Galactic bulge is randomly caused by the motion of stars in our Galaxy. Therefore, the distribution of microlensing parameters can be predicted using the Galactic model, a model of the number density distribution, velocity distribution, and mass function of stars in our Galaxy. By comparing this prediction with the distribution of planetary microlensing events, we can also investigate the distribution of stars hosting planets in our Galaxy [1]. The results from this method depend on the Galactic model used, so the model must be chosen carefully. However, Galactic models used in microlensing studies to date have been simplistic, based on Han & Gould (1995) [2]. The Besançon Galaxy Model [3], which is often used as a stellar population synthesis model in our Galaxy, is also known to be inconsistent with observations toward the Galactic bulge, e.g., the bar angle is too low.

Therefore, we developed a new Galactic model which is consistent with the latest observations [4]. The data used for model fitting include data from Gaia on the velocity distribution of stars in the disk [5], as well as various data in the Galactic bulge region such as stellar number density [6,7], radial velocity and proper motion [8,9], and the latest observations of 8000 microlensing events by the OGLE-IV survey [7,10] (Figure 1). Through the modeling, we have measured various important parameters that characterize our Galaxy, such as the scale length of the velocity dispersion distribution of the disk, the rotational angular velocity of the bar in the bulge, and the initial mass function (IMF) in the bulge region. In particular, the universality of the IMF has been controversial, and the Kroupa (2001)'s IMF [11] measured in solar neighborhood is conventionally applied to bulge regions as well. The IMF measured in this study is significantly different from that of Kroupa (2001) and may suggest that the star formation process in the bulge region is different from that in the solar neighborhood. The stellar mass-to-light ratio was estimated from the measured IMF to be $0.72^{+0.05}_{-0.02}$ $M_\odot/L_{K_\odot}$, which is about 70 % of $1.04\,M_\odot/L_{K_\odot}$ for the IMF of Kroupa (2001). Since the bulge dynamical mass is well-determined, this suggests that the stellar mass of the bulge is lighter than previously thought and that the dark matter is more massive.

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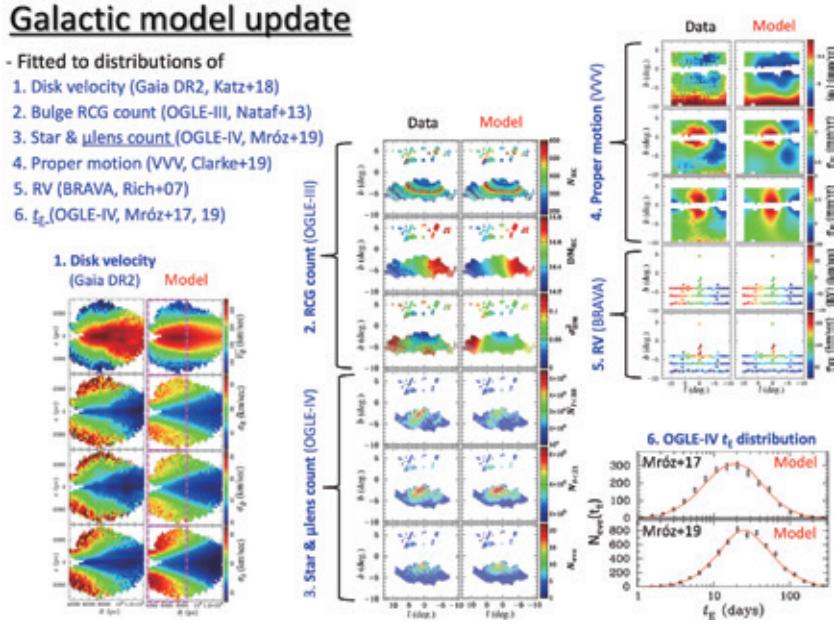


**Figure 1**: Each data-set used for the model fitting, compared with the model values (from a slide used in a conference talk).

# Orphan Cloud Bigger than Milky Way Discovered in the Leo Cluster

GE, Chong[1], LUO, Rongxin[1], SUN, Ming[1], YAGI, Masafumi[2], JÁCHYM, Pavel[3], BOSELLI, Alessandro[4], FOSSATI, Matteo[5], NULSEN, Paul E. J.[6], SARAZIN, Craig[7], EDGE, Tim[1], GAVAZZI, Giuseppe[5], GASPARI, Massimo[8/9], KODA, Jin[10], KOMIYAMA, Yutaka[2], YOSHIDA, Michitoshi[2]

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Galaxy clusters contain hundreds to thousands of galaxies. The space between cluster galaxies is not empty, but instead filled with hot gas known as intracluster medium (ICM). When galaxies are soaring in the hot gas with a velocity around one thousand kilometers per second, their cold gas between the stars known as interstellar medium (ISM) is removed by the ram pressure of hot gas. Once removed from the host galaxy, the stripped cold ISM mixes with the hot ICM, produces multi-temperature tails [1]. In nearly all the cases of stripping, the parent galaxy is obvious, as the gas cloud is connected or points to the parent.

We recently discovered an isolated multi-temperature cloud (Figure 1) without a parent galaxy in the Leo Cluster (A1367). The cloud was initially noticed from its warm gas component by the Subaru Telescope, and named as "orphan cloud (OC)" [2]. Our follow-up XMM-Newton observation (Figure 2) to study other aspects of A1367 unexpectedly discovered X-ray emission from the hot gas of this cloud, revealing that the cloud is actually bigger than the Milky Way [3]. The optical spectroscopy from VLT/MUSE confirms that the cloud is in the A1367. Its about solar metallicity suggests that the OC is stripped from an evolved giant galaxy, but no such giant galaxy is found around the cloud [3]. Compared the OC with the stripped tails [1] still attached to their parent galaxies, we found OC has higher X-ray temperature and luminosity, which indicates an advanced evolutionary stage of the OC as it has mixed with the surrounding ICM with a longer time.

This is the first discovery of such an intracluster multi-temperature clump glowing both in optical (from warm gas) and X-ray (from hot gas). This study paves a new way for research on intracluster clumps, as future warm gas optical surveys can be used to search for other orphan clouds and probe ICM clumping.

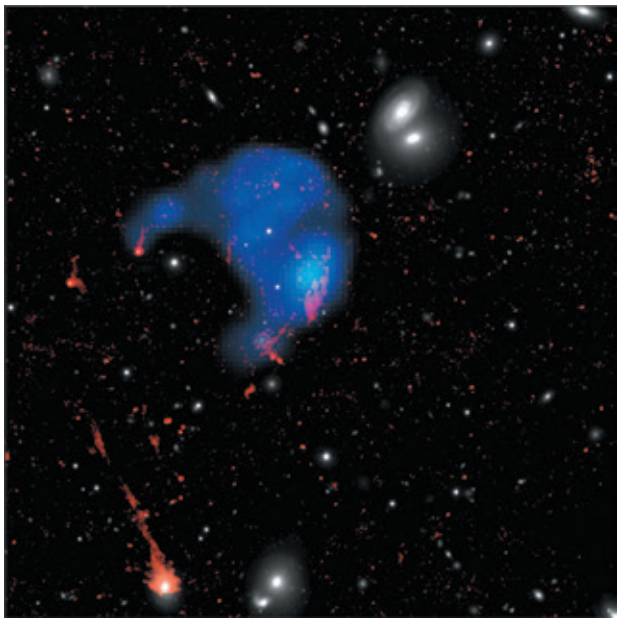

**Figure 1**: The orphan cloud blue umbrella-shaped emission is from hot gas observed by XMM-Newton, the warm gas in red and the stellar component in white are from Subaru Telescope.

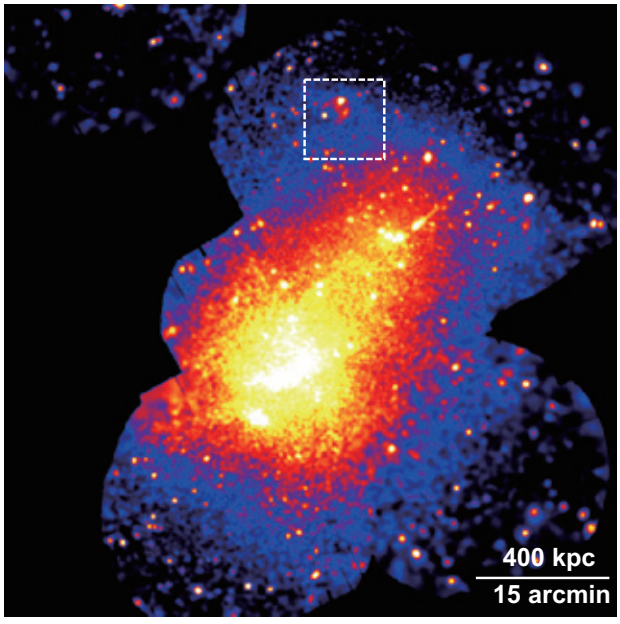


**Figure 2**: The Leo Cluster in X-ray from XMM-Newton. The white square shows the location of Figure 1.

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# Age Distribution of Stars in Boxy/Peanut/X-shaped Bulges Formed without Bar Buckling

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Revealing the formation history and structure of the bar in the Milky Way is a long-standing challenge in Galactic astronomy. Recent surveys towards the Galactic bulge, such as BRAVA and VVV, shows a clear inner boxy/peanut-shaped bulge connected to the long thinner Galactic bar and the current pattern speed of the Galactic bar is about 35–40 $\mathrm{km\,s^{-1}\,kpc^{-1}}$ [1]. However, the formation epoch of the Galactic bar is completely unknown.

In this study [2], we study the observable consequence bar formation using an *N*-body/SPH simulation of an isolated Milky Way-like galaxy. As shown in the upper panel of Figure 1, we found that a boxy/peanut/X (BPX)-shaped bulge built up quickly after bar formation via vILR heating without buckling [3]. Furthermore, we found that the BPX-shaped bulge is dominated by stars born prior to bar formation (middle panel of Figure 1). By contrast, the NSD forms after the bar formation [4]. From this simulation, we expect that the age distributions of the NSD and BPX-shaped bulge formed without bar buckling do not overlap each other. Then, the transition age between these components betrays the formation time of the bar. To separate the NSD population kinematically from the other stellar populations, the accurate measurements of the transverse velocities of stars are necessary. The near-infrared space astrometry mission, *JASMINE*, would play a crucial role to identify the formation epoch of the Galactic bar.

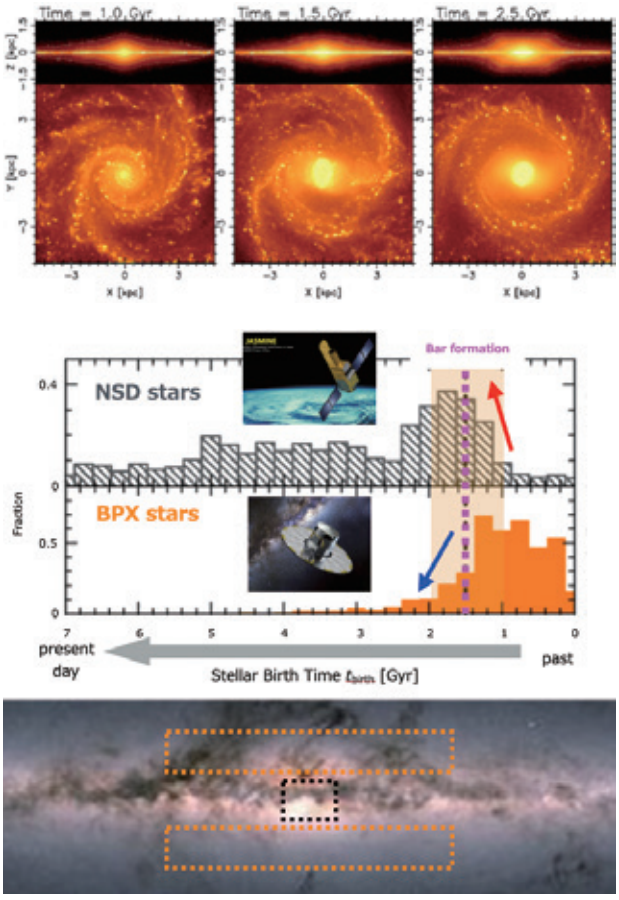


**Figure 1**: Upper: Morphological evolution of the simulated galactic disk. From [2]. Middle: Expected age distributions of stars in NSD (black square in the bottom panel) and BPX (orange squares in the bottom panel). Bottom: Gaia images of the Galactic bulge region (ESA/Gaia/DPAC).

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# Planetesimal Dynamics in the Presence of a Giant Planet

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The accretion of planetesimals during the planet-forming stage in a protoplanetary disk can be strongly affected by the secular perturbation from a massive body in the system. During this phase of planetesimal accretion, the nebula gas is still in presence in the disk. Should there be a massive body (such as a stellar companion or a planet) perturbing the disk, the coupled effect of secular perturbation (especially when the perturber is eccentric) and nebula gas drag can lower the relative velocity of planetesimal by aligning the pericenters of their orbits under certain conditions.

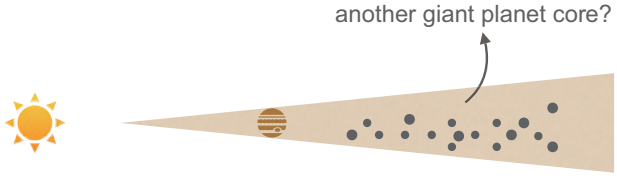


**Figure 1**: A schematic illustration of our model: formation of a planetary core outside a giant planet perturber.

In our study investigating the impact of a Jupiter like planet on planetesimal accretion (see Fig. 1 for the schematic illustration of our model), we found that the coupling effect of secular perturbation and nebula gas drag can align the orbits of planetesimals in the non-resonance regions of the disk, and thus lead to low relative velocities of planetesimal swarms there [1]. In this way, the eccentricity of planetesimals induced by the planet contribute little to the relative velocities, and the growth of another planetary core can be unaffected under certain conditions (Fig. 2).

These results have some interesting implications on the formation scenario of Saturn. Since Saturn's current semi-major axis is near 9.6 au, with some tolerance for migration, we can speculate that the growth of Saturn's core was enabled by the coupled effect of secular perturbation from Jupiter and nebula gas drag on the relative velocities of planetesimals in the outer dynamically cooler disk location. Afterwards, during its run-away gas accretion phase, the growing Saturn could have migrated inward to its current location due to disk-planet interaction. Our results show that the issue of the formation of Saturn's core, a long-standing mystery, may be mitigated.

We also explored the dependence of such an effect of orbital alignment on the planet mass and eccentricity. We found that, generally speaking, higher planet mass and eccentricity both lead to higher relative velocity of

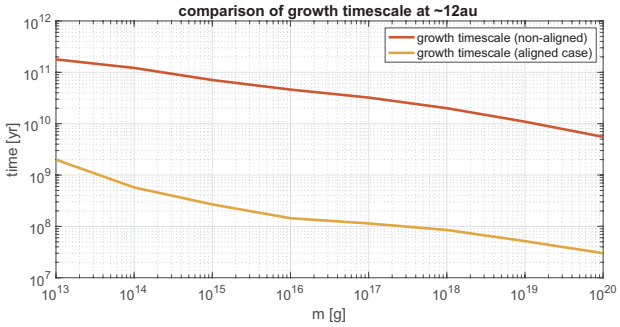


**Figure 2**: Distribution of longitudes of pericenter. Alignment seen at non-resonance locations, e.g., near 12 and 14 au.

planetesimals, which makes accretion more challenging. According to our results, when a system harbors a planet sufficiently large or eccentric, it is less likely to produce other planetary companions due to high relative velocities of planetesimals.

In the big picture, our studies contribute to improve the standard models of planet formation in the core-accretion paradigm. The standard models describe well how planets form in axisymmetric, smoothly distributed disks. However, in reality, the disks are often perturbed by bodies such as large planets or stellar companions. In such configuration, the formation of planetary bodies can deviate from the standard scenario. Our results serve as candidate theories for explaining the diverse architecutres of planetary systems observed in recent decades.

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# A Dusty Protocluster Discovered by *Planck* and Subaru Telescope

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1: NAOJ, 2: Tohoku University

Over the last years, there has been a big progress in the search for "protoclusters" at high redshifts. In particular, the deep and wide-field imaging survey performed with Subaru Hyper Suprime-Cam (HSC) successfully discovered a number of protoclusters out to $z \sim 6$. However, most of the protoclusters known to date were identified by *optical* surveys, which correspond to the rest-frame UV search for high-redshift galaxies, and therefore it is possible that galaxies heavily obscured by dust are missing in the existing surveys. An interesting approach to identify dusty protoclusters is to use the all-sky submillimeter map provided by the *Planck* satellite. With the limited sensitivity and angular resolution, it is not possible to detect individual high-$z$ galaxies with *Planck*. However, theories suggest that *Planck* can detect protoclusters as "point sources" if dusty galaxies are strongly clustered in a compact region on the sky. Indeed, by investigating the FIR–submm color informations, recent studies suggest that there exist > 2,000 high-$z$ galaxies/clusters candidates in the *Planck* compact sources [1], but multi-wavelength follow-up observations are required to confirm their redshifts and cluster membership.

In this work, we focus on one of the *Planck* high-$z$ candidate sources, PHzG237.01+42.50 (PHzG237). This source is the only *Planck* high-$z$ candidate source situated in the COSMOS field, and the distributions of spectroscopic sources in the COSMOS field suggests there is an overdensity of galaxies at $z = 2.16$ around this *Planck* source. We performed narrow-band H$\alpha$ imaging observations of the PHzG237 with NB2071 filter on Subaru/MOIRCS, and successfully identified 38 H$\alpha$ emitters at $z = 2.16$ [2] (see Fig. 1). In addition, our follow-up NIR spectroscopy with Large Binocular Telescope (LBT) also confirms an overdensity of spectroscopic members at $z = 2.15$–$2.20$ [3].

Our data also suggest that H$\alpha$ emitters residing in higher-density environments (protocluster core region) traced by the H$\alpha$ emitters tend to have higher stellar mass [2] (see Fig. 1). Furthermore, with the X-ray and optical/NIR spectroscopic data available in this field, we find that ~20 % of the galaxies in the protocluster core region have AGN activities [3]. This result suggests a strong link between the galaxy evolution processes in dense environments in the early universe and AGN activity.

The total SFR of this protocluster derived by integrating the H$\alpha$ star formation rate (SFR) of the H$\alpha$ emitters is ≈1,000 $M_\odot$/yr, while the FIR-derived SFR from *Planck*/*Herschel* photometry is ≈4,000–10,000 $M_\odot$/yr. The reason of this large (a factor of ~5–10×) discrepancy between the two SFRs is unclear, but it is possible that we may underestimate the H$\alpha$ dust attenuation levels, and perhaps there exist many H$\alpha$-undetected sources heavily obscured by dust. However, further studies are needed because FIR–submm fluxes measured with the poor spatial resolution of *Planck*/*Herschel* may be overestimated due to the contamination from sources which are not physically connected to the protocluster.

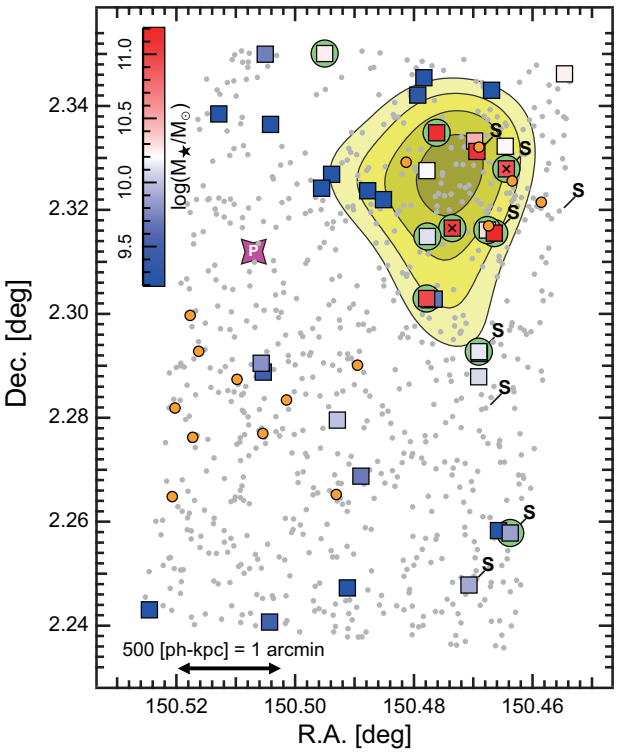


**Figure 1**: The 2-D distribution of galaxies around the PHzG237 protocluster at $z = 2.16$ discovered by this study. The colored square symbols show the H$\alpha$ emitters identified with our Subaru/MOIRCS observations, with the redder symbols indicating higher $M_\star$. The green circles and orange circles show MIR-detected H$\alpha$ emitters and Herschel FIR sources, respectively. The original Planck source position is shown with the "P" mark. The "S" and "X" marks in the plot show the spectroscopic members and X-ray sources, respectively. The yellow contours are drawn based on the number density of all the cluster members.

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[3] Polletta, M., et al.: 2021, *A&A*, **654**, 121.

# Polarization of the Corona Observed During the 2017 and 2019 Total Solar Eclipses

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1: NAOJ, 2: SEPnet, 3: Chiba Prefectural Ichihara High School, 4: NPO Kwasan Astro Network

The white-light solar corona consists of the K-corona from the million-degree plasma of the Sun and the F-corona from interplanetary dust. Linear-polarization information enables the separation of the K- and F-corona. Therefore, polarimetry has long been performed in total eclipse observations as well as in coronagraph observations. Total solar eclipses provide us very low sky-background down to just above the solar limb, which cannot be achieved in coronagraph observations. Therefore, the white-light corona has been a particularly important target for the total solar eclipse observations.

We carried out polarimetric observations of the white-light corona during the total solar eclipses on 2017 August 21 and 2019 July 2 by taking advantage of professional-amateur collaborations, and successfully obtained data at two different sites for both eclipses [1]. After eliminating the sky background, we obtained the brightness ($B_{K+F}$) and polarization ($p_{K+F}$) of the K+F corona, as presented in Figure 1.

In Figure 2, comparison of the derived brightness and polarization with other measument results is presented.

For the $B_{K+F}$, the results of the Large Angle Spectrometric Coronagraph (LASCO) C2 of the Solar and Heliospheric Observatory [2] show good coincidence with ours, but for the $p_{K+F}$, the LASCO results are systematically smaller than our results and those by Vorobiev et al. [3], which were also taken at the eclipse.

The discrepancy among the results for $p_{K+F}$, which actually corresponds to the brightness of the K-corona alone, leads the error in the estimated amount of the hot plasma. The correct amount of the hot plasma of the corona is important to study the coronal plasma-producing mechanism and to the study on the coronal variation according to the solar activity cycle. Well-calibrated eclipse data, which were taken with a wide field-of-view, enable intercomparison among various data and contribute to the correction of the systematic error in the results from other observations. The eclipse observations provide a standard to study the amount of the hot corona quantitatively.

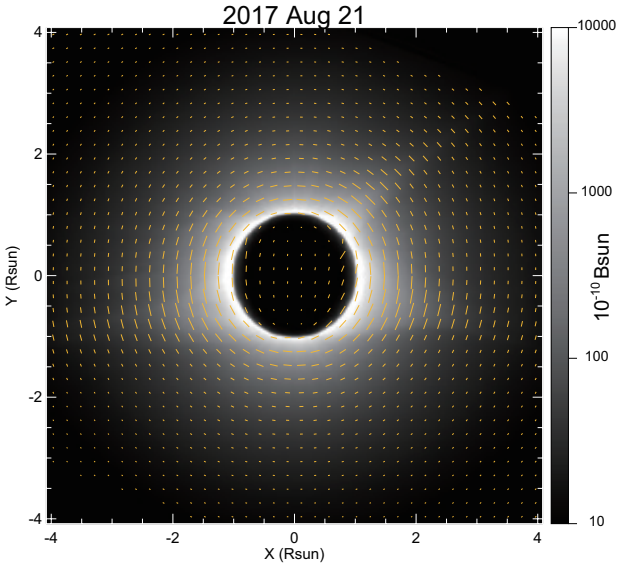


**Figure 1**: Polarization map of the K+F corona after the elimination of the sky background covering 8.2 × 8.2 $R_\odot$ area obtained during the 2017 eclipse. The grayscale image presents Stokes *I* signals, and the degree and orientation of the linear polarization signals are depicted with orange ticks. The solar north is to the top.

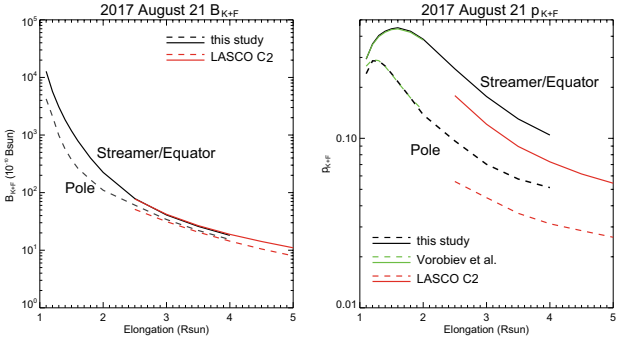


**Figure 2**: Comparison of the brightness of the K+F corona ($B_{K+F}$; left) and the degree of polarization ($p_{K+F}$; right) among the eclipse observation, LASCO C2 observation, and the results by Vorobiev et al. (only $p_{K+F}$).

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# Luminosity Functions and Clustering Revealed with ~4,000,000 Galaxies at $z \sim 2$–7 from the Subaru/Hyper-Suprime Cam Survey

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1: The University of Tokyo, 2: University College London, 3: NAOJ, 4: SOKENDAI, 5: Shanghai Jiao Tong University, 6: Saint Mary's University, 7: Kitami Institute of Technology, 8: University of Arizona, 9: Laboratoire d'Astrophysique de Marseille, 10: University of Geneva, 11: University of Copenhagen, 12: NRC Herzberg, 13: National Astronomical Observatories of China, 14: Harvard-Smithsonian Centre for Astrophysics, 15: Waseda University, 16: Ehime University

In this study [1], we present measurements of rest-UV luminosity functions and angular correlation functions from 4,100,221 galaxies at $z \sim 2$–7 identified in the Subaru/Hyper Suprime-Cam survey and CFHT Large-Area *U*-band Survey. The obtained luminosity functions at $z \sim 4$–7 cover a very wide UV luminosity range of ~0.002–2000 $L^*_{\rm UV}$ combined with previous studies (Figure 1), confirming that the dropout luminosity function is a superposition of the AGN luminosity function dominant at $M_{\rm UV} < -24$ mag and the galaxy luminosity function dominant at $M_{\rm UV} > -22$ mag, consistent with galaxy fractions based on 1037 spectroscopically-identified sources. Galaxy luminosity functions estimated from the spectroscopic galaxy fractions show the bright end excess beyond the Schechter function at $> 2\sigma$ levels. By analyzing the correlation functions at $z \sim 2$–6 with halo occupation distribution models, we find a weak redshift evolution (within 0.3 dex) of the ratio of the star formation rate (SFR) to the dark matter accretion rate, SFR/$\dot{M}_{\rm h}$ (Figure 2), indicating the almost constant star formation efficiency at $z \sim 2$–6, as suggested by our earlier work at $z \sim 4$–7 [2]. Meanwhile, the ratio gradually increases with decreasing redshift at $z < 5$ within 0.3 dex, which quantitatively reproduces the cosmic SFR density evolution, suggesting that the redshift evolution is primarily driven by the increase of the halo number density due to the structure formation, and the decrease of the accretion rate due to the cosmic expansion.

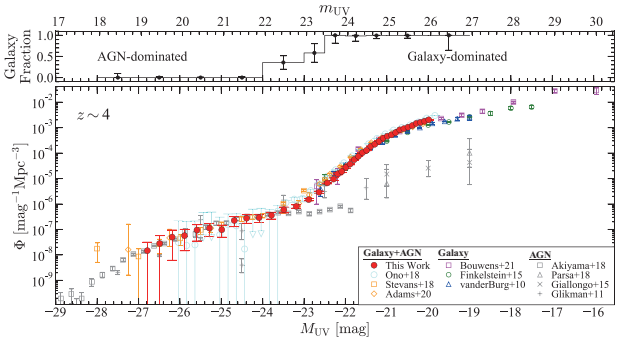


**Figure 1**: The bottom panel shows rest-frame UV luminosity functions of dropout sources (including galaxies and AGNs) at $z \sim 4$. The red circles show our results based on the HSC-SSP survey data, and other symbols are previous results. The top panel shows a fraction of galaxies in our dropout sample based on spectroscopic results.

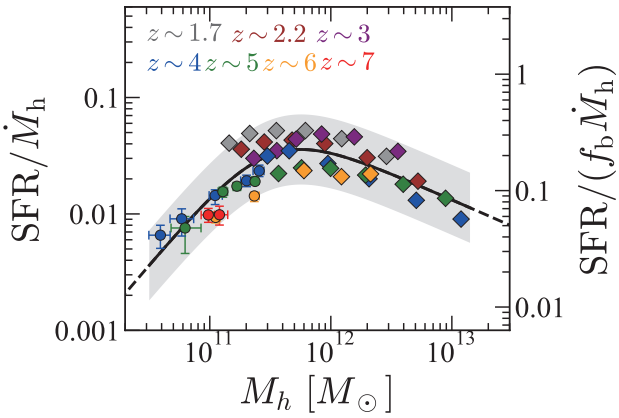


**Figure 2**: SFR/$\dot{M}_{\rm h}$ and baryon conversion efficiency (SFR/(fb $\dot{M}_{\rm h}$)) as a function of the halo mass (filled diamonds: this work, circles: [3]). The black solid curve is the fitting formulae, and the gray shaded region represents the $2\sigma$ typical scatter of the data points compared to the relation.

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# Interrelation of the Environment of Ly$\alpha$ Emitters and Massive Galaxies at $2 < z < 4.5$

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1: University of Tokyo, 2: NAOJ, 3: Ehime University, 4: University of Bath, 5: SOKENDAI

Recently, the large-scale structure in the distant universe has been explored through the distribution of various galaxy populations. On the other hand, it is not necessarily trivial that different populations trace the same structure. Indeed, some protoclusters have different distributions between Ly$\alpha$ emitters and other galaxies [1]. We have not known whether the same trend is seen even in general.

This work [2] evaluates the distribution differences of Ly$\alpha$ emitters (LAEs), massive star-forming galaxies (SFGs), and massive quiescent galaxies (QGs) at $2 < z < 4.5$ located in the COSMOS field. LAEs samples are taken from [3], and SFGs and QGs are selected from the multi-band data [4].

Firstly, we compare the cross-correlation signal with the autocorrelation signal between two galaxy populations. The cross-correlation between SFGs and QGs is as expected from their autocorrelation. However, that between SFGs and LAEs is significantly smaller than expected from their autocorrelation, suggesting that these two populations locate more differently than the difference in halo masses (Figure 1).

In addition, the overdensity distributions at the position of each galaxy population are derived. Those of SFGs and QGs do not have a significant difference. However, those of SFGs and LAEs differ, and LAEs are found to be located in lower-dense environments (Figure 2).

These results suggest that LAEs are typically located in different environments than SFGs and QGs. This difference can be due to the formation time difference of their host halos or the absorption of Ly$\alpha$ emission by Intergalactic Medium. This work implies that surveys for multiple galaxy populations are necessary to understand the actual large-scale structure at high redshift.

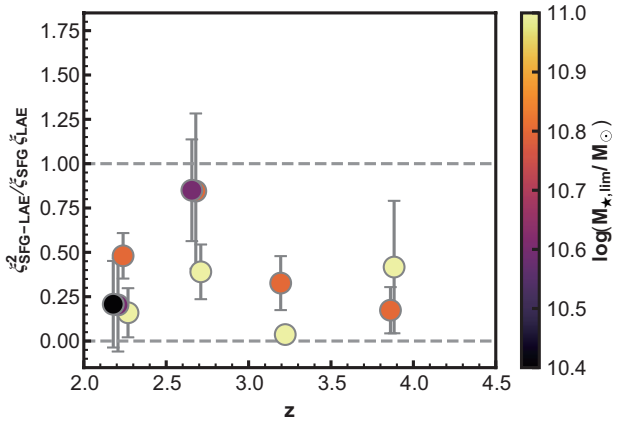


**Figure 1**: Ratio between cross- and autocorrelation function. Colors represent the lower limit of stellar mass of SFGs.

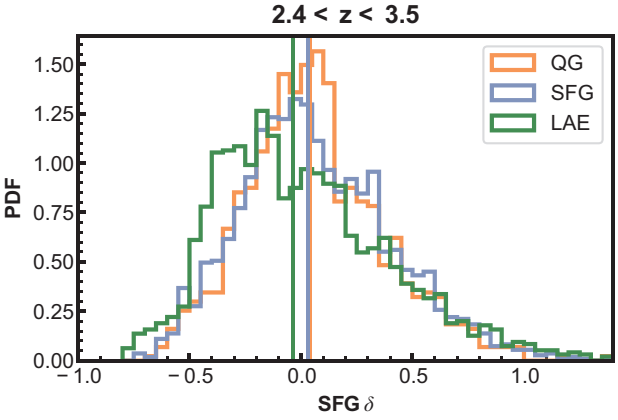


**Figure 2**: Overdensity distribution at the position of three populations measured by the distribution of SFG. The vertical lines show the median of each distribution.

## References

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# On the Hubble Constant Tension

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The Hubble constant tension problem is the discrepancy in more than $4\sigma$ between the value of the Hubble constant ($H_0$) measured with local probes such as Supernovae Ia (SNe Ia) and its value inferred by the Cosmic Microwave Background data. This open issue represents a challenge for both astrophysics and cosmology.

We have shown how $H_0$ undergoes an evolution of its value with the redshift through a statistical analysis applied to the so-called Pantheon sample which contains 1048 spectroscopically confirmed SNe Ia with a redshift range $0 \leq z \leq 2.26$. As a first step, we divided the Pantheon sample into 3, 4, 20, and 40 equally populated bins of SNe Ia ordered in redshift and we estimated $H_0$ for each bin through the Monte Carlo Markov Chain approach. As a second step, we fitted such values of $H_0$ for all the bins with the model $H_0(z) = \tilde{H}_0/(1+z)^{\alpha}$, where $z$ is the redshift, $\tilde{H}_0$ is the local value of the Hubble constant ($H_0$ at $z = 0$) and $\alpha$ is the evolutionary parameter.

The results of this analysis in 4 bins show that the $\alpha = 0.008 \pm 0.006$ and is compatible with zero in $1.5\sigma$ (namely, $\alpha\sigma_{\alpha} = 1.5$ in the cases of ΛCDM and $w_0w_a$CDM model, where $w(z) = w_0 + w_a{*}z/(1+z)$ (the so-called CPL parametrization).

We have repeated the same analysis in 3, 20, and 40 bins, and the values of the $\alpha$ parameters are all compatible with the 4 bins case in $1\sigma$. This shows that our results are reliable and independent of the particular choice of the bins division.

If the $H_0$ evolution is not due to the statistical fluctuations of the division in redshift bins and other hidden selection biases of SNe Ia parameters, we show how $H_0(z)$ could affect the definition of the luminosity distance itself. The evolved $H_0(z)$ when substituted in the distance luminosity formula induces an overestimation by $\approx 2\,\%$ at $z = 11.09$ in the ΛCDM model.

We extended this analysis [2] by deriving the values of $H_0$, but this time we left free to vary $H_0$ together with the total matter density parameter ($\Omega_{0m}$) in the ΛCDM model and together with the coefficient $w_a$ in the $w_0w_a$CDM model. Further, we added the Baryon Acoustic Oscillations (BAOs) to the aforementioned 3 bins of SNe Ia. We confirmed the decreasing trend of $H_0(z)$ with $\alpha = 0.008 \pm 0.006$ ($\alpha\sigma_{\alpha} = 1.2$) in the ΛCDM model and $\alpha = 0.033 \pm 0.005$ ($\alpha\sigma_{\alpha} = 5.8$) for the $w_0w_a$CDM model.

To understand if this trend can be due to modified gravity theories, we tested one of the most studied dark energy models in the $f(R)$ framework, the Hu-Sawicki model, in 3 bins. However, this model is not able to explain the $H_0$ tension. Nevertheless, we inferred the scalar field potential in the Jordan frame that could still reproduce the decreasing trend of $H_0$.

If we exclude the modified gravity scenario, another plausible interpretation of this tension is that the observed evolution is due to selection biases induced by the stretch of the SNe Ia, a problem that has been recently pointed out by [3].

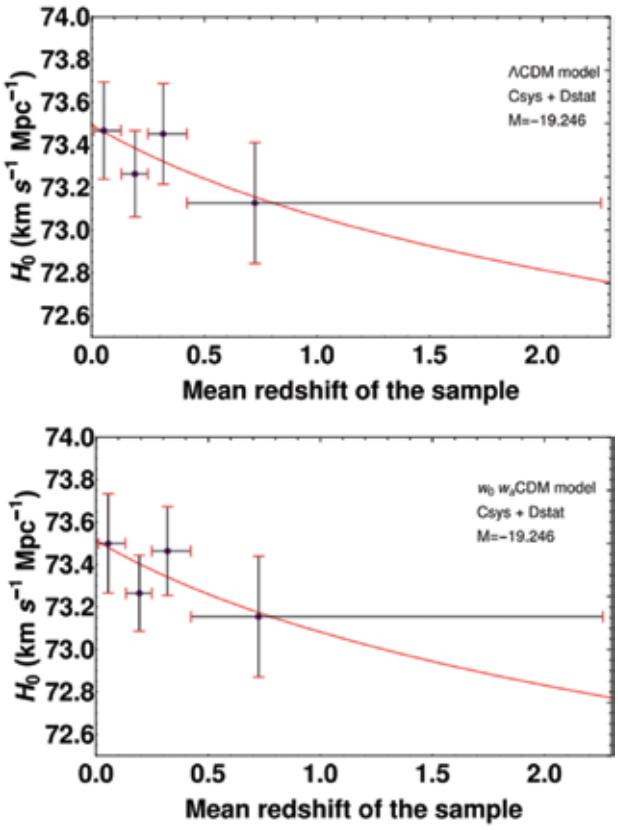


**Figure 1**: $H_0$ vs. $z$ in 4 bins of SNe Ia [1] for the ΛCDM (upper panel) and the $w_0w_a$CDM (lower panel) models.

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# Hyper Suprime-Cam Legacy Archive

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About one-third of observing time of Hyper Suprime-Cam (HSC) installed at the prime focus of the Subaru Telescope has been used for the Subaru Strategic Program (SSP) [1]. Data from HSC-SSP are processed with a dedicated reduction pipeline and the processed data are routinely released to the world-wide community [2,3,4]. The reminder of the observing time is used for PI programs. Processed data from PI programs are not always released to the public, but the scientific value of the data is high. The Subaru Telescope has launched HSC Legacy Archive (HSCLA), where pipeline-processed, science-ready data from PI programs are available.

The first release of HSCLA occurred in January 2021 (Figure 1) [5]. The release includes data taken in the first year of science operation of HSC, 2014, and covers about 580 square degrees of the sky (Figure 2). Five broad-band filters (*grizy*) and two narrow-band filters (*NB*515 and *NB*656) are used in this release, and the data reach down to 24–27th magnitudes (5$\sigma$ for point sources). We have performed extensive quality assurance (QA) tests and all the QA plots are made available at the data release site. Overall, the quality of the data is high; we reach 2–3 % photometric accuracy and 0.01 arcsec astrometric accuracy. While the data are ready for scientific explorations, there are known issues, which are summarized at the data release site.

The total data volume of HSCLA is very large. In order to efficiently exploit the data, we offer online/offline data access tools to the user. They are the same tools as used for HSC-SSP. The image data can be accessed through online tools and the catalog data can be retrieved from a custom-designed database with user-friendly interface.

We plan to process and release more data in the future to increase the scientific value of HSCLA. We hope HSCLA will become a useful resource for scientific research and it contributes to solve the mysteries of the Universe.

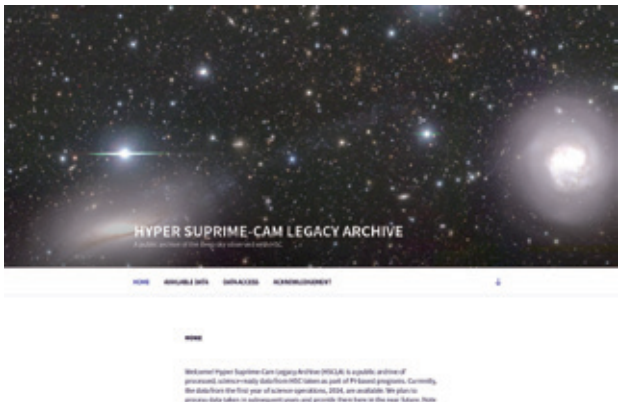


**Figure 1**: HSCLA website (https://hscla.mtk.nao.ac.jp/). The site offers not just HSC data, but all quality assurance plots as well as links to data access tools.

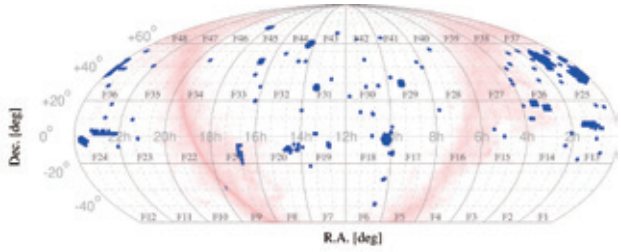


**Figure 2**: Sky area covered by HSCLA2014 is indicated in blue. The red contours in the background show the Galactic extinction.

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# EMPRESS. IV. Extremely Metal-poor Galaxies Including Very Low-massPrimordial Systems: High Fe/O Suggestive of Metal Enrichment by Hypernovae/Pair-instability Supernovae

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Primordial galaxies characterized by low gas-phase metallicities and low stellar masses ($Z \lesssim 0.01$ and $M_* \lesssim 10^6\,M_\odot$; e.g., [1]) are important to understand galaxy formation, while it is hard to observe primordial galaxies at high redshifts due to their faintness (e.g., [2]). Complementarily, various studies have actively investigated local extremely metal-poor galaxies (EMPGs). Although characteristics and formation processes of EMPGs would not be completely the same as those of high-$z$ galaxies [3], EMPGs are expected to be good local analogs of high-$z$ primordial galaxies because EMPGs have low metallicities, low stellar masses, and high specific star-formation rates. [4] have launched a project "Extremely Metal-Poor Representatives Explored by the Subaru Survey (EMPRESS)", selecting faint EMPG candidates from Subaru/Hyper Suprime-Cam (HSC) deep optical images (~26 AB mag). Remarkably, EMPRESS has pinpointed J1631+4426 having the lowest metallicity identified so far ($0.016\,Z_\odot$) with a low stellar mass ($\sim 10^6\,M_\odot$) [4].

We have conducted Keck/LRIS deep optical spectroscopy of 13 EMPG photometric candidates selected from the HSC deep images [4]. We find that nine out of the 13 candidates are EMPGs with metallicities less than $\sim 0.1\,Z_\odot$ (Figure 1 top), and four sources are contaminants of moderately metal-rich galaxies or no emission-line objects. Notably, two out of the nine EMPGs have extremely-low stellar masses ($5 \times 10^4 - 7 \times 10^5\,M_\odot$) and metallicities ($0.02–0.03\,Z_\odot$). With a sample of five EMPGs with Fe/O measurements, two (three) of which are taken from this study (the literature; [5,6]), we confirm that two EMPGs (J1631+4426 and J0811+4730) with the lowest metallicities ($\sim 0.02\,Z_\odot$) show high Fe/O ratios (~0.1) comparable to the solar abundance ratio. Comparing galaxy chemical enrichment models, we find that the two EMPGs cannot be explained by a scenario of metal-poor gas accretion/episodic star-formation history due to their low N/O ratios (Figure 1 bottom right). We conclude that the two EMPGs can be reproduced by an inclusion of bright hypernovae (BrHNe) and/or hypothetical pair-instability supernovae (PISNe; Figure 1 bottom left) preferentially produced in a metal-poor environment. This conclusion implies that primordial galaxies at $z \sim 10$ could have a high abundance of Fe that is not originated from Type Ia SNe with delays, and that Fe may not serve as a cosmic clock for primordial galaxies. This finding sheds light onto the early process of galaxy formation, providing a sneak peek of high-$z$ primordial galaxy surveys in the forthcoming era of James Webb Space Telescope. This paper is published from ApJ [2].

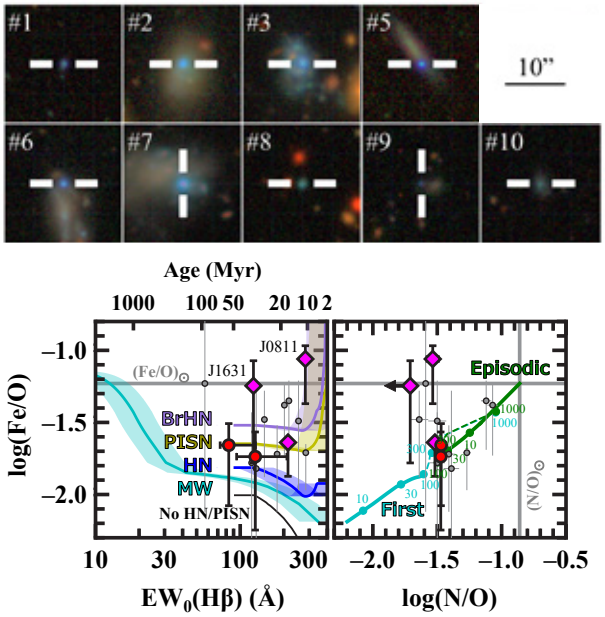


**Figure 1**: (Top) HSC *gri* images of 9 EMPGs identified by [2]. (Bottom left) Fe/O ratio as a function of H$\beta$ equivalent width and galaxy age. The points (curves) represent EMPGs (galaxy chemical enrichment model). (Bottom right) Fe/O ratio as a function of N/O.

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# A Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS). VI. Distant Filamentary Structures Pointed by High-$z$ Radio Galaxies at $z \sim 4$

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In this study [1], we have revealed that high-$z$ radio galaxies (HzRGs) at $z \sim 4$ tend to reside in the filament-like overdense regions based on Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) and Faint Images of the Radio Sky at Twenty-cm (FIRST).

Radio galaxies eject a huge amount of energy around themselves, which gives a non-negligible influence on the host/surrounding galaxy evolution and formation. Thus, in order to understand galaxy formation and evolution, it is key to understand where radio galaxies appear, that is, what the surrounding environments of radio galaxies are. However, the HzRG environments at $z > 4$ are not yet completely grasped due to the rarity of HzRGs and the lack of observations deep and wide enough to capture the surrounding galaxies, although there are some previous studies [2,3,4].

We characterize the HzRG environments statistically by embracing the largest samples of HzRGs and $g$-dropout galaxies at $z \sim 4$ constructed from radio and optical large survey data of HSC-SSP and FIRST. We find that the overdensities around the faint HzRGs with $L_{1.4\,\mathrm{GHz}} \sim 10^{26.0\text{–}26.5}\,\mathrm{W\,Hz^{-1}}$ tend to be higher than that of the $g$-dropout galaxies, while no significant difference in density environments is found between the luminous HzRGs with $L_{1.4\,\mathrm{GHz}} \sim 10^{26.5\text{–}27.0}\,\mathrm{W\,Hz^{-1}}$ and the $g$-dropout galaxies (upper panel of Figure 1). These results are consistent with a scenario where HzRGs get older and more massive as the radio-luminosity decreases. We also find that the surrounding galaxies tend to distribute along the radio-jet major axis of the HzRGs at angular distances less than $\lesssim 500$ physical kpc (lower panel of Figure 1). Our findings imply the onset of the filamentary structures around the HzRGs at $z \sim 4$.

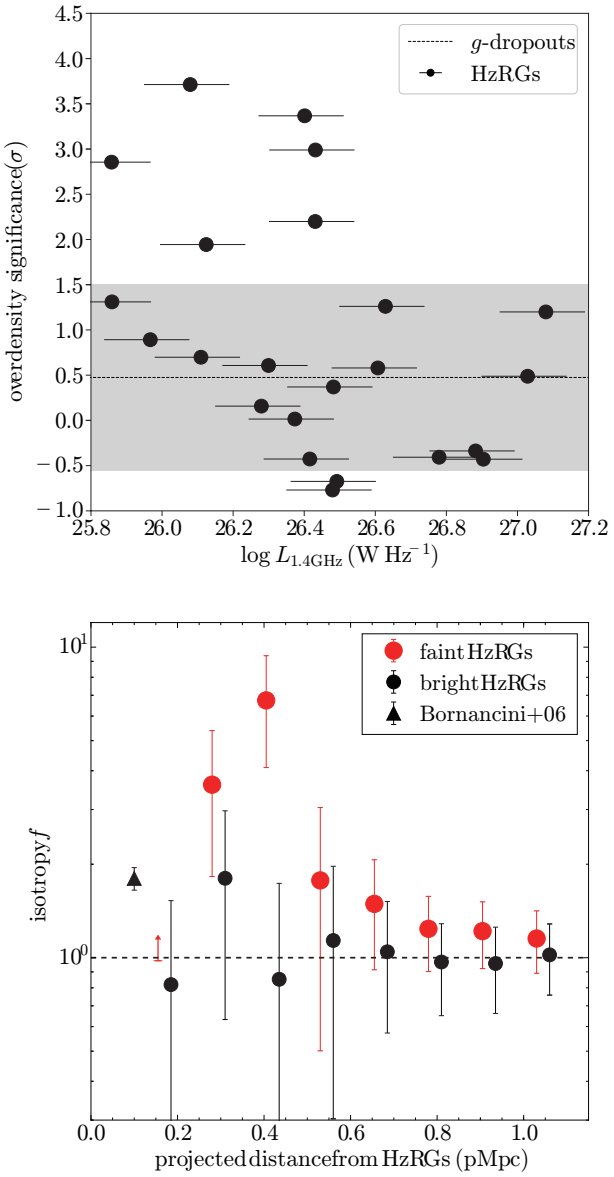


**Figure 1**: (upper panel) The overdensities around the HzRGs (black points) as a function of their rest-frame 1.4 GHz radio luminosities. The dashed line and the gray shaded region indicate the median and standard deviation of the overdensity significances of the $g$-dropout galaxies. galaxies, respectively. (lower panel) Isotropy as a function of the projected distance from the bright (black points) and faint (red points) HzRGs.

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# Discovery of a Directly Imaged Planetary-mass Companion to a Young Taurus M Dwarf Star

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Young exoplanets are thought to be important targets to test planet formation theories. Comparison between the properties of young and old exoplanets also allows us to observationally constrain the formation and evolution of exoplanet atmospheres as well as trace the long-term dynamical evolution of close-in exoplanets. However, young stars generally have higher surface activity and large rotational velocities, which in turn complicate the detection of exoplanets around them using classical methods such as radial-velocity measurements. On the other hand, young exoplanets are thought to retain the initial heat acquired through the gas accretion at their formation, and thus often luminous in the near infrared. Therefore, one can probe the presence of young exoplanets by direct imaging with high spatial resolution at near-infrared wavelengths [1].

We searched for planetary-mass companions around 2M0437, which is a young M dwarf in the Taurus star-forming region. Using IRCS and AO188 on the Subaru telescope, we performed high-resolution *H*-band imaging for 2M0437. Our first AO imaging in 2018 March revealed three "companion candidates" as shown in Figure 1 (named "b", "SW", and "E" in order of increasing distance from 2M0437). To check for the common proper motions for those companion candidates, we performed astrometric observations using Subaru/IRCS as well as the NIRC2 camera on Keck II. After three years of astrometric monitoring, we found that the candidate "b" is physically bound to 2M0437 (i.e., has a common proper motion), while the other sources ("SW" and "E") turned out to be heavily reddened background stars [2].

Isochrone fitting for 2M0437 suggests that it is a 2–5 million-year-old M dwarf with the mass of 0.15–0.17 $M_{\odot}$. The companion "b", located at ≈ 0.9 arcsecond (≈ 100 au in the projected distance) away from 2M0437, had an inferred mass of 3–5 $M_{\rm Jup}$ from its luminosity, by which we concluded that it is a "planet" (rather than a brown dwarf). Given that 2M0437b orbits a low-mass star and is one of the least massive, and youngest exoplanets ever discovered by direct imaging, it is an important benchmark to test planet formation and evolution scenarios around low-mass stars. The existence of such a giant planet around a low-mass star at a large orbital distance (~ 100 au) challenges the classical formation theories such as the core-accretion model (which requires time) and disk-instability model (which requires mass) [3]. Future observations for the atmospheric characterizations of 2M0437b such as by JWST would shed some light on the formation mechanism of such giant planets around low-mass stars.

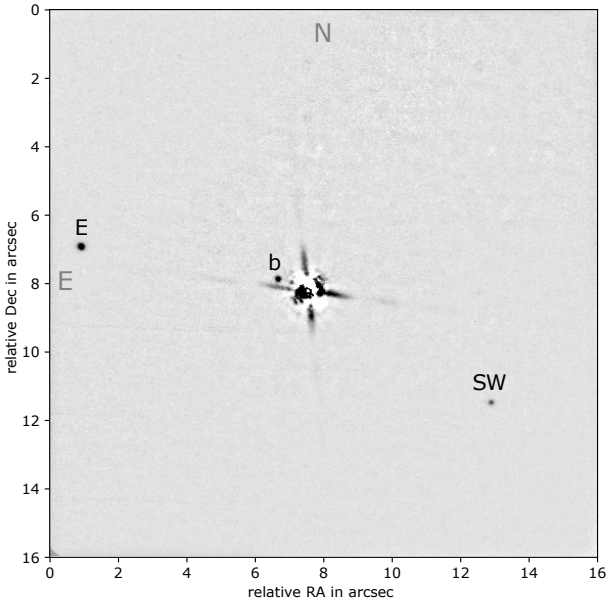


**Figure 1**: High-resolution image of 2M0437 captured by IRCS+AO188 with a field-of-view of 16° × 16° [2].

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# Ionizing Radiation from $z > 3.3$ AGNs with the Hyper Suprime-Cam Survey and the CFHT Large U-band Deep Survey

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In order to comprehend the process of cosmic reionization which is suggested to be completed by $z \sim 6$, it is essential to understand the sources of hydrogen ionizing radiation (Lyman Continuum; LyC). Because LyC is easily absorbed by the intervening HI gas, the direct measurement of LyC emission from objects at $z > 5$ is practically impossible, and we need to rely on observations at lower redshifts to assess how different galaxy populations contribute to the ionizing radiation budget. Studies of LyC escape fraction ($f_{esc}$) for star-forming galaxies at $z \sim 2$–4 have revealed that the average $f_{esc}$ is lower than 10 % while observed UV luminosity function (LF) of star-forming galaxies at $z > 6$ suggests 10–20 % $f_{esc}$ is required to keep intergalactic space ionized. Although this apparent tension could be resolved in several ways (e.g., luminosity dependence of $f_{esc}$ or its evolution), it is important to evaluate the contribution to ionizing photon budget by Active Galactic Nuclei (AGNs), another population which could be significant sources of LyC.

We use deep and wide imaging data from the CFHT Large Area *U*-band Deep Survey (CLAUDS) and the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) to constrain LyC $f_{esc}$ from AGNs at $z \sim 3$–4 ([1]). The unique combination of area, depths and wavelength coverage achieved by these two surveys enabled us to examine LyC from 94 AGNs with a wide UV luminosity range ($-27 < M_{1450} < -19$ in absolute magnitude) at spectroscopic redshift between 3.3 and 4.0. We use their *U*-band / *i*-band flux ratios to estimate LyC transmission (a ratio of observed ionizing photon flux density to the flux density expected from the fiducial intrinsic quasar spectrum) of individual AGNs. The distribution of their LyC transmission shows values lower than the range of LyC transmission values for IGM of the same redshift range (Figure 1), which suggests that LyC $f_{esc}$ of AGNs at $z > 3.3$ is considerably lower than unity in most cases. We do not find any trend in LyC transmission values depending on their UV luminosities. By using the photometry of stacked images and assuming average IGM attenuation degrees at the redshifts and a fiducial intrinsic SED of AGN, we estimate the average LyC escape fraction $f_{esc} = 0.303 \pm 0.072$ for AGNs at $3.3 < z < 3.6$. Based on the estimated LyC escape fraction and the UV LF of AGNs, we argue that UV-selected AGNs' contribution to the LyC emissivity at the epoch is minor, although the size of their contribution largely depends on the shape of the UV LF.

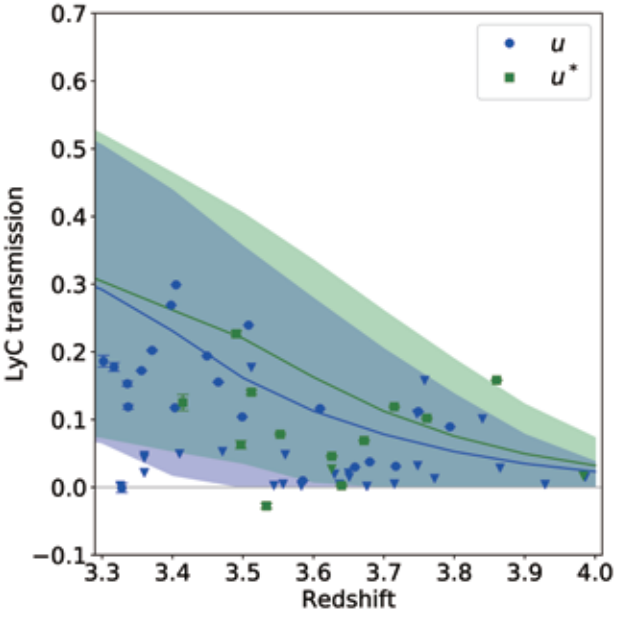


**Figure 1**: LyC transmission for the sample AGNs, plotted against their redshifts. Blue circles are the values estimated using *u*-band photometry, and green squares are those using $u^*$-band photometry. These two filters used in the CLAUDS have slightly different transmission curves against wavelength. Downward triangles are $3\sigma$ upper limits for the AGNs without detection in *u*-band or $u^*$-band. The blue and green solid lines show the average IGM transmission for *u*-band and $u^*$-band, respectively, from the Monte Carlo simulations, and shaded areas represent their 68 %-ile fluctuations.

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# Horizontal Velocity Estimation with Neural Network

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Observation of the solar surface reveals cellular patterns, termed granules, created by thermal convection. Each convection cell is not stable and causes the turbulent dynamics of the solar surface. Turbulent flows on the solar surface is thought to play a role in supplying heating energy to the solar corona by amplifying and shaking the magnetic field. Therefore, it is necessary to measure the velocity of turbulence and its spatial distribution.

Vertical velocity can be measured by the Doppler effect, but horizontal motion cannot be measured directly. Traditionally, local correlation tracking methods have been used to measure the horizontal velocity from the time variation of the granular patterns. This method is limited to estimating convective motion on spatial scales equal to or larger than the size of the granular spots. The interaction between the magnetic field and flow field that occurs at smaller scales has been attracting attention, and estimation accuracy at smaller scales has become an issue. In recent years, attempts have been made to estimate horizontal velocities by utilizing deep learning. However, the accuracy of the estimation remains limited.

We constructed a deep learning model that takes multi-scale nature into account, since there is a variety of spatial scales of granules. In this model, kernels of various sizes were used for convolution. Data from several numerical simulations simulating solar thermal convection were used for training. The network was constructed to learn the relationship between the temperature and vertical velocity structures that are easy to observe and the horizontal motion (Figure 1). Each of the simulations used has a different physical process to produce the thermal convection, which yields a different convective pattern. The characteristics of the deep learning model can be examined by comparing the difference in estimation accuracy for each of the simulations.

To evaluate the performance in detail, we developed a method to evaluate the estimation accuracy at each spatial scale. It shows that our model achieves higher accuracy than the existing method for all simulations at all scales. While achieving high accuracy at large spatial scales, the accuracy ie still limited at scales smaller than the typical scale of convection (Figure 2). The clarification of the validity and estimation accuracy provides clues for further improvement of the method.

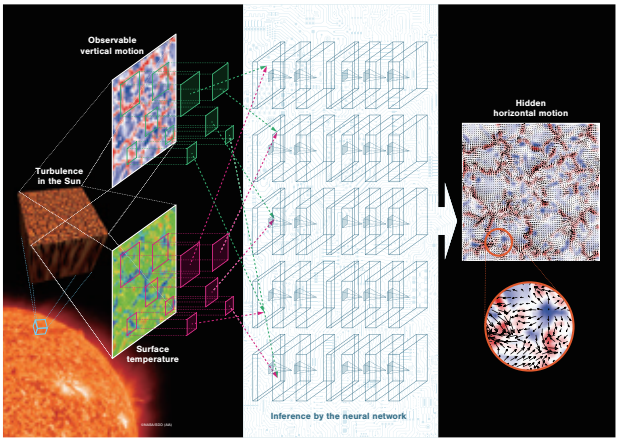


**Figure 1**: Conceptual diagram of this study using deep learning. Based on the vertical motion and surface temperature that can be observed on the solar surface, we estimate the horizontal motion that is difficult to observe. We use a neural network model taht is one of the deep learning methods.

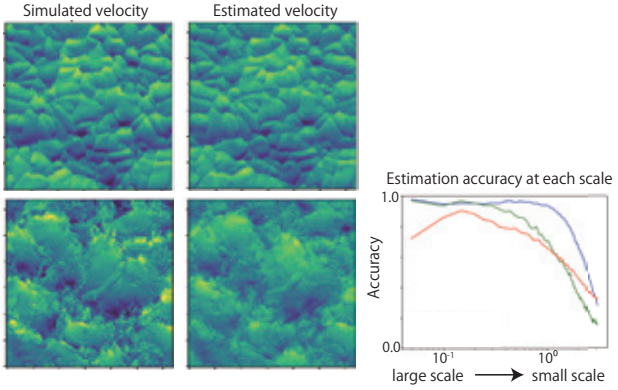


**Figure 2**: (left panel) Horizontal motion in different simulations and horizontal motion estimated with the neural network model. The light and dark colors correspond to upward and downward flow, respectively. (Right panel) Estimation accuracy at different spatial scales. The different colors of the lines indicate the estimation accuracy for horizontal motions in the different simulations.

## Reference

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# Chemical Abundances of nearby M Dwarfs Investigated with IRD-SSP Data

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1: Astrobiology Center, 2: NAOJ, 3: SOKENDAI, 4: Subaru Telescope, 5: Tokyo University of Agriculture and Technology, 6: Komaba Institute for Science/The Univ. of Tokyo, 7: JST/PRESTO, 8: Instituto de Astrofísica de Canarias, 9: Tokyo Institute of Technology, 10: NASA-Ames Research Center, 11: Eureka Scientific, 12: Max-Planck-Institut für Astronomie, 13: The Ohio State University, 14: The University of Tokyo, 15: Kyushu University, 16: NASA Goddard Space Flight Center, 17: ISAS/JAXA

M dwarfs are the ubiquitous stars in our Galaxy and have been the main targets for exoplanet search programs. However, due to their faintness in visible light and the difficulties associated with low temperatures, the abundance ratios of individual elements have rarely been investigated. We have developed a method to investigate the individual elemental abundances (abundance ratios of Na, Mg, K, Ti, Cr, Mn, Fe, and Sr to H) of M dwarfs in the solar neighborhood using data from high-resolution near-infrared spectroscopy [1].

This study [2] uses high-resolution spectra in 9800–17500 Å obtained by the IRD Subaru Telescope Strategic Program (IRD-SSP), which searches for terrestrial planets around nearby M dwarfs, to determine the elemental abundances of 13 M dwarfs ($2900 < T_{\rm eff} < 3500$ K).

The results show that while the majority of the stars have a composition similar to that of the Sun, there are also stars with low metallicities. The correlations between different abundance ratios of the 13 targets are similar to those of FGK-type stars in the solar neighborhood (upper panel of Fig. 1). In addition, the kinematics of the 13 stars in the Galaxy was investigated by combining data from the *Gaia*. It was found that M dwarfs with lower metallicities tend to have kinematics different from the Sun (lower panel of Fig. 1). This trend is also known for FGK-type stars and is interpreted to reflect the chemical evolution of the Galaxy. A well-known M dwarf "Barnard's star" is included in the targets. Many previous studies have reported evidence indicating that this star has a relatively old origin, and the individual elemental abundances obtained for the first time by this study are consistent with this.

These results suggest that while most of the nearby M dwarfs studied here are of Galactic thin disk origin, some are of older origin, given their lower metallicity and different kinematics than the Sun.

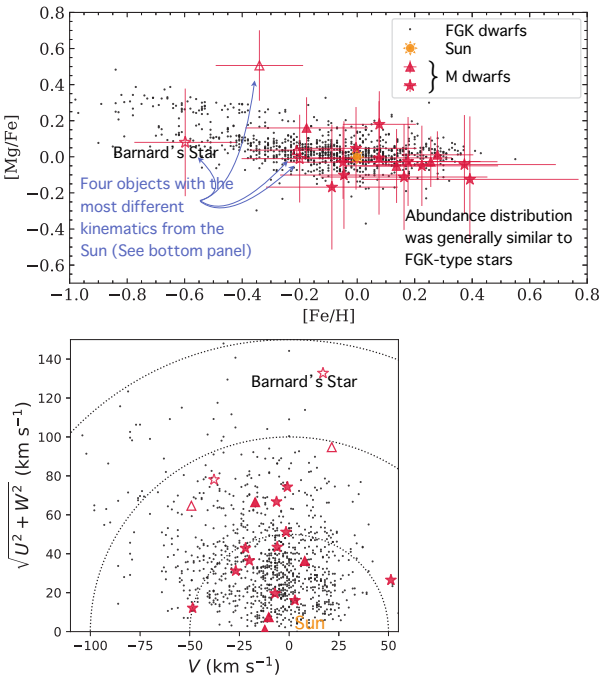



**Figure 1**: The upper panel shows the abundance ratios of magnesium to iron as a function of the abundance ratios of iron to hydrogen. The lower panel shows the Galactocentric space velocities. In both panels, red stars indicate the 13 M dwarfs treated in this study, and red triangles indicate the results for the M dwarfs treated in our previous study [1]. For comparison, the literature values for about 1000 FGK-type stars [3] are shown as black dots.

## References

[1] Ishikawa, H. T., et al.: 2020, *PASJ*, **72**, 102.
[2] Ishikawa, H. T., et al.: 2022, *AJ*, **163**, 72.
[3] Adibekyan V. Z., et al.: 2012, *A&A*, **545**, A32.

# II Status Reports of Research Activities

## 01. Subaru Telescope

### 1. Subaru Telescope Staff

As of the end of FY 2021, the Subaru Telescope staff consisted of 21 dedicated faculty members including five stationed at Mitaka and two stationed at Okayama, five engineers, one project associate professor, five senior specialist, and three administrative staff members. Additional staff members include one project professor, one project associate professor, two project assistant professors, ten project research staff, 11 senior specialist, six administration associates, one public outreach staff member, and one research supporter, all of whom are stationed at Mitaka. Additional staff members include one project associate professor, and three administration associates, all of whom are stationed at Okayama. Moreover, 16 research/teaching staff members, 13 of whom are stationed at Mitaka and three of whom are stationed at Pasadena, and three engineers, one of whom is stationed at Mitaka, one of whom is stationed at Nobeyama, and one of whom is stationed at Mizusawa, are posted concurrently. The project also has 67 local staff members dispatched from the Research Corporation of the University of Hawai`i (RCUH), including scientific assistants; engineers in charge of software and observational instruments; technicians for facilities, machinery, vehicles, and laboratories; telescope/instrument operators; administrative staff; researchers employed for Grant-in-Aid for Scientific Research; Post-Doctoral fellows; and graduate students. These staff members work together in operating the telescope, observational instruments, and observational facilities; and in conducting open-use observations, R&D, public outreach, and educational activities.

### 2. Science Highlights

In FY 2021, Subaru Telescope produced many outstanding scientific outcomes which were published in major international journals. Below are some examples:

(1) A group of astronomers discovered two rocky super-Earth exoplanets lacking thick primordial atmospheres in very close orbits around two different red dwarf stars. The two planet candidates (TOI-1634b and TOI-1685b, originally identified by NASA's TESS spacecraft) around red dwarf stars were confirmed as rocky super-Earths in ultra-short-period orbits by using the Subaru Telescope and other telescopes. The InfraRed Doppler (IRD) spectrograph revealed that the planets are "bare," meaning that they lack primordial thick hydrogen-helium atmospheres, possibly due to interactions with the extremely close host stars. The results also show that TOI-1634b is one of the largest (1.8 Earth radii) and most massive (10 Earth masses) planets among the known ultra-short period rocky planets. These new planets offer excellent opportunities to study what kinds of atmospheres, if any, can develop on ultra-short-period rocky planets, and provide clues to help understand how such unusual planets are formed.

(2) One of the youngest planets ever found around a distant infant star has been discovered using the Infrared Camera and Spectrograph (IRCS) on the Subaru Telescope. The researchers estimate that the planet, named 2M0437b, is a few times more massive than Jupiter, and that it formed with its star several million years ago, around the time the main Hawaiian Islands first emerged above the ocean. It joins a handful of objects advancing our understanding of how planets form and change with time, helping to shed new light on the origin of the Solar System and Earth.

(3) Using the High Dispersion Spectrograph (HDS), a new study of lithium production in a classical nova V5669 Sgr found a production rate of only a couple of percent that seen in other examples. This shows that there is a large diversity within classical novae and implies that nova explosions alone cannot explain the amount of lithium seen in the current Universe. This is an important result for understanding both the explosion mechanism of classical novae and the overall chemical evolution of the Universe.

(4) Astronomers have found tails of gas and/or stars trailing behind a sample of young galaxies without current star formation using Hyper Suprime-Cam and Suprime-Cam data in the archive. Based on this result, the team concludes that about half of the ultra-diffuse galaxies in the Coma cluster are likely to have evolved through collisions with external gas. Ultra-diffuse galaxies, together with similar dwarf elliptical galaxies, account for about 80 % of the members of galaxy clusters, so understanding their evolution is an important part of modeling the evolution of the Universe.

### 3. Open-use

In S21A, 34 programs (58.3 nights including 2.5 nights for ToO programs) were accepted out of 138 submitted proposals, requesting 286.9 nights in total. In S21B, 37 proposals (60.3 nights including 1.5 nights for ToO programs) were accepted out of 135 submitted proposals, requesting 307.8 nights in total. In S21A and S21B, 25.5 nights (5 programs) and 13 nights (4 programs) were allocated respectively for the continuous intensive programs. Service observations were allocated for 2.5 nights in each semester. In S21A and S21B, 1 and 2 programs accepted as open-use proposals were by foreign principal investigators, excluding the University of Hawai`i.

The number of applicants in submitted proposals was 2315 for Japanese researchers (Japanese astronomers at any institute and non-Japanese astronomers belonging to Japanese institutes) and 951 for foreign researchers. The number of researchers in accepted proposals was 712 for Japanese astronomers and 306 for foreign astronomers. In S21A and S21B, the number of open-use visiting observers was 490, and 71 were foreign astronomers. 84 astronomers observed remotely from Mitaka. In S21A and S21B, 92.29 % of the open use time (including University of Hawai`i time) was used for actual astronomical observations after excluding weather factors and scheduled maintenance downtime. About 1.39 %, 0.11 %, 6.14 %, and 0.07 % of observing time was lost due to instrument trouble, communication trouble, telescope trouble, and operation trouble, respectively. In S21A and S21B, remote observations from Hilo were conducted for 11 programs with 13 nights. On the other hand, remote observations from Mitaka were conducted for 17.5 nights with 6 programs including HSC SSP. The numbers of telescope time exchange nights between Subaru Telescope and Keck were 5.0 nights in S21A and 8.0 nights in S21B. For those between Subaru Telescope and Gemini, Subaru Telescope users used Gemini time 4.5 nights in S21A and 2.5 nights in S21B (not including Fast Track programs) while Gemini users used Subaru Telescope time 5.3 nights in S21A and 4.1 nights in S21B.

## 4. Telescope Maintenance and Performance Improvement

The following major repairs, maintenance, and changes were implemented in FY 2021.

(1) Replacement of the primary UPS at the Summit facility:

As part of the preventive maintenance work for stable operation of the telescope, the primary UPS were replaced.

(2) Top Unit Exchange system maintenance:

Maintenance and inspection of the Top Unit Exchange system, which had been postponed due to COVID 19, was performed. However, due to the coronavirus, the replacement of some large equipment was postponed until next year or later.

(3) Other activities:

We are accepting new observational instruments, repairing the outer wall of the dome, performing annual maintenance of the mechanical and electrical systems of the telescope / dome, and repairing sudden failures.

In addition, we have been working to renew the dome air conditioning system, prepare for the recoating of the primary mirror, and to upgrade the telescope software to improve observation efficiency.

The other hand, we started the “Telescope Maintenance Group collaboration of NAOJ”. The purpose of this activity is to share know-how and maintenance plans for maintenance of telescopes owned by NAOJ, and to carry out, evaluate, and improve maintenance activities through cooperation among observatories.

## 5. Instrumentation

The following five facility instruments were provided for the open-use observations in FY 2021: Hyper Suprime-Cam (HSC), Faint Object Camera And Spectrograph (FOCAS), High Dispersion Spectrograph (HDS), Infrared Camera and Spectrograph (IRCS), and the 188-elements Adaptive Optics and Laser Guide Star system (AO188/LGS). As for the carry-in instruments, the Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS), Fast Near-Infrared Polarization Differential Imaging (FastPDI), and MKID Exoplanet Camera (MEC) were newly opened for the open-use programs, in addition to the existing carry-in instruments of Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS), and Visible Aperture Masking Polarimetric Imager for Resolved Exoplanetary Structures (VAMPIRES).

The operation of the Multi-Object Infrared Camera and Spectrograph (MOIRCS), one of the facility instruments, has been hibernated since February, 2021 to facilitate the science operation of the carry-in instrument SWIMS which has a similar capability to MOIRCS. In addition, the operation of LGS has been temporarily suspended for its upgrading project.

Among the upgrade projects of the facility instruments, the installation of the new LGS system was completed in FY 2021 and it successfully achieved the engineering first light in March 2022. Its integration and test are still ongoing and it will be opened for open-use programs from S23A. For HSC, fabrication of new filters is still ongoing by HSC users and we received a narrow-band filter “NB506” and extremely wide-band filter “EB-gri” in FY 2021. They passed the acceptance test and have been approved to be opened from S22B. For the Nasmyth Beam Switcher, we completed the final design, which was done in collaboration with Australian Astronomical Optics, Macquarie University, and fabricated the optical and mechanical parts in FY 2021. Its assembly, integration, and test are planned in FY 2022.

## 6. Computer and Network

The Subaru Telescope computing and network systems core system remained stable with remote work being a key component. CDM(Computer and Data Management) continued to operate necessary network services. CDM worked on-site periodically to assist with users’ needs, install new equipment, and perform regular housekeeping of working areas. CDM is working with other groups to become the managers of network and server equipment, allowing different groups to be released from those responsibilities. CDM is planning to implement a new network layout for the GEN2 base and summit environment. The primary goal is to replace the aging network equipment for OCS (Software Division), and implement new fail-over technology with 25/40/100 Gbps uplinks to maximize the bandwidth between data transfer sub-systems. CDM continues on-site monitoring and maintenance for the HSC and PFS analysis environment; and installation and configuration of new servers.

Major improvements came from the Fully-Remote Project. CDM assisted in the procurement of servers and 100 Gbps network equipment for a high-speed data transfer network from the Maunakea summit region to Hilo and Mitaka Campus. The equipment was installed during February by Mitaka ITSO (Information Technology Security Office) engineers, assisted by a CDM technician. The University of Hawai`i – Information Technology and Network Department played a key role in configuring the network infrastructure for this project. In early May, an initial test of the 100 Gbps network during HSC observations, provided a glimpse of the great potential that the high-speed network will provide. Between the efforts of ITSO, CDM, OCS, and HSC Mitaka Teams, network connections between Maunakea and Mitaka were successful in transferring near real-time HSC observation data. Other parts of this project include Zoom PC based systems, which replaced physical Video Conferencing equipment; new GERS (GEN2 Remote Users Observation Portal); Mitaka Data Analysis server; and an on-site HSCA (Hypersuprime Cam Analysis Cluster) storage array with a 40 Gbps interface.

CDM with the guidance of Associate Director Hideki Takami, started the process to replace STN5 contract equipment by February 2023. The next computer and network system, basically called STN6 will be considerably smaller in physical size, but CDM is committed to continue all services necessary for users. CDM will reduce not only the servers, but also the network core switches. CDM will leverage 100 G network switches to maintain the necessary number of network connections. Our goal with STN6 is to run as efficiently as possible in power, heating, and processing. Specifications are being decided, and the contract process will begin in June 2022. CDM at this moment is working to virtualize and update to a long-term supported OS of all services currently running. The hope is to have the new virtual systems run STN5 until the end of the contract, and easily migrate to new servers.

### 7. Education (Under-graduate and Graduate Courses)

The number of Subaru Telescope staff members in Hilo who were concurrently appointed by SOKENDAI (graduate school) was ten. The number of SOKENDAI students who had primary supervisors affiliated with Subaru Telescope (including those concurrently belonging to Subaru Telescope) was 11, which constituted more than one-third of the total 30 SOKENDAI students hosted in NAOJ. Of those, six had supervisors who belonged primarily to Subaru Telescope.

In FY 2021, Subaru Telescope hosted 1 graduate student for a long stay in Hilo (there were no SOKENDAI students). On top of that, intensive education activities were seen also in the Subaru Telescope Mitaka Office. The numbers of graduate course students in all of Japan who obtained master's degrees and PhDs based on Subaru Telescope data were 16 and eight, respectively, of which two and two were related to the Subaru Telescope Mitaka Office.

We also regularly hosted a series of educational programs at Subaru Telescope. We hosted a Subaru Telescope observation training course for three new SOKENDAI students held in January 2022. This was done remotely from Mitaka, due to the worldwide COVID-19 pandemic. In the Hilo and Mitaka offices, we had many official and informal seminars (remotely this year), many of which were jointly organized with other divisions in NAOJ and/or neighboring universities.

## Subaru Telescope Okayama Branch

The Okayama Branch was established in FY 2018 primarily to provide open-use observing time to universities nationwide utilizing half of the observation time of the 3.8-meter New Technology Optical-Infrared Telescope (now named as "Seimei Telescope") at Okayama Observatory, Astronomical Observatory, Graduate School of Science, Kyoto University. It also cooperates in the use of the telescopes of the former Okayama Astrophysical Observatory by universities and the local government. Two research and academic staff members, one project associate professor, and two administrative supporters belong to the Okayama Branch as of the end of FY 2021.

### 1. Seimei Telescope

(1) Open-use (calendar year)

In the first half of 2021 (January-June), 70 nights were provided. The number of applications was 20 (Classical: 12, Classical + ToO: 1, ToO: 7) and the number of nights requested was 115.2 (Classical: 95, ToO: 20.2), while the number of accepted applications was 16 (8, 1, 7) and the number of awarded nights was 81.4 (62.5, 18.9). Note that "Classical" refers to an observation that will be made on a pre-assigned date, and "ToO" refers to an observation that will be made upon the occurrence of an event of interest at a date and time indicated by the proposer. The total lost time during this period was 1.0 night. In the second half of 2021 (August-December) 62 nights were provided. The number of applications was 24 (13, 1, 10) and the number of nights requested was 114.77 (84, 30.77), while the number of accepted applications was 21 (10, 1, 10) and the number of awarded nights was 79.1 (52, 27.1). Total lost time during this period was 3.0 nights. During these periods, we provided accommodations for observers to stay onsite while taking appropriate measures to prevent the spread of novel coronavirus infections, and we carried out the open-use without causing any infection clusters.

(2) Observing instruments

In the first half of 2021, only the Kyoto-Okayama Optical Low-dispersion Spectrograph with the optical-fiber Integral Field Unit (KOOLS-IFU) was available. In the second half of 2021, the imaging mode (< 10 fps) of the TriColor CMOS Camera and Spectrograph (TriCCS) was newly available. Activities also included management and operation of environmental monitors, storage of acquired data, maintenance of computers and networks, and maintenance of facilities.

(3) Development of remote and queue observations

In cooperation with Okayama Observatory of Kyoto University, the remote observation environment was conditionally opened to open-use in the first half of 2022 (within FY 2021).

(4) Research results

The following example of important research results from observations with the Seimei Telescope was published in a paper in FY 2021.

(a) Continuous spectroscopic observations of the young solar-type star EK Draconis by several telescopes, the mainstay of which is the Seimei Telescope, and photometric observations with NASA's TESS satellite detected an Hα line brightening phenomenon by spectroscopic observations at the same time as a white light brightening in photometric observations. This was the first successful spectroscopic observation of a super-flare in visible light for a solar-type star. The Doppler shift of the Hα line caused by the super-flare was also observed, and the motion of material with a temperature of about 10,000 K was captured as it approached along the line of sight. They found that this is very similar to filamentary ejections in the Sun, and discovered for the first time in the world that a super-flare in a solar-type star is accompanied by a supermassive filamentary ejection. This is a very important achievement in understanding the motion of matter associated with super-flares in solar-type stars, their effects on the surrounding interplanetary space, and the impact of the young Sun or other young solar-type stars on the atmosphere of the young Earth or young exoplanets orbiting other stars.

(5) Meetings

(a) Seimei Users Meeting

The third Users' Meeting was held online on August 11–12, 2021. Meeting Managers: Akito Tajitsu (NAOJ) (Representative), Mikio Kurita (Kyoto Univ.), Masaaki Otsuka (Kyoto Univ.), Masayuki Akiyama (Tohoku Univ.), Shigeyuki Sako (Univ. Tokyo), Satoshi Honda (Univ. Hyogo). The maximum number of simultaneous connections was about 90, and the total number of participants was 117.

(b) Seimei Subcommittee

The Subcommittee met eight times in FY 2021. Two of these meetings were for the time allocation to the open-use observing proposals for the second half of 2021 and the first half of 2022. The second term committee was dissolved at the end of September 2021, and the third term committee was established in October.

(c) Kyoto University 3.8-m Telescope Council

On September 24, 2021, the Kyoto University Graduate School of Science and the National Astronomical Observatory of Japan (NAOJ) held online the fourth meeting of the Kyoto University 3.8-m Telescope Council regarding the operation of the Seimei Telescope. The meeting was attended by the Dean of the Graduate School of Science, Kyoto University, the Director General of NAOJ, and many others. The status of the operation was reviewed and research results were reported.

## 2. Telescopes of the former Okayama Astrophysical Observatory

(1) 188-cm reflecting telescope

(a) On July 27, 2021 and March 14, 2022, the National Astronomical Observatory of Japan (NAOJ), the Exoplanet Observation Research Center at the School of Science of the Tokyo Institute of Technology (TITech), and Asakuchi City held online the operational council meetings to discuss the use of the 188-cm reflecting telescope.

(b) The revenue from the 188-cm telescope fee enabled us to repair the slit door guide rail, replace the slit door drive wire rope, install a safety fence on the upper deck access ladder, renew the safety fence for the elevating floors, install a storage room for observing instruments, conduct an annual inspection of the crane, renew the air conditioners, install LED lighting, repair the restrooms, renew some interior doors, replace furniture, do west entrance stage renovation, implement west entrance door renewal, exterior tile repair, and eave painting. In addition, the 188-cm primary mirror cover was repaired; the vacuum evaporation chamber was inspected and maintained; the small vacuum evaporator was upgraded; the remote observation environment on the second floor of the Main Building was prepared; Wonder Eye for viewing parties was maintained; and a drone was introduced for dome maintenance inspections.

(c) We cooperated with the Tokyo Institute of Technology-led aluminization work on the primary mirror of the 188-cm reflecting telescope from November 8 to 10, and saw the completion of all work without incident. We then accepted the aluminization work on the 1.5-m primary mirror of the Kiso Schmidt Telescope of the University of Tokyo from November 10 to 11, and on the 1.5-m primary mirror of the Kanata Telescope of Hiroshima University from November 11 to 12, and saw the completion of all the work successfully.

(2) Other telescopes

We also cooperated in the operation of the 91-cm reflecting telescope, the 50-cm reflecting telescope (MITSuME), and the Thirty Milli-Meter Telescope (TMMT).

## 3. Public Outreach

The Okayama Branch has no staff assigned to public relations and dissemination activities, so only the minimum necessary activities are carried out.

(1) In June 2021, the Okayama Branch received an award from the Okayama Prefectural Tourism Federation for its contribution to Okayama Prefecture's tourism and industry in Fiscal Year 2021, in recognition of the more than 2 million visitors to the publicly accessible portions of the observatory campus since its opening in 1960.

(2) In July 2021, the Okayama Branch opened a webpage, in Japanese (http://okayama.mtk.nao.ac.jp/index.html).

(3) In December 2021, “Fiery Dragon’s Breath May Scorch Young Planets” was released on the web as a result of cooperative observations by multiple telescopes including the Seimei Telescope.

# 02. Nobeyama Radio Observatory

## 1. Nobeyama 45-m Radio Telescope

(1) Open Use Observations

The 40th open use observations term started on December 1, 2021. The statistics of the successful proposals are as follows. "General Programs": 10 programs were accepted out of 26 submitted proposals including three programs from abroad (out of 10 submitted), "GTO (Guaranteed Time Observation) Programs": one submitted proposal was accepted, VLBI open use observations including the 45-m telescope: five proposals were accepted out of six submitted.

Remote observations were conducted from Mitaka, Iriki, Mizusawa, Kagoshima University, Osaka Prefecture University, University of Tokyo, Keio University, Shibaura Institute of Technology, and ASIAA (Taiwan).

(2) Improvements and Developments

(a) New Developments

The observatory started the design and fabrication of a new focal plane array receiver system for observations at 72–116 GHz. It employs seven beam elements, and allows observations of two polarizations and three bands. This development was supported by JSPS grant-in-aid KAKENHI Kiban S (PI: K. Tatematsu).

(b) Approved Development Programs

A total of five programs are in progress as follows. The Nobeyama Radio Observatory (NRO) supported each program team in the installation of the instruments, particularly in hardware and software interfaces and in test runs.

- 3-band simultaneous observing system HINOTORI. Simultaneous observations of H22 and Z45 receivers were realized by developing and installing a frequency selective filter.
- Frequency-modulation local oscillation FMLO.
- Band 1 (30–50 GHz) receiver (named "eQ") developed in Taiwan was installed on the 45-m telescope and commissioned to carry out performance evaluations as well as test observations.
- Millimetric Adaptive Optics (MAO): Development of a Wave-front Sensor.
- 100-GHz, 109-element MKID camera.

(c) Maintenance and improvements

Maintenance of the 45-m telescope, the receiver systems, computing system, etc. were performed as follows.

- Regularly scheduled and preventative maintenance were performed.
- Corrective maintenance due to some malfunctions in the following systems.
  - The sub-reflector controller unit of the antenna
  - The FFT board of the SAM45 spectrometer
  - The power supply unit of the NTP server
  - The compressor of the refrigerator for FOREST
- The replacement of the computer-control system of the M5 mirror, in the older beam transmission optics, was completed.
- Development of the observation preparation tool for overseas observers is underway.

(3) Scientific Results

A total of 35 refereed journal papers were published on the basis of research using the 45-m radio telescope.

1) Results from the Legacy Programs and Open Use General Programs with the 45-m Telescope

Amada et al. observed an evolved star IRAS16552-3050 and found that SiO maser emissions are emitted from this object. This is the second object for which the SiO maser emissions were found in evolved stars accompanying a high-velocity outflow in the $H_2O$ line, and the paper concludes that the massive outflow that appeared at the end of the asymptotic giant branch phase drives the emission of the SiO maser. Kohno, M. et al. observed CO lines toward the Vulpecula OB association in the Local Spur and found the evidence of cloud collisions from observations of the gas around the OB association. Yamada et al. observed the Orion B giant molecular cloud to investigate gas kinematics around the high-mass star-forming region. Sofue et al. showed that the drastic feedback from the high-mass star cluster in M17 created an unusual high velocity component in surrounding gas. Murase et al. observed the $NH_3$ line to investigate gas heating around high-mass stars. Sato et al. investigated a star forming ring in a bared spiral galaxy NGC613 and concluded that the difference of star formation activity in the ring is related to the velocity difference between the ring and the bar. Xu et al. applied a deep learning technique to detect outflow objects in the molecular gas data of nearby molecular clouds and found the outflows can provide sufficient energy to sustain the turbulence in the clouds. Dewangan et al. used CO data observed with the 45-m telescope and archival data for other wavelengths to investigate the galactic HII region G25.4-0.14 and concluded that the formation of the stellar cluster located in the central region of the hub-filament is explainable with the global non-isotropic collapse scenario.

## 2. Research Support

(1) 1.85-m Radio Telescope (Osaka Prefecture University)

With the 1.85-m radio telescope, we have conducted an extensive survey of molecular clouds along the Galactic plane using the molecular lines of carbon monoxide isotopologues in the 230 GHz band. In FY 2018, we started a new project supported by JSPS (Grant-in-Aid for Scientific Research on Innovative Areas). In this project, we will relocate the telescope to the Atacama site in Chile at an altitude of 2400 m, equipped with an ultra-wideband receiver (230–345 GHz), and carry out

an extensive survey of molecular clouds along the Galactic plane and in the Magellanic Clouds in the southern sky. In FY 2019–2021, in preparation for this relocation, we renewed the telescope system and radome, and developed and tested an ultra-wideband receiver in cooperation with ATC in NAOJ Mitaka Campus. We have successfully developed a wideband receiver system using superconducting receivers at 230 and 345 GHz, a horn covering the frequency band (210–375 GHz), and an intermediate frequency (IF) band circuit covering 4–21 GHz. The system can observe six spectra ($^{12}$CO, $^{13}$CO, and C$^{18}$O) simultaneously across the two frequency bands. It was mounted on the 1.85-m telescope, and we succeeded in the commissioning observations; we successfully mapped the molecular clouds in the six emission lines toward several star-forming regions. In FY 2021, one peer-reviewed paper (Gregorio-Hetem et al. 2021), which used the archive data obtained by the telescope for the analysis and, three papers on the commissioning observations (Nishimura et al. 2021, Masui et al. 2021, Yamazaki et al. 2021) were published.

## 3. Public Outreach

(1) PR activities at Nobeyama Campus

Nobeyama Campus received a cumulative total of 30,371 visitors throughout the year. The open area for visitors is limited to outdoor areas as a precaution against the spread of COVID-19. During the COVID-19 situation, staff members conducted only two guided tours for local schools and granted 12 requests for on-site filming and interviews. One workplace visit by local junior-high schools was conducted. There was no request for Super Science High School (SSH) student visits. The filming and interview requests were mainly about research activities, cooperation with the local government, promotion of the "Nagano Prefecture is Astro-Prefecture," introducing NRO, and the new operation scheme of NRO starting in April 2022.

In the visitors' open area, the NINS Nobeyama Exhibition Room has been forced to close during the COVID-19 situation.

The annual Nobeyama Special Open House was held as an online event. The total number of connections for live streaming was about 6,700 and the total number of views for all content was about 130,000 in one month after the event.

Moreover, we received and answered about 162 phone calls this year from the public regarding the regular opening of the observatory, observatory events, and general astronomy (including 10 interviews).

(2) Cooperation with Local Communities

The annual Nobeyama Special Open House was held online with contributions by Nagano Prefecture as well as Minamimaki Village. However, "Jimoto Kansha Day (Thanks Day for the Locals)" for local communities (Minamimaki and Kawakami Villages) by 3 Nobeyama institutes was cancelled. The sora-girl event "Tebura de Hoshizora Kansho-kai (Drop-by Star Gazing Event)," hosted by the Minamimaki Tourism Association and the photography event for the Nobeyama starry sky in Nobeyama Campus by Minamimaki Village were held and we supported them.

Moreover, the "Nagano Prefecture is Astro-Prefecture" liaison council, which was founded in 2016 through cooperation with Kiso Observatory and other organizations promoted the activities such as monitoring night sky condition in the prefecture. The sixth meeting was held online and on-site at Syogaigakushu-center in Chino on November 13 with about 60 participants. Some activity reports and a discussion on future activities were presented.

(3) NINS Nobeyama Exhibition Room

Although the NINS Nobeyama Exhibition Room had been opened throughout the year in cooperation with NINS and other institutes, it was forced to close during the COVID-19 situation. Furthermore, the 4D2U theater could not be presented during this year. However, the 4D2U theater was presented online 24 times, mainly on holidays.

## 4. Education

Three master's course students from Osaka Prefecture University were accepted for education.

## 5. Misc. Activities

(1) Activities related to the Agreement on Mutual Cooperation between NAOJ and Minamimaki Village

In 2018, NAOJ and Minamimaki Village signed an agreement on mutual cooperation to support PR activities for scientific results of NAOJ and the utilization of the facilities of NRO for the tourist and education activities of Minamimaki Village. Some activities were conducted, such as paid sigh-seeing tours around Nobeyama Campus by the promotion corporation of Minamimaki Village. They had 28 paid group tours and filmings.

(2) Hiring, Transfer (incoming)

Nishimura, Atsushi: Project Associate Professor,New recruit

(3) Retirement, Transfer (outgoing)

Uchiyama, Yoshifumi: Senior Staff of Accounting Section, moved to Shinshu University
Kinugasa, Kenzo: Senior Specialist, retired
Ide, Hidemi: Technical Expert, retired
Hayashi, Mitsuru: Technical Expert, retired
Inoe, Norio: Technical Expert, retired
Kodaira, Toshiko: Administrative Supporter, retired

(4) NRO Conference Workshops and Users Meeting

- December 14, 16, and 21, 2022, On-line
  FY 2021 ALMA/45-m/ASTE Users Meeting (Organizing Committee: Hiroshi Nagai, Misato Fukagawa, Daisuke Iono, Alvaro Gonzalez, Ken Tatematsu, Takeshi Kamazaki (NAOJ))

# 03. Mizusawa VLBI Observatory

Mizusawa VLBI Observatory operates VLBI (Very Long Baseline Interferometry) arrays to provide their machine time for open use, and conduct observational studies of Galactic structure, maser sources, active galaxy nuclei, and so on. As its main facility, the observatory operates the VERA array consisting of four 20 m radio telescopes in cooperation with Kagoshima University. The observatory also operates the Yamaguchi 32-m Radio Telescope and Hitachi / Takahagi 32-m radio telescopes in collaboration with Yamaguchi and Ibaraki University, respectively, contributing to research in Japanese VLBI Networks. Furthermore, KaVA (KVN and VERA Array), which combines VERA and KVN (Korean VLBI Network) in Korea, and the East Asian VLBI Network (EAVN), which consists of Japanese, Chinese, and Korean radio telescopes, are also being operated and opened to the international community. As a member organization of the Event Horizon Telescope project, the observatory contributes to the promotion of millimeter-wave VLBI as well.

In addition to these VLBI-related activities, the observatory plays a wide range of roles beyond astronomy, such as operation of the Timekeeping Office, which determines the official time in Japan, and also the Esashi Earth Tide Observation Facility, which is used for research in geophysics.

## 1. VERA

(1) Observations and Common-Use Observations

The four stations of VERA were operated by remote control from AOC (Array Operation Center) at NAOJ Mizusawa Campus. In FY 2021, due to long-term maintenance work from November 2021 to February 2022, the regular VLBI operations except for EAVN Common Use were suspended, and the annual observation time has decreased by about 30% from the usual year. A total of 188 (1,814 hours) VLBI observations were conducted with VERA; such as VERA project observations; fringe detection observations for maser and reference sources; geodetic observations; and JVN (Japanese VLBI Network) observations. In addition to these, we conducted KaVA (KVN and VERA Array) and EAVN (East Asian VLBI Network) observations, which will be described in the following sections. These VLBI data, except for KaVA and EAVN, were processed at the Mizusawa Correlation Center in NAOJ Mizusawa Campus. The correlated data were sent to each researcher for the case of common-use and JVN observations and to persons in charge of data analyses in the case of project data and geodesy data. VERA common-use calls-for-proposals in FY 2021 were not conducted by VERA alone. This is because almost all observing modes became available in the EAVN common-use, which was released at the same time, and hence, all proposals were submitted to EAVN.

(2) Science Research

In FY 2021, Mizusawa VLBI Observatory published a total of 37 refereed journal papers for scientific achievements. Among them, 4 papers were published by the Observatory members as a PI and 2 of them were published by graduate students in SOKENDAI and University of Tokyo as a PI. Using the facilities operated by Mizusawa VLBI Observatory, one paper was published to report the VERA astrometry results for the structure of the Milky Way Galaxy, one for the pulsar study using the VERA 20-m antennas as single-dish telescopes, one for an active galactic nuclei (AGN) using the Korea-Japan international collaboration project KaVA (KVN and VERA Array), and three for the performance evaluation, variability study, and high-sensitivity imaging of AGNs with the East Asian VLBI Network (EAVN). In addition, five papers were published on the AGN studies from the international project Event Horizon Telescope (EHT) in which Mizusawa VLBI Observatory is participating. Instead of observational studies on the Milky Way Galaxy, star-formation, and stellar evolution through maser astrometry with VERA, multi-wavelength studies from radio to optical, X-ray, and gamma-ray for AGNs and pulsars are newly developing under international collaborations with EAVN and EHT. Consequently, 6 related papers were published in FY 2021. Furthermore, results from the precursors and pathfinders of the Square Kilometre Array (SKA), which is being planned in Mizusawa VLBI Observatory by the SKA1 Study Group, were published, including 2 papers from VERA as introduced above. There were 4 papers for cosmology (Epoch of Reionization) from the Murchison Widefield Array (MWA) in Australia, 2 for a radio galaxy and galaxy cluster from MeerKAT in South Africa, and 1 for maser variability in a star-forming region from VLA (Very Large Array) in the US.

## 2. The Japanese VLBI Network (JVN)

The University VLBI Collaboration Observation project is carried out as a joint research project between NAOJ and six universities. We organize the radio telescopes of VERA, universities, and research institutes (JAXA/ISAS) to make the Japanese VLBI Network (JVN), which is operated at three bands of 6.7 GHz, 8 GHz, and 22 GHz. VLBI observations were carried out for 225 hours in total in FY 2021. The main research subjects are compact objects toward the galactic center, gamma-ray active galactic nuclei, and methanol masers. In addition, over 4000 hours of single-dish observations were carried out as research related to JVN by Ibaraki University.

In FY 2021, JVN was in the last year of being an A-project of NAOJ. The term of this project is three years, and the purpose of this project is to promote time-domain VLBI astronomy with three research targets as follows: (1) $CH_3OH$ masers with periodic flux variations, (2) extremely compact HII regions just after the onset of nuclear burning, and (3) time domain VLBI astronomy of high-energy astrophysical events. The high-sensitivity telescopes larger than 30 m of JVN

constitute the key baseline. A survey of extremely compact HII regions and gamma-ray emitting AGN candidates were examples of the JVN observations in 2021.

In this year, some papers, such as Imazato et al. (2021) and Huda et al. (2021), led by JVN researchers were published. The activities of JVN were presented in some workshops and conferences. A joint research seminar, Ibaraki-Yamaguchi Joint Seminar, was held for students of these two universities.

For development study, Imai (Kagoshima University), Niinuma (Yamaguchi University), and Yonekura (Ibaraki University) led the upgrading the VLBI observation system at the Nobeyama 45-m Radio Telescope and Ibaraki Station by obtaining Grants-in-Aid for Scientific Research. Some students of Ibaraki and Yamaguchi Universities were supervised by Professor Ogawa in Osaka Prefecture University.

## 3. International observations with Korea-Japan VLBI, East Asian VLBI, and mm-VLBI

(1) Observations and Common Use Observations of EAVN

In FY 2020, EAVN (East Asian VLBI Network) observations, utilizing KaVA, the Tianma 65-m, Sheshan 25-m, Nanshan 26-m, Nobeyama 45-m, and Yamguchi/Hitachi/Takahagi 32-m radio telescopes, were conducted for a total of 186 observations (1,395 hours), including common use observation, test, and verification observations. The total observation time has increased by 20 % from last year. Most of the scheduled observations were successfully conducted without any major issues despite the global COVID-19 pandemic.

EAVN open-use calls for proposals for semesters 2021B and 2022A were released in April and October of 2021, respectively. In total, 36 proposals requesting a total time of 1,290 hours were submitted from Japan, Korea, China, UK, Italy, and Thailand. Through the evaluations by 60 referees nominated from scientists in related fields and the subsequent decision made by the EAVN combined Time Allocation Committee, a total of 29 proposals (1,051 hours) were accepted in 2021B and 2022A.

Regarding global mm-VLBI, EHT observations were carried out remotely in March 2022 due to the outbreak of COVID-19.

(2) Results of Research

In FY 2021, 3 papers based on KaVA (2 on active galactic nuclei, 1 on massive star forming regions), and 3 papers based on EAVN (1 on array performance evaluation, 2 on active galactic nuclei) were published in peer-reviewed journals. Five of them include significant contributions from members of Mizusawa VLBI Observatory as the lead author or co-authors. Here some works are highlighted. Kino et al. (2021) monitored the jet motion of the radio galaxy 3C84 over several years using KaVA. They captured the moment when the jet collided with a high-density gas cloud in the circumnuclear region. This provides evidence that the gravitational energy of the central black hole is fed back into the galaxy through a jet. EHT Multi-wavelength Science WG et al. (2021) reported the results from the 2017 M87 multi-wavelength observing campaign including EHT and EAVN, and the study revealed a historically low activity state of the M87 black hole in 2017. Members of Mizusawa VLBI Observatory played a leading role in paper coordination, and a press release was also made. As for EAVN papers two studies, Cui et al. (2021) and Cho et al. (2022), were led by graduate students. Cho et al. (2022) analyzed in detail the EAVN SgrA* 22/43 GHz data acquired near in time to EHT2017, and evaluated the influence of interstellar scattering, which is a necessary piece of information for successful imaging of SgrA* with EHT. In addition, one M87 paper based on the KaVA Large Program was submitted to a refereed journal during FY 2021.

Regarding mmVLBI/EHT, 5 papers (including the above-mentioned multi-wavelength paper) were published in peer-reviewed journals. In particular, Janssen et al. (2021) obtained an EHT image of the core of the nearest radio galaxy Centaurus A based on 2017 observations, and provided important insights into the formation mechanisms of black hole jets. In addition, SgrA * papers (6 main papers and 4 official papers) based on 2017 EHT observations were compiled and submitted to a peer-reviewed journal (some of which were accepted during 2021).

## 4. Future Planning for SKA

The SKA1 Study Group (SKA1SG) was organized under Mizusawa VLBI Observatory for a three-year period since FY 2019 to conduct preparation studies aimed at project proposals and in-kind contributions to the SKA1 construction according to the charge from NAOJ HQ. The project plan of Japanese participation for SKA1 was proposed in October 2021 by SKA1SG which describes a 2 % contribution to the total SKA program. For the contribution to SKA1 construction, the Japanese contribution is planned to be mainly Assembling, Integration, and Verification (AIV) along with other parts of the SKA Observatory Development Program. Japan will also contribute 2 % to the construction of the SKA Science Reginal Center (SRC), which is assumed as the same ratio as the construction contribution. On the scientific side, the project proposed the plan to focus on promoting major Japanese scientific themes and providing user support including stimulating joint-use observation proposals and supporting data analysis and archival data use for not only focused themes but also wider SKA scientific research. At first, this agreement was to be for the period 2022–2028, during the construction of SKA1, but in the course of deliberations by the Project Review Committee, it was requested that the project period be extended to 2033, when initial research results are expected. The proposal was revised accordingly.

An SKA science strategy workshop was held on July 12–14, 2021, to discuss Japan's research strategy in cooperation with SKA-JP, a Japanese SKA user community organization. We have a consensus that a strategic Japanese science plan is important to promote the research by setting up research themes that Japan should focus on, while participating in the

wide range of scientific research expected to be conducted by the SKA. The meeting discussed scientific impact, expected results, and fostering work by young researchers on possible themes; and selected cosmic reionization, cosmic magnetic fields, and pulsars as priority research areas.

In addition, SKA-JP proposed participation in the SKA as a priority large-scale plan to the Science Council of Japan Master Plan 2023. As requested from the SCJ astronomy and astrophysics subcommittee, SKA-JP presented a scientific research plan and Japanese participation plan at the Japan Radio Astronomy Forum Symposium on the Future Plan of Radio Astronomy 2021. And the SKA participation plan was recommended as one of prioritized plans by the Japan Radio Astronomy Forum. In response, SKA1SG and the SKA-JP made a joint proposal at the Science Council of Japan's "Symposium on Large and Medium-Sized Future Plans in Astronomy and Astrophysics" (held on August 10, 2021), but the Master Plan 2023 itself was subsequently cancelled.

We continued to employ a project research staff member based on the agreement with the SKA Observatory to plan scientific research, and also to develop a testing machine for the network-type data analysis and archiving system for Japanese SRC, which we started to study jointly with the SKA consortium in FY 2020. A group of networked data analysis servers was constructed and tested at NAOJ, Kumamoto University, and Nagoya University. We also continued our commitment in the Australian MWA to develop methods for analyzing and calibrating cosmic reionization observation data and other data. On March 7–8, 2022, a data analysis workshop for cosmic reionization, cosmic magnetism, and pulsar data was held with the participation of a large number of young researchers, mainly from Japan.

The MoU on the Japanese AIV commitment was signed with the SKA Observatory, agreeing on a 1.5 FTE contribution for 3 years starting from 2022. Based on this MoU, we are participating in the AIV of SKA LOW and preparing a test plan. We have also started to discuss with SKAO the detailed plan for SKA MID AIV participation.

We are working closely with SKA-JP. We are jointly sharing the cost of participation in the MWA, the SKA precursor, and preserving the right of Japanese researchers to access observations and achieved data at the MWA. SKA1SG helped SKA-JP prepare the SKA-JP Engineering Book, which outlines plans for Japanese technical participation and the publication of the SKA-JP Science Book in an academic journal, which was published in FY 2021. In addition, the East Asian SKA WS was jointly held on May 26–28, 2021, to promote collaboration and activate research activities using the SKA and pathfinders in East Asia.

In the area of VLBI research, we have been preparing for the development of a VLBI system in the SKA. The preparation for the development of a VLBI system in the SKA was carried out in cooperation with JIVE and was discussed at global activities like an international symposium 'VLBI in the Era of SKA' which was held during February 14–18, 2022. We are also participating in discussions at the Global VLBI Consortium as a key member. We are also working with India on preliminary VLBI observations in the SKA LOW frequency band below 320 MHz. We succeeded in detecting fringes at 320 MHz between the Tohoku University Iitate Station and the Indian NCRA's Ooty Station.

## 5. Geodesy and Geophysics

In order to monitor the position and shape of the VERA network, regular geodetic observations were conducted 1–2 times a month. VERA internal geodetic observation sessions using K band were conducted once or twice a month. Mizusawa Station conducted IVS sessions (IVS-T2P and AOV) using S- and X-bands once every one or two months. In AOV and IVS-T2P, wideband observations using OCTAD-OCTADISK2 have been routinely operated. In FY 2021, VERA internal geodetic observation was conducted 12 times and we participated in IVS sessions 6 times. The final estimates of the station positions of VERA were reconstructed based on ITRF2014 and supplied to the astrometric analysis performed by VERA.

We carried out continuous GNSS (GPS) observations at VERA stations in order to monitor short term coordinate variations and to estimate atmospheric propagation delays. The propagation delays (excess pass delays) vary irregularly in time. We produce essential correction data for VERA accurate astrometry through GNSS observations. The positioning result of GNSS at Mizusawa shows the viscosity relaxation process of the 2011 off the Pacific coast of Tohoku Earthquake. Mizusawa is moving to the East-Southeast direction even though 11 years have passed since the occurrence of the earthquake. The gravity observation at Mizusawa also shows the process of viscosity relaxation. The gravity change observation at Ishigaki Island, which was the joint work with the Earthquake Research Institute of the University of Tokyo and the Geological Survey of Japan, AIST, terminated in February 2022. The strain and tilt observation data obtained at the Esashi Earth Tides Station are distributed in real time to several institutes and universities based on the research agreement among them.

## 6. System Development

As a development group, we are currently developing the dual-polarization and dual-frequency (K, Q) receiver system with a rate of 32 Gbps for VERA in accordance with the next EAVN broad-band observing mode. In 2021, we modified (redesigned and adjusted) the RF and IF integrated switches with 16 inputs and 4 outputs for dual polarizations of five bands (Q, K, C, S, L) to improve the temperature characteristics and reinstalled them at all stations. We have also identified a problem in the design of the input clock alignment section of OCTAD, which had been causing a degradation in SNR since last year, and have corrected the problem, completing the AIV of this new observing system together with the integrated switch. After that, as a CSV (Commissioning and Science Verification), we conducted VLBI test observations using a RF direct A/D system at K-band left polarization, which is one

of the features of this system and achieved agreement within 2–3 % SNR compared to the fringe results in the normal IF band. The above results have enabled the ultra-wideband, dual-polarization observations at a rate of 16 Gbps (all stations) and in addition to that, simultaneous K and Q-band observation using the world's first K-band RF A/D system at Iriki station. As a CSV, we have started some test observations in various observing modes.

As an extension of the observable frequency band, we improved the method of the patch antenna array synthesis of the L-band receiver system installed in 2020. We modified and re-installed it at Mizusawa and Ishigaki-jima Stations, measured RFI and EMI, and examined the observable frequency range to conduct VLBI observations.

## 7. Timekeeping Office Operations

The Time Keeping Office operates four cesium atomic clocks together with a hydrogen maser atomic clock at Mizusawa VERA Station, and sets the "Central Standard Time" of Japan. The facilities contribute to the determination of UTC (Coordinated Universal Time) by BIPM (Bureau International des Poids et Mesures) through international time comparison. The NTP (Network Time Protocol) server at the Time Keeping Office provides standard time on a network. This service has been in great demand; about 7 million daily visits have been recorded.

## 8. Public Relations (PR) and Awareness Promotion Activities

(1) Open House Events

The following open house events are held every year at each telescope site operated by Mizusawa VLBI Observatory. In 2021, we canceled all open house events to prevent the spread of the novel coronavirus.

- The Open Observatory Event held by the Ibaraki University Center for Astronomy, and NAOJ Mizusawa VLBI Observatory, Ibaraki Station.
- The special open house event at VERA Ishigaki-jima Station held together with "The Southern Island Star Festival."
- The special open house of VERA Iriki Station jointly held with "The Yaeyama Highland Star Festival."
- "Iwate Galaxy Festival" is the open house event held at NAOJ Mizusawa Campus.
- "Star Island" is the open house event held at VERA Ogasawara Station.

The Southern Island Star Festival was held on January 29 (Saturday) and 30 (Sunday), 2022 at the Ishigaki Civic Hall, and the VERA Ishigaki-jima Station exhibited panels and distributed goods.

(2) Regular Public Visits

Throughout the year, the following stations are open to the public on a regular basis. The four VERA stations are open to the public approximately every day except during the New Year's season.

The numbers of visitors to each facility are as follows.

a) Mizusawa VLBI Observatory (VERA Mizusawa Station) 7,991
   The campus is regularly open to the general public with the cooperation of the Oshu Uchu Yugakukan (OSAM: Oshu Space & Astronomy Museum) located in the campus.
b) VERA Iriki Station 1,338
c) VERA Ogasawara Station 4,090
d) VERA Ishigakijima Station 1,698

At Mizusawa VLBI Observatory, the Oshu Space & Astronomy Museum was closed from August 14, 2021 to September 22, and from January 30, 2022 to February 28, to prevent the spread of the novel coronavirus infections. The number of visitors during that period is not included. The Kimura Hisashi Memorial Museum was closed.

(3) Cooperation with Local Communities

Various events were held in cooperation with Iwate Prefecture and Oshu City. Here are some of the most notable events.

We cooperated with special exhibitions, lectures, and workshops at libraries co-sponsored by the Southern Iwate Regional Development Bureau and the municipalities in the southern part of Iwate Prefecture.

- Special exhibitions
  Jul 7, 2021(Wed)-Jul 18, 2021(Sun) Hiraizumi Municipal Library
  Jul 24, 2021(Wed)-Aug 22, 2021(Sun) Kanegasaki Municipal Library
  Aug 6, 2021(Fri)-Aug 11, 2021(Wed) Tono City Library
  Aug 27, 2021(Fri)-Sep 23, 2021(Thu) Ichinoseki Library of Ichinoseki Public Libraries
  Sep 1, 2021(Wed)-Sep 26, 2021(Sun) Nishiwaga Town Culture Creation Hall (Galaxy Hall)
  Nov 5, 2021(Fri)-Nov 17, 2021(Ewd) Mizusawa Library of Oshu City Libraries
  Nov 27, 2021(Sat)-Dec 23, 2021(Thu) Higashiyama Library of Ichinoseki Public Libraries
  Jan 20, 2022(Thu)-Feb 2, 2022(Thu) Hanamaki Library of Hanamaki City Libraries

- Lectures and Workshops
  Jul 17, 2021 (Sat) Kanegasaki Municipal Library / Prof. Honma talk event "How to walk in space"
  Jul 29, 2021 (Thu) Ohta Library (Nishiwaga town) / Workshop "Let's make a jack-in-the-box of jets that jump out of the black hole!"
  Aug 8, 2021(Sun) Tono City Library / Summer Vacation Workshop "Let's make a spinning top like galaxy!"
  Sep 22, 2021 (Wed) Kitakami District Fire Association Nishiwaga Fire Department / 5th Townspeople culture school "Get familiar with the Universe in the Milky Way town of Nishiwaga"
  Jan 22, 2022 (Sat) Hanamaki City Culture Hall / Hanamaki

Library Lecture “Forefront of black hole research”

The Iwate Marugoto Science Museum will be held under the initiative of Iwate Prefecture. It is held every year at two locations, in Morioka City and the coastal area, but this year it was held online to prevent the spread of the novel coronavirus.

In 2021, we held a “Kirari ☆ Oshu City Astronomical Class” for elementary and junior high schools in Oshu City.
Jul 19, 2021 (Mon) Kuroishi Elementary School 5th and 6th grade / What is a black hole?
Sep 7, 2021 (Tue) Mizusawa Minami Elementary School 5th grade joint / What is a black hole?
Sep 13, 2021 (Mon) Ide Elementary School 6th grade / Earth, Moon, and Solar System
Sep 17, 2021 (Fri) Mizusawa Minami Elementary School 6th grade joint / Earth, Moon, and Solar System
Oct 7, 2021 (Thu) Maesawa Junior High School 3rd grade joint / Hayabusa2 challenge
Oct 12, 2021 (Tue) Higashimizusawa Junior High School 3rd grade 1st to 4th joint / What is a black hole?
Nov 19, 2021 (Fri) Maesawa Elementary School 5th grade joint / What is a black hole?
Dec 20, 2021 (Mon) Tamasato Elementary School 6th grade / Earth, Moon, and Solar System

## 9. Education

(1) University and Post-Graduate Education

Regarding postgraduate education, Mizusawa VLBI Observatory assisted 1 doctor course student from SOKENDAI, and 3 doctor and 3 master’s course graduate students from the University of Tokyo with their research. Three of them were from foreign countries. The SOKENDI student got her Ph.D. degree and graduated in December 2021. One of the students in the university got his master's degree in March 2022. In addition, staff members of Mizusawa VLBI Observatory give lectures at the University of Tokyo, Tohoku University, and Niigata University as visiting professors.

(2) Research Experience for High School Students

Although the educational program for high school students in Ishigaki Island, “The Churaboshi Research Team Workshop” with the support of JSPS, was held during summer vacation in the past, the Mizusawa VLBI Observatory organized the event in March 2022 this time due to the serious COVID-19 situation. The event was co-organized with the Public Relations Center of NAOJ on-site at the VERA Ishigaki-jima Station and Ishigakijima Astronomical Observatory, while it was reduced to two days’ sessions. Including participants from outside Ishigaki Island, a total 9 high school students experienced the lectures on astronomy, observatory tours, and observational studies with the VERA 20-m antenna. In order to complement The Churaboshi Research Team Workshop, an on-line event “The VERA-Star Challenge” was held in 2022 January for the first time, through broadcasting from Mizusawa Observatory. The first half of the event was aimed at junior-high school to university students, providing lectures and virtual tours of VERA; and the second half was held for high school students to experience remote observations with the VERA 20-m antenna. There were 46 and 24 participants for the first and second half of the event, respectively.

# 04. Solar Science Observatory (SOL)

The Solar Science Observatory (SOL) project, as a COE of solar observations in Japan, operates the Hinode satellite and ground-based solar telescopes to pursue the development of solar research by acquiring and accumulating multi-wavelength data. The project also carries out the development of advanced technology for next-generation solar observations.

## 1. Hinode Space Observatory

The scientific satellite Hinode is an earth-orbiting satellite that was launched on September 23, 2006, by ISAS/JAXA, as Japan's third solar observational satellite following Hinotori (1981) and Yohkoh (1991). Hinode is equipped with three telescopes: the solar optical telescope (SOT), the X-ray telescope (XRT), and the extreme ultraviolet imaging spectrometer (EIS). In addition to observations of the detailed magnetic field and velocity field of the solar photosphere, it carries out simultaneous observations of the radiance and velocity field from the chromosphere to the corona. The telescopes equipped on the Hinode satellite were developed through international collaboration based on cooperation between ISAS/JAXA and NAOJ with contributions by the US NASA and the UK STFC. The European Space Agency ESA, and the Norwegian Space Center NSC also join in its scientific operations. NAOJ played a central role in the development of the science payload in Japan and has been making a significant contribution to the science operation and data analysis since its launch. The data acquired with Hinode are released to everyone as soon as the data are ready for analysis. The Hinode Science Working Group (SWG), composed of representatives from the international teams, offers support in scientific operation and data analysis. It has a total of 17 members, including three from SOL: Y. Katsukawa as SOT PI, H. Hara as EIS PI, and T. Sakurai, professor emeritus, as a project scientist. The Science Schedule Coordinators (SSC) have been organized to leverage the open-use observation system. Two Japanese members from SOL (T. Sekii for SOT and T. Watanabe, professor emeritus, for EIS) join the SSC activity. The SSC serves as a contact point for observation proposals from world solar physics researchers to use Hinode and promotes joint observations between Hinode and the other science satellites and ground-based observatories. New science results have been obtained via joint observations with SDO, IRIS, and ALMA as well as long-term standalone observations by Hinode. The number of Hinode-related refereed papers published in FY 2021 is about 60.

The Hinode science payload had been steadily observing the Sun from space, except for the SOT filtergraph instrument which was terminated in February 2016. Near the end of December 2021, an anomaly occurred in the attitude control around the Sun-directed axis, and the satellite entered a safe-hold state leading to the suspension of observations. The attitude around the Sun-directed axis had been controlled by the star tracker, but we established an operational procedure to control the attitude using a geomagnetic sensor and gyro and were able to resume normal observations from the beginning of March 2022.

ISAS/JAXA approved the fourth mission extension for the period from FY 2021 to FY 2023. The scientific motivation in the coming period is to continuously observe rising activity toward the solar maximum using techniques such as observations of magnetic fields in the polar regions and full-disk mosaic observations, as well as to promote joint observations with rocket and balloon experiments conducted by the SOL project and with inner heliosphere observations by new satellites such as Solar Orbiter. Another aim is to conduct collaborative observations with DKIST, a large aperture ground-based telescope described below.

Solar Data Archive System (SDAS) in the Astronomy Data Center (ADC), which developed from the open-use data analysis system of the Hinode Science Center and NSRO (Nobeyama Solar Radio Observatory) in addition to the data archive/public release system of the former Solar Observatory, takes the role of archiving and public release of the solar data. The data analysis functionality has been integrated into the ADC Multi-wavelength Data Analysis System (MDAS). The SOL project is jointly operating SDAS and MDAS with ADC. The SOL project is jointly operating Hinode Science Center at the Institute for Space-Earth Environmental Research, Nagoya University, where value-added Hinode data are maintained such as a flare catalog, model of magnetic fields above active regions, and magnetic field data in the solar polar regions. Joint research is ongoing for a comparative study between radiative magnetohydrodynamic numerical simulations and Hinode observations.

## 2. Ground-based Observations at Mitaka Campus

The SOL project continues to conduct observations at Mitaka Campus to obtain basic data for solar research and to help satisfy the public demand for monitoring its possible influence on the global environment. The primary observations are infrared spectro-polarimetry for full-disk magnetic field measurements both in the photosphere at 1.565 microns and in the chromosphere at 1.083 microns with the Solar Flare Telescope (SFT). The other observations include full-disk Hα, Ca K, continuum, and G-band imaging observations, and relative sunspot number measurements as a proxy of long-term solar magnetic activity. The solar activity has been gradually increasing since 2019 after the solar minimum, and useful data such as active regions and flares have been obtained in the new cycle. To ensure stable operation, we are replacing aging parts of the instruments.

The observation data are available at a data analysis server of ADC and on the web page of the SOL project. The data storage server is continuously upgraded to accommodate the increasing amount of data. In FY 2021, we replaced a

file server and prepared the data format for accommodating data retrieval from outside as part of the promotion of data use. Some of the most advanced data accumulated are those for magnetic field. The magnetic field observations that were conducted with SFT starting from 1992 have provided vector magnetic fields in the photosphere with a field of view covering active regions by observing an absorption line in the visible wavelength range. These observations have now been replaced with near-infrared Stokes polarimetric observations since 2010 for higher precision measurements of magnetic fields both in the photosphere and in the chromosphere. NAOJ has long-term solar observation data in the form of films, photographic plates, and sketches acquired since the time of its predecessor, the Tokyo Astronomical Observatory. The data are being digitized for the study of long-term variations in solar activity. The sunspot observations that started in 1929 continue, although they were upgraded to imaging observation using a digital camera in 1998.

In addition, the SOL project continues to observe total solar eclipses and has recently achieved success in polarimetric measurements of the corona. We are developing key technologies required in future solar observing instruments, such as an infrared camera with an H2RG detector.

## 3. Nobeyama Solar Radio Polarimeters

The Nobeyama Radio Polarimeters (NoRP) monitor the microwave radiation from the Sun, especially at seven frequencies (1, 2, 3.75, 9.4, 17, 34, and 80 GHz), and measure its circular polarization to study solar cycle activity and particle acceleration phenomena associated with solar flares. Although the Nobeyama Solar Radio Observatory (NSRO) was closed at the end of FY 2014, the observation of intensity and circular polarization at the seven frequencies, conducted over 70 years, continues because of its importance in monitoring long-term solar activity. Since FY 2019, the SOL project started to take responsibility for the operation and maintenance of the radio polarimeters in cooperation with Nobeyama Radio Observatory (NRO). Before the increase in solar activity, the 35 and 80 GHz antennas, which had previously suspended observations due to problems caused by a gear failure, were repaired, and observations at all the frequencies were able to resume in October 2021. Since then, stable observations have been made, and we have succeeded in acquiring 1-80 GHz microwave spectra during several solar flares that occurred in April 2022.

## 4. Rocket and Balloon Experiments

The SOL project is working to carry out the development of advanced technology for next-generation solar observations by sounding-rocket and stratospheric balloon experiments.

The CLASP series of sounding rocket experiments aim to measure solar magnetic fields in the chromosphere and transition region through high-precision polarization observations in the ultraviolet wavelengths. Following CLASP2 (flight in 2019, the world's first successful polarization spectroscopic observation of ionized magnesium lines [Mg II h&k lines, wavelength 280 nm]), the CLASP2 re-flight project (CLASP2.1, Japanese PI: Ishikawa) was led by the SOL project. Preparations were made with the cooperation of the Advanced Technology Center (ATC), and after a month and a half of launch-site testing at the White Sands Missile Range in the United States, CLASP2.1 was launched on October 8, 2021 (local time). Slit-scan observations of an active region were successfully made for about 6 minutes, and polarized spectra of the Mg II h&k lines induced by the Zeeman effect were obtained with high quality. By applying the method constructed by Ishikawa et al. (2021) to these data and combining them with the Hinode satellite data obtained jointly with CLASP2.1, we expect to be able to reveal the three-dimensional (two spatial dimensions plus height) structure of the magnetic field from the photosphere to the upper chromosphere. Currently, data calibration is underway in cooperation with the US team.

SUNRISE-3 is the third flight of the international balloon project Sunrise, in which Germany, Japan, the United States, and Spain are participating, and is scheduled to fly in the summer of 2022. The SOL project is in charge of the near-infrared spectro-polarimeter SCIP (Japanese PI: Katsukawa), which will be installed on the 1-meter aperture telescope of SUNRISE-3 and will simultaneously observe many spectral lines with a resolution higher than that of the Hinode satellite. These observations will allow us to observe the three-dimensional magnetic field structure and its time evolution from the photosphere to the chromosphere and clarify the transport and dissipation processes of magnetic energies. In cooperation with the ATC and ISAS/JAXA, the SCIP optical unit has been developed to achieve high imaging, spectral, and polarization performance. After the completion of assembly and performance evaluation in air, we confirmed the optical performance and thermal control of the instrument under the low pressure and thermal environment expected during balloon flight using a large vacuum chamber at ATC. After the completion of the development at NAOJ, SCIP was shipped to Germany in August 2021, where it was integrated into the 1-meter telescope. We conducted verification and calibration of combined performance with other instruments, and evaluation of performance with natural sunlight. The final test at the balloon launch site in Kiruna, Sweden, has been underway since April 2022. We are preparing refereed papers on the technology development for high-precision spectro-polarimetry as well as opto-mechanical design and analysis obtained through the development of SCIP. Methods for analyzing high-precision polarimetric data of the chromosphere are studied through international collaboration, which is beneficial not only for the SUNRISE-3 balloon observations but also for observations with the large solar telescope DKIST.

The Focusing Optics X-ray Solar Imager (FOXSI) is a joint Japan-US sounding rocket experiment to observe X-rays emitted from the solar corona by 2D focusing imaging and spectroscopy. It has successfully flown three times (FOXSI-1 to -3) to make the world's first observations of the solar corona during non-flaring periods; FOXSI-1 and FOXSI-2 (launched

in 2012 and 2014) made focusing X-ray imaging spectroscopic observations in the hard X-ray band (5 keV to 15 keV), and FOXSI-3 (launched in 2018) succeeded in imaging spectroscopy observations in the soft X-ray band (0.5 keV to 5 keV). The fourth flight, FOXSI-4, aiming to observe solar flares, was proposed to NASA and was approved with the highest rank in 2019. In 2021, the budget for FOXSI-4 was adopted by the ISAS/JAXA small-scale program and the Grant-in-Aid for Scientific Research, International Cooperative Research Acceleration Fund (B) (Japanse PI: Narukage). FOXSI-4 is scheduled for launch in 2024 and aims to understand plasma heating, energy transport, and particle acceleration in a solar flare. The Japanese group led by the project is developing key components such as a high-speed camera for X-rays, a high-precision X-ray mirror, a pre-collimator, and an X-ray filter. These developments are being carried out in collaboration with the ATC and the CMOS camera team of the Subaru Telescope. The team is also working on the data calibration of the last three FOXSI experiments as well as on the creation of scientific results.

## 5. Cooperation with SOLAR-C Project

To refine the observation plan for Solar-C (EUVST), we are running research on how the key processes of atmospheric heating are observed spectroscopically using numerical simulations in the framework of the Hinode Science Center, which is jointly operated with Nagoya University. The research is being conducted not only in the visible and near-infrared spectra targeted by SUNRISE-3 balloon observations but also in the ultraviolet spectra to be observed by CLASP and Solar-C. The SOL project contributes to realizing Solar-C, especially in the development of critical technologies, based on the technical assets accumulated through the rocket and balloon experiments.

## 6. Education

The SOL project accepted and supervised three Ph.D. students from SOKENDAI and three contract graduate students from the University of Tokyo. One received a Ph.D. degree at SOKENDAI. One undergraduate student was accepted into a summer student program of SOKENDAI and was supervised online. The SOL project participated in the Tour of Solar Research Frontiers (March 2022, online) and introduced solar research at NAOJ to undergraduate students.

## 7. Public Outreach (PO) Activity

The SOL project has been conducting various public outreach activities for education and delivering the latest solar activity and the results obtained through the scientific research of the Sun to the public: web releases, homepage, social media, cooperation for exhibitions at science museums, media appearances in response to requests for media interviews, and providing materials to the media, etc.

## 8. Science and Community Meetings

The international Hinode Science Meetings have been regularly held to advance the solar physics research with the Hinode satellite. The 14th Hinode Science Meeting was originally scheduled in 2020 but was postponed due to COVID-19 and held in October 2021. A meeting of the Hinode Science Working Group was held online on October 29, 2021, to discuss ways to continuously generate scientific results from Hinode and to share the status of mission extension in participating countries. The Japan Solar Physics Community Symposium was held online on February 14–15, 2022, where the latest research results from domestic instruments and foreign space- and ground-based observations were presented, and future plans for Solar-C and beyond were introduced and discussed.

## 9. Others

The Daniel K. Inouye Solar Telescope (DKIST) on Haleakala in Hawai`i, a 4-meter aperture solar telescope led by the US, obtained its first-light images in January 2020. One member of SOL (Y. Katsukawa) is a member of the Science Working Group and helped to develop the Critical Science Plan for the initial observations of DKIST, which was published as a paper. In the first call for observation proposals for DKIST (Operation Commissioning Phase 1, OCP1) issued in 2020, five proposals submitted by Japanese researchers were accepted. The observations of OCP1 were delayed by COVID-19 but began in February 2022. Based on a grant for enhancing collaborative research with DKIST (co-I: M. Kubo), we are conducting numerical simulation studies until we obtain DKIST observation data. A study for the next-generation focal plane instrument for DKIST has begun in cooperation with Kyoto University. For the European Solar Telescope (EST, 4 m) the SOL project is participating in the SOLARNET project (January 2019 to December 2022) of the European solar community to develop a prototype IFU (Integral Field Unit) for the EST-prototype GREGOR solar telescope. An image slicer unit for the IFU was designed and fabricated with a Grant-in-Aid for Scientific Research. In the next-generation global network solar observation project (ngGONG), which is led by NSO in the US, the SOL project has expressed our intention to cooperate with NSO for its realization based on the scientific and technological heritage obtained through near-infrared spectro-polarimetry with SFT at Mitaka Campus.

The 10 cm coronagraph from the former Norikura Corona Observatory has been relocated to Yunnan, China, and discussions have started to move the new coronagraph (10 cm aperture) from the former Norikura Corona Observatory to Peru. The University of Ica, Peru, has instruments for solar observations that were jointly developed by SOL and Kyoto University, and we will resume our cooperation to use them for education and research after the COVID-19 pandemic has ended.

# 05. ALMA Project, NAOJ Chile, and ASTE Project

The ALMA project is a global partnership of East Asia (led by Japan), Europe, and North America (led by the United States) in cooperation with the Republic of Chile to operate a gigantic millimeter/submillimeter radio telescope deploying 66 high-precision parabolic antennas in the 5000-m altitude Atacama highlands in northern Chile. ALMA achieves a spatial resolution nearly ten times higher than that of the Subaru Telescope and the Hubble Space Telescope. Early scientific observations with ALMA began in FY 2011 with a partial number of antennas and full operation commenced in FY 2012. This fiscal year marks the 10th anniversary of ALMA observations. This report describes the progress of the ALMA project, which includes the results of the open-use scientific observations and public outreach activities.

The ASTE telescope is a single-dish 10-m submillimeter (a radio wave with a wavelength of 1 mm or less) telescope located at Pampa la Bola in the Atacama highlands where ALMA is also located. It has been operated in the Southern Hemisphere to make headway into submillimeter astronomy that explores the spectrum invisible to the human eye, providing various possibilities and future prospects for research and development of ALMA. This report describes the progress of the ASTE telescope as well.

The mission of the NAOJ ALMA Project is to: implement the functions of the East Asian ALMA Regional Center, which provides support for users in East Asia; coordinate international project activities based on global partnership; formulate future project plans; and make budget requests. On the other hand, the mission of NAOJ Chile is to: take appropriate safety and security measures for Chile-based staff members and their families, and establish an environment where they can engage in their activities safely and securely; provide the interface in Chile with the Joint ALMA Observatory (JAO), the other ALMA Executives, and Chilean institutions; and establish, organize, and maintain an exchange scheme for scientists and engineers between NAOJ and Chilean universities and institutes.

Under NAOJ Chile, the ASTE project has been promoting and pioneering submillimeter astronomy while providing a platform for new technology development and submillimeter observation data to the scientific community through the operation of the ASTE telescope. In addition, NAOJ established a Study Group for the Next Generation Very Large Array (ngVLA) in FY 2019, under the umbrella of the ALMA Project. The ngVLA Study Group has been assessing, together with the scientific community, scientific opportunities for a possible future contribution from Japan to ngVLA; and has initiated development studies which will allow NAOJ to contribute timely to construction if supported by the Japanese scientific community and budget processes.

## 1. Progress of the ALMA Project

Due to the outbreak of the novel coronavirus (COVID-19) in Chile, ALMA temporarily closed the Array Operations Site (AOS) and Operations Support Facility (OSF) on March 22, 2020. After one year of careful monitoring, planning, and return to operation efforts, scientific observations resumed as best-effort on March 17, 2021. The support on site by the Engineering team was critical in the recovery of Atacama Compact Array (ACA) antennas. About 75 % of the originally offered 12 m array time was completed by the end of Cycle 7 (end of September 2021). Cycle 8 observations started on October 1, 2021. The ALMA Management Team made important progress in the definition of the framework to upgrade the bandwidth of ALMA receivers by at least a factor of 2 (goal: a factor of 4) and upgrade the associated electronics, such as the correlators and data transmission system. In terms of development of new instrumentation, the Band 1 receivers, covering the frequency range between 35 and 50 GHz, were installed for the first time in the ALMA antennas and successfully achieved their first light in August 2021. After a successful internal ALMA review in December 2021, it was decided that 3D printed horns fabricated at NAOJ would be integrated into the final Band 1 receivers. On February 22, 2022, the newly developed spectrometer for the Total Power Array successfully acquired its first radio spectra towards Orion KL. As the ALMA system hardware and software ages, efforts have been devoted in the preparation of a comprehensive obsolescence and aging management plan towards sustainable operations. The publication rate slowed down in 2020 possibly due to the pandemic, but it has recovered in 2021 and recorded the highest number of ALMA publications in a single year.

## 2. ALMA Open-Use and Scientific Observations

The 9th round of ALMA open-use observations commenced in October 2021 as Cycle 8. A total of 1,735 proposals were submitted for Cycle 8. The total required observation hours for all proposals was the most every requested in a single cycle. The main capabilities of Cycle 8 include: interferometric observations using at least forty-three 12-m antennas; ACA observations (interferometric observation with at least ten 7-m antennas and single-dish observation with at least three 12-m antennas); eight frequency bands (Bands 3, 4, 5, 6, 7, 8, 9 and 10); and maximum baselines of 8.5 km. From Cycle 8, Band 5 is available for solar observations, and Bands 9 and 10 are available for stand-alone 7-m Array observations. In addition to these, Cycle 8 provides spectral scan observations with the 7-m Array, mosaicking of continuum linear polarization observations in Bands 3 to 7 with the 12-m Array, and new VLBI observation modes.

ALMA open-use observations have been producing a number of scientific results. The following paragraphs highlight some of the scientific achievements made by East Asian researchers.

Dr. Xing Lu (NAOJ) used ALMA Band 6 to observe the

Central Molecular Zone (CMZ) of our Milky Way. The 2000 au resolution observations identified 834 dense cores and 43 protostellar outflows associated with the cores. However, they found no significant evidence of outflow for the remaining 800 or so cores. The outflow is unambiguous evidence of ongoing star formation. Therefore, the ubiquitous presence of the dense cores without outflow may suggest that these clouds in the CMZ are at a very early phase of star formation, and there can be a future burst of star formation, despite the harsh conditions with strong tidal force, magnetic field, high energy particles, and frequent supernova explosions.

SOKENDAI graduate student Takafumi Tsukui (SOKENDAI/NAOJ) and NAOJ Professor Dr. Satoru Iguchi investigated the archival ALMA Band 7 data of a z = 4.4 galaxy called BRI 1335-0417, finding convincing evidence of spiral structure in a galaxy which is located only 1.4 billion years after the Big Bang. The [CII] distribution and kinematics show evidence of a rising rotation curve toward the galactic center, suggesting a central mass distribution which could be explained by the presence of a galactic bulge. The Toomre Q parameter provides evidence of an extended dynamically cold outer disk, suggesting large-scale cosmological inflow or minor mergers as possible mechanisms to explain the spiral structure.

A team led by Dr. Takuma Izumi (NAOJ/SOKENDAI) observed the redshifted [CII] line in a z = 7.07 quasar J1243+0100 using ALMA. This is the only low-luminosity quasar at z > 7 known to date, and it offers an exciting possibility to study the detailed gas dynamics when the Universe was less than a billion years old. They find that the gas dynamics in the central region are dominated by rotation, with a possibility to form a compact bulge with a mass of ~$3\times10^{10}$ Msun. In addition, the presence of broad wings of ~1000 km/s suggests a strong galactic-scale quasar-driven outflow that will likely quench the star formation activity in the host galaxy within a relatively short time.

Drs. Hiroshi Nagai (NAOJ/SOKENDAI) and Nozomu Kawakatsu (Kure College) used data from ALMA and VLBI to investigate the physical conditions of the central region of NGC 1275, a galaxy 70 Mpc away that harbors an active galactic nucleus. Their analysis found solid evidence of the coexistence of supernovae explosions (traced by synchrotron radiation) and the circumnuclear molecular disk (traced by CO), which suggests that star formation can occur in the circumnuclear disk. They further indicate that the supernova explosions can efficiently remove the angular momentum of the rotating gas, accelerating the mass accretion process to the central AGN.

A team led by Dr. Patricio Sanhueza (NAOJ) used 700 au resolution ALMA data of IRAS 18089-1732, a high-mass star-forming region in the Milky Way Galaxy, finding a well-organized magnetic field that resembles a spiral "whirlpool". Their analysis of the energy balance suggests that gravity in this system overwhelms all other physical mechanisms such as turbulence, rotation, and magnetic field. The minor contribution of the magnetic field caught them by surprise since previous studies found evidence of a strong magnetic field in a similar star-forming environment. This work suggests that high-mass star formation can occur in weakly magnetized environments, with gravity taking the dominant role.

A team led by Dr. Takanori Ichikawa (a former graduate student at Kagoshima University) and Dr. Shigehisa Takakuwa (Kagoshima University), used ALMA archival data to analyze a Class II binary system XZ Tau at Bands 3, 4, and 6. They found that the CO emission associated with the circum-stellar disk is consistent with Keplerian rotation, and that the rotational axes are misaligned with each other. From the multi-epoch ALMA data, they have identified the relative orbital motion of the binary, leading to the conclusion that the two disks and the orbital plane of the XZ Tau system are all misaligned with each other.

An international team led by Gianni Cataldi (University of Tokyo/NAOJ) and Dr. Yuri Aikawa (University of Tokyo) analyzed DCN/HCN and $N_2D^+/N_2H^+$ column density ratios toward five protoplanetary disks observed by the "Molecules with ALMA at Planet-forming scales (MAPS)" Large Program. They found that the DCN/HCN varies considerably for different parts of the disks, ranging from $10^{-3}$ to $10^{-1}$. The inner-disk regions generally show significantly lower HCN deuteration compared with the outer disk. In addition, they found N2D+ in the cold outer regions beyond ~50 au from the central star, and $N_2D^+/N_2H^+$ ranges between $10^{-2}$ and 1 across the disk sample. This finding is consistent with the theoretical models which predicts that $N_2H^+$ deuteration proceeds via the low-temperature channel only.

A team lead by Dr. Takashi Shimonishi (Niigata University) used ALMA to observe a star forming region in the outer galaxy called WB89-789, detecting a variety of species that contain carbon, oxygen, nitrogen, sulfur, and silicon. Their detection includes complex organic molecules and deuterated species. For the first time, they detected a hot molecular core in the outer galaxy, which is known as an excellent laboratory to study star formation in a low-metallicity environment. The ALMA observations reveal that various kinds of complex organic molecules, such as methanol ($CH_3OH$), ethanol ($C_2H_5OH$), methyl formate ($HCOOCH_3$), dimethyl ether ($CH_3OCH_3$), formamide ($NH_2CHO$), propanenitrile ($C_2H_5CN$), etc., are present even in the primordial environment of the extreme outer Galaxy. From their detailed comparison between the inner and outer disk, they conclude that organic molecules form with similar efficiency even at the edge of our Galaxy, where the environment is very different from the solar neighborhood.

## 3. Educational Activities and Internships

The NAOJ ALMA Project continues to collaborate with the Joint ALMA Observatory to create and maintain a Japanese version of "ALMA Kids," a website for children, with the aim of providing opportunities for more people to learn about the mechanism of the ALMA telescope and its scientific results in a fun way. ALMA Kids provides up-to-date content for the younger audiences, introducing various results from the latest ALMA observations. In addition, the Project has developed educational content, mainly targeting elementary school

students, called “Why ALMA Workshop” which explains the basics of radio astronomy by combining videos and worksheets. This content is available on the Project website.

The Project continues to release science news posters aimed for the younger generation visiting science centers and planetariums. Three new posters were released in FY 2021. In addition, the Project now provides short anime (“manga”) explaining the basics of radio astronomy and interferometry. All posters and manga are available on the NAOJ ALMA website.

The NAOJ ALMA Project initiated the radio astronomy/interferometry summer school for university students with SOKENDAI, which was organized and held on September 16, 17, 21, 22, 24 in 2021 in collaboration with Nobeyama Radio Observatory, Mizusawa VLBI Observatory, and the ALMA and VLBI Science Advisory Committees. Of the total 185 participants, 65 were undergraduates, 93 were graduate students, 12 were faculty, and 2 were high school students.

## 4. Public Outreach Activities

In FY 2021, ALMA scientific observation results were covered by 75 newspaper/journal articles, and the ALMA telescope was featured by two television/radio programs. The NAOJ ALMA website posted 38 news articles and 11 press releases. Mailing-list-based newsletters have been issued on a monthly basis with approximately 2,200 subscribers. Day-to-day information is posted in a timely manner on Twitter (@ALMA_Japan) with nearly 64,300 followers as of the end of FY 2021.

In FY 2021, 14 lectures were given for the general public and most of them were held online to prevent the spread of COVID-19 infections. In May-June 2021, the NAOJ ALMA Project exhibited a booth for the ALMA telescope at the Japan Geoscience Union Meeting (held online). Six new short educational movies (“Why ALMA?”) were released on YouTube. In June and July, the NAOJ ALMA Project hosted special Twitter and online events related to Tanabata. The main lectures at the NAOJ open house held online in October were given by NAOJ ALMA Project Manager Alvaro Gonzalez and the head of the ALMA Department of Engineering Norikazu Mizuno. In December 2021 – January 2022, a special ALMA exhibition was held at the Mitaka Information Space of Astronomy and Science. A webpage dedicated to promoting the 10 year anniversary of ALMA was launched in March 2022. This website highlights a subset of the key scientific results achieved over the past 10 years as well as the development activities of new instruments and components for the future of ALMA. The website also features interviews with artists. Three new science promotion movies “Progress in Planet Formation Research”, “Seeds of Life: Exploration of Organic Molecules”, and “Tracing Back the History of the Universe” were released to celebrate the 10-year anniversary. The NAOJ ALMA Project continues to release quarterly online newsletters for scientists.

From mid-March 2015, ALMA began accepting public visitors to the ALMA Operations Support Facility (OSF) at an altitude of 2,900 meters, but due to the outbreak of COVID-19 in Chile, it stopped accepting public visits in March 2020. As of the end of FY 2021, public visits remain suspended.

## 5. International Collaboration (Committees, etc.)

For the international ALMA project, meetings are held frequently by various committees. In FY 2021, all face-to-face meetings were replaced by online meetings, affected by the COVID-19 pandemic. The ALMA Board and the ALMA Scientific Advisory Committee (ASAC) held online meetings when necessary, while the ALMA East Asian Science Advisory Committee (EASAC) held online meetings twice. Meetings were held more frequently by groups in charge of specific tasks to implement the international project in close cooperation.

## 6. Workshops

- June 15–16, 2021: ALMA Data reduction tutorial (introductory level), held with the Astronomy Data Center, held online
- Jul. 15–16, 2021: ngVLA Development Days 2021 held online
- Nov. 1 and 2: Cold outflows near and far: crossroad of our current understandings held online
- Nov. 2 and 5, 2021: ALMA Data reduction tutorial (intermediate level), held with the Astronomy Data Center, held online
- Nov. 30–Dec 1, 2021: Linking the Science of Large Interferometers in the 2030s held online
- Dec. 6 and 13, 2021: ALMA Grant Fellow Symposium held online
- Dec. 14, 16, and 21, 2021: ALMA/45m/ASTE Users Meeting 2021 held online
- Dec. 20 and 22, 2021: Millimeter/submillimeter VLBI sciences with ALMA
- Jan. 18–21, 2022: East Asian ALMA Science Workshop 2022 held online
- Mar. 9–10, 2022: East Asian ALMA Development Workshop 2022 held online
- Mar. 29–30, 2022: ALMA Cycle 9 Proposal Preparation Meeting held online

## 7. Obtained External Grants Other Than Grants-in-Aid for Scientific Research, including Industry–University Collaboration Expenses

- Yusuke Miyamoto: funded by the National Institutes of Natural Sciences (NINS) research support project (Interdisciplinary Research by Young Researchers Project)

## 8. Changes in Project Researchers

(1) Hired
- Yu Cheng: Project Researcher
- Tomonari Michiyama: Project Researcher (secondment to Osaka University)
- Toshiki Saito: Project Researcher (secondment to Nihon University)
- Hiddo Algera: Project Researcher (secondment to Hiroshima

University)
• Mitsuyoshi Yamagishi: Project Researcher (secondment to University of Tokyo)

(2) Departed or transferred
• Toshiki Saito: Project Researcher
• Mitsuyoshi Yamagishi: Project Researcher
• Sarolta Zahorecz: Project Researcher
• Kazuki Tokuda: Project Researcher
• Yuri Nishimura: Project Researcher
• Kohei Kurahara: Project Researcher
• Tomoko Suzuki: Project Researcher
• Seokho Lee: Project Researcher
• Shigeki Inoue: Project Researcher
• Yang Yi: Project Researcher

## 9. Main Visitors

• Apr. 12, 2021
Hinako Takahashi, Vice Minister of Education, Culture, Sports, Science and Technology (MEXT) visited NAOJ Mitaka Campus

## 10. Progress of the ASTE Telescope

In FY 2021, the ASTE telescope operation started in late May, which was about a month behind schedule due to the continuing outbreak of COVID-19 that began to spread worldwide from February 2020. However, the telescope operation was suspended by heavy snowfall shortly after the start, and furthermore, hardware failures occurred at the driving mechanism of the sub-reflector during the snowfall. A close investigation into the sub-reflector was prevented by bad weather conditions of weekly snowfall and strong wind, and a manlift malfunction caused by low temperature, and we could not expect to allocate appropriate time slots to the open-use program observations planned in FY 2021. Thus, we cancelled all the open-use program observations. The investigation was finally done in October, and based on it, a possibly malfunctioning motor for the driving mechanism was replaced in March 2022. However, the sub-reflector is still out of commission due to different hardware alarms. Its recovery work will continue in FY 2022.

As for new observation instruments, two development projects were carried out with Grants-in-Aid for Scientific Research: (1) the development of a wide intermediate-frequency bandwidth for the Band 8 (385–500 GHz band) receiver, and (2) the development of a new spectrometer together with a frequency converter that converts the receiver signal for the spectrometer. The Band 8 receiver, the new spectrometer, and the frequency converter were assembled and evaluated in Mitaka. Then, they were shipped to the ASTE site and successfully installed in the telescope on schedule between November and December. The Commissioning and Science Verification was not available due to the sub-reflector problem mentioned above, but test observations using them ran without errors, and it was confirmed that the newly deployed instruments and their control software basically work as designed. The Band 10 receiver (787–950 GHz band) developed with Grants-in-Aid for Scientific Research also continued to be evaluated. We continued performance evaluation and data reduction of the receiver using data taken in FY 2019. The resultant images of demo science data obtained toward Orion KL with [CI]($^3P_2$-$^3P_1$) and CO($J$ = 7–6) were released to the public.

In FY 2021, four peer-reviewed papers were published, including two papers written by domestic researchers (outside NAOJ) and one by overseas researchers. The decrease in the number of papers published was unavoidable due to the suspension of scientific observations due to the COVID-19 pandemic between FY 2020 and FY 2021.

# 06. Center for Computational Astrophysics (CfCA)

## 1. Overview

The Center for Computational Astrophysics (CfCA) has been operating a system of open-use computers for simulations centered around a general-purpose supercomputer, the special-purpose computer for gravitational many-body problems/general-purpose graphic processing units (GPGPU), and a general-purpose PC cluster for small-scale calculations, carrying out research and development for computational astrophysics, and performing astronomical research with simulations. The new main supercomputer of the present system renewed in 2018, ATERUI II (Cray XC50), has a theoretical peak performance of 3 Pflops, which is the world's fastest supercomputer for astronomy. This fiscal year, CfCA discontinued operation of GRAPE-DR and GRAPE-9 dedicated to gravitational many-body problems, and augmented the GPGPU and general-purpose PC cluster. Efforts in visualizing astronomical data also continue.

## 2. Open Use of Computers

(1) General status

This year marked the fourth year of the upgraded astronomical simulation system, which includes the new open-use supercomputer Cray XC50. This computer is installed and under operation at Mizusawa VLBI Observatory. The users have been making academically significant progress as before.

While XC50 is leased for six years from Hewlett-Packard Enterprise (which acquired Cray), the center has built the following equipment to aid the open-use computer operations: a series of dedicated computers for gravitational N-body problems (known as GRAPE's) together with several GPU nodes; PC clusters for small to medium-scale computation; large-scale file servers; a group of servers for processing computational output data; and an instrument network to encompass the overall computer system. These components are central to numerical simulations by researchers in Japan and overseas.

Computational resources of the XC50, GRAPE's including GPU, and smaller PC clusters are allocated in accordance with a formal review process. The statistics of applications and approvals for this year are listed in the next subsection. Our center conducted a survey on the number of peer-reviewed papers published in English in this fiscal year on studies that involved the project's open-use computers. It turned out that 150 refereed papers (written in English) were published in this fiscal year.

The center uses Drupal, a content management system introduced for data exchange with users of open-use computers. The acceptance of various applications and the management of the users' personal information are all handled through Drupal. The regular CfCA News is an additional channel of information dissemination. The center leverages this newsletter to inform people of all useful and necessary information regarding the computer system. A subsidy system for publishing and advertising is continuing this year for research papers whose major results were obtained by using the center's computers.

(2) Operation stats for each of the facilities

**Cray XC50**

- Operating hours
  Annual operating hours: 8639.8
  Annual core operation ratio by users' PBS jobs: 93.43 %
- Number of users
  Category S: 0 adopted in the first term, 0 in the second term; total 0
  Category A: 13 adopted at the beginning of the year, 0 in the second term; total 13
  Category B+: 20 adopted at the beginning of the year, 2 in the second term; total 22
  Category B: 127 adopted at the beginning of the year, 9 in the second term; total 136
  Category MD: 34 adopted at the beginning of the year, 6 in the second term; total 40
  Category Trial: 41 (year total)

**GRAPE/GPU system**

- Number of users
  18 (at the end of the fiscal year)

**General-Purpose PC farm**

- Operating hours
  Annual operating hours: 8688 (a ballpark figure)
  Total number of submitted PBS jobs: 547,026
  Annual core operation ratio by users' PBS jobs: 98% (a ballpark figure)
- Number of users
  62 (at the end of the fiscal year)

(3) Tutorials and Users Meeting

The center organized various lectures and workshops to provide the users of the open-use computer system with educational and promotional opportunities, as well as to train young researchers. The details are shown below. In addition, the CfCA Users Meeting was held to serve as a forum for direct information exchange. Many participated in the meeting, and discussions were fruitful.

- Tutorial sessions for iSALE (WebEx + Slack)
  Lecture and hands-on training on the basics of the iSALE shock physics code
  June 11 - July 9, 2021
  7 attendees
- Cray XC50 workshop for novice users (zoom)
  Introduction to the basic usage of XC50 for novice users
  September 29, 2020
  13 attendees

● Cray XC50 workshop for intermediate users (zoom)
Introduction to debugging, performance analysis, and optimization of XC50 for intermediate users
September 30, 2020
15 attendees
● CfCA Users' Meeting (zoom + Slack)
Presentation of research results using the open-use facilities in this department, and discussion of the operation of the equipment
January 19–20, 2021
95 attendees (January 19), 70 attendees (January 20)
● Early spring school for N-body numerical simulations (zoom + Slack)
Lectures on N-body simulations, and programming practice using GPU and GRAPE-Library
February 14–17, 2022
16 attendees (for hands-on training and lectures), 2 attendees (for lectures only)
● GPU Workshop (zoom + Slack)
Lectures on CUDA programming basics and optimization technics for CUDA programming
February 28, 2022
45 attendees
● Numerical simulation school for hydrodynamics (zoom + Slack)
Lecture and practice for MHD numerical simulations using the public code Athena++
March 10–12 and 22–23, 2021
65 attendees

## 3. PR Activity

In FY 2021, the following press releases were issued from the center:

● "Telescopes Unite in Unprecedented Observations of Famous Black Hole"
April 14, 2021, Event Horizon Telescope Science Multi-Wavelength Science Working Group et al.
● "A New Window to See Hidden Side of the Magnetized Universe"
May 6, 2021, Takumi Ohmura (The University of Tokyo), Mami Machida (NAOJ/CfCA) et al.
● "Observation, Simulation, and AI Join Forces to Reveal a Clear Universe"
July 2, 2021, Masato Shirasaki (NAOJ/the Institute of Statistical Mathematics)
● "Largest Virtual Universe Free for Anyone to Explore"
September 10, 2021, Tomoaki Ishiyama (Chiba University)
● "Simulations Provide Clue to Missing Planets Mystery"
November 13, 2021, Kazuhiro Kanagawa (Ibaraki University) et al.
● "Stellar 'Ashfall' Could Help Distant Planets Grow"
December 14, 2021, Yusuke Tsukamoto (Kagoshima University)

In addition, the following research results and news appeared on the CfCA website:

● "A New Type of Supernova Illuminates an Old Mystery"
June 29, 2021, Takashi Moriya, Nozomu Tominaga (NAOJ/CfCA)
● "Assistant Professor Akimasa Kataoka wins the JSPS Outstanding Young Scientist Award 2020"
October 29, 2021, Akimasa Kataoka (NAOJ/CfCA)

In December 2021, "Galileo X" (produced by WAC Corporation) broadcast on BS Fuji featured a Japanese press release entitled "World's Largest 'Simulated Universe' Unveiled," which reported on the role of ATERUI II in Japanese astronomy and the current state of astronomical research using simulations.

During the Mitaka Open House Day 2021 held online on October 23, 2021, a video and an interview with CfCA staff members were made available on the CfCA website. The movie features CfCA staff introducing the group of computers operated by the Mitaka CfCA Computer Room, and explains the role of each computer and the activities of CfCA. In addition to the Japanese version shown at the event, an English subtitled version was also created to communicate CfCA's activities to a wider audience. Interview articles were created and published as content to introduce the activities of CfCA and familiarize people with the staff members by introducing their daily work and personal backgrounds, focusing on individual staff members who cannot be introduced at the annual Mitaka Open House Day.

A Twitter account @CfCA_NAOJ and YouTube channel have been operated to provide the information on CfCA.

## 4. 4D2U Project

In FY 2021, the 4D2U project continued to develop and provide movie content and software.

The visualization of simulations was mainly the production of images and videos published in the CfCA press releases. In May 2021, "A New Window to See Hidden Side of the Magnetized Universe" (Simulation: Takumi Ohmura/The University of Tokyo, Visualization: Hirotaka Nakayama/4D2U), and in September 2021, "Largest Virtual Universe Free for Anyone to Explore" (Simulation: Tomoaki Ishiyama/Chiba University, Visualization: Hirotaka Nakayama/4D2U) were released in image and movie format as visual materials of press releases.

Version 1.7.0 of the four-dimensional digital universe viewer "Mitaka" was released in June 2021, and upgraded to version 1.7.2 by January 2022. These versions can now display asterisms such as the Summer Triangle, display in the equirectangular cylinder method, and display interstellar objects. Online workshops on how to use the latest version of Mitaka were held by the Mitaka Working Group of the Japan Society for the Promotion of Astronomy Education in May 2021.

4D2U content was provided both domestically and internationally for TV programs, planetarium programs, lecture presentations, books, and so on. In February and March 2022, NHK educational TV broadcasted "Space Taxi" (produced by Planet film), a comedy program about space travel using Mitaka

and 4D2U video contents.

For the 2021 Mitaka Open House Day, 4D2U staff and researchers produced a video explaining the contents and made it available on the CfCA website. In the introduction of the video content "Chariklo's Double Rings," Shugo Michikoshi (Kyoto Women's University), who performed the simulation, introduces his research and explains the video, and Hirotaka Nakayama (NAOJ/4D2U), who performed the visualization, gives a behind-the-scenes introduction of the video production. In the Mitaka introductory video, "A 'special' space tour by the developer," developer Tsunehiko Kato (NAOJ/4D2U) gives a demonstration of Mitaka and introduces some of its highlights.

A Twitter account @4d2u and YouTube channel have been operated to provide information on 4D2U.

## 5. External Activities

(1) Joint Institute for Computational Fundamental Science

The Joint Institute for Computational Fundamental Science (JICFuS) is an inter-organizational institute established in February 2009 as a collaboration base between three organizations including the Center for Computational Sciences (CCS) of the University of Tsukuba; the High Energy Accelerator Research Organization, known as KEK; and NAOJ to provide active support for computational scientific research. This organization continues to expand: 8 institutions joined in 2016, and 13 institutions in 2020. CfCA forms the core of NAOJ's contribution to JICFuS. In particular, the institute engages primarily in computer-aided theoretical research into the fundamental physics in elementary particle physics, nuclear physics, astrophysics, and planetary science. The scientific goal of the institute is to promote fundamental research based on computational science to encourage interdisciplinary research between these fields. In addition to its ability as a single organization, a major feature of the institute is the cooperation of each community to provide considerate and rigorous support to present and future researchers. Another important mission of the institute is to provide researchers around Japan with advice regarding efficient supercomputer use and the development of novel algorithms for high-performance computing to meet research goals from the perspective of computer specialists. In addition, JICFuS was chosen as the organization responsible for "Priority Issue 9 to be Tackled by Using the Post-K Computer" in FY 2014. From FY 2020, JICFuS performs two new programs: Programs for Promoting Research on the Supercomputer Fugaku. One is "Simulation for basic science: from fundamental laws of particles to creation of nuclei" and the other is "Toward a unified view of the Universe: from large scale structures to planets." CfCA mainly joins the second one.

This year, Eiichiro Kokubo conducted research on "Accumulation of Microplanets and Planet Formation in Protoplanetary Disks" using N-body and SPH codes. Kazunari Iwasaki conducted research on "Formation of molecular clouds and molecular cloud cores in the Milky Way and global magnetohydrodynamic simulation considering solid particles in protoplanetary disks" using a mesh-type fluid code. Mami Machida and Tomoya Takiwaki conducted research on "black hole accretion disks and relativistic jets," and "Elucidation of the mechanism of 3D supernova explosions by first-principles calculations of neutrino radiation transport" using a mesh-type fluid code, respectivelty. These four projects are still in the process of tuning the code in preparation for the large scale run at Fugaku. In addition, the budget was mainly used to increase the storage capacity in order to store the huge amount of data that will be generated in future large-scale calculations.

Representing CfCA, Professor Eiichiro Kokubo and Associate Professor Tomoya Takiwaki of NAOJ participate in bimonthly JICFuS steering committee meetings to engage in deliberations on spurring computational-science-based developments in astrophysics research through discussions with other committee members who specialize in nuclear and elementary particle physics.

(2) HPCI Consortium

As a participant in the government-led High-Performance Computing Infrastructure (HPCI) project since its planning stage in FY 2010, the center has engaged in the promotion of the HPC research field in Japan, centering on the use of the national "K" and "Fugaku" supercomputers. Note that although the center is involved with the activity at JICFuS mentioned in Section 5.1, the activity in the HPCI consortium is basically independent from it. The HPCI consortium is an incorporated association established in April 2012, and the center is currently an associate member that is able to express views, obtain information, and observe overall trends in the planning, although we are devoid of voting rights as well as the obligation to pay membership fees. Continuing from last year, a number of conferences and WG's have been held where participants discussed a next-generation national supercomputing framework. The national HPC flagship supercomputer, "Fugaku," has already been put into full-scale service, and there is much scientific discussion on how the user community should make the best use of this equipment.

## 6. Staff Transfers

(1) Staff members hired in this FY
Associate Professor: Takiwaki, Tomoya
Project Research Staff: Matsumoto, Yuji
Research Supporter: Ideguchi, Shinsuke

(2) Staff members who departed in this FY
Project Research Staff: Ishikawa, Shogo
Research Supporter: Ban, Makiko

# 07. Gravitational Wave Science Project

In FY 2021, the updated event catalog GWTC-2.1 for the first half of the 3rd international gravitational wave observations (O3) (April 1 – October 1, 2019) and the second half (November 1, 2019 – March 27, 2022) event catalog GWTC-3 were released. In total, 90 gravitational wave events have been reported to date. In addition, the results of joint observations made by KAGRA and GEO600 in Germany in April 2020 were released. Thus, gravitational wave astronomy is making steady progress.

The NAOJ Gravitational Wave Science Project (GWSP) is leading gravitational wave research in Japan by promoting gravitational wave observations using KAGRA, and the development of advanced gravitational wave detector technology using TAMA300 at Mitaka Campus.

## 1. Gravitational Wave Telescope, KAGRA

NAOJ GWSP plays an important role in the operation and management of KAGRA as one of the promoting organizations under the "Memorandum of Understanding on Promotion of Gravitational Wave Astronomy Using the Large-scale Cryogenic Gravitational Wave Telescope, KAGRA" with the Institute for Cosmic Ray Research of the University of Tokyo and the High Energy Accelerator Research Organization. In particular, the GWSP is in charge of the Low Frequency Vibration Isolators, Auxiliary Optics, Mirror Evaluation, and Main Interferometer, and also contributes to the operation by providing many members for the Executive Office, System Engineering Office, etc.

In FY 2021, KAGRA equipment was refurbished in preparation for the 4th international gravitational wave observations (O4, scheduled to begin mid-December 2022). Specifically, the following has been carried out.

(1) **Vibration Isolation Systems**

A total of 19 vibration isolators of 4 types (Type-A, Type-B, Type-Bp, and Type-C) were retrofitted; problems found in O3 were corrected and new high-sensitivity accelerometers were introduced. Operational testing of all the vibration isolators is ongoing.

(2) **Auxiliary Optics**

In conjunction with the laser-axis adjustment, installation of mid-size optical baffles has begun in the vacuum chambers of the central laboratory to prevent stray light. These are being implemented in cooperation with the Advanced Technology Center (ATC).

(3) **Main Interferometer**

The Output Mode Cleaner was taken out of KAGRA and improved in a clean booth at Mitaka ATC, and will be reinstalled in 2022. The GWSP also played a central role in the reconstruction of the main interferometer.

(4) **Mirror Evaluation**

To replace the two KAGRA input-test-mass mirrors (ITMs) with higher performance ones before the start of O5, ITM specifications were formulated, test polishing was done, and sapphire mirror base materials were evaluated in order. In particular, we found a correlation between the optical absorption and birefringence distributions, which paved the way for the selection of a high-performance mirror substrate. In addition, the Y-end mirror that was contaminated was cleaned and reinstalled. These activities were conducted at the TAMA300 and ATC laboratories in Mitaka Campus.

(5) **Others**

An environmental monitoring system was developed by installing various sensors in KAGRA. These sensors detected various signals from a large volcanic eruption in Tonga, and the results were published in the press. The noise reduction for PCAL, a photon-pressure calibrator for gravitaional wave signals, was successfully achieved, and preparations were made for signal calibration during O4. The GWSP also contributed to the reinstallation of KAGRA's cryogenic mirror suspension system.

The above renovation work is scheduled to continue through FY 2022.

## 2. R&D in TAMA300 and ATC

The TAMA300, a first-generation interferometric gravitational wave antenna constructed in the 1990s, is being effectively utilized to develop next-generation gravitational wave telescope technology. In addition, table-top technology development and assembly of KAGRA instruments are also being conducted at the ATC laboratory.

(1) **Development of frequency-dependent squeezing technology in TAMA300**

In TAMA300, developing a quantum optics technology called FDS (Frequency-Dependent Squeezing) to improve the sensitivity of gravitational wave telescopes over a wide bandwidth is ongoing. In FY 2021, improvements were made in alignment control, and two research papers were published. In addition, we started detailed design of FDS for KAGRA in order to introduce this FDS technology in KAGRA to achieve higher sensitivity; FDS for KAGRA is being conducted through collaboration between NAOJ, National Tsing Hua University in Taiwan, and the Korea Astronomy and Space Science Institute (KASI).

## 3. Education

A master student in the Astronomy Department of the University of Tokyo was admitted. A student in the Tokyo

Institute of Technology received a master's degree for research on mirrors for KAGRA at the TAMA300 facility. As for graduate school and university education, lectures were given at the University of Tokyo Graduate School and Hosei University. In addition, we actively engaged in social education activities such as "FUREAI (Friendly) Astronomy" and visiting lectures at high schools.

## 4. Outreach

A publicity video produced jointly by the Public Relations Center and the Gravitational Wave Science Project won the Science Museum Director's Award at the Science and Technology Film/Video Festival. In addition, a virtual tour of TAMA300 was conducted at an open house held online. In addition, the GWSP cooperated with NAOJ in introducing KAGRA's vacuum technology at the Vacuum Exhibition.

## 5. International Collaboration and Visitors

Under the restrictions of the COVID-19 situation, we had fewer visitors than normal, actually no visitors. On the other hand, international cooperation has been actively carried out, and joint research with CNRS / APC (France), iLM (France), National Tsing Hua University (Taiwan), Myongji University (Republic of Korea), KASI (Republic of Korea), etc. has progressed.

## 6. Publications, Presentations, and Workshop Organization

The GWSP members were authors of 37 refereed publications in international journals. There were 11 non-refereed publications in European languages and 2 in Japanese. There were 12 presentations at international conferences and 49 presentations in domestic conferences. There were no other reports printed in either European languages or Japanese.

## 7. Acquisition of External Funds

In FY 2021, no external funds other than scientific research funds were obtained.

## 8. Staff

Transfer / Retirement

- Hideharu Ishizaki: Research engineer (Retired)
- Atsumi Sawagaki: Administrative Supporter (Retired)
- Naoatsu Hirata: Senior Specialist (transferred to engineer in ATC)
- Dan Chen: Project Research Staff (transferred to assistant professor in GWSP)
- Tasuki Washimi: JSPS PD (transferred to project assistant professor in GWSP)

# 08. Thirty Meter Telescope Project

The Thirty Meter Telescope (TMT) Project is a project to build an extremely large 30-meter telescope under the collaboration of research institutes in five countries: Japan, the United States, Canada, China, and India (Figure 1). For Japan's part, the National Institutes of Natural Sciences (NINS) is the ultimately responsible body, and NAOJ is the executing institute. In 2014, an agreement was executed among the participating organizations to found the TMT International Observatory (TIO) for the purpose of the construction and operation of the observatory; the construction was subsequently commenced. Japan is responsible for the production of the telescope primary mirror, the design and production of the telescope structure as well as its on-site installation and adjustment, and the design and production of science instruments. Heading the project for Japan is the TMT Project established at NAOJ.

In Hawai'i where TMT is slated to be built, with the State of Hawai'i's approval of a Conservation District Use Permit (CDUP) for TMT construction on Maunakea in 2017, on-site construction was planned to start in FY 2019. However, demonstrations and a road blockade by those opposed to construction of TMT on Maunakea prevented full-fledged construction work at the summit region. Currently, as a TIO member, NAOJ provides assistance for TIO's continued efforts for building trust in Hawai'i through direct dialogue, educational support, and other community engagement activities together with relevant organizations. In the Hawai'i State Legislature, a bill was submitted and deliberated to review Maunakea management in consideration of recommendations by a working group which involved Native Hawaiian members. In the U.S., the Decadal Survey, which is a report of the research community that identifies priorities for the coming decade, ranked a joint program called the U.S. Extremely Large Telescope Program (the US-ELT Program), including the TMT project, as a top priority for ground-based astronomy. Discussion with the U.S. National Science Foundation (NSF) began for its possible participation in the project. Seeing major progress in the situation in Hawai'i and NSF's possible participation in the project, TIO, NAOJ, and the other members are focused on essential activities in the overall process, including those that will lead the way to full-fledged construction once on-site efforts restart, while minimizing their expenditures.

## 1. TMT Project Progress and Status of the Construction Site

The construction of TMT is led by the participating countries and organizations under TIO established in 2014. The current officially participating countries and organizations are NINS (Japan), the University of California, the California Institute of Technology, the National Research Council of Canada, the Department of Science and Technology of India, the National Astronomical Observatories of the Chinese Academy of Sciences, as well as the U.S. Association of Universities for Research in Astronomy (AURA) participating as an Associate Member which envisages future participation of the NSF.

TIO, operated according to deliberations and decisions made at meetings of the TMT Board of Governors, is overseeing the construction work performed in each country as well as developing the on-site infrastructure. For the purpose of discussing activities for the official participation of NSF, the on-site construction issues, and other matters, the Board of Governors was convened 11 times in FY 2021, including regular meetings on a quarterly basis. The board meetings were attended by three representatives from Japan, Director General Tsuneta, Vice-Director General Iguchi, and NAOJ TMT Project Manager Usuda. Different working groups were created under the board to consider efforts for construction in Hawai'i, as well as issues of the project operation, by holding meetings frequently. One of them is the Business Plan Working Group chaired by the NAOJ Director General. Convened seven times in FY 2021, this working group focused on discussion of the status of the members' in-kind contributions and the valuation method. These meetings were held online due to COVID-19 restrictions.

In the U.S., the Decadal Survey, which decennially evaluates and identifies the most compelling challenges in the field of astronomy, started in 2019, and the report was announced in November 2021. The US-ELT Program, which will allow all-sky observation by working in concert with TMT and the Giant Magellan Telescope (GMT, a telescope with an aperture of 24 m currently under construction in Chile), was ranked as a top priority of the Decadal Survey for ground-based astronomy. In response to the release by the Decadal Survey, discussion began with NSF toward a review of design proposals

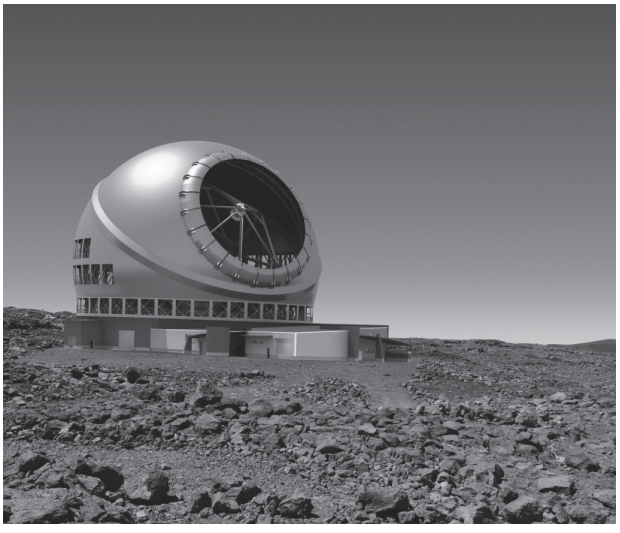


**Figure 1**: Conceptual image of TMT (provided by TIO).

for the US-ELT Program submitted by TIO along with NSF's National Optical-Infrared Astronomy Research Laboratory (NSF's NOIRLab) and GMT. Considering that the U.S. federal investment in the TMT project through NSF is essential for the project's success, TIO is presently working for NSF's preliminary design review (PDR) scheduled for the near future. In November 2021, as part of the preparation for the NSF PDR, a panel of independent, internationally recognized experts comprehensively reviewed the TMT project for its technical maturity, scheduling, budgeting, risks, etc., and concluded that the project is ready for the PDR. The NAOJ TMT Project fully cooperated with TIO for this independent review.

The final decision on the federal funding for the construction of TMT through NSF participation will be made by the U.S. Congress. Prior to the decision to participate, NSF made informal outreach efforts with stakeholders in Hawai'i in FY 2020 in a move to lay the groundwork for an environmental impact assessment and a consensus-building process in accordance with the National Historic Preservation Act. In addition, TIO worked on a proposal for NSF's development funding of the primary mirror control system, the secondary mirror, and other components for an interval before NSF participation.

As for the situation in Hawai'i, a CDUP was approved for the TMT planned site on Maunakea in September 2017, but several parties appealed this decision. In October 2018, the State Supreme Court found that due process was followed for issuance of the CDUP, which completed all the legal process for TMT. However, those opposed to TMT on Maunakea staged demonstrations, including some sit-ins on the access road to the summit region, preventing the full-fledged construction in July 2019. The Board of Governors recognized they had neither well understood the social issues behind the demonstration nor engaged in dialogue with the broader communities in Hawai'i, which had led to the failure to fully build trust with the Hawai'i community. The Board decided to implement phased relocation of the TIO headquarters to Hawai'i, with the first step being to relocate the Project Manager to start community-based activities. Both the NAOJ TMT Project Manager who moved to Hawai'i Island in July 2021 and a Senior Specialist based in Hawai'i fully contribute to TIO's community engagement activities. Through dialogue with the community, the strong need was expressed for educational support for children, in particular, those from low-income families. TIO started tutoring activities at schools (Figure 2) that Maunakea observatories had not engaged, which generated a great interest among local communities. TIO further developed an educational support program for the broader communities, and incorporated it in the development proposal which was submitted to NSF.

In May 2021, the House of Representatives of the Hawai'i State Legislature created a working group to discuss a new management structure for Maunakea, which subsequently released a report of recommendations in December. Based on the recommendations of the working group, a bill was developed and deliberated at the state legislature for creation of a new management structure for Maunakea that particularly engages with the Native Hawaiian community. Since this may affect the TMT Project, its development is being closely monitored (as of March 2022).


**Figure 2**: Educational support program at Hilo Intermediate School (after-school tutoring).

As for the alternative site on the island of La Palma of the Canary Islands in Spain selected in 2016, the process for all permits needed for construction was completed in November 2019, including an environment impact assessment. In an administrative appeal against one of the permits, a court determined in July 2021 there was a procedural problem, against which TIO appealed together with a local government and a local research institute. NAOJ expresses its support for relocation to La Palma in the case that construction in Hawai'i becomes infeasible, as long as the project is expected to receive the U.S. federal funding.

## 2. Japan's Progress on Its Work Share – Development of the Telescope Structure, the Primary Mirror, and the Science Instruments

For the construction of TMT, Japan is responsible for essential components of the telescope: the design and production of the telescope structure and its control system; and the manufacturing of the primary mirror, in accordance with the executed agreements. It also takes part in production of a portion of the science instruments which are developed through international partnerships. While the restart of onsite construction is halted, Japan worked on designs and preparation for production in FY 2021, concentrating its efforts on essential work for the overall process instead of production. In FY 2021, the following progress was made.

(1) Manufacturing of the Primary Mirror Segments

The TMT primary mirror, comprised of 492 segment mirrors, requires the manufacturing of 574 segment mirrors in all with the replacements to be used during mirror coating included. The processes of manufacturing mirror segments are: fabrication of the mirror blanks, spherical grinding of the front and back surfaces, aspherical grinding and polishing of the front surface, hexagonal shaping, and mounting of the mirror segments onto support assemblies. These processes are followed by final surface finish to be completed in the U.S. and coating with reflective metal to be performed on site, before the

mirror segments are finally installed on the telescope.

Of these processes, the plan calls for Japan to fabricate all the mirror blanks and to perform spherical grinding on all 574 segment mirrors. With the share of work for the processes beginning from aspherical grinding and polishing and ending with mounting of the mirror segment on a support assembly distributed among four countries, Japan is leading this work for 175 of the mirror segments. In FY 2021, the primary mirror team identified and examined a measure to protect the mirror surface during the hexagonal shaping as necessary work in an effort to facilitate production of the primary mirror when full-fledged manufacturing of the mirror segments is resumed, without affecting the entire schedule. The team investigated low-alkaline and other grinding fluids used for grinding work that may have little effect on the protection coating. The highlights of FY 2021 included completion and successful passage of TIO's review of 13 segments that were aspherically polished by FY 2019 to confirm that they meet the technical conformance criteria before being cut into their hexagonal shape. (Figure 3)

(2) Design and Production of the Telescope Structure and Its Control System

Japan is responsible for the design and production of the telescope structure, as well as its control system, which functions as a mount for the optics systems, such as the primary mirror, and the science instruments, and points them in the direction of a target astronomical object. Following the baseline and detailed designs developed by FY 2016 and preparation for fabrication in FY 2017, FY 2018 saw the launch of the fabrication process for the telescope structure. In FY 2021, continuing on from the previous fiscal year, with an eye toward a production readiness review scheduled before full-scale production, the work was focused on completion of interface documents and development of production drawings of a cryo-platform, instrument support structures, etc., as well as refinement of production drawings of the elevation journal and the Nasmyth structure, which will pave the way for future production. As for the examination and determination of the interfaces, the structure team provided TIO with assistance in definitions of interfaces from the telescope to the support facility, with a focus on the piping and wiring subsystems that were reviewed for the final designs.

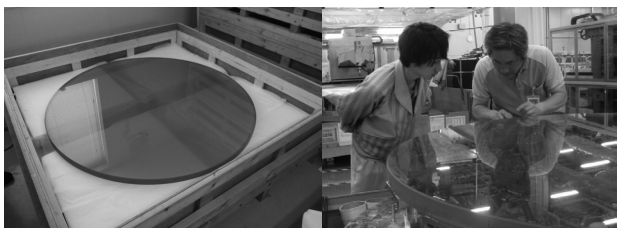


**Figure 3**: Polishing and measuring processes of mirror segments in Japan. In April 2021, the quality review was conducted for mirror segments that underwent the aspherical polishing process. A total of 13 segments passed the review, which will be followed by the next step of the process, hexagonal shaping.

(3) Science Instruments

Steady progress was made through international collaboration in the design and fabrication of three first-light science instruments, which will be commissioned once the telescope is complete.

One of them is IRIS that stands for an InfraRed Imaging Spectrograph. Being in charge of its imager, the NAOJ TMT Project currently engages in development that includes designing and prototyping in cooperation with the Advanced Technology Center. IRIS has been in the detailed design phase since FY 2017. In FY 2021, as part of the first detailed design review held from April to June, the imager which Japan is responsible for was reviewed. The IRIS team provided documents related to systems engineering (such as requirement documents, interface documents, risk management, and assembly adjustment plans), and reported designs and analysis of optical, mechanical, and electric systems, and results of prototype tests. In response to the review, the team identified action items to address, and performed thermal analysis of the entire system, vibration analysis, prototype tests (such as repeatability of the slicer pickoff mirror's position, and the position sensor's thermal cycle test). Progress was also made in other areas, including development of software engineering documents, the surface figure measurement of a large mirror in a cryogenic environment, and detailed analysis of stray light.

A Wide Field Optical Spectrometer or WFOS is in the conceptual design phase. The WFOS team engaged in development of concepts for the slitmask exchanger, the slitmask fabrication facility, and the Integral Field Unit, as well as setting a code for the slitmask exchanger, followed by development of the mechanical design. In response to changes from the original WFOS design, revisions were made to the concept for the Integral Field Unit, along with examination of a concept for a case where a physically narrow slicer is employed. Hoping to verify the technology for devolvement of the WFOS Integral Field Unit, the team made headway on an optical design of an Integral Field Unit demonstrator to be mounted on the Subaru Telescope's visible spectrophotometer called the Faint Object Camera and Spectrograph. In February 2022, a conceptual design review of WFOS, including Japan's parts, was successfully completed, and ushered the instrument into the preliminary design phase.

A Multi-Objective Diffraction-limited High-Resolution Infrared Spectrograph (MODHIS) is expected to pioneer the field of exoplanets, which was emphasized in the U.S. Decadal Survey. With its project management led by an NAOJ faculty member, MODHIS officially kicked off the first phase of a conceptual design in August 2021 in partnership with the California Institute of Technology and the University of California, Los Angeles and San Diego. This phase aims to clarify the concept of an adaptive optics to be combined with the instrument and develop a conceptual design of the interface to TMT adaptive optics. The team's effort also went into defining scientific and technical requirements to be satisfied by MODHIS. With the sights set on establishing an international development team, a role for the Astrobiology Center in the

MODHIS development is currently under consideration.

TIO's development efforts are also contributed to by NAOJ staff who are based at the NAOJ California Office in Pasadena. Their contributions are a considerable asset for TIO work, including a major role in developing a conceptual design of a coating facility for the secondary and tertiary mirrors and its review by another NAOJ member. One of the staff members in Pasadena served on a preliminary design review of maintenance and operation of mirror segments.

## 3. Planning of TMT Science, Instrumentation, and Operation with Communities of Researchers

TIO's Science Advisory Committee, consisting of researchers from the participating countries and institutions, discusses science programs and instrumentation envisioned with TMT. In FY 2021, 7 meetings were held online, attended by 4 university researchers and NAOJ TMT Project Manager Usuda on behalf of Japan. In view of the preliminary design review for potential participation by NSF, the committee held joint science meetings with GMT. As for development of instruments through international partnerships, a subcommittee on observation of exoplanets with TMT, chaired by Professor Norio Narita of the University of Tokyo, discussed research themes based on results of surveys conducted in each country. A sub-working group, created to work on development of a science operations plan once the telescope is completed, was attended by Associate Professor Wako Aoki of NAOJ.

The TMT Science Advisory Committee, which is a domestic committee consisting of 12 researchers from universities and other institutes, reviewed issues of science programs, instrumentation, and operations. NAOJ's funding program for research and development of TMT science instruments, which did not call for applications due to budgetary restrictions in FY 2020, resumed in FY 2021, with adoption of 6 proposals to carry out research for development by 26 researchers of 12 universities and research institutions. Seeing a science operations plan being developed in the U.S. as part of planning by the US-ELT Program toward possible participation by NSF, a working group was created under the TMT Science Advisory Committee to continue examination of science operations, and submitted Japan's opinion to TIO.

More meetings for larger communities of astronomy in Japan were actively organized to explain the status of the project and engage in discussions. The NAOJ TMT Project held an online meeting to explain about the results of the U.S. Decadal Survey in December, as well as a workshop for the instrument development, and another for the science operation in June 2021. A series of meetings were held with participation by researcher communities representing a broader range of fields, such as radio astronomy, theoretical astronomy, and solar research, as well as the community of optical and infrared astronomy. The NAOJ Director General provided the latest information on the TMT project for the astronomy and astrophysics subcommittee of the Science Council of Japan. For the purpose of facilitating communication with the Earth and planetary science community, the NAOJ TMT Project presented a talk at the fall session of the Japanese Society for Planetary Sciences in September 2021 to introduce the project, as well as a lecture on research on the Solar System and observation of exoplanets envisioned with TMT.

## 4. Public Relations, Outreach, and Education

Information on the TMT Project is provided on NAOJ's TMT Project website with a focus on updates regarding the situation at the Maunakea construction site and the work share progress made by Japan. Additionally, TMT Newsletters No.70 through 73 were delivered.

The outreach activities, which mostly shifted from in-person to online lectures and classes in FY 2020 due to the COVID-19 pandemic, continued to capitalize on online opportunities in FY 2021, including a program of NAOJ called FUREAI (Friendly) Astronomy, which offers school children in Japan and overseas opportunities to learn about astronomy directly from astronomers. At the same time, some of the events returned to an in-person format. There was a total of 30 sessions of lectures for the public and classes on demand.

In Hawai'i as well, where TMT is to be constructed, events were held online. The NAOJ TMT Project participated as on-demand lecturers in a science/technology education and PR event called "Journey Through the Universe" in March 2022.

## 5. Organization

By the end of the fiscal year, three Professors, six Associate Professors, two Assistant Professors, two Research Engineers, and a Senior Specialist held full-time positions for the NAOJ TMT Project. In addition, two Professors, an Associate Professor, a Senior Lecturer, an Assistant Professor, and a Senior Engineer from the Advanced Technology Center, the Subaru Telescope, and the NAOJ Chile Observatory have concurrent positions in the TMT Project, and take part in activities that include the development of TMT science instruments at the Advanced Technology Center.

With the aim of strengthening the close partnership with TIO, five members are assigned to the NAOJ California Office in Pasadena. There are three members in Hawai'i working for TMT, one of whom is from the Office of International Relations.

In light of integrated operation of the Subaru Telescope and TMT in the future, schedules and staffing allocation models were formulated in line with the long-term plan for operation with the Subaru Telescope. As part of the efforts, the domestic administration and the public relations are integrated with the Subaru Telescope.

# 09. JASMINE Project

## 1. Planning and Development of the JASMINE (Japan Astrometry Satellite Mission for Infrared Exploration) Project

(1) Overview

The purpose of the JASMINE Project, NAOJ, is as follows. We participate in and contribute to the Small-JASMINE mission of ISAS/JAXA (Institute of Space and Astronautical Science/ the Japan Aerospace Exploration Agency), aiming to realize the world's first near-infrared high-precision astrometry and time-series photometry.

We will perform the following missions to achieve the above purpose of the JASMINE Project.

1) To contribute to scientific verification and development of the instruments and the data analysis software for the Small-JASMINE mission of ISAS/JAXA.

2) To provide the scientific community with a catalogue of physical information, including parallaxes, proper motions, and light curves, for stars in the Galactic Center, through an international framework under the leadership of ISAS/JAXA.

Small-JASMINE (hereafter, referred to as JASMINE. In the future, JAXA will officially change the name to JASMINE) was selected by ISAS/JAXA in May 2019 as the unique candidate for the JAXA Competitive Middle-Class Science Missions No.3. At the present, according to the progress schedule in the Space Basic Plan established by the Cabinet Office in Japan, the launch of JASMINE is scheduled for 2028. We are promoting JASMINE with the aim of gradually improving the development stage at JAXA. JASMINE has the following three primary scientific goals.

1) To reveal the Milky Way's central core structure and formation history by measuring the distances and the motions of stars located as far as 26 thousand light-years away with high-precision astrometry observations in the near-infrared band.

2) To explore the formation history of the Milky Way related to the origin of human beings by revealing the evolution of the Galactic structures, which caused the radial migration of the Sun and other stars with their planetary systems.

3) To find Earth-like habitable exoplanets, taking advantage of the time-series photometry capability required for the precision infrared astrometry.

The mission objective of JASMINE is to use an optical telescope with a primary mirror aperture of around 30 cm to perform infrared astrometric observations (Hw band: 1.1–1.6 $\mu$m (TBD)) (to be determined in detail). A mission goal is to measure as the highest precision annual parallaxes at a precision of less than or equal to 25 $\mu$as and proper motions, or transverse angular velocities across the celestial sphere, at a precision of less than or equal to 25 $\mu$as/year in the direction of an area of a few square degrees of the Galactic nuclear bulge and in the directions of a number of specific astronomical objects of interest in order to create a catalogue of the positions and movements of stars within these regions. The project is unique in that unlike the optical space astrometry mission, "Gaia Project," operated by the European Space Agency (ESA), the same astronomical object can be observed frequently, and observation will be performed in the near-infrared band, in which the effect of absorption by dust is weak. This project will help to achieve revolutionary breakthroughs in astronomy and basic physics, including the formation history of the Galactic nuclear bulge (Galactic Center Archeology); Galacto-seismology; the supermassive black hole at the Galactic Center; the gravitational field in the Galactic Nuclear Bulge; the activity around the Galactic Center; formation of star clusters; the orbital elements of X-ray binary stars and the identification of the compact object in an X-ray binary; the physics of fixed stars; star formation; planetary systems; and gravitational lensing. Such data will allow for the compilation of a more meaningful catalog when combined with data from ground based observations of the line-of-sight velocities and chemical compositions of stars in the bulge.

Due to satellite operations, there are periods when astrometric observations towards the Galactic center direction are not possible. In such a period, in order to utilize the unique features of the JASMINE satellite (its capability of high-precision photometric and highly frequent observations in the near-infrared region), we can plan to observe a few specific astronomical objects in the Galaxy. Therefore, JASMINE will carry out transit observations utilizing the continuous photometric observations. It is possible to search for Earth-type planets that are expected to be in the habitable zones around M-type stars, which are low mass red stars belonging to the main sequence. JASMINE dominates the other missions for explorations of this type of exo-planet. Furthermore, JASMINE will be Japan's first satellite mission for the exploration of exo-planets.

The JASMINE Project has also been promoting the plan of a micro-satellite project, Nano-JASMINE, with a primary mirror aperture of 5 cm. Nano-JASMINE aims to produce scientific results based on the astrometric information for bright objects in the vicinity of the Solar System. Despite its small aperture, the satellite is capable of observational precision comparable to the Hipparcos satellite. The combination of observational data from Nano-JASMINE and the Hipparcos Catalogue is expected to produce data on proper motions for very bright stars which will be more precise than those of Gaia. Launch opportunities for the Nano-JASMINE satellite are under consideration.

(2) Major Progress in FY 2021

1) Organization of the office

The JASMINE Project is composed of eight full-time staff members, one technical supporter, and two graduate students. Significant contributions were also made by members of the following organizations: Kyoto University's Graduate School of Science; ISAS/JAXA; the University of Tokyo; and the University College London.

2) Overview of planning and developing the JASMINE Project

The JASMINE Project established a JASMINE consortium consisting of researchers. The purposes of the consortium are to conduct the science study, and to prepare a data analysis team, data validation team, and outreach team. At present, about 60 domestic members are participating. In December 2021, a consortium meeting was held online, which also served as an open science workshop for JASMINE.

Regarding the development of observation instruments, an infrared detector developed by the NAOJ Advanced Technology Center for ground based astronomy, is now being adapted for space use. The development progressed smoothly, such as passing some radiation resistance tests, completing prototypes, completing designs for large formatting of a detector, and examining concepts on the thermal structure of a detector box. In addition, the specifications of the observation instruments have been examined with satellite manufacturer company candidates. For the satellite system as a whole, the risks that should be resolved at this point were examined in cooperation with multiple satellite manufacturer company candidates. Regarding data analysis, a data-analysis group has been developing and carrying out simulations of stellar image creation and a series of end-to-end simulations from estimations of stellar image centers to deriving astrometric parameters such as annual parallaxes. After the proof of principle, the group started development considering more realistic and complex noise. In international cooperation, we proceeded with preparations for analysis of astrometric data with researchers at Heidelberg University.

3) Progress of the Nano-JASMINE Project

Assembly of the flight model of Nano-JASMINE that will be actually launched into space was completed in FY 2010. However, it is difficult to get a launch service, and coordination with the launch company is still ongoing.

# 10. RISE (Research of Interior Structure and Evolution of Solar System Bodies) Project

## 1. Project Overview

In FY 2021, the RISE Project first and foremost worked as the Martian Moons eXploration (MMX) Geodesy sub-science team (G-SST) to continuously investigate the operation plans of MMX, introduce new software, and support designing and manufacturing an onboard instrument. (i) To prepare for simulation studies of the internal structure of Phobos after the data acquisition, we examined the accuracy and spatial resolution of the Phobos gravity field that is expected to be retrieved from two- and three-dimensional Quasi-Satellite Orbits (2D-QSO/3D-QSO) at the various altitudes. We investigated how the gravity field model estimated only from the spacecraft tracking range-rate data would be improved by incorporating laser altimeter (LIDAR) data and image data. A paper describing science requirements and an observation plan for geodetic study of MMX was accepted in the Earth, Planets, and Space journal. (ii) We selected the orbit/gravity field estimation software produced by CNES in France as the one to be nominally used in MMX and regularly had meetings online to train expected users. (iii) To activate international collaborations of G-SST, we attended domestic and international Science Board meetings and discussed possible achievements of scientific research. All meetings were held online to prevent COVID-19 infections. (iv) Regarding utilization of the stereophotoclinometry shape-modeling software (SPC), we negotiated with the Planetary Science Institute (PSI), which developed the SPC and confirmed consistency with NASA Participating Scientist Program. Once the prospect of introducing SPC software was attained, we could make a detailed plan for imaging Phobos to produce the shape model. (v) To support the development of the Flight Model (FM) of LIDAR, we attended development meetings and the field test and contributed to the development and performance evaluation of the Engineering Model (EM). (vi) We continued regular seminars to review recent research on Phobos's internal structure and discussed relationships between orbit evolution, shape changes, and internal physical properties (Love number, $k_2$ and energy attenuation, $Q$) of Phobos. In addition, (vii) we contributed to long-term operation planning in the Mission Operation Working Team (MOWT) and made a list of expected data products of G-SST and LIDAR in ground Data Processing WT (DPWT) to organize the data processing flow.

Second, we produced Level 0 data of the Hayabusa2 LIDAR to be included in the opened data archive and added a description of how to calculate Level 1 data from Level 0 data to the Software Interface Specification (SIS) document. We continuously arranged with the Hayabusa2 data archive team for publication. An international board reviewed our production. On the other hand, we studied the slope stability of the top-shape of the asteroid Ryugu considering the deceleration of its spin rate and began writing a paper. Also, in March we submitted a paper as coauthors on the surface albedo of Ryugu, which used LIDAR data. Regarding the laser-link experiment conducted during the return to Earth of Hayabusa2 with the Institute of Space and Astronautical Science (ISAS) and National Institute of Information and Communications Technology (NICT), one of the RISE Project members led writing a paper and submitted it as the first author in March.

Third, we held team meetings of the Planetary Science Working Group under the Science Strategy Committee and considered the role of planetary explorations in the National Astronomical Observatory of Japan. We had online meetings on April 19, June 28, August 17, October 18, December 27, and February 28 to discuss research on exoplanets and the Solar System in the Division of Science, visible and near-infrared observation of exoplanets, observation of protoplanetary disks by radio telescopes, and observation of trans-Neptunian objects.

## 2. Educational Activities

One RISE member educated a third-year graduate student of the University of Tokyo as an assistant advisor.

## 3. Outreach/PR

In FY 2021, the Project members volunteered two times for Kirari Oshu City Astronomy School as well as six times for FUREAI (Friendly) Astronomy classes. In addition, RISE members provided five special lectures for the public.

# 11. SOLAR-C Project

## 1. SOLAR-C Project Overview

SOLAR-C is a planned satellite project and may become Japan's fourth solar observation satellite mission after Hinotori, Yohkoh, and Hinode. The plan is to realize the launch in the mid-to-late 2020s. Through observations from the satellite, this project aims to elucidate the following mechanisms of solar magnetic plasma activities, which are significant problems in the field of solar physics and have an impact on space weather and space climate around the Earth.

(1) Formation mechanism of the hot solar atmosphere and solar wind
(2) Energy release mechanism of solar explosions

The primary science instrument on the satellite has high imaging resolution and sensitivity that are improved by nearly an order of magnitude compared with the similar instrument on the Hinode satellite. It also has the feature of being able to observe the hot solar plasma with temperatures ranging from twenty thousand to twenty million degrees nearly seamlessly. Since its establishment, the JAXA SOLAR-C project WG has involved many non-Japanese specialists in addition to Japanese researchers. Japan will be responsible for the launch vehicle, satellite bus, and telescope section of the science instrument. The spectrograph section will be developed through international collaborations with the U.S. and European space agencies and institutions. NAOJ will play a leading role in the development of the telescope section.

The SOLAR-C project was proposed as the Solar-C_EUVST small satellite project in the JAXA public small satellite solicitation opportunity in January 2018. This proposal was nominated as a candidate for Publicly Offered Small Satellites 3 or 4 in July 2018, and the plan has moved to the Mission Definition Phase (Pre-Phase-A2) in FY2019. After the pre-project candidate down-selection pre-screening in February 2020, this project was selected as the JAXA Small Satellite 4 project in May 2020. In terms of international cooperation, NASA's participation in this project was decided in December 2020 based on NASA's Phase A study that had been underway since 2019, followed by the participation of European space agencies. In FY 2021, we prepared for the mission definition review while proceeding with feasibility studies with overseas partner organizations.

## 2. Progress of the SOLAR-C Project Activity in FY2021

In FY 2021, the following aspects of the telescope section and satellite bus, for which Japan is responsible, were studied using the JAXA front-loading expenses: (1) The design study of the primary mirror assembly with tip-tilt and focusing mechanisms, (2) the redesign and refinement of the structure model, (3) the on-orbit temperature prediction and thermal deformation prediction by the thermal mathematical model, (4) the study of mechanical interface conditions between the satellite and the observation equipment and those within the science payload, (5) the examination of requirements for the small satellite standard bus, (6) the performance evaluation of the prototype model of the Ultra Fine Sun Sensor, and (7) the investigation of outgassing characteristics of candidate adhesives. Through these design studies, the validity of the design has been confirmed for some critical items, while some issues in the initial design have been clarified. For the primary mirror, it was decided to increase the thickness of the primary mirror to prevent degradation of spatial resolution due to deformation caused by coating stress, and the actuator and sensor to be used in the scanning mechanism were selected. In addition, outgassing data were obtained for candidate adhesives to be used in the primary mirror support points, which are expected to reach a high temperature of approximately 110 degrees C. To accommodate the increased weight of the primary mirror assembly, we have updated the design of the focus adjustment mechanism while utilizing the developed model. From the latter half of the fiscal year, we have been focusing on preparation for the mission definition review and interface coordination with overseas components.

## 3. SUNRISE-3 Project Support

While the Solar Science Observatory (SSO) has handled the short-term experiment projects since this fiscal year, most SOLAR-C project members continue to contribute to developing the science payload for the Balloon Project SUNRISE-3. In FY 2021, the project completed its development activities in Japan and proceeded to assembly and testing in Germany. Refer to the report of the Solar Science Observatory for details.

## 4. Educational and Publicity Outreach Activity

Two SOKENDAI graduate students and one contracted graduate student (University of Tokyo) were supervised. The project also participated in the Tour of the Solar Research Frontline to introduce domestic solar research to undergraduate students and introduced the project activities in research and development through the web.

## 5. Others

While NAOJ reimbursed the SOLAR-C project for its general operation and contingencies, a large part of the expenses for supporting the project preparation was funded by other external sources such as the JAXA's study-acceleration and basic development fund. From the viewpoint of smoothing out the administrative work volume of SOLAR-C and SSO projects, the expense processes for the short-term experiment projects were conducted by this project.

T. Oba, Project Research Staff, was appointed in April 2021, and T. Okamoto, Assistant Professor, in November 2021. Y. Kawabata, Project Research Staff, moves to the Solar Science Observatory in April 2022.

# 12. The Subaru Prime Focus Spectrograph (PFS) Project

## 1. Overview of the PFS Project

The Prime Focus Spectrograph (PFS) is a next generation large-scale facility instrument of the Subaru Telescope. PFS will enable us to obtain spectra of ~2400 objects simultaneously at wavelengths ranging from 0.38 $\mu$m to 1.26 $\mu$m with a spectral resolution of R ~ 2000 – 4000. It is expected to start open-use observation from FY 2024.

PFS has been developed under an international collaboration led by Kavli IPMU, Tokyo University. The collaboration consists of Kavli IPMU (Tokyo Univ.), NAOJ, ASIAA (Taiwan), Caltech/JPL, Princeton Univ., Johns Hopkins Univ., North East Participation Group (6 institutions, USA), Brazilian consortium, LAM (France), MPE/MPA (Germany), and Chinese PFS Participation Consortium (6 institutions, China). The subsystems of the PFS instrument have been developed at designated institutions, and NAOJ is responsible for modifying the telescope/dome, preparing a temperature-controlled clean room for the spectrograph system, and operation of the instrument. NAOJ is also committed to its commissioning, its data pipeline and science database.

NAOJ approved these activities as an A-project from FY 2019. The mission of the A-project is to complete on-site assembly and installation into the Subaru Telescope, verify its system requirements, then perform science commissioning and performance verification. The A-project work will lead to the start of PFS operation, at which point PFS will transition to a Subaru facility instrument, and the A-project will be dissolved.

## 2. PFS A-project Leadership Changes

In May 2021, while working in Taiwan for PFS, Takato-san, the PFS A-project leader at NAOJ, passed away. This was a terrible loss for everyone at NAOJ and Subaru.

Following this dramatic event, a period of transition started to reorganize the PFS A-project leadership. The new PFS A-project leadership was assigned to Julien Rousselle (leader) and Shintaro Koshida (co-leader).

## 3. Progress in FY 2021

(1) Subsystems delivery and assembly

SuNSS (Subaru Night-Sky Spectrograph) was installed on the Subaru telescope spider arm in Feb. 2021 and successfully tested on sky in March 2021. This instrument uses two small optics, the first PFS fiber cable, and the first PFS spectrograph, to take spectra of the night sky background when PFS is not used. This data will be very valuable for PFS data processing, as well as for other Subaru instruments.

In June 2021, the Prime Focus Instrument (PFI) was delivered from ASIAA (Taiwan) and we have performed AIT (Assembly, Integration and Test) activities since then, including on-sky engineering observation.

During testing, the auxiliary electronics of PFI were found to be unstable and necessitated extensive work to fix. We now finished stabilizing the electronics, for PFI to be used during the scheduled engineering run in mid. June, but further work is needed to improve its long-term reliability.

The fit test of PFI on the telescope also revealed a design flow of PFI rotator which required the modification of the rotator limit switches.

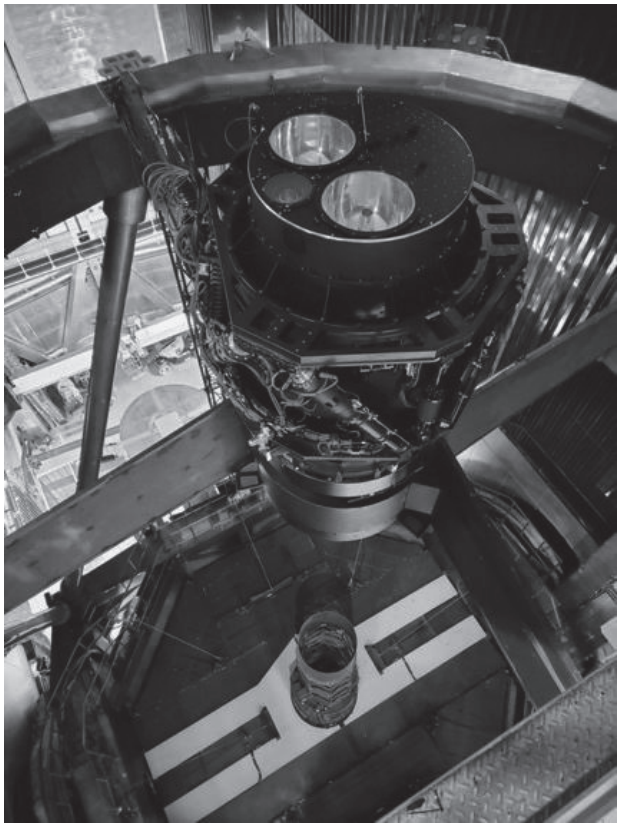


**Figure 1**: PFI installed on the telescope for fit test.

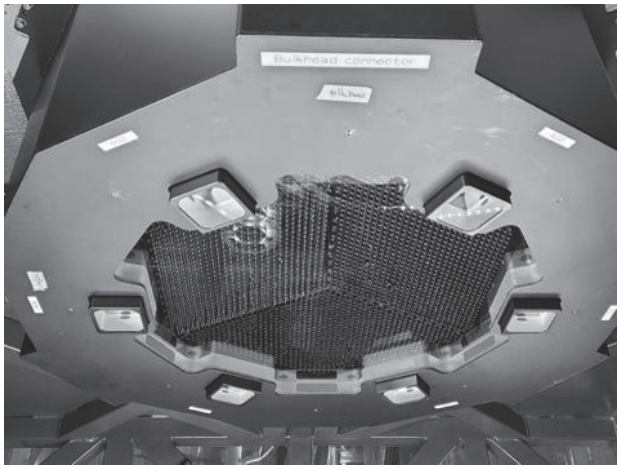


**Figure 2**: PFI focal plane with ~2400 optical fibers, their positioners and 6 auto-guiding cameras.

In April, the second fiber cable (out of 4) was successfully installed on the telescope and passed our initial performance test.

(2) On-telescope test and Engineering run

In Sept. PFI was successfully installed on the telescope prime focus for a fit test, as well as an "end-to-end" test involving all PFS subsystems already installed (the metrology camera, PFI, the first spectrograph and the first fiber cable). This test was also successful and the first sky spectra were taken (see Fig. 3–4).

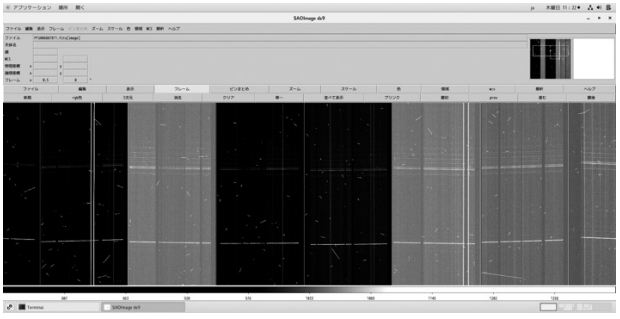


**Figure 3**: First sky spectra in Blue camera taken on 2021.09.26

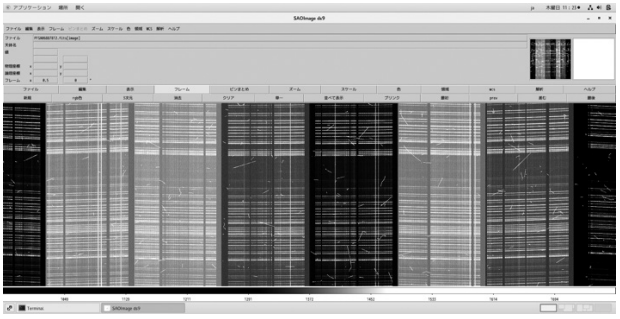


**Figure 4**: First sky spectra in Red camera taken on 2021.09.26

In Nov. PFS had its first engineering run for 3 nights. Unfortunately, a design flow of PFI limit switches prevented us from using the rotator during this run, but we were still able to take images with the auto-guiding cameras and close the autoguiding loop on the telescope. We also successfully tested the fiber positioners using the Metrology Camera System (MCS) installed on the Cassegrain focus.

(3) Science operation updates

During FY 2021 a lot of software development has been done in both Mitaka and Hilo groups to develop the PFS science operation. This includes the development of the science and target databases and data format, as well as the flux calibration, object selection, pointing planner and fiber allocation.

We also started to work on the data access policy for open use, as well as the archiving policy needed to store the large amount of data created by PFS.

# 13. The Subaru Ground Layer Adaptive Optics (GLAO) Project

## 1. Project Overview

ULTIMATE-Subaru is a survey instrument that will enable unprecedentedly wide-field and high-sensitivity survey observations with a high resolution comparable to the Hubble Space Telescope. The Subaru Ground Layer Adaptive Optics (GLAO) project aims to develop a GLAO system as a part of ULTIMATE, which will uniformly improve the seeing by a factor of 2 over a wide field of view up to ~20 arcmin in diameter. A primary science goal of ULTIMATE is to reveal the history of galaxy formation and evolution by an unprecedented near-infrared survey of the distant Universe.

The GLAO project successfully completed the conceptual design phase in FY 2018. In FY 2019, the GLAO project was accepted for the NAOJ's call for A project proposals and has started the preliminary design phase. In the A-project period, the GLAO project aims to complete the preliminary design of the GLAO system and the prototyping of the key subsystems within 3 years, followed by final design, production, assembly, integration, and test phases. The GLAO project is planning to implement the GLAO system at the Subaru Telescope and start its commissioning run by the end of FY 2028.

## 2. Staff

The GLAO project team mainly consists of members of Subaru Telescope. At the end of FY 2021 there was one associate professor dedicated for the GLAO project. There were also 1 project associated professor, 1 senior specialist, 4 assistant professors, and 7 RCUH employees (4 research staff and 3 engineering staff) appointed concurrently. In addition, the GLAO project received support from the instrument division technicians, day crews, and administration staff at Subaru Telescope.

## 3. Major Progress in FY 2021

The ULTIMATE science team, consisting of domestic and international scientists, has been conducting studies of science cases for ULTIMATE, in alignment with the strategy of the Japanese optical/infrared astronomy community looking ahead to the 2030s (TMT era). In FY 2021, the ULTIAMTE science team has published an "ULTIMATE Science White Paper," which summarized the past studies on the main and extended science cases for ULTIAMTE and top-level science requirements drawn from the science cases. The ULTIMATE development team has also summarized the technical studies on the science instruments that will satisfy the science requirements when used with the GLAO system. The technical studies for the relocation of MOIRCS to the Nasmyth IR focus to provide a multi-object spectroscopic capability and for the wide-field near-infrared imager (WFI) that covers 20 arcmin field of view in diameter at the Cassegrain focus were compiled in a conceptual design report. A conceptual design review for the ULTIMATE science cases and the science instruments to realize them was held in June 2021 by inviting external reviewers. The review committee highly evaluated the science cases and the instrument development plan and endorsed the project to move forward to the next design phase with some suggestions to improve the project.

The GLAO design has been conducted for its main subsystems. In FY 2021, the final design of the adaptive secondary mirror (ASM) has been completed and we are ready to proceed with the production phase. In addition, we continued the preliminary design of the wavefront sensor (WFS), the laser guide star facility (LGSF), and the real-time control system (RTC) based on their system requirements. The optical and mechanical interface designs have been completed to use WFS at the Cassegrain focus with the wide-field imager (WFI). The preliminary design of the other subsystem will be completed in the first half of FY 2022. We are planning to hold a preliminary design review of the GLAO system in October 2022.

The GLAO project has been conduction prototyping instruments for the GLAO system. We have been upgrading the laser system for the existing AO system at the Subaru Telescope to demonstrate the technology for the LGSF. We have also been developing a Laser Tomography AO (LTAO) system to demonstrate the technology for Shack-Hartman WFSs with four laser guide stars. In FY 2021, the upgrade of the laser system for the existing AO system was completed. We have conducted a first launch of the laser from the Subaru Telescope and conducted the performance evaluation of the upgraded laser system. The performance of the GLAO system highly depends on the fraction of the atmospheric turbulence in the ground layer. We have been developing an atmospheric turbulence profiler to directly measure the ground-layer turbulence from the Subaru Telescope. The profiler has been assembled and tested in a laboratory in FY 2021. In FY 2022, we will install the profiler on the Subaru Telescope to measure the ground-layer turbulence.

## 4. Outreach

To inform the astronomical community and general public about the Subaru GLAO project and its scientific motivation and goals, we released news articles from the project on a public website (https://ultimate.naoj.org/english/index.html). In FY 2021, the GLAO project wrote a web release on the first laser launch from the upgraded laser guide star facility.

## 5. International Collaboration

The GLAO project has been closely collaborating with the Australian National University (ANU) and the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) for the preliminary study of the GLAO system. In FY 2021, we continued the collaboration with ANU for the preliminary

design study of the WFS and the LGSF and with ASIAA for the conceptual design studies of the ULTIMATE science instruments.

In FY 2021, the Japan Society for the Promotion of Science (JSPS) core-to-core program “International research network toward the era of deep and wide near-infrared survey of the Universe with space and ground-based telescopes”, led by the ULTIMATE science team, has started its activities. We regularly held seminars to introduce wide-field survey projects planned in each country and discussed them with participants from the USA, France, Australia, Taiwan, and Japan.

# 14. Astronomy Data Center

## 1. Introduction

The Astronomy Data Center (ADC) collaborates with observatories and universities to consolidate astronomical observation data. ADC archives them permanently and opens them to the astronomy community in a user-friendly way together with the data analysis environment to facilitate scientific research. These activities are supported by the DB/DA project team, the JVO project team, the HSC data analysis and archiving software development project team, and the open-use services team.

## 2. DB/DA Project

The DB/DA project conducts research and development on astronomical Databases and Data Analysis. SMOKA (https://smoka.nao.ac.jp/) is the core of the DB/DA project and opens archival data of Subaru Telescope, Okayama 188-cm telescope, Kiso 105-cm Schmidt telescope (the University of Tokyo), two MITSuME 50-cm telescopes (Tokyo Institute of Technology), Kanata 150-cm telescope (Hiroshima University), NAYUTA 2-m telescope (University of Hyogo), and Seimei 3.8-m Telescope (Kyoto University). The total amount of opened raw observation data in SMOKA is about 34 million frames (328 TB) as of May 2022. SMOKA contributes to many astronomical publications. The total number of refereed papers using SMOKA data is 270 including 8 new publications as of March 2022.

Data taken with the observing instruments VAMPIRES and REACH attached to the Subaru Telescope and OBJECT frames of KOOLS-IFS on the Seimei Telescope were newly opened in FY 2021. Development of new functions requested by users and improvements for efficient operation were also conducted. The information on astrometric calibration of Kiso KWFC was also opened to the public.

We are operating a system that makes original all-sky monitor images at Higashi-Hiroshima, Okayama, Akeno, and Kiso available to the public (https://ozskymon.nao.ac.jp/ ; 28 TB as of May 2022). A system to publish digitized data from photographic plates taken at the Kiso Observatory several decades ago was developed and operated (https://pplate.nao.ac.jp/ ; 4 TB). A new data service of Tomo-e Gozen (Kiso Observatory) stacked data was opened in November 2021 (https://archive.nao.ac.jp/tomoe ; 80 TB as of May 2022).

## 3. JVO Project

Detection of atomic and molecular emission lines was performed on the published ALMA FITS data, and the information on the detected lines was compiled into a database that can be searched on the JVO ALMA FITS archive. This makes it possible to search for FITS data based on the emission line information of target objects in the large amount of data acquired by ALMA.

ALMA's data size per file now exceeds 300 GB, with plans to deliver 1 TB of data in the future. We have developed FITS WebQL, which implements a distributed processing mechanism to show the contents of such huge data cubes on the web browser interactively at high speed without downloading. A total of seven computers read FITS data in parallel and synthesize images, enabling even 1 TB of data to be displayed within a few minutes. We also confirmed that the spectrum calculated at any position on the image plane can be smoothly plotted in real time. The development status of FITS WebQL was presented at ADASS 2021 and the 2022 Spring Meeting of the Astronomical Society of Japan.

Two achievements made in the last fiscal year, the release of the processed data obtained with the Subaru Telescope's former observing instrument Suprime-Cam, and the development of the Gaia EDR3 visualization system, were reported at the 2021 Fall Meeting of the Astronomical Society of Japan. AGN survey data from JAXA's scientific satellite HALCA was registered in the JVO system and was opened to the public through the VO interface. Updates to the VO Crawler DB, a system for high-speed search of metadata for observational data collected from VO services around the world, were implemented.

The total access count for all JVO services in FY 2021 was 7.6 million and the total download volume was 14 TB.

## 4. HSC Data Analysis/Archiving Software Development Project

This project, started in January 2009, primarily develops the data analysis pipeline and data archiving software for Hyper Suprime-Cam (HSC). Our main subject is to implement the software for efficient and accurate data analysis and archiving. In the Subaru Strategic Program (SSP) with HSC (March 2014-), we have been analyzing the data with the developed pipeline and producing databases to store the processed results for researchers. We made the 10th data release (S21A) to the SSP team collaborators in June 2021, which covers roughly 740 degree$^2$ on the sky with sufficient quality, with a total of 700 TB of files. The catalog database includes about 920 million objects.

We have continued developing various user interface software for providing images and catalog products. This fiscal year, we have finished all of the originally scheduled HSC-SSP observations. The next internal data release is planned to include all data sets from the entire SSP period. We are updating and carefully testing the pipeline for production. We have also been supporting the on-site data evaluation for HSC observations. We have continued development of a fast catalog query system with a next-generation database for huge HSC catalogs as well.

In the course of PFS commissioning, we have been involved in discussions of data formats based on engineering

data, and development of science data archives in cooperation with Subaru Telescope.

## 5. Open-use computer systems and services

"National Astronomical Observatory of Japan: Data analysis, archive and service system," which is the open-use computer system procured under a rental contract, has been in operation since March 2018. The system plays a leading role as part of the Inter-University Research Institute.

The system consists of "Multi-Wavelength data analysis subsystem (MDAS)", "Large data archive and service subsystem (MASTARS, SMOKA, HSC science, ALMA, VERA, NRO, Okayama, and Solar data archives)", "JVO subsystem", "Data analysis subsystem in Mizusawa Campus", "Development subsystem", and "Open-use terminals and printers in Mitaka Campus". The current system will be replaced by a new one by the end of Feburay 2023, and we are preparing for the replacement.

We have been constructing the "Large-scale data analysis system (LSC)" for analyzing the big astronomical observational data such as HSC. The LSC system has been in operation for general HSC observers since September 2019. A major upgrade of the LSC system to add several computing nodes with another 1,500 CPU cores was completed in 2020. A small system upgrade continues. Starting in October 2020, the LSC system became available for researchers wishing to use HSC archival data, and further expansion has been made since January 2022 for those who want to use the LSC system for analyzing observation data taken with instruments other than HSC.

As part of the tasks as an Inter-University Research Institute, several workshops and hands-on tutorials were held to demonstrate to users how to use the specific software, applications, and the open-use systems. All workshops in FY 2021 were held online due to the COVID-19 situation. The dates and numbers of participants in FY 2021 were as follows.

1. ALMA data analysis school (1st, Co-host), June 15–16, 2021, 12 users
2. PyRAF mini school, July 14–15, 2021, 10 users
3. SOKENDAI summer student program (provided analysis computers), August – October 2021, 12 users
4. IDL school for beginners, September 29-30 and October 6–7, 2021, 9 users
5. ALMA data analysis school (2nd, Co-host), November 2 and 5, 2021, 10 users
6. Subaru Telescope data analysis school (Co-host), November 16–18, 2021, 12 users
7. Database school for beginners, December 21–22, 2021, 12 users.

The total number of participants in the workshops and tutorials in FY 2021 was 77 users. The number of workshops held in FY 2021 more than doubled compared to last year.

## 6. Others

ADC user's meetings were held online on May 19 and June 24, 2021. Since it was time to consider a replacement of the ADC open-use computer system, those meetings were good opportunities to collect opinions from the astronomy community on the expected role of ADC; the evaluation and issues for the current system; and requests and expectations for the next system.

As part of outreach and promotion activities, 151 issues of "ADC News" were published from No. 1055 to No. 1206 and 28 announcements for LSC users were published from No. 40 to No. 67 in FY 2021. These articles were distributed to users by E-mail and posted on the ADC public web pages.

# 15. Advanced Technology Center

## 1. Summary of Activities in ATC

The Advanced Technology Center (ATC) is the core research organization of the technological development at the National Astronomical Observatory of Japan (NAOJ), and is the research and development (R&D) center for advanced astronomical observation instruments, from radio waves to visible and ultraviolet light, both on the ground and in space. In FY 2021, as in the previous fiscal year, many ATC staff members were forced to work from home due to the declaration of a state of emergency in relation to COVID-19 and the subsequent issuance of priority measures to prevent the spread of the virus. Since some staff members are required to come to work due to on-site work, as in the previous fiscal year, ATC continued to maintain an environment where staff members can work safely and obeyed our own COVID-19 control manual developed by ATC last fiscal year. By sharing the manual with ATC staff, users inside and outside NAOJ, and visitors, the measures against COVID-19 have been thoroughly implemented. Through these efforts, we successfully minimized delays in work in the "Open-Facility Program, Joint Research and Development Program", NAOJ project work such as "Prioritized Area Developments," and the development/manufacturing of other instruments and related technology for projects inside and outside of NAOJ.

The restructuring of the current organization to develop the instruments more systematically, which has been considered since FY 2019, officially began operating under the new organizational structure this fiscal year (refer to Figure 1). In the process, several issues have been clarified, such as the establishment of a process to determine whether or not to accept jobs requested by external projects, and it is necessary to solve the issues for the management of the matrix organization to establish the new scheme.

Although the number of visitors was significantly smaller than usual due to the COVID-19 situation, we were able to stress the importance of ATC in NAOJ for visitors from MEXT such as the Vice Minister, the Deputy Director-General, the Director of the Space Utilization Division, and so on. We also provided ATC tours for visitors from private companies and online tours for students.

One of the most notable events in FY 2021 was the implementation of an independent international external evaluation of ATC. This was the first international external evaluation conducted in six years since 2015 (the previous evaluation was conducted as part of the international external evaluation of NAOJ as a whole).

Details of the activities in FY 2021 are described below.

## 2. Prioritized Area Developments

(1) TMT Instruments

1) Infrared Imaging Spectrograph (IRIS)

IRIS was in the 4th year of its final design phase, and most

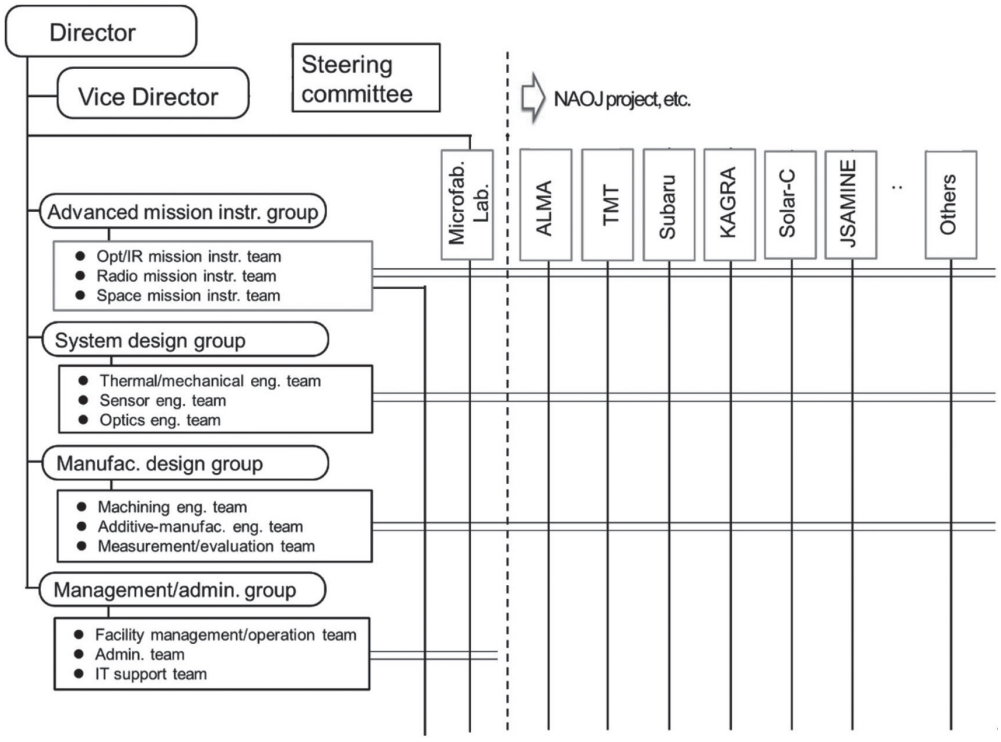



**Figure 1**: Matrix organization structure of ATC.

IRIS subsystems, including the IRIS Imager which ATC has been developing, had their final design review. The final design review for the IRIS Imager was held online on June 2021 with optical design, mechanical design, thermal design, vibration, prototyping, and systems engineering (requirements, interfaces, verifications, integration plan) included in the scope of the review. The review follows the TMT standard, i.e., after delivery of the review documents, in-depth pre-review discussions using an online discussion tool were organized, and the 3-day review was focused on topics that were not settled in the pre-review discussion. While our quality deliverables were highly credited by the review committee, we also received some honest critical comments. The review was an invaluable opportunity to collect feedback from experts for designs that were nourished and built up throughout the final design phase. The remainder of this year was devoted to closing action items that were pointed out in the review panel report such as vibration analysis, opto-mechanical-thermal analysis, and stray light analysis.

2) Wide Field Optical Spectrometer (WFOS)

WFOS successfully passed the conceptual design review in February 2022 and is going to the preliminary design phase from April 2022. NAOJ conducted the design studies on the slit mask exchanger, the slit mask fabrication system, and the integral field unit (IFU). Details are as follows.

i) In terms of the slit mask exchanger, we developed several exchange methods and selected the most suitable method based on a trade study considering their exchange times and mechanical complexities. In addition, we modified the design considering safety for operators.
ii) There are two possible locations for the slit mask fabrication system: the summit and the base facilities. A trade study about the location was conducted. The final decision will be made in the next phase.
iii) The IFU optical design was modified in response to the WFOS design modification. A new IFU mode with a narrower slicer was studied. We proceeded with optical design of a technology validation IFU which will be installed into the optical spectrograph, FOCAS, on the Subaru Telescope.
iv) We summarized the conceptual study reports on the slit mask exchanger, the slit mask fabrication system, and the IFU, and estimated their costs and development schedules.

(2) ALMA

1) ALMA Receiver Maintenance of Bands 4, 8, and 10

NAOJ is in charge of the maintenance of the cold cartridge assemblies (CCAs) for three receiver bands - Band 4 (observation frequency: 125–163 GHz), Band 8 (385–500 GHz), and Band 10 (787–950 GHz) - for ALMA. By FY 2013, a total of 219 CCAs which had been developed and manufactured at NAOJ, or 73 units including 7 spares for each band, were shipped to the ALMA site. Most of the receivers have been installed and operated in the ALMA antennas for scientific observation. At ATC, the ALMA receiver maintenance team has been repairing the receiver cartridges that failed during operation since FY 2014. In FY 2021, one Band 4 receiver was repaired and delivered to the ALMA Operations Support Facility (OSF) in Chile. Currently, one Band 4 receiver and one Band 10 receiver have been sent back from Chile for repair, and are in the process of being repaired, which will be completed in the next fiscal year. The receivers installed in antennas and scheduled to be repaired are one Band 4 and two Band 10 receivers. They will be removed from the receiver systems in the course of regular maintenance, and will be returned for repair in the next fiscal year or later.

Although the frequency of repairs caused by aging failure is currently kept low, an increase of the failure rate cannot be denied when the wear failure period begins according to the bathtub curve. In order to continue the stable operation of ALMA, it is important to maintain a maintenance system in ATC that can quickly respond to ALMA receiver failures.

To address the issue of long-term maintenance work, multiple persons were assigned to disassemble/ assemble receivers and conduct comprehensive evaluation tests for repaired Band 4 receivers to increase the number of experienced persons, record videos, improve procedures, and update procedure manuals. In addition, a remote conference system and remote operation of measuring equipment were used to provide instructions for key tasks and to discuss interpretation of the test results from receiver maintenance specialists working in remote locations.

The ALMA receiver maintenance team in ATC worked together with a resident engineer in Chile, who experienced the production of the receivers in Japan, to support the Joint ALMA Observatory for solving the problems for smooth operation of ALMA.

2) ALMA receiver development and upgrade

For development and upgrade of heterodyne receivers, we focus on two main activities in close coordination with the NAOJ ALMA Project. Firstly, we are involved in international collaboration for the development of ALMA receivers for the frequency bands not implemented in the array yet: Band 1 and Band 2. Secondly, we have engaged in receiver development to upgrade the ALMA telescope system in three main directions: wideband, terahertz, and multibeam receivers based on microfabrication technologies.

2-1) Receiver development for Bands 1 and 2

The Band 1 project (35–50 GHz) led by Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) as a contribution to East Asia ALMA is in the middle of the production phase. We have been contributing to the testing and production of corrugated horns, the support for cryogenic maintenance of cryocoolers at ASIAA, support for procurement and shipping of several important components, and support for shipment of receivers in cooperation with the NAOJ ALMA project. To ensure the smooth logistics from ASIAA to Chile, NAOJ has lent out 14 shipping containers in addition to two that had been already used. As of the end of FY 2021, ASIAA has completed production and in-house testing of more than

50 receivers, and the receiver acceptance in the ALMA OSF, and Assembly, Integration and Verification (AIV) activities are accordingly proceeded with the Joint ALMA Observatory.

Following from last FY, corrugated horns have been fabricated with the metal 3D printer and evaluated in close collaboration with the Manufacturing Design Group at ATC. In this FY, thanks to investigation of the 3D printed metal properties for the purpose of practical use in a cryogenic receiver, optimization of the fabrication method and process, and the detailed characterization of the corrugated horn, we have successfully manufactured the 3D printed corrugated horn products that meet the ALMA Band 1 receiver requirements. Accordingly, NAOJ held an internal review with ALMA partners about the 3D printed corrugated horn to be implemented into the ALMA Band 1 receivers. We have completed the RF testing at ATC and shipment of the 3D printed corrugated horns. They are being integrated on the Band 1 cartridge receivers and the final cryogenic performance test in-house will be conducted in ASIAA in FY 2022. NAOJ will also be in charge of Band 1 receiver maintenance in the operation phase, and therefore, the organization and facility for the maintenance will be established taking over from ASIAA from the end of FY 2022.

We have contributed to the Band 2 project (67–116 GHz) led by the European Organization for Astronomical Research in the Southern Hemisphere (ESO) with the design, fabrication, and testing of waveguide components and receiver optics based on a dielectric lens. For the Band 2 receiver preproduction (first 6 receivers) initiated in April 2019, NAOJ has manufactured optics and waveguide components including a corrugated horn, circular-square waveguide transition, and waveguide orthogonal mode transducer (OMT). Their RF characterizations have been performed at room temperature, and 4 Feed-OMT assemblies have been initially delivered to ESO for preproduction receivers. For the remaining assemblies, detailed verification has been conducted with respect to the RF evaluation. For the dielectric lens development, we have investigated the materials in terms of low loss properties and stability for machining and operation. The material candidates have been verified to check the influence of ultra-violet irradiation on the mechanical and electric properties. For the material properties, we have used the material characterization system established at ATC based on the free-space method and have obtained repeatable and reliable measurements. In close collaboration with the Manufacturing Design Group, the precision test pieces could be fabricated by a combination of normal and ultra-precision machining equipment. Thanks to these activities, we could obtain accurate and useful evaluation results for the material selection. The Band 2 project plans to hold the critical design review in April 2022. NAOJ has created the reports for detailed design verification of optics components and optics design based on evaluation result of the lens material.

2-2) Development for the next generation projects

Wideband receivers are being developed for ALMA Band 8 receiver upgrades. In this FY, we have designed and fabricated a corrugated horn and OMT implementing the recent technology development in collaboration with NICT. We also have designed a sideband separating mixer module that integrates waveguide circuits, mixer chips, and IF cryogenic amplifiers into a single block in collaboration with the University of Electro-Communications. Besides, for practical use of double sideband (DSB) mixers in this frequency band which has been developed until last fiscal year, we have provided the DSB mixers to domestic universities and institutes such as Keio University/ ASTE project, the University of Tsukuba/Kwansei Gakuin Universities, and the University of Electro-Communications/ RIKEN, and supported their installation and experiments in their laboratories. NAOJ has also collaborated with Osaka Prefecture University on the development of Band 6+7 (211–373 GHz) receivers. In this FY, we have successfully demonstrated the quantum limited performance over the IF 4–20 GHz across the RF range. This is the first demonstration of the wide IF mixer in this RF range, building on our success in the Band 7+8 (275–500 GHz) mixers reported in past years.

As for the terahertz technologies, we have designed and fabricated a two-layer anti-reflection structure on a silicon substrate in collaboration with the Microfabrication Laboratory. The fabricated one showed low-loss transmission characteristics across the Band 10 frequencies. This development will be continued towards practical use as a vacuum window for cryogenic receiver installation.

The multibeam heterodyne receiver technology based on monolithic microwave integrated circuits (MMIC) was further investigated in terms of transmission loss and its impact to sensitivity. An innovative method based on on-chip resonators was applied to accurately measure the transmission loss of superconducting thin film transmission lines adopted in the MMICs. The results showed reasonably low loss and provided favorable evidence that justifies the application of superconducting MMIC technology at millimeter frequencies.

In the Microfabrication group, we maintained the fabrication capability for Nb/Al/$AlN_x$/Al/Nb junctions with unusually high critical current density, which is the crucial requirement for broadband SIS receivers. We also proceeded with the investigation into fabrication of MMIC-type SIS mixers and anti-reflection surfaces based on the silicon micromachining technique. With these activities, the foundation is now in place for the stable production of high-quality devices for future ALMA development.

(3) KAGRA

In collaboration with the Gravitational Wave Project, we are developing vibration isolation systems (VIS) and auxiliary optics systems (AOS) of the KAGRA interferometer, and preparing instruments for evaluating the performance of its mirrors. Here the AOS includes optical devices or elements required for completing the interferometer, such as optical baffles to mitigate stray light effects, optical angle sensors, beam reduction optics (BRT), cameras for beam monitoring, and viewport windows. At the Kamioka site, overhauling the interferometer has continued since the last fiscal year as quickly as possible in order to be ready by the start of the 4th international gravitational-wave

observation run (O4; to start December 2022 or later). ATC contributed to this activity by assembling and delivering some AOS instruments such as a balancer for the vibration-isolation stage of the BRT, mechanical covers for the optical angular sensors, and their optical filters. We also responded quickly to one of the unexpected issues in the VIS instruments during the overhaul work. In addition, we continued to develop the mirror performance evaluation system.

(4) Next-generation Solar-observing Satellite: Solar-C (EUVST)

ATC has supported the SOLAR-C project in completing the design study of the EUVST spectrometer and contributed to the interface coordination between the main instrument structure and the components being provided by overseas partners. In addition, ATC has helped to prepare cleanroom facilities with a coelostat system that introduces the sunlight into the cleanroom for instrument calibration, vacuum chambers of various volumes, and contamination monitoring systems planned to be used during the development phase of the SOLAR-C project.

(5) Infrared Astrometric Observation Satellite: JASMINE

ATC is in charge of developing detectors for imaging and a detector box (DBA) for holding and cooling the detector.

The detector is a near-infrared detector using an InGaAs device and is being developed by the Optical Infrared Mission Instrument Team of the Advanced Mission Instrumentation Group. The status of the development in FY 2021 is described in section 3(2).

The DBA is being developed by the Thermal and Mechanical Design Team of the System Design Group, and in FY 2021, the team was able to demonstrate a feasible architectural design, and thermal and structural analysis in a conceptual study.

## 3. Advanced Technology Development

(1) Terahertz Technology

The terahertz experiment group supports development of superconducting detectors, cryogenic electronics, and cryogenic systems. Development of SIS photon detectors in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST) continued to improve the quantum efficiency of detectors with electromagnetic simulations using HFSS and FEKO software. A new development program for 1.5-THz SIS photon detectors was initiated using superconducting thin film facilities in ATC. Construction and improvement of two cryostats, one for photon statistics another for intensity interferometry, resulted in the good cryogenic performance required for optical experiments in the following year. Development of an MKID camera in collaboration with the University of Tsukuba has advanced by evaluation of test observation data followed by scientific observation of a star-forming region using the Nobeyama 45-m Radio Telescope. Evaluation of anti-reflection coating of silicon optical components using subwavelength structure was performed using the submillimeter-wave Fourier transform spectrometer, the results of which were published in Hasebe et al. (2021).

(2) Near-infrared Image Sensor

Image sensors for astronomical observation need extremely high performance, such as low noise, to detect faint objects. Near infrared image sensors for astronomy were only available from one company in the US until now. Since an image sensor is the heart of a scientific instrument, image sensors manufactured by a domestic company are highly desired especially for a space application to be able to proceed independent of foreign groups. We have successfully developed a near infrared image sensor in cooperation with a domestic company for a Subaru Telescope instrument proposed by us. In this year, we worked for fixing the specifications and design of a new domestic image sensor to be widely applicable for space use funded by the Front Loading program of JAXA's Institute of Space and Astronautical Science. The sensor will also achieve several performance improvements such as better sensitivity at the same time. The first prototype is planned to be manufactured next year. The new sensor has already been adopted by the JASMINE project instead of the US sensor. We also evaluated the effect of proton radiation on an InGaAs sensor in cooperation with the JASMINE group, and found it was within an acceptable range for the JASMINE project.

(3) Near-infrared Multi-object Spectrograph: SWIMS-IFU

ATC, in cooperation with RIKEN and Institute of Astronomy, the University of Tokyo has been developing a near-infrared integral-field spectroscopy unit (IFU) using ultra-precision cutting technology.

It is designed to be installed on the near-infrared multi-object spectrograph SWIMS, which is operated at the Subaru Telescope as a PI instrument since 2021. Its optics consists of more than 70 small mirrorlets of a few mm square. It divides the 14 x 10.4 arcsec field of view into 26 slitlets of 0.4 arcsec width, and spectra in the wavelength range of 0.9–2.5 μm can be obtained with a single exposure.

The problems in its development are how to suppress the effect of thermal deformation when cooling the whole system below 150 K to suppress thermal radiation, and how to align the axes of the many mirror surfaces. We are trying to solve these problems by making the entire structure out of aluminum alloy and using ultra-precision machining technology to cut and form all the mirror surfaces directly from the aluminum base material.

In FY 2021, we completed all of the mirror processing using RIKEN's ultra-precision machine. After assembly and testing at ATC, the IFU were transported to Subaru Telescope, installed on SWIMS, and successfully saw first light at the end of March. As a result, it was confirmed that the performance of the IFU mostly complies with the requirements.

(4) Sounding Rocket Experiment: CLASP2.1

The CLASP 2.1 project began full-scale preparations for the launch, which was scheduled for the fall of 2021, and ATC supported the planning of operations at the launch site. Particular attention was paid to the risk assessment for the re-flight of the instrument and the investigations of measures to be taken at the launch site. With these and other careful

preparations, the month-and-a-half long activities at the launch site went generally smoothly, and CLASP2.1 was launched on October 8, 2021 (local time) at the White Sands Missile Range in the United States. Both the sounding rocket and instruments performed flawlessly and successfully scanned the active region for approximately 6 minutes.

(5) US-Japan Solar Flare X-ray Focusing Imaging-spectroscopic Sounding Rocket Experiment: FOXSI-4

FOXSI-4 is being prepared for the launch in the spring of 2024. ATC is supporting the development and evaluation of high-speed cameras for soft X-rays using back-illuminated CMOS image sensors and a pre-collimator fabricated by the metal 3D printer. In FY 2021, a reflective type light reduction system using mirrors was developed for evaluation of CMOS sensors using a synchrotron radiation beam. This system overcomes the weakness of the conventional transmission-type attenuation method using filters (where contamination by higher-order wavelengths is inevitable) and enables us to easily obtain monochromatic X-rays with an appropriate flux, thus establishing an ideal evaluation method for CMOS sensors. In addition, FOXSI-4's camera system was started to be developed by the Optics Engineering Team of the System Design Group. In the development of the pre-collimator, the Additive Manufacturing Engineering Team of the Manufacturing Design Group started to take a development policy that would contribute to the advancement of the metal 3D printer technology.

(6) Balloon-borne Solar Observatory: SUNRISE-3/SCIP

For the SUNRISE-3 balloon experiment, NAOJ leads the development of a near-infrared spectro-polarimeter called SCIP. The optical unit of SCIP was designed and developed at ATC to achieve high imaging, spectral, and polarization performance in the thermal vacuum environment during the balloon flight. To repair a problem with the CMOS camera installed inside, the SCIP optical unit was reassembled and tested for imaging and polarization performance at the ATC clean-room, and the thermal, electrical, and optical functions were verified in vacuum using the ATC large space chamber. The SCIP development at NAOJ was completed in August 2021, and tests combined with the SUNRISE--3 1-meter aperture telescope were conducted in Germany. A paper is under preparation on the results of opto-mechanical design and analysis obtained in the development of SCIP.

## 4. System Design Group

The System Design Group designs and develops instruments for various astronomical projects and supports the planning and implementation of instrument performance verification. The System Design Group consists of three teams: thermal and mechanical engineering, optics engineering, and sensor engineering. From this year, the teams for instrument development have been organized into one group, enabling closer cooperation. In particular, thermal and mechanical engineering and optical engineering are inseparable in instrument development, and we have taken the first step toward optomechanical design that handles them in a unified manner.

(1) Thermal and Mechanical Engineering Team

The team continued the mechanical design and related tests of TMT/IRIS, TMT/WFOS, TMT/STR, KAGRA, Solar-C (EUVST), SUNRISE-3, and CLASP2.1 from the previous fiscal year. In addition, the design study of JASMINE was newly started this year.

The TMT/IRIS Imager team successfully passed the final design review in June after a two-year final design phase and continued to address the issues raised by the review board. Specifically, we created an FE (Finite Element) model of the entire Imager for vibration and thermal analysis, optimized the design of the ADC prism support mechanism, took measures against thermal stress in the Imager mounting bracket, and conducted a lifetime test of the slicer pick-off mechanism.

Conceptual design of the slit mask exchanger and slitmask fabrication facility was conducted for TMT/WFOS. After developing multiple concepts and discussing their trade-offs, the functional and physical designs were completed and reported in the WFOS conceptual design review held in February 2022. In addition, a cost evaluation of the future design phase was provided for TMT internal reviews.

TMT/STR finalized the interface documentation, drew the ISS and cooling system platforms, and supported the design review board for the piping and wiring subsystem (TUS) for the manufacturing readiness review scheduled before the start of the manufacturing process. In addition, an interim review meeting for the primary mirror replacement system (SHS) was held to prepare for the pre-production review meeting.

At KAGRA, a movable mass balancer was installed on the transmission monitor system on the vibration isolation stage and its performance was confirmed. Functional improvements were also made through the design of various hardware and modification of the control program. In addition to the above, improvements and modifications were made to the anti-vibration system and auxiliary optics for O4 observation at the site. Reinstallation of the Type-A (Y-end) vibration isolator was almost completed, and adjustment of Type-B (BS and SR systems) and Type-Bp (PR system) was also completed. In addition, an earthquake and other problems were addressed.

Our contribution has also advanced the conceptual study of the Solar-C(EUVST) mission payload, particularly for the telescope structure including analytical estimation of optical element deformation and mechanical interface control with components which will be provided by international partners. For the solar sounding rocket and balloon-borne experiments, we supported the shipping of SUNRISE -3/SCIP and the range operation planning for CLASP2.1.

In JASMINE, we were in charge of the thermal and structural design and analysis of the detector box (DBA) during the conceptual phase and confirmed its feasibility. In addition, we developed test equipment to investigate the performance

characteristics under the operational environment (around 200 K) of the TEC, which is being considered as one of the elements.

(2) Optics Engineering Team

The Optics Engineering Team is responsible for the development of optical systems and coating for astronomical instruments.

1) Development of optical systems

The team has been involved in numerous astronomical instrument projects in NAOJ, universities and research institutes, and has contributed to their development through its optical design to its performance verification. In FY 2021, the team contributed to NAOJ projects such as Solar-C(EUVST), KAGRA, SUNRISE-3, and TMT/WFOS. In addition, the team contributed to the following collaborative research projects: (1) development for the focal plane instrument for the Antarctic submillimeter-wave telescope, (2) development of the IFU for a Seimei Telescope instrument, (3) feasibility study of a large space telescope using a group of microsatellites, and (4) performance evaluation of the Gregorian reflecting telescope built in the Edo period. In addition to developments, the team collects development needs from several projects and conducts activities to introduce the optical equipment needed in the future. In FY 2021, we procured the parallel plane-plate measurement option and the ultra-high-precision reflective/transmissive flat for the high-precision Fizeau interferometer.

2) Development of coating

Fundamental experiments continued for improving coatings using inhomogeneous multilayers. The coating process monitor was renewed and improved, and various data as to the relation between the status of the coater and the film characteristics were obtained for longer processes in detail. A number of experiments modifying the ion-source electrodes to improve long-time stability of the beam current and its profile have been undertaken. And improvements of the control software have continued.

(3) Sensor Engineering Team

The Sensor Engineering Team consists of engineers who have been involved in the development of detectors and receivers for both domestic and international astronomical instruments. Specifically, the team has contributed to the design, development, and manufacturing of ALMA Band 1 and Band 2 receiver components; maintenance of ALMA receivers (Band 4, Band 8, and Band 10); micro-fabrication based on superconducting SIS devices; and the IPMU PFS project at the University of Tokyo. The development of detectors requires not only a single technology, but also the ability to deal with various technological areas such as electronics, mechanics, vacuum, and cryogenics. We will contribute to the development of astronomy with these comprehensive capabilities.

## 5. Manufacturing Design Group

The Manufacturing Design Group engages in a comprehensive manufacturing process to fabricate experimental and observational instruments, from fabrication to verification. All three teams (Additive Manufacturing (AM) Engineering Team, Machining Engineering Team, and Measurement and Evaluation Team) cooperate with each other to meet the various needs from NAOJ projects and other institutions through manufacturing. In this fiscal year, the AM Engineering Team, now in its second year of operation, responded to several requests. And the whole group had the opportunity to study and implement the process from additive manufacturing to finishing key parts such as interfaces by machining. We also work with the Thermal and Mechanical Engineering Team of the System Design Group on fabrication work.

One engineer was assigned to the project (June 2021).

(1) Machining Engineering Team

The Machining Engineering Team has responded to fabrication consultations and fabrication requests ranging from major NAOJ projects, groups at ATC, and open-use users. And, for users who wanted to work on their own, we provided guidance as needed. In addition, the 5-axis machining center is now in regular operation, and an ultra-high-precision wire electrical discharge machine was newly introduced and put into operation (March 2022).

The main requests are as follows:

i) Regarding TMT/IRIS, fabrication of parts for element tests is being conducted by the Thermal and Mechanical Engineering Team of the System Design Group.

ii) The fabrication of the mask frame for the near-infrared multi-object spectrograph SWIMS, to be mounted on the Subaru Telescope, was completed (continued from the previous fiscal year).

iii) Post-processing of metal 3D printer modeling for corrugated horns for ALMA Band 1 receiver, and KAGRA QPD circuit covers.

iv) Fabrication of a folding pendulum for KAGRA was started (to be continued in the following fiscal year).

As for fabrication by the Ultra-Precision Section, we have begun processing thin polyethylene sheets to be used as samples for material property tests in the ALMA radio frequency range. The work will be carried over to the next fiscal year since the number of samples is too many for ultra-precision processing, but some completed samples have already been delivered.

(2) Additive Manufacturing (AM) Engineering Team

As in the previous fiscal year, the AM Engineering Team has continued to learn about AM techniques including operation of the 3D printer and peripheral equipment, and modeling design.

FY 2021 was the second year of operation phase for AM Engineering Team, and we proceeded to develop and manufacture ALMA Band 1 corrugated horns which are set as the first item for the NAOJ AM Team. In this fiscal year, the detailed material property verification and fine-tuning of manufacturing parameters were conducted, and finally, we succeeded in making a component that completely meets specifications. This Fiscal Year, 32 horns were manufactured

as production components, and delivered to the NAOJ ALMA Band 1 team. Of particular note, in the material property verification we checked the effect of the thermal stress in the production component and annealing as a post process of the manufacturing for releasing the thermal stress, and reported the results in the 41st Symposium on Engineering in Astronomy. The electric board case for KAGRA, which like the ALMA Band 1 components is also a continuing item, proceeded to make a trial for checking the design and fitting for mounting. Then, 18 of the cover were manufactured and delivered. Through this manufacturing, we considered the design which allows one-touch assembly and disassembly despite being made of metal, and surface treatment which is suitable for putting inside of KAGRA.

As for new items, consideration and manufacturing of the first trial for some of the waveguide components were started, drawing on the experience gained through ALMA horn development. In addition, R&D collaboration was started with JAXA, the University of Tokyo, and Cybernet Systems Co., Ltd., in order to get deeper knowledge and apply it to astronomical observation devices. These new items will be continued to the next fiscal year.

(3) Measurement and Evaluation Team

The Measurement and Evaluation Team makes full use of various measurement instruments to verify and confirm the accuracy of products by the Machining Engineering Team and AM Engineering Team. In addition, LEGEX910, a large 3D measurement machine managed by the Management and Administration Group, is used to respond to requests for measurements for open use. In FY 2021, in addition to the usual evaluation, verification, and response to requests for measurement, to augment the team, our staff attended a measurement workshop for LEGEX910 arranged by the Management and Administration Group and started on-the-job training

The request for fabrication and measurement in FY 2021 are listed in Table 1.

**Table 1**: The requests for fabrication and measurement in FY 2021.

| | |
|---|---|
| From FY 2020 | 5 |
| FY 2021 | |
| Advanced Technology Center | 16 |
| ALMA, ASTE | 12 |
| TMT/IRIS, Subaru Telescope | 8 |
| KAGRA | 4 |
| Solar science, SOLAR-C, FOXSI-4 | 5 |
| RISE | 3 |
| JASMINE | 1 |
| Public Relations Center | 1 |
| Astrobiology Center/Exoplanets | 2 |
| Others | 2 |
| External Organizations | |
| University of Tokyo (TAO, SWIMS) | 7 |
| Osaka Prefectural University | 1 |
| Oita University | 1 |
| Total | 63 |
| To FY 2022 | 5 |

## 6. Management and Administration Group

As part of the reorganization of ATC, the Management and Administration Group has been established. The group consists of the Facility Management and Operation Team, the Administration Team, and the IT Support Team. The Facility Management and Operation team was reorganized from the former Facility Management Unit, Space Chamber and Space Optics Shop, and Optical Shop. The Management and Administration Group will support the smooth progress of projects from within ATC and NAOJ as well as for open-use research.

Facilities for open-use research are currently managed with the minimal personnel. ATC will discuss how much personnel will be allocated in the future.

Operation of the facilities for Fiscal Year 2021 are as follows:

(1) Optical shop

1) Management

At the Optical shop, measurement equipment such as non-contact and contact 3D measurement machines, spectrophotometers, and microscopes are available for open use. The equipment maintenance, including daily inspections, and technical consultations for measurement were provided, and this fiscal year, we arranged a workshop at the request of the Measurement and Evaluation Team of the Manufacturing Design Group.

2) Repairing and upgrading for measurement systems

• Replacement of Spectrophotometer (UV-3600iPlus)

3) Arrangement of workshop

• LEGEX910 measurement workshop (December 2021), attendance: 3

4) Open use

• The number of annual users: 199
  NAOJ: 132 (including 114 from ATC)
  External organizations: 67
• Use of LEGEX910 (large 3D measurement machine): 37 (including 19 from the Measurement and Evaluation Team of the Manufacturing Design Group.)
  Number of operating days: 43
• Technical consultation and troubleshooting: 21

(2) Space Chamber

As project support, we have participated in development activities of the balloon experiment Sunrise-3. We contributed to the preparation and operation of equipment for a thermal vacuum optical test of the SUNRISE-3/SCIP using a large space chamber in a clean room. We have also assisted the Solar-

C(EUVST) and the JASMINE Projects to conduct experiments using vacuum chambers in ATC.

In terms of equipment management, a dry vacuum pump for a large space chamber was overhauled in preparation for future environmental tests of a satellite telescope. In addition, a new high/low temperature bath circulator used for thermal vacuum tests was introduced due to the failure of the previous one. Software for the measuring instruments was continuously developed and operated, and new functions were added in response to user requests.

(3) Facility Management and Operation Team

The Facility Management and Operation Team conducted periodic inspections of the buildings, electrical equipment, cold evaporator (CE), cranes, forklifts, draft chambers, and other equipment according to law; and implemented the overall repair plan, including construction and hazardous materials for laboratories including clean rooms (CR). In addition, CE practical skills training was conducted as appropriate among the safety training courses. To correct the concentration of inspection workload on certain members of the team, we promoted the acquisition of qualifications within the team. In response to the COVID-19 disaster, we regularly replenished the alcohol used for disinfection in ATC building entrances and rooms. In addition, we gave a talk about COVID-19 preparedness at the 17th NIFS Workshop on Industrial Safety and Health.

After the renovation of the SIS CR two years ago, we have had problems such as temperature anomalies in the CR and fan filter unit (FFU) stoppage. The temperature anomaly in the CR was improved by modifying the temperature control parameters. And we tried to reduce the load on the FFU, such as changing the air supply position by root change, to improve the FFU stoppage. However, the FFU stoppage problem was not solved, so we will continue to investigate the cause of the FFU stoppage. In addition, the circulating cooling water pipelines in particular buildings were inspected and cleaned to reduce deterioration of water quality.

To accommodate the increase in the number of staff in ATC, a CR and the electronics shop were converted into office rooms, and the facilities in the previous rooms were relocated to other rooms.

Promoting the ALMA 2 project, we planned to expand the existing SIS CR. Since the conventional vertical laminar flow CR could not provide the necessary ceiling height for the installation of process machines after the renovation, we planned a side laminar flow CR in this facility.

## 7. Open-Facility Program, Joint Research and Development Program

ATC accepts external researchers based on two programs, one is an Open-Facility program which only uses common-use facilities of ATC and the other is a Joint Research and Development program which is a collaborative development with ATC members.

In FY 2021 we made calls for these programs twice, then accepted 20/3 Joint Research Development programs in the first/last calls, and 13 Open Facility programs.

Due to COVID-19, visits of external researchers to ATC were significantly restricted since FY 2020, however, we resumed the use of the facility with high urgency by taking countermeasures against infection.

## 8. International External Evaluation

The international external evaluation was conducted as an online meeting in March 2022. The evaluation committee consisted of six reviewers from four countries (Japan, the U.S., Italy, and Australia), including two women. In this evaluation, ATC's activities over the past five years were assessed from the following five perspectives and evaluation criteria.

1) Are the goals of ATC appropriately defined in line with the third mid-term goals of NAOJ, and is the organization being managed in an appropriate manner?
2) Does ATC produce internationally outstanding results, especially when compared to the size of the center?
3) Does ATC contribute to the creation of results in accordance with NAOJ's third mid-term plans?
4) As an Inter-University Research Institute, does ATC cooperate with universities and other organizations to contribute to their achievements and the development of young researchers?
5) Does ATC respond appropriately to the evaluation results?

The review meeting was held online due to the COVID-19 disaster. However, since the participating members were located in multiple time zones (Japan, the U.S., Europe, and Australia), it was not possible to hold a long meeting in one day, so the meeting was held over three days in short sessions. The virtual lab tour was also very well received, as it allowed for a real-time question-and-answer session to be conducted as appropriate, with an explainer guiding the participants through the interior of ATC with a camera.

As a result of the review, we received 'Excellent' for criteria (2) and (3), and 'Excellent/Good' for (1), (4), and (5). The most important thing was that we ourselves objectively recognized the achievements of our activities. We will work earnestly to resolve the issues that were pointed out by the review board.

# 16. Public Relations Center

## 1. Overview

The Public Relations Center engages in the publication, promulgation, and promotion of scientific achievements made not only by NAOJ but also by others in the field of astronomy in general to raise public awareness; responds to reports of discoveries of new astronomical objects; and provides the ephemeris and other astronomical information directly related to people's everyday activities, such as sunrise and sunset times. The Public Relations Center is comprised of 7 offices, 1 unit, and 1 observatory: the Public Relations Office, the Outreach and Education Office, the Spectrum Management Office, the Ephemeris Computation Office, the Library Unit, the Publications Office, the IAU Office for Astronomy Outreach (OAO), Ishigakijima Astronomical Observatory, and the General Affairs Office.

## 2. Personnel

In FY 2021, the Public Relations Center was composed of Director Hitoshi Yamaoka and the following staff members: 2 project professors, 2 associate professors, 2 assistant professors (each holds concurrent posts), 1 research engineer, 1 engineer, 1 unit leader, 6 senior specialists, 3 project research staff members, 2 research experts, 2 administrative experts, 2 research supporters, 14 public outreach staff members, and 3 re-employment staff members.

On April 1, research supporter Shizuka Nakajima arrived in the IAU Office for Astronomy Outreach.

On May 1, project researcher Takashi Shibata arrived in the Ephemeris Computation Office.

On June 1, senior lecturer Masaaki Hiramatsu arrived in the Spectrum Management Office.

On August 31, senior specialist Kumiko Usuda-Sato (Public Relations Office) and senior specialist Hansen, Izumi Ka Hoku Hula O Kekai (IAU Office for Astronomy Outreach), resigned.

On September 1, senior specialist Hiroko Komiyama arrived in the Public Relations Office.

On September 11, senior specialist Hiroko Tsuzuki (Public Relations Office) resigned.

On November 1, senior specialist Filipecki Martins Suzana arrived in the IAU Office for Astronomy Outreach.

On February 28, project research staff Member Takashi Horiuchi (Ishigakijima Astronomical Observatory) resigned.

On March 1, senior specialist Blumenthal Kelly arrived in the IAU Office for Astronomy Outreach and project research staff member Hidekazu Hanayama (Ishigakijima Astronomical Observatory) advanced to senior lecturer.

On March 31, unit leader Mizuho Tamefusa (Library) resigned.

## 3. Public Relations Office

Through press conferences and web releases, the Public Relations Office actively developed public outreach activities focused around the results of each research project, first and foremost ALMA and Subaru Telescope, including open-use and collaborative results with other universities and research institutes. In addition, our office hosted lectures to publicize cutting-edge astronomy. In cooperation with the Outreach and Education Office, the Public Relations Office also created content that explains various astronomical phenomena. We conduct not only public outreach activities using social media and video streaming services, but also new forms of public outreach such as Citizen Astronomy and exhibits at international events in response to the mid-term goals and suggestions from the External Review.

(1) Online-Based Information Sharing

The Public Relations Office runs the NAOJ website (https://www.nao.ac.jp/en/), disseminating information via the internet. Table 1 shows the access counts for the website.

The Office opened Twitter, Facebook, and Instagram accounts in both Japanese and English sequentially from 2010, actively disseminating information on social networking services. Our office disseminates information on the status of various NAOJ projects such as public visits, regular stargazing parties at Mitaka Campus, and position openings, both in English and Japanese. As of the end of March 2022, we have over 240,000 followers on our Japanese Twitter account and over 8,800 followers on our English Twitter account. Information dissemination via the English version of Twitter, as well as the release of visual images on Instagram have been conducted continuously this year.

NAOJ e-mail newsletters No.227–236 were issued, introducing research results and NAOJ hosted events. A total of

| Month | Access counts | Month | Access counts | Month | Access counts |
|---|---|---|---|---|---|
| April 2021 | 534,726 | August 2021 | 1,042,804 | December 2021 | 1,280,021 |
| May 2021 | 1,184,064 | September 2021 | 1,088,705 | January 2022 | 897,306 |
| June 2021 | 605,150 | October 2021 | 877,586 | February 2022 | 549,401 |
| July 2021 | 762,820 | November 2021 | 1,457,828 | March 2022 | 423,532 |
| Total: 10,703,943 | | | | | |

**Table 1**: Monthly website access statistics for the Public Relations Office website, NAOJ Public Relations Center (April 2021–March 2022).

10,967 subscription addresses have been registered as of March 31, 2022.

We continued to produce videos explaining astronomical phenomena and research results, and videos introducing outreach activities. Including English versions, 23 original videos were produced (Table 2). The videos are uploaded mainly on YouTube. During FY 2021 these videos accumulated a total of 5.92 million hours of play time (2.39 million hours in FY 2020) and 9.24 million views (3.75 million views in FY 2020). Both figures represented an approximately 2.5-fold increase compared to those of the previous fiscal year.

"Gravitational Wave Telescope KAGRA—Revealing the Universe Through the Curvature of Space-time," a video created this fiscal year, received the Science Museum Director's Award at the 63rd Science and Technology Film/Video Festival. We also focused on livestreaming. We received positive feedback for our live stream of celestial bodies with the 50-cm Telescope for Public Outreach, and of a lunar eclipse, which was observed simultaneously from three locations: Mitaka Campus, Ishigakijima Astronomical Observatory, and the Subaru Telescope. In addition to uploading videos on our YouTube channel, we have been approved as an official program by DWANGO Co., Ltd., which manages niconico Live, a video streaming service, and our viewers are increasing. The livestream of the total lunar eclipse on May 26, 2021, attracted 425,128 viewers and the recorded video achieved over 2.20 million views. The recorded video of the partial lunar eclipse livestream from November 19, 2021, also garnered nearly 300,000 views. These high numbers of views are likely due to people staying at home during the lingering novel coronavirus (COVID-19) pandemic. From November 2020 to December 2021, an online mini-lecture for elementary school students was delivered once a month. In addition, explainer videos were created before the lunar eclipses. Nobeyama Radio Observatory Special Open House Day and Mitaka Open House Day were both held online and livestreamed.

(2) Research Result PR

There were 23 research result announcements (compared to 30 in FY 2020 and 33 in FY 2019). We released all the research releases in both English and Japanese. For domestic audiences, we have continued to organize press conferences, as well as mail press releases to an original media list. For press releases aimed towards overseas audiences, we have continued to use the delivery services of AlphaGalileo, and EurekAlert! from AAAS, and mail press releases to an original media list.

This fiscal year, no sessions of "Astronomy Lecture for Science Journalists" were held.

(3) Activities as NAOJ's Public Relations Center

The following activities were pursued in addition to the Center's regular task of aiding research result releases.

We have started a Public Relations blog since May to provide various information related to astronomy and NAOJ. By March 31, 45 articles were posted and viewed a total of 450,000 times.

The Public Relations Office organized the 33rd National Institutes of Natural Sciences Symposium "The Universe, Molecules, and Us." The lectures by 4 speakers were held online on NAOJ's official YouTube channel on March 13, 2022. The live event was viewed by up to 393 simultaneous viewers, and its video archive was viewed over 20,000 times by April 21. To raise NAOJ's international profile, we regularly hold booths at international meetings where the press, researchers, and educational officials gather. This fiscal year, we held the sponsored session "KAGRA, Japan's Large Gravitational Wave Telescope" at the European Astronomical Society Annual Meeting 2021 (EAS 2021) on June 28, 2021, and this session was attended by over 70 people. We also hosted an online exhibition booth at the 2022 AAAS Annual Meeting (AAAS 2022, held online from February 17 to 20). This booth featured the English versions of videos we have produced so far and downloadable content, such as the Four-Dimensional Digital Universe Viewer Mitaka, in addition to materials describing NAOJ's projects.

We also worked to enrich the existing web content by creating interview articles for four staff members; revamping NAOJ VR, a 360-degree panorama viewer that enables users

| | |
|---|---|
| Astronomical Event Information Movies (April 2021 to March 2022, uploaded monthly, totaling 12 videos) | Japanese Version |
| Let's Watch the Total Lunar Eclipse on May 26, 2021 | Japanese Version |
| Gravitational Wave Telescope KAGRA—Revealing the Universe Through the Curvature of Space-time | Japanese Version |
| NINS Young Researcher Award Lecture | Japanese Versions |
| How to Use the NAOJ Telescope Kit | Japanese Version |
| GALAXY CRUISE: Report by the Captain - A new picture of the galaxy | Japanese/English Versions |
| Let's Watch the Partial Lunar Eclipse on November 19, 2021 | Japanese Version |
| Venus Occultation (November 8, 2021) | Japanese Version |
| Mars Occultation (December 2, 2021) | Japanese Version |
| Asteroid 7482 (1994 PC1) | Japanese Version |
| 30-Second NAOJ Introduction Video for NINS Symposium | Japanese Version |

**Table 2**: Summary of Produced Videos.

| | |
|---|---|
| April 6, 2021 | Exploring Comet Thermal History: Burnt-out Comet Covered with Talcum Powder |
| April 16, 2021 | Surprise Twist Suggests Stars Grow Competitively |
| April 22, 2021 | ALMA Discovers Rotating Infant Galaxy with Help of Natural Cosmic Telescope |
| May 6, 2021 | A New Window to See Hidden Side of Magnetized Universe |
| May 10, 2021 | Star Formation Triggered by Cloud–Cloud Collisions |
| May 14, 2021 | Charting the Expansion History of the Universe with Supernovae |
| June 11, 2021 | ALMA Discovers Earliest Gigantic Black Hole Storm |
| June 29, 2021 | A New Type of Supernova Illuminates an Old One |
| July 2, 2021 | Observation, Simulation, and AI Join Forces to Reveal a Clear Universe |
| July 7, 2021 | Small Amount of Lithium Production in Classical Nova |
| July 8, 2021 | New Radio Receiver Opens Wider Window to Radio Universe |
| September 8, 2021 | First Light with the ALMA Band 1 Receiver |
| September 10, 2021 | Largest Virtual Universe Free for Anyone to Explore |
| September 15, 2021 | Untangling the Formation of Planetary Systems with Deuterium |
| October 7, 2021 | First ALMA Animation of Circling Twin Young Stars |
| November 13, 2021 | Simulations Provide Clue to Missing Planets Mystery |
| December 2, 2021 | Stellar Cocoon with Organic Molecules at the Edge of our Galaxy |
| December 14, 2021 | Stellar "Ashfall" Could Help Distant Planets Grow |
| December 23, 2021 | Billions of Starless Planets Haunt Dark Cloud Cradles |
| February 25, 2022 | Deep Neural Network to Find Hidden Turbulent Motion on the Sun |

**Table 3**: Web Releases.

| | |
|---|---|
| April 14, 2021 | Telescopes Unite in Unprecedented Observations of Famous Black Hole |
| May 19, 2021 | ALMA Discovers the Most Ancient Galaxy with Spiral Morphology |
| September 21, 2021 | Unveiling Galaxies at Cosmic Dawn That Were Hiding |
| December 9, 2021 | Fiery Dragon's Breath May Scorch Young Planets |

**Table 4**: Press Conferences.

to virtually visit popular places in Mitaka Campus; and adding information on notable astronomical phenomena (Venus and Mars occultations) and images and videos of celestial objects (M45 and M37).

The website terms of use were revised to improve the usability, particularly in the secondary use of copyrighted material. To support outreach efforts of other projects, we contributed to revamping the website for the Office of International Relations (website creation and translation).

(4) New Astronomical Objects

Four staff members, including one full-time and three contract employees, handled reports of new astronomical objects and other communications submitted to NAOJ. In this fiscal year, there were a total of 34 reports including confirmation requests for new celestial object candidates and other reports. The contents were: 27 novae/supernovae, 4 comets/cometary objects, 1 luminous object, and 2 moving objects. Although no new astronomical objects (novae, supernovae, or comets) were confirmed in these reports, 10 of them were confirmed to be dwarf novae or flare stars.

(5) Citizen Astronomy (Shimin Tenmongaku)

The GALAXY CRUISE website, through which citizens participate in galaxy classification, was developed and launched in 2019 as a joint effort with Subaru Telescope. As in last fiscal year, we implemented campaigns in August and the end of the year, striving to boost the number of both participants and classified galaxies. As of April 1, 2022, a total of 9,742 people (of which 6,854 are from Japan) from 92 countries and regions have registered, and the total number of classification results has exceeded 2.5 million. Sufficient classification results have already been obtained to allow a statistical analysis of each one of the classified galaxies. The initial analysis of the results has confirmed that galactic structures and collisional remnants are more visible in GALAXY CRUISE than in any preceding similar projects. We also advanced the planning and development for launching GALAXY CRUISE Season 2, in which fainter galaxies are to be classified, in the next fiscal year. The GALAXY CRUISE project appeared in news coverage on TV and in newspapers repeatedly, and we received many invitations to speak at international conferences and seminars.

"Citizen Astronomy" ("Shimin Tenmongaku" in Japanese)

| | Solar Ephemeris | Lunar Ephemeris | Ephemeris | Time | Solar System | Universe | Astronomy | Other | Total |
|---|---|---|---|---|---|---|---|---|---|
| April–June | 111 | 176 | 36 | 10 | 129 | 66 | 46 | 255 | 829 |
| July–September | 77 | 53 | 41 | 4 | 173 | 108 | 56 | 178 | 690 |
| October–December | 125 | 151 | 25 | 3 | 315 | 91 | 48 | 332 | 1,090 |
| January–March | 89 | 70 | 28 | 8 | 111 | 66 | 39 | 207 | 618 |
| Total | 402 | 450 | 130 | 25 | 728 | 331 | 189 | 972 | 3,227 |

**Table 5**: Telephone inquiries made to the Outreach and Education Office of the NAOJ Public Relations Center (April 2021–March 2022).

conducted at NAOJ is an example of "Citizen Science" in which researchers / research institutes and the public collaborate on scientific activities.

## 4. Outreach and Education Office

In FY 2021, the COVID-19 pandemic forced us to suspend, scale down, or restructure many of our outreach and education activities.

(1) Public Visits

A total of 6,750 people participated in Mitaka Campus Public Visits (former name was Visitors' Area) in FY 2021. In addition, the group tours in 2021 consisted of 15 general tours (436 guests), for a total of 7,186 guests visiting Mitaka Campus. Public visits scheduled for April 25–June 20, 2021, and July 12–September 30, 2021, were all canceled to prevent the potential spread of COVID-19. Even after the public visits program resumed, we implemented preventive measures, restricting public access to within the outdoor areas, and canceling the acceptance of general group tours.

Regular stargazing parties, which are usually held twice a month (the day before the 2nd Saturday and the 4th Saturday) with the 50-cm Telescope for Public Outreach, were canceled in FY 2021 due to the COVID-19 pandemic as they were last fiscal year. Instead of on-site stargazing parties, "online stargazing parties" were held on YouTube Live every fourth Saturday from April 2021 to January 2022 (excluding October due to Mitaka Open House Day), and on every Friday before the second Saturday and every fourth Saturday from February to March 2022. These online events have taken place 13 times and accumulated 15,178 views as of April 7, 2021. Using the 50-cm telescope, we also photographed an asteroid making a close approach to Earth and shared the photos and information on social media.

Regular public screenings at the 4D2U Dome Theater were originally scheduled to be held three times a month (1st, 3rd Saturday, and the day before the 2nd Saturday) on a reservation basis. However, the reduced event days (35 days to 9 days) and capacity (from 40 seats to 14 seats) due to the COVID-19 pandemic resulted in only 340 visitors. "Astronomers' Talks" mini-lectures and public screenings for groups were both canceled. In addition, 22 group tours (141 people) were organized and a total of 481 guests watched the 4D2U stereoscopic movies.

(2) Telephone Inquiries

Since this fiscal year, the starting hours for telephone inquiries have been changed from 9:00 a.m. to 9:30 a.m. to ensure sufficient time for preparation.

Since last fiscal year, our inquiry service has continued to operate on a rotating shift basis with one person assigned to each shift, except for seasons in which many inquiries are expected. This fiscal year, two people were assigned to each shift during the seasons around the Perseids (August) and a partial solar eclipse (November 19). As they did last year, inquiries operators worked on-site or from home at their discretion to prevent the spread of COVID-19.

The number of telephone inquiries to which we responded this fiscal year totaled 3,227, of which 457 were from the media (Table 5), whereas the number of letter inquiries totaled 72, of which 28 were official documents.

(3) Media Reception

We received 110 interview and filming requests from various media. Among these, we dealt with 101 requests. The contents were: 29 newspaper articles; 36 TV programs (11 news programs, 2 science programs, 23 others); 19 publications (7 magazines, 3 books, 9 others); 9 websites and contents; 4 radio programs; 4 others (2 private location shootings, 1 commercial, 1 event). From FY 2019, we started to charge a fee for commercial filming and photography in the campus. This fiscal year, we received filming requests for 1 TV program and 1 Web TV program.

(4) Educational and Outreach Activities

The "FUREAI (Friendly) Astronomy" project, now in its 12th year, continued to provide the online lectures introduced last fiscal year in addition to conventional on-site lectures. These lectures were delivered at 118 schools, 75 in Japan and 43 overseas, by 65 instructors and attended by 9,480 pupils, with the number of attendees per lecture ranging from 3 to 996. In 12 years, 82,678 students in total have attended the lectures in 872 schools inside and outside Japan.

"Mitaka Open House Day" was held online this year as it was last year, and we participated as part of the secretariat under the direction of the steering committee, and contributed to some pieces of the content. This year's event was held on October 23 (Saturday) with the theme "Looking back on the 10 years ALMA's research findings." It was co-hosted by the Astrobiology Center, National Institutes of Natural Sciences; the Institute of Astronomy, the School of Science,

the University of Tokyo; and the Department of Astronomical Science at the School of Physical Sciences of the Graduate University of Advanced Studies. Unlike last year's event, where a single live program was created, this year's event consisted of 3 main online lectures, livestreams by NAOJ's projects, video contents, and web contents. The number of event contents totaled 103, including 21 livestreams (including YouTube Premiere events), 45 video contents, and 37 other web contents. The total number of simultaneous connections reached 2,054, and the video garnered 60,300 views in the first month of its release.

(5) Community Activities

The "Mitaka Picture Book House in the Astronomical Observatory Forest" welcomed 17,472 visitors in FY 2021. The Office supervised an exhibition, "The Unfolding Universe—Past, Present, and Future." (July 2021 to June 2022). Unfortunately, the COVID-19 pandemic forced this year's traditional Tanabata and moon viewing events to be canceled. In addition, through the "Mitaka Picture Book House in the Astronomical Observatory Forest, Picture Book Original Drawings Hallway Exhibit Contest" which started from FY 2013, the Outreach and Education Office cooperated in the selection of 7 winning books.

"Mitaka TAIYOKEI walk," a stamp collecting event that takes place every fall under the joint auspices of Mitaka City and Mitaka NETWORK University Organization, was held in a contactless way to avoid any potential spread of COVID-19, with a smartphone application collecting digital stamps instead of physical ones. During the event, lectures on the Solar System, a stargazing party, and a workshop for building an actual telescope were held as "Mitaka TAIYOKEI walk-related lectures," in which NAOJ cooperated.

The Office also provided the venue for "Astronomy Course for Apprentice Starry Sky Guides, Star Sommelier Mitaka - Let's Become Apprentice Starry Sky Guides! -" hosted by Mitaka NETWORK University Organization, and assisted by providing teachers and workshops. We also contributed to selecting lecturers for "Astronomy Pub" (currently held online).

The "Information Space of Astronomy and Science," which is jointly operated by Mitaka City, Mitaka NETWORK University Organization, and Mitaka Town Management Organization, marked the sixth anniversary since its opening in September 2015. In FY 2021, a total of seven exhibitions were held at this facility, of which the one titled "Exploring Our Origin in the Universe—Ten Years of ALMA" was planned and held by NAOJ. This event ran from December 3 (Friday), 2021 to January 30 (Sunday), 2022, and attracted 1,279 visitors. At the facility, the Office played videos on large displays to publicize NAOJ and provide information about the night sky and distributed NAOJ News bulletins and monthly guide materials about the night sky. This fiscal year saw a total of 9,945 visitors. Although the number dropped by about 5,300 compared to an average year before 2019 due to an entry restriction implemented in response to the COVID-19 pandemic, the facility has received over 94,000 visitors since its opening. It is now recognized as a place where the public can get to know more about science in an urban environment.

(6) Merchandizing Business

The NAOJ Telescope Kit has been on the market since FY 2019. In Japan, this kit goes by the name "NAOJ Telescope Kit," whereas the IAU calls it "Kaifu-NAOJ Telescope Kit." This 5-cm aperture telescope kit, with eyepieces of 16x and 66x magnification, started to be sold and distributed in July 2019. A total of 3,249 kits were sold this fiscal year, with the total cumulative sales reaching 7,644 kits.

We run "Astronomical Events Information" on the NAOJ website to provide monthly star charts and information on planetary and other remarkable astronomical phenomena.

This fiscal year, intended particularly for the media, articles detailing the remarkable astronomical phenomena of the year (the Perseids in August and a partial lunar eclipse on November 19) were created and posted on "Astronomical Events Information."

## 5. Spectrum Management Office

This is the third year since the establishment of the Spectrum Management Office (SMO) in 2019. With a new associate professor (senior lecturer) appointed on June 1, 2021, the SMO currently consists of four members, of which three are dedicated members (Head, an associate professor, and a research supporter) and one holds a concurrent post. The SMO handles a broad range of operations, both domestic and international. At the time of establishment, we focused mainly on the protection of the radio astronomy environment, but since the rise of mega-constellations issues we have been acting on light pollution as well.

In fiscal year 2021, the SMO participated in 18 international meetings and 28 domestic meetings. In addition to these, the SMO also participated in e-mail discussions and video conferences and responded to media inquiries.

(1) International Meetings

The SMO participated in Working Party 7D (WP7D) hosted by ITU-R, the radiocommunication sector of the International Telecommunication Union (ITU) responsible for radio astronomy issues, and contributed to the discussion.

This year's WP7D meetings were held online from April 12 to 16, 2021, and from September 16 to 23, 2021, because the ITU headquarters were temporarily closed and travel to and from Europe was restricted due to the COVID-19 pandemic. Both meetings focused on topics such as the compatibility between mobile phone use and radio astronomy in the 6–7 GHz and 43 GHz bands, issues to be studied for realizing radio astronomy observations in lunar surface radio quiet zones, and sharing of the frequency bands above 71 GHz between active services and radio astronomy. These meetings also discussed a new draft report to emphasize the importance of geodetic VLBI and a new draft report on radio observations with distributed antennas in the millimeter and submillimeter bands, as well as

revising a report on radio quiet zones.

The SMO also held online meetings as needed to exchange opinions and strengthen relationships with people involved in the protection of radio astronomy.

(2) Results and Current Status of Domestic Issues Discussed

Among the issues discussed by the MIC Information and Communications Council, the major ones related to radio astronomy are described here.

1) Frequency Expansion for Wireless LAN into the 6 GHz Band: Although wireless LAN systems currently operate in the 2.5/5 GHz bands, these frequency bands are increasingly congested. Given this situation, the possible allocation of the 6 GHz band (5.925–7.125 GHz) to the wireless LAN service was discussed. In this frequency band, frequencies ranging from 6.665 to 6.66752 GHz, where $CH_3OH$ maser emissions exist, are reserved for the radio astronomy service. Sharing studies with the radio astronomy service found that Low Power Indoor and other even lower power modes were likely to cause significant interference and thus concluded that the sharing of this frequency band is not feasible. It was also found that for some other services, sharing of the band is not feasible, and thus the 5.925–6.425 GHz band was newly selected to be allocated to the wireless LAN service. No harmful interference with $CH_3OH$ maser observations are therefore to be expected for the time being.

2) Studies on the 76–77 GHz Band Sharing with Vehicle-Borne Millimeter Wave Radar: To ensure a wide angle and a sufficient range, studies to improve vehicle-borne radar have been ongoing. In this frequency band, both radar (radiolocation) and radio astronomy are supposed to use the same frequency band. To prevent radar systems from interfering with radio astronomy observations, the SMO participated in informal meetings with vehicle millimeter-wave radar manufacturers and discussions in the MIC 76 GHz Low Power Millimeter-Wave Radar Working Group. The SMO reviewed the acceptable interference level described in the ITU's recommendation and exchanged opinions about the calculation method for interference estimation. These studies are expected to continue into FY 2022.

3) Outdoor Use of UWB Systems: To avoid $CH_3OH$ maser observations at 6.7 GHz being adversely affected, it was agreed that operational manuals for UWB systems must instruct the users not to use the systems around radio observatories.

4) Wireless Power Transmission (WPT) Systems: WPT systems use the 920 MHz, 2.4 GHz, and 5.7 GHz bands to transfer electric power, and thus they should adversely affect not only ratio astronomy observations but also various radio communication systems. To prevent any interference from occurring, it was decided to register radio observatories in a database and avoid using WPT systems around these observatories. When the MIC later called for public comments on this matter, the descriptions on the setting of operation coordination areas included a factual error, which the SMO pointed out and requested correction in its public comment.

5) Space Cellular: Space Cellular allows existing mobile phones to communicate directly with satellites, thereby enabling the devices to connect to the internet even in ground areas with no base stations. Japanese cell phone companies are considering introducing Space Cellular. Because the frequencies used for communications between the satellites and the ground base stations were expected to affect the 42.5–43.5 GHz and 49 GHz radio astronomy bands (SiO and CS), the SMO carried out studies evaluating potential interference to the radio astronomy service. These studies found that the main beams from the satellites must not be directed towards radio astronomy antennas, and that the 42.0–42.5 GHz band needs to be excluded from the emission bands. Bringing Space Cellular into practical use needs not only technological evaluations, but also changes to the Radio Law and the Radio Regulations. Many issues remain to be discussed.

(3) Application for Receiving Equipment Designation: Designation of receiving equipment should be conducted based on the Radio Law, Article 56. Once it is approved, a radio station must be operated in such a way as not to cause interference or any other obstruction that impairs the operation of radio astronomy stations or equipment designated by the Ministry of Internal Affairs and Communications. In Fiscal Year 2021, we submitted no applications for designating or renewing facilities.

(4) Light Pollution

1) Light Pollution Caused by Mega-constellations (such as Starlink): The IAU and NAOJ issued statements in 2019 that express concerns over the possible impacts of mega-constellations, such as Starlink and OneWeb, which aim to deploy large swarms of satellites to provide internet access around the world. SpaceX, which operates the Starlink satellites, has committed to reducing the satellites' reflectivity by developing a dark-painted satellite called "DarkSat" and a visor-equipped satellite called "VisorSat." In response to these efforts, Ishigakijima Astronomical Observatory observed these satellites in the U, B, g', Rc, Ic, J, H, and K bands, working together with the Optical and Infrared Synergetic Telescopes for Education and Research (OISTER). The SMO assisted in analyzing and interpreting the data obtained by Ishigakijima Astronomical Observatory.

The IAU Office for Astronomy Outreach (OAO) recently launched a new project, "Dark and Quiet Sky," to raise international public awareness about light pollution. The SMO supports this project and helped the OAO create an interview video. An SMO member served as part of the Scientific Organizing Committee of the IAU co-sponsored Dark and Quiet Skies Workshop 2 and contributed to making the workshop successful.

(5) Activities for Raising Awareness of Frequency Resource Management

To make more people aware of frequency resource management, the SMO created a brochure explaining the SMO's activities and the importance of frequency resource management, particularly in radio frequencies. This brochure is to be distributed at Mitaka Campus, Nobeyama Campus, the VERA stations, and Ishigakijima Astronomical Observatory. The SMO informed domestic radio observatory operators of our intention to provide the brochure as needed and sent it to 14 of them, including MIC, MEXT, and local communication stations.

The SMO website has been updated on a continual basis. This fiscal year, in addition to enriching the glossary of radio astronomy terms, we launched the English website to provide information to international audiences.

## 6. Ephemeris Computation Office

The Ephemeris Computation Office (ECO) estimates annual astronomical phenomena including the apparent places of the Sun, Moon, and planets based on international standards and publishes the "Calendar and Ephemeris" as part of the compilation of almanacs, which is one of NAOJ's raisons d'être.

Project researcher Takashi Shibata has joined ECO since May 2021.

(1) ECO published the "Calendar and Ephemeris 2022" and compiled the ephemeris section and several parts of the astronomy section from the "Rika Nenpyo 2022" (Chronological Scientific Tables). ECO also posted the "Reki Yoko 2023" in the official gazette on February 1, 2022. In addition to those paper-oriented products, ECO maintains web versions of the "Calendar and Ephemeris" and the "Reki Yoko" and updated their data simultaneously with the release of "Reki Yoko." In the "Calendar and Ephemeris 2022," ECO revised the visual magnitude of planets for the first time in over 30 years and explained the details in its topics page. As for the "Rika Nenpyo," ECO has taken responsibility for several pages in the ephemeris and astronomy section since FY 2020.

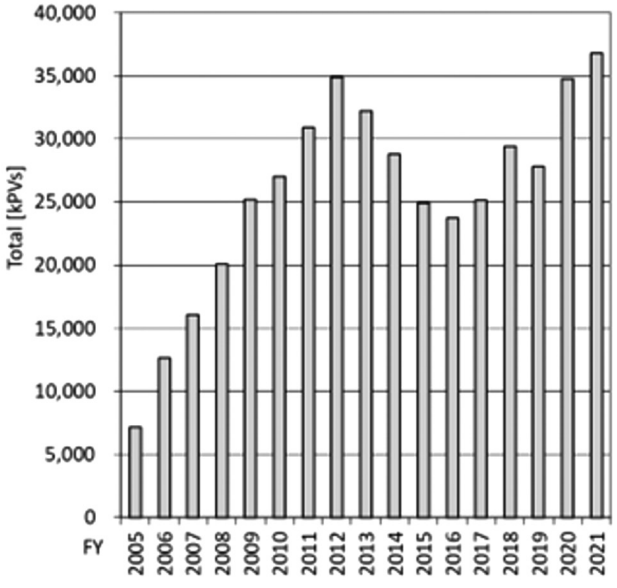



**Figure 1**: Pageviews for ECO Website.

(2) ECO featured lunar eclipses and the 1st sunrise of the year on its website. Despite the end of the astronomical phenomena awareness campaigns by OEO, ECO displayed the radiant points of the Perseid, Geminid, and Quadrantid meteor showers and the place of Comet Leonard in the Sky Viewer. In FY 2021, there were over 36 million page views for the ECO website.
https://eco.mtk.nao.ac.jp/koyomi/index.html.en

(3) The Japan Association for Calendars and Culture Promotion, hereafter JACCP, held a mini forum and its 11th General Meeting via remote conference service. JACCP also held the annual Calendar Presentation Ceremony with a limited number of people and delivered its lecture via a remote conference service. The update of the Yoshiro Okada collection site which holds the research materials collected by the late Dr. Yoshiro Okada, the Supreme Academic Advisor of JACCP, is still under way.
https://library.nao.ac.jp/kichou/okada.html

(4) ECO holds a regular exhibition presenting NAOJ's invaluable collection of historical archives of Japanese and Chinese books in collaboration with the library. ECO started the 59th exhibition "Promotional Calendars from the Yoshiro Okada Collection" which was delayed due to the COVID-19 pandemic. Past exhibitions are available at the Rare Materials Exhibition website.
https://eco.mtk.nao.ac.jp/koyomi/exhibition/

## 7. Library Unit

The Library Unit collects and sorts scientific journals and books in order to make them available for the research and study of NAOJ researchers and students. In recent years, with the continuing digitalization of scientific materials, the portion of the materials in electronic format has increased.

Mitaka Library was originally open to non-NAOJ affiliated users on weekdays, but the COVID-19 pandemic has forced the library to close public access since March 2020. Even in such a situation, however, the library continues to lend materials that are not available at any other libraries or provide photocopies of these materials to non-NAOJ affiliated users. The library materials are provided to the general users through their local public libraries, and to researchers and students affiliated to other institutions through the libraries of their institutions. With both original materials and photocopies combined, 29 materials were provided this fiscal year.

The library also offered a remote service to NAOJ members off-campus.

The library holds many important documents, the most prominent of which are those written by the Tenmonkata,

Shogunate Astronomers of the Edo Era. These documents are stored in a dedicated room where the environment is strictly controlled. Some of the collections are digitized and available on the Library Unit website and have appeared in multiple publications outside NAOJ.

For the 2021 Special Open House Day, held online in October, the Library Unit created special web pages listing books related to this year's theme and other materials housed in the library. The unit also launched a web page for tips on how to search in the online public access catalog.

The number of books and journals owned by Mitaka Library and each observatory and the condition of continuing NAOJ publications are published in Section XI Library, Publications.

## 8. Publications Office

The Publications Office continued its activities in planning, editing, and printing NAOJ's original materials for PR and promotions. The following periodicals were also published this year:

- Annual Report of the National Astronomical Observatory of Japan Volume 33 Fiscal 2020 (Japanese)
- Annual Report of the National Astronomical Observatory of Japan Volume 23 Fiscal 2020 (English)
- 22nd Report of the National Astronomical Observatory of Japan
- Publications of the National Astronomical Observatory of Japan Volume 16
- NAOJ 2021 Pamphlet (Japanese)
- NAOJ News, No. 333 – No. 336 (April 2020 – March 2021)
- NAOJ Calendar (The 17th in the series)

In FY 2021, the office revised the NAOJ pamphlet (Japanese), and published the Annual Report of the NAOJ (Japanese/English versions), the 22nd Report of the National Astronomical Observatory of Japan, and Publications of the National Astronomical Observatory of Japan Volume 16. In preparation for a shift to digital publication, we changed NAOJ News to a quarterly format while increasing the page count. In the systematic production of NAOJ News special editions with the goal of developing project outreach support, we produced the issues "VERA and Mizusawa VLBI Observatory" (Summer 2021), "ALMA 10th Anniversary" (Autumn-Winter 2021), and "Ishigakijima Astronomical Observatory 150,000 Visitors – A report on the activities of the past 5 years" (Spring 2022). Other than periodicals, the 2021 calendar "The Universe Seen by the Subaru Telescope Ultra-Wide Field-of-View Prime-Focus Camera HSC (Hyper Suprime-Cam) 2022" (the 17th since 2005, this time produced taking universal design and accessibility into consideration) was created. As in other years, editing support was also given to the publication of the "Rika Nenpyo 2022 (Chronological Scientific Tables, Astronomy section)." In addition, the office continued to support the English production and editing of releases, publications, and web content both inside and outside of NAOJ.

In relation to the shift to digital publication, digital versions of the past 18 years of Publication Office publications (Annual Report Highlights, NAOJ Pamphlets, NAOJ News, NAOJ Calendar, posters of the various NAOJ branches, etc.) were compiled into a library, and preparation is ongoing for the release of original (electronic) publications.

Also, in an attempt at research development in the new field of "Cultural Astronomy" we are creating "arcAstroVR" a precise astronomical simulator for archeoastronomy research.

## 9. IAU Office for Astronomy Outreach (OAO)

The IAU Office for Astronomy Outreach (OAO) is a joint venture between the IAU and the National Astronomical Observatory of Japan (NAOJ). The OAO is primarily responsible for managing the IAU's communication and accessibility initiatives and supporting the international network of IAU National Outreach Coordinators (NOCs) in over 125 countries.

During Fiscal Year 2021, we highlight the successful renewal of the IAU-NAOJ Agreement for the OAO until 2024, the increase of the OAO core team to three full-time members, the NOCs Funding Scheme being officially attributed to OAO's annual fixed budget by the IAU and the establishment of the OAO Steering Committee, composed of 4 members, moving towards a structure more similar to the other IAU sister offices.

Among the key activities carried out by the office during the period of this report, we highlight the NOC's management and engagement, leading to an increase in representation of the network, nominating representatives in nearly 130 countries and territories. We concluded the NOCs Funding Scheme 2021 with three projects funded and implemented the 2022 edition that received 12 proposals.

During FY 2021 we also implemented the IAU Outreach Global Projects highlighting Telescopes for All 2021 that received over 225 submissions from 54 countries; 100 Hours of Astronomy 2021 which was implemented in over 60 countries; and Women and Girls in Astronomy 2022 with 782 entries for the Draw an Astronaut competition and a total of 251 events in 39 countries.

We highlight the co-organization with IAU Commission C2 for the CAP conference in May 2022 with over 1200 registered participants from 84 countries. The OAO and NAOJ are also the publishers of the conference proceedings. Issue #30 of the Communicating Astronomy with the Public (CAP) Journal was published. Issue #30 was a special 30th edition in November 2021 (Astronomy Communication in a Time of Confinement) with 7 articles in total (2 peer-reviewed) from a total of 58 submissions.

Regarding IAU communication channels, we have successfully generated a 15 % growth in our IAU Facebook channel with 21,400+ Followers. On IAU Twitter we had a 13 % growth rate, reaching 14,700+ followers. In our OAO channels, we have successfully generated a 26 % growth in our OAO Facebook channel with 10,200+ Followers. On OAO Twitter we

had a 5% growth rate, reaching 3,700+ followers. The office also delivered 220+ astronomy outreach/education news items through 24 issues of the IAU Astronomy Outreach Newsletter to 4,368+ subscribers worldwide, and translated into 6 different languages by volunteers.

## 10. Ishigakijima Astronomical Observatory

In the first half of FY 2021, public access was almost entirely canceled due to the COVID-19 pandemic and the closure of Maesedake Rindo, the road leading to the observatory. In public outreach, the facilities were gradually reopened to the public from October. The total cumulative number of visitors since opening passed 150,000 in January and the annual total reached approximately 1,400 visitors. Moreover, the observatory was involved in many online activities, such as broadcasts of astronomical events. In education, we welcomed group tours and gave visiting lectures and online lectures for the public. In research, 1 refereed paper was published on observation of small celestial bodies in the Solar System, bringing the total number of papers published based on data from Ishigakijima Astronomical Observatory to 30.

(1) Public Outreach Activities

[Guided Tours, 4D2U Theater, Stargazing Sessions]

The facilities closed entirely to the public, including guided tours, screenings at the 4D2U theater, and stargazing sessions because of the closure of Maesedake Rindo which is the only road leading to the observatory, from July, 2020 until the end of repair work in September, 2021. In October, 2021, we re-opened to the public, limited to walking around the outside of the facilities, and from November restarted inside activities including guided tours, the 4D2U Theater, and Stargazing sessions. We limit the number of visitors, hours, and the number of times, and disinfects thoroughly as preventative measures against the COVID-19 pandemic. The total cumulative number of visitors passed 150,000 in January, and the annual total was approximately 1,400 visitors.

[Special Events, Co-sponsorships, Cooperative Events, etc.]

In May, we participated in the total lunar eclipse broadcast (anchored at Mitaka Campus) by providing a live image feed, etc. Moreover, we observed Asteroid Kushiike, Supernova 2021qvv, and so on for public outreach, and released the results through web news.

The Southern Cross Monitor that started in 2020 held an observing season from December to June, and was active as a Milky Way monitor from July to November. For the third year in a row, entries from observatory employees received Excellence Awards in the "'Local' Star View Photo Contest (GOTO INC.)." In addition, together with Nayoro Observatory, we conducted an alternative stamp rally from December to March.

(2) Educational Activities

After October, the public access road reopened and we began accepting educational group tours again. In November, we welcomed an Ishigaki City Council inspection. Also, we worked for local education activities such as providing a visiting lecture at "Ishigaki City Senior University" hosted by the Ishigaki City Board of Education. In February, an introductory program was broadcast as a collaboration between NAOJ and "Hamagin Space Science Center," and the Chuaraboshi Research Team Workshop for high school students was held in March with 9 participants from across Japan.

(3) Research Activities

One refereed paper in a western journal was published in FY 2021, on the topic of small celestial bodies in the Solar System. The total number of papers including results based on Ishigakijima Astronomical Observatory observational data reached 30. There were 5 presentations at domestic and international conferences. In particular, project research staff member Horiuchi is leading efforts to compile the results for observing Starlink satellites through collaborative OISTER observations. We observed 46 objects over 101 nights. Collaborative observations with OISTER, etc. observed 14 objects over 53 nights. Research fellow observations consisted of 20 objects over 69 nights. Public outreach observations consisted of 12 objects over 49 nights.

# 17. Division of Science

## 1. Overview

We will report the FY 2021 research activities in the Division of Science based on the following vision and philosophy of the division:

- Achieve fruitful results of research based on liberal ideas of individuals, and achieve world-leading scientific results. Expand the horizons of astronomical knowledge by developing new fields such as efficient collaborations between theory and observations, multi-wavelength astronomy, and multi-messenger astronomy. In addition to developing important research, nurture creative ideas to develop new fields.
- Utilize large telescopes and supercomputers in NAOJ to achieve top-level research results as a world-leading research division. Contribute to the promotion of future plans of NAOJ from a scientific perspective.
- Actively promote education of young researchers, including students at graduate schools, to attract both Japanese and oversea researchers in the next generation who will lead world-wide research activities. Become a career path center for astronomical research in the world.
- Strengthen the astronomical field in Japan by creating new science by collaboration with domestic and international researchers, including other Projects in NAOJ. Play an important role to promote internationalization in the astronomical field in Japan.

The members of the Division of Science cover a wide variety of themes in astronomy research from the early Universe to formation and evolution of galaxies, stars, and planets; activities of compact objects; and plasma phenomena in astronomy and astrophysics – from various aspects of the astronomical hierarchical structure, such as dynamics and material evolution. Taking advantages of the facilities of NAOJ, such as super-computers of CfCA, the Subaru Telescope, ALMA, and the Nobeyama 45-m Radio Telescope, we stimulate collaborations among theoretical and observational astronomers working on various wavelength ranges. Also, we advance interdisciplinary research on the physics of neutrinos, gravitational waves, elementary particles, and atomic nuclei as well as planetary science. The division members are also actively participating in developing the science for future ground-based and space-based observational projects.

In order to facilitate highly competitive world leading research activities, the Division of Science offers a superb research environment as a base for astronomy research accessible to researchers in Japan and overseas. However, due to COVID-19, visitors from abroad are severely restricted in FY 2021, following FY 2020. Domestic visitors came back gradually in FY 2021. To compensate for the decrease of visitors, the division has been actively inviting international and domestic researchers to the division's online colloquia and seminars to promote discussions. The division also provides the online opportunities to facilitate the communication among the division members, including lunch meetings, informal gatherings, and internal workshops. In addition, the division actively organizes international and domestic workshops for the fields of theoretical and observational astronomy, as well as the cross-disciplinary field between astronomy and planetary science, leading research activities in various related fields of astronomical science.

## 2. Current Members and Transfers

In FY 2021, the dedicated faculty of the Division of Science included five professors, three associate professors, and seven assistant professors in addition to one adjunct professor, one adjunct associate professor (from February 1), and one adjunct assistant professor who concurrently held a primary position at the Center for Computation Astrophysics (CfCA). Professors Masahiro Ikoma and Nozomu Tominaga have newly arrived in FY 2021 while Professors Kohji Tomisaka and Toshiki Kajino retired in FY 2020. Accordingly, the research activities on exoplanets; formation and evolution of planets; supernovae; time domain astronomy; and multi-messenger astronomy have been strengthened. Also Dr. Tomoya Takiwaki was promoted from Assistant Professor in the Division of Science to Associate Professor with a primary position at CfCA. In addition to these faculty members, the division was served by ten project assistant professors (including NAOJ fellows), five project research fellows, four special postdoctoral researchers of the Japan Society for the Promotion of Science (JSPS), one research supporter, and three administrative supporters (one started from February 1) who gave full support to all activities of the division.

## 3. Research Results

The refereed research papers published by the division members as authors are more than 190 in number. Some of the research results are presented as the research highlights listed at the beginning of this report. The following includes research in which the division members took leading roles:

- Planetesimal dynamics in the presence of a giant planet (Kangrou Guo, Eiichiro Kokubo)
- On the Hubble Constant Tension (Dainotti, M.G. et al.)
- High Spatial Resolution Observations of Molecular Lines toward the Protoplanetary Disk around TW Hya with ALMA Revealing Detailed Physical and Chemical Structure (Nomura, Tsukagoshi, Kawabe et al.)
- Observation of hydrogen line emission from a young gas giant planet and constraints of planetary accretion process (Uyama, Ikoma)

The following research results are released on the division's website (https://sci.nao.ac.jp/main/articles-en/) as research highlights:

- Surprise Twist Suggests Stars Grow Competitively (Takemura, Nakamura, Tsukagoshi, Kawabe et al.)
- A New Window to See Hidden Side of Magnetized Universe (Machida et al.)
- Charting the Expansion History of the Universe with Supernovae (Dainotti et al.)
- A New Type of Supernova Illuminates an Old Mystery (Moriya, Tominaga et al.)
- Planetesimal Dynamics in the Presence of a Giant Planet (Guo, Kokubo)
- ALMA Finds Super-Fast Rotation of Baby Star's Jet (Matsushita, Tomisaka et al.)
- Unveiling a century-old mystery: Where the Milky Way's cosmic rays come from (Sano et al.)
- The ultra-wideband, high sensitivity 7 mm radio receiver installed on the 45 m! (Nakamura, Kawabe, Taniguchi et al.)

## 4. International and Domestic Collaborations and Cooperation

(1) International and Domestic Workshops

Due to COVID-19, international conferences continued to be severely limited in FY 2021. The members of the division organized or co-organized the following international and domestic workshops, as a hub of science activities, collaborating with international and domestic colleagues, which contributed to stimulating research activities in the field of astronomy and the cross-disciplinary fields. All the following meetings were held online.

International Meetings
- The Isotopic Link from the Planet Forming Region to the Solar System (July 27–29, 2021)
- Mini workshop on GRBs correlations and machine learning for GRBs and AGN (July 29–30, 2021)
- SAZERAC SIPS Early Galaxy Formation Near and Far — Preparing for a Long Journey with JWST — (November 29–December 3, 2021)

Domestic meetings
- W50/SS433 workshop (May 18, 2021)
- Workshop on Galactic Star Formation (November 16–December 2, 2021)
- The 10th observational cosmology workshop (November 17–19, 2021)
- SNR workshop 2022 (March 28–29, 2022)

(2) International Organization Committees and Reviews of International Funds

- IAU Commission F2 Exoplanets and the Solar system organization committee (Kokubo)
- "Forming and Exploring Habitable Worlds" scientific steering committee (Kokubo)
- National Fund for Scientific and Technological Research, Chile (Ouchi, Ikoma)
- The Dutch Research Council (NWO) funds, Netherland (Ouchi)
- National Research Agency (ANR), France (Ikoma)
- Research Projects of National Relevance (PRIN), Italy (Ikoma)

(3) International and Domestic Observation Projects

In order to advance efficient collaborations between theory and observations, and multi-wavelength astronomy, the members of the division contributed to the following observation projects. Also, the members contributed to the promotion of international and domestic future plans related to astronomy, including the plans for large telescopes in NAOJ, from a scientific perspective.

- Subaru Intensive Program: EMPRESS 3D (PI)(Ouchi)
- Subaru Intensive Program: IRD TESS Follow-up Project II. (Ikoma)
- HSC SSP transient working group (Chair)(Moriya)
- Subaru IRD SSP (Kokubo)
- Hyper SuprimeCam Survey weak lensing science research group (Hamana)
- Subaru SAC (Ikoma, Moriya)
- Subaru proposal review (Nomura, Tsukagoshi)
- Subaru PFS Galaxy Evolution Group (Ouchi)
- ULTIMATE-Subaru Science Study Group (Moriya)
- NINJA project (Moriya, Ouchi)
- TMT-J SAC (Tominaga)
- Nobeyama 45-m KAGONMA project (Kobayashi)
- Nobeyama proposal review (Sano, Furuya)
- JCMT BISTRO-J, JCMT CLOGS survey (Kobayashi)
- JCMT proposal review (Arzoumanian)
- ngVLA Japan Science Study group (Kobayashi)
- SKA-JP Science Study group (Fujii, Machida)
- LST Science Study group (Kobayashi, Sano, Tsukagoshi, Nomura, Harada, Furuya)
- Seimei Telescope proposal review (Tominaga)
- Hubble Space Telescope proposal review (Moriya)
- Swift Senior review (Dainotti)
- Fermi-LAT member (Dainotti)
- Theseus member (Dainotti)
- JOVIAL (JP Co-PI) (Ikoma)
- Ariel Consortium (Co-PI), Ariel-JP Science Study group (PI) (Ikoma)
- WSO-UV Science Study group (Ikoma)
- Roman Science Investigation Team (Ouchi, Moriya)
- Euclid Consortium (Moriya)
- GREX-PLUS Science Study group (Ouchi, Nomura, Moriya, Fujii)
- GOPIRA 2030s Future Study Working Group (Ouchi)
- GOPIRA Future Plan Study Advisory Committee (Ouchi)

## 5. Educational and Outreach Activities

The division actively promotes education of young researchers, including students at graduate schools, to become a career path center for astronomical research in the world. In FY 2021 the graduate students in the Division of Science included ten SOKENDAI students (five doctoral and five master's course students) and fourteen students in the University of Tokyo (ten doctoral and four master's course students). The number of students was twenty-four in total. In addition, the members in the division engaged in the education of graduate and undergraduate students in the following universities and also high school students.

- Graduate students: U. of Tokyo (Ikoma), Tokyo Tech. (Nomura), Konan U. (Tominaga), U. of Tokyo/Nanjing Normal U. (Harada), Nagoya U. (Sano), [Italy] Salerno U., Naples U., Pisa U., [Poland] Jagiellonian U., AGH U., [USA] Maryland U., UC Davis, Cornell U, MU Amherst (Dainotti)
- Undergraduate students: [Poland] Jagiellonian U. [India] Mithibai U., IIT Kharagpur U., [USA] Maryland U., Pennsylvania U., Arizona State U., New York U., Carnegie Mellon U., Michigan U., Los Angeles U., Tufts U., Purdue U. (Dainotti)
- High school students: [USA] Caribbean Education Foundation (Dainotti)

The members of the division actively engaged in both graduate and undergraduate lectures at the University of Tokyo and many other institutes and universities. including classes at Super Science High Schools. In addition, the online open house (admission guidance) of the Division of Science for undergraduate and master course students was organized in March 2022. The members also engaged in outreach activities by offering lectures to the public.

## 6. Awards

The members in the division were awarded in recognition of their excellent research achievements in this year as follows.

- The 51th Summer School Oral Awards for Young Astronomy and Astrophysics (Kiyoaki Doi)
- 2020 ASJ Young Astronomer Award (Akimasa Kataoka, Kimihiko Nakajima, Takashi Moriya)
- The Best Researcher Award 2020 of the Japanese Society of Planetary Science (Akimasa Kataoka)
- FY 2021 NAOJ Young Researchers Award (Akimasa Kataoka)
- 2021 ASJ PASJ Excellent Paper Award
  "Big Three Dragons: $z = 7.15$ Lyman-break galaxy detected in [O III] 88 $\mu$m, [C II] 158 $\mu$m, and dust continuum with ALMA" (Masami Ouchi is coauthor)
  "The formation of massive molecular filaments and massive stars triggered by a magnetohydrodynamic shock wave" (Kazunari Iwasaki is coauthor)
- The University of Tokyo, The School of Science, Encouragement Award AY2021 (Misako Tatsuuma)
- Highly Cited Researchers 2021 (Clarivate Analytics, USA) (Masami Ouchi)

# 18. Office of International Relations

The Office of International Relations (OIR) strives to promote internationalization at NAOJ by collecting and providing information on international research exchange and education and creating an environment where multi-cultural researchers and students can engage cooperatively in research and educational activities. Specifically, the main activities of the OIR include promoting international research collaboration, supporting visiting international researchers and students, and disseminating information at international conferences. In FY 2021, some of our activities had to be reduced because of the decrease in the number of incoming international visitors and the cancellation or postponement of scheduled events due to the spread of COVID-19. Despite the circumstances, we took advantage of this time to focus on activities that were not affected by the pandemic.

## 1. Promoting International Research Collaboration

The OIR serves as the contact point for the East Asian Core Observatories Association (EACOA) and the East Asian Observatory (EAO). The EACOA consists of four core observatories representing the East Asian regions: the NAOJ (Japan), the National Astronomical Observatories of China (China), the Korea Astronomy and Space Science Institute (South Korea), and the Academia Sinica Institute of Astronomy and Astrophysics (Taiwan), and the EAO is operated by these EACOA members and the National Astronomical Research Institute of Thailand. During FY 2021, the OIR assisted the Director General of NAOJ in each of the EACOA/EAO online board meetings and supported one post-doctoral young researcher who was hosted by NAOJ under the EACOA Fellowship Program.

Besides the duties mentioned above, the OIR has been in charge of reviewing legal documents such as agreements and memoranda for international collaboration between NAOJ and overseas institutions. In FY 2021, we reviewed a total of 33 new or renewed international agreements and drafted revisions as needed. One such document was the Memorandum of Understanding (MOU) with the Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA), concerning the joint development of new instruments for the Subaru Telescope. The OIR worked in close collaboration with the National Institutes of Natural Sciences (NINS) to organize a virtual signing ceremony for this MOU, and in August 2021, the President of NINS and the Director General of NAOJ, as well as the President of Academia Sinica and the Acting Director of the ASIAA met online to conclude the MOU. This ceremony created an opportunity for the parties to confirm their willingness to deepen their ties and cooperation between Japan and Taiwan in astronomical research.

## 2. Support Services for International Researchers and Students

The Support Desk (SD) of the OIR offers a broad range of services to help international researchers and students overcome their difficulties in living in Japan. During FY 2021, to prevent the spread of COVID-19, the SD staff worked remotely where possible by providing consultation services over the phone, e-mail, and online conference systems. However, in some instances where on-site assistance was necessary or requested, the SD staff accompanied international researchers and students to municipal offices and other places to complete various procedures. In addition, as part of an effort to strengthen support by the SD, the "NAOJ Support Desk Registration Form" was developed and put into operation. By having international researchers and students submit this form before their visit, the SD staff can obtain accurate information in a timely manner and be prepared to provide appropriate support for facilitating the relocation process to help establish an environment in which incomers can concentrate on their research as quickly as possible.

Furthermore, in July 2021, the OIR launched its newly redesigned website to provide information to international researchers and students both inside and outside NAOJ. The website contains information on immigration procedures, accommodations, campus neighborhoods, and daily life, as well as reference information for NAOJ host researchers and staff. Although all information is provided in both Japanese and English, according to the current statistics, one-fourth of the website visitors have read the English version, indicating that it is widely used among non-Japanese speakers.

In parallel with these services, the OIR continues to collaborate with a specialized company to offer beginner-level Japanese language classes to help international researchers and students quickly adjust to life in Japan. In FY 2021, a new intermediate course was established. Both courses offer lessons that have been tailored in response to the requests of former students, where a speech-centered method is used to provide "practical Japanese for daily life." In addition, by using supplementary learning tools such as e-learning and enhancing instructor presence, students are given the freedom to study at their convenience. The courses were well received by the students, who remained highly motivated to learn and were able to acquire more practical Japanese language skills.

## 3. Information Dissemination at International Conferences

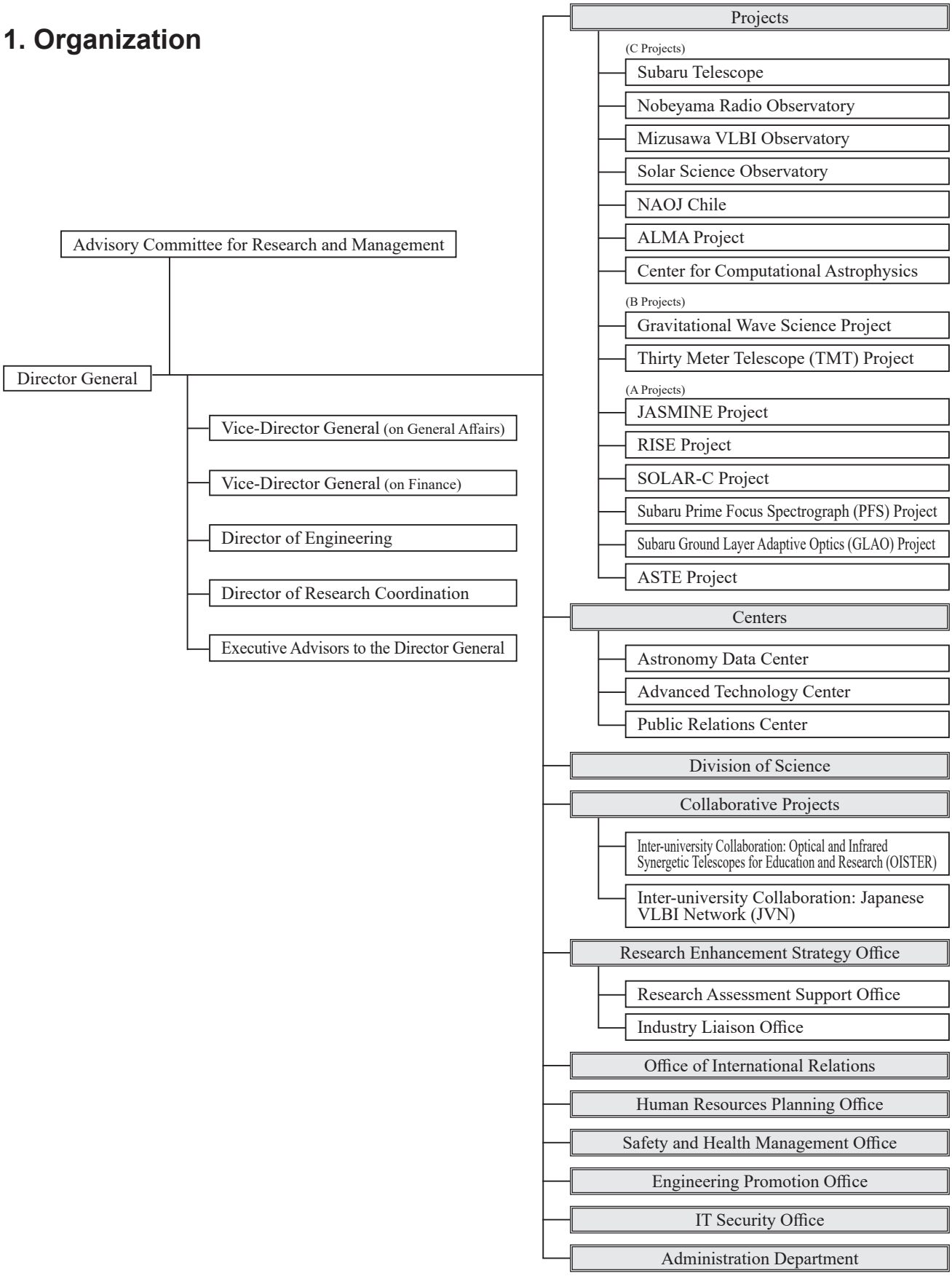
The OIR has been exhibiting booths at international conferences to recruit international researchers by providing information about NAOJ's research activities and invitational programs. Although the 239th AAS Meeting was canceled due to the spread of COVID-19, we have already started our

preparations for setting up a booth at the IAU GA 2022, which will be held in Busan, Republic of Korea, in August 2022.

Furthermore, the OIR supports other NAOJ departments that plan to have an exhibition booth at international conferences. During FY 2021, the OIR assisted the Public Relations Center in exhibiting a virtual booth at the European Astronomical Society (EAS) 2021 Annual Meeting held in June and July 2021. Also, as a member of the local organizing committee, the OIR has started preparations to support visa procedures for participants in the Asia-Pacific Regional IAU Meeting (APRIM 2023), to be held in August 2023 in Aizu, Fukushima Prefecture.

# III Organization

## 1. Organization



## 2. Number of Staff Members

(2022/3/31)

| | |
|---|---|
| Director General | 1 |
| Research and Academic Staff | 147 |
| Professor | 28 |
| Executive Engineer | 1 |
| Associate Professor | 35 |
| Senior Research Engineer | 10 |
| Associate Professor (Senior Lecturer) | 6 |
| Associate Senior Research Engineer | 2 |
| Assistant Professor | 53 |
| Research Associate | 0 |
| Research Engineer | 12 |
| Engineering Staff | 39 |
| Administrative Staff | 57 |
| Research Administrator Staff | 6 |
| Employees on Annual Salary System | 152 |
| Research Administrator Staff Transferring to the Mandatory Retirement System | 1 |
| Employees on Annual Salary System Transferring to the Mandatory Retirement System | 1 |
| Full-time Contract Employees | 33 |
| Full-time Contract Employees Transferring to the Mandatory Retirement System | 2 |
| Part-time Contract Employees | 74 |
| Part-time Contract Employees Transferring to the Mandatory Retirement System | 18 |

## 3. Executives

| | |
|---|---|
| **Director General** | Tsuneta, Saku |
| **Vice-Director General** | |
| **on General Affairs** | Watanabe, Junichi |
| **on Finance** | Iguchi, Satoru |
| **Director of Engineering** | Mitsuda, Kazuhisa |
| **Director of Research Coordination** | Saito, Masao |
| | |
| **Executive Advisor to the Director General** | Hiramatsu, Masaaki |
| **Executive Advisor to the Director General** | Kurasaki, Takaaki |
| **Executive Advisor to the Director General** | Sekiguchi, Kazuhiro |

# 4. Research Departments

## Projects

### C Projects

**Subaru Telescope**

| | |
|---|---|
| Director | Yoshida, Michitoshi |
| Vice-Director | Hayano, Yutaka |
| Professor | Hayano, Yutaka |
| Professor | Yoshida, Michitoshi |
| Project Professor | Takami, Hideki |
| Project Professor * | Tamura, Motohide |
| Associate Professor | Minowa, Yosuke |
| Associate Professor | Tanaka, Masayuki |
| Project Associate Professor | Kambe, Eiji |
| Project Associate Professor | Oya, Shin |
| Senior Research Engineer | Iwashita, Hiroyuki |
| Senior Research Engineer | Kumura, Yoshinori |
| Assistant Professor * | Hirano, Teruyuki |
| Assistant Professor | Imanishi, Masatoshi |
| Assistant Professor | Ishigaki, Miho |
| Assistant Professor | Komiyama, Yutaka |
| Assistant Professor * | Kotani, Takayuki |
| Assistant Professor | Koyama, Yusei |
| Assistant Professor | Moritani, Yuki |
| Assistant Professor * | Nakajima, Tadashi |
| Assistant Professor | Okamoto, Sakurako |
| Assistant Professor | Okita, Hirofumi |
| Assistant Professor | Onodera, Masato |
| Assistant Professor | Oono, Yoshito |
| Assistant Professor | Pyo, Tae-Soo |
| Assistant Professor * | Suto, Hiroshi |
| Assistant Professor | Yanagisawa, Kenshi |
| Project Assistant Professor * | Hashimoto, Jun |
| Project Assistant Professor * | Hori, Yasunori |
| Project Assistant Professor | Izumi, Takuma |
| Project Assistant Professor * | Kuzuhara, Masayuki |
| Project Assistant Professor * | Livingston, John Henry |
| Project Assistant Professor | Shimakawa, Rhythm |
| Research Engineer | Bando, Takamasa |
| Research Engineer | Omiya, Jun |
| Senior Engineer | Namikawa, Kazuhito |
| Engineer (Shunin Gijutsuin) | Sato, Tatsuhiro |
| Engineer (Shunin Gijutsuin) | Tsutsui, Hironori |
| Engineer (Gijutsuin) | Hirano, Ken |
| Engineer (Gijutsuin) | Sawatari, Koichi |
| Project Research Staff | Hamano, Satoshi |
| Project Research Staff | He, Wanqiu |
| Project Research Staff * | Ishikawa, Hiroyuki |
| Project Research Staff | Kawanomoto, Satoshi |
| Project Research Staff * | Komatsu, Yu |
| Project Research Staff * | Krishnamurthy, Vigneshwaran |
| Project Research Staff | Mawatari, Ken |
| Project Research Staff | Murata, Kazumi |
| Project Research Staff | Nakata, Fumiaki |
| Project Research Staff | Nashimoto, Masashi |
| Project Research Staff * | Nugroho, Stevanus Kristianto |
| Project Research Staff * | Omiya, Masashi |
| Project Research Staff * | Suzuki, Taiki |
| Project Research Staff * | Takahashi, Aoi |
| Project Research Staff * | Takarada, Takuya |
| Project Research Staff | Wong, Kenneth Christopher |
| Project Research Staff | Yamashita, Takuji |
| Senior Specialist (Tokuninsenmonin) | Fujinawa, Toshiyuki |
| Senior Specialist (Tokuninsenmonin) | Harasawa, Sumiko |
| Senior Specialist (Tokuninsenmonin) | Ishizuka, Yuki |
| Senior Specialist (Tokuninsenmonin) | Ishii, Miki |
| Senior Specialist (Tokuninsenmonin) | Katakura, Junichi |
| Senior Specialist (Tokuninsenmonin) | Kobayakawa, Naoki |
| Senior Specialist (Tokuninsenmonin) | Koike, Michitaro |
| Senior Specialist (Tokuninsenmonin)* | Kusakabe, Nobuhiko |
| Senior Specialist (Tokuninsenmonin) | Mineo, Sogo |
| Senior Specialist (Tokuninsenmonin) | Morishima, Takahiro |
| Senior Specialist (Tokuninsenmonin) | Nakajima, Masayo |
| Senior Specialist (Tokuninsenmonin) | Oka, Shinji |
| Senior Specialist (Tokuninsenmonin) | Okura, Yuki |
| Senior Specialist (Tokuninsenmonin) | Shindo, Miwa |
| Senior Specialist (Tokuninsenmonin) | Tanaka, Mitsuhiro |
| Re-employment Staff | 3 |

| | |
|---|---|
| Research Supporter | 1 |
| Public Outreach Staff | 1 |
| Administrative Supporters | 3 |
| Research Assistant Staff | 1 |
| *concurrently appointed in NINS | |

**Administration Department**

| | |
|---|---|
| Manager | Furuhata, Tomoyuki |
| General Affairs Unit | |
| Staff | Tamura, Makoto |
| Accounting Unit | |
| Leader | Sugawara, Satoshi |

**RCUH**

| | |
|---|---|
| RCUH Staff | 68 |

**Okayama Branch Office**

| | |
|---|---|
| Director | Izumiura, Hideyuki |
| Associate Professor | Izumiura, Hideyuki |
| Project Associate Professor | Tajitsu, Akito |
| Assistant Professor | Maehara, Hiroyuki |
| Research Assistant Staff | 3 |

**Nobeyama Radio Observatory**

| | |
|---|---|
| Director | Tatematsu, Ken'Ichi |
| Professor | Tatematsu, Ken'Ichi |
| Project Associate Professor | Nishimura, Atsushi |
| Assistant Professor | Umemoto, Tomofumi |
| Engineer (Gishi) | Handa, Kazuyuki |
| Engineer (Gishi) | Kurakami, Tomio |
| Engineer (Gishi) | Miyazawa, Chieko |
| Engineer (Gishi) | Takahashi, Toshikazu |
| Senior Specialist (Tokuninsenmonin) | Kinugasa, Kenzou |
| Senior Specialist (Tokuninsenmonin) | Takahashi, Shigeru |
| Re-employment Staff | 1 |
| Technical Experts | 1 |
| Research Supporter | 1 |

**Administration Office**

| | |
|---|---|
| General Affairs Unit | |
| Re-employment Staff | 1 |
| Administrative Supporters | 2 |
| Accounting Unit | |
| Leader | Takami, Masaki |
| Administrative Supporters | 2 |

**Mizusawa VLBI Observatory**

| | |
|---|---|
| Director | Honma, Mareki |
| Professor | Honma, Mareki |
| Project Professor | Kobayashi, Hideyuki |
| Assistant Professor | Hada, Kazuhiro |
| Assistant Professor | Hirota, Tomoya |
| Assistant Professor | Jike, Takaaki |
| Assistant Professor | Kameya, Osamu |
| Assistant Professor | Kouno, Yusuke |
| Assistant Professor | Sunada, Kazuyoshi |
| Assistant Professor | Tamura, Yoshiaki |
| Engineer (Gishi) | Ueno, Yuji |
| Engineer (Gijutsuin) | Sato, Gen |
| Engineer (Gijutsuin) | Takahashi, Ken |
| Project Research Staff | Akahori, Takuya |
| Project Research Staff | Kurahara, Kohei |
| Senior Specialist (Tokuninsenmonin) | Hachisuka, Kazuya |
| Senior Specialist (Tokuninsenmonin) | Oyama, Tomoaki |
| Senior Specialist (Tokuninsenmonin) | Ozawa, Tomohiko |
| Technical Experts | 4 |
| Research Supporter | 1 |
| Technical Supporter | 1 |
| Administrative Supporters | 2 |

**Administration Office**

| | |
|---|---|
| Head of Administration Office | Onuma, Toru |
| General Affairs Unit | |
| Leader | Onuma, Toru |
| Re-employment Staff | 1 |
| Administrative Supporters | 3 |
| Accounting Unit | |
| Leader | Kogawa, Hiroshi |
| Administrative Supporters | 2 |

**Time Keeping Office**

| | |
|---|---|
| Director | Tamura, Yoshiaki |

**Solar Science Observatory**

| | |
|---|---|
| Director | Katsukawa, Yukio |
| Associate Professor | Hanaoka, Yoichiro |
| Associate Professor | Ishikawa, Ryoko |
| Associate Professor | Katsukawa, Yukio |
| Associate Professor | Sekii, Takashi |
| Assistant Professor | Narukage, Noriyuki |
| Project Assistant Professor | Benomar, Othman Michel |
| Engineer (Gishi) | Shinohara, Noriyuki |
| Project Research Staff | Matsumoto, Takuma |
| Senior Specialist (Tokuninsenmonin) | Iju, Tomoya |
| Senior Specialist (Tokuninsenmonin) | Morita, Satoshi |
| Research Supporter | 2 |
| Administrative Supporter | 1 |
| Research Assistant Staff | 1 |

**NAOJ Chile**

| | |
|---|---|
| Vice-Director | Mizuno, Norikazu |
| Associate Professor | Minamidani, Tetsuhiro |
| Engineer (Gishi) | Kobiki, Toshihiko |
| Chile Employees | |
| Chile Employees | 6 |

**Administration Department**

| | |
|---|---|
| Manager | Watanabe, Teruyuki |

| | |
|---|---|
| General Affairs Unit | |
| Staff | Iwasaki, Yumi |
| Accounting Unit | |
| Senior Staff | Yamafuji, Yasuto |

**ALMA Project**

| | |
|---|---|
| Director | Gonzalez Garcia, Alvaro |
| Professor | Fukagawa, Misato |
| Professor | Gonzalez Garcia, Alvaro |
| Professor | Iguchi, Satoru |
| Professor | Kameno, Seiji |
| Professor | Mizuno, Norikazu |
| Professor | Sakamoto, Seiichi |
| Project Professor | Kiuchi, Hitoshi |
| Associate Professor | Asaki, Yoshiharu |
| Associate Professor | Iono, Daisuke |
| Associate Professor | Okuda, Takeshi |
| Associate Professor | Sawada, Tsuyoshi |
| Associate Professor | Shimojo, Masumi |
| Associate Professor | Takahashi, Satoko |
| Project Associate Professor | Ishii, Shun |
| Project Associate Professor | Nagai, Hiroshi |
| Project Associate Professor | Nakanishi, Koichiro |
| Project Associate Professor | Shimajiri, Yoshito |
| Senior Research Engineer | Kikuchi, Kenichi |
| Senior Research Engineer | Sugimoto, Kanako |
| Senior Research Engineer | Watanabe, Manabu |
| Assistant Professor | Ezawa, Hajime |
| Assistant Professor | Hirota, Akihiko |
| Assistant Professor | Kamazaki, Takeshi |
| Assistant Professor | Matsuda, Yuichi |
| Project Assistant Professor | Hull, Charles Lindsay Hopkins |
| Project Assistant Professor | Imada, Hiroaki |
| Project Assistant Professor | Miyamoto, Yusuke |
| Project Assistant Professor | Sanhueza, Nunez Patricio Andres |
| Project Assistant Professor | Tadaki, Kenichi |
| Project Assistant Professor | Ueda, Junko |
| Project Assistant Professor | Zavala Sorano, Jorge Armando |
| Research Engineer | Nakazato, Takeshi |
| Research Engineer | Yamada, Masumi |
| Engineer (Gishi) | Kato, Yoshihiro |
| Engineer (Gishi) | Nakamura, Kyoko |
| Engineer (Shunin Gijyutuin) | Ito, Tetsuya |
| Engineer (Shunin Gijyutuin) | Nishitani, Hiroyuki |
| Engineer (Shunin Gijyutuin) | Shizugami, Makoto |
| Project Research Staff | Algera, Hiddo Sunny Bouwe |
| Project Research Staff | Bakx, Tom Johannes Lucinde Cyrillus |
| Project Research Staff | Cataldi, Gianni |
| Project Research Staff | Chen, Xiaoyang |
| Project Research Staff | Cheng, Yu |
| Project Research Staff | Fudamoto, Yoshinobu |
| Project Research Staff | Kaneko, Hiroyuki |
| Project Research Staff | Kudo, Yuki |
| Project Research Staff | Michiyama, Tomonari |
| Project Research Staff | Miley, James Maxwell |
| Project Research Staff | Nishimura, Yuri |
| Project Research Staff | Saito, Toshiki |
| Project Research Staff | Sorahana, Satoko |
| Project Research Staff | Sugahara, Yuma |
| Project Research Staff | Wu, Yu-Ting |
| Project Research Staff | Yamagishi, Mitsuyoshi |
| Project Research Staff | Yan, Yi |
| Senior Specialist (Tokuninsenmonin) | Curotto, Molina Franco Andreas |
| Senior Specialist (Tokuninsenmonin) | Fujimoto, Yasuhiro |
| Senior Specialist (Tokuninsenmonin) | Fukui, Hideharu |
| Senior Specialist (Tokuninsenmonin) | Funakawa, Takashi |
| Senior Specialist (Tokuninsenmonin) | Hayashi, Yohei |
| Senior Specialist (Tokuninsenmonin) | Ikeda, Emi |
| Senior Specialist (Tokuninsenmonin) | Kawasaki, Wataru |
| Senior Specialist (Tokuninsenmonin) | Konuma, Mika |
| Senior Specialist (Tokuninsenmonin) | Miel, Renaud |
| Senior Specialist (Tokuninsenmonin) | Nakanishi, Takashi |
| Senior Specialist (Tokuninsenmonin) | Nakayama, Susumu |
| Senior Specialist (Tokuninsenmonin) | Ohtawara, Kazushige |
| Senior Specialist (Tokuninsenmonin) | Shimada, Kazuhiko |
| Senior Specialist (Tokuninsenmonin) | So, Ryoken |
| Senior Specialist (Tokuninsenmonin) | Uemizu, Kazunori |
| Senior Specialist (Tokuninsenmonin) | Yoshino, Akira |

| | |
|---|---|
| Senior Specialist (Tokuninsenmonin) | Zahorecz, Sarolta |
| Technical Expert | 1 |
| Administrative Expert | 1 |
| Re-employment Staff | 1 |
| Research Supporter | 1 |
| Administrative Supporters | 3 |
| Research Assistant Staff | 1 |

**Center for Computational Astrophysics**

| | |
|---|---|
| Director | Kokubo, Eiichiro |
| Professor | Kokubo, Eiichiro |
| Associate Professor | Takiwaki, Tomoya |
| Associate Professor (Senior Lecturer) | Ito, Takashi |
| Assistant Professor | Iwasaki, Kazunari |
| Project Research Staff | Ishikawa, Shogo |
| Project Research Staff | Matsumoto, Yuji |
| Project Research Staff | Taki, Tetsuo |
| Senior Specialist (Tokuninsenmonin) | Fukushi, Hinako |
| Senior Specialist (Tokuninsenmonin) | Hohokabe, Hirotaka |
| Senior Specialist (Tokuninsenmonin) | Kato, Tsunehiko |
| Research Expert | 1 |
| Research Supporters | 3 |
| Administrative Supporter | 1 |

## B Projects

**Gravitational Wave Science Project**

| | |
|---|---|
| Director | Tomaru, Takayuki |
| Professor | Tomaru, Takayuki |
| Associate Professor | Aso, Yoichi |
| Assistant Professor | Akutsu, Tomotada |
| Assistant Professor | Leonardi, Matteo |
| Assistant Professor | Takahashi, Ryutaro |
| Research Engineer | Ishizaki, Hideharu |
| Engineer (Shunin Gijyutuin) | Tanaka, Nobuyuki |
| Project Research Staff | Aritomi, Naoki |
| Administrative Expert | 1 |
| Administrative Supporter | 1 |

**Kamioka Branch**

| | |
|---|---|
| Director | Tomaru, Takayuki |
| Project Research Staff | Chen, Dan |
| Senior Specialist (Tokuninsenmonin) | Ikeda, Satoru |
| Administrative Supporter | 1 |

**Thirty Meter Telescope (TMT) Project**

| | |
|---|---|
| Director | Usuda, Tomonori |
| Vice-Director | Aoki, Wako |
| Professor | Saito, Masao |
| Professor | Yamashita, Takuya |
| Associate Professor | Aoki, Wako |
| Associate Professor | Noumaru, Junichi |
| Associate Professor | Sugimoto, Masahiro |
| Associate Professor | Terada, Hiroshi |
| Assistant Professor | Nishikawa, Jun |
| Research Engineer | Tazawa, Seiichi |
| Senior Specialist (Tokuninsenmonin) | Kishimoto, Mayumi |

**NAOJ California Office**

| | |
|---|---|
| Professor | Usuda, Tomonori |
| Associate Professor | Hayashi, Saeko |
| Associate Professor | Suzuki, Ryuji |
| Assistant Professor | Yasui, Chikako |
| Research Engineer | Nakamoto, Takashi |

## A Projects

**JASMINE Project**

| | |
|---|---|
| Director | Goda, Naoteru |
| Professor | Goda, Naoteru |
| Professor | Kano, Ryohei |
| Assistant Professor | Miyoshi, Makoto |
| Assistant Professor | Tatsumi, Daisuke |
| Assistant Professor | Tsujimoto, Takuji |
| Assistant Professor | Ueda, Akitoshi |
| Assistant Professor | Yano, Taihei |
| Project Assistant Professor | Baba, Junichi |
| Technical Supporter | 1 |

**RISE Project**

| | |
|---|---|
| Director | Namiki, Noriyuki |
| Professor | Namiki, Noriyuki |
| Associate Professor | Matsumoto, Koji |
| Assistant Professor | Araki, Hiroshi |
| Assistant Professor | Noda, Hirotomo |
| Research Engineer | Asari, Kazuyoshi |
| Project Research Staff | Yamamoto, Keiko |
| Administrative Expert | 1 |

**SOLAR-C Project**

| | |
|---|---|
| Director | Hara, Hirohisa |
| Professor | Hara, Hirohisa |
| Assistant Professor | Kubo, Masahito |
| Assistant Professor | Okamoto, Takenori |
| Engineer (Gishi) | Shinoda, Kazuya |
| Project Research Staff | Kawabata, Yusuke |
| Project Research Staff | Oba, Takayoshi |
| Senior Specialist (Tokuninsenmonin) | Nodomi, Yoshifumi |
| Administrative Supporter | 1 |

**Subaru Prime Focus Spectrograph (PFS) Project**

| | |
|---|---|
| Director | Rousselle, Julien |

**Subaru Ground Layer Adaptive Optics (GLAO) Project**

| | |
|---|---|
| Director | Minowa, Yosuke |

**ASTE Project**

| | |
|---|---|
| Acting Director | Kamazaki, Takeshi |

## Centers

**Astronomy Data Center**

| | |
|---|---|
| Director | Kosugi, George |
| Associate Professor | Ichikawa, Shinichi |
| Associate Professor | Kosugi, George |
| Associate Professor | Takata, Tadafumi |
| Associate Senior Research Engineer | Morita, Eisuke |
| Assistant Professor | Furusawa, Hisanori |
| Assistant Professor | Shirasaki, Yuji |
| Assistant Professor | Yagi, Masafumi |
| Project Research Staff | Furusawa, Junko |
| Project Research Staff | Kakuwa, Jun |
| Project Research Staff | Onozato, Hiroki |
| Project Research Staff | Otsubo, Takafumi |
| Project Research Staff | Otsubo, Takafumi |
| Senior Specialist (Tokuninsenmonin) | Isogai, Mizuki |
| Senior Specialist (Tokuninsenmonin) | Kitada, Chihiro |
| Senior Specialist (Tokuninsenmonin) | Makiuchi, Shinichiro |
| Senior Specialist (Tokuninsenmonin) | Nakajima, Yasushi |
| Senior Specialist (Tokuninsenmonin) | Ozawa, Takeaki |
| Senior Specialist (Tokuninsenmonin) | Tanaka, Nobuhiro |
| Senior Specialist (Tokuninsenmonin) | Yamane, Satoru |
| Senior Specialist (Tokuninsenmonin) | Zapart, Christopher Andrew |
| Re-employment Staff | 1 |

**Advanced Technology Center**

| | |
|---|---|
| Director | Uzawa, Yoshinori |
| Vice-Director | Motohara, Kentarou |
| Professor | Miyazaki, Satoshi |
| Professor | Motohara, Kentarou |
| Professor | Uzawa, Yoshinori |
| Project Professor | Mitsuda, Kazuhisa |
| Executive Engineer | Hirabayashi, Masayuki |
| Associate Professor | Kojima, Takafumi |
| Associate Professor | Makise, Kazumasa |
| Associate Professor | Matsuo, Hiroshi |
| Associate Professor | Shan, Wenlei |
| Senior Research Engineer | Fujii, Yasunori |
| Senior Research Engineer | Fukushima, Mitsuhiro |
| Senior Research Engineer | Kanzawa, Tomio |
| Senior Research Engineer | Okada, Norio |
| Associate Professor (Senior Lecturer) | Nakaya, Hidehiko |
| Associate Professor (Senior Lecturer) | Ozaki, Shinobu |
| Associate Senior Research Engineer | Obuchi, Yoshiyuki |
| Assistant Professor | Oshima, Tai |
| Project Assistant Professor | Hattori, Masayuki |
| Project Assistant Professor | Tokoku, Chihiro |
| Research Engineer | Ezaki, Shohei |
| Research Engineer | Sato, Naohisa |
| Research Engineer | Tsuzuki, Toshihiro |
| Engineer (Gishi) | Kamata, Yukiko |
| Engineer (Gishi) | Kaneko, Keiko |
| Engineer (Gishi) | Omata, Koji |
| Engineer (Gishi) | Tamura, Tomonori |
| Engineer (Gishi) | Uraguchi, Fumihiro |
| Engineer (Shunin Gijyutuin) | Fukuda, Takeo |
| Engineer (Shunin Gijyutuin) | Hirata, Naoatsu |
| Engineer (Shunin Gijyutuin) | Hoshino, Masayuki |
| Engineer (Shunin Gijyutuin) | Ikenoue, Bungo |
| Engineer (Shunin Gijyutuin) | Inata, Motoko |
| Engineer (Shunin Gijyutuin) | Iwashita, Hikaru |
| Engineer (Shunin Gijyutuin) | Mitsui, Kenji |
| Engineer (Shunin Gijyutuin) | Miyachi, Akihira |
| Engineer (Shunin Gijyutuin) | Waseda, Koichi |
| Engineer (Gijyutsuin) | Sakai, Ryo |
| Engineer (Gijyutsuin) | Shimizu, Risa |
| Project Research Staff | Nagai, Makoto |
| Senior Specialist (Tokuninsenmonin) | Kusumoto, Hiroshi |
| Senior Specialist (Tokuninsenmonin) | Saito, Sakae |
| Re-employment Staff | 1 |
| Technical Experts | 2 |
| Administrative Supporters | 3 |
| Research Assistant Staff | 1 |
| Senior Specialist (Tokuninsenmonin) | 1 |

**Public Relations Center**

| | |
|---|---|
| Director | Yamaoka, Hitoshi |
| Project Professor | Oishi, Masatoshi |
| Project Professor | Watanabe, Junichi |
| Associate Professor | Agata, Hidehiko |
| Associate Professor | Yamaoka, Hitoshi |
| Associate Professor (Senior Lecturer) | Hanayama, Hidekazu |
| Associate Professor (Senior Lecturer) | Hiramatsu, Masaaki |
| Research Engineer | Katayama, Masato |
| Engineer (Shunin Gijyutuin) | Nagayama, Shogo |
| Project Research Staff | Shibata, Takashi |
| Senior Specialist (Tokuninsenmonin) | Blumenthal, Kelly Anne |
| Senior Specialist (Tokuninsenmonin) | Filipecki Martins, Suzana |
| Senior Specialist (Tokuninsenmonin) | Ishikawa, Naomi |
| Senior Specialist (Tokuninsenmonin) | Komiyama, Hiroko |
| Senior Specialist (Tokuninsenmonin) | Lundock, Ramsey Guy |
| Senior Specialist (Tokuninsenmonin) | Pires, Canas Lina Isabel |
| Re-employment Staff | 3 |
| Research Experts | 2 |
| Administrative Experts | 2 |
| Research Supporter | 1 |
| Public Outreach Staff | 14 |

**Public Relations Office**

Yamaoka, Hitoshi

**Outreach and Education Office**

Director Agata, Hidehiko

**Ephemeris Computation Office**

Director Katayama, Masato

**Spectrum Management Office**

Director Oishi, Masatoshi

**Library Unit**

Leader Tamefusa, Mizuho

**Publications Office**

Director Yamaoka, Hitoshi

**The Office for Astronomy Outreach of the IAU**

Director Pires, Canas Lina Isabel

**Administration Office**

Director Matsuda, Ko

**Ishigakijima Astronomical Observatory**

Director Hanayama, Hidekazu

## Division of Science

| | |
|---|---|
| Division Head | Nomura, Hideko |
| Professor | Ikoma, Masahiro |
| Professor | Kawabe, Ryohei |
| Professor | Nomura, Hideko |
| Professor | Ouchi, Masami |
| Professor | Tominaga, Nozomu |
| Associate Professor | Fujii, Yuka |
| Associate Professor | Machida, Mami |
| Associate Professor | Nakamura, Fumitaka |
| Assistant Professor | Dainotti, Maria Giovanna |
| Assistant Professor | Hamana, Takashi |
| Assistant Professor | Harada, Nanase |
| Assistant Professor | Kataoka, Akimasa |
| Assistant Professor | Morino, Jun-Ichi |
| Assistant Professor | Moriya, Takashi |
| Project Assistant Professor | Arzoumanian, Doris |
| Project Assistant Professor | Furuya, Kenji |
| Project Assistant Professor | Nagakura, Hiroki |
| Project Assistant Professor | Nakajima, Kimihiko |
| Project Assistant Professor | Sano, Hidetoshi |
| Project Assistant Professor | Sugiyama, Naonori |
| Project Assistant Professor | Suzuki, Akihiro |
| Project Assistant Professor | Takahashi, Sanemichi |
| Project Assistant Professor | Taniguchi, Kotomi |
| Project Assistant Professor | Tsukagoshi, Takashi |
| Project Research Staff | Burns, Ross Alexander |
| Project Research Staff | Ito, Yuichi |
| Project Research Staff | Kobayashi, Masato |
| Project Research Staff | Nozawa, Takaya |
| Project Research Staff | Ogami, Takayuki |
| Administrative Experts | 2 |
| Research Supporter | 1 |
| Administrative Supporter | 1 |
| Research Assistant Staffs | 3 |

# 5. Research Support Departments

**Research Enhancement Strategy Office**

| | |
|---|---|
| Director | Iguchi, Satoru |
| Professor | Sekiguchi, Kazuhiro |
| Assistant Professor | Hattori, Kohei |
| Assistant Professor | Ishizuki, Sumio |
| Assistant Professor | Shirasaki, Masato |
| Senior Specialist (Tokuninsenmonin) | Asaga, Akitaka |
| Senior Specialist (Tokuninsenmonin) | Chapman, Junko |
| Senior Specialist (Tokuninsenmonin) | Fukui, Hideharu |
| Senior Specialist (Tokuninsenmonin) | Hori, Kuniko |
| Senior Specialist (Tokuninsenmonin) | Noda, Noboru |
| Senior Specialist (Tokuninsenmonin) | Okamoto, Koichi |
| Senior Specialist (Tokuninsenmonin) | Suzui, Mitsukazu |

**Research Assessment Support Office**

| | |
|---|---|
| Director | Saito, Masao |
| Assistant Professor | Ishizuki, Sumio |
| Senior Specialist (Tokuninsenmonin) | Hori, Kuniko |

**Industry Liaison Office**

| | |
|---|---|
| Director | Hayano, Yutaka |

**Office of International Relations**

| | |
|---|---|
| Director | Sekiguchi, Kazuhiro |
| Senior Specialist (Tokuninsenmonin) | Chapman, Junko |
| Senior Specialist (Tokuninsenmonin) | Kakazu, Yuko |
| Senior Specialist (Tokuninsenmonin) | Matsumoto, Mizuho |
| Research Supporters | 1 |

**Support Desk**

| | |
|---|---|
| Research Supporters | 2 |

**Human Resources Planning Office**

| | |
|---|---|
| Director | Noda, Noboru |

**Safety and Health Management Office**

| | |
|---|---|
| Director | Okamoto, Koichi |
| Technical Expert | 1 |

**Engineering Promotion Office**

| | |
|---|---|
| Director | Mitsuda, Kazuhisa |
| Senior Specialist (Tokuninsenmonin) | Suzui, Mitsukazu |

**IT Security Office**

| | |
|---|---|
| Director | Iguchi, Satoru |
| Vice Director | Oe, Masafumi |
| Senior Research Engineer | Nakamura, Koji |
| Associate Professor (Senior Lecturer) | Oe, Masafumi |
| Engineer | Matsushita, Sayaka |
| Senior Specialist (Tokuninsenmonin) | Shingu, Uken |
| Administrative Expert | 1 |

**Administration Department**

| | |
|---|---|
| General Manager | Fujita, Hisashi |
| Manager for SpecialMissions (International Relations) | Seto, Yoji |
| Senior Specialist (Tokuninsenmonin) | Harada, Eiichiro |

**General Affairs Group**

| | |
|---|---|
| Manager | Nagata, Yuki |
| Deputy Manager | Onishi, Tomoyuki |
| Specialist (Information Technology) | Kawashima, Ryota |
| Specialist (Personnel Relations) | Yoshimura, Tetsuya |
| Senior Specialist (Tokuninsenmonin) | Ito, Yuko |
| Senior Specialist (Tokuninsenmonin) | Murakami, Sachiko |
| Senior Specialist (Tokuninsenmonin) | Suzuki, Yoshihiro |
| Re-employment Staff | 1 |

General Affairs Unit

| | |
|---|---|
| Leader | Kawashima, Ryota |
| Staff | Isozaki, Yuka |
| Staff | Saito, Masahiro |
| Re-employment Staff | 2 |
| Administrative Expert | 1 |
| Administrative Supporter | 1 |

Personnel Unit

| | |
|---|---|
| Leader | Chiba, Yoko |
| Staff | Matsukura, Koji |
| Staff | Okawa, Makoto |
| Staff | Ouchi, Kaori |
| Administrative Expert | 1 |

Payroll Unit

| | |
|---|---|
| Leader | Furukawa, Shinichiro |
| Staff | Fukuhara, Miyuki |
| Staff | Inoue, Wakaho |
| Staff | Takahashi, Sachiko |
| Staff | Yokota, Banri |
| Administrative Supporters | 2 |

Employee Affairs Unit

| | |
|---|---|
| Leader | Yamaura, Mari |

| | |
|---|---|
| Staff | Manabe, Yuta |
| Staff | Tanaka, Masashi |
| Administrative Expert | 1 |

**Research Promotion Group**

| | |
|---|---|
| Manager | Hosoya, Akio |
| Senior Specialist (International Relations) | Seto, Yoji |
| Specialist (External Funding) | Ihara, Hiroko |
| Senior Specialist (Tokuninsenmonin) | Baba, Takashi |

Research Support Unit

| | |
|---|---|
| Leader | Goto, Michiru |
| Administrative Expert | 1 |
| Administrative Supporter | 1 |

External Funding Unit

| | |
|---|---|
| Specialist (External Funding) | Ihara, Yuko |
| Staff | Kashiwa, Hidekazu |
| Administrative Supporters | 2 |

Graduate Student Affairs Unit

| | |
|---|---|
| Leader | Kitabayashi, Kaya |
| Administrative Experts | 2 |
| Administrative Supporter | 1 |

International Academic Affairs Unit

| | |
|---|---|
| Leader | Sato, Yoko |

**Financial Affairs Group**

| | |
|---|---|
| Manager | Kawazu, Hironori |
| Deputy Manager | Iwashita, Kanefumi |
| Specialist (Audit) | Tsukano, Satomi |

General Affairs Unit

| | |
|---|---|
| Leader | Kikkawa, Hiroko |
| Staff | Naraoka, Aone |
| Administrative Supporter | 1 |

Budget Unit

| | |
|---|---|
| Leader | Yamamoto, Shinichi |
| Staff | Sugimoto, Naomi |
| Administrative Supporter | 1 |

Asset Management Unit

| | |
|---|---|
| Leader | Ishikawa, Junya |
| Senior Staff | Okubo, Kazuhiko |

Receiving Unit

| | |
|---|---|
| Leader | Ishikawa, Junya |
| Administrative Supporters | 5 |

**Accounting Group**

| | |
|---|---|
| Manager | Tahara, Yuji |
| Specialist (Contracts) | Sato, Kanako |

Accounting Unit

| | |
|---|---|
| Leader | Akeno, Aya |
| Administrative Supporters | 2 |

Procurement Unit

| | |
|---|---|
| Leader | Miura, Susumu |
| Senior Staff | Nakagawa, Yukie |
| Staff | Morita, Akitsugu |
| Administrative Expert | 1 |
| Administrative Supporter | 1 |

**Facilities Group**

| | |
|---|---|
| Manager | Kataoka, Toru |
| Deputy Manager | Murakami, Kazuhiro |
| Senior Specialist | Yamanouchi, Mika |

General Affairs Unit

| | |
|---|---|
| Leader | Yamanouchi, Mika |
| Staff | Hiramatsu, Naoya |
| Administrative Supporter | 1 |

Facilities Direction Unit

| | |
|---|---|
| Leader | Murakami, Kazuhiro |
| Administrative Supporters | 2 |

Maintenance Unit

| | |
|---|---|
| Leader | Watanabe, Tsuyoshi |
| Staff | Hayashi, Yuki |
| Staff | Kawahara, Iori |

# 6. Personnel Change

Research and Academic Staff

| Date | Name | Change | New Affiliated Institute, Position | Previous Affiliated Institute, Position |
|---|---|---|---|---|
| 2021/4/1 | Ikoma, Masahiro | Hired | Division of Science, Professor | |
| 2021/4/1 | Tominaga, Nozomu | Hired | Division of Science, Professor | |
| 2021/5/1 | Hirabayashi, Masayuki | Hired | Advanced Technology Center, Executive Engineer | |
| 2021/9/1 | Moritani, Yuki | Hired | Subaru Telescope, Assistant Professor | |
| 2021/11/1 | Okamoto, Takenori | Hired | SOLAR-C Project, Assistant Professor | |
| 2022/3/1 | Hanayama, Hidekazu | Hired | Public Relations Center, Associate Professor (Senior Lecturer) | (Public Relations Center, Project Researcher) |
| 2022/3/1 | Morita, Eisuke | Hired | Astronomy Data Center, Associate Senior Research Engineer | (ALMA Project, Senior Specialist) |
| 2022/1/31 | Iwata, Ikuru | Resigned | | Thirty Meter Telescope Project, Associate Professor |
| 2022/1/31 | Ashitagawa, Kyoko | Resigned | | ALMA Project, Research Engineer |
| 2022/3/31 | Komiyama, Yutaka | Resigned | | Subaru Telescope, Assistant Professor |
| 2021/5/14 | Takato, Naruhisa | Departed | | Subaru Telescope, Professor |
| 2022/3/31 | Okada, Norio | Retired | | Advanced Technology Center, Senior Research Engineer |
| 2022/3/31 | Kameya, Osamu | Retired | | Mizusawa VLBI Observatory, Assistant Professor |
| 2022/3/31 | Tamura, Yoshiaki | Retired | | Mizusawa VLBI Observatory, Assistant Professor |
| 2022/3/31 | Ishizaki, Hideharu | Retired | | Gravitational Wave Science Project, Research Engineer |
| 2022/3/31 | Asari, Kazuyoshi | Retired | | RISE Project, Research Engineer |
| 2021/6/1 | Hara, Hirohisa | Promoted | SOLAR-C Project, Professor | SOLAR-C Project, Associate Professor |
| 2021/6/1 | Hiramatsu, Masaaki | Promoted | Public Relations Center, Associate Professor (Senior Lecturer) | ALMA Project, Assistant Professor |
| 2021/6/21 | Ishikawa, Ryoko | Promoted | Solar Science Observatory, Associate Professor | SOLAR-C Project, Asistant Professor |
| 2021/10/1 | Hayano, Yutaka | Promoted | Subaru Telescope, Professor | Advanced Technology Center, Associate Professor |
| 2021/11/1 | Gonzalez Garcia, Alvaro | Promoted | ALMA Project, Professor | ALMA Project, Associate Professor |
| 2022/2/1 | Takiwaki, Tomoya | Promoted | Center for Computational Astrophysics, Associate Professor | Division of Science, Assistant Professor |
| 2022/2/1 | Suzuki, Ryuji | Promoted | Thirty Meter Telescope Project, Associate Professor | Thirty Meter Telescope Project, Assistant Professor |

Engineering Staff

| Date | Name | Change | New Affiliated Institute, Position | Previous Affiliated Institute, Position |
|---|---|---|---|---|
| 2021/6/1 | Hoshino, Masayuki | Hired | Advanced Technology Center, Engineer | |
| 2021/7/1 | Sawatari, Koichi | Hired | Subaru Telescope, Engineer | |
| 2021/10/1 | Takahashi, Ken | Hired | Mizusawa VLBI Observatory, Engineer | |
| 2021/11/1 | Sato, Gen | Hired | Mizusawa VLBI Observatory, Engineer | |
| 2021/12/1 | Hirata, Naoatsu | Hired | Advanced Technology Center, Engineer | (Gravitational Wave Science Project, Senior Specialist) |

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|---|---|---|---|---|
| 2021/4/30 | Miura, Takuya | Resigned | | Subaru Telescope, Engineer |

| | | | | |
|---|---|---|---|---|
| 2021/4/1 | Namikawa, Kazuhito | Promoted | Subaru Telescope, Senior Engineer | Subaru Telescope, Engineer |
| 2021/4/1 | Ueno, Yuji | Promoted | Mizusawa VLBI Observatory, Engineer | Mizusawa VLBI Observatory, Engineer |
| 2021/4/1 | Kaneko, Keiko | Promoted | Advanced Technology Center, Engineer | Advanced Technology Center, Engineer |
| 2021/10/1 | Tsutsui, Hironori | Promoted | Subaru Telescope, Engineer | Subaru Telescope, Engineer |
| 2021/10/1 | Shizugami, Makoto | Promoted | ALMA Project, Engineer | ALMA Project, Engineer |

Administrative Staff

| Date | Name | Change | New Affiliated Institute, Position | Previous Affiliated Institute, Position |
|---|---|---|---|---|
| 2021/4/1 | Fujita, Hisashi | Hired | Administration Department, General Manager | (Tokai National Higher Education and Research System) |
| 2021/4/1 | Kawazu, Hironori | Hired | Administration Department Financial Affairs Group, Manager | (Japan Society for the Promotion of Science) |
| 2021/4/1 | Kataoka, Toru | Hired | Administration Department Facilities Group, Manager | (The University of Tokyo) |
| 2021/4/1 | Watanabe, Tsuyoshi | Hired | Administration Department Facilities Group Maintenance Unit, Leader | (Japan Aerospace Exploration Agency) |
| 2021/4/1 | Inoue, Wakaho | Hired | Administration Department General Affairs Group Payroll Unit, Staff | |
| 2021/7/1 | Kogawa, Hiroshi | Hired | Mizusawa VLBI Observatory Administration Office Accounting Unit, Leader | (Iwate University) |
| 2021/10/1 | Kawahara, Iori | Hired | Administration Department Facilities Group Maintenance Unit, Staff | |
| 2021/11/1 | Kashiwa, Hidekazu | Hired | Administration Department Research Promotion Group Resaerch Support Unit (External Funding), Staff | |

| | | | | |
|---|---|---|---|---|
| 2021/6/30 | Yamaguchi, Shin'ichi | Resigned | (Iwate University) | Mizusawa VLBI Observatory Administration Office Accounting Unit, Leader |
| 2021/7/31 | Uchiyama, Yoshifumi | Resigned | (Shinshu University) | Nobeyama Radio Observatory Administration Office Accounting Unit, Senior Staff |
| 2021/9/30 | Kayamori, Shinji | Resigned | | Administration Department General Affairs Group Payroll Unit, Staff |
| 2022/3/31 | Nagata, Yuki | Resigned | (National Institution For Youth Education) | Administration Department General Affairs Group, Manager |
| 2022/3/31 | Iwashita, Kanefumi | Resigned | (The University of Tokyo) | Administration Department Financial Affairs Group, Deputy Manager |
| 2022/3/31 | Tamefusa, Mizuho | Resigned | (The University of Tokyo) | Public Relations Center Administration Office Library, Leader |
| 2022/3/31 | Akeno, Aya | Resigned | (Tokyo Medical and Dental University) | Administration Department Accounting Group Accounting Unit, Leader |
| 2022/3/31 | Tsukano, Satomi | Resigned | (Tokyo Medical and Dental University) | Administration Department Financial Affairs Group, Specialist (Audit) |

| | | | | |
|---|---|---|---|---|
| 2021/4/1 | Sakamoto, Misato | Promoted | National Institutes of Natural Sciences Administrative Bureau General Affairs Division, Senior Staff (Ministry of Education, Culture, Sports, Science and Technology-Japan, Administrative Intern Trainee) | Administration Department General Affairs Group Personnel Unit, Staff |

| | | | | |
|---|---|---|---|---|
| 2021/4/1 | Yamafuji, Yasuto | Promoted | NAOJ Chile Administration Office Accounting Unit, Senior Staff | NAOJ Chile Administration Office Accounting Unit, Staff |
| 2021/4/1 | Okubo, Kazuhiko | Promoted | Administration Department Financial Affairs Group Asset Management Unit, Senior Staff | Administration Department Financial Affairs Group Asset Management Unit, Staff |
| 2021/4/1 | Nakagawa, Yukie | Promoted | Administration Department Accounting Group Procurement Unit, Senior Staff | Administration Department Research Promotion Group Research Support Unit, Staff |
| 2021/7/1 | Yoshimura, Tetsuya | Promoted | Administration Department General Affairs Group, Specialist (Personnel) | Administration Department Financial Affairs Group Budget Unit, Senior Staff |
| 2021/8/1 | Furuhata, Tomoyuki | Promoted | Subaru Telescope Administration Department, Manager | Administration Department General Affairs Group, Deputy Manager |

| | | | | |
|---|---|---|---|---|
| 2021/4/1 | Yokota, Banri | Reassigned | Administration Department Research Promotion Group, Staff | National Institutes of Natural Sciences Administrative Bureau General Affairs Division, Staff (Ministry of Education, Culture, Sports, Science and Technology-Japan, Administrative Intern Trainee) |
| 2021/8/1 | Seto, Yoji | Reassigned | Administration Department, Manager for Special Missions (International Relations) | Subaru Telescope Administration Department, Manager |

Employee on Annual Salary System

| Date | Name | Change | New Affiliated Institute, Position | Previous Affiliated Institute, Position |
|---|---|---|---|---|
| 2021/4/1 | Watanabe, Junichi | Hired | Public Relations Center, Project Professor (Distinguished Professor) | (Public Relations Center, Professor) |
| 2021/4/1 | Taniguchi, Kotomi | Hired | Division of Science, Project Assistant Professor | |
| 2021/4/1 | Mawatari, Ken | Hired | Subaru Telescope, Project Researcher | |
| 2021/4/1 | Saito, Toshiki | Hired | ALMA Project, Project Researcher | |
| 2021/4/1 | Michiyama, Tomonari | Hired | ALMA Project, Project Researcher | |
| 2021/4/1 | Yamagishi, Mitsuyoshi | Hired | ALMA Project, Project Researcher | |
| 2021/4/1 | Aritomi, Naoki | Hired | Gravitational Wave Science Project, Project Researcher | |
| 2021/4/1 | Yamamoto, Keiko | Hired | RISE Project, Project Researcher | (RISE Project, Project Researcher) |
| 2021/4/1 | Oba, Takayoshi | Hired | SOLAR-C Project, Project Researcher | |
| 2021/4/1 | Ohgami, Takayuki | Hired | Division of Science, Project Researcher | |
| 2021/4/1 | Hachisuka, Kazuya | Hired | Mizusawa VLBI Observatory, Senior Specialist | |
| 2021/4/1 | Kobayakawa, Naoki | Hired | Subaru Telescope, Senior Specialist | |
| 2021/4/1 | Funakawa, Takashi | Hired | ALMA Project, Senior Specialist | |
| 2021/4/1 | Ozawa, Takeaki | Hired | Astronomy Data Center, Senior Specialist | (Astronomy Data Center, Senior Specialist) |
| 2021/4/1 | Kitada, Chihiro | Hired | Astronomy Data Center, Senior Specialist | |
| 2021/4/1 | Makiuchi, Shin'ichiro | Hired | Astronomy Data Center, Senior Specialist | (Astronomy Data Center, Senior Specialist) |
| 2021/4/1 | Kusumoto, Hiroshi | Hired | Advanced Technology Center, Senior Specialist | (Advanced Technology Center, Senior Specialist) |
| 2021/4/1 | Toukoku, Chihiro | Hired | Advanced Technology Center, Senior Specialist | |
| 2021/4/1 | Watanebe, Yoichi | Hired | Administration Department General Affairs Group, Senior Specialist | |
| 2021/5/1 | Matsumoto, Yuji | Hired | Center for Computational Astrophysics, Project Researcher | |
| 2021/5/1 | Kurahara, Kohei | Hired | ALMA Project, Project Researcher | |

| | | | | |
|---|---|---|---|---|
| 2021/5/1 | Onozato, Hiroki | Hired | Astronomy Data Center, Project Researcher | |
| 2021/5/1 | Shibata, Takashi | Hired | Public Relations Center, Project Researcher | |
| 2021/5/1 | Shimada, Kazuhiko | Hired | ALMA Project, Senior Specialist | |
| 2021/5/1 | Lo, Yu Hsian | Hired | IT Security Office, Senior Specialist | |
| 2021/6/10 | Zavala Solano, Jorge Armando | Hired | ALMA Project, Project Assistant Professor | |
| 2021/7/1 | Wong, Kenneth Christopher | Hired | Subaru Telescope, Project Researcher | |
| 2021/7/1 | Ito, Yuichi | Hired | Division of Science, Project Researcher | |
| 2021/9/1 | Komiyama, Hiroko | Hired | Public Relations Center, Senior Specialist | |
| 2021/9/1 | Nagakura, Hiroki | Hired | Division of Science, Project Assistant Professor | |
| 2021/9/27 | Arzoumanian, Doris | Hired | Division of Science, Project Assistant Professor | |
| 2021/9/30 | Kobayashi, Masato | Hired | Division of Science, Project Researcher | |
| 2021/10/1 | Nishimura, Atsushi | Hired | Nobeyama Radio Observatory, Project Associate Professor | |
| 2021/10/1 | Kurahara, Kohei | Hired | Mizusawa VLBI Observatory, Project Researcher | (ALMA Project, Project Researcher) |
| 2021/10/1 | Cheng, Yu | Hired | ALMA Project, Project Researcher | |
| 2021/11/1 | Algera, Hiddo Sunny Bouwe | Hired | ALMA Project, Project Researcher | |
| 2021/11/1 | Zahorecz, Sarolta | Hired | ALMA Project, Senior Specialist | (ALMA Project, Project Researcher) |
| 2021/11/1 | Konuma, Mika | Hired | ALMA Project, Senior Specialist | |
| 2021/11/1 | Filipecki Martins, Suzana | Hired | Public Relations Center, Senior Specialist | |
| 2021/11/1 | Suzuki, Yoshihiro | Hired | Administration Department General Affairs Group, Senior Specialist | |
| 2021/12/1 | Burns, Ross Alexander | Hired | Division of Science, Project Researcher | |
| 2022/2/1 | Tokoku, Chihiro | Hired | Advanced Technology Center, Project Assistant Professor | (Subaru Telescope, Senior Specialist) |
| 2022/3/1 | Blumenthal, Kelly Anne | Hired | Public Relations Center, Senior Specialist | |

| | | | | |
|---|---|---|---|---|
| 2021/6/30 | Watanebe, Yoichi | Resigned | | Administration Department General Affairs Group, Senior Specialist |
| 2021/7/31 | Song, Donguk | Resigned | | Solar Science Observatory, Project Researcher |
| 2021/8/31 | Nishikawa, Tomoko | Resigned | | ALMA Project, Senior Specialist |
| 2021/8/31 | Usuda, Kumiko | Resigned | | Public Relations Center, Senior Specialist |
| 2021/8/31 | Hansen, Izumi Ka Hoku Hula O Kekai | Resigned | | Public Relations Center, Senior Specialist |
| 2021/9/30 | Inoue, Shigeki | Resigned | | ALMA Project, Project Researcher |
| 2021/9/30 | Kurahara, Kohei | Resigned | (Mizusawa VLBI Observatory, Project Researcher) | ALMA Project, Project Researcher |
| 2021/9/30 | Lu, Xing | Resigned | | ALMA Project, Project Researcher |
| 2021/10/31 | Lee, Seokho | Resigned | | ALMA Project, Project Researcher |
| 2021/10/31 | Zahorecz, Sarolta | Resigned | (ALMA Project, Senior Specialist) | ALMA Project, Project Researcher |
| 2021/11/30 | Hirata, Naoatsu | Resigned | (Advanced Technology Center, Engineer) | Gravitational Wave Science Project, Senior Specialist |
| 2022/1/31 | Tokoku, Chihiro | Resigned | (Advanced Technology Center, Project Assistant Professor) | Subaru Telescope, Senior Specialist |

| | | | | |
|---|---|---|---|---|
| 2022/2/28 | Hanayama, Hidekazu | Resigned | (Public Relations Center, Associate Professor (Senior Lecturer)) | Public Relations Center, Project Researcher |
| 2022/2/28 | Horiuchi, Takashi | Resigned | | Public Relations Center, Project Researcher |
| 2022/2/28 | Morita, Eisuke | Resigned | (Astronomy Data Center, Associate Senior Research Engineer) | ALMA Project, Senior Specialist |
| 2022/3/31 | Shimajiri, Yoshito | Resigned | | ALMA Project, Project Associate Professor |
| 2022/3/31 | Miyamoto, Yusuke | Resigned | | ALMA Project, Project Assistant Professor |
| 2022/3/31 | Sano, Hidetoshi | Resigned | | Division of Science, Project Assistant Professor |
| 2022/3/31 | Suzuki, Akihiro | Resigned | | Division of Science, Project Assistant Professor |
| 2022/3/31 | Ishikawa, Shogo | Resigned | | Center for Computational Astrophysics, Project Researcher |
| 2022/3/31 | Saito, Toshiki | Resigned | (ALMA Project, Project Assistant Professor) | ALMA Project, Project Researcher |
| 2022/3/31 | Kawabata, Yusuke | Resigned | | SOLAR-C Project, Project Researcher |
| 2022/3/31 | Kakuwa, Jun | Resigned | | Astronomy Data Center, Project Researcher |

| | | | | |
|---|---|---|---|---|
| 2021/4/30 | Nishie, Suminori | Contract Expired | | ALMA Project, Senior Specialist |
| 2021/6/13 | Guzman Fernandez, Andres Ernesto | Contract Expired | | ALMA Project, Project Researcher |
| 2021/8/31 | Saigo, Kazuya | Contract Expired | | ALMA Project, Project Assistant Professor |
| 2021/9/11 | Tsuzuki, Hiroko | Contract Expired | | Public Relations Center, Senior Specialist |
| 2022/1/31 | Tokuda, Kazuki | Contract Expired | | ALMA Project, Project Researcher |
| 2022/3/30 | Kurasaki, Takaaki | Contract Expired | | Project Professor |
| 2022/3/31 | Izumi, Takuma | Contract Expired | (ALMA Project, Project Researcher) | Subaru Telescope, Project Assistant Professor |
| 2022/3/31 | Matsumoto, Takuma | Contract Expired | | Solar Science Observatory, Project Researcher |
| 2022/3/31 | Nashimoto, Masashi | Contract Expired | | Subaru Telescope, Project Researcher |
| 2022/3/31 | Nishimura, Yuri | Contract Expired | | ALMA Project, Project Researcher |
| 2022/3/31 | Yamagishi, Mitsuyoshi | Contract Expired | | ALMA Project, Project Researcher |
| 2022/3/31 | Yang, Yi | Contract Expired | | ALMA Project, Project Researcher |
| 2022/3/31 | Chen, Dan | Contract Expired | (Gravitational Wave Science Project, Assistant Professor) | Gravitational Wave Science Project, Project Researcher |
| 2022/3/31 | Ohgami, Takayuki | Contract Expired | | Division of Science, Project Researcher |
| 2022/3/31 | Nozawa, Takaya | Contract Expired | (Center for Computational Astrophysics, Project Researcher) | Division of Science, Project Researcher |
| 2022/3/31 | Kinugasa, Kenzo | Contract Expired | | Nobeyama Radio Observatory, Senior Specialist |
| 2022/3/31 | Takahashi, Shigeru | Contract Expired | | Nobeyama Radio Observatory, Senior Specialist |

| | | | | |
|---|---|---|---|---|
| 2022/3/31 | Morita, Satoshi | Contract Expired | (Solar Science Observatory, Senior Specialist) | Solar Science Observatory, Senior Specialist |
| 2022/3/31 | Fujimoto, Yasuhiro | Contract Expired | | ALMA Project, Senior Specialist |
| 2022/3/31 | Kishimoto, Mayumi | Contract Expired | | Thirty Meter Telescope Project, Senior Specialist |
| 2022/3/31 | Saito, Sakae | Contract Expired | | Advanced Techonology Center, Senior Specialist |

Research Administrator Staff

| Date | Name | Change | New Affiliated Institute, Position | Previous Affiliated Institute, Position |
|---|---|---|---|---|
| 2022/3/31 | Okamoto, Koichi | Contract Expired | | Research Enhancement Strategy Office (Safety and Health Management Office), Senior Specialist |
| 2022/3/31 | Fukui, Hideharu | Contract Expired | (ALMA Project, Senior Specialist of Employee on Annual Salary System ) | Research Enhancement Strategy Office (ALMA Project), Senior Specialist |

Foreign Visiting Researcher

There were no Foreign Visiting Researchers this Fiscal Year, due to the effects of the novel coronavirus.

# 7. Advisory Committee for Research and Management

## Members

**From universities and related institutes**

| | | |
|---|---|---|
| ○ | Doi, Mamoru | Professor at the Graduate School of Science, University of Tokyo |
| | Fujisawa, Kenta | Professor at the Research Institute for Time Studies, Yamagichi University |
| | Inutsuka, Shuichiro | Professor at the Graduate School of Science, Nagoya University |
| | Kawakita, Hideyo | Professor at the Faculty of Science, Kyoto Sangyo University |
| | Kodama, Tadayuki | Professor at the Graduate School of Science, Tohoku University |
| | Kusano, Kanya | Professor at the Institute for Space-Earth Environmental Research, Nagoya University |
| | Ohashi, Masatake | Professor at the Institute for Cosmic Ray Research, University of Tokyo |
| | Sakai, Nami | Chief Scientist at the RIKEN |
| | Takada, Masahito | Professor at the Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo |
| | Tosaki, Tomoka | Professor at the Graduate School of Education, Joetsu University of Education |
| | Yamasaki, Noriko | Professor at the Institute of Space and Astronautical Science, JAXA |

**From NAOJ**

| | | |
|---|---|---|
| | Fukagawa, Misato | Professor in ALMA Project |
| | Iguchi, Satoru | Vice-Director General (on Finance) |
| | Kobayashi, Hideyuki | Project Professor in the Mizusawa VLBI Observatory |
| | Kokubo, Eiichiro | Professor in the Center for Computational Astrophyscis |
| | Mituda, Kazuhisa | Director of Engineering |
| | Nomura, Hideko | Professor in the Division of Science |
| | Saito, Masao | Director of Research Coordination |
| | Uzawa, Yoshinori | Professor in the Advanced Technology Center |
| ● | Watanabe, Junichi | Vice-Director General (on General Affairs) |
| | Yoshida, Michitoshi | Professor in Subaru Telescope |

● Chairperson ○ Vise-Chairperson

Period: June 18, 2020 – March 31, 2022

# 8. Professors Emeriti

**Professors Emeriti (NAOJ)**

Ando, Hiroyasu
Arimoto, Nobuo
Chikada, Yoshihiro
Fujimoto, Masakatsu
Fukushima, Toshio
Hasegawa, Tetsuo
Hayashi, Masahiko
Hiei, Eijiro
Hirayama, Tadashi
Inoue, Makoto
Ishiguro, Masato
Iye, Masanori
Karoji, Hiroshi
Kawaguchi, Noriyuki
Kawano, Nobuyuki
Kinoshita, Hiroshi
Kobayashi, Yukiyasu
Kodaira, Keiichi
Manabe, Seiji
Miyama, Shiyoken
Miyamoto, Masanori
Mizumoto, Yoshihiko
Nakano, Takenori
Nariai, Kyoji
Nishimura, Shiro
Nishimura, Tetsuo
Noguchi, Kunio
Noguchi, Takashi
Oe, Masatsugu
Ogasawara, Ryusuke
Okamoto, Isao
Sakurai, Takashi
Shibasaki, Kiyoto
Tomisaka, Koji
Watanabe, Tetsuya
Yamashita, Yasumasa
Yoshida, Haruo

# IV Finance

## Revenue and Expenses (FY 2021)

(Unit: ¥1,000)

| Revenue | Budget | Final Account | Budget − Final Account |
|---|---|---|---|
| Management Expenses Grants | 9,962,017 | 10,753,314 | −791,297 |
| Facilities Maintenance Grants | 1,444,111 | 834,803 | 609,308 |
| Subsidy Income | 1,535,146 | 1,445,146 | 90,000 |
| Miscellaneous Income | 27,666 | 139,839 | −112,173 |
| Industry-Academia Research Income and Donation Income | 464,864 | 448,798 | 16,066 |
| Reversals of Reserves for Specific Purposes | 0 | 5,635 | −5,635 |
| Total | 13,433,804 | 13,627,535 | −193,731 |
| Expenses | Budget | Final Account | Budget − Final Account |
| Management Expenses | 9,989,683 | 10,763,788 | −774,105 |
| Employee Personnel Expenses | 3,767,678 | 3,572,220 | 195,458 |
| Operating Expenses | 6,222,005 | 7,191,568 | −969,563 |
| Facilities Maintenance Expenses | 1,444,111 | 834,803 | 609,308 |
| Subsidy Expenses | 1,535,146 | 1,445,146 | 90,000 |
| Industry-Academia Research Expenses and Donation Expenses | 464,864 | 339,693 | 125,171 |
| Total | 13,433,804 | 13,383,430 | 50,374 |
| Revenue-Expenses | Budget | Final Account | Budget − Final Account |
| | 0 | 244,105 | −244,105 |

# V KAKENHI (Grants-in-Aid for Scientific Research)

## 1. Series of Single-year Grants for FY 2021

| Research Categories | Number of Selected Projects | Budget (Unit: ¥1,000) | | |
|---|---|---|---|---|
| | | Direct Funding | Indirect Funding | Total |
| Scientific Research on Innovative Areas (Research in a proposed research area) | 11 | 73,800 | 22,140 | 95,940 |
| Transformative Research Areas (A) | 2 | 59,900 | 17,970 | 77,870 |
| Scientific Research (S) | 4 | 101,700 | 30,510 | 132,210 |
| Scientific Research (A) | 9 | 68,600 | 20,580 | 89,180 |
| Scientific Research (B) | 16 | 51,600 | 15,480 | 67,080 |
| JSPS Research Fellows | 8 | 9,200 | 2,520 | 11,720 |
| JSPS International Research Fellows | 2 | 1,900 | 0 | 1,900 |
| Publication of Scientific Research Results | 2 | 1,190 | 0 | 1,190 |
| Total | 54 | 367,890 | 109,200 | 477,090 |

## 2. Series of Multi-year Funds for FY 2021

| Research Categories | Number of Selected Projects | Budget (Unit: ¥1,000) | | |
|---|---|---|---|---|
| | | Direct Funding | Indirect Funding | Total |
| Scientific Research (C) | 27 | 23,100 | 6,930 | 30,030 |
| Early-Career Scientists | 23 | 17,800 | 5,340 | 23,140 |
| Challenging Research (Pioneering) | 1 | 1,900 | 570 | 2,470 |
| Research Activity Start-up | 2 | 2,200 | 660 | 2,860 |
| Promotion of Joint International Research | 3 | 8,300 | 2,490 | 10,790 |
| Total | 56 | 53,300 | 15,990 | 69,290 |

# VI Research Collaboration

## 1. Open Use

| Type | Project/Center | Category | Number of Accepted Proposals | Total Number of Researchers | Notes |
|---|---|---|---|---|---|
| Open Use at Project/Center | Subaru Telescope | Subaru Telescope | 71 | 490 (94) | 59 Institutes, 12 Countries |
| | Subaru Telescope Okayama Branch | SEIMEI Telescope | 37 | 152 (2) | 9 Institutes, 1 Country |
| | Solar Science Observatory | Ground-based Solar Observatory | * | * | * |
| | | Sun-observing satellite “Hinode” | ** | ** | ** |
| | Nobeyama Radio Observatory | 45-m telescope (Regular Program) | 16 | 120 (55) | 49 Institutes, 17 Countries |
| | Mizusawa VLBI Observatory | VERA | 29 | 141 (110) | 46 Institutes, 19 Countries |
| | Astronomy Data Center | | 336 | 336 (23) | 81 Institutes, 14 Countries |
| | Center for Computational Astrophysics | | 330 | 330 (19) | 63 Institutes, 6 Countries |
| | Advanced Technology Center | Facility Use | 13 | 46 | 5 Institutes |
| | | Joint Research and Development | 22 | 81 | 12 Institutes |
| | ALMA Project | ALMA (Cycle 7) | 398 | 4429 (3858) | 397 Institutes, 44 Countries |
| | | ASTE | *** | *** | *** |
| | RISE Project | | 0 | 0 | 0 |
| Joint Development Research | | | 8 | | 7 Institutes, 0 Countries |
| Research Assembly | | | 12 | | 8 Institutes, 0 Countries |
| NAOJ Symposium | | | 0 | | |

The number of researchers at foreign institutes shown in brackets ( ) is included in the total.

The country count does not include Japan.

The period of ALMA (Cycle 7) is from October 2019 to September 2021 due to a period of interruption caused by the spread of COVID-19.

* The observation data is open to the public on the web. No application is needed to use the data.

** Since the functions of the Hinode Science Center have shifted to the Astronomy Data Center, there is no procedure of application and adoption as “Hinode.”

***ASTE has cancelled the joint-use observations scheduled for FY 2021 due to the spread of the COVID-19 and malfunctions. The possibility of postponing adopted observation proposals to the following fiscal year or later is being considered.

# 2. Commissioned Research Fellows

## Visiting Scholars (Domestic)

| Name | Position at NAOJ | Affiliated Institute | Period | Host Project/Center/ Division |
|---|---|---|---|---|
| Takahashi, Keitaro | Visiting Professor | Faculty of Advanced Science and Technology, Kumamoto University | 2021/4/1–2022/3/31 | Mizusawa VLBI Observatory |
| Kawaguchi, Toshihiro | Visiting Associate Professor | Faculty of Economics, Management and Information Science, Onomichi City University | 2021/4/1–2022/3/31 | Advanced Technology Center |
| Nishimura, Nobuya | Visiting Research Fellow | RIKEN | 2021/4/1–2022/3/31 | Division of Science |

## JSPS (Japan Society for the Promotion of Science) Postdoctoral Research Fellows

| Name | Research Subject | Acceptance Period | Host Researcher |
|---|---|---|---|
| Luo, Yudong | Impacts of astrophysical magnetized plasma on the related nucleosynthesis | 2021/10/1–2022/3/31 | Nakamura, Fumitaka |
| Namekata, Kosuke | Observational and numerical studies of solar and stellar magnetic activities | 2021/4/1–2024/3/31 | Shimojo, Masumi |
| Yoshiura, Shintaro | Analysing the 21cm line at the Epoch of Reionisation using the sparse modelling | 2021/4/1–2024/3/31 | Honma, Mareki |
| Uyama, Taichi | Developing exoplanetary science by high-contrast imaging | 2021/4/1–2024/3/31 | Fujii, Yuka |
| Sakemi, Haruka | Analysis of magnetic fields and feedback of a jet terminal region through radio observation | 2021/4/1–2021/9/30 | Nagai, Hiroshi |
| Hatta, Yoshiki | Mixed-mode asteroseismology of stellar rotation | 2021/4/1–2022/3/31 | Sekii, Takashi |
| Arakawa, Sota | The birth environment of the Solar System unraveled by the thermal history of small bodies | 2020/4/1–2022/3/31 | Kokubo, Eiichiro |
| Shoda, Munehito | Simulation and observation study of the solar wind acceleration | 2019/4/1–2022/2/28 | Katsukawa, Yukio |
| Baba, Shunsuke | Study of a link between AGN torus formation and circum-nuclear starbursts | 2019/4/1–2021/9/30 | Imanishi, Masatoshi |
| Ueda, Takashiro | Probing rocky and icy planetesimal formation through two-dimensional simulations of gas and dust co-evolution | 2019/4/1–2022/3/31 | Kataoka, Akimasa |
| Washimi, Tatsuki | Evaluation of the glitch noise for burst gravitational wave detection | 2019/4/1–2022/3/31 | Tomaru, Takayuki |

## JSPS (Japan Society for the Promotion of Science) Foreign Research Fellows

| Name | Period | Host Researcher |
|---|---|---|
| Page, Michael Anthony | 2020/11/30–2022/11/29 | Aso, Yoichi |
| Eisenmann, Marc | 2020/11/30–2022/11/29 | Leonardi, Matteo |

# VII Graduate Education

## 1. Department of Astronomical Science, School of Physical Sciences, SOKENDAI (The Graduate University for Advanced Studies)

SOKENDAI (The Graduate University for Advanced Studies) was established in 1988 as an independent graduate university without undergraduate courses via partnerships with inter-university research institutes for the purpose of advancing graduate education.

There used to be four schools – Cultural and Social Studies, Mathematical and Physical Sciences, Life Science, and Advanced Sciences before the reorganization of School of Mathematical and Physical Sciences into the schools of Physical Sciences, High Energy Accelerator Science, and Multidisciplinary Sciences in April 2004. Now the total of six schools are offering doctoral education and research opportunities.

NAOJ has been accepting three-year doctoral-course students since FY 1992 and five-year- course students since FY 2006 for Department of Astronomical Science, School of Physical Sciences.

**(1) Objective of Department of Astronomical Science**

Department of Astronomical Science aims to train students, through observational, theoretical, or instrument development research in astronomy or in related fields, in an environment with the most advanced observational instruments and supercomputers, to be researchers who work at the forefront of world-class research; experts who carry out development of advanced technology; and specialists who endeavor in education and public outreach activities equipped with advanced and specialized knowledge.

Numbers of students to be admitted annually:
Two (for the five-year doctoral course)
Three (for the three-year doctoral course)
Degree: Doctor of Philosophy (Doctor of Science, or Doctor of Engineering, depending on the topic of Doctoral thesis)

**(2) Admission Policy**

Department of Astronomical Science seeks students with a strong interest in astronomy and the universe; a passion for unraveling scientific questions through theoretical, observational, and instrument-development research; and who have not only basic academic skills, but also the logical and creative aptitude required for advanced research.

**(3) Department Details** (Course Offerings)

Optical and Infrared Astronomy
[Fields of education and research supervision]
Ground-based astronomy / Optical and infrared telescope systems / Planets / Sun, stars, and interstellar matter / Galaxies and cosmology

Radio Astronomy
[Fields of education and research supervision]
Ground-based astronomy / Radio telescope systems / Sun, stars, and interstellar matter / Galaxies

General Astronomy and Astrophysics
[Fields of education and research supervision]
High-precision astronomical measurement / Astronomy from space / Data analysis and numerical simulation / Earth, Planets, and the Sun / Galaxies and cosmology

**(4) Education and Research Supervision**

In observational research with the state-of-the-art optical-IR and radio telescopes, and theoretical research, the research efforts and the educational efforts are fused together to offer advanced-level education in astronomy and astrophysics. The department consists of the Optical and Infrared Astronomy Unit, Radio Astronomy Unit, and General Astronomy and Astrophysics Unit, but all three units cooperate in the education and research supervision of the students. To ensure that the students with a wide variety of backgrounds can perform original and creative research in the ever-developing field of astronomy, they are guided to focus on learning basic astronomy in the first year. In order to focus on astronomical research, including the basis of observational astronomy, instrument development, and theoretical astronomy, from the second year onwards students learn subjects ranging from principles to applications of advanced technologies that will be the basis of astronomical observations; how to design, fabricate and test new instruments; and the forefronts of data acquisition and data analyses.

**(5) Financial Supports**

In order to provide the students the economical basis upon which they can develop into young researchers skilled in conducting research effectively, the department has set up the Associate Researcher program in addition to the Research Assistant system. In addition, the department has introduced the 'NAOJ Junior Fellow' system from FY 2020 to create an environment in which outstanding students can devote themselves more to their studies and research, and to further improve the standards of researchers produced by the department.

In FY 2021 there were 8 NAOJ Junior Fellows, 19 Associate Researchers, and 2 Research Assistants.

To further improve the research environment for the students, the department provides Oversea Travel Fund, to encourage the students to participate in international conferences to give English talks, conduct observations at various oversea observational facilities and so on, and Research Fund to help them pursue their own original ideas to plan and carry out

research, experiments, etc.

**(6) Undergraduate Students**

For undergraduate students, and for students abroad, we run the SOKENDAI Summer Students Program, Spring School, and Asian Winter School to offer chances to experience research at Department of Astronomical Science. Admission Guidance also targets undergraduate students.

In FY 2021, 26 students participated in the SOKENDAI Summer Students program. The Asian Winter School, conducted online, received 499 applications from 15 countries, and of these, 257 students participated in the program. In addition, 45 students participated in the Spring School, which was also conducted online.

**(7) Number of Affiliated Staff (2022/3/31)**

| | |
|---|---|
| Chair of the Department of Astronomical Science | 1 |
| Optical and Infrared Astronomy Course | |
| Professors | 10 |
| Associate Professors | 8 |
| Assistant Professors | 10 |
| Radio Astronomy Course | |
| Professors | 10 |
| Associate Professors | 11 |
| Associate Professor (Senior Lecturer) | 1 |
| Assistant Professors | 18 |
| General Astronomy and Astrophysics Course | |
| Professors | 9 |
| Associate Professors | 16 |
| Associate Professors (Senior Lecturers) | 2 |
| Assistant Professors | 19 |
| Total | 115 |

**(8) Graduate Students (30 students)**

1st year (5 student)

| Name | Principal Supervisor | Supervisor | Title of Research Project |
|---|---|---|---|
| Ikeda, Ryota | Iono, Daisuke | Tadaki, Kenichi | Observational Studies of Submillimeter Galaxies using ALMA |
| Ishigami, Shun | Hara, Hirohisa | Katsukawa, Yukio | Spectroscopic study at the site of coronal heating |
| Koshisaka, Shiori | Kotani, Takayuki | Fukagawa, Misato | Study of disks around pre-main sequence stars and extrasolar planets by high-contrast polarization direct imaging |
| Nishigaki, Moka | Ouchi, Masami | Takata, Tadafumi | Statistical Study for Galaxies at the Early Formation Stage Identified by Machine-Learning Technique |
| Yoshida, Tomohiro | Nomura, Hideko | Fukagawa, Misato | Research on Chemical Structure of Planet-Forming Regions by ALMA Observations of Molecular Lines |

2nd year (6 students)

| Name | Principal Supervisor | Supervisor | Title of Research Project |
|---|---|---|---|
| Ishihara, Kousuke | Saito, Masao | Nakamura, Fumitaka | The study of high-mass star formation process focusing on the hierarchical fragmentation |
| Sasaki, Shunsuke | Takiwaki, Tomoya | Machida, Mami | Explosion Mechanism of Core-Collapse Supernovae |
| Sugimori, Kanako | Tanaka, Masayuki | Iwata, Ikuru | Evolution of spectral energy distributions of galaxies over cosmic time |
| Tada, Shotaro | Kotani, Takayuki | Hayano, Yutaka<br>Minowa, Yosuke | Development of a single-mode fiber spectrometer and characterization of exoplanet atmospheres |
| Doi, Kiyoaki | Kataoka, Akimasa | Nomura, Hideko<br>Fukagawa, Misato | Unveiling planet formation via protoplanetary disk observations |
| Naufal, Abdurrahman | Tanaka, Masayuki | Koyama, Yusei | Morphological Evolution of Galaxies across Cosmic Environment |

3rd year (9 students)

| Name | Principal Supervisor | Supervisor | Title of Research Project |
|---|---|---|---|
| Omae, Rikuto | Machida, Mami | Ouchi, Masami | Study of galactic magnetic field evolution using the polarization properties of intervening galaxies |
| Kasagi,Yui | Kotani, Takayuki | Hayashi, Saeko<br>Aoki, Wako | Search for extra-solar planets around young to late stars, and brown dwarfs for understandings planet formation at various evolutionary stages |
| Kashiwagi, Raiga | Iwasaki, Kazunari | Takiwaki, Tomoya | A Study on Star Formation Processes in Filamentary Molecular Clouds by Numerical Simulations |
| Kobayashi, Umi | Tanaka, Masayuki | Nakanishi, Koichiro | Influence of galaxy interactions and mergers on AGN activities |
| Tashima, Yuta | Machida, Mami | Nakamura, Fumitaka | Study of the galactic magnetic field using the MHD simulation and observational visualization |
| Nakano, Suzuka | Nakanishi, Koichiro | Sekii, Takashi | The interplay and co-evolution between galaxies and active supermassive blackholes |
| Hosokawa, Kou | Kotani, Takayuki | Minowa, Yosuke<br>Fujii, Yuka | Development of high-contrast and high-spectral resolution spectrometer for the Subaru Telescope and characterization of exoplanet atmospheres |
| Masai, Takaho | Gonzalez, Alvaro | Uzawa, Yoshinori<br>Kojima, Takafumi | Development of (sub-)mm-wave optics and waveguide components for radio astronomy receivers |
| Seo, Chanoul | Fujii, Yuka | Nomura, Hideko<br>Ikoma, Masahiro | Atmospheres of sub-Neptune-sized exoplanets in contact with magma ocean |

4th year (2 students)

| Name | Principal Supervisor | Supervisor | Title of Research Project |
|---|---|---|---|
| Takemura, Hideaki | Nakamura, Fumitaka | Hirota, Tomoya | Study of the star formation processes focusing on the CMF |
| Nishiumi, Taku | Hori, Yasunori | Aoki, Wako<br>Izumiura, Hideyuki | Characterization of exoplanets with MuSCAT series telescopes and MuSCAT series |

5th year (8 students)

| Name | Principal Supervisor | Supervisor | Title of Research Project |
|---|---|---|---|
| Ito, Kei | Tanaka, Masayuki | Matsuda, Yuichi | The systematical study of a protocluster based on the Subaru Telescope wide field survey |
| Isikawa, Ryohtaro | Sekii, Takashi | Katsukawa, Yukio | Study of interactions between turbulence and magnetic fields with spectro-polarimetric observations |
| Kambara, Nagaaki | Hara, Hirohisa | Murakami, Izumi (NIFS) | Spectroscopic diagnostics of highly ionised astrophysical plasma |
| Tsukui, Takafumi | Iguchi, Satoru | Nagai, Hiroshi | Formation and evolution of galactic structures using gas and stellar kinematics |
| Namiki, Shigeru | Koyama, Yusei | Tanaka, Masayuki | What determines the galaxy morphology? A detailed comparison between the visual smoothness and various morphological indicators |
| Fukagawa, Nao | Aoki, Wako | Iono, Daisuke | Contribution of rotating massive stars to the chemical enrichment in the low-metallicity environments of dwarf galaxies |
| Cui, Yuzhu | Honma, Mareki | Nagai, Hiroshi | Observational study of jets in active galactic nuclei with the East Asian VLBI Network |
| Liang, Yongming | Tanaka, Masayuki | Matsuda, Yuichi | Correlation between galaxy and IGM at z≈2 mapped by Subaru/HSC |

## 2. Education and Research Collaboration with Graduate Schools

| Name | Affiliated Institute | Supervisor | Title of Research Project |
|---|---|---|---|
| Ikebe, Souta | The University of Tokyo | Honma, Mareki | Observational research of Fast Radio Bursts |
| Nishino, Yohei | The University of Tokyo | Tomaru, Takayuki | Studies for Gravitational Wave Telescope, KAGRA |
| Fukumitsu, Kakeru | The University of Tokyo | Katsukawa, Yukio | Study on an image restoration technique for high-resolution solar images |
| Homan, Shogo | The University of Tokyo | Motohara, Kentaro | Development of a camera unit for Y-band high dispersion spectrograph TARdYS for TAO telescope and evaluation of NIR array detectors. |
| Mizutani, Yohsuke | The University of Tokyo | Kokubo, Eiichiro | Theoretical study of formation of planetary systems |
| Yano, Yuta | The University of Tokyo | Nakamura, Fumitaka | Numerical Simulations of Star Formation Process |
| Fariyanto, Elika Prameswari | The University of Tokyo | Honma, Mareki | Study of AGN Jets with VLBI observations |
| Adachi, Hiroaki | The University of Tokyo | Fukagawa, Misato | Observational Research on Planetary-system Formation around Young Stars |
| Ogawa, Takuma | The University of Tokyo | Kano, Ryohei | Study on the Galactic dynamics by the use of astrometric data |
| Ono, Kyohei | The University of Tokyo | Kokubo, Eiichiro | Theoritical Study on Formation of Planetary Systems |
| Kofuji, Yutaro | The University of Tokyo | Honma, Mareki | Imaging super-massive black holes with mm VLBI |
| Chen, Nuo | The University of Tokyo | Motohara, Kentaro | Observational Study of Galaxy Formation and Evolution in the ZFOURGE-COSMOS Field |
| Honda, Yuichi | The University of Tokyo | Sakamoto, Seiichi | The study of star formation region by new analysis of FUGIN data |
| Morii, Kaho | The University of Tokyo | Nakamura, Fumitaka | Testing and Constructing High-mass Star Formation Theories by ALMA Observations |
| Moritsuka, Akie | The University of Tokyo | Katsukawa, Yukio | Study of magneto-convection on the solar surface with spectro-polarimetric observations |
| Kinoshita, Shinichi | The University of Tokyo | Nakamura, Fumitaka | Investigation of triggered star formation by using numerical simulation |
| Takamura, Mieko | The University of Tokyo | Honma, Mareki | Exploration of the environment of the Narrow-line Seyfert 1 galaxies' core with VLBI |
| Nakatsuno, Naoki | The University of Tokyo | Kano, Ryohei | The mechanical effect of central mass concentration on the double bar structure |
| Mitsuhashi, Ikki | The University of Tokyo | Sakamoto, Seiichi | Exploration of the star-formation process in high-redshift galaxies using observations of submillimeter galaxies. |
| Yoshida, Yuki | The University of Tokyo | Kokubo, Eiichiro | Theoretical Study on Formation of Planetary Systems |
| Guo, Kangrou | The University of Tokyo | Kokubo, Eiichiro | Planetesimal Dynamics in the Presence of a Massive Companion |
| Lee, Sujin | The University of Tokyo | Honma, Mareki | Observational study of pulsars/magnetars in the radio band |
| Okino, Hiroki | The University of Tokyo | Honma, Mareki | Observational study of AGN jets with Global VLBI |
| Kushibiki, Kosuke | The University of Tokyo | Motohara, Kentaro | Development of an Integral Field Unit SWIMS-IFU and an Observational Study of Nearby LIRGs |
| Hoshino, Haruka | The University of Tokyo | Kokubo, Eiichiro | Theoretical Study on Formation of Planetary Systems |
| Yamazaki, Yuta | The University of Tokyo | Nakamura, Fumitaka | The Evolution of Heavy Elements in the Universe and the Galaxy |
| Tatsuuma, Misako | The University of Tokyo | Kokubo, Eiichiro | Formation Process of Planetesimals Investigated with Numerical Calculation of Material Strength of Small Solar System Bodies |
| Yamaguchi, Masayuki | The University of Tokyo | Nakamura, Fumitaka | The Statistical Properties of the Detailed Structures of the Protoplanetary Disks in the Taurus Star-forming Region with ALMA Super-resolution Imaging Technique |
| Ishizuka, Noriyoshi | The University of Tokyo | Katsukawa, Yukio | Study on Magnetic Reconnection Site in Solar Flares |
| Luo, Yudong | The University of Tokyo | Nakamura, Fumitaka | Cosmic time Evolution of r-process isotopic abundances |

## 3. Commissioned Graduate Students

| Doctoral Course | Affiliated Institute | Period | Supervisor | Title of Research Project |
|---|---|---|---|---|
| Kang, Haoran | The University of Tokyo | 2020/10/1–2021/9/30 | Gonzalez, Alvaro | Study of array receivers in millimeter/submillimeter waves |
| Yamasaki, Yasumasa | Osaka Prefecture University | 2021/4/1–2022/3/31 | Kojima, Takafumi | Development of multi-beam and wideband optics for radio telescope |
| Huang, Shuo | The University of Tokyo | 2021/4/1–2022/3/31 | Kawabe, Ryohei | Multiwavelength Study of Bright Submillimeter Galaxies |
| Masui, Sho | Osaka Prefecture University | 2021/4/1–2022/3/31 | Kojima, Takafumi | Development of superconductive circuits |
| Chin, Kah-wuy | The University of Tokyo | 2021/4/1–2022/3/31 | Kawabe, Ryohei | Development of multi-chroic detector for millimeter/submillimeter multi-chroic camera |
| Kozuki, Yuto | The University of Electro-Communications | 2021/9/1–2022/3/31 | Uzawa, Yoshinori | Study of Frequency Up-Conversion by SIS Mixers |
| Narita, Kanako | The University of Tokyo | 2021/11/1–2022/3/31 | Sakamoto, Seiichi | Observational Study of Material Evolution in Interstellar Space |

| Master's Course | Affiliated Institute | Period | Supervisor | Title of Research Project |
|---|---|---|---|---|
| Ogami, Itsuki | Hosei University | 2020/10/1–2021/9/30 | Aoki, Wako | The Structure of the Andromeda Galaxy's Stellar Halo using Subaru/Hyper Suprime-Cam NB515 |
| Ishida, Mizuki | Tokyo City University | 2021/4/1–2022/3/31 | Agata, Hidehiko | Development of teaching materials for easy use of astronomical image data in educational fields |
| Naganuma, Toyo | The University of Electro-Communications | 2021/4/1–2022/3/31 | Uzawa, Yoshinori | Development of the multi-chroic mm/submm wave camera |
| Niwa, Ayako | University of Tsukuba | 2021/4/1–2022/3/31 | Matsuo, Hiroshi | Development of photon counting THz intensity interferometry |
| Noji, Ryohei | University of Tsukuba | 2021/4/1–2022/3/31 | Shan, Wenlei | Development of dual-polarization MKIDs for surface measurements of radio telescopes |
| Miyazawa, Hiromu | University of Tsukuba | 2021/4/1–2022/3/31 | Shan, Wenlei | Development of 1000 pixel MKID arrays for submillimeter-wave band wide-field observations |
| Le Ngoc Uyen | The University of Electro-Communications | 2021/6/1–2022/3/31 | Tamura, Motohide | Hydrodynamic Simulations of Giant Impact between Protoplanets |
| Katsuki, Riku | The University of Electro-Communications | 2021/8/1–2022/3/31 | Aso, Yoichi | Characterization of the absorption and birefringence of sapphire substrates used for cryogenic test mass mirrors of interferometric gravitational wave detectors |
| Kizaki, Taiga | The University of Electro-Communications | 2021/10/1–2022/3/31 | Makise, Kazumasa | Fabrication and characterization of Nb/CuNi/Nb Josephson junction arrays |
| Ouchi, Shu | Tokyo University of Science | 2021/10/1–2022/3/31 | Makise, Kazumasa | Development and evaluation of high-Q superconducting resonators for superconducting quantum computers |
| Abe, Homare | Tokyo Institute of Technology | 2021/10/1–2022/3/31 | Aso, Yoichi | Measurement of birefringence in a sapphire mirror for the gravitational-wave telescope KAGRA |
| Kawashita, Sana | Osaka Prefecture University | 2021/10/1–2022/3/31 | Tatematsu, Ken'Ichi | Development and commissioning of new 72–116 GHz 7-beam receiver for 45m telescope |
| Chinen, Tsubasa | Osaka Prefecture University | 2021/10/1–2022/3/31 | Tatematsu, Ken'Ichi | Development and commissioning of new 72–116 GHz 7-beam receiver for 45m telescope |
| Yoneyama, Sho | Osaka Prefecture University | 2021/10/1–2022/3/31 | Tatematsu, Ken'Ichi | Development and commissioning of new 72–116 GHz 7-beam receiver for 45m telescope |
| Masukura, Akihiro | Nagoya University | 2022/1/1–2022/12/31 | Shan, Wenlei | Research on the superconducting planar circuit for MMIC SIS receiver |

## 4. Degrees Achieved with NAOJ Facilities

| Name | Degree | Title of Research Project |
|---|---|---|
| Cui, Yuzhu | Doctor of Philosophy, SOKENDAI | Probing the formation region of relativistic jet in nearby active galactic nucleus M87 with the East Asian VLBI Network |
| Ito, Kei | Doctor of Philosophy, SOKENDAI | Star Formation Activity of Galaxies and its Relationship to Environment in Distant Universe |
| Tsukui, Takafumi | Doctor of Philosophy, SOKENDAI | Formation and Evolution of Galactic Structures Using Gas and Stellar Kinematics |
| Namiki, Shigeru | Doctor of Philosophy, SOKENDAI | Origin of the Relation between Galaxy Morphology and its Gas Content |
| Isikawa,Ryohtaro | Doctor of Philosophy, SOKENDAI | Observational Studies on Turbulent Convection in the Solar Photosphere |

# VIII Public Access to Facilities

## 1. Mitaka Campus

[Open year-round]

Dates: April to March, 10:00–17:00

Every day except for New Year's season (December 28–January 4) and the following temporary closure days (145 days in total): April 25–June 20 and July 12–September 30 (due to COVID-19), November 13 (due to equipment inspection), and February 10–14 (due to snowfalls)

Visitors: 7,186 (of which 436 were in groups)

As a measure against the COVID-19 pandemic, all group activities were suspended, except for those recognized as school activities.

Open Facilities: Observatory History Museum (65-cm Telescope Dome), 20-cm Telescope Dome, Solar Tower Telescope, Exhibit Room, Repsold Transit Instrument Building (Transit Instrument Museum), Astronomical Instruments Museum, Gautier Meridian Circle Building, Old Library, 6-m Millimeter-Wave Radio Telescope

As a measure against the COVID-19 pandemic, only the building exteriors and the areas around the entrances were open to the public.

From November 26 to January 16, public access to solar observation parties and inside the Observatory History Museum were allowed mainly on Saturdays and Sundays (but suspended again from January 17 because of a declared state of quasi-emergency).

[Regular Star Gazing Party]

Dates: (On-site) Friday before second Saturday; fourth Saturday

(Online) April–January, fourth Saturday; February–March, Friday before second Saturday and fourth Saturday

Visitors: 0 (23 events planned and 0 events held)

Viewers: (On-site) 0 (23 events planned and 0 events held)

(Online) Held 13 times, with the total number of maximum simultaneous connections reaching 1,359

Total Views: 15,178 (As of March 31, 2022)

All on-site events were canceled due to the COVID-19 pandemic. Online events were broadcasted via Zoom to YouTube Live.

[4D2U Theater Showings]

Dates: Friday before second Saturday; first and third Saturdays

Capacity: 42 people per day (reduced due to the COVID-19 pandemic)

Visitors: 340 (35 events planned and 9 events held)

The events scheduled for April to September, October 2 and 8, and February to March (26 events in total) were canceled as a measure against COVID-19.

[Special Open-House Event] Mitaka Open House Day

Dates: October 22 (Fri.), 2021, 14:00–19:00 (Canceled)
October 23 (Sat.), 2021, 10:00–19:00 (Held online)

Topic: Looking back on the 10 years ALMA's research findings

Number of Contents:

Live streams and YouTube Premier events: 21
Video Contents: 45
Others: 37
Total Contents: 103

Total Maximum Simultaneous Connections: 2054

Total Views in the First Month after the Release: 60,300

This event is jointly sponsored by NAOJ, the University of Tokyo Graduate School of Science Institute of Astronomy, the SOKENDAI Department of Astronomical Science, and the NINS Astrobiology Center. In FY 2021, instead of being held on-site at Mitaka Campus, Mitaka Open House Day was held online only on Saturday (broadcasted on YouTube Live and archived on our YouTube channel).

*As a measure against COVID-19, we had to reduce public access to Mitaka Campus during this fiscal year.

**Ishigaki Island: Ishigakijima Astronomical Observatory**

[Open year-round]

Dates: April to March (except for April 1–September 30[*1] and October 1–31[*2])

Open Hours: Wednesdays through Saturdays, 10:00–16:30; Sundays and Holidays, 13:00–16:30 (except for the New Year's season; when Monday is a national holiday, the facility is closed on the following Tuesday/Wednesday)

Stargazing Sessions: Evenings on Saturdays, Sundays, and Holidays, (19:00–21:00), one 30-minute session per evening

4D2U Theater: 15:30–16:00, from Wednesdays to Sundays and on Holidays

Visitors: 1,400

Open Facilities: Murikabushi 105-cm optical/infrared telescope, Hoshizora Manabi no Heya (Starry Sky Study Room) (featuring the 4D2U "four-dimensional digital universe" and stargazing sessions with the 40-cm telescope), interior of observation dome, and corridors (including exhibits of astronomical images)

*1 Closed from April 1–September 30 due to a partial closure of the road leading to the observatory (Maesedake Rindo).
*2 Public access was limited to the outdoor areas due to the COVID-19 pandemic.

[Special Open Day]
[Southern Island Star Festival 2021] (co-sponsored and held partially online)

Dates: January 29 (Sat.)–February 6 (Sun.), 2021

Star Festival Live & the Ishigaki Island Starry Sky and Star Culture Lecture:
Held on January 29 (Sat.) at Ishigaki City Hall, live streamed with no audience on-site, and viewed 5,290 times on YouTube

Star Festival Memorial Lecture: Held on January 30 (Sun.) at Ishigaki City Hall with 45 visitors

Star Festival Week Events: Held from January 29 (Sat.) to February 6 (Sun.) at Ishigakijima Astronomical Observatory with 52 visitors

## 2. Mizusawa Campus

[Open year-round]
Dates: April to March (except for New Year's season), 9:00–17:00 daily
Visitors: 7,991
Open Facilities: Kimura Hisashi Memorial Museum, VERA 20-m antenna, 10-m VLBI antenna

The open house event is held at the campus with the cooperation of the Oshu Space and Astronomy Museum (OSAM: Yugakukan) located in the campus.
However, in order to prevent the spread of the novel coronavirus infection, the Kimura Hisashi Memorial Museum has been temporarily closed during the following periods: From April 1, 2021 to present

[Special Open Day]
In light of the fact that novel coronavirus infections have not yet ended, we consulted with Oshu City and the Oshu Space and Astronomy Museum (OSAM: Yugakukan), and decided to cancel this event in consideration of the health and safety of the participants and related people, and to prevent the spread of the infection.

**Iriki: VERA Iriki Station**
[Open year-round]
Dates: April to March (except for New Year's season)
Visitors: 1,338

[Special Open Day]
The special open house is usually held as the "Yaeyama Highland Star Festival" organized by the executive committee led by Satsuma-sendai city hall and Kagoshima University. This year, in light of the measures to prevent the spread of the novel coronavirus, it was expected that the situation would continue to require that events be cancelled, or at least infection prevention measures would be needed to avoid crowding during the event period, and even if the event period was postponed, it would be difficult to implement. After consultation with the main committee members, it was decided to cancel the conference.

**Ogasawara: VERA Ogasawara Station**
[Open year-round]
Dates: April to March (except for New Year's season)
Visitors: 4,090

[Special Open Day]
In view of the fact that novel coronavirus infections have not yet ended, we decided to cancel this event in order to protect the health and safety of the participants and related people and to prevent the spread of the infection.

**Ishigaki Island: VERA Ishigaki-jima Station**
[Open year-round]
Dates: April to March (except for New Year's season); premises are open to the public 24 hours/day, and the observation rooms are open during the hours of 10:00–16:30.
Visitors: 1,698

[Special Open day] The Special Open Day was held as a part of the Southern Island Star Festival.
Dates: January 29 (Sat.), 2022, 18:00–21:00
January 30 (Sun.), 2022, 13:30–16:00

In view of the fact that novel coronavirus infections have not yet ended, this was the first time the event was held in winter, in order to protect the health and safety of the participants and related people and to prevent the spread of the infection.
A "Star Festival Commemorative Lecture" was held on the second day, and a panel booth was set up at the venue to distribute VERA goods to participants.

## 3. Nobeyama Campus

[Regular Open Facilities]

Open Time: 8:30–17:00 (every day except around New Year's Day (December 29 to January 3))

Visitors: 30,371

Open Facilities: 45-m Radio Telescope, Nobeyama Millimeter Array, Nobeyama Radioheliograph, etc. (just viewing)

[Open House Day] (held online only)

Date: August 28 (Saturday), 2021, 10:00–15:30 (available for access after the day)

Participants: 6715 (total number of views for live stream) about 130,000 (total number of views for all content in about the first 30 days)

Nobeyama Open Campus Day 2021 was held online as a precaution against the spread of COVID-19. The theme was "People who support the science." We had a special lecture, which attracts a large audience every year. It was held online with the title "Developing, repairing, and using observation instruments: case for radio astronomy" by Associate Prof. Minamidani, Tetsuhiro (Chile Observatory, NAOJ). The number of views for this live streaming reached over 3500. Moreover, the total number of views in the first 30 days was more than 15 thousand. We also proceeded with online streaming content such as a 4D2U theater, mini lectures led by the ALMA project, demonstration of the 45-m radio telescope, and a live broadcast from Nobeyama Campus. We prepared many movie contents including an introduction to our research, a tour inside the 45-m radio telescope, antenna origami, and so on. Moreover, we had a "quiz rally," event for communicating with participants. The participants look for and collect quiz answers in some movies and write the answers in a form to get NRO original goods.

[Jimoto Kansha Day (Thanks Day for the locals)]

This event could not be held due to prevention measures against the spread of COVID-19.

## 4. Subaru Telescope

[Summit Facility Tour]

Public tours have been suspended due to various factors
Special tours resumed in September 2021 in a limited way:
2 groups, 8 visitors

[Base Facility Tour]

Special tours resumed in March 2022 in a limited way:
1 group, 7 visitors

[Public information]

○ Primary means of public information is posting at the official website https://subarutelescope.org
- Science results from the Subaru Telescope – 15 Japanese and 14 English articles
- Depicting special activities or making announcements on Call for Proposals, recruitment – 34 Japanese and 29 English articles.

○ Web postings are supplemented by social media via official accounts
- Twitter accounts – SubaruTelescope (for Japanese), SubaruTel_Eng (for English)
- Facebook pages – 国立天文台 (for Japanese), National Astronomical Observatory of Japan, and Subaru Telescope Hawaii Outreach (for English)
- YouTube channels – SubaruTelescopeNAOJ (for Japanese), SubaruTelescopeNAOJe (for English)

[Outreach]

1. Lectures, workshops, etc. at nearby facilities:
3 cases, 200 people in total

(Breakdown as follows)
- Mentorship for high school robotics teams
- Judges at 2022 Hawai`i VEX IQ Elementary School State Championship, in-person tournament
- Internal Citizen Science Project "PANOPTES" helped high school and undergraduate students build a PANOPTES unit.

2. Others

1) In person Activities:
4 events, able to interact with about 2,300 people

(Breakdown as follows)
- AstroDay
- AstroDay West
- Lili`uokalani Gardens Christmas Light Show (as member of Maunakea Observatories volunteer group Na Hoku Huihui)
- Maunakea Coin Contest (as members of Maunakea Astronomy Outreach Committee)

*Due to the COVID-19 pandemic, the in-person events were held by minimizing the close contact.

2) Online Activities:
4 events, able to interact remotely with about 2,200 people

(Breakdown as follows)
- Girl Scout STEM Fest
- Hawai`i Island Virtual Career Expo
- Judges at 2022 Hawai`i VEX IQ Elementary School State Championship, pre-interview
- Journey Through The Universe: 8 staff members gave an online lecture or spoke on a career panel

3. YouTube Live Streaming:
4 cases, about 3,081, 500 views

(Breakdown as follows)
- Live broadcast of the total lunar eclipse
- Live broadcast of the partial lunar eclipse
- Live broadcast from the summit facility to the live viewing event of Akashi Municipal Planetarium for the partial lunar eclipse
- Live Talk event hosted by Hamagin Space Science Center

*In April 2021, the Subaru Telescope started a 24/7 live stream from Maunakea with the Subaru-Asahi Star Camera in collaboration with The Asahi Shimbun Company.

4. Volunteer Activities: 8 cases
In addition to traditional outreach activities, staff members participated in volunteer activities to contribute to the local community of Hawai`i.

(Main Activities)
- Invasive Species Weed Pulls at Halepohaku, the mid-elevation facilities of Maunakea
- Maunakea Forest Restoration Project
- The Food Basket (Hawai`i Island's Food Bank), packing and delivery

The following local annual events were canceled due to the COVID-19 pandemic:
- The Mary Monarch Parade
- The Tanabata Hoshimatsuri Festival
- Hawaii Explorations Expo
- Onizuka Science Day

5. Media Interview/Filming: 5 cases (4 Japanese, 1 English), 35 articles were featured in Japanese newspapers

# IX Overseas Travel

## Research and Academic Staff Overseas Travel

(Including employees on annual salary system.)

| category / country/area | Business Trip | Training | Total |
|---|---|---|---|
| South Korea | 0 | 0 | 0 |
| China | 0 | 0 | 0 |
| Thailand | 0 | 0 | 0 |
| Taiwan | 0 | 0 | 0 |
| Hong Kong | 0 | 0 | 0 |
| Singapore | 0 | 0 | 0 |
| Indonesia | 0 | 0 | 0 |
| Philippines | 0 | 0 | 0 |
| Other areas in Asia | 0 | 0 | 0 |
| Hawai`i | 14 | 0 | 14 |
| U.S.A. | 5 | 0 | 5 |
| Australia | 1 | 0 | 1 |
| Italy | 1 | 0 | 1 |
| U.K. | 1 | 0 | 1 |
| France | 1 | 0 | 1 |
| Canada | 0 | 0 | 0 |
| Guam, Saipan | 0 | 0 | 0 |
| Germany | 4 | 0 | 4 |
| Other areas in Europe and Oceania | 2 | 0 | 2 |
| Mexico | 0 | 0 | 0 |
| Brazil | 0 | 0 | 0 |
| Africa | 0 | 0 | 0 |
| Other areas in South and Central America * | 11 | 0 | 11 |
| Total | 40 | 0 | 40 |

* In typical years, most travelers to South and Central America go to Chile.

# X Award Winners

| Award Recipients | Affiliated Division | Job Title | Award | Date |
|---|---|---|---|---|
| Usuda-Sato, Kumiko; Tanaka, Masayuki; Koike, Michitaro; Shibata, Junko | Subaru Telescope | RCUH; Associate Professor ; Senior Specialist; Public Outreach Staff | FY 2021 The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Awards for Science and Technology (Public Understanding Promotion Category) | 2021/4/14 |
| Kojima, Takafumi | Advanced Technology Center | Associate Professor | FY 2021 The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, The Young Scientists' Award | 2021/4/14 |
| Kataoka, Akimasa | Division of Science | Assistant Professor | FY2020 JSPS Outstanding Young Scientist Award | 2021/6/3 |
| Okayama Branch Office, Subaru Telescope | | | Commendation for Meritorious Service to Tourism and Product Business | 2021/6/17 |
| Moriya, Takashi | Division of Science | Assistant Professor | FY 2020 The ASJ Young Astronomer Award | 2021/9/14 |
| Nakajima, Kimihiko | Division of Science | Project Assistant Professor | FY 2020 The ASJ Young Astronomer Award | 2021/9/14 |
| Kataoka, Akimasa | Division of Science | Assistant Professor | FY 2020 The ASJ Young Astronomer Award | 2021/9/14 |
| Nugroho, Stevanus Kristianto | Subaru Telescope | Project Researcher | The 13th Senshu-kai Award | 2021/10/30 |
| Agata, Hidehiko | Public Relations Center | Associate Professor | Letter of Appreciation for the 70th Anniversary of Mitaka City (Sports and Culture Division) | 2021/11/3 |
| Iguchi, Satoru; Saito, Masao et al. | ALMA Project; TMT Project | Professor; Professor | FY 2021 Award of Invention and Innovation in Kinki Region, Invention Encouragement Award | 2021/11/4 |
| Ouchi, Masami | Division of Science | Professor | Highly Cited Researcher 2021 | 2021/11/16 |
| Hanayama, Hidekazu | Public Relations Center | Associate Professor (Senior Lecturer) | 2021 Photo Contest of Local Landscape with Starry Sky | 2021/11/26 |
| Miyazaki, Satoshi | Advanced Technology Center | Professor | FY2021 The 67th Nishina Memorial Prize | 2021/12/6 |
| The SEIMEI Telescope | | | The Society of Instrument and Control Engineers System Integration Department, Technical Achievement Award | 2021/12/17 |
| Kameno, Seiji | ALMA Project | Professor | ALMA-JAO Fundamental Statements Awards (Curiosity) | 2021/12/17 |
| Hanayama, Hidekazu | Public Relations Center | Associate Professor (Senior Lecturer) | Letter of Appreciation from Hayabusa 2 | 2021/12/19 |
| Ishigakijima Astronomical Observatory, Public Relations Center | | | Letter of Appreciation from Hayabusa 2 | 2021/12/19 |
| Kataoka, Akimasa | Division of Science | Assistant Professor | FY 2021 NAOJ Young Researchers Award | 2022/1/5 |
| Nagai, Hiroshi; Nakanishi, Koichiro; Hull, Charles; Kameno, Seiji | ALMA Project | Project Associate Professor; Project Associate Professor; Project Assistant Professor; Professor | FY 2021 Shoichiro Yoshida Memorial/ Nikon Astronomy Achievement Award | 2022/1/31 |
| Wong, Kenneth Christopher | Subaru Telescope | Project Researcher | FY 2021 The ASJ Young Astronomer Award | 2022/3/4 |
| National Astronomical Observatory of Japan | | | The 63rd Science and Technology Film/ Video Festival Science Museum Director Award | 2022/3/11 |
| Aritomi, Naoki | Gravitational Wave Science Project | Project Researcher | The 16th Young Scientist Award of the Physical Society of Japan | 2022/3/16 |

# XI Library, Publications

## 1. Library

Number of books in each library (2022/3/31)

| | Japanese Books | Foreign Books | Total |
|---|---|---|---|
| Mitaka | 18,452 | 49,227 | 67,679 |
| Nobeyama | 1,128 | 5,891 | 7,019 |
| Mizusawa | 4,986 | 18,113 | 23,099 |
| Hawai`i | 1,699 | 4,683 | 6,382 |
| Total | 26,265 | 77,914 | 104,179 |

Number of journal titles in each library (2022/3/31)

| | Japanese Journals | Foreign Journals | Total |
|---|---|---|---|
| Mitaka | 371 | 1,675 | 2,046 |
| Nobeyama | 16 | 82 | 98 |
| Mizusawa | 659 | 828 | 1,487 |
| Hawai`i | 15 | 12 | 27 |
| Total | 1,061 | 2,597 | 3,658 |

## 2. Publication

Here we list continuing publications produced by NAOJ in FY 2021.

**(Mitaka)**
01) Report of the National Astronomical Observatory of Japan, Vol. 22: 1 issue (Digital Publication Only).
02) Annual Report of the National Astronomical Observatory of Japan (Japanese), no. 33, Fiscal Year 2020: 1 issue
03) Annual Report of the National Astronomical Observatory of Japan (English), vol. 23 Fiscal Year 2020: 1 issue
04) Calendar and Ephemeris, 2022: 1 issue
05) NAOJ News, No. 333–336: 4 issues
06) NAOJ Pamphlet 2021 (Japanese): 1 issue
07) Rika Nenpyo (Chronological Scientific Tables), 2022: 1 issue
08) Publication of the National Astronomical Observatory of Japan Volume16: 1 issue (Digital Publication Only)

## 3. Publication Support

In FY 2021, the NAOJ Reprints were replaced by publication support.

National Astronomical Observatory publication support, No. 3479–3580: 101 issues.
(No. 3537 is missing.)

# XII Important Dates

## April 1, 2021 – March 31, 2022

| 2021 | |
|---|---|
| April 3 | The Subaru Telescope started the 24/7 live streaming from Maunakea with the Subaru-Asahi Star Camera in collaboration with The Asahi Shimbun Company. |
| April 12 | Vice Minister of Education, Culture, Sports, Science and Technology Hinako Takahashi visited Mitaka Campus. |
| April 14 | A press conference “Telescopes Unite in Unprecedented Observations of Famous Black Hole” was held online, with satellite venues at Mizusawa VLBI Observatory and Kagoshima University connected. The conference was jointly hosted with the University of Tokyo ICRR, Kogakuin University, Hiroshima University, the Graduate University for Advanced Studies, Ibaraki University, Yamaguchi University, and other institutes, attended by 27 representatives from 23 media organizations. |
| April 14 | GALAXY CRUISE members Kumiko Usuda-Sato, Masayuki Tanaka, Michitaro Koike, and Junko Shibata were awarded The 2021 Commendation for Science and Technology (Public Understanding Promotion Category) by the Minister of Education, Culture, Sports, Science and Technology. |
| April 14 | Associate professor Takafumi Kojima received the Young Scientists’ Award, 2021 Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (MEXT) for his study on the improvement of sensitivity and bandwidth of receivers for radio astronomy. |
| April 22 | Event Horizon Telescope’s research released new learning content, a poster titled “What have we learned? The Frontiers of Black Hole Research.” |
| April 30~May 2 | Subaru Telescope participated in the AstroDay event at a shopping mall in Hilo on the Island of Hawai`i with minimum contact and distributed bags containing hands-on astronomy kits. |
| May 6 | Radio interferometric observations captured in detail the jets emanating from the center of a galaxy as they bent within the galaxy cluster. |
| May 19 | A press conference “ALMA Discovers the Most Ancient Galaxy with Spiral Morphology” was held online jointly with SOKENDAI, attended by 15 representatives from 12 media organizations. |
| May 20 | Using images of the M87 giant black hole released in 2019 by the Event Horizon Telescope research team to test various theories of gravity, including general relativity, the team presented that general relativity agrees very well with the observed data and that there is still room for other theories of gravity to describe the observed black hole. |
| May 24 | Based on donations from many people to the National Astronomical Observatory of Japan’s Mizusawa VLBI Observatory, the exterior of the Kimura Hisashi Memorial Hall was repainted between May 27 and June 30, 2021. |
| May 25~May 26 | Subaru Telescope and its internal citizen science project PANOPTES live-broadcasted the total lunar eclipse from the Island of Hawai`i. |
| May 28 | Subaru Telescope's website for children, “Subaru Kids” relaunched in Japanese. |
| June 15~June 16 | ALMA Data Analysis Workshop (Beginner Level) was held jointly with the Astronomy Data Center online. |
| July 7 | In cooperation with the Iwate Prefectural Kenan Regional Promotion Bureau, an exhibition was planned and exhibited at libraries and other venues in the Kenan area through February 2, 2022. |
| July 7 | Associate professor Yoshiharu Asaki gave a lecture at Santiago Japanese School in Chile. |
| July 7 | Associate Professor (Senior Lecturer) Masaaki Hiramatsu gave an online lecture at a Star Festival Event. |
| July 9 | Vice Minister of MEXT Hinako Takahashi visited the National Astronomical Observatory of Japan Mizusawa VLBI Observatory, in Oshu City, Iwate Prefecture, and listened to presentaions on a wide range of topics from the latest astronomical research techniques and results, to the history of this site where astronomical observation has been conducted since the Meiji Era. |
| July 19 | Event Horizon Telescope’s research team took unprecedented high-resolution images of the root of the Centaurus A jet, pinpointing the location of the giant black hole and revealing how the massive jet is born. |
| July 15~July 16 | ngVLA Development Days 2021 was held online. |
| August 3 | An undergraduate intern of the Akamai Workforce Initiative program, supervised by Subaru Telescope mentors, presented at the Akamai Internship Symposium. |
| August 9 | Minister of Education, Culture, Sports, Science and Technology, Koichi Hagiuda, visited the Subaru Telescope. |
| August 17 | Professor Seiichi Sakamoto gave an online lecture at the Camara monthly meeting. |
| August 18 | Professor Seiichi Sakamoto participated as lecturers in the online event organized by “Hoshi-tsumugi no mura,” a general incorporated association, for children hospitalaized for a long time or home care, their families and healthcare professionals. |

| | |
|---|---|
| August 28 | Open House day of Nobeyama Radio Observatory was held online. The total number of viewers for live streaming reached about 6700, and total number of views for all content in about the first 30 days was about 130,000. |
| August 31 | The third public data set of the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) was released. |
| September 17 | Undergraduate students of the SOKENDAI Summer Student program, supervised by Subaru Telescope scientists, gave online presentations about their study results. |
| September 21 | A press conference “Unveiling Galaxies at Cosmic Dawn That Were Hiding Behind the Dust” was held online. The conference was jointly hosted with Waseda University, Hiroshima University, the University of Geneva, and the Joint ALMA Observatory, attended by 11 representatives from 10 media organizations. |
| October 7 | Nour Skaf at Subaru Telescope received the “L’Oréal-UNESCO for Women in Science - Rising Talents - France 2021” award. |
| October 12 | An international research team consisting of Kogakuin University, Yamaguchi University, Go National College of Technology, National Astronomical Observatory of Japan, National Astrophysical Institute of Italy, Korean Astronomical Institute, and Harvard University has conducted detailed radio observations using the Japan-Korea Joint VLBI Observation Network (KaVA: KVN and VERA Array). The team succeeded for the first time in capturing the dramatic phenomenon of an active galactic nuclear jet, which has just been ejected from a supermassive black hole, colliding with a high-density gas cloud and being intercepted by it. |
| October 23 | The Mitaka Open House Day event consisted of 3 main lectures and a total of 103 contents, including 21 live streams (including YouTube Premiere events) by NAOJ’s projects, 45 video contents, 37 other web contents. The maximum number of simultaneous connections was 2,054. The archived video garnered 60,300 views in the first month of its release. |
| November 1 ~November2 | “Cold outflows near and far: crossroad of our current understandings” was held online. |
| November 2, November 5 | ALMA Data Analysis Workshop (Intermediate Level) was held jointly with the astronomy data center online. |
| November 11 | The National Astronomical Observatory of Japan (NAOJ) and Iwate Nippo held a signing ceremony for a comprehensive collaboration agreement at the National Astronomical Observatory of Japan's Mizusawa VLBI Observatory. This agreement was planned as a “Next Generation Researcher Support Project” with the aim of creating a path to secure excellent doctoral human resources. This agreement began with a pleasant conversation between Dr. Azumane, President of Iwate Nippo, and NAOJ Director General Tsuneta, and came to fruition after Dr. Azumane made a proposal after attending a lecture by Homma, Director of Mizusawa VLBI Observatory. We are looking forward to its further development as a powerful means of securing human resources for the promotion of science. |
| November 11 | Subaru Telescope and NAOJ TMT Project members gave an online presentation at Girl Scout STEM Fest in Hawai`i. |
| November 13 | The Sixth “Nagano Prefecture is Astro-Prefecture” meeting was held online at Syogaigakushu-center in Chino by “Nagano Prefecture is Astro-Prefecture” liaison council, which consists of Nobeyama Radio Observatory, Kiso Observatory of the University of Tokyo, and so on. There were about 60 participants in the meeting. |
| November 14 | Subaru Telescope, Project PANOPTES, and TMT Project participated in the AstroDay West event at a shopping center in Kailua-Kona on the Island of Hawai`i. |
| November 18 | Subaru Telescope and Project PANOPTES participated in the online Hawai`i Island Virtual Career Expo and chatted lively with students. |
| November 18 ~November 19 | Subaru Telescope and Project PANOPTES live-broadcasted the partial lunar eclipse from the Island of Hawai`i. |
| November 30 ~December 1 | Linking the Science of Large Interferometers in the 2030s was held online. |
| December | Subaru Telescope received a letter of appreciation from the Japan Aerospace Exploration Agency (JAXA) to commemorate the success of the asteroid explorer Hayabusa2. |
| December 4 | Subaru Telescope scientists presented at the online live talk event hosted by Hamagin Space Science Center. |
| December 6, December 13 | ALMA Grant Fellow Symposium 2021 was held online. |
| December 9 | A press conference “Fiery Dragon’s Breath May Scorch Young Planets” was held online. The conference was jointly hosted with Kyoto University and the University of Hyogo, attended by 15 representatives from 14 media organizations. |
| December 14, 16 and 21 | FY 2021 ALMA/45m/ASTE Users Meeting was held online. |

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| December 20, December 22 | Millimeter/submillimeter VLBI sciences with ALMA was held online. |
| December 23 ~December 25 | Subaru Telescope participated in the Lili`uokalani Gardens Christmas Light Show in Hilo on the Island of Hawai`i as a member of Maunakea Observatories volunteer group Na Hoku Huihui. |

**2022**

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| January | Observations of the Hyper Surpime-Cam Subaru Strategic Program (HSC-SSP) since 2014 completed. |
| January 5 | Ishigakijima Astronomical Observatory welcomed the 150,000th visitor to its public facilities. |
| January 11 ~January 13 | The annual Subaru Users Meeting FY 2021 was held in a hybrid style of on-site and online. |
| January 17 ~March 21 | The Maunakea Coin Contest, open to K-12 students on the Island of Hawai`i, was held by the Maunakea Astronomy Outreach Committee. A Subaru Telescope staff member was one of the leaders of the contest. |
| January 18 ~January 21 | East Asian ALMA Science Workshop 2022 was held online. |
| January 29 ~February 6 | Southern Island Star Festival 2021 was held partially online. The Star Festival Live & the Ishigaki Island Starry Sky and Star Culture Lecture on January 29 were viewed 5290 times on YouTube. The memorial lecture on January 30 was attended by 45 people. |
| February ~April | As a part of the NAOJ's FY2021 Project Review, the international external evaluation of the Subaru Telescope was conducted online. |
| February 5 | Professor Seiichi Sakamoto participated as lecturers in the event organized by Japan Space Forum. |
| February 8 | Ceremony for the 40th anniversary of Nobeyama Radio Observatory was held online. About 120 people participated in it. A memorial magazine was created and distributed. |
| February 22 | Radio observations in the 1.3 cm and 7 mm wavelength bands by the East Asian VLBI network revealed the detailed structure of the giant black hole object Sagittarius A (ASTER), which lies at the center of the Milky Way Galaxy. The size of the emitting region suggests that the gas flow accreting onto the giant black hole contains non-thermal electrons accelerated to extremely high energies, and the nearly circular shape of the emitting region suggests that the accretion disk's axis of rotation (or the direction of the weak jet) may point almost exactly in the direction of the Earth. |
| February 27, March 5 | A total of seven Subaru Telescope and NAOJ TMT Project staff members contributed to the 2022 Hawai`i VEX IQ Elementary School State Championship as judges at online interviews (February 27) and in-person tournament (March 5). |
| February 28 ~March 4 | A total of 13 Subaru Telescope and NAOJ TMT Project staff members participated in the 2022 online Journey Through the Universe and provided presentations and participated in a career panel. |
| March | As a part of the NAOJ's FY2021 Project Review, the international external evaluations of the Advanced Technology Center, Optical and Infrared Synergetic Telescopes for Education and Research (OISTER), and Japanese VLBI Network (JVN) were each conducted online. |
| March 3 | The Subaru Telescope achieved the first launch of a new laser guide star system, upgraded and used for the Subaru Telescope's adaptive optics system. |
| March 5 | Kenneth Wong, a Project Research Fellow at the Subaru Telescope, was selected to receive the 2021 ASJ Young Astronomer Award. |
| March 9 ~March 10 | East Asian ALMA Development Workshop 2022 was held online. |
| March 20 ~March 21 | Chura-boshi Research Team workshop for high school students was held at VERA Ishigaki-jima Station and Ishigakijima Astronomical Observatory for the first time in two years. Although it was postponed from the original schedule due to the decision to continue a state of emergency, it was successfully held while taking precautions against novel coronavirus infection. |
| March 24 ~March 25 | Workshop on "Astronomy investigated with data science approaches" was held as part of the project "Understanding the 3-D structure of the Milky Way Galaxy based on a machine learning method applied on large-scale data of molecular clouds" which is one of the projects of the "Interdisciplinary research by young researchers Project" by NINS. About 80 researchers in fields of astronomy and informatics including young researchers participated in it. |
| March 24 | Subaru Telescope's website for "Subaru Telescope 2.0" launched in Japanese. |
| March 28 | There was an exhibition booth at the Reception for the Emperor's Birthday held in the Embassy of Japan in Chile. |
| March 29 ~March 30 | ALMA Cycle 9 2022 Proposal Preparation Meeting was held online. |

# XIII Publications, Presentations

## 1. Refereed Publications

Abbas, M., Grebel, E. K., **Simunovic, M.**: 2021, RR Lyrae Stars in Stellar Streams with Gaia: The Escapers, *ApJ*, **915**, 49.

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NAOJ
National Astronomical Observatory of Japan