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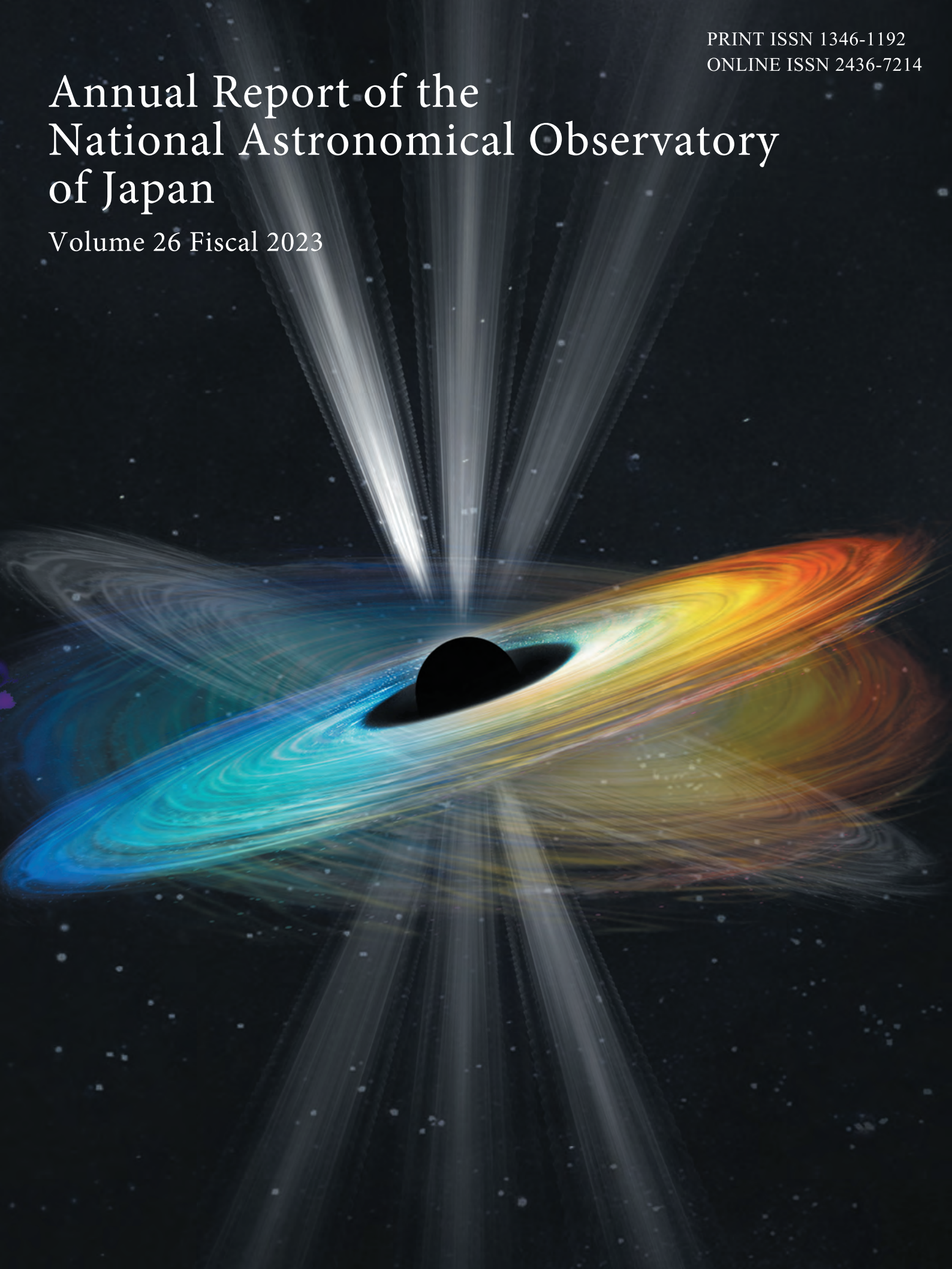
Volume 26 Fiscal 2023



Cover Caption

Illustration: A conceptual image of the accretion disk and jet precessing around a rotating supermassive black hole. If the rotation axis of the disk is tilted with respect to the spin axis of the black hole, precession of the jet occurs due to the effect of general relativity.

Credit: Cui et al. (2023), Intouchable Lab@Openverse and Zhejiang Lab

Radio Image: The jet emanating from the central region of the elliptical galaxy M87, captured by the East Asian VLBI Network.

Credit: Cui, Y., EAVN Collaboration

Postscript

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Annual Report of the National Astronomical Observatory of Japan

Volume 26, Fiscal 2023

PREFACE

Mamoru DOI
Director General of NAOJ

I am pleased to present the Annual Report of the National Astronomical Observatory of Japan for FY 2023.

The main mission of NAOJ is to provide large astronomical facilities that cannot be supported by individual universities to researchers throughout Japan through open use. As of FY 2023, NAOJ conducts open use observations with the Subaru Telescope and ALMA; radio observations with the East Asian VLBI Network and the Nobeyama 45-m Radio Telescope; synergetic observations with small and medium-sized telescopes in the optical-infrared wavelength domain; and solar observations with Hinode. In addition, we are promoting the Thirty Meter Telescope (TMT) project for the future. In theoretical research, we provide a numerical simulation environment through ATERUI, as well as archiving and publishing observation data acquired not only by NAOJ's telescopes such as the Subaru Telescope and ALMA but also including data acquired by university owned telescopes in Japan. Furthermore, the Advanced Technology Center leads various development activities. And many research results have been published, most notably those coming out of the Division of Science. In addition, educational activities are conducted in cooperation with the Graduate University for Advanced Studies and other universities. NAOJ also conducts various outreach activities, mainly through our Public Relations Center. In addition, a number of offices and other organizational infrastructure have been established to deal with various matters both internal and external. Here, I will mention the highlights of FY 2023. For full details, please refer to the reports contained in this volume.

Through high spatial resolution radio observations over the course of a decade, the East Asian VLBI Network EAVN, which includes Mizusawa VLBI Observatory, discovered that the jet from the black hole at the center of galaxy M87 precesses (wobbles). This is an important result for understanding active galactic nuclei, galaxy centers hosting an active supermassive black, and the surrounding phenomena. At the same time, it can also be said to show the importance of continuous, long-term astronomy observations over 10 years and the importance of international cooperation.

Observations with the Nobeyama 45-m Radio Telescope have revealed a structure with a broad velocity-width associated with a molecular cloud within the Galaxy. Taken together with the presence of a nearby cavity in the galactic plane in the vicinity, this discovery may have captured traces of dark matter subhaloes passing through the galactic plane.

In the Solar Science Project, HINODE and the Solar Flare Telescope have continued to observe the increase in solar activity rising toward the solar maximum. Data captured by HINODE contributed to the publication of more than 50 papers. The Solar Flare Telescope conducted infrared polarization spectroscopic observations to obtain full-disk magnetic field measurements in the photosphere and chromosphere, and full-disk Hα imaging observations. In addition, relative sunspot number measurements with a sunspot telescope continued as an indicator of long-term variations in solar magnetic activity.

Results using Subaru Telescope's wide-field camera HSC to observe a large number of distant galaxies and investigate the formation of structures of galaxies using gravitational lensing effects, were found to not agree with the results obtained from observations of fluctuations in the cosmic microwave background radiation with a confidence of over 95%, indicating a possible breakdown in the standard theory of structure formation in the Universe. In addition, observations of low-metallicity stars in the Milky Way Galaxy with the Subaru Telescope's High Dispersion Spectrograph (HDS) revealed one star with an elemental composition similar to that produced by a pair-instability supernova, the end of a massive star. This result strongly supports the theory that stars over 140 times the mass of the Sun formed in the early Universe.

The Seimei Telescope, for which NAOJ administrates the open use, monitored a solar-type star and succeeded in capturing the world's first optical observation of a superflare, and determined that it was accompanied by prominence eruptions.

In one of the results from the Center for Computational Astronomy, simulations using the “general purpose PC cluster” of the formation process of multiple ring basins on the surface of the Jovian satellite Europa succeeded in finding the thickness of Europa's ice shell.

At ALMA, among the various newly developed observing capabilities, observations in the highest observation band, Band 10, with an antenna array configuration with a maximum baseline length of 16 km successfully achieved a spatial resolution of 5 milli-arcseconds, the best to date. In terms of scientific results, numerous results were presented on the formation and evolution of stars, planets, galaxies, and galaxy clusters; as well as on explosive phenomena.

Instrument development progressed at the ASTE telescope, and test observations were conducted for four observational instruments.

KAGRA participated in the 4th International Gravitational-Wave Joint Observation (O4) from May to June 2023, and succeeded in greatly improving the sensitivity to an average of 1.3 Mpc in terms of binary-neutron star merger distance stably with a duty cycle of around 80 %.

In the TMT project, an end-term evaluation was conducted by the Working Group on Large Scientific Research Projects, the Research Environment Infrastructure Subcommittee, the Science Committee of the MEXT’s Council for Science and Technology. Although the TMT project has been suspended due to unexpected external factors, it received a high evaluation based on its achievement, implementation structure, academic significance and ripple effects, and societal significance and ripple effects. In addition, the TMT plan was included in the same working group’s fundamental concepts for promoting large scientific research projects - Roadmap 2023. NAOJ, as a member of the TMT International Observatory, has been actively involved in activities such as building trust through direct dialogue and educational support in Hawai`i, where TMT is slated to be built, and the local situation has improved significantly. In addition, the U.S. National Science Foundation (NSF) convened two panels to consider NSF participation in the TMT project, and TMT was highly evaluated by both panels.

In the JASMINE Project, we have been discussing the concept with satellite development manufacturer candidates and have compiled a proposal for a feasible observation instrument. In parallel to the development of the infrared detector, a simplified and scaled-down simulation of the mission (a simulated observational survey) was performed, and the proper motion and annual parallax of the target were successfully reproduced with the expected accuracy.

The RISE Project, as the MMX Geodesy Science Strategy Team, developed and verified analysis software, worked with the manufacturer to develop the laser altimeter, and contributed to the formulation of a mid- to long-term operation plan in the Mission Operation Working Team.

The SOLAR-C project conducted a feasibility study on 11 items of the science payload, and confirmed the design validity of the critical items and clarified the issues to be addressed in the initial design. As a result, the JAXA SOLAR-C pre-project passed the System Definition Review in December 2023, and the project was officially launched as a JAXA project in March

2024.

The Subaru Telescope's ultra-wide-field multi-object spectrograph PFS conducted commissioning observations in a partially completed state. Software development is ongoing. As of the end of FY 2023, observations using all of the approximately 2400 fibers have been conducted using 10 cameras (4 red, 4 blue, 2 infrared).

The Subaru wide-field adaptive optics project began prototype development for a wavefront sensor, a laser guide star launching system, and part of the control system, as well as procurement and technical demonstration testing of parts for the wavefront sensor for laser tomography adaptive optics and the four-beam laser guide star launching system. For the adaptive secondary mirror, fabrication of the main optical components continued, and fabrication of the mechanical and electrical components was completed.

The Astronomical Data Center (ADC) continued new database technique development and migration to a new rental system for the SMOKA, MASTARS, and JVO data archives for data from the Subaru Telescope, the 188-cm telescope at the Okayama Branch (former Okayama Astrophysical Observatory), and university telescopes. In addition, the development and operation of the Subaru Telescope HSC data analysis and archiving system continued in collaboration with Subaru Telescope, and preparations were made to accept new data from the Seimei Telescope GAOES-RV instrument, and data acquired during the commissioning of PFS on the Subaru Telescope. In addition, ADC conducted development, maintenance, and preparations for renewal of the data analysis computer system and open-use computer systems.

In the Advanced Technology Center (ATC), design work continued for TMT's Infrared Imaging Spectrograph (IRIS) and Wide-Field Optical Spectrometer (WFOS). Development began for next-generation wideband receivers and a data transmission system for ALMA; and maintenance was performed for existing receivers. Development continued for the Subaru Telescope's wide-field adaptive optics instrument and KAGRA's vibration isolation system and auxiliary optics. ATC led the revision of the specifications for the telescope section of the SOLAR-C instrument and the optical design of the spectrograph section, and made important contributions to the conceptual design of the JASMINE payload instrument. They also developed advanced techniques in fields including infrared detectors, integral field spectroscopy techniques, adaptive optics, and terahertz technology. As part of the Social Implementation Program, research and development was conducted for repurposing techniques cultivated through radio receiver development to quantum computers and repurposing optical-infrared adaptive optics techniques cultivated at the Subaru Telescope to satellite communications networks.

The Public Relations Center was busy with 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; responding to reports of discoveries of new astronomical objects; and providing the ephemeris and other astronomical information directly related to people's everyday activities, such as sunrise and sunset times. The NAOJ Japanese webpage was renewed, and social media was actively utilized, including a Japanese X account with over 270,000 followers. The Public Relations Center is also active in spectrum management activities and light pollution countermeasures. They also provide fundamental data for society and academia through the Calendar and Ephemeris; and Rika Nenpyo (Chronological Scientific Tables). The Library reopened to the public in May 2023. Among the important documents passed down from the Tenmonkata, Shogunate Astronomers of the Edo Era, the Seigaku Shukan was named an Important Cultural property of Japan. Images of this and other important documents are available on the webpage.

In the Division of Science, 218 papers were published, including: quantum kinetic neutrino transport simulations; rapid increase in oxygen in early Universe; comparison of scattering cross sections and phase matrices of ground-state hydrogen atoms with ultraviolet observations of galactic nuclei; stochastic gravitational wave background discovered using radio waves from pulsars; and an upper limit on optical emissions from binary black hole coalescence. They also presented other results such as the chemical evolution of interstellar molecular clouds; radio follow-up observations of a supernova; interactions between molecular clouds and a black hole in the Milky Way Galaxy; and the discovery of numerous supermassive black holes in the early Universe.

In these ways, we have had many scientific achievements. On the other hand, problems with telescopes or enclosures have made it necessary to suspend operations for months at a time at the Subaru Telescope, Okayama 188-cm Reflecting Telescope, ASTE telescope, and two VERA antenna stations. These failures are mainly due to aging. Going forward, we must be diligent about preventative maintenance before large problems occur. At KAGRA, some equipment failed due to the Noto Peninsula earthquake in January 2024, and restoration work is underway.

As for the activities of the various offices, the Information Security Office strengthened the security system and international cooperation, and prepared for the replacement of the information network service. The Research Enhancement Strategy Office facilitated external reviews for NAOJ as a whole, Mizusawa VLBI Observatory, Nobeyama Radio Observatory, and ASTE project; in addition to other activities related to the evaluation and research capability enhancement of NAOJ. The Industry Liaison Office responded to requests for collaboration from private companies, participated in exhibitions, and released press releases on technological developments. The Office of International Relations supported the activities of the East Asian Core Observatories Association (EACOA) and the East Asian Observatory (EAO), handled international agreements and memorandums-of-understanding with overseas institutions, provided support for international researchers and students, and disseminated information at international conferences. In particular, as a member of the Local Organizing Committee for APRIM 2023, the office helped receive the keynote speakers and participants. The Human Resources Planning Office handled employment management for fixed-term employees in general, harassment and mental health cases, and individual labor issues, and conducted two types of in-person training for leaders three times. The Safety and Health Management Office convened Safety and Health Committee meetings; promoted information exchange; and conducted periodic safety and health patrols and work environment measurements. They also held a safety and health workshop. The Engineering Promotion Office held training sessions and The 43rd Symposium on Engineering in Astronomy 2023 as part of human resource development for technical staff.

This concludes my overview of NAOJ's activities in FY 2023. More details can be found in the full report.

I Scientific Highlights

(April 2023 – March 2024)

Trigonometric Parallax and Proper Motion of Sagittarius A* Measured by VERA Using the New Broad-band Back-end System OCTAVE-DAS

OYAMA, Tomoaki[1], NAGAYAMA, Takumi[1], YAMAUCHI, Aya[1], SAKAI, Daisuke[1], IMAI, Hiroshi[2], HONMA, Mareki[1/3], ASAKURA, Yu[1], HADA, Kazuhiro[1/4], HAGIWARA, Yoshiaki[5], HIROTA, Tomoya[1/4], JIKE, Takaaki[1/4], KONO, Yusuke[1/4], SUZUKI, Syunsaku[1], KOBAYASHI, Hideyuki[1/4], KAWAGUCHI, Noriyuki[1]

1: NAOJ, 2: Kagoshima University, 3: The University of Tokyo, 4: The Graduate University for Advanced Studies, 5: Toyo University

We developed a new broad-band digital back-end and software correlator system, named "OCTAVE-DAS." [1] This system is capable of recording at a rate of 16 Gbps (512-MHz bandwidth × 8 streams), therefore, the detectable baseline length for Sagittarius A* (Sgr A*) extends up to 250 Mλ (1800 km) which almost covers the entire range of the VLBI Exploration of Radio Astrometry (VERA) baselines.

We conducted observations of Sgr A* using OCTAVE-DAS with VERA over 26 epochs between 2014 and 2020. In a result, we successfully measured the trigonometric parallax of Sgr A* to be 117 ± 17 micro-arcseconds (μas). The measured parallax corresponds to a Galactocentric distance at the Sun of $R_0 = 8.5\ ^{+1.5}_{-1.1}$ kpc. By combining the astrometric results with VERA and the Very Long Baseline Array (VLBA) [3] over a monitoring period of 25 years, the proper motion of Sgr A* is obtained to be $(\mu_\alpha, \mu_\beta) = (-3.133 \pm 0.003, -5.575 \pm 0.005)$ mas yr^{-1} in equatorial coordinates, corresponding to $(\mu_l, \mu_b) = (-6.391 \pm 0.005, -0.230 \pm 0.004)$ mas yr−1 in Galactic coordinates. This gives an angular orbital velocity of the Sun of $\Omega_\odot = 30.30 \pm 0.02$ km s^{-1} kpc^{-1}.

Also, the 1σ upper limit of the core wander ($\Delta\theta$), peculiar motion (Δv), and acceleration (a) of Sgr A* are estimated to be $\Delta\theta < 0.20$ mas (1.6 AU), $\Delta v < 0.10$ mas yr^{-1} (3.7 km s^{-1}), and $a < 2.6\,\mu$as yr^{-2} (0.10 km s^{-1} yr^{-1}), respectively. Therefore, Sgr A* appears to be at rest with respect to the dynamical center of the Galactic rotation. We obtained upper mass limits of $\approx 3 \times 10^4\,M_\odot$ and $\approx 3 \times 10^3\,M_\odot$ for the supposed intermediate-mass black holes at 0.1 and 0.01 pc from the Galactic center, respectively.

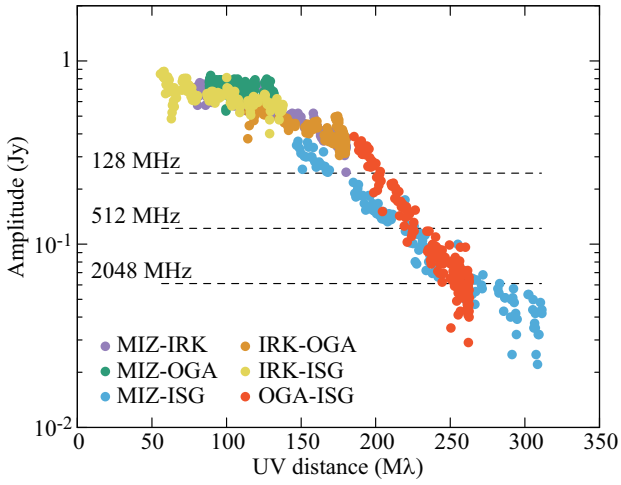

Figure 1: Oyama et al. (2024) [2]. Visibility amplitude vs *UV* distance plot of Sgr A* for the VERA 43-GHz observation. The visibility data are shown after self-calibration. The dashed lines show 5σ detection limits of bandwidths of 128, 512, and 2048 MHz, where σ is the baseline-based noise level estimated from the system noise temperature of 300 K, the averaging time is 60 s, the antenna dish diameter is 20 m, and the antenna aperture efficiency is 0.5.

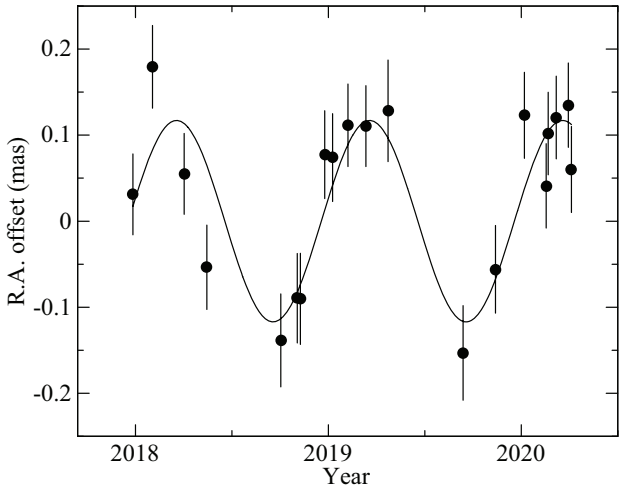

Figure 2: Oyama et al. (2024) [2]. Trigonometric parallax of Sgr A* in RA. The best-fit proper motion and the constant position offset are removed, allowing the effect of only the parallax to be seen. The solid lines show the best-fitted parallax of 0.117 ± 0.017 mas.

References

[1] Oyama, T., et al.: 2016, *PASJ*, **68**, 105.
[2] Oyama, T., et al.: 2024, *PASJ*, **76**, 163.
[3] Reid, M. J., Brunthaler, A.: 2020, *ApJ*, **892**, 39.

Precessing Jet Nozzle Connecting to a Spinning Black Hole in M87

CUI, Yuzhu[1], HADA, Kazuhiro[2/3], EAVN AGN Science Working Group, et al.

1: Zhejang Lab, 2: Nagoya City University, 3: NAOJ

The jets of active galaxies are among the most energetic phenomena in the universe, and their formation mechanisms remain a major question in astronomy. M87 is one of the nearest jets and is also known as the object whose black hole shadow was captured by the Event Horizon Telescope (EHT) in 2019. However, whether the M87 supermassive black hole is spinning or not has remained uncertain.

In this study, we analyzed 170 radio images of the M87 jet, accumulated over more than 20 years, primarily using observational data at 22 GHz and 43 GHz from the East Asian VLBI Network (EAVN) and the U.S. VLBA. We investigated the long-term temporal changes in the shape of the jet base [1]. As a result, we discovered that the jet's ejection direction changes periodically with an approximately 11-year cycle (Figure 1). Previous studies by Walker et al. [2] suggested the presence of lateral oscillations of the jet, but whether a period exists or not was uncertain.

To identify the cause of this periodic change, we conducted theoretical simulations of black hole jet formation using the ATERUI II supercomputer and compared with the observational results. We found that the observed 11-year periodic jet oscillation can be well explained by the Lense-Thirring precession, where a rotating jet drags the surrounding spacetime. This result supports the idea that the supermassive black hole in M87 is spinning. Additionally, the results support the Blandford-Znajek mechanism, which the extraction of the rotational energy from a spinning black hole is required to produce a powerful jet.

To further accumulate the evidence of spin, it is important to capture more periodic precession motions. Our intensive and long-term EAVN monitoring of M87 is ongoing.

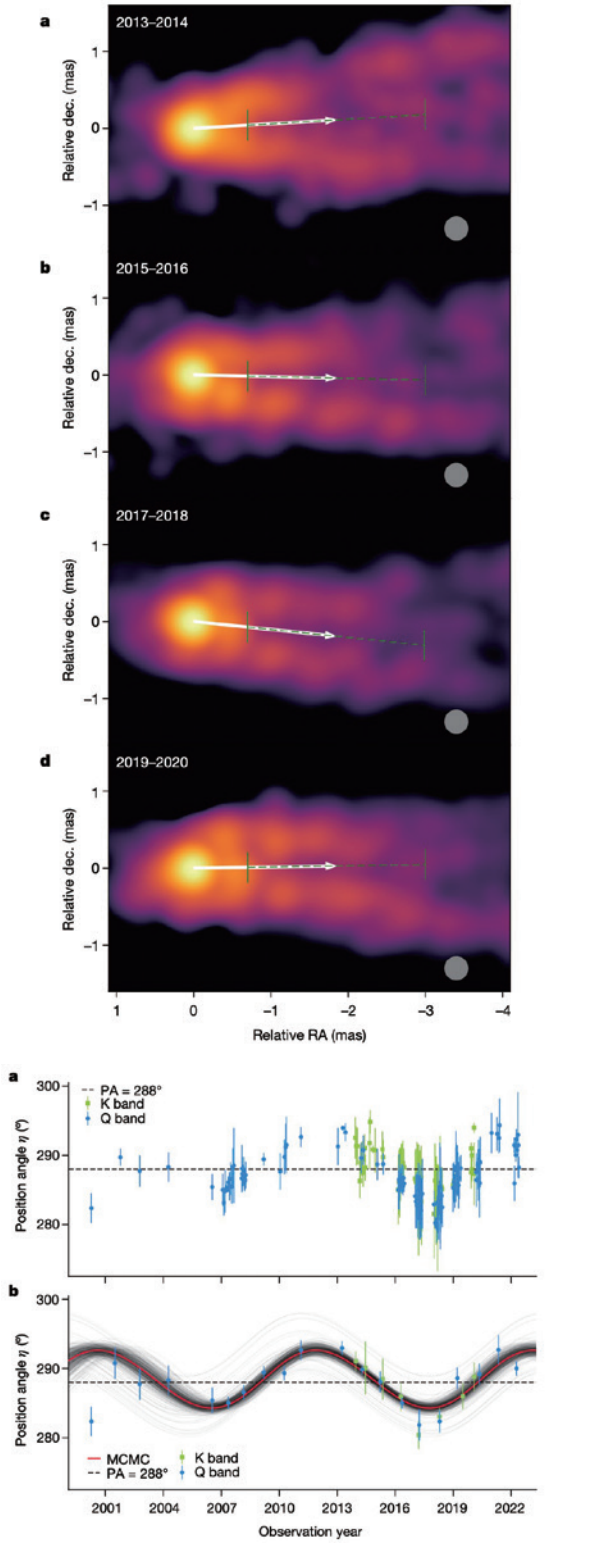

Figure 1: (Top) Observed jet images at 43 GHz. (Bottom) Time evolution of observed jet position angle.

References

[1] Cui, Y., Hada, K., et al: 2023, *Nature*, **621**, 711.
[2] Walker, R., Hardee, P., et al: 2018, *ApJ*, **855**, 128.

Nuclear Dense Molecular Gas Properties of Ultraluminous Infrared Galaxies Revealed from Multi-molecular, Multi-transition Line Data

IMANISHI, Masatoshi[1], BABA, Shunsuke[2], NAKANISHI, Kouichiro[1], IZUMI, Takuma[1]

1: NAOJ, 2: Kagoshima University

Luminous infrared galaxies (LIRGs) and ultraluminous infrared galaxies (ULIRGs) are galaxies which radiate infrared dust thermal emission with $10^{11–12}$ and $10^{12–13}$ solar luminosity, respectively. Almost all (U)LIRGs are observed as gas-rich galaxy mergers. Through the galaxy merging processes, a large amount of gas and dust are transferred to the nuclear regions, where active starbursts and mass-accretion onto supermassive black holes (SMBH) (the so-called AGN activity) occur, and heat the surrounding dust. Thus, scrutinizing the nature of (U)LIRGs' nuclei is vital to understand how stars are formed and SMBHs grow in mass through galaxy mergers which must have happened very frequently in the early universe. Molecular rotational transition (J) line observations at (sub)millimeter are a powerful tool to investigate the highly dust-obscured ULIRGs' nuclei, because of small dust extinction effects.

We conducted HCN and HCO^+, multiple J-transition line observations, with 1–2 kpc physical resolution, of 10 nearby ($z < 0.15$) ULIRGs and 1 LIRG, using ALMA. We then derive dense molecular gas properties at ULIRGs' nuclei by fitting HCN-to-HCO^+ flux ratios at the same J-transition and high-J to low-J flux ratios of HCN and HCO^+, with non-LTE model calculations using the widely used code RADEX. We find the following main results. (1) HCN-to-HCO^+ flux ratios at each J are better explained with enhanced HCN abundance relative to HCO^+ than comparable HCN-to-HCO^+ abundance ratio (Figure 1). (2) (U)LIRGs' nuclei contain dense ($> 10^{3–4}$ cm^{-3}) and high temperature (> 100 K) molecular gas (Figure 2). (3) Molecular gas density and temperature are lower in starburst-dominated (U)LIRGs than in AGN-important ones (Figure 3). Our results clearly demonstrate that multiple-molecular, multiple J-transition line observations are very powerful to derive molecular gas properties and diagnose energy sources at (U)LIRGs' nuclei [1].

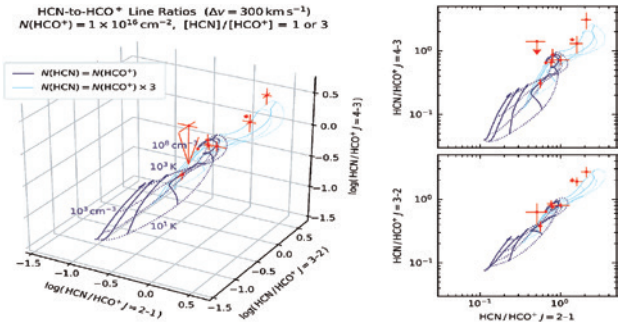

Figure 1: Observed data (red dots) are better reproduced with models of enhanced HCN abundance (HCN-to-HCO^+ ratio =3) (light blue) than those with comparable HCN-to-HCO^+ abundance ratio (dark blue) under a wide range of gas temperature and density [1].

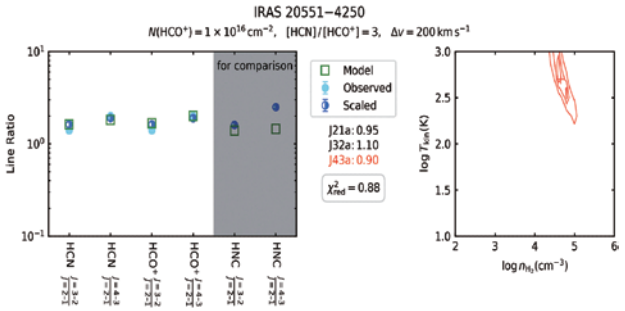

Figure 2: (Left): Comparison of observed data and non-LTE model calculations. (Right): Derived molecular gas density (abscissa) and temperature (ordinate) at (U)LIRGs' nuclei. Only simultaneously obtained HCN and HCO^+ data are used for the fit, and HNC data are not (grey shaded) [1].

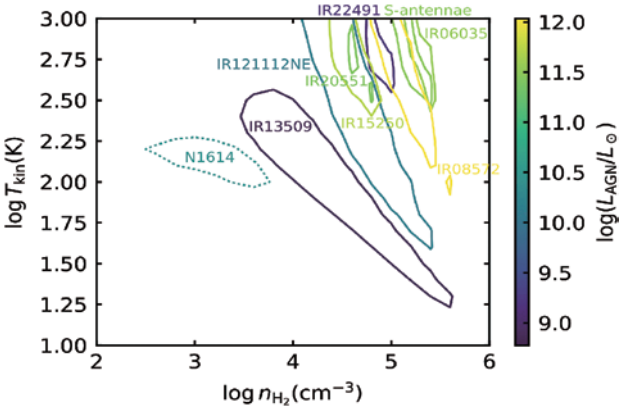

Figure 3: (U)LIRGs' nuclear gas density (abscissa) and temperature (ordinate), as a function of AGN luminosity (color bar). Dotted line corresponds to a starburst-dominated (~100 %) LIRG. (U)LIRGs with larger AGN luminosity tend to show higher gas density and temperature [1].

Reference

[1] Imanishi, M., et al.: 2023, *ApJ*, **950**, 75.

Spatially Resolved HCN and HCO^+ Multi-line Investigations of Nuclear Dense Molecular Gas Properties in Nearby Ultraluminous Infrared Galaxies

IMANISHI, Masatoshi[1], BABA, Shunsuke[2], NAKANISHI, Kouichiro[1], IZUMI, Takuma[1]

1: NAOJ, 2: Kagoshima University

Ultraluminous infrared galaxies (ULIRGs) radiate strong infrared dust thermal emission with luminosity $> 10^{12}\,L_{\odot}$ and are usually found in gas-rich galaxy mergers. Starbursts and/or AGN activity (mass-accreting supermassive black holes [SMBHs]) hidden behind dust are believed to be responsible for the observed strong infrared emission. When compared to starbursts, AGNs are spatially compact and can be easily buried deep inside gas and dust. Elucidating the energetic importance of such elusive AGNs in gas/dust-rich merging ULIRGs' nuclei is vital to understand how SMBHs grow in mass in galaxy mergers which are widely happening throughout the history of the universe. (Sub)millimeter rotational J-transition emission lines of dense molecular gas tracers can provide important information of the hidden energy sources in ULIRGs' nuclei because of strong penetrating power in this wavelength range.

We have conducted ALMA spatially resolved HCN and HCO^+ three rotational transition line (J = 4–3, 3–2, 2–1) observations, with < 0.5 kpc resolution, of 12 nearby (z < 0.15) ULIRGs' nuclei (< 2 kpc regions). We compare the observed data with non-LTE model calculations and found the following main results. (1) Molecular gas in the innermost < 0.5 kpc region is very dense ($> 10^5\,cm^{-3}$) and warm (> 300 K) (Figure 1). (2) For ULIRGs' nuclei which are diagnosed to possess luminous obscured AGNs, the gas temperature and HCN-to-HCO^+ abundance ratio are higher in the innermost < 0.5 kpc regions than in outer 0.5–1 kpc and 1–2 kpc annular regions, while no such trend is seen in a galaxy which is energetically dominated by spatially extended starburst activity (Figure 2). We interpret that the trend found in the former class of ULIRGs as AGN effects. Our results clearly demonstrate that spatially resolved multi-transition dense molecular line observations in the (sub)millimeter wavelength range are very effective to elucidate the hidden energy sources at gas/dust-rich merging ULIRGs' nuclei [1].

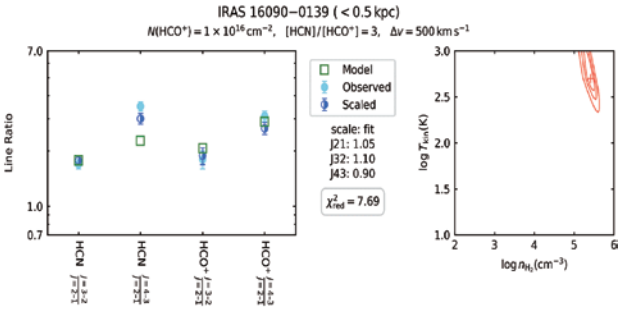

Figure 1: Comparison between observed molecular line flux ratios and non-LTE model calculations (left), and derived molecular gas density (abscissa) and temperature (ordinate) in the innermost < 0.5 kpc regions of ULIRGs' nuclei (right) [1].

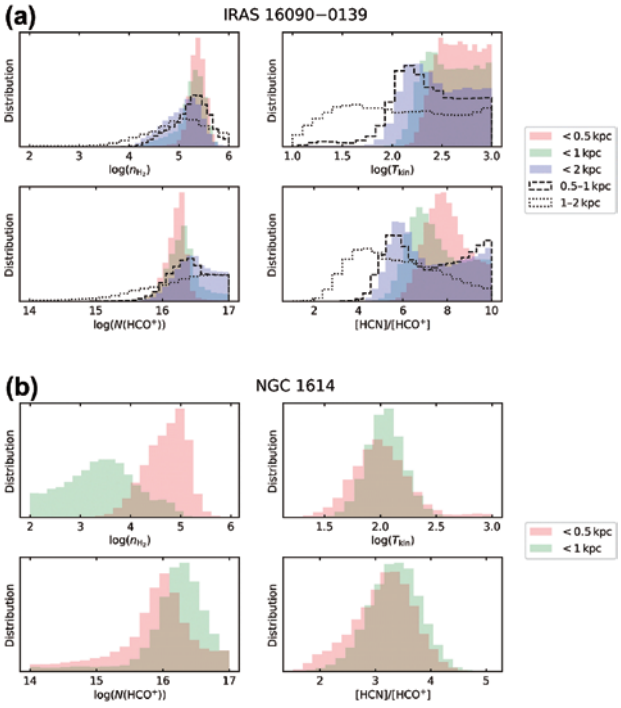

Figure 2: Spatial variation of derived gas density (upper left of four panels), temperature (upper right), HCO^+ column density (lower left), and HCN-to-HCO^+ abundance ratio (lower right). In the AGN-important ULIRG (upper object), the gas temperature and HCN-to-HCO^+ abundance ratio are higher inside, while no such spatial variation is seen for the same parameters in the starburst dominated galaxy (lower object) [1].

Reference

[1] Imanishi, M., et al.: 2023, *ApJ*, **954**, 148.

Quantum Kinetic Neutrino Transport Simulations

NAGAKURA, Hiroki
(NAOJ)

In high-energy astrophysical phenomena such as core-collapse supernova (CCSN) and binary neutron star merger (BNSM), hot and dense environments are formed, in which a copious amount of neutrinos are produced. Neutrinos have at least three different flavors, and they undergo flavor conversions (which are known as neutrino oscillations) during propagation. In dense neutrino environments, neutrino self-interactions can induce flavor conversions, and it recently turned out that such flavor conversions ubiquitously occur in both CCSN and BNSM environments. For this reason, the quantum kinetic neutrino simulations have been currently progressing rapidly.

In the fiscal year of 2023, we performed global simulations of quantum kinetic neutrino transport in CCSN and BNSM environments by using FUGAKU [1-3]. These simulations correspond to very massive parallel simulations, in which we used approximately 50 k and 500 k CPU simultaneously for CCSN and BNSM models, respectively. In Figure 1, we show the result of CCSN model. This portrays the radial profile of neutrino-cooling and heating rate. The black and other colors correspond to classical- and quantum kinetic transport models, respectively. We found that neutrino flavor conversions change neutrino cooling and heating rate substatinally, which would affect the explosion mechanims of CCSN.

In Figure 2, we show the result of BNSM model. This figure displays the intensity map of neutrino coherency. The red and blue regions correspond to the place where neutrino flavor conversions vigorously occur. As shown in the plot, neutrino flavor conversions occur very narrow regions, which are qualitatively different from previous studies in the leterature. We also found that the neutrinos can undergo flavor swap in BNSM environments, which is also qualitatively diferent from CCSN. Our results suggest that the modeling of neutrino radiation field in CCSN and BNSM requires quantum kinetic treatment.

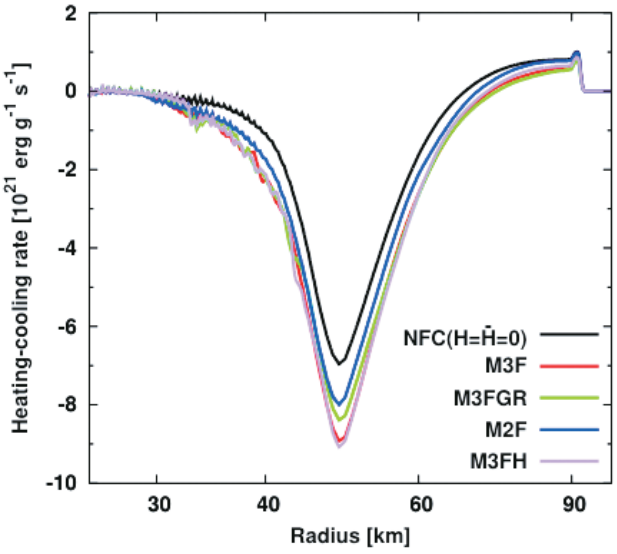

Figure 1: Radial profiles of neutrino energy deposition rate [1]. Black and other colors show results of classical- and quantum kinetic transport, respectively.

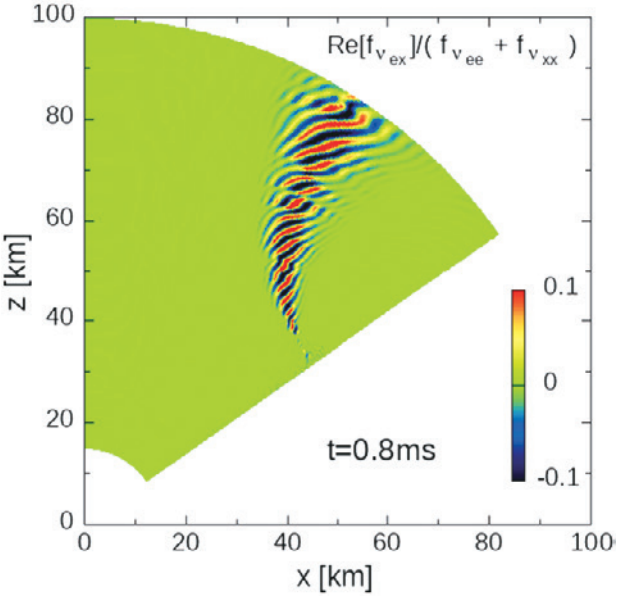

Figure 2: 2D color map of neutrino coherency [2]. Red and blue regions represent occurrences of strong flavor conversions.

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Rayleigh and Raman Scattering Cross-sections and Phase Matrices of the Ground-state Hydrogen Atom, and Their Astrophysical Implications

KOKUBO, Mitsuru
(NAOJ)

The neutral hydrogen atom in most astrophysical environments is in the ground-state where the atomic electron is in the 1*s* orbital. The photon scattering by the 1*s*-state hydrogen happens in two ways: first, the elastic Rayleigh scattering where the final atomic state is the same as the initial 1*s* state ($1s \rightarrow 1s$), and second, the inelastic Raman scattering where the final atomic state is either *ns* orbital ($1s \rightarrow ns$; $n \geq 2$) or *nd* orbital ($1s \rightarrow nd$; $n \geq 3$). According to the energy conversion law between the initial and final states (hydrogen atom and photon), the Raman scattering occurs when the incident photon has a frequency higher than Lyman-α. After the Raman scattering, the hydrogen atomic state is excited to *ns* or *nd* state and the frequency of the outgoing photon is reduced as $\hbar\omega' = \hbar\omega - (E_n - E_1)$, where ω and ω' are the frequencies of the incident and outgoing photons, respectively, and E_1 and E_n are the eigenenergies of the initial (1*s*) and final (*ns* or *nd*) atomic states. In this way, the Raman scattering of the ground-state hydrogen converts the incident UV photons with wavelengths shorter than Lyman-α into optical/infrared (IR) photons.

In accordance with the frequency-dependent cross-sections of the scattering process, the Raman scattering spontaneously generates broad emission features in the optical/infrared (IR) wavelengths (Figure 1). The broad emission features presumably produced by the hydrogen Raman scattering are observed in several symbiotic stars, planetary nebulae, and Galactic and extragalactic HII regions (e.g., [1]). Recently, we have found an extremely broad Hα emission line of the equivalent velocity width of 12,400 km s^{-1} in the blue compact galaxy SBS 0335-052E, for which we propose the Raman scattering as a viable emission production mechanism [2].

Although the total cross sections of the hydrogen Rayleigh/Raman scattering have been known since early 1930s (e.g., [3]), the differential scattering cross sections and phase matrices to characterize the scattering angular distributions and polarization properties have not been explicitly given in the literature. In Kokubo (2024) [4], we presented the explicit formulae of the differential Rayleigh/Raman scattering cross sections and phase matrices of the ground-state hydrogen atom, and calculated the Raman-scattered broad emission features in the optical-IR wavelengths under the assumption of a plane-parallel hydrogen gas (characterized by a gas column density log $N_{\rm H}$) irradiated by a featureless UV continuum emission (Figures 1). The formulae presented in this work will serve as a basis for future more detailed radiative transfer simulation studies.

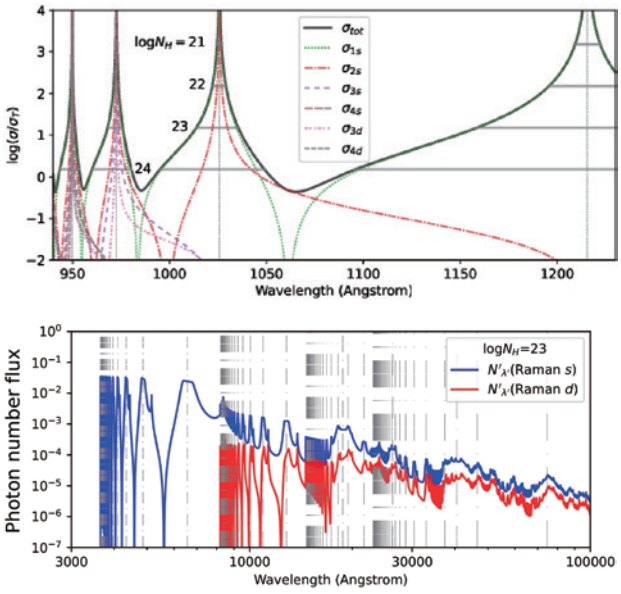

Figure 1: **Top**: Cross-sections of Rayleigh scattering (σ_{1s}) and Raman scattering of the ground-state hydrogen atom as a function of the wavelength of the incident photon. $\sigma_{\rm tot}$ is the gross cross-section. **Bottom**: the Raman-converted optical-IR photon number flux $N'_{\lambda'}$ from each of the Raman *s*-branch and Raman *d*-branch. The vertical lines indicate the Lyman, Balmer, Paschen, Brackett, and Pfund resonance wavelengths.

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[4] Kokubo, M.: 2024, *MNRAS*, **529**, 2131.

AGN Number Fraction in Galaxy Groups and Clusters at $z < 1.4$ from the Subaru Hyper Suprime-Cam Survey

HASHIGUCHI, Aoi[1], TOBA, Yoshiki[2/1/3/4], OTA, Naomi[1], OGURI, Masamune[5], OKABE, Nobuhiro[6], UEDA, Yoshihiro[7], IMANISHI, Masatoshi[2], YAMADA, Satoshi[8], GOTO, Tomotsugu[9], KOYAMA, Shuhei[10], LEE, Kianhong[11], MITSUISHI, Ikuyuki[12], NAGAO, Tohru[4], NISHIZAWA, J. Atsushi[13/12], NOBORIGUCHI, Akatoki[14], OOGI, Taira[4], SAKUTA, Koki[12], SCHRAMM, Malte[15], SHIBATA, Mio[1], TERASHIMA, Yuichi[4], YAMASHITA, Takuji[2], YANAGAWA, Anri[1], YOSHIMOTO, Anje[1]

1: Nara Women's University, 2: NAOJ, 3: ASIAA, 4: Ehime University, 5: Chiba University, 6: Hiroshima University, 7: Kyoto University, 8: RIKEN, 9: NTHU, 10: University of Tokyo, 11: Tohoku University, 12: Nagoya University, 13: Gifu Shotoku Gakuen University, 14: Shinshu University, 15: University of Potsdam

Recent studies have revealed that the emergence of active galactic nuclei (AGNs) depends not only on their host galaxies but also on the environment in which they reside. Galaxy clusters, the largest self-gravitating structures in the Universe, are ideal objects for studying the environmental effects of AGNs. However, statistical studies based on sufficient clusters and AGNs are still limited. Therefore, we focused on galaxy groups and clusters (the CAMIRA cluster [1]) found by Hyper Suprime-Cam (HSC) on the Subaru Telescope. The CAMIRA catalog contains more than 27,000 clusters at $0.1 < z < 1.4$ with ~1 million member galaxies. The CAMIRA catalog is used in conjunction with a complete AGN sample identified using multi-wavelength infrared, radio, and X-ray data to investigate how the AGN number fraction ($f_{\rm AGN}$) on clusters depends on (i) cluster's redshift and (ii) cluster-centric radius. Figure 1 shows AGNs in a CAMIRA galaxy cluster identified in this study.

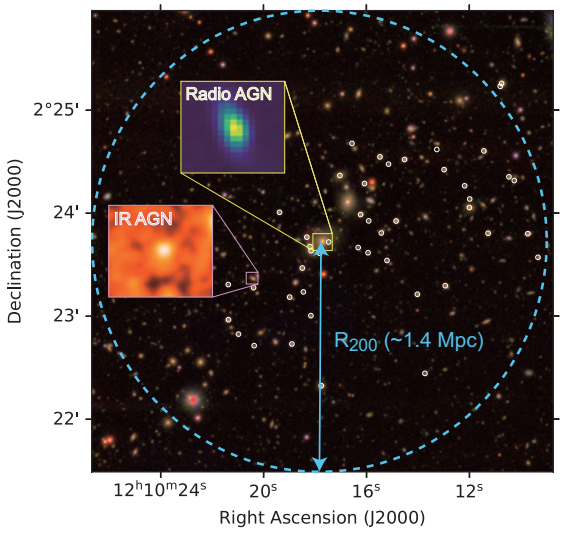

Figure 1: HSC color image of a CAMIRA cluster. The white circles indicate its member galaxies.

Our analysis revealed that the AGN number fraction ($f_{\rm AGN}$) increased (i) with increasing redshift and (ii) toward the cluster center (Figure 2). Among them, AGNs detected in the infrared and the radio contribute to redshift dependence and the AGN excess at the cluster center, respectively. Because the wavelength at which AGNs are detected could depend on their evolutionary stage (e.g., [2]), these results suggest that the emergence of AGN is environmentally dependent, which is also closely related to the evolutionary stage of AGNs [3].

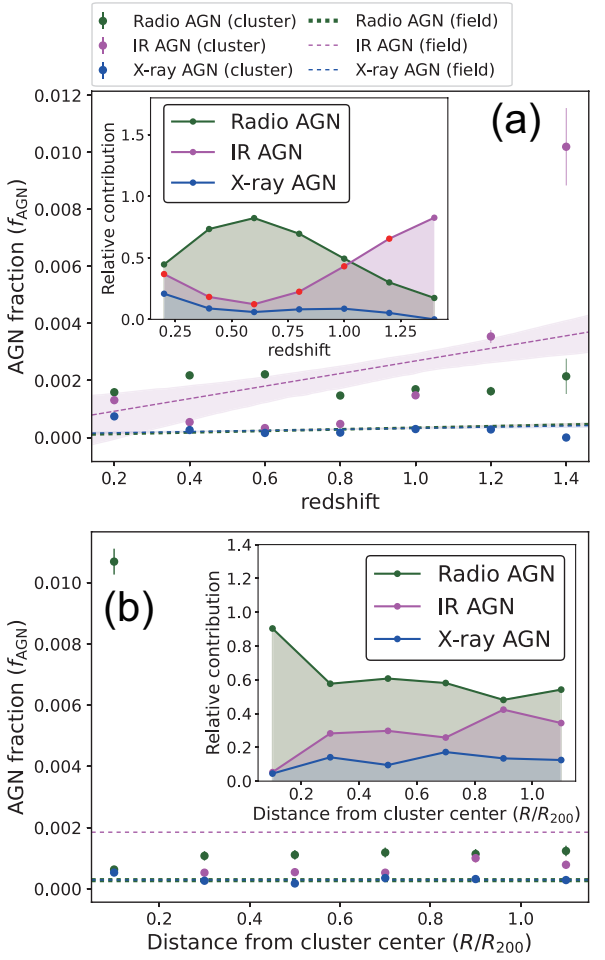

Figure 2: AGN fraction ($f_{\rm AGN}$ as a function of (a) redshift and (b) cluster-centric radius (R/R_{200}).

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The Jet and Resolved Features of the Central Supermassive Black Hole of M 87 Observed with EHT in 2017 — Comparison with the GMVA 86 GHz Results —

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1: NAOJ, 2: RIKEN, 3: Japan Meteorological Agency, 4: Kobe University, 5: Meisei University

M 87 is the best target for studying black hole accretion and jet formation. Reanalysis of the EHT public data at 230 GHz shows a core-knots structure at the center and jet features. We here compare this with the new results of GMVA at 86 GHz [1] and show a spatially resolved central core we obtained [2]. There are similarities and differences between the two. At 86 GHz, "two bright regions" are seen on the ring in the core. "Core-Knot-Westknot", triple structure in the 230 GHz image shows apparent appearance of two peaks similar to the "two bright regions" when convolved with the GMVA beam. This similarity suggests that both frequencies reveal the same objects in the core area (Figure 1). Protrusions are observed on both the south and north sides of the core at both frequencies, becoming prominent and wing-like at 230 GHz. The 86 GHz image shows a triple ridge jet structure, while the 230 GHz image shows only a bright central ridge with two roots. Both frequencies show a shade between the core and the central ridge (Figure 2). To detect the faint features from the EHT 2017 data, we found that the use of all baseline data is essential. Using all including the ultrashort baseline data, revealed the jet and faint structures. Without the ultrashort baselines, these structures were not detectable. The lack of detection of any faint structures other than the ring in the M 87 data by the EHTC is presumably due to the exclusion of ultrashort baselines from their analysis.

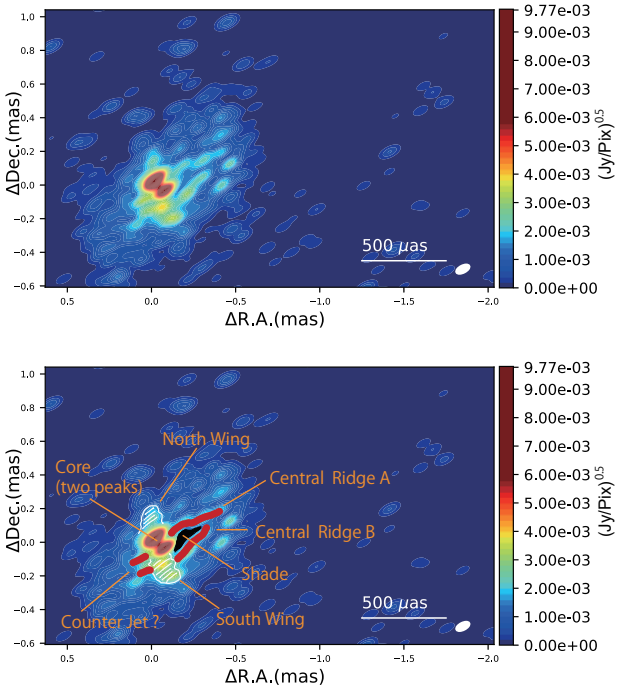

Figure 2: Our image of M 87 (large scale) [2].

References

[1] Lu, R.-S., et al.: 2023, *Nature*, **616**, 686-690.
[2] Miyoshi, M., et al.: 2024, *ApJL*, **963**, L18.
[3] Miyoshi, M., et al.: 2022, *ApJ*, **933**, 36.

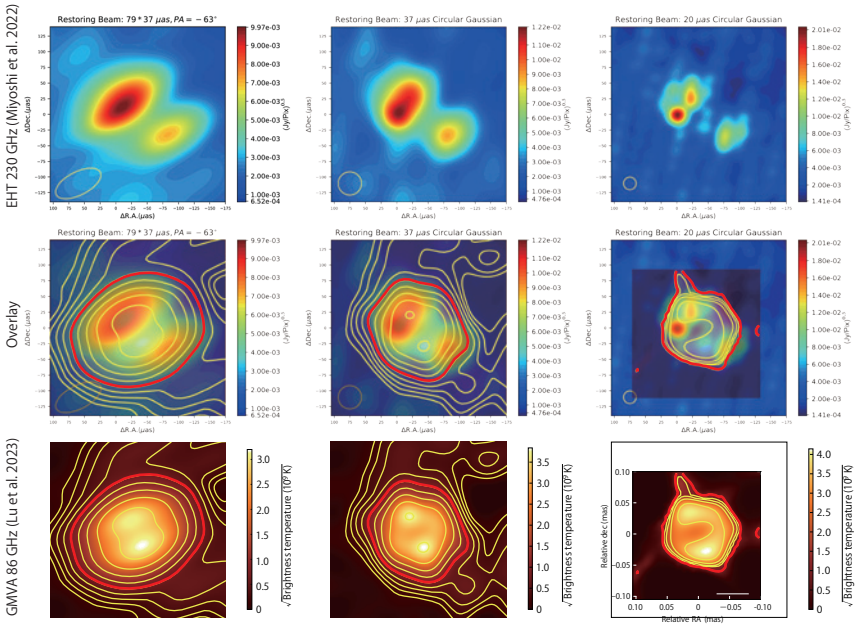

Figure 1: Comparison of core structures between the GMVA2018 86 GHz results and our 230 GHz reanalysis. Top: Our images from the paper [3] with three different spatial resolutions [2]. Bottom: The GMVA 86 GHz results from the paper [1]. Middle: Overlays of them. See the paper [2] about the detail.

Discovered at Last! Stochastic Gravitational Waves Background – Implications of 15 Years of NANOGrav Data –

KOHRI, Kazunori
(NAOJ)

What kind of observations will allow us to capture the moment of the birth of the Universe? The quantum effects of the inflaton field that induced inflation in the early Universe created density fluctuations of approximately $\mathcal{O}(10^{-5})$ on the large scale of the Universe. Galaxies were created when matter gravitationally collapsed in regions of high density. Here, matter refers to both baryons, and dark matter, which is five times more abundant than baryons.

At the end of June in 2023, it was reported that the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) had observed stochastic gravitational wave (GW) background (SGWB) [1] that have existed since the early Universe.

After 15 years of observing the correlation of radio signals periodically emitted by multiple pulsars, NANOGrav has observed a signal specific to the SGWBs in the nanohertz band. If SGWBs are present, they are observed because they modify the periodicity of the precise pulsar radio waves.

SGWBs are also known to be produced by mergers of supermassive black holes at the centers of galaxies, but this signal has a different spectral shape. If the small-scale density fluctuations produced by inflation are large, the second-order nonlinear effect of the density fluctuations can produce large SGWBs (called the induced gravitational waves). We have proposed that these induced GWs match the signal exactly [2]. Furthermore, such a large density fluctuation is expected to collapse into a primordial black hole that is lighter than the Sun. Its abundance amounts to about 2 % of the total of dark matter. The Einstein Telescope (ET) and Cosmic Explorer (CE) can in the future discover GWs emitted by the coalescence of binary primordial black holes. Such future gravitational wave experiments are expected to verify the quantum nature of the inflaton field and discover the primordial black holes.

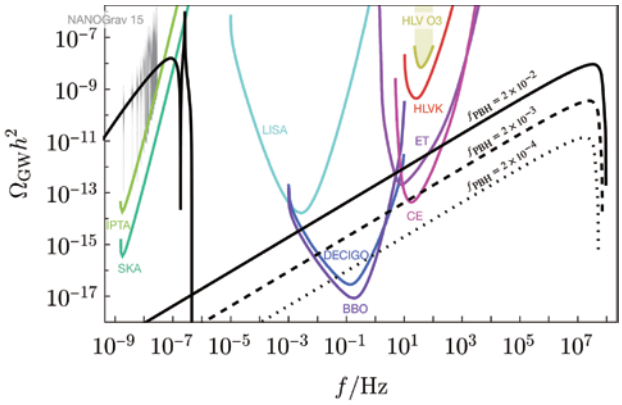

Figure 1: NANOGrav data of background gravity waves in the 10^{-9} Hertz band over a 15-year period (shaded in gray). The data are explained by the induced gravity waves (black curves) created by density fluctuations of the early Universe origin, and will be tested in detail in future observations IPTA and SKA. The gravitational wave signal (black diagonal line) produced by the coalescence of the binary primordial black holes (PBHs) corresponds to 2 % of dark matter, which will be tested by future gravitational wave observations such as DECIGO, BBO, ET, CE, etc. For other detailed explanation, please refer to the original paper [2].

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[2] Inomata, K., Kohri, K., Terada, T.: 2024, *Phys. Rev. D*, **109**, 063506.

GALAXY CRUISE: Deep Insights into Interacting Galaxies in the Local Universe

TANAKA, Masayuki[1], KOIKE, Michitaro[1], NAITO, Sei'ichiro[1], SHIBATA, Junko[1], USUDA-SATO, Kumiko[1], YAMAOKA, Hitoshi[1], KOBAYASHI, Umi[1], NAKANO, Suzuka[1], TSUCHIYA, Chie[1], UMEMOTO, Tomofumi[1], ANDO, Makoto[2], ITO, Kei[2], KOFUJI, Yutaro[2], KUWATA, Atsuki[2], TAKEBAYASHI, Suguru[2], SHIMAKAWA, Rhythm[3], TADAKI, Ken'ichi[4], BOTTRELL, Connor[5]

1: NAOJ, 2: University of Tokyo, 3: Waseda University, 4: Hokkai-Gakuen University, 5: The University of Western Australia

Galaxies collide and merge with each other and become progressively more massive through the cosmic time. However, exactly what happens during mergers is one of the biggest unresolved problems. For instance, whether star formation activities and supermassive black hole activities are enhanced during mergers is a long-standing, unsettled question.

Hyper Suprime-Cam (HSC) Subaru Strategic Program conducted at the Subaru Telescope has imaged a wide area of the sky to an unprecedented depth with superb image quality. This data set is ideal for identifying interacting/merging galaxies. However, galaxies captured in the images are way too numerous for astronomers to carefully inspect.

We have launched a citizen science project, GALAXY CRUISE, to ask citizen astronomers to identify merging galaxies from the HSC data set. The target galaxies are bright galaxies with spectroscopic redshifts and they are classified between November 2019 and April 2022 as part of "season 1" of GALAXY CRUISE. We have collected more than 2 million classifications.

GALAXY CRUISE's galaxy classifications are more accurate than previous studies thanks to the image quality of the HSC data [1]. We also have identified a large number of interacting/merging galaxies that went unnoticed in previous work. These interacting/merging galaxies show a clear sign of enhanced star formation and super massive black hole activities. Furthermore, such an enhancement is particularly significant for violent mergers, which are in the final coalescence phase of mergers (Figure 1). In addition, we have applied a machine-learning technique to galaxies classified by the citizen scientists to make a large sample of spiral galaxies and ring galaxies [2].

Currently, GALAXY CRUISE season 2 is running, targeting fainter galaxies than season 1. We also ran a separate campaign to classify galaxies from recent computer simulations. We hope to gain deeper insights into interacting/merging galaxies in our future work.

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[2] Shimakawa, R., et al.: 2023, *PASJ*, **76**, 191.

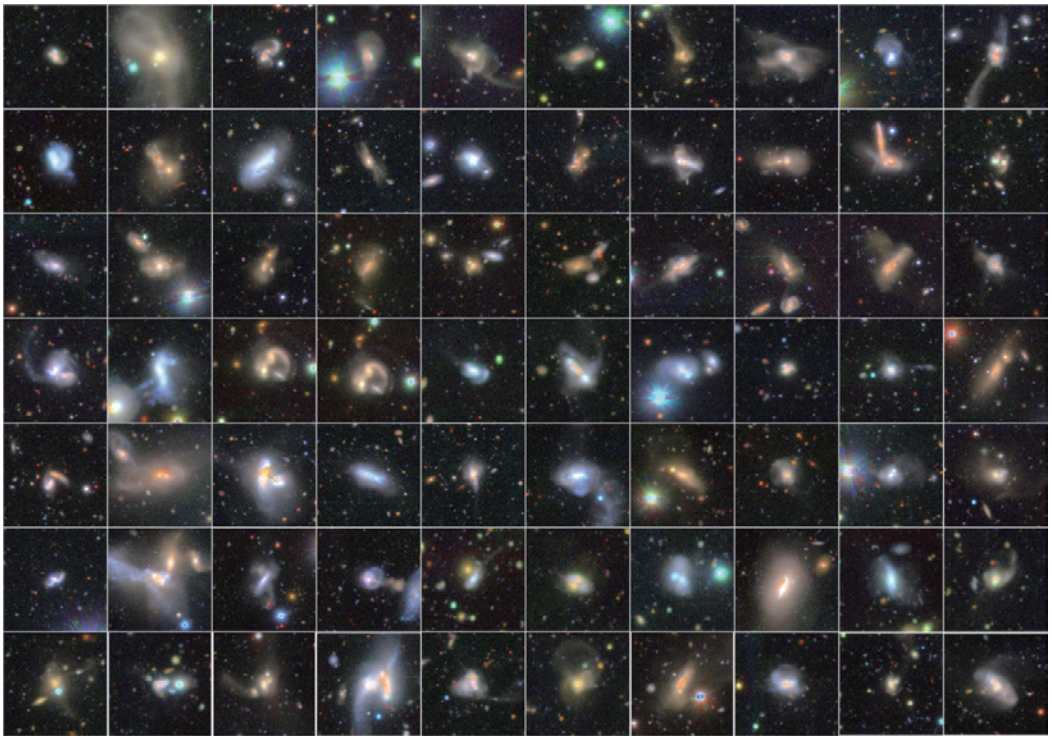

Figure 1: Violent mergers discovered by the citizen astronomers.

An Extremely Young Protostellar Core, MMS 1/OMC-3: Episodic Mass Ejection History Traced by the Very Compact Jet [1]

TAKAHASHI, Satoko[1/2], MACHIDA, N. Masahiro[3], OMURA, Mitsuki[3], JOHNSTONE, Doug[4/5], SAIGO, Kazuya[6], HARADA, Naoto[3], TOMISAKA, Kohji[1], HO, T. P. Paul[7/8], ZAPATA, A. Luis[9], MAIRS, Steve[8/4], HERCZEG, J. Gregory[10], TANIGUCHI, Kotomi[1], LIU, Yuhua[3], SATO, Asako[3]

1: NAOJ, 2: SOKENDAI, 3: Kyushu University, 4: NRC Herzberg Astronomy and Astrophysics, 5: University of Victoria, 6: Kagoshima University., 7: ASIAA, 8: EAO, 9: UNAM, 10: Kavli institute for Astronomy and Astrophysics, Peking University

Molecular outflows and protostellar jets are fundamental mass ejection phenomena to describe the star formation process [2,3]. Observationally, the molecular outflows are accompanied with a wide-opening angle cavity, having the low- and intermediate-velocity ranges of gas ($\lesssim 50\,\mathrm{km\,s^{-1}}$). Protostellar jets shows a collimated morphology with high velocity gas ($\gtrsim 50\,\mathrm{km\,s^{-1}}$). Studies of outflows and jets have grown with the improved sensitivity and angular resolution achieved with the Atacama large millimeter/submillimeter array (ALMA).

Here, we report ~0.2 arcsec resolution observations of the CO(2–1) and SiO(5–4) lines made with ALMA toward an extremely young intermediate-mass protostellar source, MMS 1 located in the Orion Molecular Cloud-3 (OMC-3) region. As presented in Figure 1, we have successfully imaged a very compact CO molecular outflow associated with MMS 1, having outflow lobe sizes of ~18000 au (red-shifted lobe) and ~35000 au (blue-shifted lobe). We have also detected an extremely compact ($\lesssim 1000$ au) and collimated SiO protostellar jet within the CO outflow. The maximum jet speed is calculated to be as high as $93\,\mathrm{km\,s^{-1}}$. Our detection of the molecular outflow and jet is the first direct evidence that MMS 1 already hosts a protostar. The SiO jet wiggles and displays a chain of knots as denoted by a dashed green line in Figure 1. The jet dynamical timescale is estimated to be ~60 years. The dynamical timescale of each SiO knot with respect to the protostar location are estimated between 5 years and 53 years, possibly related to the timescale of episodic mass accretion events.

The SiO jet shows two distinct velocity structures: (i) bow-shocks associated with the tips of the outflow, and (ii) a collimated jet, showing the jet velocities linearly increasing with the distance from the protostar. Comparisons between the observations and numerical simulations quantitatively share similarities such as multiple-mass ejection events within the jet and Hubble-like flow associated with each mass ejection event.

Finally, our ALMA jet study was compared with a submillimeter flux variability study performed using the Submillimetre Common-User Bolometer Array 2 (SCUBA 2) equipped on the James Clerk Maxwell Telescope (JCMT) [4]. While there is a weak flux decline seen in the 850 μm light curve obtained with JCMT/SCUBA 2 toward MMS 1, no dramatic flux change events are detected. This suggests that there has not been a clear burst event associated with the mass accretion onto the protostar within the last 8 years.

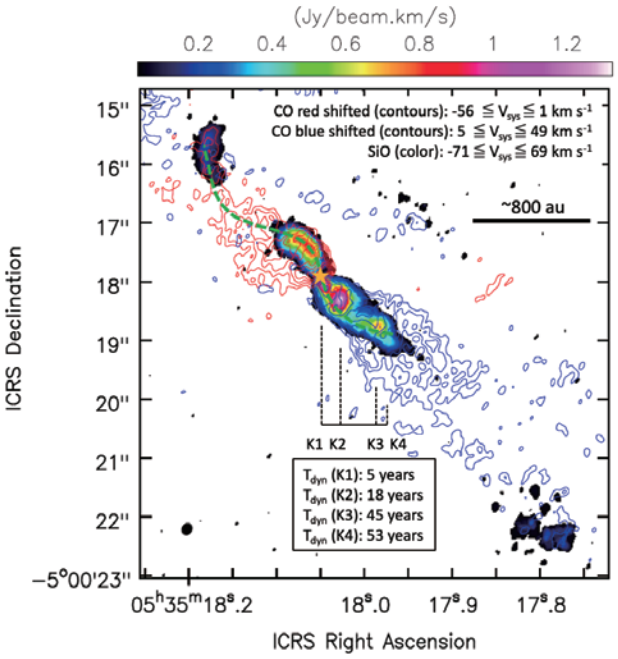

Figure 1: Detected molecular outflow and protostellar jet associated with MMS 1/OMC-3 [1]. Integrated intensity image obtained from the CO(2–1) red-/ blue-shifted components (red-/ blue-contours) overlaid with the integrated intensity image obtained from the SiO(5–4) denoted in colour. The precession of the jet is denoted in the green dashed line. Detected SiO knots are noted as K1-K4 and the dynamical timescale between each knot and protostar location is described as T_{dyn}.

References

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[4] Herczeg, J. G., et al.: 2007, *ApJ*, **849**, 43.

Multicolor and Multi-spot Observations of Visorsat with the OISTER Collanolation

HORIUCHI, Takashi[1/2], HANAYAMA, Hidekazu[2], OHISHI, Masatoshi[2], NAKAOKA, Tatsuya[3], IMAZAWA, Ryo[3], KAWABATA, Koji S.[3], TAKAHASHI, Jun[4], ONOZATO, Hiroki[4], SAITO, Tomoki[4], YAMANAKA, Masayuki[5], NOGAMI, Daisaku[6], TAMPO, Yusuke[6], KOJIGUCHI, Naoto[6], ITO, Jumpei[6], SHIBATA, Masaaki[6], SCHRAMM, Malte[7], OASA, Yumiko[8], KANAI, Takahiro[8], OIDE, Kohei[8], MURATA, Katsuhiro, L.[9], HOSOKAWA, Ryohei[9], TAKAMATSU, Yutaka[9], IMAI, Yuri[9], ITO, Naohiro[9], NIWANO, Masafumi[9], TAKAGI, Seiko[10], ONO, Tatsuharu[10], KOUPRIANOV, Vladimir, V.[11]

1: University of Tokyo, 2: NAOJ, 3: Hiroshima University, 4: University of Hyogo, 5: Kagoshima University, 6: Kyoto University, 7: Universität Potsdam, 8: Saitama University, 9: Tokyo Institute of Technology, 10: Hokkaido University, 11: University of North Carolina

The US satellite operator SpaceX has developed or are developing the Starlink satellite to facilitate enhanced high-speed Internet services, launching the first 60 satellites in May 2019; they planned to launch 42,000 satellites by the mid-2020s. The operation altitude of the Starlink satellites is 550 km, which is classified as a low earth orbit. Moreover, the number of Starlink satellites is huge. In order to reduce sunlight reflection to the earth SpaceX has also developed Visorsat with a sunshade attached to its body (Figure 1). The first one (STARLINK-1436) was launched on June 2020.

In this study [1], we measured the brightness of STARLINK-1436 (hereafter Visorsat) and one of the conventional Starlink satellites, STARLINK-1113 (hereafter normal Starlink), in wide wavelength bands in the UV, optical and infrared. In order to conduct the multi-wavelength observations, we proposed those to the observation collaboration of optical and infrared synergetic telescopes for education and research (OISTER), which is an observation project consisting of nine national universities and the National Astronomical Observatory of Japan (NAOJ).

We measured the magnitudes of the Visorsat and normal Starlink trails (Figure 2) and compared their brightness. Consequently, the following results were found: (1) Visorsat tended to be half as bright in the optical and infrared ranges as the normal Starlink, (2) both satellites were about the naked-eye limiting magnitude, (3) both satellites tended to be brighter in the near-infrared than in the optical range. Furthermore, by applying blackbody radiation to a physical model of satellite reflection, we evaluated the reflectivity of those satellites and the covering factor of the sunshade on Visorsat. We found that (i) the reflectivity tended to be higher in the near-infrared (14–47 %) than in the optical range (6–15 %), (ii) the averaged covering factor of Visorsat was ~50 %, and (iii) Visorsat tended to become darker with increasing the covering factor estimated from the blackbody radiation. These results suggest that the sunshade of Visorsat is effective in suppressing sunlight reflection. On the other hand, it is also clear that the negative impact on observations remains, since the satellite trails appears bright enough.

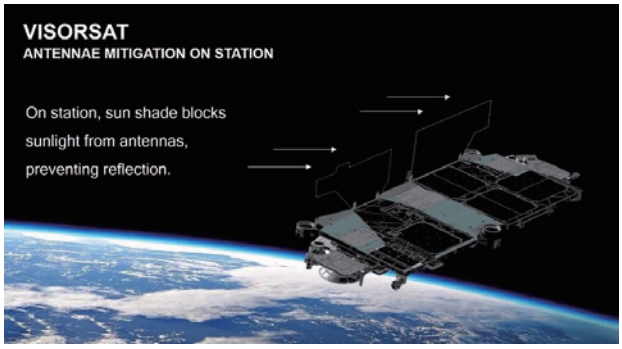

Figure 1: Approximate shape of Visorsat (©SpaceX). The sun visor attached to the satellite's body is expected to suppress the reflection of sunlight to the ground.

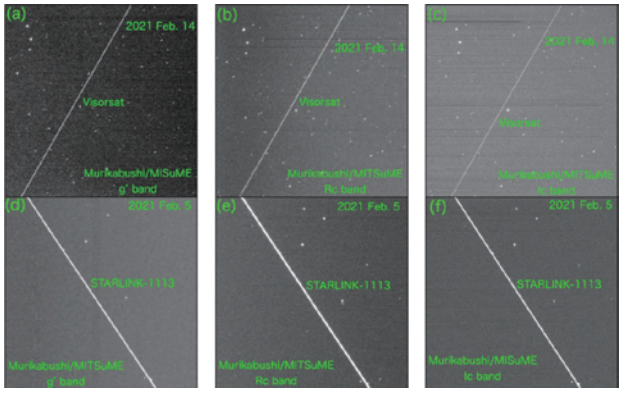

Figure 2: Examples of Visorsat (upper three panels) and normal Starlink streaks (lower three panels).

Reference

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The Progenitor of the Peculiar Galaxy NGC 3077

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FERGUSON, Annette M. N.[3], ŽEMAITIS, Rokas[3], IRWIN, Mike J.[4]

1: SOKENDAI, 2: NAOJ, 3: University of Edinburgh, 4: University of Cambridge

NGC 3077 is a member galaxy of the M81 Group located at a distance of 3.8 Mpc from the Milky Way. This peculiar galaxy has been classified as an Irr II, Seyfert, I0pec, and S0/Sa, and commented as one of the few galaxies that cannot be accommodated by the Hubble scheme. Together with M81 and M82, NGC 3077 belongs to one of the most famous galaxy triplets. Conspicuous streams of atomic hydrogen gas (HI) result from tidal interactions in the past [1], and both NGC 3077 and M82 exhibit recent starburst activity in their central areas. A study using Hyper Suprime-Cam (HSC) on the Subaru Telescope showed the young stars closely follow the HI distribution and can be found in a stellar stream between M81 and NGC 3077 and in numerous outlying stellar associations [2]. Numerical simulations of the M81, M82, and NGC 3077 showed that spiral arms and HI streams connecting M81 and NGC 3077 are the results of the interaction between the two galaxies [3], and three inner galaxies in the M81 Group are likely to merge within the next 1–2 Gyr [4].

We investigate the structure and metallicity distribution function of NGC 3077 [5]. Based on the M81 galaxy group survey with HSC [2], we have constructed the deep color-magnitude diagram that reached the old RGB population of NGC 3077 and covered well beyond the tidal radius, which allows us to derive the structural properties and stellar content of the peripheral regions (see Figure 1 top). NGC 3077 has the extended stellar halo and the "S-shaped" tidal feature, which is not well-matched by the position angle and the ellipticity derived from the fit to the full star count distribution. The average metallicity of individual RGBs decreases with the distance from the NGC 3077 center (see Figure 1 bottom). The metallicity at the S-shape area shows a comparable or slightly metal-poor population with that of $r \sim 4 \times R_h$ area, implying this structure is made up of stars that have been stripped from the outermost part of NGC 3077 due to the tidal interaction with M81 and M82. The old stellar component of NGC 3077 is on the mass-metallicity relation of nearby low-mass ellipticals and shows the mild metallicity gradient [M/H] = -0.14 dex R_h^{-1}, which is comparable with that of the dwarf elliptical galaxy NGC 185. These results, as well as the oxygen abundance of NGC 3077, and M81, suggest that this peculiar galaxy had been a normal dwarf elliptical galaxy before the interaction with M81 and M82. The close encounters with M81 and M82 might supply the gas to NGC 3077 center and induce the current central starburst. The ongoing strong tidal effect on NGC 3077 is also stripping the stellar constituent from the outer envelope, which is now seen as the "S-shaped" structure. We also examine the evidence in our dataset for the six recently reported ultra-faint dwarf candidates around NGC 3077 [6]. We recover a spatial overdensity of sources coinciding with only one of these.

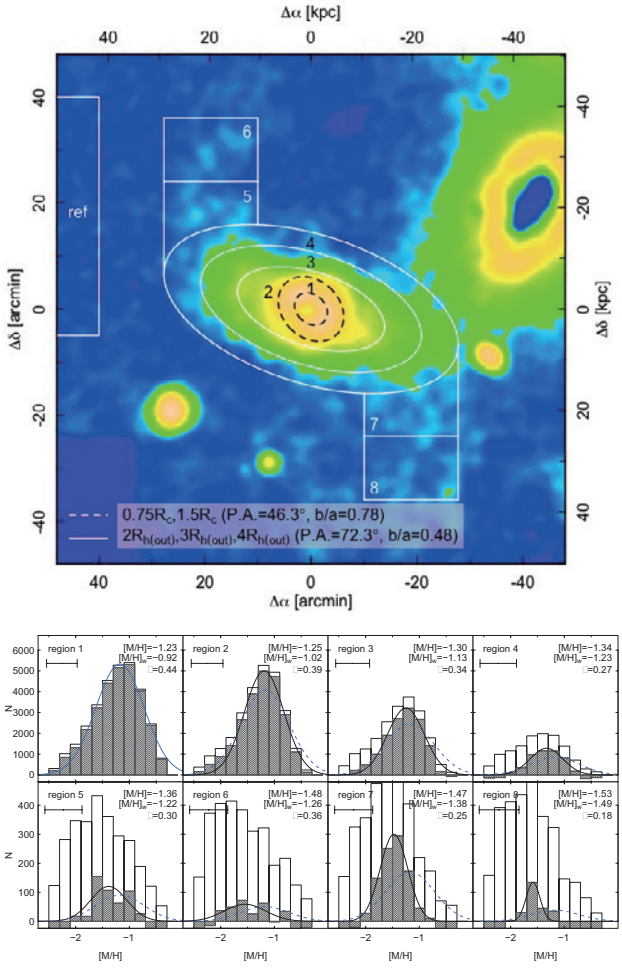

Figure 1: Top: The smoothed density map of RGB stars. Bottom: Metallicity distribution function of RGB stars in regions 1–8 defined in the top panel.

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Investigating the Origin of Gas in Debris Disk with ALMA

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Debris disks can be seen as the extrasolar analogues of the solar system's Kuiper belt. They consist of dust that is produced from the collisional destruction of asteroidal or cometary bodies (e.g. [1]). Debris disks are remnants of the planet formation process. Thus, they can help us to understand the evolution of planetary systems.

Traditionally, debris disks were considered to be devoid of gas. However, observations with ALMA have revealed about 20 debris disks with CO gas emission, mainly around young (ages of tens of Myr) A-type stars (e.g. [2]). The origin of this gas is still under debate. It could be *primordial*, that is, leftover from the earlier, gas-rich protoplanetary phase (e.g. [3]). If true, this would challenge the current view that protoplanetary disks only survive for a few million years. The other option is a *secondary* origin where the gas is derived from cometary material. This would be interesting because the gas would allow us to study the composition of the exocomets.

Models of the secondary origin predict that CO-rich debris disks should contain considerable amounts of neutral C that shields the CO molecules from the stellar and interstellar radiation field (e.g. [4]). Without C, the CO would be quickly destroyed and thus unobservable. For the primordial scenario, chemical models by [5] are able to predict the C/CO ratio.

To test these models, we used ALMA observations of C I and CO emission towards a sample of 14 debris disks [6]. We derived the C and CO column densities, as shown in Figure 1. We find two groups of disks: CO-poor disks where the C column density is too low for CO shielding, and CO-rich disks where the C column density is sufficient for CO shielding, as required by the secondary scenario. However, comparison of the C and CO column densities with secondary models by [7] indicates that the models over-predict the C column density. Thus, either the gas in CO-rich debris disks is not secondary, or the models are missing important physics. On the other hand, a comparison of the C/CO ratios to the primordial model by [5] yields promising results, but more detailed investigations are necessary to conclude.

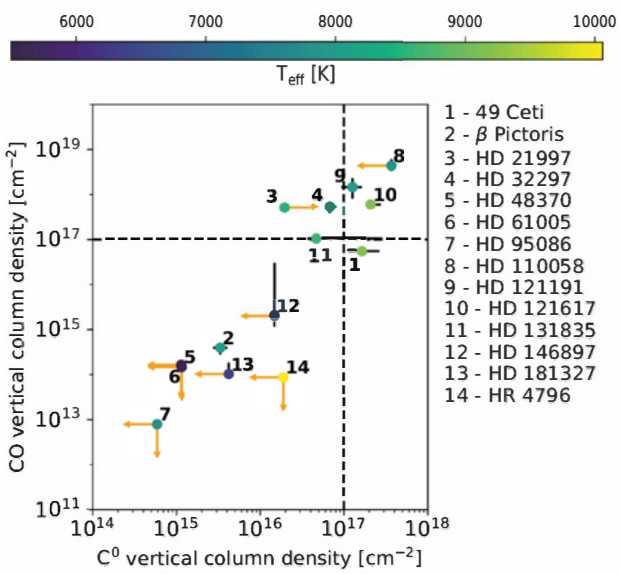

Figure 1: Measured CO and C column densities for our debris disk sample. The colours indicate the effective stellar temperature. Upper/lower limits are indicated by orange arrows. The vertical and horizontal dashed lines indicate the column densities where CO shielding by C and CO self-shielding become effective, respectively.

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The Dark Matter Halo Mass of Quasars at $z \sim 6$

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The good correlation between the stellar mass of a galaxy and the mass of a supermassive black hole (SMBH) suggests co-evolution. SMBHs drive quasars by the accretion of massive stars and gas onto their disks. Since both galaxy and SMBH masses are related to the dark matter halo (DMH) mass, constraining the DMH mass of quasars at high-z is important for understanding co-evolution. Clustering analysis is a common method to estimate the DMH masses of objects but clustering analysis of quasars has been limited up to $z \sim 4$ because the number density of quasars decreases at high-z.

However, a wide survey by Hyper Suprime-Cam on Subaru Telescope (HSC-SSP) provided deep imaging data over ~1200 deg^2. The Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs [1]) project utilized this data to select low-luminosity quasar candidates at $z \sim 6$ with a Bayesian algorithm and has discovered 162 new quasars at $z \sim 6$ spectroscopically so far. The number density of high-z quasars has been dramatically increased by detecting fainter quasars than ever before in SHELLQs. Therefore, we conducted a clustering analysis of quasars at $z \sim 6$ with SHELLQs quasars and bright quasars detected by SDSS and Pan-STARRS in the HSC-SSP region. In this study, 107 quasars were selected considering the homogeneity of the sample, and the typical DMH masses of quasars were evaluated from our analysis. Figure 1 shows the distribution of the quasars used in the analysis on the celestial plane.

Based on the clustering analysis, we evaluated the typical DMH mass of the quasar at $z \sim 6$ as $M_{\rm halo} = 5.0^{+7.4}_{-4.0} \times 10^{12}\,h^{-1}\,M_\odot$ [2]. This mass corresponds to the massive DMHs at $z \sim 6$, and these DMHs will grow to be as massive as $2 \times 10^{14}\,h^{-1}\,M_\odot$ at $z = 0$, which is equivalent to the DMH of a galaxy cluster (Figure 2 black line) based on the extended Press-Schechter theory. Figure 2 also compares our results with those of the previous quasar clustering analysis at $z < 4$. Interestingly, we found that the DMH mass of the quasars is almost independent of redshift, and there exists a typical quasar DMH mass range of $10^{12}\,h^{-1}\,M_{\rm halo} \leq M_{\rm halo} \leq 10^{13}\,h^{-1}\,M_\odot$. Although a similar trend has been reported at $z < 4$ before, this study reveals that this trend persists up to $z \sim 6$ for the first time. This result suggests that SMBHs require high-mass DMHs to accrete enough gas and stars onto the accretion disk in order to shine brightly as quasars, while extraordinarily high DMH mass hinders accretion due to strong feedback from quasars in a wide redshift range. This study suggests that the mechanism to activate quasars is at work in a wide range of cosmic history.

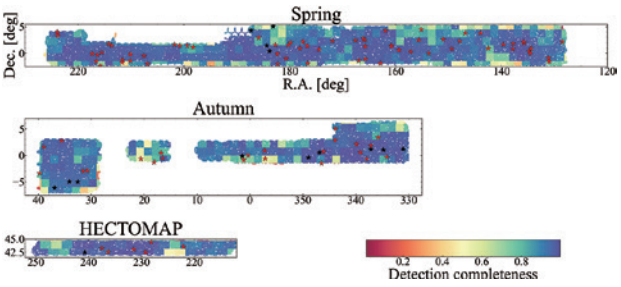

Figure 1: Detection completeness map of the HSC-SSP S20A region. Red and black stars show SHELLQs quasars and bright quasars, respectively.

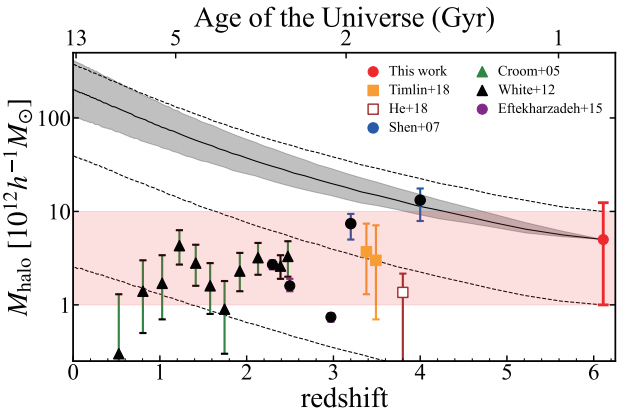

Figure 2: The DMH mass from clustering analysis as a function of redshift. The black solid line shows the redshift evolution of the DMH mass. The red region represents the typical DMH mass range of quasars.

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EMPRESS. IX. Extremely Metal-Poor Galaxies are Very Gas-Rich Dispersion-Dominated Systems: Will JWST Witness Gaseous Turbulent High-z Primordial Galaxies?

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Understanding galaxy formation is crucial for studying primordial galaxies characterized by low metallicities and low stellar masses ($Z \lesssim 0.01\,Z_\odot$ and $M_* \lesssim 10^6\,M_\odot$; e.g., [1]). One approach is to study local analogs of high-z primordial galaxies. Among the local analogs, we focus on extremely metal-poor galaxies (EMPGs), defined to have metallicities less than 10 % of the solar. While the properties of EMPGs do not perfectly mirror those of high-z galaxies [2], their low metallicities, low stellar masses, and high specific star-formation rates (sSFRs) suggest the early stages of galaxy formation. Selecting faint EMPG candidates from Subaru/HSC deep optical images (~26 AB mag), Kojima et al. [3] initiated the project "Extremely Metal-Poor Representatives Explored by the Subaru Survey (EMPRESS),". Notably, EMPRESS identified J1631+4426 with the lowest metallicity ever detected (0.016 $Z_\odot$) and a low stellar mass (~$10^6\,M_\odot$) [3].

To investigate gas dynamics of such EMPGs, we initiated a new project, EMPRESS 3D (PI: M. Ouchi), utilizing Subaru/FOCAS IFU. This study [4] presents kinematics of six local extremely metal-poor galaxies (EMPGs), including J1631+4426. These EMPGs possess low metallicities (0.016–0.098 $Z_\odot$) and low stellar masses ($10^{4.7}$–$10^{7.6}\,M_\odot$). Utilizing deep, medium-high resolution ($R \sim 7500$) spectra with Hα emission, we resolve the small inner velocity gradients and dispersions of the EMPGs. Figure 1 shows the observed Hα flux, velocity and velocity-dispersion maps of J1631+4426 as an example, suggesting that J1631+4426 is irregular and dominated by dispersion rather than rotation, as are the other five EMPGs. Carefully masking out substructures, we fit 3-dimensional disk models to the observed Hα data. All the EMPGs show rotational velocities ($v_{\rm rot}$) of 5–23 km s^{-1} smaller than the velocity dispersions (σ_0) of 17–31 km s^{-1}, indicating dispersion-dominated ($v_{\rm rot}/\sigma_0 = 0.29$–$0.80 < 1$) systems affected by inflow and/or outflow. Combining our results with other Hα kinematics studies (e.g., [5]), we find a trend where the ratio $v_{\rm rot}/\sigma_0$ decreases and the gas fraction ($f_{\rm gas}$) increases with decreasing metallicity, stellar mass, and increasing specific star-formation rate (Figure 2). We also find that a simulated high-z ($z \sim 7$) forming galaxy [6] has a gas fraction and dynamics similar to the observed EMPGs.

Our EMPG observations and the simulation suggest that primordial galaxies are gas-rich dispersion-dominated systems. The James Webb Space Telescope will reveal dynamics of actual high-z galaxies soon.

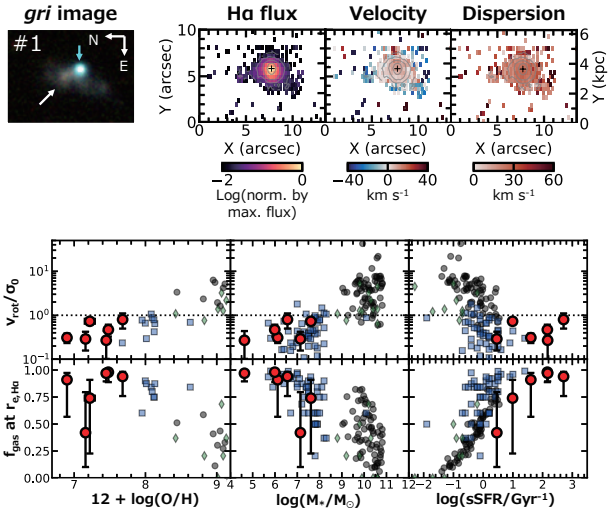

Figure 1: (Top) A Subaru/HSC *gri* image and Hα flux, velocity and velocity-dispersion maps observed with Subaru/FOCAS IFU. Only J1631+4426 is shown as an example of our EMPGs. (Bottom) $v_{\rm rot}/\sigma_0$ and $f_{\rm gas}$ as a function of 12 + log(O/H), M_*, and sSFR. The red circles represent our EMPGs.

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Centimeter-sized Grains in the Compact Dust Ring around Very Low Mass Star CIDA 1

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The initial phase of planet formation in protoplanetary disks involves grain growth, a critical process that establishes the maximum grain size. This is pivotal because subsequent planet formation mechanisms, such as pebble accretion [1], rely on these factors [2].

In a study of the dust ring surrounding the 0.19 $M_\odot$ T Tauri star CIDA 1 using the Karl G. Jansky Very Large Array (JVLA) at centimeter wavelengths, we identified distinct partial-ring structures [3]. Through spatial distributions and spectral indexes, we confirmed that these emissions originated from dust. The dominant flux densities at (sub)millimeter and centimeter wavelengths can be attributed to the dusty ring, which can be further divided into multiple dust emission components through analysis of the spectral energy distribution (SED). Utilizing radiative transfer calculations and comparing observed SEDs, we estimated a maximum grain size ($a_{\rm max}$) of approximately 2.5 cm within the ring. This suggests grain growth within the CIDA 1 ring, potentially facilitating more efficient planet formation through pebble accretion involving centimeter-sized pebbles.

Pebble accretion models predict accelerated planet formation with larger grains. Our analysis of ZZ Tau IRS indicates that planet formation in the crescent containing millimeter-sized grains may proceed more efficiently than in regions with submillimeter-sized grains [4]. Limited observations of very low-mass (VLM) stars at centimeter wavelengths, with ZZ Tau IRS being the only detection, leave uncertainties about the prevalence of (sub-)millimeter-sized grains or the growth of pebbles to centimeter or larger sizes in disks around VLM stars. To enhance understanding, expanding the sample size through sensitive centimeter observations is necessary to investigate grain growth and planet formation in disks around VLM stars.

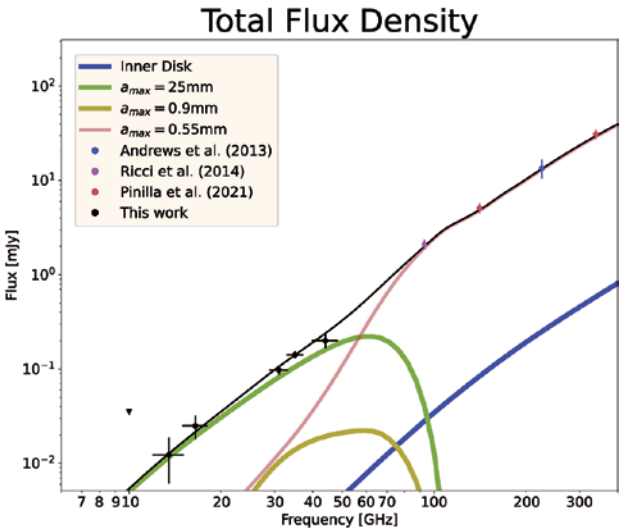

Figure 1: The observed flux densities from CIDA 1 [3] are compared to our models for interpretation. The integrated flux densities from CIDA 1 are plotted on a logarithmic scale. In the panel, the blue, green, yellow, and pink lines correspond to our models for the dust emission from the inner disk, an embedded dust ring with $a_{\rm max}$ = 25 mm, a spatially compact embedded dust component with $a_{\rm max}$ = 0.9 mm, and an extended dust ring with $a_{\rm max}$ =0.55 mm, respectively. The black lines represent the total flux densities of all model components.

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UV & Lyα Halos of Lyα Emitters across Environments at $z = 2.84$

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In this study [1], we detected 3490 Lyα Emitters (LAEs) at $z = 2.84$ using deep imaging with the narrow band filter NB468 and the broadband filter (g-band) on the Hyper Suprime-Cam (HSC) mounted on the Subaru Telescope (Figure 1). We investigated the surface brightness profiles of the UV continuum and Lyα emission of LAEs through stacking analysis. By dividing the sample according to various LAE properties and exploring profile changes, we examined the origins of the extended Lyα emission (Lyα halo, see below).

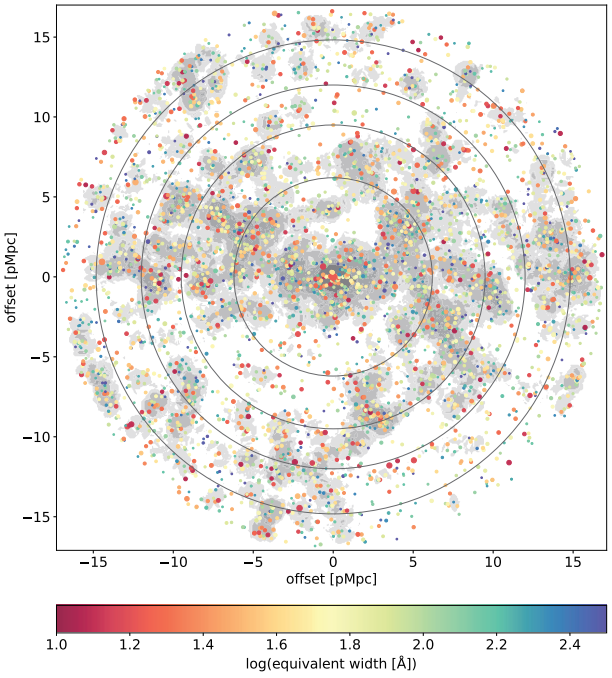

Figure 1: Spatial distribution of detected LAEs (colored dots). Color indicates Lyα emission equivalent width, size indicates UV luminosity (larger is brighter), and contours show LAE number density. Samples were divided based on these quantities, and stacking was performed for each subsample.

The surface brightness profile of Lyα emission in high-redshift star-forming galaxies shows a more extended distribution than the starlight continuum profile [2], termed the Lyα halo. This provides crucial insights into the circumgalactic medium, playing a significant role in galaxy evolution, though its physical origin is debated. We examined how it varies with UV continuum luminosity, Lyα emission equivalent width, and LAE number density within 1.8 arcminutes (environment), etc. We found minimal environmental dependence, except for LAEs in a protocluster with a hyperluminous quasar. UV and Lyα bright LAEs showed extended UV components (Figure 2). Comparisons with simulations suggest the extended UV component likely results from a few undetected satellite galaxies, primarily influencing the Lyα halo along with subsequent HI scattering. The large extent of halos in protocluster LAEs indicates that ionization from local sources, like bright quasars, can be significant at tens of kpc away from LAEs.

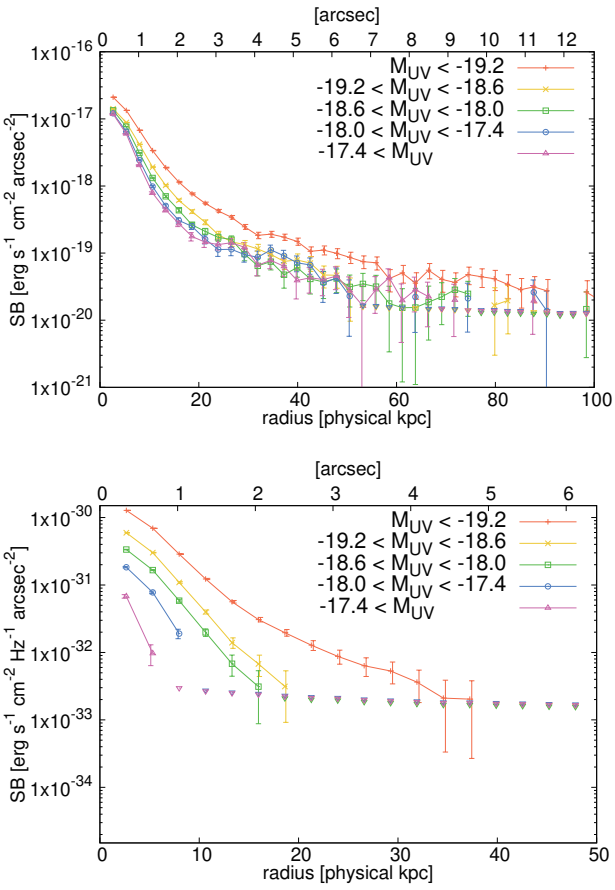

Figure 2: Surface brightness profiles of Lyα emission (top) and UV continuum (bottom) obtained by stacking in five groups according to UV luminosity.

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* In NAOJ when paper was published.

SILVERRUSH. XIII. A Catalog of 20,567 Lyα Emitters at $z = 2$–7 Identified in the Full-Depth Data of the HSC-SSP and CHORUS Surveys

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1: University of Tokyo, 2: NAOJ, 3: ICRR, 4: Sokendai, 5: Kavli IPMU, 6: Kitami Institute of Technology, 7: Waseda University, 8: NIT Toba College, 9: Carnegie Observatory, 10: NSF NOIRLab

In this study [1], we identified 20,567 Lyα Emitters (LAEs) at $z = 2.2$–7.3 using the Subaru/Hyper Suprime-Cam (HSC) through the SILVERRUSH and CHORUS [2] programs, covering a large survey area up to 25 deg^2 with deep images from five broadband and seven narrowband filters (Figure 1). LAEs were selected based on secure $> 5\sigma$ detections showing narrowband color excesses via Lyα break screening, with careful masking and visual inspection of coadded and multiepoch images to remove spurious sources. This yielded 6995, 4641, 726, 6124, 2058, 18, and 5 LAEs at $z = 2.2$, 3.3, 4.9, 5.7, 6.6, 7.0, and 7.3, respectively.

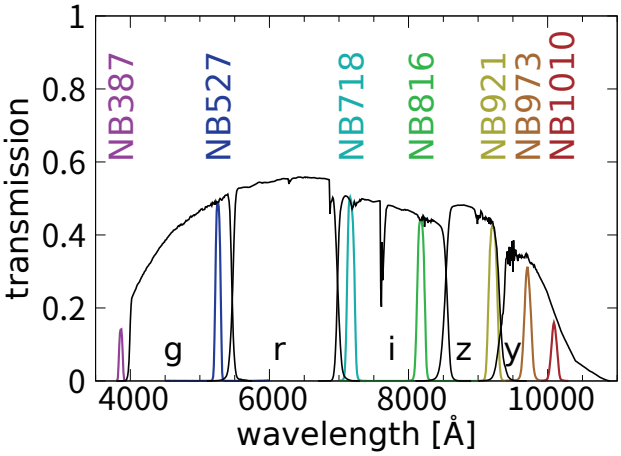

Figure 1: Total transmission curves of relevant HSC filters based on the area-weighted mean measurements. Colored thick curves show the transmission of NB filters and black curves show that of HSC broadband filters.

Unlike previous LAE catalogs using HSC-SSP data [3], the current catalog is created using data after the survey completion, making it the largest in terms of both area and depth. Furthermore, the contamination rate from artificial signals is minimized by considering the limiting magnitude variations across the survey areas when selecting candidates and performing careful visual inspection.

Figure 2 shows an example of the sky distributions of LAEs for the $z = 6.6$ sample. The study demonstrated that the number counts of LAEs are consistent with previous research and highlighted the reliability of the selection process by including 289 spectroscopically confirmed LAEs. This catalog allows for statistical studies on galaxy formation and reionization with unprecedented precision. Subsets of these LAEs will be spectroscopically confirmed in the coming PFS-SSP survey.

The new catalogs will be made publicly available on the project website[1], providing detailed descriptions and ancillary information.

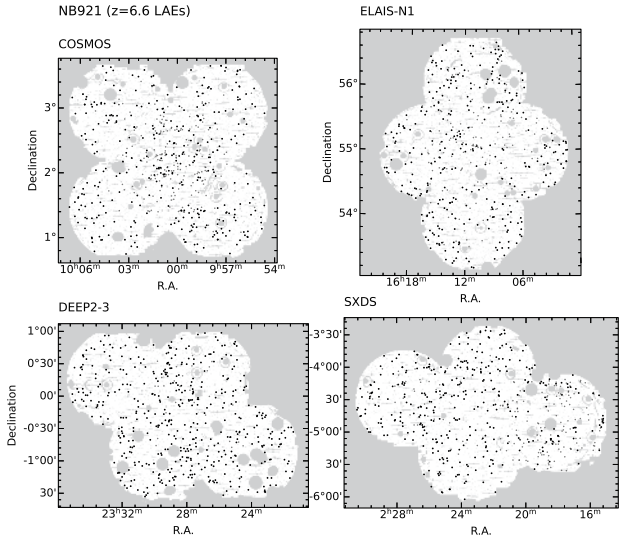

Figure 2: Sky distribution of NB921 LAEs ($z = 6.6$). Thick (thin) blue dots indicate the locations of objects brighter (fainter) than NB921 = 24.0 mag, respectively. North is up, and east is to the left. Masked regions are shown in gray.

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1 http://cos.icrr.u-tokyo.ac.jp/rush.html

Gravitational Wave Astronomy: Optical Follow-up Observation of Binary Black Hole Coalescence

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Since the first direct detection of gravitational waves in 2015, gravitational wave astronomy has attracted much attention from astronomers all over the world. In 2017, a gravitational wave event from a binary neutron star merger GW170817 was detected; this event was the first and only gravitational wave event for which the electromagnetic counterpart has been firmly detected so far.

Gravitational wave telescopes detect not only gravitational waves from binary neutron star coalescences, but also from black hole-neutron star coalescences and binary black hole coalescences. Indeed, the gravitational wave events from binary black hole coalescences account for more than 90 % of all gravitational wave detections so far.

Due to the strong gravity field, not even light can escape from a black hole, and thus it is naively not expected that binary black hole coalescences are accompanied by electromagnetic emission. However, the detection of an electromagnetic emission was claimed for the gravitational wave event GW190521 from a binary black hole coalescence in 2019. Multiple mechanisms for the electromagnetic emission have been theoretically proposed. Therefore, multi-wavelength follow-up observations are important to clarify whether binary black hole coalescences are accompanied by electromagnetic emission, and, if so, how bright the emission is.

On February 24, 2020, the gravitational wave telescopes LIGO and Virgo, detected gravitational waves from a binary black hole coalescence named GW200224_222234 (hereafter "GW200224"). The 'eyesight' of gravitational wave detectors is generally poor, and the accuracy of the arrival direction is typically comparable with about 2000 full moons (500 square degrees). However, the arrival direction of GW200224 was well determined, about 50 square degrees, because of its strong gravitational wave radiation. Then we performed follow-up observations of GW200224 with Hyper Suprime-Cam (HSC) on the Subaru Telescope and the Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy (OSIRIS) on the Gran Telescopio CANARIAS.

We started a deep and wide-field search with HSC for an electromagnetic counterpart, which is expected to be a "transient" object and succeeded in observing almost the entire possible arrival direction (91 %) of GW200224 just 12 hours after the gravitational wave event detection. This is the first achievement of deep follow-up for a binary black hole coalescence covering more than 90 % of the possible arrival direction.

By scrutinizing the luminosity variations of the transient objects found by the HSC observation, and by performing spectroscopic follow-up observations with OSIRIS to measure the distances to some of them, the team eventually identified 19 candidate objects. However, none of these objects were strongly suggested to be related to GW200224 [1].

If there is no counterpart, GW200224 accompanies no electromagnetic counterpart same as that reported for GW190521. This result indicates the diversity of electromagnetic counterparts of black hole binary coalescences.

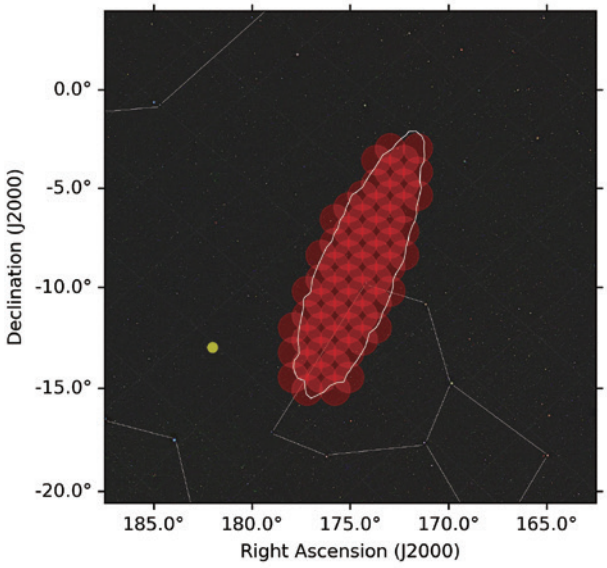

Figure 1: Possible arrival direction of GW200224_22234 (90 % probability), represented by a white line, determined by gravitational wave telescopes and the area observed by HSC, represented by red circles. A red circle represents the size of HSC's field of view, equivalent to seven full moons. The yellow circle shows the size of a full moon for comparison. (Credit: NAOJ/ Tominaga/PanSTARRS)

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Optical Measurements of Silicon Vacuum Window with Anti-reflective Sub-wavelength Structure for ASTE Band 10

NAGAI, Makoto[1], EZAKI, Shohei[1], SAKAI, Ryo[1], KANEKO, Keiko[1], IMADA, Hiroaki[1], KOJIMA, Takafumi[1], SHAN, Wenlei[1], UZAWA, Yoshinori[1], ASAYAMA, Shinichiro[2/1]

1: NAOJ, 2: SKA Organisation HQ

For millimeter and submillimeter-wave astronomy, it is highly desirable to have vacuum windows within the receiver cryostat that exhibit low reflection, low loss, and a wide bandpass. The use of antireflective (AR) sub-wavelength structures (SWS) on substrates has expanded the possibilities for creating new vacuum windows. Recently, a novel method of fabricating AR SWS on a silicon-on-insulator (SOI) wafer has been proposed, and a vacuum window with a two-layer AR SWS has been developed for use with the ASTE Band 10 receiver [1].

To assess the characteristics of the silicon window sample, we conducted transmittance measurements using a THz-TDS system, and noise and beam measurements [2]. The device under test is the AR silicon window sample and a quartz window for the ALMA Band 10 receiver as a reference. Receiver testing was performed using an ALMA Band-10 receiver and the Band-10 test systems, with procedure identical to that of the evaluation of ALMA Band-10 receivers [3].

The transmittances of the silicon window before and after a UV irradiation have consistent bandpass characteristics and fringe patterns, higher than 90 % over the Band 10 frequencies (Figure 1). Figure 2 shows the results of noise temperature excess measurement. The extracted excess noise due to the insertion loss of the silicon window considerably consistent with the transmittance measurement result shown in Figure 1 The beam maps taken with the silicon and quartz windows are almost identical within the systematic errors (Figure 3).

We found that the silicon window sample exhibits characteristics that are comparable to the quartz window of the ALMA Band 10 receiver. Our findings demonstrate that the silicon vacuum window, composed of SOI wafers and featuring an AR SWS, possesses favorable properties and is a viable option for use in the ASTE Band-10 receiver. Our investigation revealed that the thermal oxide layers did not have any discernible impact on the optical characteristics of the window. Furthermore, the implementation of this AR silicon window offers an extension of performance for next-generation receivers, indicating its potential as a valuable component for future advancements in receiver technology.

This work was supported by JSPS Kakenhi 18H03725.

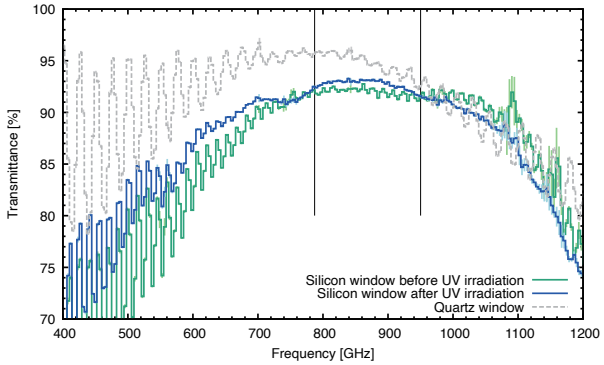

Figure 1: Transmittance of silicon window (solid) and quartz window (dashed).

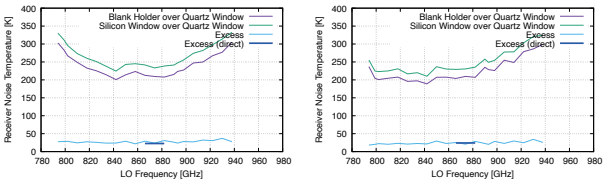

Figure 2: Receiver noise temperature excess of AR silicon window. (Left) Mixer P0. (Right) Mixer P1. The difference of the receiver noise temperatures with and without the silicon window (greeen and purple, respectively) in front of the quartz window is the excess (light blue). The noise excess obtained with a direct measurement with a fixed mixer bias point is also shown (blue).

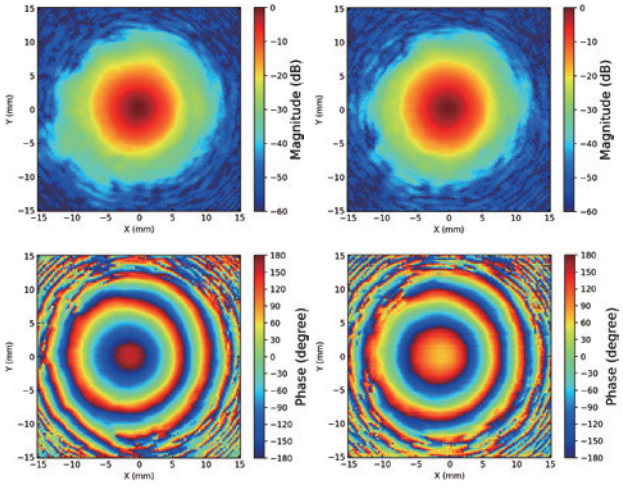

Figure 3: Example of near-field beam map of co-polarization (P1 at 879 GHz). (*Left*) Silicon window. (*Right*) Quartz window.

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Spectra of the Classical Nova V1405 Cas at the Very Beginning Indicate a Low-mass ONeMg White Dwarf Progenitor

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The lowest possible mass of ONeMg white dwarfs (WDs) has not been clarified despite its importance in the formation and evolution of WDs. We tackle this issue by studying the properties of V1405 Cas (Nova Cassiopeiae 2021), which is an outlier given a combination of its very slow light-curve evolution and the recently reported neon-nova identification [1].

Using KOOLS-IFU [2] on the 3.8 m Seimei telescope [3] at the Okayama Observatory, Kyoto University, we obtained its rapid spectral evolution in the initial phase, covering 9.88, 23.77, 33.94, 71.79, and 81.90 hours after the discovery (Figure 1). The first spectrum is characterized by lines from highly ionized species, most noticeably He II and N III. These lines are quickly replaced by lower-ionization lines, e.g., N II, Si II, and O I. In addition, Al II (6237 Å) starts emerging as an emission line at the second epoch. We also obtained a high-resolution spectrum using HDS [4] on the 8.2 m Subaru Telescope [5] after 53.53 hours since the discovery, which makes the aluminum line identification robust by splitting the Al II (6237 Å) line into its fine structure (Figure 2).

We perform emission-line strength diagnostics, showing that the density and temperature quickly decrease toward later epochs [1]. This behavior, together with the decreasing velocity seen in Hα, Hβ, and He I, indicates that the initial nova dynamics is reasonably well described by an expanding fireball on top of an expanding photosphere. Interestingly, the strengths of the N III and Al II indicate large enhancement in abundance, pointing to an ONeMg WD progenitor as is consistent with its neon-nova classification. Given its low-mass nature inferred by the slow light-curve evolution and relatively narrow emission lines, it provides a challenge to the stellar evolution theory that predicts the lower limit of the ONeMg WD mass being ~ 1.1 $M_{\odot}$.

This study makes use of data obtained by the 3.8 m Seimei telescope through the programs, 21A-N-CT06 in the open use of the observing time provided by NAOJ and 21A-K-0017 in Kyoto University time. This research is based in part on data collected at the Subaru Telescope, which is operated by the National Astronomical Observatory of Japan. We are honored and grateful for the opportunity to observe the Universe from Maunakea, which has cultural, historical, and natural significance in Hawaii.

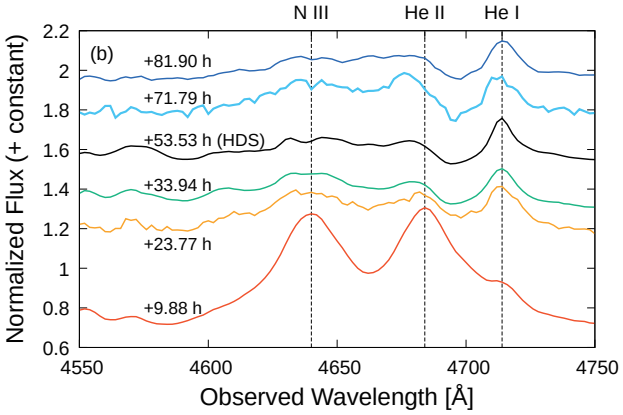

Figure 1: An enlarged view of spectra of V1405 Cas shows rapid diminishing of He II and N III. Adopted from Figure 2(b) of [1].

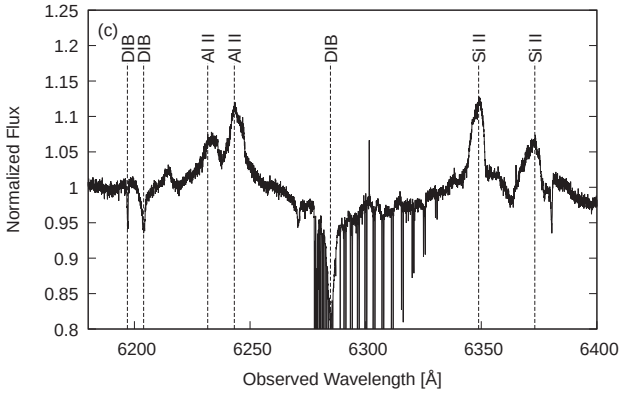

Figure 2: The spectrum of V1405 Cas taken by HDS splits "Al II (6237 Å)" into its fine structure, making the aluminum line identification robust. Adopted from Figure 3(c) of [1].

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Precision Cosmology with Weak Lensing and Galaxy Clustering Using Intermediate Data of Subaru Hyper Suprime-Cam Survey

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In the late 1990s to 2000s, the standard cosmological model known as ΛCDM was established through observations of the cosmic microwave background (CMB), baryon acoustic oscillations, and Type Ia supernovae. This model explains observational facts well but relies on the cosmological constant Λ (dark energy) and cold dark matter (CDM), whose nature remains unknown. Understanding these components or exploring models beyond ΛCDM is a significant challenge in modern cosmology.

Hyper Suprime-Cam (HSC) survey is one of the wide-field imaging surveys started in the 2010s, and designed to observe the shapes of galaxies to probe the gravitational weak lensing effect caused by the foreground large-scale structure up to high redshift. The HSC survey, under the Subaru Strategic Program, conducted 330 nights of observations from 2014 to 2021, imaging ~1,100 square degrees primarily around the equator to a limiting magnitude of $i \sim 26$ (5σ, $2''$ aperture).

In this study, we used the intermediate data of the HSC survey obtained by April 2019 (hereafter HSC-Y3) together with the Sloan Digital Sky Survey-III/Baryon Oscillation Spectroscopic Survey (BOSS), to perform a joint cosmology analysis of three different types of signals measured from HSC-Y3 and SDSS data: cosmic-shear, galaxy clustering, and galaxy-galaxy lensing. The HSC-Y3 data covers ~430 square degrees of the sky and includes ~35.7 million galaxies as weak lensing probes.

To prevent confirmation bias in our cosmology analysis, we conducted a blind analysis. We simultaneously analyzed one true catalog and two fake catalogs, keeping the central values of the inferred cosmological parameters hidden. This approach ensured that all systematics and analysis choices were fixed without comparing to external results.

In this study, in addition to analyses using large scales where linear theory can be applied [2], which is also done in other surveys, we improved the measurement accuracy of cosmological parameters using signals from quasi-nonlinear scales [3]. Analytical modeling for quasi-nonlinear scales is difficult. Therefore, we used a cosmology emulator constructed by applying machine learning to cosmological N-body simulations to accurately predict theoretical models in the quasi-nonlinear regime [4].

The results of the cosmology analysis using quasi-nonlinear scales in this study are shown in Figure 1. It can be seen that the clumpiness parameter of the Universe S_8 obtained from HSC-Y3 is smaller compared to that obtained from the *Planck* satellite's CMB observations. Additionally, other competing weak lensing surveys, Dark Energy Survey (DES) and Kilo-Degree Survey (KiDS), also suggest a smaller S_8 compared to the *Planck* satellite. This discrepancy is referred to as the S_8 tension.

If the S_8 tension is real, it may indicate the breakdown of the standard model and some new physics beyond ΛCDM. The HSC completed data acquisition in 2021 with final analysis of ~1,100 square degrees currently underway. The stage-VI galaxy surveys in the 2020s, such as LSST, the Roman Space Telescope, and the Euclid Space Telescope, will improve statistical errors significantly and test the S_8 tension more stringently.

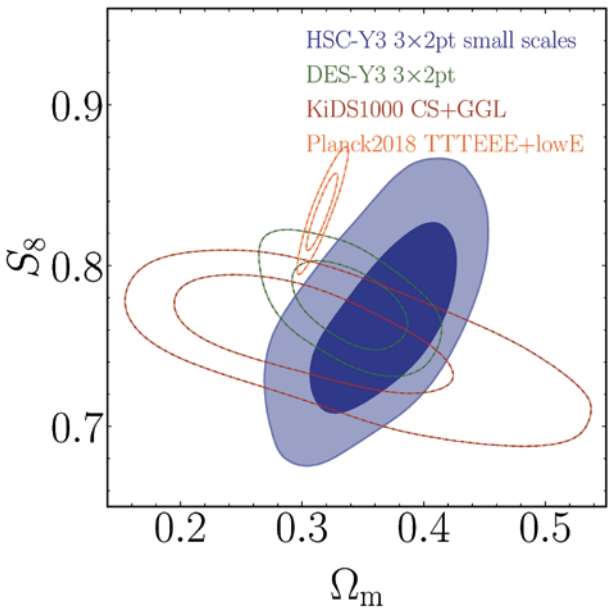

Figure 1: Constraints on the clumpiness parameter of the Universe S_8 and the matter energy density Ω_m obtained in this study. Adapted from [3].

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Inexplicable Flying Fox Found in Hydra Galaxy Cluster

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Galaxy clusters are the largest self-gravitational systems in the universe. The gravitational energy of galaxy clusters is partially converted into the motion of galaxies and the heat of the intra-cluster medium (ICM). Radio observations reveal the presence of cosmic-ray electrons and magnetic fields extending over galaxy clusters. However, the mechanisms behind electron acceleration and the origins of these magnetic fields are still in mystery. Recent developments in radio telescopes have enabled observations of galaxy clusters at lower frequencies, which can uncover previously undetected radio emissions that are crucial for investigating the origins of cosmic-ray electrons and magnetic fields.

The Hydra Cluster, which is also called Abell 1060, has been well-studied using optical and X-ray observations. Research utilizing the X-ray observatory XMM-Newton suggests that heating events, likely due to collisions and mergers, have occurred in the cluster's core over the past few billion years [1]. Despite this, previous radio observations have not found evidence of cosmic ray electrons or magnetic fields generated or amplified by these events, potentially due to weak turbulence or shock waves insufficient to accelerate electrons.

Our data analysis from the upgraded Giant Metrewave Radio Telescope (uGMRT) revealed an unreported extended radio emission near the Hydra Cluster's core. This radio source, dubbed “The Flying Fox” due to its distinct shape, was further investigated using Galactic and Extra-Galactic All-Sky MWA Survey (GLEAM) data. The spectral index of The Flying Fox was found to be approximately −1.4, significantly steeper than the typical value of −0.8 for similar radio emissions, indicating its detection at higher frequencies is challenging.

Curiously, The Flying Fox lacks counterparts in optical or infrared observations, raising questions about its origin. If associated with nearby galaxies (NGC 3311, NGC 3312), its formation would require implausible motions that contradict existing neutral hydrogen observations [2]. The most plausible scenario for The Flying Fox's origin is a past collision or merger between galaxy clusters, although its location does not align with the regions of temperature increase reported in XMM-Newton studies. Another potential scenario involves interactions with the nearby galaxy group HCG48, necessitating a complex trajectory avoiding the Hydra Cluster's center.

This study represents the first detection of unexplained radio emission in the post-merger phase of the Hydra Cluster (Abell 1060), offering a significant contribution to theoretical and observational advancements in this field. Continued investigation into The Flying Fox's formation mechanism is crucial. Observations by X-ray Imaging and Spectroscopy Mission (XRISM), launched in 2023, are expected to shed light on this mystery. XRISM, designed to observe “hot plasma” winds in and between stars and galaxies, will also be capable of detailed studies of the Hydra Cluster's hot plasma. These observations are anticipated to provide insights into the gas dynamics of galaxy clusters and galaxies, further elucidating The Bat's formation mechanism.

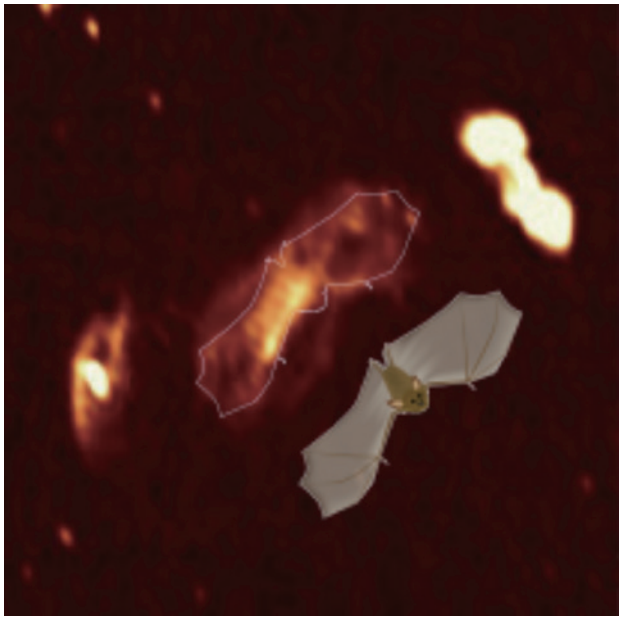

Figure 1: The radio intensity map of the Hydra Cluster (Abell 1060) observed with uGMRT. The gray contours indicate the surface brightness distribution of X-rays which observed by XMM-Newton [3].

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Subaru High-z Exploration of Low-luminosity Quasars (SHELLQs). XVII. Black Hole Mass Distribution at $z \sim 6$ Estimated via Spectral Comaprison with Low-z Quasars

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1:NAOJ, 2: Ehime Univresity, 3: Kavli IPMU, 4: Princeton University, 5: University of Tokyo, 6: University of Barcelona, 7: Tohoku University, 8: Onomichi City University, 9: Shinshu University, 10: W.M. Keck Observatory

We estimated black hole mass distribution of 131 quasars at $z \sim 6$ discoved by Subaru HSC-SSP survey and reported new way to measure black hole masses of high-z quasars by substituing low-z quasar spectra [1].

We have discoverd about 200 distant quasars (SMBHs) at $5.7 < z < 7.1$ based on the HSC-SSP. These quasars are located about two orders of magnitude lower in luminosity compared to the quasars found in previous surveys within the same redshift range, suggesting they may host low-mass black holes (BHs). However, the observational wavelength data obtained for our high-z quasars based on the HSC-SSP only covers a portion of the rest-UV wavelength range between 1200–1400 Å. For most of these quasars, except for the relatively bright ones, the spectral data does not include the wavelength ranges necessary for measuring BH masses, such as the C IV emission lines, leaving statistical analysis unaddressed. Therefore, in this study, we selected "counterparts" for each of the high-z quasars via spectral fitting with low-z quasars observed by the SDSS that have spectral shapes most similar to the high-z quasars in the overlapping wavelength. By matching these spectra, we inferred the C IV emission line profiles in the 1500–1600 Å. As a result of the spectral matching, we were able to find low-z quasar counterparts similar to the high-z quasars and measured the C IV emission line widths of the obtained counterparts to determine the BH masses of the distant quasar sample. In our sample, a direct comparison between the BH mass measurements from near-infrared spectroscopic observations of some objects and the BH masses derived from the counterparts showed that the BH masses of high-z quasars can be estimated with high accuracy using the spectra of low-z quasars as substitutes (Figure 1). The new BH mass distribution for $z \sim 6$ based on the HSC-SSP obtained using the counterpart method was found to be shifted one to two orders of magnitude lower in mass compared to the previously known distribution (Figure 2). Comparing the obtained BH masses with theoretical seeding models, it was shown that if the seeds of BHs started growing at $z = 30$ (assuming an Eddington ratio of 1 and a standard accretion disk), most quasars could grow from the remnants of the Pop-III stars to SMBHs.

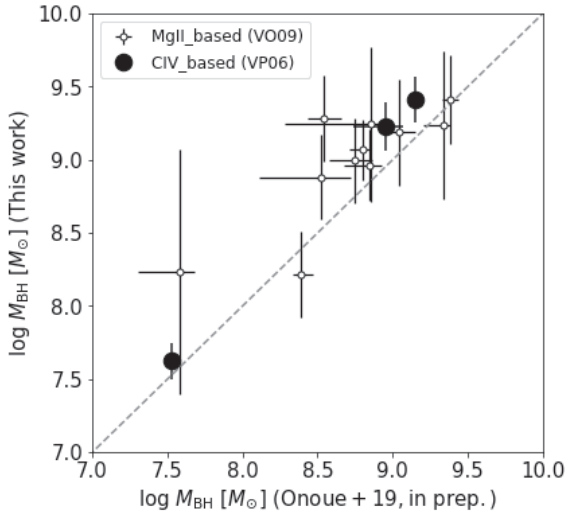

Figure 1: Comparison of BH masses between our estimates (vertical axis) and actual measurements (horizontal axis; Onoue et al. 2019, M. Onoue et al., in prep.)

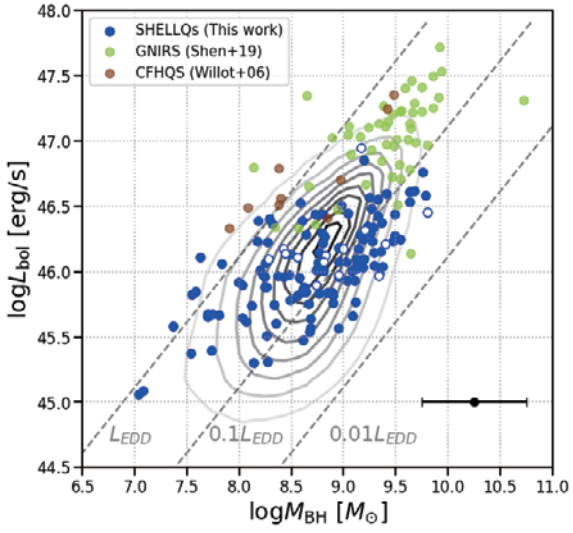

Figure 2: The supermassive BH mass-luminosity plane of high-z quasars. Blue dots represent our sample, whose BH masses were measured with the counterpart method. Other dots represent the quasars founded by previous surveys and countours show the distribution of SDSS DR14 quasars.

Reference

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* In Ehime University when paper was reported.

Multiline Stokes Synthesis of Ellerman Bombs

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Ellerman Bombs (EBs) are magnetic reconnection events in the lower solar atmosphere. There are two interesting aspects in the magnetic reconnection at lower altitude. The first aspect is the environmental dependence of the magnetic reconnection rates. From the photosphere to the chromosphere, there are significant changes in ionization degree (0.01–1 %) and plasma beta (the ratio of the plasma pressure to the magnetic pressure, 10^{-4}–10^{2}). The altitude dependence of magnetic reconnection rates are theoretically predicted [1]. The second aspect is the feasibility of obtaining magnetic fields. With the current polarimetric observations, it is difficult to obtain magnetic fields in the solar corona, where solar flares occur. On the other hand, it is becoming possible to obtain chromospheric magnetic fields. By obtaining physical quantities around magnetic reconnection regions occurring at various altitudes and investigating the environmental dependence of magnetic reconnection rates, we can significantly contribute to the understanding of reconnection behavior in weakly ionized plasma.

Aiming for high-precision observations of chromospheric magnetic fields, a Japanese group led by the National Astronomical Observatory of Japan is participating in the international balloon experiment Sunrise iii. Sunrise iii will conduct stable observations for five days in a seeing-free environment at an altitude of around 37 km. We are developing the Sunrise Chromospheric Infrared spectroPolarimeter (SCIP) [2] as a focal plane instrument for Sunrise iii. SCIP performs multiline spectropolarimetric observations in the near-infrared region.

The aim is to clarify the performance of SCIP and to enable accurate interpretation of spectropolarimetric data [3]. Using the results of magnetohydrodynamic simulations [4], we synthesized spectropolarimetric signals by solving the radiative transfer equation as shown in Figure 1.

Focusing on magnetic reconnection events occurring at two different altitudes, we investigated their characteristics using synthesized data. In the case of magnetic reconnection at lower altitudes, the photospheric lines showed a blue shift originating from the reconnection outflow. For magnetic reconnection at higher altitudes, the chromospheric lines exhibited emission lines due to the heating of the upper formation layer. These results suggest that SCIP's multiline observations have the ability to distinguish between magnetic reconnections occurring at different altitudes. By weak field approximation (WFA), we derived the magnetic fields. It was shown that the magnetic fields could be derived with high accuracy in many regions. However, in regions with large velocity and magnetic field gradients along the line of sight, the magnetic field derived from WFA differed from the actual magnetic field. In such regions, it is necessary to rely on solving the inverse problem of the radiative transfer equation.

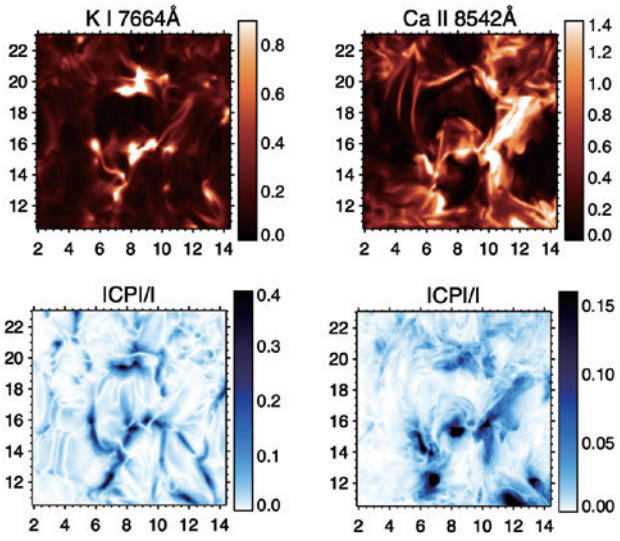

Figure 1: The results of synthesis of K i 7664 Å (left) and Ca ii 8542 Å (right). Upper: Intensity, lower: Circular polarization.

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Evolution of the Angular Momentum of Molecular Cloud Cores in Magnetized Molecular Filaments

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Molecular cloud cores are dense regions of molecular clouds and are the cradle of stars. Uncovering their physical properties is important for understanding the star and planet formation process. The angular momentum of the cores plays a key role in star formation since, for instance, it is closely related to the formation of multiple systems and the circumstellar disk. Herschel observations showed that molecular filaments are ubiquitous in molecular clouds and that prestellar cores and protostars are formed in filaments [1]. However, the evolution of the angular momentum of the core formed from the filament fragmentation is still unclear. On the other hand, the magnetic field plays an essential role in the angular momentum transfer in the star formation process [2]. Observations also show that the magnetic fields are perpendicular to the longitudinal axis of the filament [3]. In this work, we investigate the evolution of the angular momentum of molecular cloud cores in magnetized molecular filaments using the smoothed particle hydrodynamics method.

Figure 1 shows how much angular momentum is transferred during the filament fragmentation. For instance, Figure 1 suggests that the 30 % and 50 % of the angular momentum of the core with $M_{\rm ana} = 1.0\,{\rm M}_\odot$ at the initial state are removed from the core in the case of $2\,\mu$G and $10\,\mu$G , respectively. This indicates that the cores can have the rotation originated from the initial turbulence at the mass scale with $M_{\rm ana} \gtrsim 1.0\,{\rm M}_\odot$. Figure 1 also shows that the dependence of the angular momentum on the strength of the magnetic field disappears at $M_{\rm ana} \simeq 3.0\,{\rm M}_\odot$.

Previous works that investigate the angular momentum transfer starting the simulations from the molecular cloud core scale suggest that resultant disk sizes depend on the initial misalignment between the magnetic field and rotation direction of the core [5]. Figure 2 shows that the rotation direction is random with respect to the local magnetic field direction. Our results suggest that the diversity of the direction of the angular momentum still survives the core formation phase, which leads to the variety of the star and planet systems.

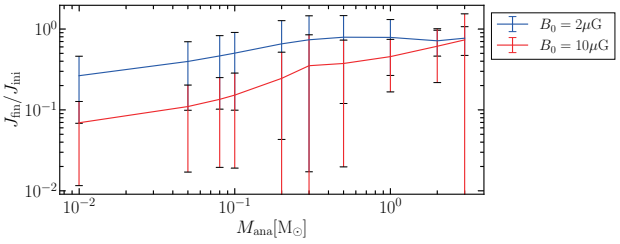

Figure 1: Ratio of the angular momentum of the core at the final state to that at the initial state. The ratio is averaged over all 40 cores. The horizontal axis represents the mass of the core. The blue and red solid lines are the results of $B_0 = 2\,\mu$G and $B_0 = 10\,\mu$G, respectively.

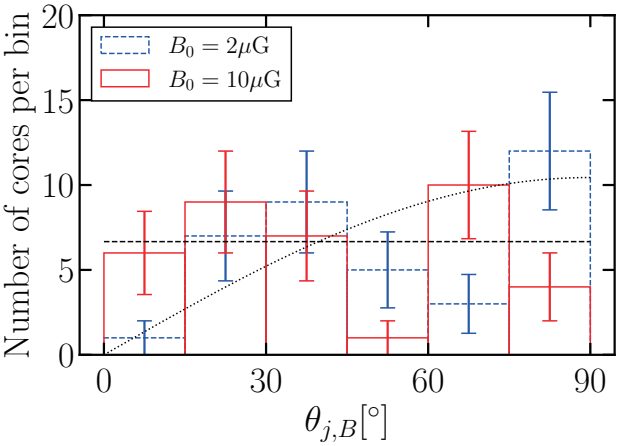

Figure 2: Histogram of the angle between the angular momentum and the local magnetic field direction measured at the final state of our simulations. The core mass is $M_{\rm ana} = 1.0\,{\rm M}_\odot$ in both panels. The black dotted and dashed lines are random distributions in the 2D and 3D, respectively. The blue dashed and red solid histograms represent the results of $B_0 = 2\,\mu$G and $B_0 = 10\,\mu$G, respectively.

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II Status Reports of Research Activities

01. 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. KaVA (KVN and VERA Array), which combines the VERA and KVN (Korean VLBI Network) in Korea, and East Asian VLBI Network (EAVN), which consists of Japanese, Chinese, and Korean radio telescopes, are being operated and opened to the international community. The observatory also operates 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. As a member organization of the Event Horizon Telescope project, the observatory contributes to the promotion of millimeter-wave VLBI as well. The observatory also plans to participate in SKA (Square Kilometre Array) as a future project. In addition to these VLBI-related activities, the observatory plays a wide range of roles beyond astronomy, such as operation of the Esashi Earth Tide Observation Facility, which is used for research in geophysics.

1. VERA and International VLBI observations

(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 2023, a total of 242 sessions (1,964 hours) of regular VLBI observations were conducted using VERA. Mizusawa VLBI Observatory has started a new observational mode "VERA Large-scale COllaborative Program (VLCOP)" since September 2022. In FY 2023, 17 projects (16 are continuation from FY 2022) have been conducted since September 2023. A total of 78 sessions (452 hours) of VLBI observations were conducted for VLCOP projects such as astrometry observations of maser emission associated with OH/IR stars and long-term monitoring and parallax measurements of Galactic center Sgr A*. In addition, single-dish observations from AOC or at local stations have been conducted for a total of 1,520 hours to monitor time-variation of maser sources in star-forming regions and search for maser sources in the Galactic center region. These observing times include commissioning observations for a newly developed receiver correlator system and geodetic observations.

VERA is participating in the international observations of KaVA together with the KVN, which consists of three 21-m antennas. Furthermore, VERA is also a member of EAVN, utilizing VERA, KVN, Sejong 22-m in Korea; the Tianma 65-m, Sheshan 25-m, Nanshan 26-m, and Kunming 40-m, in China; and Nobeyama 45-m, and Yamguchi/Hitachi/Takahagi 32-m radio telescopes in Japan. For the common-use projects, commissioning and test observations with EAVN, a total of 142 sessions (1,082 hours) of observations were conducted in FY 2023. EAVN open-use calls for proposals for semesters 2023B (first half of FY 2023) and 2024A (second half of FY 2023) were released in June and November of 2023, respectively. In total, 30 proposals requesting a total time of 1,210 hours were submitted by researchers in Japan, Korea, China, Italy, Thailand, and so on. Through the evaluations by anonymous referees nominated from scientists in related fields and the subsequent decision made by the EAVN combined Time Allocation Committee, a total of 29 proposals (930 hours) were accepted.

In FY 2023, VERA Ishigakijima and Mizusawa Stations stopped operation in the first half (until August 2023) and second half (from September 2023), respectively, due to antenna problems, and hence, VERA operations were limited to using only 3 stations. Nevertheless, the rest of the 3 VERA antennas regularly participated in the VLCOP and EAVN observations, and the reduction of total observing times were not very significant compared with those in FY 2022; 92 % and 84 % for the VLBI and single-dish modes, respectively.

The VLBI data, except for EAVN observations, were processed at the Mizusawa Correlation Center in NAOJ Mizusawa Campus. The correlated data were sent to the proposer or representative person of data analysis of each project. For some of the EAVN observations, the Mizusawa Correlator Center copied the recorded data to change frequency settings (digital filtering) and transfer the reprocessed data to the Korea-Japan Correlation Center in Daejeon in Korea for further data correlation.

Regarding global mm-VLBI, Event Horizon Telescope (EHT) observations of 2024 spring season were scheduled in April 2024, and hence there were no EHT observations within Fiscal Year 2023.

(2) Science Research

In FY 2023, staff members of Mizusawa VLBI Observatory contributed to a total of 31 refereed journal papers, and 4 of them were published by the Mizusawa staff members as the first author (including one by a graduate student of the University of Tokyo) and two were results achieved by the principal investigators during their contract in Mizusawa VLBI Observatory. One of the highlights of the VERA results is a study of magnetic field structures in active galactic nuclei (AGNs) by using new dual-polarization receiver and wide-band recording systems developed by Mizusawa VLBI Observatory. The new observing system used in this study can achieve 2 GHz bandwidth, which is 16 times larger than the nominal VERA observing system with 128 MHz bandwidth, which has a great

advantage to accurately measure frequency dependence on the polarization angles. As for maser sciences, the proceedings of the International Astronomical Union Symposium (IAUS 380, held in Kagoshima in March 2023) were published in February 2024, with one of the Mizusawa VLBI Observatory staff members contributing as the chief editor. In the proceedings of IAUS 380, Mizusawa VLBI Observatory staff members contributed to 15 articles, and another 5 articles reported results from VERA and EAVN, covering various science topics including star-formation, stellar evolution, Galactic structures, and AGNs.

Results of EAVN observations were published in 3 peer-reviewed journals. One of the most remarkable studies is the first detection of the precessing motion of the AGN jet in M87 through a 10-year-long monitoring by the EAVN large program on AGN. The discovery of the precessing jet is implicit evidence of black hole spin, and hence, it is expected to contribute to further studies on super-massive black holes, along with the imaging of the black hole shadows by EHT. In addition, another result from the EAVN large program on star-formation was published, reporting an expanding motion of the outflow in a high-mass star-forming region traced by the H_2O masers.

Related to EHT, a total of 7 related papers were published, such as observational results of the black hole shadow in M87 taken 1 year after the first imaging in 2017, and the magnetic field structure of M87 measured by polarimetry with EHT. Results of other international projects, in which Mizusawa VLBI Observatory participates, include ultra-high resolution VLBI observations of AGN jets using the VLBI satellite Radio Astron, and VLBI imaging of the Keplerian rotating disk of an accretion-burst massive protostar by the research network Maser Monitoring Organization (M2O). In Mizusawa VLBI Observatory, various VLBI-related science research was carried out using other facilities in NAOJ, such as the Nobeyama 45-m telescope and ALMA, and future planning for the Square Kilometre Array (SKA; see Section 3) is underway through collaboration with the user community.

2. The Japanese VLBI Network (JVN)

The University VLBI Collaboration Observation projects were conducted jointly by NAOJ and six universities. We organized the radio telescopes of VERA, universities, and research institutes (JAXA/ISAS) to establish the Japanese VLBI Network (JVN). The JVN operates at three frequency bands: 6.7 GHz, 8 GHz, and 22 GHz. In FY 2023, a total of 960 hours were dedicated to VLBI and Yamaguchi Interferometer observations. The primary research areas included protostars, active galactic nuclei, and X-ray binary systems. Additionally, Ibaraki University conducted over 1000 hours of single-dish observations related to JVN research.

During FY 2023, JVN focused on three research targets for time-domain VLBI astronomy:
(1) (periodic) flux variations in CH_3OH masers
(2) radio jets of high-mass protostars
(3) a water maser associated with supernova remnant.

Radio telescopes operated by the JVN-member universities were used for these observations. Throughout the year, 6 papers were published, including Tanabe et al. (2023) and Nakamura et al. (2023), as well as one short report on a transient event.

Yonekura from Ibaraki University and Niinuma from Yamaguchi University led the development study, focusing on upgrading the VLBI observation system at the Ibaraki, Yamaguchi, and VERA stations through Grants-in-Aid for Scientific Research. Several students from Ibaraki and Yamaguchi Universities were involved to the development study under the supervision of Professor Ogawa at Osaka Metropolitan University. These activities demonstrate the contributions of JVN to the education of graduate students.

3. SKA Sub-project

The phase 1 of the SKA project (SKA1), which began construction in July 2021, is progressing with procurement and installation focusing on infrastructure such as foundations and fiber networks. By March 2024, the first antennas arrived and began installation in both the MID in South Africa and the LOW in Australia. Nine countries have ratified the SKA Convention, and the remaining six countries, excluding Japan, are advancing their participation procedures. Although efforts are being made to reduce the construction budget, it remains only about 80% funded due to inflation and other factors. Therefore, additional funding from participating countries and new investors are being sought. Japan, requiring more time to secure substantial funding, was excluded from the SKA1 construction budget forecast.

From FY 2019, NAOJ organized the SKA1 study group under Mizusawa VLBI Observatory for three years, conducting preliminary research and contributing in-kind to the SKA1 project. Based on this, a project proposal was submitted in October 2021, and the study group continued to review the project during FY 2022. From FY 2023, the SKA1 sub-project was launched under Mizusawa VLBI Observatory to address several scientific and technical issues, the primary challenge being securing the necessary budget and devising feasible plans for it. The sub-project was organized into four sections: Planning, Science, SRC (SKA Regional Center), and Technology.

The Planning section participated in the SKAO Council as an observer, monitored the construction status of SKA, and explained Japan's research status. The section also participated in the SKA Finance Committee, SKA Contract Committee, and SKA In-Kind Contribution Committee. Domestically, efforts were made to secure large-scale academic frontier budgets from MEXT, and an application was prepared and submitted for the MEXT Roadmap 2023, although it was not selected. Additionally, large budget applications were submitted for the JSPS Transformative Research Areas A and Specially Promoted Research, but these were also not selected. However, the section successfully secured funding for the strategic international research exchange acceleration program of NINS and the Open Mix Lab, enabling scientific research through long-term overseas travel and the development of low-

frequency radio technology. Personnel matters included the continuation of employment based on an agreement with the SKA Observatory for the head of SRC and the recruitment of a new head of Technology from outside the organization. However, the sub-project leader retired due to reaching retirement age, and a replacement has not yet been found despite repeated requests.

The Science section co-organized a session on long-wavelength radio astronomy with ngVLA stakeholders at the 2023 autumn annual meeting of the Astronomical Society of Japan. Additionally, joint presentations with ngVLA were made at Udenkon Symposium, increasing opportunities for mutual understanding between SKA and ngVLA. In terms of scientific encouragement, a hands-on workshop on cosmic magnetism was held on February 12–13, 2024, with two international lecturers and 11 young researchers from Japan. The section also made significant contributions to the participation of the Japanese team in the SKAO's SDC3 data challenge on the Epoch of Reionization. Individual research efforts yielded results in the Epoch of Reionization, magnetism, pulsars, and AGN using precursor instruments like MWA, MeerKAT, ASKAP, GMRT, and VERA/JVN, with some outcomes being publicized. For nurturing young researchers, funding from the NINS strategic international research exchange program enabled 7 researchers to visit India for joint pulsar timing array research with GMRT. Additionally, 4 researchers from Australia were invited to Japan, and 4 Japanese researchers were sent to Australia for joint research on magnetism with ASKAP, showing promising results.

The SRC section participated as full members in the SRC Network and its Steering Committee, understanding SRC prototyping and contributing to discussions on its framework while drafting fundamental documents shaping the SRC. In international agile development, the section contributed 1–1.5 FTE to the HPC/Cloud (Olive) and East Asia Node (Lavender) teams for prototyping activities. Specifically, the development of the Japanese node, JPSRC, achieved the implementation and stable operation of a virtual machine environment using OpenStack. Tests for speed improvement of the foreground removal program for the Epoch of Reionization and the tomographic analysis program for cosmic magnetism using Japan's unique vector processor technology showed promising initial results. Tests of the domestically developed gfarm file system demonstrated its high functionality as a distributed file system despite easy implementation. Alongside node development, JPSRC also provided resources for SDC3, contributing significantly to international visibility.

The Technology section has been contributing 1.5 FTE to the Assembling, Integration, and Verification (AIV) of LOW and MID under an MOU with SKAO since January 2022. For LOW, they took on significant international responsibilities in developing test content and procedures for AA0.5, identifying issues like mutual coupling and radio interference, which could lead to new contributions from Japan. For MID, they contributed to preparations for measuring artificial radio interference and conducting test observations, paving the way for remote operations from Japan, allowing flexible participation of university researchers. For the SKA Observatory Development Program, efforts included developing a prototype high-speed VLBI recorder based on Japanese-developed technology, achieving speeds up to 150 Gbps. Collaboration with Osaka Metropolitan University began on the potential installation of a 15–29 GHz observation band for MID, involving partners from South Africa, the UK, Sweden, and Switzerland. For implementing 1 GHz band (L-band) VLBI observations domestically, radio environment surveys were conducted at VERA Mizusawa, Ishigakijima, and Ogasawara Stations, reaffirming the challenges of interference from VERA antenna equipment.

4. Geodesy and Geophysics

To monitor the position and shape of the VERA network, semi-regular geodetic VLBI observations were conducted 18 times in total during FY 2023. This includes 15 times of VERA internal observations using the K-band and three times where the Mizusawa Station participated in IVS sessions using the S- and X-bands (IVS-T2P and AOV). In AOV and IVS-T2P sessions, wideband observations using OCTAD-OCTADISK2, and recorded data transfers to the IVS correlation center have been routinely conducted. The participation of VERA stations in internal geodetic observations is incomplete due to long-term operational outages caused by antenna failures, Ishigakijima only participated from October 2023 onwards and Mizusawa until June. The final estimates of the VERA station positions were reconstructed based on ITRF2020 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 analysis software GipsyX which was developed by NASA/JPL and Caltech is used in the analysis. 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 and gravity observation data in Mizusawa show the viscoelastic relaxation process of the 2011 off the Pacific coast of Tohoku Earthquake. The strain and tilts observation data obtained at the Esashi Earth Tides Station were distributed in real time to several institutes and universities based on the research agreement among them.

As a constituent institution of GGOS-Japan we shared in the Tsuboi Award (group award) of the Geodetic Society of Japan. The award was given in recognition of "Geodetic Achievements as a GGOS Affiliate".

5. System Development

As a development group, we are currently developing the dual-polarization and dual-frequency (K, Q) receiver system at a rate of 32 Gbps for VERA in accordance with the next EAVN broad-band observing mode. In 2023, we modified RF and IF integrated switches (Ogasawara and Ishigaki stations) with 16 inputs and 4 outputs for both polarization bands (Q, K,

C, S, L) to enable coexistence with the conventional observing system. As a result, all VERA stations are now capable of the simultaneous K/Q bands with dual-polarization observing mode using the K-band RF direct A/D (OCTAD). We have conducted various CSV observations including the new observing system and obtained an annual parallax of Sgr A* using the broad-band two-beam observing mode (Oyama et al.2024)

Nine years have passed since the Mizusawa correlation center was established, and the time is approaching for replacing servers including the VLBI recorder. Therefore, as the next system, we have studied and upgraded the correlator and recording system. In FY 2023, we have upgraded our recording software "VSREC" to a new OS (rocky linux 9.X) with a view to using it in SKA-VLBI. We succeeded in transmitting data at up to 110 Gbps, which is 13 times faster than the existing recording rate (8 Gbps). However, since packet loss was still several percent, software modifications are ongoing to reduce packet loss. For the correlation system, we have achieved regular operation of the GPU correlator in high-dispersion mode (more than 1M FFT points) and are continuing to modify, develop, and verify both hardware and software to support the new OS and servers.

6. Public Outreach

(1) Open House Events (Numbers in <> are the number of participants)

The following open house events are held every year at each telescope site operated by Mizusawa VLBI Observatory.

- On April 22, 2023 The 14th Open Observatory Event held by the Ibaraki University Center for Astronomy, and NAOJ Mizusawa VLBI Observatory, Ibaraki Station. <Total 771 people>
- On August 20, 2023 The special open house event at VERA Ishigakijima Station held together with "The Southern Island Star Festival". <248 people>
- On August 26, 2023 Mizusawa district "Iwate Galaxy Festa 2023". <Total 1100 people>
- On January 27, 2024 VERA Ogasawara Station Open House Event "Star Island 20". <194 people>

(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) 12,845 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 1,140
c) VERA Ogasawara Station 6,360
d) VERA Ishigakijima Station 2,310

(3) Cooperation with Local Communities (Numbers in <> are the number of participants)

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

a) The Iwate Marugoto Kagaku Johokan (led by Iwate Prefecture), an IT science event for children and adults in Iwate Prefecture, is held every year and we participated in 2023 as well.

July 29, 2023 (Saturday) Iwate Marugoto Kagaku Johokan in Miyako. <150 people>
November 25, 2023 (Saturday) Iwate Marugoto Kagaku Johokan in Morioka at Iwate Prefectural Citizens' Information Exchange Center (Aiina) <800 people>

b) In 2023, we held a "Kirari Oshu City Astronomical Class" for elementary and junior high schools in Oshu City.

September 5, 2023 (Tuesday) Kuroishi Elementary School 5th and 6th grade joint / "Earth, Moon, and Solar System" Lecturer: Hirotomo Noda <10 people>
September 12, 2023 (Tuesday) Mizusawa Minami Elementary School 5th grade joint / "What is a black hole?" Lecturer: Kazuhiro Hada <114 people>
October 6, 2023 (Friday) Maesawa Junior High School 3rd grade joint (1st, 2nd Class) / "Expanse of the Universe" Lecturer: Kazuhiro Hada <58 people>
October 6, 2023 (Friday) Maesawa Junior High School 3rd grade joint (3rd, 4th Class) / "Expanse of the Universe" Lecturer: Kazuhiro Hada <58 people>
October 11, 2023 (Wednesday) Higashi Mizusawa Junior High School 3rd grade joint / "Expanse of the Universe" Lecturer: Mareki Honma <120 people>
November 7, 2023 (Tuesday) Isawa Junior High School 3rd grade joint / "Seasonal constellations and movement of the stars" Lecturer: Daisuke Sakai <111 people>
December 19, 2023 (Tuesday) Mizusawa Junior High School General Culture Department / "Hayabusa2 challenge" Lecturer: Koji Matsumoto <10 people>

c) In 2023, Cooperation with Oshu City childcare support activities.

March 9, 2024 (Saturday) Esashi Odaki District Center / "Stars and Constellations" Lecturer: Tomohiko Ozawa <12 people>

7. Education

(1) University and Post-Graduate Education

Regarding postgraduate education, Mizusawa VLBI Observatory assisted 3 doctoral and 3 master's course graduate students from the University of Tokyo with their research. One master's student and one doctor student are from a foreign country. One master's students obtained the degree in September 2023, and each of one master's and one doctoral student obtained the degrees in March 2024. In addition to students of the University of Tokyo, Mizusawa VLBI Observatory accepted a few graduate students and interns from domestic and foreign universities (Osaka Metropolitan

University, Yale University, University of Science and Technology of China, and so on). A staff member of Mizusawa VLBI Observatory gave lectures at Tohoku University as a visiting professor.

(2) Research Experience for High School Students

Mizusawa VLBI Observatory organized the educational program for high school students in Ishigaki Island, "The Churaboshi Research Team Workshop" with the support of JSPS, during summer vacation as usual. The event was co-organized with the Public Relations Center of NAOJ on-site at VERA Ishigakijima Station, Ishigakijima Astronomical Observatory, and Ishigaki Youth House. Including 17 participants from outside Okinawa Prefecture, a total of 23 high school students experienced the lectures on astronomy, observatory tours, star watching, and observational studies with the VERA 20-m antenna to search for new maser sources.

02. Nobeyama Radio Observatory

1. Nobeyama 45-m Radio Telescope

(1) Charged Telescope Time

The 42nd term (charged telescope time) started on September 1, 2023. The statistics of the conducted programs are as follows. "General Programs": 27 programs, "CSV Programs": 5 programs, "Observation Tutorial Programs": 3 programs. The number of the successful proposals for "Students Programs", which are reviewed scientifically, is 3 proposals out of the 4 submitted proposals.

Remote observations were conducted from Mitaka, Osaka Metropolitan University, Nagoya University, Ibaraki University, University of Tokyo, Kagoshima University, Kyushu University, Keio University, ASIAA (Taiwan), etc.

(2) Improvements and Developments

(a) New Developments

- A new focal plane array receiver system for observations at 72–116 GHz (named "7BEE") was used for CSV (Commissioning and Science Verification) measurements and test observations, but it was found that the cooled low-noise HEMT amplifiers (hereinafter referred to as CLNAs) of it deteriorated. The CLNAs were removed from the cooling dewar in December 2023 and repairs were arranged. This development was supported by JSPS grant-in-aid KAKENHI Kiban S (Grant Number JP20H05645; PI: K. Tatematsu).

(b) Approved Development Programs

A total of five programs are in progress as follows. 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.
- Frequency-modulation local oscillation FMLO.
- eQ (30–50 GHz) receiver.
- Millimetric Adaptive Optics (MAO).
- 100-GHz, 109-element MKID camera.

(c) Reopening call for development proposals

The call for development proposals has resumed. The following three proposals were accepted.

- Development of next-generation spectrometer using FPGA.
- Research on noise reduction for a 100 GHz band SIS receiver equipped with a 45 m mirror using a waveguide-type variable frequency bandpass filter.
- Development of an ultra-wideband atmospheric spectral measurement system that opens up new horizons for space-time measurements of the Earth and space.

(d) Maintenance and improvements

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

- Regularly scheduled and preventative maintenance was performed.
- The following system problems occurred and an investigation was conducted to repair them.
- The DFP-board of the SAM45 spectrometer
- Malfunction of antenna collimator shutter winding mechanism

(3) Scientific Results

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

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

Yokozuka, H., et al. searched the Broad velocity-width Molecular Feature in the FUGIN Legacy Program dataset and found a cloud named CO16.134-0.553. They performed additional multi-line observations toward this cloud and found a shell structure is associated with the cloud. In addition, from HI archive data, they found that a cavity in the Galactic plane is associated with the region and a filamentary structure is elongated from the region toward the vertical direction to the Galactic plane. According to these findings, they proposed a scenario where a dark matter subhalo with a clump of baryonic matter passed the Galactic plane. Yamamoto, H., et al. performed a CO survey toward the jet associated with the microquasar SS433 and found the associated molecular cloud. Furthermore, they compared the CO data with other archive data, including ultraviolet and infrared emissions, and concluded that the cloud is interacting with the jet and heated. Shimajiri, Y., et al. observed the molecular clouds in NGC2024 using multi-lines to map the density distribution and found that the width of the filamentary structure varies with the gas density. In addition, they found the high-density molecular cores are forming by fragmentation of the filament. Kohno, M., et al. performed wide field observations of ammonia molecules toward the infrared bubble N49 and investigated temperature distribution of the high-density cores. As a result, it was found that the feedback from formed high-mass stars is heating surrounding molecular gas over a length of ~10 light years.

2. Research Support

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

With the 1.85-m radio telescope, they 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 2023, receiver, spectrometer and observation system development was performed with the purpose of investigation of the high-mass star formation mechanism by developing an ultra-wide bandwidth mm-submm wavelength spectroscopic receiver system.

3. Public Outreach

(1) PR Activities at Nobeyama Campus

Nobeyama Campus received a cumulative total of 39,217 visitors throughout the year. Four press releases were published. Staff members conducted 19 requests for filming and interviews. One workplace visit by local high schools was conducted. The filming and interview requests were mainly about research activities and introducing NRO. We also provided a hands-on experience with radio astronomy observation for the Junior Session of the Astronomical Society of Japan.

The annual Nobeyama Special Open House was held as on-sight and online event. The maximum number of connections for live streaming was about 400 and the total number of views for all content was about 35,000 in the eight months after the event. On the other hand, 1353 people joined to the on-sight event.

Moreover, we received and answered about 110 phone calls this year from the public regarding the regular opening of the observatory, observatory events, and general astronomy.

(2) Cooperation with Local Communities

The annual Nobeyama Special Open House was held with contributions by Minamimaki Village Shinko-kosha, Minamimaki Village, Minamimaki village society of commerce and industry, Nagano Prefecture, and Nagano Prefecture Board of Education. Moreover, the "Nagano Prefecture is Astro-Prefecture" liaison council promoted activities such as monitoring night sky condition in the prefecture, and the 8th meeting was held on November 3.

4. Education

One doctoral course student from the University of Electro-Communications was 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 Minamimaki Village Shinko-kosha. They had 167 paid group tours and filmings.

(2) Hiring, Transfer (incoming)

None

(3) Retirement, Transfer (outgoing)

Yamafuji, Yasuto: Senior Staff of General Affairs Unit
(concurrently assigned to Accounting Unit), assigned
Otsuka, Tomoyoshi: Re-employment Staff, retired

(4) NRO Conference Workshops and Users Meeting

- December 21–22, 2023, Hybrid (in-person and on-line)
  FY 2023 ALMA/45-m/ASTE Users Meeting (Organizing Committee: Akiko Kawamura, Bunyo Hatsukade, Ken Tatematsu, Tetsuhiro Minamidani (NAOJ))
- June 1, 2023 Hybrid (in-person and on-line) Nobeyama Future Planning Workshop 2023 (Organizing Committee: Atsushi Nishimura, Chieko Miyazawa (NAOJ))

03. 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 in 2006 by ISAS/JAXA and 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 scientific operation is carried out based on cooperation between ISAS/JAXA and NAOJ with international contributions by the US NASA and the UK STFC, the European Space Agency ESA, and the Norwegian Space Center NSC. 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. Watanabe, professor emeritus, for EIS and J. Okamoto for SOT) 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 ground-based telescopes as well as long-term standalone observations by Hinode. The number of Hinode-related refereed papers published in FY 2023 is more than 50. The Hinode science payload has been steadily observing the Sun from space, except for the SOT filtergraph instrument which was terminated in February 2016. ISAS/JAXA approved the fourth mission extension for the period from FY 2021 to FY 2023 and has conducted science operations 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. The JAXA-led Hinode project has been terminated and shifted to a late-stage operations team within ISAS in FY 2024 to focus on the next solar mission SOLAR-C, and the results and lessons learned from Hinode will be transferred to SOLAR-C.

Solar Data Archive System (SDAS) in the Astronomy Data Center (ADC), which developed from the open-use data analysis system of Hinode, former NSRO (Nobeyama Solar Radio Observatory), and 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 and published such as a flare catalog, model of magnetic fields above active regions, and magnetic field data in the solar polar regions.

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 the 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 in addition to full-disk Hα, Ca K, continuum, and G-band imaging observations with the Solar Flare Telescope (SFT). Relative sunspot number measurements also continue as a proxy of long-term solar magnetic activity. The solar activity has been increasing toward the solar maximum, and useful data such as active regions and flares have been obtained. The most advanced data accumulated are those for magnetic fields in the solar atmosphere. The current near-infrared Stokes polarimetric observations provide measurements of magnetic fields both in the photosphere and in the chromosphere. Calibration of their data is underway for the release of magnetic field data. We are developing key technologies required in future solar observing instruments, such as an infrared camera with an H2RG detector.

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 past and new observation data are stored in the common server of ADC and are available on our webpage. In order to promote the use of the data, we have made the Hα imaging data searchable on the Virtual Solar Observatory (VSO), a solar data retrieval system in the US. We are planning to increase the number of data available on VSO in the future.

3. Nobeyama Solar Radio Polarimeters

The Nobeyama Radio Polarimeters (NoRP) monitor the microwave radiation from the Sun, specifically 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. The microwave observation conducted over 70 years since

the time of the Research Institute of Atmospherics, Nagoya University 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) and the solar physics community in Japan. The replacement of critical components was successful so that stable operation has been maintained at all the frequencies. Multiple radio bursts accompanying flares have been detected with the increasing solar activity. Construction of a new solar radio polarimeter began at the National Defense Academy of Japan (NDA) last year, and a test observation was carried out in collaboration with NDA for absolute calibration at 2 GHz.

4. Rocket and Balloon Experiments

The SOL project is working to develop advanced technology for next-generation solar observations by sounding rocket and stratospheric balloon experiments.

The CLASP series of sounding rocket experiments aims to measure solar magnetic fields in the chromosphere and transition region through high-precision polarization observations in the ultraviolet wavelengths. The SOL project has led, in cooperation with research groups in the US and Europe, three successful flight experiments CLASP (2015), CLASP2 (2019), and CLASP2.1 (2021). In FY 2023, we worked on the analysis of the observation data acquired with CLASP 2.1 and are on track to compile them into several peer-reviewed papers.

SUNRISE-3 is the third flight of the international balloon project Sunrise carrying the 1-meter aperture telescope for solar observations, in which Germany, Japan, the US, and Spain are participating. The SOL project is in charge of the near-infrared spectro-polarimeter SCIP, which is installed on SUNRISE-3 and will simultaneously observe many spectral lines with a resolution higher than that of the Hinode satellite. We could not obtain observation data in the 2022 flight, but the instrument was recovered in good condition and preparations were made in Germany for a reflight in 2024. Peer-reviewed papers were published on the results of onboard data processing, thermal design techniques, and camera development obtained through the SCIP development. Numerical modeling studies demonstrated that the elemental processes of magnetic energy conversion can be investigated from high-precision spectro-polarimetry data, and peer-reviewed papers were published.

The Focusing Optics X-ray Solar Imager (FOXSI) is a joint Japan-US sounding rocket experiment series 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. Based on these achievements, the fourth flight FOXSI-4 will realize an observation of a solar flare. FOXSI-4 is scheduled for launch in Spring 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. In FY 2023, completed flight components were shipped to the US, assembled as FOXSI-4 (observation instrument) there, and various tests were conducted. The instrument was then integrated and tested on a sounding rocket, and at the end of FY 2023 it was brought to the launch site in Poker Flat Research Range in Alaska to complete the final preparations for launch. The Japanese team for FOXSI-4 is led by the National Astronomical Observatory of Japan (PI: Narukage), with the participation of the University of Tokyo Kavli IPMU, ISAS/JAXA, and Nagoya University. Many graduate students are also participating in the FOXSI-4 project, and one doctoral thesis and four master's theses were accomplished in FY 2023, demonstrating contribution to the development of young researchers.

5. Cooperation with SOLAR-C Project

In the preliminary design of EUVST, a high-resolution, high-sensitivity UV telescope to be installed on the next solar observing satellite SOLAR-C, the SOL project contributes to realizing SOLAR-C by maximum use of the technical expertise in the optomechanical design, UV observation technology, and IF coordination with overseas institutions accumulated through the development of the rocket and balloon experiments.

6. Education

The SOL project accepted and supervised three Ph.D. students from SOKENDAI and two contract graduate students from the University of Tokyo. Three received a master's degree at SOKENDAI or the University of Tokyo. The SOL project accepted three undergraduate students to experience solar research during the SOKENDAI Summer Student Program (August 2023) and participated in the Tour of Solar Research Frontiers (March 2024) to introduce 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, media appearances for solar observations and space weather in response to requests for media interviews, providing materials to the media, etc.

8. Science and Community Meetings

To advance solar physics research with the Hinode satellite, the 16th Hinode Science Meeting, as the 6th NAOJ symposium, was held September 25–29, 2023 in Niigata. A meeting of the Hinode Science Working Group was held on September 29, 2023, 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 (JSPC) organized a future planning symposium at ISAS on

November 20, 2023, to introduce and discuss plans for future ground-based observations. The JSPC Symposium was held February 20–22, 2024 at NAOJ, where the latest solar physics research results were presented, and future plans for SOLAR-C and beyond were introduced and discussed.

9. Others

In DKIST Operation Commissioning Phase 2 (OCP2), observations proposed from NAOJ were executed and we are waiting for retrieval of the processed data. Observations using GREGOR in the Canary Islands and BBSO in the US were successfully carried out in collaboration with overseas researchers. For these observations, coordination with the Hinode satellite was also organized and efforts were made to establish a scheme for joint observations with ground-based telescopes for SOLAR-C. The 10 cm coronagraph from the former Norikura Corona Observatory has been relocated to Yunnan, China, and its observation operations are underway at the site. An agreement was made with the Chinese group for future scientific cooperation using the coronagraph data.

04. Subaru Telescope

1. Subaru Telescope Staff

As of the end of FY 2023, the Subaru Telescope staff consisted of 22 dedicated research and academic staff members including four stationed at Mitaka and two stationed at Okayama, five engineering staff members, three senior specialist, three administrative staff members, and four specially appointed teachers (including two stationed at Mitaka and one stationed at Okayama). Additional staff members include six project researchers, nine senior specialist, one administrative expert, six administrative supporters, one public outreach staff member, one research supporter, and one re-employment staff, all of whom are stationed at Mitaka. As well as two administrative supporters stationed at Okayama. Moreover, 11 there are research and academic staff members, ten of whom are stationed at Mitaka, and three engineering staff members, one of whom is stationed at Mitaka, one of whom is stationed at Nobeyama, and one of whom is stationed at Mizusawa, who are posted concurrently. The project also has 61 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 Grants-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 2023, Subaru Telescope produced many outstanding scientific outcomes, which were published in major international journals. Below are some examples:

(1)The value for the "clumpiness" of the Universe's dark matter, known to cosmologists as S8, was measured by weak lensing measurements based on the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) data. It does not align with the value derived from the cosmic microwave background data from the Planck satellite. The discrepancy between the S8 values of HSC-SSP and the Planck satellite is very subtle. However, the statistics show that there's only a one in 20 probability that the difference is just due to chance, which is compelling but not completely definitive.

(2) A massive benchmark gas giant planet around the nearby bright star HIP 99770 has been directly imaged by extreme adaptive optics (SCExAO and CHARIS). The object, HIP 99770 b, is the first extrasolar planet jointly discovered by direct imaging and precision astrometry, a new method of indirect detection. This new approach for finding imageable planets simultaneously measures their mass, orbit, and even their atmosphere.

(3) The High Dispersion Spectrograph (HDS) observed a star on the outskirts of the Milky Way. The star's chemical composition matches theoretical expectations for the chemical footprint produced by a pair-instability supernova. This is the clearest trace of such supernovae found to date, and it strongly supports the theory that stars with masses more than 140 times larger than the mass of the Sun certainly formed in the early Universe.

(4) The Multi-Object InfraRed Camera and Spectrograph (MOIRCS) observed star-forming region Sh 2-209 on the outskirts of the Milky Way, where conditions from the early Universe are still preserved. It found that the distribution of stellar masses is not radically different from what is observed near the Solar System. This is an important step toward understanding the local environment's effect on the stars' mass distribution.

(5) Based on direct imaging by the Infrared Camera and Spectrograph (IRCS) and AO188, the star S0-6 near the supermassive black hole at the center of the Milky Way was determined to be more than 10 billion years old, with a chemical composition similar to stars found in small galaxies outside the Milky Way, such as the Small Magellanic Cloud and the Sagittarius dwarf galaxy. This is the first time a star of extragalactic origin has been found in the vicinity of the supermassive black hole.

3. Open-use

The Open Use Program is conducted semiannually by inviting proposals from the public. The application period is from February 1 to July 31 (semester A) for the year's first half, and from August 1 to January 31 (semester B) for the year's second half. Applications will be accepted at the Subaru Mitaka Office of the National Astronomical Observatory of Japan. The Subaru Program Time Allocation Committee (TAC) reviews and selects proposals based on the domestic and international referee evaluations. TAC accepted 44 proposals (91.65 nights including 10 nights of ToO proposals) {out of 95 proposals (216.15 nights)} in S23A and 56 proposals (92.6 nights including 10 nights of ToO proposals) {out of 119 proposals (237.87 nights)} in S23B. For the Intensive Proposals continued from the previous semesters, 10.5 nights (2 proposals) in S23A and 18.9 nights (3 proposals) in S23B were allocated. In addition, observations Service Program observations, short-time assignments, were also conducted. Of the proposals selected for Open Use in S23A and S23B (excluding University of Hawai`i time), 5 (4 in S23A and 1 in S23B) were foreign PI proposals. The total number of applicants, including co-researchers, was 728 foreign researchers compared to 1,916 domestic applicants, and the total number of researchers in the accepted proposals was 371 foreign

researchers compared to 1036 domestic applicants.

The total number of observers using Open Use in S23A and S23B was 284 (including 45 foreign and 119 remote observers from Mitaka Campus). The Mitaka side handled the application collection and review of observation proposals, travel procedures for domestic researchers to observe, and travel expense payment administration, while the Hawai`i side prepared the observation schedule and provided support for observers' accommodation, transportation, and observations in Hawai`i. Open Use observations during S23A and S23B, including University of Hawai`i time, averaged 48.75% of available observation time, excluding weather factors and downtime due to scheduled maintenance such as the primary mirror coating. There was about 0.64% downtime due to instrument troubles, 0.16% due to communication system troubles, 50.44% due to telescope troubles, and 0.03% due to operation troubles.

Remote observations from the Hilo Base Facility were made on 13.5 nights (14 programs) during S23A and S23B. Remote observations from NAOJ Mitaka Campus were conducted for 24 nights (18 proposals including the IRD Subaru Strategic Program) with the participation of both summit observers and remote side observers, or only Mitaka remote side observers. Telescope time exchanges with Gemini and W. M. Keck observatories are driven to make the best use of the telescope resources at the summit of Mauna Kea. With W. M. Keck Observatory, the exchange time was 5.0 nights in S23A and 5.0 nights in S23B, equivalently. Telescope time use from the Subaru Telescope side to Gemini was 3.0 nights in S23A and 3.0 nights in S23B (excluding Fast-Track proposals), and from the Gemini side to Subaru Telescope was 7.5 nights in S23A and 6.2 nights in S23B.

4. Telescope Maintenance and Performance Improvement

The following major repairs, maintenance, and changes were implemented in FY 2023.

We are accepting the Prime Focus Wide-Field Spectrograph (PFS), repairing the outer wall of the dome, and performing regular maintenance of the telescope and dome's mechanical and electrical systems, as well as repairing sudden failures. We are also working on updating the dome's air conditioning and chillers, as well as inspecting, repairing, and refurbishing the telescope to improve observation efficiency.

In addition, we have been working on the renewal of the dome air conditioning system and an upgrade of the telescope software to improve observation efficiency.

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

5. Instrumentation

The following six facility instruments were provided for the open-use observations in FY 2023: Hyper Suprime-Cam (HSC), Faint Object Camera And Spectrograph (FOCAS), High Dispersion Spectrograph (HDS), Infrared Camera and Spectrograph (IRCS), Multi-Object Infrared Camera and Spectrograph (MOIRCS), and the 188-element Adaptive Optics and Laser Guide Star system (AO188/LGS). As for the carry-in instruments, Infrared Doppler (IRD) and Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) were provided for open-use observations. In addition, the following instruments/devices have been used in combination with SCExAO: Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS), Fast Near-Infrared Polarization Differential Imaging (FastPDI), MKID Exoplanet Camera (MEC), Rigorous Exoplanetary Atmosphere Characterization with High dispersion coronagraphy (REACH), and Visible Aperture Masking Polarimetric Imager for Resolved Exoplanetary Structures (VAMPIRES). From S24A, the Near Infrared WaveFront Sensor (NIR-WFS) was opened as a carry-in device to be used with AO188.

In addition to the many carry-in instruments/devices listed above, there is an increasing number of proposals for new carry-in instruments. To handle this situation more effectively, the procedure for carrying-in instruments was updated in December 2023 and introduced to the community in Subaru Users Meeting FY2023. For the IR Nasmyth focus, it is urgently needed to establish a strategy for an AO instrumentation plan, including the existing instruments, because we cannot accept all the proposed instruments in the same time period due to weight and other limitations. In Subaru Users Meeting FY2023, we introduced the current status of NsIR and proposed instruments to the community, and gathered input, such as desired functions through the discussion with the Subaru Telescope users.

As for the upgrades of the facility instruments, a new K-band grism "VB-K" was installed in MOIRCS in September 2023 and, after daytime characterizations, was offered for open-use observations. The project to replace the Deformable Mirror (DM) of AO188 with a new ~3000 element DM is still ongoing. If the project passes the readiness review, the installation of the new DM will be done around May to June 2024. For the Nasmyth Beam Switcher (NBS), which will improve the operation and management of IR Nasmyth instruments downstream of AO188, we started the design of the common platform which will interface with the mounting-base of the NsIR platform and instruments including the NBS. In FY 2024, we will complete the design and fabrication of the common platform, and also the final mechanical assembly and optical alignment of the NBS. We are planning to start the installation work of the NBS at the end of FY 2024.

6. Computers and Networks

At the end of FY 2023, CDM (Computer and Data Management division) is one year into the STN6 contract. Deployment of two Hyper-Converge Infrastructure (HCI) clusters at the Summit and Base facilities was completed. There were migrated and are now operating in a production environment. Along with Nutanix HCI, CDM has migrated STARS to a new storage array with two virtual machines for registration and query, and has deployed a new storage array for

facilities data, home directories, web content, and administration files. Final deployment and migrations have been completed for the tape backup system and summit network environment. The Veeam Backup Server tape environment using LTO9 cartridges, with two front-end storage solutions, has allowed CDM to completely backup the HCI clusters, while Bacula, an open-source tape backup server, has allow for full backup of STARS data. The summit network needed many upgrades to numerous switches located in the dome area. Many switches had reached end-of-life, and end-of-support. As of May 2024 CDM has successfully removed STN5 network equipment, upgraded necessary switches, and consolidated two racks of equipment into one. In this network upgrade, CDM was able to deploy 10, 25, 40 and 100 Gbs uplinks to different locations. This allows for future increases of data volumes in areas NS-IR, PFS IR4, and HSC and PFS servers in the Control Building Computer Room. CDM has increased its support to more groups in Subaru Telescope, deploying new collaboration software needed for remote instrument collaboration teams.

This past year the science community has seen a major increase in remote attacks. CDM has reported an incident, leading to the mitigation events of password changes, and increasing external verification services for remote access. Through this incident, CDM has worked to monitor, update, and issue alerts for possible intrusions. CDM will continue to minimize the attack fingerprint at the Subaru Telescope.

7. Education (Under-graduate and Graduate Courses)

In FY 2023, Subaru Telescope had 17 staff members jointly affiliated to SOKENDAI. These staff members, including those jointly affiliated to other divisions, are the primary supervisors of 7 students, which comprise 1/5 of all the NAOJ affiliated SOKENDAI students. Among the 7 students, 5 are supervised by staff members primarily affiliated to Subaru Telescope. Thirteen graduate students stayed long-term in Hilo, and 9 SOKENDAI students visited the telescope as part of SOKENDAI classes. However, due to the primary mirror trouble, they could only visit the summit and base facilities and have a hands-on session on data processing.

Subaru Telescope hosted 4 students through the Akamai internship program. As part of Akamai Space Grant Consortium activities, Subaru Telescope hosted 1 student intern. As part of the SOKENDAI summer student program, staff members in Mitaka supervised 2 undergraduate students.

Turning to Subaru Telescope's contributions to the larger Japanese community, 10 and 12 graduate students defended their Ph.D. and Master's theses, respectively, using data from the Subaru Telescope. Among them, one SOKENDAI student affiliated to Subaru Telescope defended her master thesis. The HSC data reduction school was not held due to the absence of HSC helpdesk.

Subaru Telescope Okayama Branch

The Okayama Branch was established in FY 2018 primarily to provide half of the observation time of the 3.8 m New Technology Optical-Infrared Telescope (commonly known as "Seimei Telescope") at the Okayama Observatory, Graduate School of Science, Kyoto University, for national university open use. Additionally, it collaborates with universities and the local municipality in the use of the telescopes at the former Okayama Astrophysical Observatory. As of the end of FY 2023, the Okayama Branch has two research and academic staff, one project associate professor, and two administrative support staff.

1. Seimei Telescope

(1) Open Use (calendar year)

In the first half of 2023 (January-June), 65.5 nights were provided. There were 25 applications consisting of 10 Classical, 2 Classical+ToO, and 13 ToO requests, with the requested nights totaling 128.0 (55.5 for Classical, 72.5 for ToO). Of these, 23 applications were accepted (8 Classical, 2 Classical+ToO, and 13 ToO), with the allocated nights totaling 89.0 (51.5 for Classical, 37.5 for ToO). The term "Classical" refers to observations conducted on pre-assigned dates, while "ToO" refers to observations scheduled by proposers upon the occurrence of specific events. The total loss of time during this period was 0.5 nights. In the second half of 2023 (August-December), 62.5 nights were provided. There were 34 applications, comprising 17 Classical, 2 Classical+ToO, and 15 ToO requests, with the requested nights totaling 176.75 (110.0 for Classical, 66.75 for ToO). Of these, 29 applications were accepted (12 Classical, 2 Classical+ToO, and 15 ToO), with the allocated nights totaling 98.55 (55.0 for Classical, 44.55 for ToO). No loss of time was recorded during this period. Until the first half of 2023, measures were taken to prevent the spread of COVID-19 while accommodating observers' stays, enabling open use without causing infection clusters.

(2) Observing Instruments

In addition to the Kyoto-Okayama Optical Low-dispersion Spectrograph with the optical-fiber Integral Field Unit (KOOLS-IFU) and the TriColor CMOS Camera and Spectrograph (TriCCS), the optical high-dispersion spectrograph for precise radial velocity measurements (GAOES-RV) became available for open use from the second half of 2023. Activities during this period included the management and operation of environmental monitors, data acquisition and storage, maintenance of computers and networks, and facility upkeep. Furthermore, development and test observations for the TriCCS spectroscopic mode were conducted.

(3) Development of Remote and Queue Observations

Since January 2024, remote observations without on-site observers, in collaboration with the Okayama Observatory

of Kyoto University, have been made available for open use. Testing of the queue observation system is currently underway.

(4) Research Results

The following example of significant research results from observations with the Seimei Telescope was published in a paper during FY 2023.

(a) A 12-day simultaneous observation campaign was conducted for the young solar-type star EK Dra using the TESS and NICER satellites, and Seimei Telescope. Previously, EK Dra was observed to exhibit superflares in optical wavelengths, marking the first observation of such events for solar-type stars. These findings were reported as a result of observations with the Seimei Telescope in 2021. In this simultaneous observation, three instances of superflare phenomena were captured, with two of them accompanied by prominence eruptions observed in the Hα emission line. Discoveries like these provide crucial information for understanding the effects of solar activity on planets like Earth during the early stages of the Solar System.

(5) Meetings

(a) Seimei Users Meeting

The fifth Users Meeting was held on September 12–13, 2023, at the Seminar House of the Faculty of Science, Kyoto University, in an online hybrid style. The organizing committee consisted of: Keisuke Isogai (Kyoto University) as the Chair, Akito Tajitsu (NAOJ), Masashi Omiya (ABC), Yuu Niino (The University of Tokyo), Miho Kawabata (Hyogo Prefectural University), as well as Mikio Kurita, Kenta Taguchi, and Haruyuki Okinaka (Kyoto University). The total number of participants was approximately 100.

(b) Seimei Subcommittee

In FY 2023, the Subcommittee met nine times. Among these, five meetings were dedicated to the time allocation for open use for the second half of 2023 and the first half of 2024. In October 2023, a committee member re-election was conducted due to the expiration of terms. The new committee members were chaired by Fumihide Iwamuro (Kyoto University), with members including Miho Konishi (Oita University), Yoichi Ito (Hyogo Prefectural University), Megumi Shidatsu (Ehime University), Masaomi Tanaka (Tohoku University), and Yoshiki Toba (NAOJ). In March 2024, a review was conducted for the release of the spectroscopic mode of TriCCS for open use in the second half of 2024, and it was decided to proceed.

(c) Kyoto University 3.8-m Telescope Council

On September 16, 2023, the Graduate School of Science at Kyoto University and NAOJ held the sixth Kyoto University 3.8 m Telescope Council meeting online. The purpose of the meeting was to discuss the operation of the Seimei Telescope. It was attended by the Dean of the Graduate School of Science at Kyoto University, the Director General of NAOJ, and numerous others. The meeting included discussions on the operational status and presentation of research outcomes.

2. Telescopes of the former Okayama Astrophysical Observatory

(1) 188-cm Reflecting Telescope

(a) The 188 cm telescope remained inoperative following the dome's upper door falling accident on September 29, 2022. Adjustments for restoration progressed, and by the end of FY 2023, the details of the restoration project were finalized. Restoration work commenced with the completion target set for the end of FY 2024.

(b) Okayama Branch has been providing regular updates and engaging in discussions with the members of the Telescope Operations Council, including Asakuchi City and Tokyo Institute of Technology, regarding the restoration efforts. This ensures transparency and allows for input and discussion on the restoration process.

(2) Other Telescopes

Okayama Branch also cooperated in the operation of several telescopes, including the 91-cm reflecting telescope, the 50-cm reflecting telescope known as MITSuME, and the Thirty Milli-Meter Telescope (TMMT) in the 4-m dome.

(4) Research Results

Despite the 188 cm telescope currently being non-operational, significant research results, such as the following example, have been published as papers using data that had already been acquired.

(a) The radial velocity data of 32 planetary systems around evolved giant stars, acquired over the past 20 years using the High Dispersion Echelle Spectrograph (HIDES) on the 188 cm telescope, have been reanalyzed. This reanalysis resulted in the discovery of a new planet with an orbital period of over 2000 days in the known planetary system 75 Ceti. Additionally, long-term trends in the radial velocities of the central stars were observed in five other planetary systems, revealing the presence of companion stars. The sample showed a trend where stars with higher metallicity tend to have more multi-planet systems and more massive planetary systems, supporting the core accretion scenario of planet formation.

3. Public Outreach

Since the Okayama Branch lacks staff assigned to public relations and dissemination activities, only essential tasks are performed.

(1) The Asakuchi City Okayama Astronomical Museum, in collaboration with Kyoto University and NAOJ, organized public stargazing events using the Seimei Telescope through general applications. In FY 2023, these events were held four times, with approximately 40 participants each time.

(2) On October 28, 2023, the second "Asakuchi Observatory

Festival" was held with the cooperation of the Asakuchi City Okayama Astronomical Museum and the Kyoto University Okayama Observatory.

(3) The 20th Okayama Astronomical Observation Environment Maintenance Liaison Meeting took place in Okayama City on October 31, 2023, under the leadership of Okayama Prefecture. Representatives from neighboring municipalities, chambers of commerce, and related organizations attended, aiming to foster cooperation in maintaining the starry sky environment for astronomical observation purposes.

05. 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, a general-purpose graphic processing unit (GPGPU) cluster, and a general-purpose PC cluster for small-scale calculations; carrying out research and development of 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. In FY 2023, replacement work for the next supercomputer system proceeded. Efforts in visualizing astronomical data also continue.

2. Open Use of Computers

(1) General status

This year marked the sixth year of the 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. Note that the lease period was extended from six years to six and a half years), the center has built the following equipment to aid the open-use computer operations: a series of GPU nodes; two sets of 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, GPU, and the 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 165 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.

Toward the end of the XC50 lease agreement, a new supercomputer was procured this year. As a result, HPE Cray XD2000 will be installed and put into operation in December 2024. Preparatory work for this has already begun.

(2) Operation stats for each of the facilities

Cray XC50

• Operating hours
  Annual operating hours: 8596.8
  Annual core operation ratio by users' PBS jobs: 95.40 %
• Number of users
  Category S: 0 adopted in the first term, 0 in the second term; total 0
  Category A: 14 adopted at the beginning of the year, 1 in the second term; total 15
  Category B+: 16 adopted at the beginning of the year, 0 in the second term; total 16
  Category B: 123 adopted at the beginning of the year, 14 in the second term; total 137
  Category MD: 23 adopted at the beginning of the year, 7 in the second term; total 30
  Category Trial: 36 (year total)

GPU system

• Number of users
  29 (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: 516702
  Annual core operation ratio by users' PBS jobs: 78 % (a ballpark figure)
• Number of users
  68 (at the end of the fiscal year)

Small Parallel Computers

• Operating hours
  Annual operating hours: 8443 (a ballpark figure)
  Total number of submitted PBS jobs: 3153
  Annual node operation ratio of each queue by users' PBS jobs (a ballpark figure) :
    Small queue node: 13 %
    Single queue node: 66 %
    Single-debug queue node: 0.01 %

(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 2–30, 2023

14 attendees (+ 1 lecturers from outside NAOJ + 1 lecturer from inside NAOJ)

- Cray XC50 workshop for novice users (zoom)
  Introduction to the basic usage of XC50 for novice users
  August 22, 2023
  11 attendees
- Cray XC50 workshop for intermediate users (zoom)
  Introduction to debugging, performance analysis, and optimization of XC50 for intermediate users
  August 23, 2023
  10 attendees
- CfCA Users' Meeting (Onsite + zoom + Slack)
  Presentation of research results obtained using the open-use facilities in this department, and discussion of the operation of the equipment
  January 29–30, 2024
  January 29: 43 attendees (Onsite) + 40 attendees(Online),
  January 30: 45 attendees (Onsite) + 40 attendees (Online)
- Early spring school for N-body numerical simulations (Onsite + zoom)
  Lectures on N-body simulations, and programming practice using GPU and GRAPE-Library
  February 13–15, 2024
  12 attendees (for hands-on training and lectures), 4 attendees (for lectures only)
- GPU Workshop (Onsite)
  Porting hydrodynamics CPU code to GPU and CUDA optimization basics
  July 25, 2023
  9 attendees

3. PR Activity

In FY 2023, the following press releases were issued from the center:

- "Out of this World Control on Ice Age Cycles"
  May 15, 2023, Yasuto Watanabe, Ayako Abe-Ouchi (The University of Tokyo), Takashi Ito (NAOJ/CfCA) et al.
- "Triple Baby Stars Reach Out Three Arms to Feed with Materials"
  August 4, 2023, Jeong-Eun Lee (Seoul National University), Tomoaki Matsumoto (Hosei University)
- "New Proof for Black Hole Spin"
  September 28, 2023, Yuzhu Cui (Zhejiang Lab), Tomohisa Kawashima (The University of Tokyo) et al.
- "Simulations of Europa Craters Suggest Thick Ice Crust"
  March 22, 2024, Shigeru Wakita (Purdue University) et al.

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

- "Thermal Convection Energizes Solar Flares – Revealed by Supercomputers Fugaku and ATERUI II"
  June 23, 2023, Toriumi Shin (JAXA/ISAS) et al.
- "Deep Learning Speeds Up Galactic Calculations – A new way to simulate supernovae may help shed light on our cosmic origins"
  November 2, 2023, Keiya Hirashima, Michiko S. Fujii (The University of Tokyo) et al.

In July 2023, our project's activities were featured as a center for computational astronomy in Japan in the TV program "Cosmic Front" (produced by NHK) broadcasted on the NHK BS Premium.

At the Iwate Ginga Festa 2023 held on August 26, 2023 (NAOJ Mizusawa Campus Open House), the supercomputer room was open to the public with about 100 visitors.

In addition, at the Mitaka Open House Day 2023 held onsite on October 28, 2023, the CfCA computer room was open for tours and about 100 visitors received tours.

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

4. 4D2U Project

In FY 2023, the 4D2U project continued to develop and provide movie content and software.

In December 2023, we published HD and VR versions of "Formation and Evolution of Dark Matter Haloes (III. Formation of Cosmic Web and Void Structures)" and distributed the Dome Master data. In March 2024, a VR version of "Asteroid Collisions and Shape Evolution" was released and the Dome Master data was distributed.

4D2U content was provided both domestically and internationally for TV programs, planetarium programs, lecture presentations, books, and so on. In June 2023, NHK Educational TV broadcasted "The Backyard" (directed by Brain Communications), which featured 4D2U videos and the visualization of simulation data in 4D2U.

For the 2023 Mitaka Open House Day, CfCA staff members introduced their research on simulated astronomy at the 4D2U dome theater together with the showing of 4D2U videos. Approximately 160 people attended the four screenings.

In August 2023, with the cooperation of PRC, the 4D2U project website was renewed and redesigned for easier viewing on tablets and smartphones. A Twitter/X 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 "Programs for Promoting Research on the Supercomputer Fugaku." The newest one is "Structure and Evolution of the Universe Unraveled by Fusion of Simulation and AI." CfCA joins this project.

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, respectively. These four projects are still in the process of tuning the code in preparation for the large scale run at Fugaku. We obtained funds for these projects. The budget was used to buy GPUs and increase the storage capacity in order to analyze and 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. The technical investigation is also in full swing considering the architecture of the next generation flagship after Fugaku.

6. Other Activities

- Internship hosting
  Maxwell Coy (University of California, Berkley) 2023.05.30–2023.08.14 (Eiichiro Kokubo)
- Committee members at international organizations
  IAU Commission F2 Organizing Committee (Eiichiro Kokubo)

7. Staff Transfers

(1) Staff members hired in this FY
(Project Researcher) Misugi, Yoshiaki

(2) Staff members who departed in this FY
N/A

06. 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. The ALMA2 project has begun from FY 2023. By continuing scientific observations and upgrading its observational capabilities, ALMA will continue to lead world astronomy in the coming decade. 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 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 provide a stably operational telescope, maximize the availability of observing time, and make the operations user-friendly to facilitate science for broader communities; to collect and deliver high-quality data sets to the scientific community by operating, maintaining, and further developing a state-of-the-art observatory; to produce outcomes to meet the scientific requirements from broader fields of research and obtain fair evaluation from the scientific community; and to dramatically improve the capabilities of the ALMA telescope during ALMA2 to provide the international academic community with unparalleled radio observation capabilities to explore the birthplace of planets and the evolution of matter in the universe, including elemental components for life. 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. 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

During 2018–2022, the ALMA Project established the framework to kick off the implementation of the Wideband Sensitivity Upgrade (WSU). East Asia is responsible for the upgrade of Band 8 receivers to expand the frequency ranges that can be simultaneously covered in observations. The proposal of the first phase of this Band 8v2 project was approved by the ALMA Board in 2023 and development is underway in ATC. Design studies were also advanced for the Data Transmission System, which carries the signals from receivers/digitizers to the correlator. Extensive discussions have also begun across the ALMA Partnership on how to implement the Wideband Sensitivity Upgrade (WSU) to be implemented during ALMA2, with many ALMA staff contributing from science, development, engineering, computing and science operations perspectives.

The instruments developed in East Asia in recent years include the ACA spectrometer led by the Republic of Korea and the Band 1 receivers led by Taiwan, both in collaboration with NAOJ. They have started to be used for scientific observations since FY 2023.

The highest resolution of ALMA was reported in 2023. An international team led by Yoshiharu Asaki (NAOJ) has successfully obtained a resolution of 5 milli-arcsec (=1/720000 degrees) in the technical test, using one of the most challenging observation functions in ALMA, through a combination of the highest frequency receivers in Band 10 and an array configuration with separations of up to 16 km between the antennas.

2. ALMA Open-Use and Scientific Observations

The 10th round of ALMA open-use observations (Cycle 9) finished on September 30, 2023. The subsequent transition to Cycle 10 on October 1 was completed on schedule. For Cycle 10, a total of 1,679 proposals were submitted requesting 29,499 hours of time on the 12-m Array, which is the most ever requested in a single cycle. The main capabilities of Cycle 10 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); nine frequency bands (Bands 3, 4, 5, 6, 7, 8, 9, 10, and Band 1 from March 2024) and maximum baselines of 8.5 km. Several new observation capabilities are introduced; Band 1 observations with the 12-m Array from March 2024, spectral scans including Total Power observations, 4x4-bit spectral mode, solar observations in full polarization in Band 3 using the 12-m Array, and expanded VLBI and Phased Array capabilities.

From Cycle 10, a Joint Proposals framework has been newly

available with three other facilities: the Space Telescope Science Institute's James Webb Space Telescope (JWST), the National Radio Astronomy Observatory's Karl G. Jansky Very Large Array (VLA), and the European Southern Observatory's Very Large Telescope (VLT).

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.

An international team led by Kaho Morii, Patricio Sanhueza, and Fumitaka Nakamura at NAOJ revealed an unprecedented number of stellar seeds concealed within environments where high-mass stars (stars with masses eight times more than the Sun) are expected to form. This statistically significant sample allows the team to shed light on a difficult-to-explore area of astrophysics, offering valuable insights into the initial phases of high-mass star and cluster formation. By scrutinizing the most extensive sample to date, the research provides fascinating information regarding the mass, density, and distribution of these stellar seeds within clouds, thereby advancing our comprehension of high-mass star formation.

An international team led by Nagayoshi Ohashi at Academia Sinica Institute of Astronomy and Astrophysics (ASIAA, Taiwan) observed disks around 19 protostars, systems that are only 10,000 to 100,000 years old, located within about 650 light-years from the Earth with a very high resolution to search for the earliest signs of planet formation. This survey, called "Early Planet Formation in Embedded Disks (eDisk)", is the first systematic study to investigate the detailed structure of disks around a large sample of protostars with such a high angular resolution. The results suggest that disks around protostars are not fully ready for planet formation, and the actual formation of the planetary system progresses rapidly in the 100,000 years to 1,000,000 years after star formation begins.

A team of astronomers led by Yoichi Tamura of Nagoya University accomplished a remarkable feat by capturing a young galaxy from a period just 600 million years after the Big Bang with unprecedented high resolution. The radio images from ALMA, depicting dust and oxygen, revealed fascinating structures where dark nebulae and emission nebulae intertwine, forming a structure resembling a giant cavity called a superbubble, created by the birth of active stars followed by the shockwaves from supernova explosions. This exceptionally detailed portrayal of nebulae associated with the birth and death of stars in the earliest cosmos offers a profound insight into the formation of galaxies and promises to unlock crucial clues.

A research team led by Kaiki Taro Inoue at Kindai University (Osaka, Japan) discovered fluctuations in dark matter distribution in the Universe on scales smaller than massive galaxies using ALMA. This is the first time that the spatial fluctuations of dark matter in the far Universe were detected on a scale of 30,000 light-years. This result shows that cold dark matter is favored even on scales smaller than massive galaxies and is an important step toward understanding the true nature of dark matter.

An international research team led by Toshiki Saito (NAOJ) and Taku Nakajima (Nagoya University) conducted an "imaging line survey" of the central region of NGC 1068 (M77), an active galactic nucleus in the direction of the constellation Cetus. Employing machine learning to analyze the chemical properties of the active galactic nucleus and decipher the physical states, they observed a significant outflow of molecular gas, believed to be the result of a bipolar jet ejected from a supermassive black hole at the core of NGC 1068. This outflow originates from a shock wave region where the jet interacts with the galactic disk, causing a dramatic increase in surrounding temperatures. The intense jet activity near the galactic center is not only altering the composition of the molecular gas, which is the fundamental building block of stars, but it may also be impeding the formation of new stars.

An international research team led by Takuya Hashimoto (University of Tsukuba, Japan) and Javier Álvarez-Márquez (El Centro de Astrobiología (CAB, CSIC-INTA), Spain) used the James Webb Space Telescope and ALMA to observe the most distant galaxy protocluster to date, 13.14 billion light-years away. The team successfully captured the "core region" of the galaxy protocluster, which corresponds to a metropolitan area with a particularly high number density of galaxies. The team revealed that many galaxies are concentrated in a small area and that the growth of galaxies is accelerated. Furthermore, the team used simulations to predict the future of the metropolitan area and found that the region will merge into one larger galaxy within tens of millions of years. These results are expected to provide important clues regarding the birth and growth of galaxies.

An international research team led by Takuma Izumi at NAOJ observed the nearby active galactic nucleus of the Circinus Galaxy, with an extremely high resolution (approximately 1 light-year) by using ALMA. This marks the world's first quantitative measurement of gas flows and their structures in the immediate vicinity, down to the scale of a few light-years, of a supermassive black hole in all phase gases including plasma, atomic, and molecular. The team clearly captured the accretion flow heading towards the supermassive black hole and revealed that this accretion flow is generated by a physical mechanism known as "gravitational instability." The team also found that a significant portion of this accretion flow is not utilized for the growth of the black hole. Instead, most of the gas is expelled from the vicinity of the black hole as atomic or molecular outflows and returns to the gas disk to again participate in an accretion flow towards the black hole: this gas recycling process is akin to a water fountain. These findings represent a crucial advancement towards a comprehensive understanding of the growth mechanisms of supermassive black holes.

3. Education and Public Outreach Activities

The NAOJ ALMA Project continues to collaborate with the Joint ALMA Observatory (JAO) to maintain a Japanese version of "ALMA Kids," a website for children, with the aim of providing opportunities for more people to learn about the mechanisms of the ALMA telescope and its scientific results in a fun way. ALMA Kids provides contents for the younger audiences, including results from the latest ALMA observations.

The Project continues to maintain science news posters

aimed for the younger generation visiting science centers and planetariums, as well as short anime ("manga") explaining the basics of radio astronomy and interferometry. In FY 2023, the manga about the data transmission system as a part of the WSU has been added to the collection. All posters and manga are available on the NAOJ ALMA website.

In FY 2023, the achievements with ALMA continued to be covered by the media, such as newspapers, magazines and TV. They included the research on planet formation led by a graduate student, the results from the combination of ALMA and the James Webb Telescope on a primordial galaxy cluster, and the achievement of 5-mas angular resolution in Band 10. The NAOJ ALMA website posted 22 news articles and 13 press releases. Mailing-list-based newsletters have been issued roughly on a monthly basis with approximately 2,000 subscribers. Day-to-day information is posted in a timely manner on X (formally Twitter) (@ALMA_Japan) with nearly 67,000 followers as of the end of FY 2023. Impressive images are often posted on Instagram with 10,000 followers.

Three lectures were given for the general public in FY 2023. In May 2023, the NAOJ ALMA Project exhibited a joint booth with the NAOJ TMT Project at the Japan Geoscience Union Meeting. In August 2023, a booth for ALMA was exhibited at the 2023 Asia-Pacific Regional IAU Meeting (APRIM). The open house of Nobeyama Radio Observatory was held in August, and posters and video contents of ALMA were also presented. NAOJ held the Mitaka Open House Day on site in October, where the ALMA Project displayed posters, models of an antenna and the Atacama Desert, gave short-lectures, and so on.

The year of 2023 marked the 10th anniversary of the ALMA telescope, which began full-scale operations in March 2013. In March 2023, a ceremony was held in Chile to commemorate the 10th anniversary, attended by officials from all ALMA regions. The commemorative ceremony for related parties in Japan was held in Tokyo on May 17.

From mid-March 2015, ALMA began accepting public visitors to the 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 2023, public visits remain suspended.

4. International Collaboration (Committees, etc.)

For the international ALMA project, meetings are held frequently by various committees. In FY 2023, the impact of the COVID-19 pandemic was lessened and many in-person meetings resumed, including the ALMA Board meeting in Santiago (Chile) in November. 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.

5. Workshops

- July 12–14, 2023: ALMA Data reduction tutorial (basic level), in collaboration with the Astronomy Data Center, NAOJ Mitaka campus
- November 13–17, 2023: Pipeline Working Group Meeting, NAOJ Mitaka Campus and online
- December 4–8, 2023: ALMA at 10 years: Past, Present, and Future, Puerto Varas, Chile and online
- December 20, 2023: ALMA Grant Fellow Symposium 2023, NAOJ Mitaka Campus and online
- December 21–22, 2023: ALMA/45m/ASTE Users Meeting 2023, NAOJ Mitaka Campus and online
- January 23–24, 2024: GPU Correlator Study Group Workshop, NAOJ Mitaka Campus and online
- March 21, 2024: ALMA Data Reduction Workshop - CASA Simulation Tutorial -, held with the Astronomy Data Center, NAOJ Mitaka Campus

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

- Tetsuhiro Minamidani: funded by the research support program of the National Institutes of Natural Sciences (NINS) (OPEN MIX LAB (OML) Program, PI: Hidetoshi Sano (Gifu University))

7. Changes in Project Researchers

(1) Hired
- Kshitiz Kumar Mallick: Project Researcher
- Liu Junhao: Project Researcher
- Yuhito Shibaike: Project Researcher
- Soh Ikarashi: Project Researcher (secondment to Nihon University)
- Lee Kianhong: Project Researcher (secondment to Tohoku University)
- Rei Enokiya: Project Researcher (secondment to Gifu University)

(2) Departed or transferred
- James Miley: Project Researcher
- Yuma Sugahara: Project Researcher
- Yoshinobu Fudamoto: Project Researcher
- Tomonari Michiyama: Project Researcher
- Samuel Barnier: Project Researcher
- Rei Enokiya: Project Researcher

8. Main Visitors

- August 30, 2023: Kazuhisa Shibuya, Ambassador of Japan to Chile, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
- October 19, 2023: Hak-Jae Kim, Ambassador of the Republic of Korea to Chile, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
- January 3, 2024: Ricardo Rojas, Ambassador of Chile to Japan, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.

• March 5, 2024: Takako Ito, Ambassador of Japan to Chile, visited NAOJ Mitaka Campus.

9. Progress of the ASTE Telescope

The ASTE Telescope has returned to Science Operations after 3+ years (2020–2023) suspension due to the COVID-19 pandemic and malfunctions of sub-reflector driving system. In FY 2023, the ASTE telescope site was reopened in May. Although a sub-reflector driving system failure occurred, it was recovered by replacing a motor. In June, commissioning and science verification using astronomical objects were conducted for the wide IF bandwidth Band 8 receiver, the new spectrometer (XFFTS), and the frequency converter (IFDC), which were installed on the ASTE Telescope in 2021 under two Grand-in-Aids for Scientific Research (PIs: Oka (Keio University) and Tosaki (Joetsu University of Education)). Science Observations with these new instruments were also conducted between July and September. In October, a new observational instrument, DESHIMA developed by TU Delft, was installed on the ASTE Telescope, and started its commissioning, with partial support by a European Research Council Consolidator Grant (PI: Akira Endo (TU Delft)). However, this activity was suspended in the middle of November due to a different malfunction of the sub-reflector driving system. The cause of this failure was identified, and its recovery work is scheduled early in the next fiscal year (FY 2024).

An international external evaluation was conducted in March. Consideration and discussion regarding future plans of the ASTE Telescope have started through various opportunities, such as the NAOJ Future Planning Symposium 2023, ALMA/45m/ASTE Users Meeting 2023, and UDENCON (Japan Radio Astronomy Forum) Symposium 2024.

In FY 2023, three peer-reviewed papers were published, which are all written by domestic researchers. Two papers are scientific research papers, and one is a technical paper. The decrease in the number of papers published was unavoidable due to the suspension of scientific observations due to the COVID-19 pandemic and sub-reflector failures during 2020–2022.

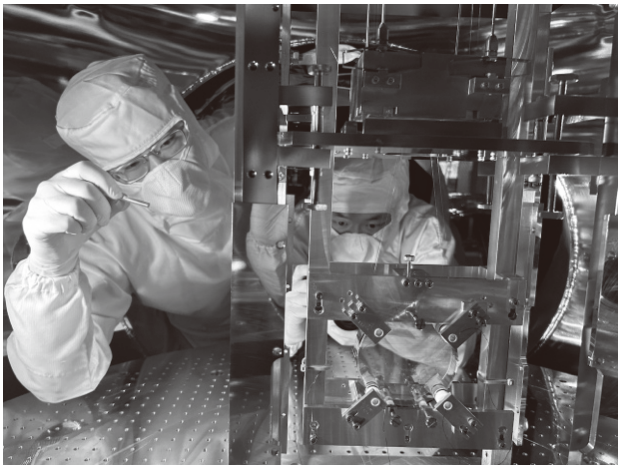
07. Gravitational Wave Science Project (GWSP)

The fourth international joint gravitational wave observation (O4) started on May 24, 2023. KAGRA, a large-scale cryogenic gravitational wave telescope promoted by NAOJ in collaboration with the Institute for Cosmic Ray Research (ICRR) at the University of Tokyo and the High Energy Accelerator Research Organization (KEK), began observation at the same time as O4, with an averaged sensitivity of 1.3 Mpc in terms of the binary neutron star merger distance. After four weeks of observation, KAGRA withdrew from the joint observation and began work on improving its sensitivity in order to achieve a sensitivity of about 10 Mpc in the latter half of O4 (O4b). However, it suffered significant damage from the Noto Peninsula earthquake that occurred on January 1, 2024, and is currently working hard to recover.

1. Gravitational Wave Telescope, KAGRA

Based on the Memorandum of Understanding with ICRR and KEK on the Promotion of Gravitational Wave Astronomy using KAGRA, NAOJ plays an important role in the operation of KAGRA. In particular, NAOJ is in charge of the vibration isolation system, auxiliary optics system, mirror evaluation, and main interferometer, and also plays a central role in signal calibration and noise evaluation. In the management of KAGRA, NAOJ has sent members to the Executive Office, System Engineering Office, KAGRA Scientific Congress, etc.

(1) **Main interferometer and commissioning**: As scheduled, we participated in O4a from May to June 2023. The sensitivity was 1.3 Mpc on average in the detectable distance of a binary neutron star merger, and the stability was in the 80 % duty cycle range, a significant improvement from the previous O3GK (approximately 0.6 Mpc and 50 %, respectively). Observations were suspended from July to proceed with commissioning, including the renewal of angle control. After the Noto Peninsula earthquake, we are focusing on not only restoring the interferometer but also on earthquake countermeasures, with the goal of rejoining O4b.



(2) **Vibration Isolation System (VIS)**: We developed and introduced the damping mechanism of the Output Mode Cleaner suspension. We conducted the control test for an inverted pendulum to be used in O4b using an accelerometer with a folding pendulum. Some of the vibration isolation system was damaged by the Noto Peninsula earthquake and is currently undergoing restoration work. We have also started development of a two-stage low-frequency vibration isolation system for the upgrade of KAGRA and the third generation gravitational wave telescope, utilizing the vibration isolation system of TAMA300.

(3) **Auxiliary Optics System (AOS)**: In order to restore the damaged VIS, we focused on temporary relocation and reinstallation/realignment of AOS. In addition, we have been studying a full-scale new system for O4b or O5, incorporating knowledge from overseas, including LIGO.

(4) **Mirror Evaluation**: In order to replace the two KAGRA Input Test Masses (ITMs, mirrors) at O5 with higher performance ones, we are remanufacturing the ITMs. Two sapphire crystals were selected from multiple sapphire crystals through quality evaluation at NAOJ, and after carrying out shaping and pre-polishing, we have moved on to the final polishing process. We are also developing a high-speed birefringence measurement device and conducting spectroscopic analysis of sapphire.

(5) **Signal Calibration**: We performed regular calibration of two Photon Calibration Systems (Pcal), electronic circuit performance measurements, and interferometer transfer function measurements. During the O4a period, we operated two Pcals and performed online reconstruction of the gravitational wave signal h(t). After O4a, we focused on estimating the errors of the Pcals and generating h(t) offline. Both Pcals were damaged by the Noto Peninsula earthquake, and one has been repaired.

(6) **Noise Evaluation**: As part of noise hunting for O4a, impact tests and acoustic injection tests were conducted across the entire KAGRA area to identify and classify weak points. In some areas, noise was successfully reduced before O4. In addition, the O4a data was used to evaluate the impact of natural phenomena such as earthquakes and weather, and man-made phenomena such as construction work, and a noise removal method was developed using machine learning. After O4a, a detailed investigation of vibration transmission inside and outside the vacuum chamber was conducted to further improve sensitivity.

(7) **Others**: In collaboration with KEK, we have begun evaluating the thermal noise of the mirror suspension system. We have constructed a setup to measure the mechanical Q value of the sapphire fiber at KEK and the dielectric coating at the ATC laboratory in Mitaka, and are conducting research into reducing the thermal noise of KAGRA.

2. R&D in TAMA300 etc.

At Mitaka Campus' first-generation interferometric gravitational wave antenna TAMA300 and ATC laboratory, we are continuing to develop cutting-edge gravitational wave telescope technology with an eye toward upgrading KAGRA and the future third-generation telescopes. In addition, based on the research collaboration between NAOJ and the University of Electro-Communications, we have also cooperated in the development of measurement technology in the biology field.

(1) **Frequency Dependent Squeezing (FDS)**: We are developing a quantum optics technology called FDS, which improves the sensitivity of gravitational wave telescopes over a wide bandwidth. For the prototype filter cavity at TAMA, we have begun preparations for high-speed quantum state tomography using machine learning. We are also developing OPOs to introduce FDS to KAGRA, and testing low-loss Faraday isolators.

(2) **R&D for GW Detection Technologies**: In order to greatly improve the sensitivity of gravitational wave telescopes in the future, we are currently researching control methods for speedmeter-type interferometers. This year, we conducted a tabletop proof-of-principle experiment and confirmed that the interferometer response was as expected. We are also discussing future uses of TAMA300, and are considering the possibility of constructing a high-frequency-specific interferometer using Long-SRC and EPR entanglement squeezing.

3. Education

Three students from the University of Tokyo's Department of Astronomy, one student from the Tokyo Institute of Technology (until September), one student from the University of Electro-Communications (from November), and one research student from overseas were enrolled at GWSP. In addition, one graduate student each from Maastricht University in the Netherlands and Claude Bernard Lyon 1 University in France was accepted as an overseas intern, and research guidance was provided. In terms of graduate and undergraduate education, lectures at the University of Tokyo Graduate School and Hosei University were provided. In addition, we are actively involved in social education activities such as “Fureai (Friendly) Astronomy” and visiting lectures at high schools.

4. Public Relations and Outreach Activities

Following the transition of COVID-19 to Category 5, a tour of the TAMA300 experimental facility was held at the Mitaka Campus Open Day 2023, and was very well received. Four Kamioka staff members and some supporters from nearby universities also participated. A new publication list was also created on our group web page.

5. International Cooperation and Major Visitors

As COVID-19 has been reclassified to Category 5, the number of visitors from overseas has increased to 26 people. Collaborative research has progressed with CNRS/APC (France), iLM (France), National Tsing Hua University (Taiwan), Myongji University (Korea), KASI (Korea), and other institutions that have traditionally been active in international research exchange. We are also proactively accepting interns from overseas.

6. Literature Reports, Presentations, and Workshops

The number of peer-reviewed papers published in international academic journals in which project members are authors was 19. There were 21 non-peer-reviewed papers written in English and 1 in Japanese. There were 27 reports of presentation at international conferences and 39 reports at Japanese conferences. No other English or Japanese publications, etc. have been reported.

7. External Funding Other than Grants-in-Aid for Scientific Research

None

8. Personnel Changes, etc.

Rishabh Bajpai (Research Support Staff (Kakenhi) → JSPS fellow)

Mariko Doi (Retirement from Administrative Expert in Mitaka office)

08. Thirty Meter Telescope Project

The Thirty Meter Telescope (TMT) Project is a project to build an extremely large 30-meter telescope under international collaboration (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 fabrication of the telescope primary mirror, the design and fabrication 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 new Conservation District Use Permit (CDUP) for TMT construction on Maunakea in 2017, on-site construction was planned in 2019. However, protests and road blockades 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 programs, and other community engagement activities together with relevant organizations, considerably improving the situation surrounding the project. With an aim to address the longstanding issue of reducing the astronomy footprint on Maunakea, the decommissioning work of two aging telescopes began in 2023. In the State of Hawai'i, a new authority, called the Mauna Kea Stewardship and Oversight Authority (MKSOA), was established in 2022 to take over the Maunakea management from the University of Hawai'i, and officially started a transition period in July 2023. Its preparatory work is progressing steadily, including appointment of the Executive Director in February 2024. With regards to potential participation by the U.S. National Science Foundation (NSF), in FY 2022, an external panel conducted a Preliminary Design Review (PDR), and highly evaluated the project. In FY 2023, NSF held two reviews, both of which produced a favorable result. NSF is currently progressing to advance to the final design phase. Since 2022, it has been also engaging in the environmental review process to evaluate environmental effects of the TMT project on the construction site, and has been assessing impacts on historic properties by consultation with the local communities under Section 106 of the National Historic Preservation Act. Seeing major progress in the situation in Hawai'i and NSF's procedures for its possible investment 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 construction restarts, while minimizing their expenditures.

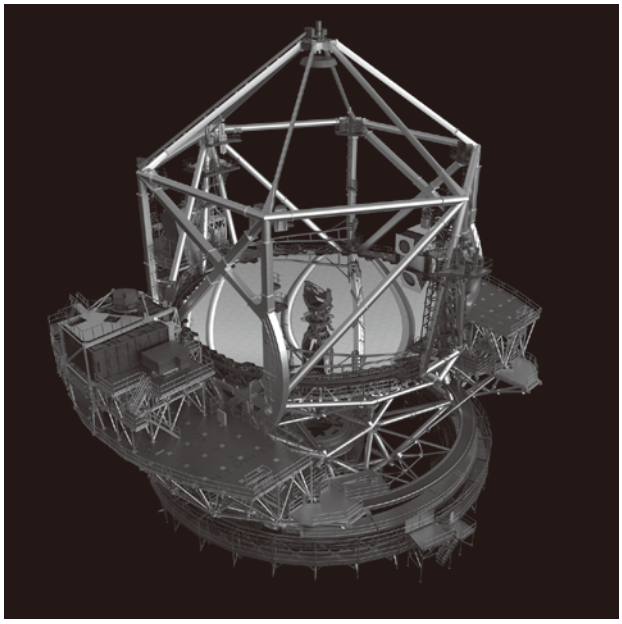


Figure 1: Rendering of TMT Telescope Structure Image. (Credit: TIO)

1. Progress in the Project and Status of the Site

NINS, as the representative for Japan, and the other participating countries and institutes, as well as TIO which was established in 2014, are constructing TMT. In addition, the U.S. Association of Universities for Research in Astronomy (AURA) is participating as an Associate Member, while the NSF is preparing for possible participation.

TIO, operated according to deliberations and decisions made by the TIO Board of Governors, is overseeing the construction work performed at the institutes, as well as developing the on-site infrastructure. In FY 2023, the Board convened eight meetings, including extraordinary meetings, to deliberate on the progress in NSF's process and issues surrounding the restart of on-site construction. Those meetings saw Japan represented through attendance by Director General Tsuneta, Vice-Director General Yoshida, and Director of the NAOJ TMT Project 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, in the same manner as last fiscal year. One of them is the Business Plan Working Group chaired by Director General Tsuneta. This working group had three meetings in FY 2023.

The project is enforced as the part of the Program for Promoting Large-scale Academic Frontiers Projects by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). At the end of the plan period that was originally scheduled as of 2013 when NAOJ started its participation, the Working Group on Large Scientific Research Projects, the Research Environment Infrastructure Subcommittee, the Science Committee of the MEXT's Council for Science and Technology, conducted an end-term evaluation in FY 2023. The working group released a report in September 2023 that, recognizing that the project has been suspended

due to unexpected external factors, favorably evaluated the project in terms of the evaluation criteria for the achievement, implementation structure, academic significance and ripple effects, and societal significance and ripple effects. The same working group's fundamental concepts for promoting large scientific research projects - Roadmap 2023, released in December 2023, selected the Promotion of the 30-Meter Optical Infrared Telescope (TMT) Project. In addition, the Science Council of Japan listed the 30-Meter Optical Infrared Telescope (TMT) Project's Revolution of Astronomy and Astrophysics and Search for Life on Exoplanets as No. 161 in the Grand Vision No. 18 for the Revelation of Birth and Co-evolution of Celestial Objects and Life.

In the U.S., in 2021, a decadal survey by the National Academies of Sciences, Engineering, and Medicine, which identifies priority projects every 10 years, recommended as a top priority of ground-based astronomy the US Extremely Large Program (the US ELT Program) which will allow all-sky observing access to TMT and the Giant Magellan Telescope (GMT, a telescope with an aperture of 24 m currently under construction in Chile). In response, in FY 2022, NSF conducted the PDR of the US ELT Program jointly proposed by TIO, the National Optical-Infrared Astronomy Research Laboratory (the NSF's NOIRLab), and the GMTO Corporation. The review panel produced a very positive review of the TMT project, including Japan's responsibilities for the telescope structure and other technical aspects and TIO's outreach activities in Hawai'i, and stated that the project is judged to be ready to proceed into the NSF Final Design Phase. In response to this outcome, the NSF's Mathematical and Physical Sciences (MPS) convened a panel of experts called a Blue Ribbon Panel which then conducted a review in July 2023. Subsequently, in October 2023, the Facilities Readiness Panel was called to assess the readiness of major facilities projects. The project was well received by both panels. In September 2023, NSF provided a fund for design and development of TMT. NSF's Major Research Equipment and Facilities Construction (MREFC) funding is essential to complete TMT. In the U.S., a budget bill is deliberated and passed by Congress, and is then signed into law by the President. NSF will release a Record of Decision that will state NSF's decision after conducting a final design review, the environmental review process, and the community consultation process under National Historic Preservation Act (NHPA) Section 106 explained below.

In Hawai'i where TMT is slated to be built, with the State of Hawai'i's approval of a new Conservation District Use Permit (CDUP) for TMT construction on Maunakea in September 2017, on-site construction was planned in July 2019. However, protests and road blockades prevented the start of construction. TIO reflected on its past activities that lacked an understanding of social issues behind the protest movement and failed to communicate more broadly with local communities, thus not being able to fully build trust with them. The TIO Board decided to relocate TIO's headquarters from Pasadena, California, to Hawai'i in a phased way. As the first step, the TIO Project Manager moved to the Island of Hawai'i in June 2021, and built a locally-based community engagement team. The team was joined by Director of NAOJ's TMT Project who was assigned to the island in July 2021, NAOJ's Senior Specialist Kakazu who was in charge of outreach activities for the Subaru Telescope for a long time, and indigenous staff to engage in community-based activities. In particular, TIO's education, outreach, and broader impact program is mainly designed to provide educational and vocational opportunities for indigenous children and those in rural areas who have not benefited from astronomy on Maunakea. This program is well received by the NSF who advocates for activities that reach underrepresented groups (the Missing Millions).

Some people had concerns and frustration over the failure to appropriately include opinions of the local and Native Hawaiian communities. Also, the need to decommission obsolete telescopes has been a longstanding issue. Against the backdrop of these reasons, a plan is in place to reduce the astronomy footprint on Maunakea. The first decommissioning work was approved by the state for the Caltech Submillimeter Observatory (CSO), whose telescope structure was removed in 2023. The decommissioning of the University of Hawai'i at Hilo's Hoku Kea was approved, and is scheduled to begin in 2024.

In 2021, the House of Representatives of the Hawai'i State Legislature created a working group to discuss a new management structure for Maunakea, which then released a report of recommendations. In response to the working group's report, a state act was enacted in 2022 to establish a new Maunakea management authority that includes Native Hawaiian representatives, called the Mauna Kea Stewardship and Oversight Authority (MKSOA). Since its establishment in November 2022, it has held a monthly meeting to discuss an extensive range of topics, including the management plan of the Maunakea Observatories, the decommissioning of the telescopes, and dialogues with communities. In July 2023, a transition period started to transfer the management from the University of Hawai'i to MKSOA. In February 2024, John De Fries was selected as Executive Director of the MKSOA.

In 2022, NSF commenced a consultation process under NHPA Section 106, followed by scoping meetings at multiple venues in Hawai'i Island and solicitation of comments. Based on the many comments received, NSF is conducting the Section 106 process under NHPA, and is preparing for a draft environmental impact statement. In December 2023, it started identifying consultation parties who will participate in the meetings under Section 106 of the NHPA to facilitate the consultation process.

As for the island of La Palma of the Canary Islands in Spain, which was selected as an alternative site in 2016, the process for all permits needed for construction was completed in 2019, including an environmental impact assessment. In an administrative appeal against one of the permits, a court issued a judgment that declared that the permit is valid. NAOJ expresses its support for relocation to La Palma in the case that construction in Hawai'i becomes infeasible, provided that the project is expected to receive U.S. federal funding.

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

For the construction of TMT, Japan is responsible for essential components of the telescope in accordance with the executed agreements: the design and production of the telescope structure and its control system; the manufacturing of the primary mirror; and the production of portions of the science instruments which are developed through international partnerships. While the restart of on-site construction is halted, Japan focused on designs and preparation for production in FY 2023, concentrating its efforts on essential work for the overall process instead of production. In FY 2023, the progress below was made.

(1) Manufacturing of Primary Mirror Segments

The TMT primary mirror, comprised of 492 segment mirrors, requires the manufacturing of 574 segment mirrors in all, with the replacements during mirror coating included. The process of manufacturing mirror segments is: 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. It is followed by the 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 the above process, 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 the mounting of the mirror segments on support assemblies distributed to other participating overseas institutes as well, Japan is leading this work for 175 of the mirror segments. In FY 2023, NAOJ's primary mirror team identified manufacturing of a blank in a renewed furnace as necessary development work that would facilitate smooth production upon the restart of production without affecting the entire process. This furnace was used for the past production, but went through measures due to replacement of its heat-resistant bricks. In FY 2023, in order to verify that blanks manufactured by this furnace meet TMT's specifications, the team conducted a process of melting raw materials and cooling and solidifying them, and manufacturing blanks by slicing the base material. In FY 2024, the coefficient of thermal expansion will be measured for samples gained from this work to see if they meet the specifications. Continuing on from FY 2022, the team further investigated how to protect the mirror surface when the hexagonal shaping work is performed. In FY 2023, it singled out a non-organic solvent that could be used for removing the protection coating after the hexagonal shaping process is done by testing candidate solvents. In addition, a load test was carried out on an adhesive-bonded part of the support assembly to simulate temperature fluctuation during the transport of segments. As the team observed a change in the thickness of the adhesive layer that resulted from humidity levels, it collected basic information that would enable them to consider any effects on the mirror shape.

(2) Design and Production of 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 primary mirror, other optics systems, and science instruments, and points them in the direction of target astronomical objects. 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. From FY 2021 to FY 2022, three separate production readiness reviews were conducted to examine the main rotating mechanical structures that move around the azimuth and elevation axes, as well as the Nasmyth structure where the science instruments and other systems will be placed. The team successfully passed all the reviews with favorable evaluation results. In FY 2023, with an eye toward production readiness reviews, the team was devoted to completion of documents related to the interface between the telescope structure and other subsystems, and review of upcoming work and verification plans for full-fledged production. As a manufacturer which planned to supply hydrostatic bearings for the project discontinued its relevant business, the team also commenced discussion on the takeover of hydrostatic bearing production by an alternate manufacturer.

(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 which stands for an InfraRed Imaging Spectrograph. Being in charge of its imager, Japan continues to engage in development that includes designing and prototyping in cooperation with the Advanced Technology Center. In FY 2023, the work was focused on action items indicated by the final design review of the imager held in FY 2021, and on preparation for a final design review of the entire instrument which is scheduled for FY 2024. The action items identified in the FY 2021 review were followed up by the team: the vibration analysis for the combined Narrow Field InfraRed Adaptive Optics System (NFIRAOS) and IRIS system; thermal analysis of the imager; verification of the position sensor's precision; and a baseline change for a detector used for the pupil optics. With an eye toward the upcoming review, the team worked on: the update of design requirement specifications and interface-related documents; a preliminary design of a mechanical system of the optical simulator that will be used for performance evaluation of the imager and the integral field spectroscopy; a conceptual design of a camera that will verify the integral field spectroscopy and the optical interface; and a redesign of the imager's mechanical system to accommodate the change in the detector in FY 2022. The team also investigated and verified a wavefront error that arose from uneven thickness of the reflective coating, and changed the coating's baseline.

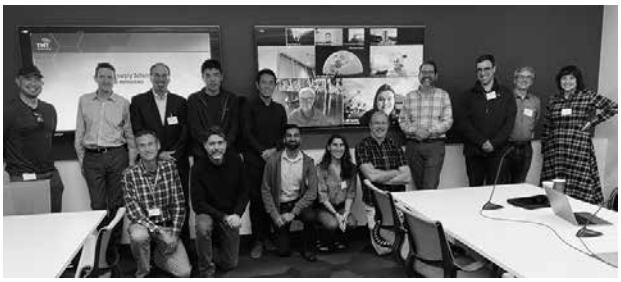


Figure 2: In January 2024, the MODHIS Midterm Conceptual Design Review (CoDR-2) was conducted at the TIO project office.

Accordingly, its efforts included creating a model that will measure the wavefront error generated when the coating is cooled, and will also reproduce the measurement.

A Wide Field Optical Spectrometer (WFOS) continued to be developed as part of the subphase 1 of the preliminary design phase since FY 2022. In FY 2023, NAOJ's WFOS team examined a mechanical design of the integral field unit which is considered as a future plan, and confirmed that it can be fit into a designated space within WFOS.

A Multi-Objective Diffraction-limited High-Resolution Infrared Spectrograph (MODHIS) is expected to pioneer the field of exoplanets, on which the U.S. Decadal Survey placed an emphasis. With its project management led by NAOJ Associate Professor Terada, MODHIS kicked off the first phase of the conceptual design in 2021 in partnership with the California Institute of Technology and the University of California (UC), Los Angeles and San Diego. This phase aims to clarify the concept of the adaptive optics to be combined with the instrument and develop a conceptual design of the interface to TMT adaptive optics. The team's efforts also go into defining scientific and technical requirements to be satisfied by MODHIS. In Japan, the Astrobiology Center's role and Japan's contribution is currently being considered in detail for MODHIS. In January 2024, the MODHIS Midterm Conceptual Design Review (CoDR-2) was conducted, where the progress in the design and the expected performance was explained (Figure 2).

NAOJ Research Engineer Nakamoto and Associate Professor Hayashi who are based at the NAOJ California Office in Pasadena engaged in TIO's development activities. Their contributions included development of the control system for the primary mirror's segments; development of user interface software for testing; developing a conceptual design of a coating facility for the secondary and tertiary mirrors; and design reviews, e.g., preliminary design review of maintenance, cleaning, and operation of mirror segments.

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

TIO's Science Advisory Committee, consisting of researchers from the participating countries and institutions, discusses science programs and instrumentation envisioned with TMT. In FY 2023, two meetings were held online along with one in-person meeting, attended by four university researchers and the Director of the NAOJ TMT Project on behalf of Japan. As for development of instruments through international partnerships, a subcommittee on observation of exoplanets with TMT, chaired by the University of Tokyo Professor Norio Narita, discussed research themes and required specifications based on results of surveys conducted in each country. A sub working group, created for development of a science operations plan once the telescope is completed, was attended by NAOJ Professor Wako Aoki.

The TMT Science Advisory Committee, which is a domestic committee consisting of thirteen researchers from universities and other institutes, reviewed issues of science programs, instrumentation, and operations. In FY 2023, there were four meetings in total, out of which two were held online, and the other two meetings were convened at Kyoto University and Hiroshima University, where talks and a session for sharing information were open to anyone, including students. The FY 2023 NAOJ's funding program for research and development of TMT science instruments was granted for five proposals to carry out research for development by twenty-five researchers at thirteen universities and research institutions.

Meetings were actively organized to explain the status of the project and engage in discussions for larger communities of astronomy in Japan. The NAOJ TMT Project held an online community meeting in May 2023 to keep participants informed on the status of Hawai'i; the reviews of the telescope structure; the progress and schedule of NSF's PDR and other processes; NAOJ's funding program for research and development of TMT science instruments; debriefing of the Science Advisory Committee, and other items. In addition to the Astronomical Society of Japan's annual meetings, NAOJ's TMT Project provided a progress report at meetings organized by the Group of Optical and Infrared Astronomers in September 2023, the High Energy Astrophysics Group in November 2023, the Group of Theoretical Astronomy and Astrophysics (Rironkon) in December 2023, the Japan Solar Physics Community in February 2024, the Symposium on Planetary Sciences in February 2024, and the Japan Radio Astronomy Forum in March 2024. The NAOJ Director General took a lead in providing an update on the project at all the meetings for the astronomy and astrophysics subcommittee of the Science Council of Japan and the Science Advisory Committee.

The TMT's science activities were re-accelerated in September 2023, with TMT-ACCESS, the first workshop of the series that aims to create new science goals with TMT. About thirty early-career researchers and engineers gathered at the TIO headquarters in Pasadena to widely discuss TMT's new science goals, science instruments, and other topics through cross-cutting group discussions, review talks by field, and panel discussions. In December 2023, a conference, The Scientific Landscape for ELTs in light of JWST Part I Americas, took place on December 11 to 15, 2023, on the UC Los Angeles Campus to discuss science in the 2030's with the next-generation ELTs, such as TMT and GMT. In response to JWST's latest observation results, researchers specializing in observation, theory, and science instrument development gathered together to discuss science, science instruments, the

Figure 3: The TMT-ACCESS was held mainly welcoming early-career researchers from Japan. About 30 early-career researchers and engineers gathered at the TIO office to engage in discussions in September 2023.

observatories' science operation, and user services that should be promoted in the era of the 2030's ELTs, including TMT. Preparation was done for the next TMT-ACCESS and the ELTs conference, both of which will be held at Tohoku University in June 2024.

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.79 through 81 were delivered.

While many of the project's outreach activities were conducted in person in FY 2023 after almost all the COVID-19 restrictions were removed, online lectures and classes also took root. The outreach activities capitalized on face-to-face, online and hybrid opportunities, 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. There was a total of sixty-three sessions of lectures for the public and classes on demand.

In Hawai'i, NAOJ's Senior Specialist was seconded to TIO in 2022, and leads its educational outreach programs, taking advantage of connections with communities and experience gained through Subaru Telescope. The proposal submitted to NSF consisted of programs centered around education, support for workforce development, cultural learning, and environmental protection and conservation in partnership with local educational institutes and non-profit organizations. It met with a favorable response from NSF. In FY 2023, NAOJ's TMT Project participated in over 30 in-person events jointly organized with other observatories and science-related organizations in Hawai'i, including on-demand lectures for a science/technology education and PR event called "Journey Through the Universe," the AstroDay that invited the local community to explore the science happening on their home islands, hands-on activities at the Onizuka Day of Exploration, the Tanabata Star Festival, star-gazing parties in areas where indigenous communities reside, and career fairs. In addition, in collaboration with local educational institutes, an educational support program, and workforce development programs were among the core engagement activities (Figure 4). In particular, a weekly tutoring program which TIO commenced in autumn 2021 to provide learning assistance for Jr. high schools was well received by local communities, effectively assisting children who were affected by the COVID-19 pandemic with their academic performance. In partnership with the County of Hawai'i and Native Hawaiian cultural successors, TIO launched a new initiative, called the 'Ale Lau Loa Global Youth Ambassador Program, to promote cultural learning and exchanges, with an emphasis on sharing indigenous culture and knowledge. In FY 2023, six high school students from the Island of Hawai'i participated in the inaugural trip to Okinawa to share their cultures, cosponsored by NAOJ.

Figure 4: (Left) TMT booth at AstroDay on the Island of Hawai'i in May 2023 to share the joys of astronomy with the local community. (Right) On-demand class for a local elementary school in April 2023.

5. Organization

By the end of the fiscal year, three Professors, one Project Professor, six Associate Professors, two Assistant Professors, two Research Engineers, a Senior Specialist, who is seconded to TIO, and another Senior Specialist held positions in the NAOJ TMT Project. In addition, one Professor, two Associate Professors, two Assistant Professors, four Senior Specialists and one Engineer from the Advanced Technology Center, and the Subaru Telescope 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, one member is assigned to the NAOJ California Office in Pasadena. There are two members in Hawai'i working for TMT, one of whom is the Director of the NAOJ TMT Project, and the other is the Senior Specialist who is seconded to TIO.

In light of integrated operation of the Subaru Telescope and TMT in the future, schedules and a staffing allocation plan were continuously discussed and formulated in line with the long-term plan for operation with the Subaru Telescope. As part of the plan, the 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 JASMINE mission of the Institute of Space and Astronautical Science/ the Japan Aerospace Exploration Agency (hereafter, referred to as ISAS/JAXA), aiming to realize the world's first near-infrared high-precision astrometry and timeseries 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 JASMINE mission of ISAS/JAXA.

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

JASMINE was selected by ISAS/JAXA in May 2019 as the unique candidate for the JAXA Competitive Middle Class Science Mission No.3. According to the current 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 improving the development stage at JAXA step-by-step. JASMINE has the following three primary scientific objectives.

1) To reveal the Milky Way's nuclear 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 36 cm to perform infrared astrometric observations (Hw band: 1.0–1.6 μm). A project objective is to measure as the highest precision annual parallaxes at a precision of less than or equal to 25 μas and proper motions, or transverse angular velocities across the celestial sphere, at a precision of less than or equal to 25 μas/year in the direction of an area of a few square degrees of the Galactic nuclear region to create a catalog of the positions and movements of stars within this region. JASMINE 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. JASMINE will help to achieve revolutionary breakthroughs in astronomy and basic physics, including the formation history of the Galactic nuclear structure (Galactic Center Archeology); the supermassive black hole at the Galactic Center; the gravitational field and dark matter distribution in the Galactic nuclear structure; 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; stellar physics; 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 periods, 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 band), we can plan to carry out transit observations 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 other missions for explorations of this type of exo-planet.

(2) Major Progress in FY 2023

1) Organization of the JASMINE Project

The JASMINE Project, NAOJ, is composed of two Professors, one Associate Professor, one Project Associate Professor, six Assistant Professors, and two Project Researchers. Significant contributions were also made by members of the following organizations: ISAS/JAXA, Kyoto University, the University of Tokyo, the University College London, etc.

2) Overview of planning and developing JASMINE

We are establishing 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 August 2023, a consortium meeting was held that also served as an open science workshop for JASMINE. We were able to listen to the opinions of many researchers and lectures in a wide range of fields. In addition, regarding astrometry, we have established a science core team, which holds regular meetings to discuss issues such as examining and expanding scientific results, collaboration

with other observation projects, and training young researchers.

Furthermore, the JASMINE Project of NAOJ started the JASMINE Joint Scientific Research Program. The primary purpose of this program is to promote researchers at Japanese universities to carry out preparatory research to produce scientific results on the Galactic center region using JASMINE's astrometric data, which are expected in the future. The JASMINE Project of NAOJ solicits applications for this program, and supports a successful applicant who proposed a selected research project for three consecutive years, including the employment cost of one Project Researcher and a research grant. The successful applicant is expected to lead the research project while supervising the Project Researcher and to produce results through scientific activities related to JASMINE.

Regarding the development of the satellite and observation instruments, we are working with a satellite manufacturer company candidate on conceptual studies, especially how to maintain high stability of the optical performance on orbit, which is important for astrometric observations in JASMINE, and then derived a feasible conceptual plan for development of the JASMINE instrument. In addition, we are developing a domestic infrared camera for space in collaboration with the NAOJ Advanced Technology Center and ISAS/JAXA. We have advanced conceptual studies on the structure/thermal design of the detector box unit and the electronics design to control the camera, as well as performance evaluation tests on prototype detectors. We have also started prototype production of large-format detectors in a package designed to be installed in JASMINE.

Regarding data analysis, we are simulating stellar images in the field to be observed by JASMINE, using actual stellar observation catalogs covering the area near the Galactic center, and also we are developing a series of end-to-end simulators from estimating stellar image centers in the field to deriving astrometric parameters such as annual parallaxes. We are proceeding with such analysis considering various realistic and complex noise sources. In particular, we conducted a simulation (mock observation survey) that simplified and reduced the size of the mission and succeeded in reproducing prospected precisions of stellar proper motions and annual parallaxes. In international cooperation, cooperation with researchers from the University of Heidelberg has continued on methods of analyzing astrometric data based on their knowledge of the Gaia data analysis. In addition, new cooperation with researchers from Technische Universitat Dresden has begun. Furthermore, discussions on cooperation with the NAOJ Astronomical Data Center for the creation of an archive of observational data have continued.

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

1. Project Overview

In FY 2023, the RISE Project first and foremost worked as the Martian Moons eXploration (MMX) Geodesy Science Strategy Team (GSST). We regularly had meetings online with the development team of the orbit/gravity field estimation software (GINS) produced by Centre national d'études spatiales (CNES) in France, and compared synthesized orbit propagation and tracking data with the JAXA orbital dynamics team to ascertain the agreement between the orbit dynamics models of the data synthesizing group (JAXA) and the analysis group (GSST) preparing for Landing Site Selection (LSS) training. In November of 2023, we invited two researchers from CNES to a GINS workshop. And four overseas members newly attended the GSST (one from NASA, two from Johns Hopkins University, and one from the Royal Observatory of Belgium). On the other hand, for the shape modeling of Phobos, we prepared image preprocessing software before the LSS training and analyzed the field of views of the two telescopic cameras, TENGOO and CAM-T, in the case of simultaneous scan operations during the high-altitude Quasi-Satellite Orbits (QSO-H). Also, the Publication Plan Table of GSST was settled. Then, we submitted a paper investigating the accuracy of the gravity field and internal structure estimated from remote-sensing observations at different QSO altitudes and in the ascent operation of the spacecraft.

Meanwhile, for the laser altimeter (LIDAR) development, we attended monthly development meetings with the manufacturer of LIADR. We also participated in Flight Model (FM) tests and contributed to the data acquisition and performance analysis of the response of the FM to various input energies, and joined the risk mitigation activity using an Engineering Model (EM). Further, we contributed to revising the Spacecraft Information Base version 2 (SIB2) and PI's Quick Look.

We contributed to mid to long-term operation planning in the Mission Operation Working Team (MOWT). Also, we incorporated MOWT and the Mission Operation Preparation Working Team (MOPWT) to establish a data downlink plan in the early stage of the MMX. We discussed the feasibility of investigating the candidate landing sites from the mid-altitude QSO. In the ground Data Processing WT (DPWT), we formulated a draft of the nomenclature rule of the products. In addition, we arranged the interface of LSS products training and confirmed the data processing flow in the Landing Site Selection Working Team (LSSWT).

Second, regarding the scientific achievements of Hayabusa2, we prepared to publicize the albedo data of the asteroid Ryugu from LIDAR observations and continued writing a draft of the paper studying the internal structure of Ryugu. Also, one of the RISE Project members published a paper as the first author on the orbital dynamics and operation plan of the Hayabusa2 extended mission in the proximity of the fast-rotating asteroid 1998 KY26 (https://doi.org/10.1016/j.actaastro.2023.06.010).

Third, Jupiter Icy Moons Exploration (JUICE) was successfully launched on April 14, 2023, from Europe's Spaceport in French Guiana and is heading for the Jupiter system. Before the launch, the Ganymede Laser Altimeter (GALA) team meeting was held in Berlin. One RISE member attended this meeting on-site and presented the performance model developed by the RISE project. This performance model, a thermal strap that was partly developed by the RISE project, and radiation tolerance tests of the receiver avalanche photodiode were described in the journal paper by Enya et al., 2022 (https://doi.org/10.1016/j.asr.2021.11.036).

2. Educational Activities

One RISE member educated a fifth-year graduate student at the University of Tokyo who obtained a Ph.D. in March 2024. The RISE Project also accepted one undergraduate student of Tokyo University as a NAOJ/SOKENDAI Summer Student and one second-year graduate student of Wuhan University in the SOKENDAI Asian Winter School (https://guas-astronomy.jp/eng/Applicants/winter2024.html). They worked on the lunar gravity analysis and Ryugu crater topography, respectively.

3. Outreach/PR

In FY 2023, the Project members volunteered two times for Kirari Oshu City Astronomy School and five times for FUREAI (Friendly) Astronomy classes. In addition, RISE members provided four special lectures for the public.

11. SOLAR-C Project

1. SOLAR-C Project Overview

SOLAR-C is a JAXA project scheduled for launch in FY 2028 and will become Japan's fourth solar observation satellite after Hinotori, Yohkoh, and Hinode. This project aims to elucidate the following mechanisms of solar magnetic plasma activities, which are significant problems in solar physics and impact 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 the establishment of the JAXA SOLAR-C project WG, many Japanese and foreign researchers and specialists have participated in the project. Japan will be responsible for the launch vehicle, satellite bus, and telescope section of the science instrument. The development of the sub-assemblies of the spectrograph has proceeded through international collaborations with the U.S. and European space agencies and institutions. NAOJ plays 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 moved to the Mission Definition Phase (Pre-Phase-A2) in FY 2019. 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. Regarding 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. After passing the Mission Definition Review in July 2022, the plan became a JAXA Pre-Project and later finished the System Requirement Review in December 2022. Afterward, we passed the System Definition Review in December 2023, and the JAXA SOLAR-C Project has started since March 2024.

2. Progress of the NAOJ SOLAR-C Project Activity in FY 2023

In FY 2023, the feasibility studies of the following aspects of the science payload have proceeded using the JAXA front-loading and preliminary design expenses: (1) The redesign of the primary mirror assembly (PMA) to reduce the operational temperature of the primary mirror, (2) the evaluation of the adhesive fatigue at the primary mirror support, (3) the design of the focus adjustment mechanism and the breadboard model development, (4) the design of the PMA launch lock, (5) the prototype evaluation of the pre-slit black coating, (6) the design of the mechanical, thermal, and electrical interfaces within the science payload, (7) the on-orbit temperature prediction and thermal deformation of the observation instrument structure, (8) the design of the mechanical, thermal, and electrical interfaces with the spacecraft bus, (9) the design study of the optical alignment methodology, (10) the design study of mechanical and optical measurements at the spacecraft micro-vibration test, and (11) the investigation of outgassing characteristics of candidate materials and the preparation of the measurement systems. 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.

While most design meetings with overseas partner institutions were conducted through internet conferencing, on-site design meetings have restarted and were held in the U.S. in May 2023 and at ISAS in October 2023, as the constraints imposed due to COVID-19 were relaxed. The NAOJ project staff also visited the site for the integration and test activity in the U.S. and the development supplier for the primary mirror coating in Germany.

In March 2024, the SOLAR-C Science Meeting was held at Nagoya University in a hybrid on-site/online format. During the meeting, the participants discussed specific examples of observations envisaged by SOLAR-C, cooperative observations with other satellites and ground stations, and research involving computer simulations.

3. SUNRISE-3 Project Support

The re-flight experiment of the balloon project SUNRISE-3, in which many project members contributed to developing the science payload, will take place in 2024, and there were contributions in the preparation activity.

4. Educational and Publicity Outreach Activity

The project staff has supervised two SOKENDAI graduate students. The project also participated in the Tour of the Solar Research Frontline to introduce domestic solar physics research to undergraduate students. The project activities in research and development have been introduced through the web.

5. Others

While NAOJ reimbursed the NAOJ SOLAR-C project activity for its general operation and contingencies, JAXA funds the expenses for designing and developing the science payload.

The changes in the project staff are as follows:
M. Mitsutake was appointed as a Senior Specialist in April 2023.
Y. Suzuki was appointed as an Administrative Supporter in May 2023.
T. Oba, Project Researcher, left the SOLAR-C project in January 2024.

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 the observation of ~2400 objects simultaneously at wavelengths ranging from 0.38 μm to 1.26 μm with a spectral resolution of R ~ 2000 – 5000. It is expected to start open-use observation from FY 2024.

PFS has been developed under an international collaboration lead 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 (8 institutions, USA), Brazilian consortium, LAM (France), MPE/MPA (Germany), and Chinese PFS Participation Consortium (6 institutions, China).

The PFS A-project started in FY 2019 at NAOJ. It is responsible for the design and construction of the telescope infrastructure needed for PFS, as well as the operation and maintenance of the instrument. The PFS A-project is also heavily involved with PFS integration, commissioning, performance verification, and the development of the data reduction pipeline and science database.

The A-project work will lead to the start of PFS operation, at which point PFS will transition to a Subaru Telescope facility instrument, and the PFS A-project will be dissolved.

2. Progress in FY 2023

(a) Subsystems delivery and integration

PFS is composed of four subsystems, starting with the Prime Focus Instrument (PFI), hosting the ~2400 science fibers and their individual positioners, at the prime focus of the telescope. The next subsystem is made of 4 science fiber cables (CableB) running along the telescope. They bring the light to the 4 spectrograph modules (SpS) located in a dedicated clean room on the upper level of the dome. Each module is composed of 3 cameras, with a blue, red, and near infrared (NIR) channel. The last PFS subsystem is the Metrology Camera (MCS) located at the Cassegrain focus of the telescope, imaging and processing the positions of PFI and each science fiber.

At the time of the previous annual report, PFI, MCS and 4 sets of CableB had already been installed on the telescope and were undergoing operational tests. One of the four spectrograph modules (SMs), SM1, with the blue and the red camera and another, SM3, with the full set of cameras of blue, red, and NIR were also installed in the SCR.

In November of 2023, the other two SMs were delivered to the Subaru Telescope and installed (Figure 1). SM2 is equipped with all three cameras while SM4 is equipped with two cameras in optical wavelengths. We tested these SMs immediately after delivery. They joined the engineering on-sky operation in March 2024.

Additionally, the instrument throughputs measured from the engineering data and discussions on them revealed that

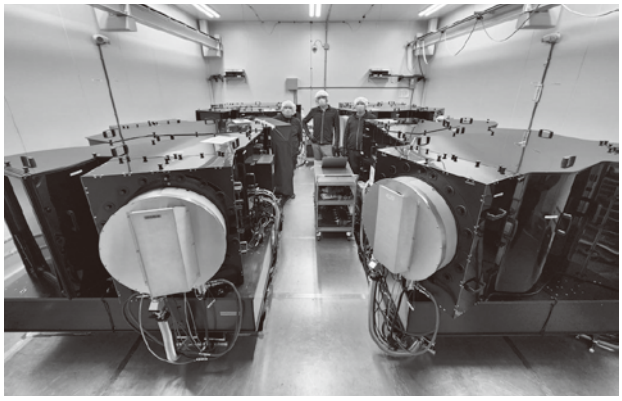


Figure 1: The PFS SCR fully equipped with all of four SMs (November 2023).

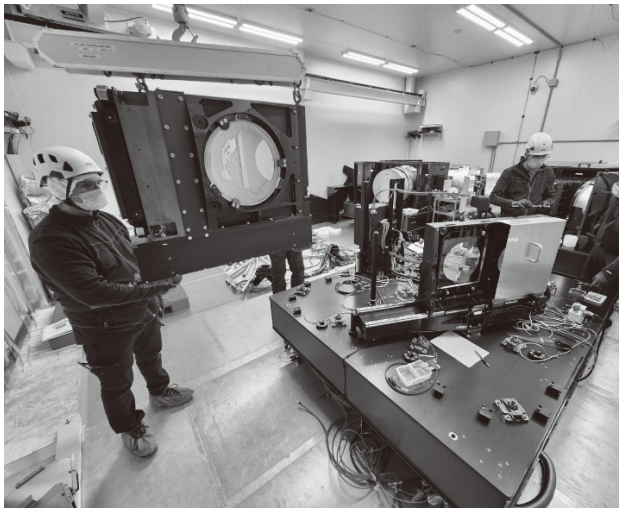


Figure 2: The corrective work for the low dispersion grating positions in November 2023. The medium dispersion grating positions were corrected in February 2024.

the dispersers of the SMs were installed in a flipped positions compared to the design and that made the instrument throughput lower than expected. The corrective work to fix this problem took place in November and February of this FY, which led to the recovery of the throughput (see Figure 2 and section b. Engineering observation run). We also found lowered quantum efficiency for the NIR camera for SM1. The camera was shipped back to JHU for recovery of the efficiency.

By the end of FY 2023, the installed equipment allowed us to observe celestial objects with all fibers (about 2400) and 10 cameras (4 red cameras, 4 blue cameras, and 2 NIR cameras). The remaining two NIR cameras will be delivered and installed on the Subaru Telescope in June and July 2024.

(b) Engineering observation runs

In FY 2023, there were 5 engineering observations scheduled with 45 nights in total. The runs were carried out as planned except for those in October and December 2023, which were cancelled due to telescope troubles. However, we had an opportunity to take calibration data with the telescope fixed at

zenith in December 2023.

The major achievements of the engineering observations in FY 2023 are:

- Engineering first light of the NIR cameras
- Data acquisition of ~2400 spectra using 4 Spectrograph Modules
- Confirmation of recovery of the throughput after modifying the VPHG orientations
- Improvement of fiber configuration time
- Improvement of fiber configuration accuracy
- Demonstration of queues for open use observation

In the April 2023 run, the power and communication devices in the PFI controller box became unstable, which often caused the AG cameras to stop running. By renewing the design of communication to the AG cameras, they have been stabilized in the later runs. Measured fiber positions and their accuracies were also degraded after an incident where MCS was dropped in December 2023. Software for the calculation was modified to improve the accuracy during the March 2024 observation.

The instrument delivery to Subaru Telescope showed substantial progress in FY 2023. The full four Spectrograph Modules got ready for observations with up to 11 cameras in November 2023, which enabled us to acquire ~2400 spectra in one exposure. Also, engineering first light of a NIR camera was achieved in April 2023.

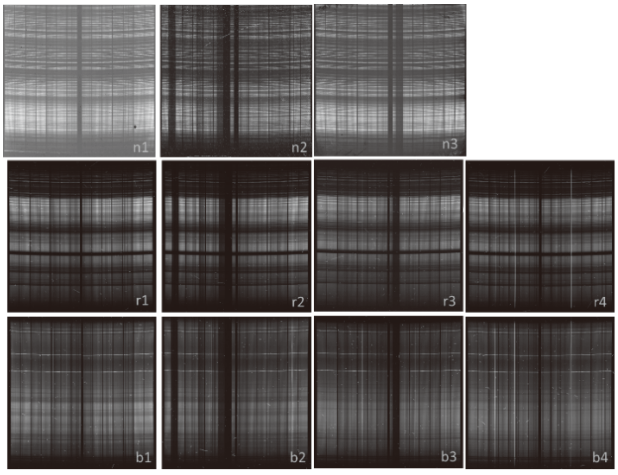


Figure 3: Twilight sky spectra with 11 cameras of 4 Spectrograph Modules.

Analysis using spectrophotometric standards revealed that the measured instrument throughput was quite lower than expected, and the throughput of the blue camera was about half that of the red cameras. From the discussions, it turned out that the VPHG orientation was wrong. The wrong orientation was corrected when two Spectrograph Modules were assembled at the Subaru Telescope in November 2023. The halogen lamp spectra taken in December confirmed the throughput recovery. The correction of the grating orientation in the medium-resolution mode with red cameras was also done in February 2024.

Regarding the fiber configurations, analysis of processing time and its optimization proceeded. As a result, the processing time which used to be approximately 400 seconds with 12 iterations was reduced to 120 seconds with 8 iterations without losing configuration accuracy. Analysis of fiber configuration accuracy also proceeded, and 95 % of the allocated fibers achieved an accuracy of approximately 50 μm or less, which corresponds to half of the fiber size.

Furthermore, we demonstrated queue observation which is used for open-use observation. In FY 2023, we achieved the process of collecting the targets from users, creating queue plans, and executing the queue observations. By actually carrying out observations, points to be improved were well clarified. In the future engineering observations, we aim to simulate the process of updating the queued programs based on the results of actual night operations.

(c) Observation procedures and policies

In FY 2023, much progress has been made on the open-use observation framework through discussions with the community at the two PFS community meetings and the Subaru Users' Meeting. We have defined policies and procedures around phase 1 such the proposal submission, target list upload, estimating observing time required to complete a program, etc. The online exposure time calculator and target uploader have been developed and usable versions are now available. Also, we had a discussion meeting with TAC regarding the proposal evaluation process.

Queue observations have also been tested in the commissioning runs, including PFS pointing optimization by combining multiple observing programs, optima fiber assignments to targets, guide star selection, queue optimization accounting for the target visibility, and OPE file generation. We also made progress in the quality assessment process at the post-observation phase and tools are being developed. Furthermore, a prototype system to track the progress of queue programs has been developed. In addition to queue observations, we also largely defined the policy for classical and ToO observations. Only the filler category is yet to be defined.

(d) Data reduction pipeline

The PFS team at NAOJ has been continuously contributing to the data reduction pipeline (DRP) in close collaboration with Princeton University and other PFS collaborators. One of the significant contributions of the NAOJ team is the flux calibration part of DRP. In this fiscal year, by using actual data obtained in the engineering observations, we tested the method we developed so far, identified issues, and implemented some fixes. We also reconsidered some algorithms and successfully improved the processing speed. Another significant contribution is the quality assurance of the reduced data. The NAOJ team developed a tool to analyze and visualize the accuracy of fiber trace position and wavelength calibration (detectorMap). We also developed a tool to analyze quantitatively the quality of the spectral extraction such as residuals of the extracted spectra and visualize the quality. These tools are utilized for the reduced data of the engineering runs and to give feedback to the DRP development. Using the current version of DRP, we confirmed that the data obtained in the engineering runs could be processed

end-to-end from the raw data to the flux-calibrated 1D spectra from which physical quantities such as redshifts are obtained. The framework for distributing these processed data to users is under development, and we conducted two trial releases internally in this fiscal year.

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.

In FY 2019, the GLAO project was accepted for the NAOJ call for A project proposals and started the preliminary design studies. The GLAO project completed the preliminary design of the GLAO system in FY 2022 and started prototyping the key subsystems and final design in FY 2023. The GLAO project aims to complete the final design phase in FY 2025, followed by production, assembly, integration, and test phases to start the commissioning observations in FY 2028.

2. Staff

The GLAO project consists mainly of members from Subaru Telescope. At the end of FY 2023, there were 1 associate professor and 1 research fellow dedicated to the GLAO project. There were also 1 associate professor, 1 senior specialist, 2 assistant professors, 1 research engineer, and 2 RCUH employees (engineering staff) appointed concurrently. There were also 1 associate professor and 1 Special Senior Specialist at the Advanced Technology Center (ATC) who participated in the GLAO project in FY 2023. In addition, the GLAO project received support from the instrument division technicians, day crews, and administration staff at Subaru Telescope and engineers at ATC.

3. Major Progress in FY 2023

As part of the completion of the preliminary design, prototype development has been started for key components for the wavefront sensor (WFS), the laser guide star facility (LGSF), and the control system have been started. In FY 2023, we fabricated prototypes of the WFS optics and opto-mechanics and procured a fast tip/tilt stage for the jitter control mirror at the LGSF. We also developed the prototype of the WFS image acquisition system and evaluated the performance of the camera cooling system and the image readout system.

To validate the key technology for the GLAO system, the GLAO project has been collaborating with Tohoku University to develop a WFS for the Laser Tomography Adaptive Optics (LTAO) system and a four-beam laser guide star system (4LGSF). In FY 2023, the transportation of LTAO WFS to the Subaru Telescope base facility was completed, and the laboratory tests, including the optical alignment and development of the real-time control system, were started.

ATC participated in the final design of the GLAO system starting in FY 2023. In the final design, ATC is responsible for the design of the thermally insulated electric cabinet that holds the electronics of the WFS and LGSF, the platform for attaching the LGSF components to the telescope, and the cooling system for the LGSF. ATC is also participating in the systems engineering activities for the GLAO system. In FY 2023, ATC summarized the system requirements and interface that are required for starting the final design. In addition, ATC reviewed the preliminary design of the GLAO WFS and LGSF to improve the design and investigate the feasibility of manufacturing at ATC.

Fabrication of the adaptive secondary mirror (ASM) has been started in advance since FY 2022. In FY 2023, we continued the fabrication of the main optical components and completed the fabrication of the mechanical and electrical components. We also summarized the interface with the telescope and investigated the verification plan using a dedicated calibration system.

To conduct the development of a wide-field near-infrared imager (WFI) to be used with the GLAO system, an application for the JSPS Grant-in-Aid for Specially Promoted Research led by Prof. Tadayuki Kodama at Tohoku University to conduct the development of a wide-field near-infrared imager (WFI) was accepted in FY 2023. This will allow us to start the production of WFI following the schedule for the GLAO development. We will conduct the final design in FY 2024, followed by the production in FY 2025, aiming to start the commissioning observations with the GLAO system in FY 2028. We recently developed a tool to predict the sensitivity of the science observations using GLAO and WFI. We have been summarizing the instrument capabilities and science cases to prepare for the future Subaru Strategic Survey program in collaboration with the GLAO science team.

4. Education Activities and Internships

In FY 2023, the research staff of the GLAO project continued to accept a student from the University of Hawai`i as an intern of the Hawai`i Space Grant Consortium (HSGC) to provide research experience on observational studies of galaxies. In addition, we hosted four graduate students from Tohoku University and one from Sokendai staying for 1–2 months at the Subaru Telescope to conduct research related to the LTAO development or observational studies of galaxies.

5. Outreach

To inform the astronomical community and general public about the Subaru GLAO project and its scientific motivation and goals, we released news from the project on a public website (https://ultimate.naoj.org). In FY 2022, the “Subaru Telescope 2.0” project was officially launched and a special web page for the “Subaru Telescope 2.0” project has been released on the Subaru Telescope official website. ULTIMATE-Subaru was highlighted on the Subaru Telescope 2.0 web page.

6. International Collaboration

The ULTIMATE science team is playing a central role in promoting the activities of the 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 (as known as SUPER-IRNET)”. This program aims to significantly advance the next-generation near-infrared wide-field observation program, including ULTIMATE, through the collaboration of Japan, the United States, France, Australia, and Taiwan. In FY 2023, travel restrictions under COVID-19 were lifted and many young researchers were sent to the partner countries. We have been closely collaborating with the Australian National University (ANU) on the development of the GLAO system. To further expand this cooperation, we applied for funds from the “Australian-Japan Foundation (AJF)” with the ANU. The proposal was selected as a two-year project. There will be various meetings and exchanges planned for FY 2024 and 2025. The AJF is the Australian government's official support for Australia-Japan cooperation in all fields, including education, economy, culture, and sports, not just science and technology, and was formally announced by the Australian Minister for Foreign Affairs in January 2024 (https://www.dfat.gov.au/people-to-people/foundations-councils-institutes/australia-japan-foundation/grants/Pages/ajf-grant-recipients-2023-24)

14. Astronomy Data Center

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. To sustain and develop these activities and functionalities in the future, and to serve as a cross-project organization that supports the various projects and observatories in NAOJ through the sharing of personnel, computers, scientific data assets, experience, and technology, we are restructuring the organization.

The rental computer system installed in March 2018, which has been used as an open-use data analysis system and data archiving systems (current rental system), was scheduled to cease operation at the end of June 2024. The procurement procedures for a new rental computer system (new rental system) are underway and the system migration has begun in 2023.

The major activities in ADC are described below.

1. SMOKA

The SMOKA team has been conducting research and development on astronomical databases, data archiving, and data analysis. SMOKA (https://smoka.nao.ac.jp/) publishes archival data from the Subaru Telescope, the Okayama 188-cm Telescope, the Kiso 105-cm Schmidt Telescope (the University of Tokyo), two MITSuME 50-cm telescopes (Tokyo Institute of Technology), the Kanata 150-cm Telescope (Hiroshima University), the NAYUTA 2-m Telescope (University of Hyogo), and the Seimei 3.8-m Telescope (Kyoto University).

SMOKA continues to operate stably in cooperation with the various observatories and has produced many scientific results. SMOKA is also a research infrastructure that enables the revalidation of research results and supports the credibility of research results. SMOKA also serves as the framework to open Subaru Telescope data to the public.

The total amount of opened raw observational data in SMOKA is about 39 million frames (457 TB) as of May 2024. SMOKA has contributed to many astronomical publications. The total number of refereed papers using SMOKA data is 290 including 10 new publications in FY 2023 as of March 2024. A significant number of papers have recently listed “SMOKA” as a source of “Data Availability”. In FY 2023, we prepared a mechanism for receiving data from a new instrument GAOES-RV on the Seimei Telescope under commissioning. Preparations are underway to receive data from PFS being commissioned on the Subaru Telescope. Data storing and distribution for TriCCS on the Seimei Telescope have been in stable operation this fiscal year as well. Raw data transmission from another high-data-rate instrument Tomo-e Gozen (Kiso Observatory) was replaced with broadband network transmission.

We are operating a system that makes 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 2024). A system for publishing digitized data from photographic plates taken at Kiso Observatory several decades ago has also continued to operate (https://pplate.nao.ac.jp/ ; 4 TB). A data service of Tomo-e Gozen stacked data also continued to operate (https://archive.nao.ac.jp/tomoe ; 241 TB as of May 2024).

Work to update to the new rental system is being carried out in parallel with operations, and the migration of the above functions is progressing in 2023. Two papers on the development of the TriCCS archive system and on the acceleration of astronomical database searches were published in the Report of NAOJ Volume 24.

2. MASTARS

MASTARS, a data archive system in Mitaka for the Subaru Telescope observers, continued to operate working closely with the STARS data archive system at Subaru Telescope. In preparation for the hardware replacement scheduled in FY 2024, the stored data were copied to the new rental system. The archive application was tested and verified in a test environment for porting to the new OS version. In the operation of the current system, the failure of data transfer by network and other troubles were recovered, and inconsistencies in the past data were investigated and fixed along with the data copying. The data were also backed up to a commercial cloud for data preservation in case of a disaster.

3. JVO (Japanese Virtual Observatory)

Operations of JVO portal, VO services for various data, and metadata data service were carried out by the JVO team, and their functionality was updated. To reduce costs of service operation, some services operated on the current rental system were migrated to run on the purchased computing system.

To increase the number of processed Subaru Telescope HDS data, which are currently open to the public from the JVO portal, we have developed a data reduction pipeline for automatic processing. The data processed by the developed pipeline are planned to be released to the public in FY 2024.

We have improved the functionality of FITS WebQL, an application for easy browsing of observation data on a web browser. Specifically, we implemented a function to make it easier to find detected lines by adjusting the frequency resolution of a spectral plot, and a function to display markers on specified coordinates. In addition, a function for displaying X-ray data was developed, and its test release as XWebQL was started.

The overall access count for all the JVO services in FY 2023 was 25 million and the total download volume was 6.5 TB.

4. HSC Data Analysis/Archiving Software Development

We continued to develop data analysis pipeline software to process Hyper Suprime-Cam (HSC) data accurately and

efficiently, conducted data analysis, and developed and operated data archiving systems to make effective use of the processed data.

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. The originally scheduled HSC-SSP observations were completed in December 2021, and the total full-color full-depth survey footprint has reached over 1000 square degrees. We are processing all the obtained data with an updated pipeline for the next (11th) data release for SSP collaborators. During the last fiscal year, we conducted extensive testing of the new pipeline, as the structure of the pipeline was significantly changed. However, several new problems were discovered after we started the formal large-scale production run and we worked together with the Subaru Telescope and the development team to resolve them. Although the system upgrade work has continued from the last year, we have also maintained the data service functions and continued to develop various user interface software for providing images and catalog products. We have been involved in establishing data formats for PFS and developing and testing a science archive for PFS linked to the HSC data products in cooperation with Subaru Telescope.

In addition, the development to apply next-generation technology to large astronomical catalogs such as HSC-SSP continues after minor updates to the collaborative framework. This fiscal year, we have mainly developed and evaluated a function for fast querying of Solar System bodies. Our goal is to make the products of this development widely available to the astronomical community. The backend database management system development project is preparing a light version for general users. Our application will benefit from the new database system for faster query and data analysis.

5. Open-use Computer Systems and Services

Open-use of the data analysis computer system for astronomical research is one of the key services provided by the ADC. “The Multi-wavelength Data Analysis System (MDAS)” procured under a rental contract has been in operation since March 2018. Since the current system is scheduled to cease operation at the end of June 2024, preparations have been made for the procurement and construction of the next system, which is planned to begin operation in July 2024. The next system will be operated using a combination of new rental computers, other computers procured under the lease contract, and purchased computers.

“The Large-scale Data Analysis System (LSC)” is a cluster computer system dedicated to the analysis of large astronomical observation data and began operations for Subaru Telescope/HSC observers in 2019. While upgrading the system, such as adding computation nodes, we have sequentially expanded the target users and the types of data to be reduced. From 2022, we began accepting users who analyze and process observation data other than HSC data. Although five years have passed since the installation, we keep operating the system with necessary updates and maintenance.

The open-use computer systems are used in various workshops and provided as a computer environment for data analysis training, with the aim of promoting the use of astronomical data, archive systems, and astronomical software. The dates and number of participants for the workshops using MDAS held in FY 2023 are as follows. All these workshops were held at NAOJ's Mitaka Campus.

1. ALMA Data Reduction Workshop, July 12–14, 2023, 11 users
2. SOKENDAI Summer Student Program, August 1 – September 1, 2023, 10 users (used MDAS)
3. Long Wavelength Polarization Analysis Workshop, February 12–13, 2024, 11 users

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.

The year 2023 marks the 30th anniversary of the establishment of the ATC (Japanese name 天文機器開発実験センター) in 1993, the predecessor of the current ATC (Japanese name 先端技術センター), and was a year to reflect on the past and renew our commitment to the future. In June, a successful commemorative ceremony was held with the participation of about 80 people, including current staff, related personnel, and alumni (see Figure 1). A new logo for ATC was also established in conjunction with the ceremony. In May, the new coronavirus infection was moved to category 5, and business was conducted almost as usual.

Figure 1: 30th Anniversary ceremony.

The reorganization into a matrix-type organization (see Figure 2) entered its third year of operation and has been substantially put into practice. In July, a survey team led by the center director visited Netherlands Institute for Space Research (SRON) and UK Astronomy Technology Centre (UK-ATC) to inspect and exchange opinions mainly on organizational management methods. Based on the discussions there, regular resource coordination meetings were initiated to bring together representatives of each project who wished to request work from ATC and the ATC Steering Committee. The meeting has become an important opportunity not only for communication between ATC and the projects but also for communication and information sharing among the projects.

Facility tours exceeded those before the COVID-19 pandemic and we welcomed more than 400 people on 41 occasions. We were able to stress the importance of ATC in NAOJ for Sociedad Chilena de Astronomia; National Radio Astronomy Observatory (NRAO); The Institut de Radioastronomie Millimétrique; European Space Agency (ESA); the Japanese Ambassador to Chile; the Cabinet Office; Ministry of Foreign Affairs; Senior Vice Minister of MEXT; Vice Minister of MEXT; private companies; and students; etc.

In cooperation with the Industry Liaison Office, ATC

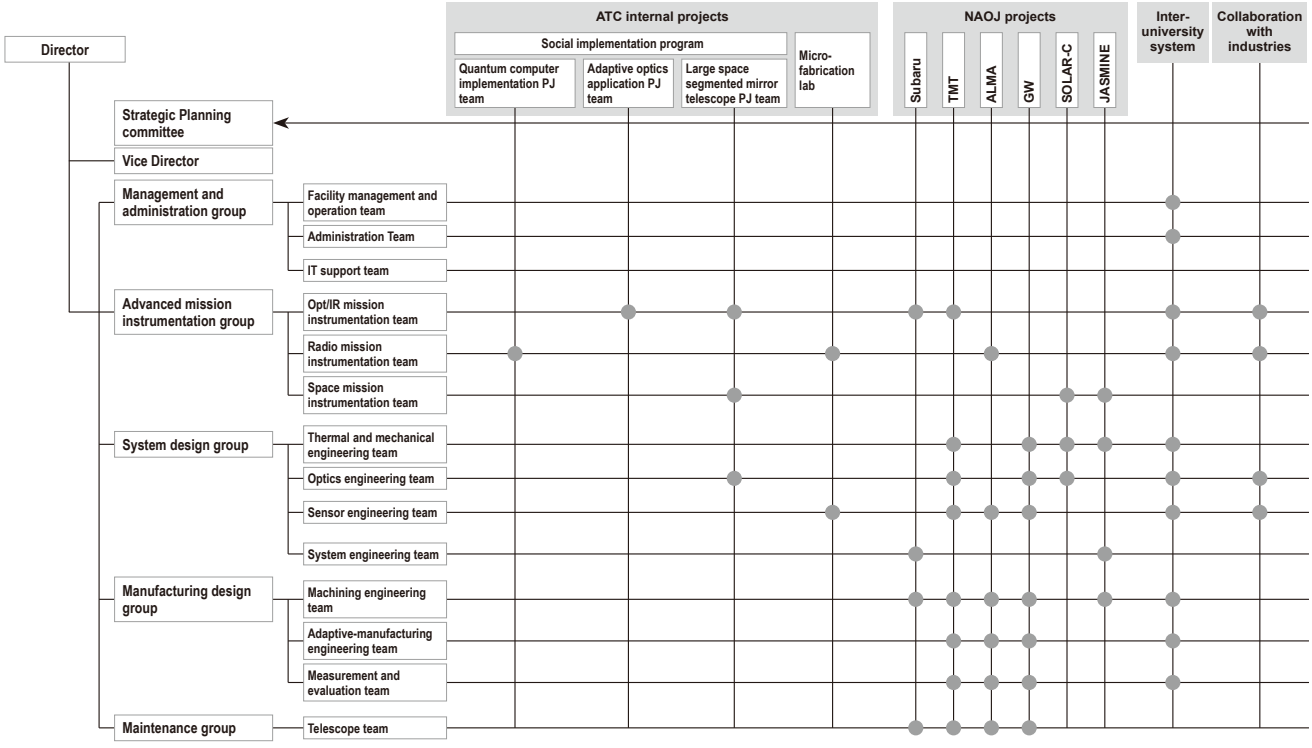


Figure 2: Matrix organization structure of ATC.

exhibited at OPIE'23 and the Microwave Exhibition 2023 held at Pacifico Yokohama; exhibited a general-purpose AO system at the University Trade Show ~Enovation Japan; and presented its superconducting amplifier technology at JST New Technology Presentation Meeting, thus widely promoting ATC's technology to the industrial world.

We also actively engaged in industrial collaboration activities to apply the technologies developed at ATC to industrial applications, and launched the Social Implementation Program in April 2023 to apply a microwave amplifier with ultra-low power consumption to quantum computers and to apply adaptive optics technology which is also used in the Subaru Telescope to industrial applications. In January 2024, the Large Space Segmented Mirror Telescope Project Team was added to the program, further expanding the scope of activities.

The Maintenance Group was established in February 2024 to centrally manage the resources allocated to each observatory for telescope maintenance and operation and to effectively use resources within NAOJ.

Details of the activities in FY 2023 are described below.

2. Developments for Prioritized Projects

(1) TMT Instruments

1) Infrared Imaging Spectrograph (IRIS)

The IRIS team continued to work on issues (homework) identified at the final design review for the IRIS Imager held in June 2021. The system-level analysis and documentation are also being prepared for the system-level final design review scheduled for FY 2024. The former includes vibration analysis with adaptive optics NFIRAOS and IRIS, opto-mechanical thermal analysis, and accuracy verification of the position sensor. The latter involves the preliminary design of the mechanical part of the optical simulator used to evaluate the performance of the Imager and the integral field spectrograph. In addition, the majority of the Imager mechanisms were redesigned to accommodate changes in the detector that occurred in FY 2022. The wavefront error caused by coating non-uniformity was investigated, and the baseline of the reflective coating was changed. We have been measuring the wavefront error that occurs when the new coating is cooled and creating a model to reproduce the measurement.

2) Wide Field Optical Spectrometer (WFOS)

WFOS continued the first subphase of the preliminary design phase (PDP1) started in FY 2022. In FY 2023, ATC conducted the mechanical design of the integral field unit (IFU) which has been studied mainly by NAOJ as a future upgrade of WFOS. As a result, we confirmed the current IFU design can be installed in the allowed space in WFOS.

(2) ALMA

1) ALMA receiver development and upgrades

With the start of ALMA2 in FY 2023, the project continued the development of the data transmission system from FY 2022 and initiated upgrading the Band 8 receiver. We also supported the development of Band 2 receivers.

1-1) Band 8 version 2 receiver upgrade

NAOJ has developed an upgrade plan for the current ALMA Band 8 receiver to improve its intermediate frequency and sensitivity and has initiated the upgrade of the receiver. This is called the ALMA Band 8 version 2 receiver upgrade project (hereafter Band 8v2) and is a part of the ALMA 2030 Wideband Sensitivity Upgrade (WSU) to be conducted in ALMA2. This project is divided into Phase 1 to conduct the preliminary and detailed design of the receiver and Phase 2 for the receiver production and integration on the antennas. The Phase 1 project proposal was documented in NAOJ and approved at the ALMA Board meeting held in November 2023. Within NAOJ, in addition to strengthening the development organization between the ALMA project, the receiver development team, and the microfabrication lab in ATC, a development collaboration has been established including domestic and overseas research institutes and universities.

In FY 2023, the design of the Band 8v2 receiver proceeded with the aim of satisfying the performance requirements at WSU. In the relay optics, in order to improve optical performance and sensitivity as a receiver system, we proceeded with the conceptual design of several configurations, and also with the design of optics components such as reflector mirrors, corrugated horns, and waveguide OMTs. In addition, for the development of a superconductor-insulator-superconductor (SIS) mixer, which is critical for wideband and low-noise receivers, we designed the first prototype to verify the characteristics targeting the designed frequency range. In cooperation with the microfabrication lab, we fabricated the SIS mixer and associated superconducting devices and evaluated their radio frequency characteristics. We also developed a waveguide component for the sideband-separating mixer, and obtained improved performance over the components currently used in the Band 8 receiver. For broadband cryogenic low-noise amplifiers, which have a significant impact on the performance of the intermediate frequency band, several candidates were selected and procured. We have extracted the characteristics of each product as a result of individual cryogenic performance tests, and next, we will conduct a performance evaluation with the amplifier integrated into the receiver in the near future and proceed with the selection based on the results of the evaluation. We are also working on the development of a wideband hybrid coupler in collaboration with the University of Electro-Communications, and have obtained a design solution that is expected to improve performance by devising a circuit structure. Based on the results of the above component design and subsystem studies, one receiver system configuration was extracted, and the mechanical design of the receiver cartridge was advanced. So far, we obtained a practically viable conceptual design solution based on the consideration of the structural and thermal aspects, assembly, etc., while ensuring receiver performance.

1-2) Receiver development for Band 2

For the Band 2 (67–116 GHz) receivers led by the European Southern Observatory (ESO), NAOJ has been contributing to the design of the optics system and the design, manufacturing, and testing of optical components. Following the previous integration test of the first receiver conducted in the last fiscal year, we contributed to the second assembly and integration of a pre-produced receiver on an antenna in the ALMA site in April and May of FY 2023, to perform verification for the issues found in the first integration test and prepared for the integration of the produced receivers. The first fringe was achieved with a combination of three Band 2 receivers in August, and the performance of the receivers on the antennas was verified. Based on the results of the pre-production receiver, the project passed the Manufacturing Readiness Review (MRR) held in September and moved into the production phase. We have established a collaboration with the University of Chile and the National Radio Astronomy Observatory (NRAO), while it was agreed that NAOJ will make a technical contribution to the NRAO's Band 6 receiver upgrade project (Band 6v2). NAOJ has collaborated on the evaluation of the current Band 6 optics, and designed, manufactured, and evaluated a Band 6v2 prototype orthogonal mode transducer (OMT).

In addition, a press release was issued regarding the establishment of a dielectric material characterization system with a high-precision analysis method, which was published in a paper last fiscal year.

1-3) Data transmission system

As one of the ALMA 2030 WSU projects, NAOJ is leading the upgrade of the Data Transmission System (hereafter DTS). The DTS upgrade is a development project under collaboration with NRAO, and the design, component selection, and evaluation are underway for the Preliminary Design Review (PDR) scheduled for October 2024. In FY 2023, the basic design was advanced while considering the progress of related development projects. As a result, we adopted the basic configuration of the DTS that assigns a 400 Gbps capacity to each sideband of each polarization for the 4-channel (= 2 polarizations × 2 sidebands) receiver signals from each antenna employing a total of 4 × 400 GbE, and multiplexing them using Dense Wavelength Division Multiplexing (DWDM) technology to transmit them to the correlator via a pair of optical fibers. We then selected and evaluated components that satisfy the DTS system requirements. In particular, 400 GbE-ZR standard optical transceivers were newly procured and tested as a key device. First, as a basic demonstration, we constructed a test environment to simulate the optical fiber length and its loss as assumed in the WSU using the Koganei-Otemachi link in the NICT testbed. Then we performed a 90 km transmission experiment by multiplexing two signals from the optical transceivers and the two other signals from the 400 Gbps transponders using DWDM. The result showed stable data transmission with a Bit-Error Rate < 1e−15. Also, since the optical transceiver is mounted in the antenna receiver cabin of the ALMA antennas, the optical fiber that serves as the transmission path is subject to bending and twisting caused by the antenna motion, which may degrade the quality of data transmission. In order to evaluate the impact of the antenna motion on DTS, we conducted a communication test of a 400 GbE-ZR standard optical transceiver using the optical fiber of the 11-m VLBI antenna in NICT and confirmed a stable link without missing data even during antenna drive. These results were reported at URSI GASS 2023 and published as an article of the ALMA memo series.

2) ALMA Receiver Maintenance

2-1) Band 4, 8, 10 receiver maintenance

NAOJ has been responsible for 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. Since more than 10 years have already passed since 2011, when ALMA started its initial scientific operation, it is undeniable that the failure rate of the receivers will increase in the future when they enters the wear failure phase according to the characteristic life 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.

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. The Band 8 receiver tends to have a gradual and slight fluctuation in receiving power immediately after startup, and has conventionally been used after stabilization over an extended period of time. In this preliminary investigation, the cause of the fluctuation was identified, and the operating procedure was studied together with the Joint ALMA Observatory and an adjustment procedure was found to stabilize the system in a short time. Furthermore, the optimal procedure was established through verification tests on a number of actual ALMA antennas. The new adjustment procedure will be reflected in future operations.

2-2) Band 1 receiver maintenance

The Band 1 (35–50 GHz) receiver development project, which was led by Taiwan's Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), in collaboration with NAOJ, etc., as a contribution to East Asia ALMA, completed its production phase. The production and performance verification of the Band 1 cartridge receivers in Taiwan has proceeded as planned, and the shipment of all receivers, including spares, was completed within FY 2022. The integration of the receivers in the telescope in Chile is still ongoing but and some of the receivers began common-use observation mode in FY 2023.

NAOJ has taken responsibility for the maintenance of the Band 1 receivers in the operation phase, in parallel with the Band 4, 8, and 10 receivers. In FY 2023, the test equipment for the maintenance of the Band 1 receivers was transferred to ATC, as agreed and equipment for testing the warm cartridge assembly has been rebuilt, and the spare cartridges and parts have been stored safely, taking over responsibility from ASIAA.

We have already received two Band 1 warm cartridge assemblies that were found to be defective during the integration procedure in the telescope and are investigating the defect in preparation for repair.

(3) ULTIMATE-Subaru Ground-Layer Adaptive Optics (GLAO)

GLAO is a wide-field adaptive optics instrument being developed at Subaru Telescope. The GLAO development is currently in the critical design phase in collaboration with Subaru Telescope, ATC, and the Australian National University (ANU). In the final design, ATC is responsible for the design of the thermally insulated electric cabinet that holds the electronics of the wavefront sensor (WFS) and laser guide star facility (LGSF), the platform for attaching the LGSF components to the telescope, and the cooling system for the LGSF. ATC is also participating in the systems engineering activities for GLAO and is responsible for creating the system model and documents that summarize the interfaces, requirements, and system error budgets. In 2023, ATC reviewed the preliminary design of the WFS and LGS, and discussed with ANU about improving the design, understanding the system requirements and interfaces, and investigating the possibility of manufacturing the WFS/LGSF components at ATC. In addition, requirements and interfaces were defined for the insulated cabinet, platform, and cooling system prior to their detailed design.

(4) KAGRA

In collaboration with the Gravitational Wave Project, we are developing the vibration isolation system (VIS) and auxiliary optical system (AOS) of the KAGRA interferometer, and also evaluating its new mirror's performance. KAGRA participated in the fourth international joint observation run (called O4a) from May to June 2023, together with LIGO in the United States and Virgo in Europe. In this context, we have continued to cooperate in the development and maintenance of instruments necessary to improve sensitivity and stability for the start of this observation run since FY 2022. As a result, in O4a, KAGRA achieved a twofold improvement in sensitivity compared to the previous operation (O3GK), and a considerable improvement in stability. ATC is particularly relevant in terms of reproducibility and reliability in the recovery process from interferometer downtime. The speedy recovery of the interferometer leads to the increase of commissioning time, which directly leads to the improvement of sensitivity and stability mentioned above. The equipment and devices contributed by ATC, such as the jig for initial optical alignment and the optical angle sensors for the relevant mirrors (optical levers), were essential for establishing this improved recovery process. At this point, KAGRA's schedule was to resume observation in early spring 2024. However, the interferometer was severely damaged by the Noto Peninsula earthquake on January 1, 2024. Currently, restoration work is proceeding in Kamioka, and based on an urgent request from the Gravitational Wave Project Office, ATC has assigned one engineer who is familiar with the VIS and AOS instruments to work exclusively on the restoration work.

Other activities include the development of the necessary upgrades for the fifth and subsequent observation runs. Specifically, we fabricated and evaluated folding pendulums, which are the core devices of accelerometers for the VIS instruments, and continued design of a compact vibration isolator, and prototyped its core component (mini-GAS filter). Also, upgrading of the mirror evaluation system has been continued from FY 2022.

(5) High-sensitivity Solar Ultraviolet Spectroscopic Satellite: SOLAR-C

ATC has led in revising the specifications for the telescope section of the SOLAR-C instrument and the optical design of the spectrograph section; and has assisted in coordinating mechanical and thermal interfaces for the optical and electrical assembly provided by foreign partner institutes and cooperating to build a baseline optical alignment plan. ATC has also assisted in preparing clean room facilities, including vacuum chambers of various volumes and contamination monitoring systems, which are to be used during the development phase of the SOLAR-C project. The JAXA SOLAR-C pre-project has moved on to a JAXA project since March 2024.

(6) Infrared Astrometric Observation Satellite: JASMINE

ATC has performed the conceptual study of the JASMINE payload instrument together with the JASMINE Project. The Thermal and Mechanical Design Team of the System Design Group is in charge of studying a detector box unit (DBU) that holds detectors in focus and cools them down to ~170 K with a radiator and Peltier devices. In FY 2023, the team contributed the definition of the mechanical interface of the InGaAs detectors under development, evaluated the performance of a candidate Peltier device in the low-temperature environment (~200 K) repeatedly, and proceeded with the DBU thermal and structural design based on the evaluated performance. The group has also supported the conceptual study of the JASMINE telescope, especially preparing a plan for telescope assembly and verification based on the experience of telescope development for the Hinode satellite. The Advanced Mission Instrumentation Group studied the development of an electric system for the detector driving and the onboard data processing.

3. Advanced Technology Development

(1) Near-infrared Image Sensor

Until now, the only option for a high-sensitivity, low-noise near-infrared image sensors applicable for astronomical observation, with sensitivity in the wavelength range from 1 um to 2.5 μm, were sensors manufactured by one US company that uses mercury-cadmium-telluride compound semiconductors.

Our group has been collaborating with a domestic company to develop image sensors applicable for astronomical observations, based on sensors using indium-gallium-arsenide compound semiconductors, which are widely used in industrial applications. In FY 2023, we tested the 10-μm pitch prototype image sensor with 1.7 μm cut-off wavelength delivered last year. In the first 10-μm pitch prototype, we newly introduced a 10 μm narrower pitch, a higher number of pixels, and a thinned substrate to increase sensitivity and radiation tolerance in the sensor part. Additionally, a narrower pitch pixel circuit and radiation tolerant circuits were partially adopted in the CMOS circuit. Their operation was tested at a cooled temperature.

(2) Technologies for integral field spectroscopy

Integral field spectroscopy (IFS) enables us to obtain spectra over an entire field of view in one exposure, which is suitable for studies on extended objects such as galaxies. Owing to this feature, IFS is becoming one of the major observing methods in optical and infrared astronomy. An integral field unit (IFU) is a key optical module realizing IFS. Generally, the IFU is a complex optical system requiring high precision, and therefore there are few institutions developing an IFU. ATC has developed basic technologies for the IFU such as manufacturing technology of an image slicer which is a key device of the IFU. In FY 2023, we improved the assembling jig for an image slicer to improve assembling accuracy, and conducted measurement tests of the reflectivity measurement system we developed. In parallel, ATC is now developing an IFU to verify the basic technologies developed so far, and plans to conduct a test observation using it. In FY 2023, we finished the optical designing of the IFU and carried out its conceptual mechanical designing.

(3) Adaptive Optics Technology

The adaptive optics system, which improves the accuracy of imaging and spectroscopy by correcting turbulent wavefronts, is becoming an important technique in optical and infrared astronomy. Basic studies on adaptive optics are in progress at the Advanced Technology Center of NAOJ. The experimental adaptive optics system is built for the purpose of such basic studies, and this year, modifications were considered to improve the speed and the sensitivity of the wavefront sensor and the stroke of the deformable mirror. Also, the use of this experimental system as a light source with highly accurate wavefront control is in consideration, for use in experimental studies of phase diversity method as the method of wavefront measurement in the development of TMT/IRIS, and the elemental experiments were carried out in this year. Besides the experimental adaptive optics system above, the basic studies on a phase contrast wavefront sensor, to realize high accuracy under low-light levels by using Zernike interference, are continued while considering the details of experimental realization.

(4) Terahertz Technology

The terahertz experiment group supports developments of superconducting detectors, cryogenic electronics, and cryogenic systems. In 2023, evaluations of submillimeter-wave SIS photon detectors as well as cryogenic readout electronics composed of two-stage source followers were made in a cryostat for optical evaluation of terahertz intensity interferometry. For cryogenic system development, two 0.8-K sorption coolers were recycled alternately to realize continuous cooling. Wide bandwidth readout of the detector signal and measurements of intensity correlation are the next step.

The MKID camera development in collaboration with University of Tsukuba was delayed due to a cryogenics malfunction, but development of lumped element kinetic inductance detectors (LEKID) were made in collaboration with a French group for future installation on the Nobeyama 45-m telescope.

The Antarctic astronomy program was promoted in collaboration with University of Tsukuba, Kwansei Gakuin University and the National Institute of Polar Research. Evaluation of 30-cm antenna performance and receiver development were made at the University of Tsukuba. The basement of the telescope, wind power generators, and battery systems were sent out and received in Showa-station, Antarctica.

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 four teams: thermal and mechanical engineering, optics engineering, sensor engineering, and systems engineering. In FY 2023, as in the previous fiscal year, we continued to respond to requests from projects both inside and outside NAOJ, and worked on instrument development, focusing on design work. In addition, a female research engineer specializing in systems engineering was hired and a team was set up organizationally to improve the systems engineering capability.

(1) Thermal and Mechanical Engineering Team

The team continued the mechanical design and related tests of TMT/IRIS, TMT/STR, KAGRA, SOLAR-C, and JASMINE from FY 2022. In addition, the mechanical design of SUBARU/GLAO was newly started in FY 2023.

TMT: For TMT/IRIS, we continued to address the issues raised at the final design review meeting (FDR1). In preparation for FDR2, we conducted thermal and structural analyses using the Imager finite element model, mirror deformation measurement at cryogenic temperature, design of a NFIRAOS simulator, and optimization of mechanical design to accommodate the updated optical design.

TMT/STR: As a follow-up to the Production Readiness Review conducted in FY 2022, NAOJ expanded the scope of checking the consistency between requirements and fabrication drawings, and confirmed that manufacturing drawings appropriately reflected the requirements. Preparatory work is continuing for the resumption of production.

SUBARU: The critical design of the WFS electrical cabinet

and LGSF platform/cooling system started, and the team focused on compiling the design constraints. The team also contributed to design improvements for the entire subsystem by identifying issues on the preliminary design.

KAGRA: We took turns performing operational work during the O4a observations and are continuing on-site work for earthquake restoration following the Noto Peninsula earthquake in January. In instrument development, two types of OMC dampers were designed and provided. In addition, a conceptual study of a KAGRA Filter Cavity (KFC) compact vibration isolator was conducted.

Spaceborne Instrumentation: For SOLAR-C, the team assisted in the coordination of the thermal-structural interfaces between the telescope and onboard equipment among the international partners, and also contributed to the delivery of the telescope development specification in terms of systems engineering, including requirement definition. For JASMINE, the conceptual study of the Detector Box Unit was continued, and one of the feasible solutions was proposed for the MDR. The thermoelectric cooler and the thermal strap, identified as technical risks, were characterized at operational temperatures (200 K).

Other projects: For the Seimei telescope Tricolor CMOS Camera and Spectrograph/TriCCS, detailed design, manufacturing, assembly, and alignment measurement were performed that satisfied the installation accuracy and adjustment accuracy of the optical elements for the field spectrograph. For the South Africa Near-infrared Doppler/SAND, the basic design of the mirror holders that includes an alignment plan and adjustment mechanisms was done. The required specifications were confirmed to be met by structural analysis and modal analysis. Manufacturing drawings and design documents were prepared, and manufacturing and assembling test were also done.

(2) Optical engineering team

The optical engineering team is responsible for the development of optical systems and specialized coatings in astronomical instrument development. The team is involved in numerous projects for developing astronomical observation instruments for both inside and outside NAOJ. Their tasks include optical design, analysis, measurement, alignment, and the development of optical elements. In FY 2023, they developed optical systems for multiple NAOJ projects such as SOLAR-C (EUVST), KAGRA, and JASMINE. Additionally, the team has conducted joint research and development, including (1) Development of a surface spectrograph system for the TriCCS of the Seimei Telescope, (2) Feasibility study of large space telescopes using the formation flight of small satellites with diffractive optical elements, (3) Development support for the formation flight technology demonstration satellite SILVIA (IFO).

Furthermore, they conducted follow-up activities for several joint development research projects they were involved in the previous year.

To enhance optical metrology capabilities, they established an optical experimentation environment with an optical bench and booth on an isolated footing. Additionally, they promoted the use of their optical measurement equipment and provided training for users.

(3) Sensor Engineering Team

The sensor engineering team has contributed to the development and maintenance of ALMA receivers and Subaru Telescope instruments (PFS, HSC).

For the ALMA receiver development, a mechanical design of the ALMA2 Band 8 receiver cartridge is being implemented. In addition, a measurement system for component evaluation was set up, and maintenance work on existing receivers was carried out.

For the development of superconducting devices, our team has fabricated SIS devices for a mixer in a Band 8 receiver, and evaluation of the devices is underway. Our team also conducted experiments to confirm the controllability of the current density of SIS junctions and to evaluate the performance of exposure equipment.

In the development of a next generation visible light detector, we are responsible for the overall coordination of a CMOS evaluation and the development of readout electronics.

(4) Systems Engineering Team

A systems engineering team was newly established within the system design group in September 2023. The systems engineering team supports the implementation of systems engineering in the development of astronomical instrumentation and is also responsible for creating related management documents and managing instrument manufacturing, assembly, integration, and test plans. In 2023, we conducted activities on the following two projects.

Subaru Ground Layer Adaptive Optics Project (GLAO): We worked to understand the system configuration of the entire GLAO system. Then we compiled interface information. Our final goal is to manage models and interfaces in Model-Based Systems Engineering (MBSE) software. In FY 2024, we plan to proceed with system error budget management, system requirements specifications, interface management documents, and error management tables in preparation for the Critical Design Review (CDR) scheduled for the end of 2024.

JASMINE Project: We mainly collected and organized information on the satellite service module (bus system in Japanese) in preparation for the mission definition review (MDR) scheduled in 2024. We also studied low thermal expansion material for the structures of the telescope.

5. Manufacturing Design Group

The Manufacturing Design Group engages in a comprehensive manufacturing process to fabricate experimental equipment. All three teams (Additive Manufacturing (AM) Engineering Team, Machining Engineering Team, and Measurement and Evaluation Team) are supporting equipment development by leveraging their respective expertise.

We also work with the Thermal and Mechanical Engineering Team of the System Design Group on fabrication work.

The following table shows the number of requests for FY 2023.

Table 1: The number of requests in FY 2023.

Breakdown	Number
From FY 2022	10
FY 2023	
Advanced Technology Center	25
ALMA	9
Subaru Telescope, TMT/IRIS	13
KAGRA	12
Others	
Internal organizations	19
External organizations	10
Total	88
To FY 2024	4

(1) Machining Engineering Team

The Machining Engineering Team has responded to fabrication consultations and fabrication requests ranging from major NAOJ projects to groups at ATC and open-use users.

Also, after the shape was created by the AM Engineering Team, key parts were mechanically finished.

For users who wanted to work on their own, we provided guidance as needed.

The main requests are as follows:

i. TMT/IRIS

- TMT/IRIS strength testing machine
- Alignment adjustment plate prototype

ii. ALMA

- Started production of three types of lens holders for Band 2 receivers
  (continued into 2024)
- Manufactured a test tank for Helium leak tests

iii. Others, open use

- Mechanical finishing of molded parts using metal 3D printers
  - Turnstile OMT (Osaka Metropolitan University, Yamaguchi University)
  - Magic-Tee (The Graduate University for Advanced Studies (SOKENDAI))
- Machining
  - Filter mount tube (FOXSI-4)
  - TriCCS 3-axis flexure (Kyoto University)

(2) Additive Manufacturing (AM) Engineering Team

In FY 2023, we will focus on applications based on our experience in modeling with aluminum materials and internal development to gain knowledge within the group. As for application development, we received feedback from the electrical performance evaluation of the first prototype of the Turnstile OMT for VLBI by Osaka Metropolitan University, Yamaguchi University, and others, and devised a manufacturing method to further improve performance.

As for the development of similar waveguide components for radio astronomy observation, the students of SOKENDAI designed and fabricated the Magic-Tee by modeling, and attempted the 4-port waveguide component, which has never been modeled before. For the prototype of a lightweight near-infrared FP spectrometer model requested by the University of Tokyo, a fabrication method using a combination of modeling and machining was studied in detail, and fabrication was started. It will be continued in the next fiscal year.

As for internal development, the surface treatment of molding products was studied as in the previous year, and "hybrid molding," in which a subplate is placed on a regular base plate and molding is performed on top of it, was attempted.

This is expected to be advantageous in the future, as it will make it easier to mold products that have been machined in advance and to secure the standards needed for post-processing after molding. The plan is to continue to study this issue.

In addition, topology optimization software was installed at the end of the fiscal year. In the future, we will promote the study of designs suitable for modeling, aiming to reflect them in the design and implement them in products.

(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. Using a large 3D measuring machine LEGEX910, the team is also available for requested measurements for open use.

In FY 2023, we conducted research on the latest measurement instruments and shared the information among the staff.

6. Management and Administration Group

The Management and Administration Group ensures the smooth operation of projects both within ATC and outside the Institute, including open-use. The Administrative Support Team is continuing to be widely active in office work as well as open-use, tours, and public relations. There were 41 tours with a total of 405 people in FY 2023. It is an increase of 7 tours and 115 people compared to FY 2022. It seems that there is more interest in ATC than ever before. A new social implementation program has been launched in ATC, and we added a note to the pamphlet about the efforts for the program. In addition, a leaflet for the Quantum Computer Application Project team of the Social Implementation Program was prepared, and the news page was created on the ATC website. The official ATC logo created in FY 2023 was incorporated into the web page and leaflet. Since ATC has increased the number of opportunities to exhibit at trade shows in collaboration with the Industrial Liaison Office, ATC has prepared original tablecloths. The IT Support Team continues to work on the registration of information assets and compliance with information security. Operation of the other facilities for FY 2023 are as follows.

(1) Optical shop

We are providing some optical measurement systems and technical consulting about the measurement system for open-

use users as usual and doing daily inspections in order to keep the measurement systems in good condition.

In FY 2023, we repaired the vibration-isolation table of the NH-3 (Point autofocus probe 3-D measuring instrument), calibration of LEGEX910 (large scale 3-D measurement machine), and replaced the lamps of the UV-Vis-NIR spectrophotometer UV3600. In addition, the Optical shop is maintaining clean and stable operation with the cooperation of the Optical Design Team of System Design Group. The number of users in FY 2023 is as follows.

- The number of users for open use
  - The number of annual users: 412
    NAOJ: 353 (including 141 from ATC)
    External organizations: 59
  - Use of LEGEX910 (large-scale 3-D measurement machine): 33
    Number of operating days: 36
- Technical consulting for users: 32
  - Giving lectures on how to use the measurement instruments
  - Technical support on measurement methods

(2) Space chamber

As part of project experiment and development support, we assisted fundamental experiments and outgassing measurements of materials used with vacuum chambers by projects such as SOLAR-C. We also provided our 3D CAD model of a vacuum chamber to a project. In terms of facility management, we replaced and repaired a turbo molecular pump in a medium-sized vacuum chamber. Software for measuring instruments used by users has been continuously developed and operated. Furthermore, safety measures are being studied and implemented for working at heights associated with vacuum chamber operations.

(3) Facility Management and Operation Team

The Facilities Management and Operations Team performed periodic inspections of the building, electrical equipment, cold evaporator (CE) equipment, cranes, forklifts, draft chambers, and other equipment as required by law, as well as the overall operation and renovation plans for laboratories, including clean rooms (CR), construction, hazardous materials, and laboratories. In addition, we supplied and managed frequently used organic solvents in ATC and performed procedures for liquid waste disposal. In addition, the Facility Management Team has taken the lead in organizing meetings as needed for people who were unable to attend the NAOJ safety training course (including CE practical training) in the spring. In response to the revision of the Occupational Health and Safety Law, a new employee with expertise in chemicals was hired, and work began on the management of chemicals and the establishment of an operational system. Moreover, we are promoting the acquisition of qualifications for team members and encouraging them to share inspection and operation duties for each facility.

7. Maintenance Group

The ATC Maintenance Group was established on February 1, 2024 to centrally manage the resources allocated to each observatory for telescope maintenance and operation, and to make effective use of resources within NAOJ. Similar to the matrix structure already in place at ATC, the group aims to collect common and individual issues related to telescope maintenance and operation and provide telescope maintenance and operation services to each observatory.

8. Microfabrication Lab

In the microfabrication lab, measures were continued in FY 2022 to address aging facilities and equipment, as well as the introduction of ALMA2 and analysis equipment for future development.

The automated resist coater/developer and substrate cleaner were introduced at the end of FY 2023, and although they are still in the start-up phase, they have shown extremely good results, indicating that significant progress is on the way toward improving the quality of future device development.

The NbTiN sputtering machine necessary for the ALMA2 Band 10 device, which is scheduled to be developed in the future, is also performing well. With the full-scale production of ALMA Band 8 devices, the Band 8 Device Fabrication Team and a Device Control Team were established.

In FY 2024, the Device Control Team and Band 8 Device Fabrication Team will be divided and independent. The Band 8 Device Fabrication Team will focus on device production, and the Device Control Team will focus on clean room equipment, infrastructure development, equipment start-up, and process control, in order to further enhance ALMA device development.

(1) Expansion of equipment to the SIS clean room

The SIS Clean Room (CR) expansion was completed in FY 2022.

In the CR area, atomic layer deposition equipment, which will be essential for future development, has been installed, and various thin films are currently being evaluated. In superconducting devices, controlling film thickness and film quality at the atomic layer level is the key to device quality, and this equipment has laid the foundation for the development of the world's highest performance superconducting mixer. We are also planning to use the mechanical and chemical polishing system to planarize superconducting devices by multilayer layering, similar to the semiconductor process, in order to fabricate larger-scale and more precise devices in the future.

(2) Enhanced safety

In FY 2022, we made improvements to the dedicated storage rooms for devices and reticles to strengthen the management system for superconducting devices. In addition to strengthening management, in FY 2023, 16 network cameras were installed in the clean room area and 4 in the device evaluation and storage rooms to monitor the overall clean

room situation, as there are many cases of development using high-pressure gas and toxic substances, which are hazardous operations in the clean room.

In addition, in response to the increased use of process gases, gas cylinders that had been installed in the clean room were installed in a dedicated outdoor facility with a cylinder station, and are now in operation. In the future, the number of indoor gas cylinders will be reduced and centralized at the cylinder station, aiming for safer operation.

9. 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.

We make calls for these programs twice every fiscal year. In FY 2023, we accepted 14 Joint Research Development programs in the first call, and 25/4 Open Facility programs in the first/last calls. Because COVID-19 was reclassified to Class 5 (the lowest risk in infectiousness and severity) in the Infectious Diseases Control law, these programs were operated normally like before COVID-19.

10. Social Implementation Program

The Advanced Technology Center, in cooperation with the Industry Liaison Office, established a new organization in FY 2023 called the Social Implementation Program, which aims to apply the technology of astronomical instruments developed at the Center to society. This program is externally funded. The activities of the two projects are described below.

(1) Quantum computer implementation project team

In this project team, we propose a new concept of superconducting microwave amplifiers that use Superconductor-Insulator-Superconductor (SIS) mixers, which have been widely used in astronomy for radio wave observation, as amplifying elements, aiming at power consumption operation three or more orders of magnitude lower than that of semiconductor amplifiers. The amplifier utilizes the quantum noise performance and frequency conversion gain of the SIS mixers. Microwaves are amplified by up-converting them to millimeter waves with a SIS mixer and down-converting the millimeter waves to microwaves with another SIS mixer. A local oscillator signal required for mixing is also generated by a superconducting Josephson array oscillator, and everything will be integrated in a chip. This amplifier is expected to contribute to the realization of large-scale multi-pixel heterodyne receivers, fault-tolerant quantum computers, and so on. After the successful proof-of-principle demonstration of the amplifier, in FY 2023 we demonstrated that an isolator, which is one of the most important components for high-frequency circuits, can be realized by adding a phase control circuit to the two frequency mixers. This achievement was widely publicized through a web release (https://atc.mtk.nao.ac.jp/en/news/20230704/).

In addition, by utilizing the ultra-high frequency technology cultivated through the development of receivers for radio wave observation, we succeeded in establishing a high-precision material characterization technology in the millimeter wave band, which is expected to be used in Beyond 5G/6G mobile communication systems. This achievement was also widely publicized through a web release (https://atc.mtk.nao.ac.jp/news/20230808/).

(2) Adaptive optics application project team

In this project team, the studies for the possible applications of adaptive optics are pursued without being restricted to astronomy. Recently, the application of adaptive optics in satellite communication networks is in progress. The main purpose of adaptive optics in such applications is to prevent the degradation of the speed of the feeder-link which connects the ground station with the orbiting communication satellites beyond the turbulent atmosphere. In this project, development of adaptive optics for satellite optical communication is being conducted in cooperation with external organizations, in which we are contributing to the development of a control system taking advantage of our technologies for wavefront sensing developed for the ground layer adaptive optics for Subaru Telescope. In FY 2023, in addition to basic conditions for the operation of adaptive optics for satellite communication and the configuration of wavefront-sensor, the optical system concept was considered, along with improving the experimental facilities by procuring the needed instruments and the devices.

Also, the adaptive optics system developed for microscopy was expanded and reconfigured as a general purpose experimental adaptive optics system, not only for the study of microscopy but also for the study of the correction of atmospheric turbulence by appending a small telescope and turbulence generator on the system. This experimental adaptive optics system was further modified to be transportable, to carry out field studies or demonstrations outside of the laboratory. This portable, general purpose adaptive optics system is utilized for the determination of operational parameters in various applications with field experiments and is also available for the purpose of public relations by demonstrating realistic operation of adaptive optics in the expositions (Innovation Japan 2023) or visitor tours at NAOJ.

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 8 offices, 1 observatory, and 1 unit: 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), the Time Keeping Office, Ishigakijima Astronomical Observatory, and the General Affairs Office.

2. Personnel

In FY 2023, the Public Relations Center was composed of Director Hitoshi Yamaoka and the following staff members: 2 associate professors, 2 associate professors (senior lecturers), 2 assistant professors (one of whom holds concurrent posts), 2 Associate Senior Research Engineers,1 research engineer, 1 engineer, 1 unit leader, 1 project professor, 5 senior specialists, 2 project researchers, 2 research experts, 2 administrative experts, 1 research supporter, 14 public outreach staff members, and 3 re-employment staff members.

On April 1, public relations staff members Shiomi Nemoto and Manami Yuzawa arrived in the Outreach and Education Office.

On July 28, Senior Specialist PIRES CANAS LINA ISABEL (OAO) resigned.

On August 31, Senior Specialist FILIPECKI MARTINS SUZANA (OAO) resigned.

On September 31, public outreach staff member Takaaki Takeda (Outreach and Education Office) resigned.

On January 1, public outreach staff member Yumi Iwashita arrived in the Outreach and Education Office.

On March 31, re-employment staff members Ko Matsuda (General Affairs Office) and Akio Koike (Outreach and Education Office) resigned.

3. Public Relations Office

The results of NAOJ's research projects and joint research with other universities and research institutes were actively publicized through press conferences and web releases. In addition, we are producing and posting online videos and news article to widely disseminate information about topics at the forefront of astronomy and astronomical phenomena, and promoting the use of SNS. We conduct 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) Information Sharing through Various Means

The Public Relations Office runs the NAOJ website (https://www.nao.ac.jp/en/), disseminating information via the internet. In Fiscal Year 2023, the total access count for the NAOJ website was approximately 9.34 million page views. In July 2023, we renewed the NAOJ Japanese website, with the goal of improving convenience.

The Office opened X (formerly Twitter), Facebook, Instagram, and Flickr accounts in both Japanese and English sequentially from 2010, actively disseminating information on social networking services. As of the end of March 2024, the Japanese X account has nearly 277,000 followers, and the English version of the X account has more than 9,700 followers. The release of visual images on Instagram and Flickr have been conducted continuously this year.

NAOJ e-mail newsletters No.244–249 were issued, introducing research results and NAOJ hosted events. A total of about 11,100 subscription addresses have been registered (almost unchanged from the previous year).

We continued to produce videos explaining astronomical phenomena and research results, and videos introducing outreach activities, producing 16 original videos. In addition, a total of 6 livestreams were held, including astronomical phenomena such as the partial solar eclipse; Special Open House Day lectures; and livestreams of celestial objects using the 50-cm Telescope for Public Outreach. In particular, the YouTube livestream of the partial solar eclipse attracted a lot of attention, with 89 thousand live views and a total of 116 thousand views including archive views. The livestreams of celestial objects have been very popular, and in addition to distribution via YouTube, they are an official program by DWANGO Co., Ltd., which manages niconico Live, a video streaming service, and our viewers are increasing. On September 7, 2023, we conducted an international online stargazing event in cooperation with JAXA's Space Education Center. The ALMA Project, Subaru Telescope, Ishigakijima Astronomical Observatory, and various overseas observatories cooperated for this event in which a total of 200 people, primarily elementary and junior-high school students in over 7 countries and regions, participated.

(2) Research Result PR

There were 30 research result announcements (compared to 30 in FY 2022 and 23 in FY 2021). We released all the research releases in both English and Japanese. Press conferences (including online conferences) were held in connection with 4 of these releases. All releases were sent to reporters via e-mail press releases to an original media list in addition to being published online.

(3) Activities as NAOJ's Public Relations Center

In addition to the Center's regular task of aiding research result releases, in order to raise awareness of NAOJ overseas, NAOJ holds booths at international conferences where the press, researchers, and educational officials gather. This year, we exhibited at the American Association for the Advancement of Science Annual Meeting (AAAS2024, February 15–17, 2024, Denver). At APRIM 2023 (August 7-11, 2023) we cooperated with the OAO (Office for Astronomy Outreach) and the International Astronomical Union. To support outreach efforts of other projects, we contributed to the creation of the Harassment Prevention Committee website and the renewal of the 4D2U project website.

The Citizens Astronomy project "GALAXY CRUISE" conducted with the support of Subaru Telescope, is continuing its second season, which targets fainter galaxies, and also ran the "2023 Special Campaign" from September 12, 2023 until the end of March 2024 to classify simulated galaxies. In addition, a year-end campaign with free giveaways was held. As of the end of March 2024, a total of 12,615 people from 109 countries and regions (including 8,428 participants from Japan) had registered to participate. This fiscal year, in addition to many presentations at research conferences, two scientific reports were published.

(4) New Astronomical Objects

In cooperation with the Outreach and Education Office, four staff members handled reports of new astronomical objects and other communications submitted to NAOJ. In this fiscal year, there were a total of 60 reports including confirmation requests for new celestial object candidates and other reports. The contents were: 44 novae/supernovae/transient objects, 8 comets/cometary objects, 4 luminous object, and 4 moving objects. Among many reports of previously known celestial bodies, photodetector errors, or ghosts as new objects, the following discoveries and independent discoveries where handled: independent discovery of nova V1716 Sco (April 2023), independent discovery of nova V6598 Sgr (July 2023), discovery of comet C/2023 P1 (Nishimura) (August 2023), discovery of supernova(SN) 2023zvq (December 2023), discovery of nova V6620 Sgr (January 2024), and three independent discoveries of nova V4370 Oph (March 2024). In addition, a total of 17 dwarf novae and flare stars were reported.

4. Outreach and Education Office

Accompanying the reclassification of COVID-19 to Class 5 on May 8, 2023, restrictions on Public Visits were lifted.

(1) Public Visits

A total of 15,508 people participated in Mitaka Campus Public Visits (former name was Visitors' Area) in FY 2023. In addition, the group tours in 2023 consisted of 83 general tours (2,704 guests), for a total of 18,212 guests visiting Mitaka Campus.

Regular stargazing parties were held twice a month (the day before the 2nd Saturday [online] and the 4th Saturday [onsite/advance registration, limited capacity]). Online events were held 9 times, reaching up to 909 simultaneous connections, and accumulated 10,429 views as of the end of March 2023. Onsite events were held 11 times, and a total of 749 people participated.

Regular public screenings at the 4D2U Dome Theater were scheduled to be held three times a month (1st, 3rd Saturday, and the day before the 2nd Saturday) on a reservation basis. Screenings were held on 35 days during the year, and 3,314 people participated. In addition, a total of 1,154 people participated in 44 group screenings. "Astronomers' Talks" mini-lectures were not held. There were also 56 inspection group tours, etc. (886 people) organized and a total of 5,354 guests watched the 4D2U movies.

(2) Telephone Inquiries

Telephone inquiries are accepted from 9:30 to 17:00 on normal business days, with 1 person assigned to this duty. With the introduction of the Working from Home System, the duty is also being appropriately handed from home in some cases. The number of telephone inquiries to which we responded this fiscal year totaled 3,355, of which 336 were from the media. The topics (and number) of the inquiries were: Solar Ephemeris (318), Lunar Ephemeris (293), Ephemeris (79), Time (22), Solar System (693), Universe (269), Astronomy (239), Other (1,442).

Due to the time required to respond to letter inquires where the content of the letter cannot be easily understood and other reasons, we stopped accepting letters from the general public at the end of FY 2022. But in FY 2023, as a transitionary measure to disseminate information about the new system, one letter per writer was accepted. We continued to accept questions from elementary/junior-high/high students and others enrolled in an educational curriculum and official documents. The number of letter inquiries totaled 30, of which 22 were official documents.

(3) Media Reception

We received 115 interview and filming requests from various media, out of which the following filmings were conducted: 32 newspaper articles; 33 TV programs (12 news programs, 21 others); 9 publications; 14 websites and contents; 3 radio programs; 4 others. There were no requests for charged commercial filming or photography.

(4) Educational and Outreach Activities

The "FUREAI (Friendly) Astronomy" project, now in its 14th year, continued to provide classroom visits and online lectures as in the previous year. These lectures were delivered at 117 schools, 83 in Japan and 34 overseas, by 72 instructors and attended by 7,914 pupils, with the number of attendees per lecture ranging from 4 to 510. In 14 years, 98,495 students in total have attended the lectures in 1,130 schools inside and outside Japan.

"Mitaka Open House Day" was held primarily on-site. We participated as part of the secretariat under the direction of the steering committee, and contributed to some of the displays and content. This year's event was held on October 28 (Saturday) with the theme "The Universe Explored by Supercomputers and AI." 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 Astronomical Science Program at the Graduate Institute for Advanced Studies of the Graduate University of Advanced Studies. Hands-on exhibits, mini-lectures, tours of research facilities usually inaccessible to the public, etc. were restarted and 1,114 people selected from among the applicants participated. It was a lively Open House Day. The two main lectures were streamed online, and they had a maximum total of 1,169 simultaneous connections, and the total number of views in the first three weeks after release was 14,945.

(5) Community Activities

The "Mitaka Picture Book House in the Astronomical Observatory Forest" welcomed 30,082 visitors in FY 2023. The Office supervised an exhibition, "Watery Planet" (July 2023 to June 2024). We also cooperated with an opening ceremony, modern and traditional Tanabata events, moon viewing event, and other events. 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 6 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 in FY 2023 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 sotargazing 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" which held its 200th event in March 2024.

The "Information Space of Astronomy and Science," jointly established with Mitaka City, Mitaka NETWORK University Organization, and Mitaka Town Management Organization, marked the 8th anniversary since its opening in September 2015. In FY 2023, a total of six exhibitions were held at this facility. In addition the permanent display panel, "Gazing into space, NAOJ Challenges the Mysteries of the Universe" was planned and produced by NAOJ, and was displayed 3 times: from June 9 to July 23, September 29 to October 15, and December 1 to January 7. The total number of visitors was 12,364 in 2023, almost the same as the previous year.

(6) Content Creation

We run "Astronomical Events Information" on the NAOJ website to provide monthly star charts and information on planetary and other remarkable astronomical phenomena. We created a breaking-news page in response to Comet C/2023 P1 (Nishimura), whose discovery was reported through NAOJ in August, and which then brightened in September.

This fiscal year, intended particularly for the media, documents detailing the remarkable astronomical phenomena of the year (the solar eclipse on April 20 which could be seen as a partial eclipse from parts of Japan, and the Geminid meteor shower in mid-December) were created and posted on "Astronomical Events Information."

5. Spectrum Management Office

The Spectrum Management Office (SMO) is tasked with protecting the astronomical observation environment from visible light to radio waves. The SMO currently consists of three members, of which two are dedicated members (Head and a research supporter) and one holds a concurrent post. SMO members participated in 5 international meetings and 33 domestic meetings this year. In addition to these, the SMO also participated in email discussions organized by the Ministry of Internal Affairs and Communications (MIC) and responded to requests from MIC to study frequency sharing with experimental radio transmitters. In addition, the Radio Astronomy Frequency Committee met three times where parties involved in radio astronomy in Japan engaged in the exchange of information and opinions.

(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 also participated in the World Radiocommunication Conference (WRC) held once every three to four years, and contributed to the discussion. This year's WP7D meetings were held from October 5 to 11, in a hybrid format online and at the ITU headquarters. The main topics on the agenda were the study of compatibility between radio astronomy and cell phones in 43 GHz, harmonics in radio astronomy bands, and revisions of the ITU-R recommendation on spectral lines important to astronomy, and preparation of a report on protective measures against harmful interference to radio astronomy observations conducted from the Shielded Zone of the Moon. WRC was held from November 20 to December 15 at the Dubai World Trade Center. Many topics were discussed, ranging from cell phones to satellite communications, but none of the topics discussed this time will have a significant effect on radio astronomy observations. Agenda items for the next WRC in 2027 were also discussed and two new agenda items closely tied to radio astronomy were approved: protection for radio astronomy from satellite constellations; and protection for radio astronomy and Earth observation satellites from active radio services utilizing bands above 76 GHz. Based on this, a WP7D meeting was held from March 19 to 22, and discussed how to respond to the WRC agenda. The SMO also participated in 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 and Broadband Wireless LAN: In response to the growth of transmission traffic, discussions were held on how to respond to the IEEE802.11be wireless LAN standard with a maximum bandwidth of 320 MHz. These frequency bands are already used for wireless LAN, so no new effects on radio astronomy are expected. On the other hand, discussions continued regarding the frequency expansion of the 6 GHz band (6425–7125 MHz) investigated in previous years. In this frequency band, radio astronomy is protected in the frequencies around the CH_3OH maser emission line (6.6650–6.6752 GHz). Discussions continued regarding the introduction of a mechanism to prohibit radio emissions or adjust the output power of wireless LANs only in areas around radio telescopes and other users' radio stations. This investigation will be carried over to FY 2024.

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 and radio astronomy are supposed to use the same frequency band. Discussion with radar manufacturers to prevent radar systems from interfering with radio astronomy observations started in January 2022, but no progress was made in FY 2023.

3) Sharing Study for 90 GHz Band Airport Runway Surface Foreign Object Detection Radar: Foreign object detection radar has been developed to prevent aircraft from accidentally colliding with foreign objects which have fallen onto the surface of an airport runway. Based on the results of the technical study conducted in FY 2019, a working group of the MIC started discussion from October 2023. A sharing study was conducted for radio astronomy in the 81–109.5 GHz frequency band, and it was shown that a necessary condition for use is that in the case that the radar and radio telescopes face each other, a separation of 112 km is needed; and if a separation distance of 112 km cannot be secured, the radar should be installed so that it is facing away from the radio telescope.

4) In March 2024, a study on the technical conditions for mobile satellite communication systems using non-geostationary satellites was initiated. Technical conditions are being studied for two systems: Ka-band (20/30 GHz band) communications using a satellite constellation at an orbital altitude of about 600 km, and 2 GHz communications for mobile phones using a satellite constellation. Since both of them are close to, but do not overlap with, frequency bands assigned for radio astronomy, we are participating in discussions to insure that observations in these frequency bands are not affected.

(3) Light Pollution:

There are concerns about the detrimental effects to astronomy from mega-constellations such as Starlink and OneWeb comprised of a large number of satellites. In response to these concerns, the International Astronomical Union established the Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS) in 2022 and in August 2023, the SMO submitted an application to participate on behalf of NAOJ. In addition, IAUS385 Symposium on "Astronomy and Satellite Constellations: Pathways Forward" was held in La Palma in October 2023 to discuss this issue. The SMO also participated in it for information gathering.

As for the light pollution on the ground, the SMO hosted a research meeting as the first step to understand the mechanisms of light pollution and study mitigation measures in September 2023 and had 99 participants. This is the first research meeting in Japan to focus on the scientific aspects of light pollution. The SMO continued to participate in the night sky brightness survey using digital cameras conducted by the Ministry of the Environment and submitted the results of measurements in Mitaka City and Chichijima Island in the Ogasawara Islands.

(4) Activities for Raising Awareness of Frequency Resource Management

To make more people aware of frequency resource management, the SMO participated in the Special Open House Day of Nobeyama Radio Observatory and Mitaka Open House Day 2023, explaining our activities to the guests. In FY 2023, there were 13 media interviews about negative impacts on astronomy by light pollution from ground-based sources or mega-constellations, and those situations were covered by television, newspapers, web articles, etc. Also, on May 31, 2023, the head of the office gave a lecture on spectrum management as part of the online seminar "The Cultural Relevance of Dark and Quiet Sky Protection" hosted by the IAU Office for Astronomy Outreach (OAO).

6. Ephemeris Computation Office

(1) ECO published the "Calendar and Ephemeris 2024" and compiled the ephemeris section and several parts of the astronomy section from the "Rika Nenpyo 2024" (Chronological Scientific Tables). ECO also posted the "Reki Yoko 2025" in the official gazette on February 1, 2024. In addition to those paper-oriented products, ECO maintains web versions of the "Calendar and Ephemeris" and updated their data simultaneously with the release of "Reki Yoko." On May 1, ECO posted a PDF version of the "Calendar and Ephemeris 2024" on its website. Also, in cooperation with the Office of International Relations, we promoted the "Handbook of Scientific Tables" -The international edition of Rika Nenpyo- through leaflet distribution and sample presentations at the APRIM 2023 and American Astronomical Society meetings.

(2) ECO featured the annular-total solar eclipse; partial lunar eclipse; and the 1st sunrise of the year on its website. In cooperation with the "Astronomical Events Information" by the Outreach and Education Office, ECO displayed the radiant points of the Perseid and Geminid meteor showers; and the location of Comet Nishimura and Comet Pons-Brooks in the

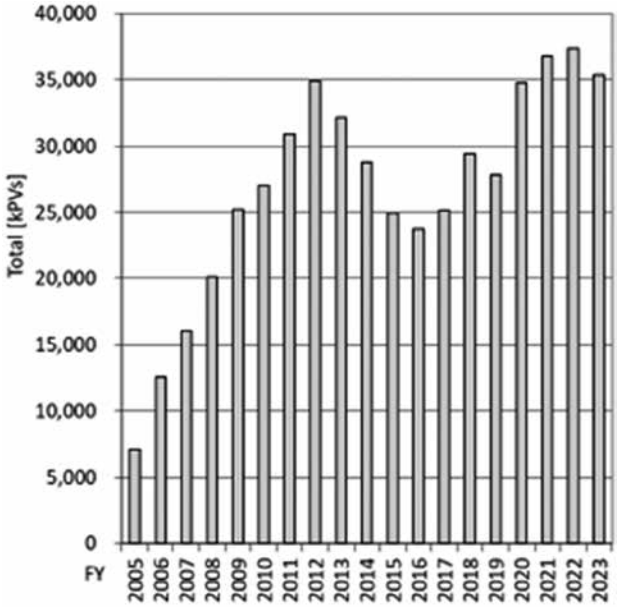


Figure 1: Pageviews for ECO Website.

Sky Viewer. In FY 2023, there were over 35 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 hosted Mini Forum, its 13th General Meeting, and the Calendar Presentation Ceremony. These were also delivered via a remote conference service.

(4) ECO holds regular exhibitions presenting NAOJ's invaluable collection of historical archives of Japanese and Chinese books in collaboration with the library. The theme of the 61st regular exhibition was "Seigaku Shukan - the National Important Cultural Property." Past exhibitions are available at the following site.
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. With the continuing digitalization of scientific materials, it has also become our responsibility to ensure access to electronic media academic resources.

The Mitaka Library, which had been closed during the COVID-19 pandemic, reopened to non-NAOJ affiliated users on weekdays starting from May 15, 2023. The library also 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, 60 materials were provided this fiscal year. Remote services, requesting books from other libraries, were also provided for NAOJ users.

The library holds many important documents, the most prominent of which are those written by the Tenmonkata, Shogunate Astronomers of the Edo Era. Among these, the Seigaku Shukan was named an Important Cultural Property of Japan on June 27, 2023. 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.

For the Mitaka Open House Day 2023, held 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 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 education and outreach. The following periodicals were also published this year:

- Annual Report of the National Astronomical Observatory of Japan Volume 35 Fiscal 2022 (Japanese)
- Annual Report of the National Astronomical Observatory of Japan Volume 25 Fiscal 2022 (English)
- 24th Report of the National Astronomical Observatory of Japan (Digital Publication Only)
- NAOJ 2023 Pamphlet (Japanese)
- NAOJ News, No. 340–No. 342 (Spring-Summer 2023, Autumn 2023, Winter-Spring 2023–2024)
- NAOJ Calendar (The 19th in the series)

Copies of NAOJ News for distribution were sent to schools and community facilities in Mitaka City, as well as member institutions of the Japanese Society for Education and Popularization of Astronomy, planetariums, and public observatories nationwide. Website development is continuing for the shift to digital publication. In new publications, the Japanese edition of the Sandcastle TRPG was released.

9. IAU Office for Astronomy Outreach (OAO)

The International Astronomical Union Office for Astronomy Outreach (IAU OAO) is a joint venture between the IAU and the National Astronomical Observatory of Japan (NAOJ). The OAO is primarily responsible for supporting the IAU's goal of engaging the general public in the science of astronomy through accessible and equitable astronomy communication. The OAO additionally manages the international network of IAU National Outreach Coordinators (NOCs) in over 120 countries and regions and with more than 350 volunteer representatives. Despite experiencing two resignations this fiscal year, the OAO has continued to deliver an exciting and impactful array of projects and programs.

The Office is working on the next agreement between the IAU and NAOJ, securing our partnership for another six years.

As an example of our dedication to supporting NAOJ in its international efforts, in August 2023, the OAO collaborated with the Local Organising Committee for the Asia-Pacific Regional IAU Meeting (APRIM) 2023 in Koriyama, Japan, to bring together an international group of professional and student astronomers. At this meeting, we organized an IAU booth and a special OAO session that were both well received by conference attendees. Beyond the 2023 APRIM meeting, the OAO represented NAOJ at four additional international meetings, extending NAOJ's reach beyond Japan. More locally, the OAO continues to support NAOJ in its Open House Day and GALAXY CRUISE initiatives.

In addition to these efforts, we highlight the Communicating Astronomy with the Public (CAP) Triptych, which comprises CAP Conference, CAP Journal, and CAP Training. In 2023, we announced the location of the 2024 edition of CAP Conference, which will be held in Toulouse, France at Cité de l'espace and online. This year, we began our efforts to coordinate the CAP 2024 Conference, working closely with the LOC to produce an exciting in-person and virtual experience. CAP Journal, the only professional journal for astronomy communication, produced two issues in 2023: a special edition highlighting some of the most impactful works from the CAP 2022 Conference, and a special edition celebrating the 100-year anniversary of the planetarium. In early 2024, we anticipate publishing the second part of our special edition on the planetarium's centenary, showcasing planetarium stories worldwide. Our CAP Training program this year focused on the NOCs in support of the full schedule of their OAO-funded projects, from conception through to project management.

In September 2023, the OAO underwent an external review. The panel was excited about the OAO's progress toward its and the IAU's goals and provided important suggestions on how to improve the OAO's impact in the years ahead. Some highlights from this year include: over 450 initiatives engaging people in 65 countries and regions that were registered in our 2023 Events Calendar; tens of thousands of people reached through the OAO social media and communication networks; and annual projects such as Women and Girls in Astronomy, Dark and Quiet Skies, and 100 Hours of Astronomy, two of which were supported by our second science communication intern from Leiden University.

10. Timekeeping Office Operations

The Time Keeping Office operates four cesium atomic clocks together with a hydrogen maser atomic clock at Mizusawa VERA Station, and constructs "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. Three of the cesium atomic clocks continued stable operation at Mizusawa Campus throughout this fiscal year, while routine maintenance was carried out on one of the clocks. Site preparations continued in order to move the atomic clocks to Mitaka Campus. 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 2.4 million daily visits have been recorded.

11. Ishigakijima Astronomical Observatory

FY 2023 saw an increase in visitors to the facility. In public outreach, we increased both the number of days the facilities are open and the number of hours per open day. The facilities were open to the public throughout the year, and the total number of guests was 5,435. Moreover, the observatory was involved in activities such as broadcasts of astronomical events. In education, we welcomed group tours and inspections (457 guests), and visiting lectures, etc. were given. In research, 1 refereed paper was published, bringing the total number of papers published based on data from Ishigakijima Astronomical Observatory to 32.

(1) Public Outreach Activities

[Guided Tours, Space Theater, Stargazing Sessions]

The facility was opened to the public through cooperation with Ishigaki City, Ishigaki City Education Committee, and Specified Nonprofit Corporation Yaeyama Hoshinokai. The annual number of visitors was 5,435, and the cumulative number of visitors was 159,598.

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

We were involved in photography for public outreach including the partial solar eclipse; photography and streaming videos with the "Southern Cross Monitor" and "Milky Way Monitor;" and online activities including a broadcast of the partial solar eclipse and international online astronomical telescope events. The "Southern Island Star Festival" we co-hosted in August had approximately 3000 participants. And 300 people attended the star festival held in Iriomote Island in September which we also co-sponsored. There were 49 articles in newspapers and other media, and there were 47 cases of assistance with news gathering. In January, 6 organizers were awarded the NAOJ Director General's Prize for "stable operation through regional cooperation and important contributions to education and outreach as well as scientific research." The 3,200 km "Stamp Rally" held with Nayoro Observatory KITASUBARU had 39 people complete it.

(2) Educational Activities

There were 5 inspections (29 guests) and 21 educational group tours (428 guests) held in cooperation with Ishigaki City, Ishigaki City Education Committee, Specified Nonprofit Corporation Yaeyama Hoshinokai, and the Ishigaki Youth House. The Chura-boshi Research Team Workshop for high school students in August hosted 23 participants from across Japan, and the results were reported at the Junior Session of the Astronomical Society of Japan. We also worked for local education activities, including lectures at University of the Ryukyus (55 attendees), collaborative activities with the Hachioji City Children's Science Museum (108 participants),

and a lecture at the Ishigaki City Retirees' University (30 participants).

(3) Research Activities

One refereed paper in a western journal was published in FY 2023, on the topic of Starlink satellites. The total number of papers including results based on Ishigakijima Astronomical Observatory observational data reached 32. There were 9 presentations at domestic conferences and 5 presentations at international conferences. In observations, collaborative observations with universities were conducted on SN 2023gps; in addition a web release highlighted our successful observations of the afterglow from GRB230723B.

17. Division of Science

1. Overview

We will report on the FY 2023 research activities in the Division of Science based on the following vision and philosophy of the division:

- Achieve fruitful research results through liberal ideas of individuals and achieve world-leading scientific results. Expand 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, we nurture creative ideas that can lead to new fields.

- Utilize large telescopes and supercomputers at NAOJ to achieve top-level research results as a world-leading research division. Contribute to promoting future plans of NAOJ from a scientific perspective.

- Actively promote the education of young researchers, including graduate students, to attract both Japanese and international researchers in the next generation who will lead worldwide research activities. Become a career path center for astronomical researchers worldwide.

- Foster collaborations with Japan domestic and international researchers, including those in other NAOJ projects, to advance astronomy research and create new scientific breakthroughs. Play an important role in promoting internationalization in Japan's astronomical field.

The members of the Division of Science cover a wide variety of themes in astronomy research, from the early Universe to the 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 - including dynamics and material evolution. Taking advantage of the facilities of NAOJ, such as the supercomputers of NAOJ, the Subaru Telescope, ALMA, and the Nobeyama radio telescope, the division fosters collaborations among theoretical and observational astronomers working across different wavelength ranges. We conduct interdisciplinary astronomical research with the physics of neutrinos, gravitational waves, elementary particles, atomic nuclei, and planetary science. The division members are also actively involved in developing scientific projects for future observational missions.

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. We have arranged opportunities for interaction among members with an all-member workshop with external invited speakers, science colloquium, and social events in a hybrid format. The division actively organizes international and domestic workshops to promote research activities in various related fields of astronomy and astrophysics.

2. Current Members and Transfers

In FY 2023, the dedicated faculty members of the Division of Science included five Professors, three Associate Professors, two Project Associate Professors, and seven Assistant Professors, in addition to one adjunct Professor, one adjunct Associate Professor, and one adjunct Assistant Professor, who concurrently held a primary position at the Center for Computation Astrophysics (CfCA). In addition to these faculty members, the division was served by ten Project Assistant Professors including NAOJ Fellows, four Project Researchers, seven Japan Society for the Promotion of Science (JSPS) Postdoctoral Fellows, one JSPS International Research Fellow, one East Asia Core Observatories Association (EACOA) Fellow, one NINS Project Researcher, and two Research Supporters. Two Administrative Experts, including one who resigned in December 2023, and one Administrative Supporter, from March 2024, gave full support to all activities of the division.

3. Output of Our Research

There were 218 refereed research papers published by the division members as authors. The research highlights listed at the beginning of this report include some of the research results. Research in which division members took leading roles includes the following:

- Quantum kinetic neutrino transport simulations (Nagakura)
- Rapid Increase in Oxygen in Early Universe (Nakajima, Ouchi et al.)
- Rayleigh and Raman Scattering Cross-sections and Phase Matrices of the Ground-state Hydrogen Atom, and Their Astrophysical Implications (Kokubo)
- Discovered at Last! Stochastic Gravitational Waves Background – Implications of 15 Years of NANOGrav Data –. (Kohri)
- Gravitational wave astronomy: optical follow-up observation of binary black hole coalescence (Tominaga)

Research highlights on the division's website (https://sci.nao.ac.jp/main/articles-en/) include the following results:

- Does Light Emerge from a Black Hole Merger? Subaru+GTC Collaboration to Target Gravitational Wave Events (Ohgami, Tominaga et al.)
- First Detection of Hot Molecular Cloud Cores in the Small Magellanic Cloud (Shimonishi et al. incl. Furuya)
- A radio-detected Type Ia supernova with helium-rich circumstellar material (Kool et al. incl. Moriya)

- Reveal chemical links involving NH_2CHO that contains a peptide bond around high-mass protostars (Taniguchi et al.)
- Electromagnetic emission from black hole mergers in a giant disk of gas (Tagawa et al.)
- Newly discovered molecular clouds that may be interacting with the astrophysical jets of the most active microquasar in our galaxy (Sakemi et al. incl. Machida)
- Observations of High-Mass Star Seeds Defy Models (Morii and Nakamura et al.)
- Discovery of a new type of carbon-chain chemistry around massive young stellar objects – Hot Carbon-Chain Chemistry (HCCC) – (Taniguchi, Nakamura et al.)
- Molecular Filament Shielded Young Solar System from Supernova (Arzoumanian, Kobayashi, Iwasaki, Kokubo et al.)
- The Automated Reaction Pathway Search Reveals the Energetically Favorable Synthesis of Interstellar CH_3OCH_3 and $HCOOCH_3$ (Komatsu and Furuya)
- Rapid Increase in Oxygen in Early Universe (Nakajima, Ouchi et al.)
- Did the Solar System Originate 10,000 Light-Years Away? (Baba et al.)
- The James Webb Space Telescope discovered numerous supermassive black holes in the distant universe (Harikane et al. incl. Zhang, Nakajima, Ouchi, and Hatano)

4. International and Domestic Collaborations and Cooperation

(1) International and Domestic Workshops

The division members organized or co-organized the following international and domestic workshops as a hub of science activities, collaborating with international and domestic colleagues. This contributed to stimulating research activities in astronomy and cross-disciplinary fields.

International Meetings:

- Cosmology and Particle Astrophysics (CosPA) 2023 - (November 10–13, 2023, at The Chinese University of Hong Kong, Hong Kong)
- KEK-Cosmo 2024 "Statistical Analysis of Random Fields in Cosmology" - (March 4–9, 2024, at KEK Tsukuba)
- Magnetic Fields from Clouds to Stars (Bfields-2024) - (March 25–29, 2024, at NAOJ Mitaka)

Combined Domestic and International Meetings:

- Galaxy-IGM Workshop 2023 - (July 31 – August 4, 2023, Act Tower, Hamamatsu)
- Galaxy Mini-Workshop - (November 13, 2023, Univ. of Tokyo)
- Milky Way Workshop 2024 - (March 6–8, 2024, Kagoshima-Univ.)

Domestic Meetings:

- MHD2023 - (August 21–23, 2023, at Chiba-Univ.)
- W50/SS433 Workshop 2023 - (September 4–6, 2023, NAOJ Mitaka)
- 12th Observational Cosmology - (December 11–13, 2023, Saga-Univ.)

(2) International Organization Committees and Reviews of International Funds

- The Association of Asia Pacific Physical Societies (AAPPS) / Division of Astrophysics, Cosmology and Gravitation (DACG) (executive committee: Kohri)

(3) International and Domestic Observation Projects

To proceed with 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 promoting international and domestic future astronomy plans, including those for large telescopes in NAOJ from a scientific perspective.

- CALET (theory group: Kohri)
- CTA-Japan (theory group: Kohri)
- DECIGO (theory group: Kohri)
- Einstein Telescope (ET) (Kohri)
- Euclid Supernova and Transient Science Working Group (Lead: Moriya)
- FIR probe (Nomura)
- GREX-PLUS (Nomura; Ouchi; Moriya; Nakajima)
- Habitable Worlds Observatory (Nakajima)
- HST Cycle 31 Review (External reviewer: Ouchi)
- JASMINE (Kohri)
- JWST Cycle 2 Review (Panel member: Ouchi)
- KAGRA (KAGRA Scientific Congress (KSC) member: Kohri)
- LAPYUTA (Science goal 3 Chief: Ouchi)
- LiteBIRD (Publication Board member: Kohri)
- Magic (theory group: Kohri)
- NINJA (project scientist: Moriya)
- Roman HLTDS CCS definition committee (Moriya)
- Roman Space Telescope SPQR Project (Member: Ouchi)
- SKA1 sub project (Head of Science: Machida)
- SKA-JP steering committee (public relations: Machida)
- SKA-JP High-z Universe and Galaxy evolution /Cosmology (Kohri)
- Subaru SAC (Moriya)
- Subaru PFS survey Galaxy Evolution Team (co-chairman: Ouchi)
- TMT JSAC (Tominaga)
- TMT ISDT (Nakajima)
- ULTIMATE-Subaru (science working group: Moriya)
- VLBI advisory committee (Machida)
- Group of Optical and Infrared Astronomers (GOPIRA) Future plan review expert committee (chair: Ouchi)

5. Educational and Outreach Activities

The division promotes the education of young researchers, including students at graduate schools. In FY 2023, the graduate students in the Division of Science included seventeen SOKENDAI students (twelve doctoral, four master's course students, and one research student), eight students in the University of Tokyo (four doctoral and four master's course students), and one student in the University of Hyogo (doctoral course student). The members of the division delivered lectures at the University of Tokyo and many other institutes and universities. In addition, a spring school organized by the Division of Science for undergraduate students was organized in February 2024. The members also engaged in outreach activities through public lectures.

18. Library

The purpose of the National Astronomical Observatory of Japan (NAOJ) Library is to organize and preserve books and other valuable materials, and to make them available to NAOJ staff, collaborating researchers, and others who wish to conduct academic research or surveys. The library was established in 1988, taking over the collection of the Tokyo Astronomical Observatory of the University of Tokyo in the Mitaka, Okayama, and Nobeyama areas and the Latitude Observatory in the Mizusawa area. With the incorporation of NAOJ in 2004, the Library was established in accordance with Article 20.3 of the General Rules for Organization and Operation of the National Institutes of Natural Sciences (General Rules No. 1, April 1, 2004). According to the Rules of the Library of the National Astronomical Observatory of Japan (National Institute of Natural Sciences Rules No. 41, April 1, 2004), the Director of the Library is the Director of the Public Relations Center (PRC), and the administrative work of the Library is handled by the Library Section of PRC.

The collection includes many Japanese and Chinese books and documents related to the history of astronomy and calendar studies, including those originating from the Shogunate's astronomical office in the Edo period. As part of the storage and management of these materials, we have been microfilming rare Japanese and Chinese books and documents since 1984, when the Tokyo Astronomical Observatory started to do it, in cooperation with the Calendar Computation Office, and have been providing these materials to researchers. From 2009 to 2010, the microfilms were digitized and made publicly available on the website, and from 2013, digital images of the rare books themselves are being created.

In order to comply with the new application of the Information Disclosure Act related to incorporation, a new entrance for off-premises users was established in FY 2004, and began operation in April 2005. On the other hand, a common MISHOP entry card key system was installed at the existing entrance for internal users, allowing them to enter and leave the building throughout the day.

See page 082 for details on the activities of the Library Section in FY 2023, and Chapter XI, 1 (page 125) for the library collection.

19. IT Security Office

The IT Security Office (ITSO) has the following missions to ensure information security at NAOJ and to operate and protect information assets at NAOJ.

A) Managing servers that are open to the public.
B) Management education for the administrators of servers, etc., and matters related to operation rights and licenses.
C) Inspection and measures related to services for the public.
D) Management of accounts and licenses for network usage.
E) Management of recording, storage, and analysis of traffic data.
F) Management of high-level confidential information management ledgers.
G) Management of the network operation.
H) Other matters necessary to ensure information security.

Based on these tasks, ITSO is performing the following six items.

① Build and operate zero-trust and integrated communications services based on Microsoft 365 services, etc.
② Build, migrate, and operate network and telephony services.
③ Provide information service infrastructure such as virtualization and bare metal public servers.
④ Operate cost-effective external and internal network services in cooperation with various R&D networks, etc.
⑤ Conduct security-related operations (CSIRT) in cooperation with NAOJ Administrative Division, NINS, and MEXT
⑥ Collect information and collaborate with other organizations.

The highlights of our action in FY 2023 are as follows.

(1) Enhancement of Security System and International Collaboration

ITSO has assigned a staff member specialized in security to re-build the system to improve information security and information compliance; and has collaborated with APIDT (Australia) (an organization that funds Internet technology in the Asia-Pacific region) and the University of Hawai`i to upgrade the networking infrastructure, focusing on Hawai`i and Chile in particular.

(2) Replacement Plan

The replacement of the information network services system is scheduled in 2026. The main issue related to this activity is the costs for renting and operating the system. To reduce the costs, we are extending the current service contracts, reducing the size of the network facilities, and verifying low-cost equipment.

20. Research Enhancement Strategy Office

The Research Enhancement Strategy Office was established as part of the functional enhancement program of the National Institutes of Natural Sciences (NINS) to promote the enhancement of research capabilities in NAOJ. In addition, to promote cross-disciplinary research, a research agreement was concluded with the Institute of Statistical Mathematics (ISM), and two young researchers (assistant professors) were seconded from NAOJ to ISM to develop astroinformatics/astrostatics, which attempts to discover new phenomena from large-scale observational data obtained with large telescopes, etc. In terms of finance, the financial controller played a crucial role in budget planning through annual interviews with various projects, centers, a division, etc. Additionally, he contributed as a corresponding financial committee member to the East Asian Observatory, ALMA Project, and TMT Project. Furthermore, the Research Assessment Support Office and the Industry Liaison Office were established under the Research Enhancement Strategy Office to contribute to the acceleration of NAOJ's research capabilities through their respective specialized work. The activities of each office in FY 2023 are as follows.

1. Research Assessment Support Office

(1) International External Evaluation

As the secretariat of the NAOJ Project Review Committee[1], we prepared FY 2023 project reviews, i.e., the international external reviews of Mizusawa VLBI Observatory, Nobeyama Radio Observatory, and the ASTE Project, based on the committee's discussions. The office supported the reviews by three external evaluation committees (each consisting of two international and three domestic members) conducted at each campus in March 2024. Additionally, we assisted in the finalization of one FY 2022 project review report.

As a member of the secretariat of NAOJ's External Review Panel (consisting of five international and four domestic members), we prepared for the first review in nine years, the evaluation at Mitaka Campus (October 5–6, 2023), and supported the compilation of the review report[2].

(2) Participation in NINS Activities Related to Evaluation and Enhancement of Research Capabilities

We attended the "NINS Task Force on Evaluation" (Evaluation TF) and supported the preparation of institutional evaluation materials (the 2022 self-assessment report[3] and the progress confirmation table for the fourth mid-term plan) together with the NAOJ Evaluation TF (consisting of the Director of the Research Assessment Support Office Saito, Director of Research Coordination Motohara, and Associate Professor Machida) and the General Affairs Unit of the General Affairs Group.

As a member of the "NINS Collaborative Research Team" and the "NINS Research and Management Strategy Team," we regularly exchanged information on initiatives and achievements to enhance universities' research capabilities. Additionally, we participated in the "NINS Working Group on Institutional Repository Development" established under the NINS Research Collaboration Committee, and began preparations for the Ministry of Education, Culture, Sports, Science and Technology's "Open Access Acceleration Project" (Immediate Sharing of Research Results), which was open for applications at the end of FY 2023.

(3) Enhancement of Research Infrastructure

With the cooperation of various project offices and centers in NAOJ, we collected and organized IR (Institutional Research) information such as papers. Based on this information, we prepared materials, provided information, and made proposals in response to requests (mainly from within NAOJ).

As a member of the LOC for the "2023 NAOJ Future Symposium - Science Roadmap of NAOJ" (November 7–8, 2023)[4], we supported the SOC meetings and the symposium organization in collaboration with the Research Promotion Group.

2. Industry Liaison Office

(1) Collaboration with private companies

Four cases of joint research, one case of entrusted research, and two cases of commissioned business were contracted with private companies. Most cases are based on engineering, but two cases are related to knowledge of Astronomy. The variation of industrial collaboration is expanding.

(2) Participation in exhibitions

In order to promote NAOJ's technologies, we provided support for participation in exhibitions for the industrial sector.

- OPIE 23 (April 19–21): ALMA receiver cartridges, things fabricated with the 3D metal printer
- Innovation Japan 2023 (August 24–25): Adaptive optics technology
- MWE 2023 (November 29–December 2): ALMA receiver cartridges
- JST new technology presentation meeting (January 23): lecture on microwave technology

(3) Press releases on technology

In order to promote NAOJ's technologies, we issued press releases to explain the results of NAOJ's technology development research.

- Press release on successful demonstration of an isolator using connected frequency mixers (July 4). This was covered by Nikkan Kogyo Shimbun.
- Press release on a new method to measure permittivity (August 8, joint press release with NICT). This was covered by Dempa Shimbun Daily and several technical websites.

[1] https://www.nao.ac.jp/recommend/project-review-committee/
[2] https://www.nao.ac.jp/en/about-naoj/reports/external-review.html
[3] https://www.nins.jp/about/assets/b4b53312a0394676bcf0f728d4a80c03421a0f53.pdf
[4] https://www.nao.ac.jp/for-researchers/naoj-symposium2023/indexE.html

21. 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 multicultural 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.

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) and manages both the EAO/EACOA budgets within NAOJ. The EACOA consists of four core observatories representing the East Asian regions: NAOJ (Japan), the National Astronomical Observatories of China (China), the Korea Astronomy and Space Science Institute (Republic of 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. In November 2023, the EAO held its regular Board of Directors (BOD) meeting in hybrid format including in-person sessions at NAOJ Mitaka Campus. The OIR played a central role in facilitating the travel and logistics of meeting participants from abroad and handling various tasks related to its organization. In addition, the OIR provided onboarding and continuing support to three post-doctoral young researchers (EACOA Fellow) hosted by NAOJ under the EACOA Fellowship Program.

Alongside these duties, the OIR also handles legal document review, such as agreements and memoranda for international collaboration between NAOJ and overseas institutions. In FY 2023, the office reviewed a total of 30 new or renewed international agreements and drafted revisions as needed.

2. Support Services for International Researchers and Students

In FY 2023, following the downgrading of COVID-19 to a Category 5 infectious disease, international travel resumed and the number of international visitors at NAOJ recovered to pre-pandemic levels. As a result, the Support Desk (SD) of the OIR, which supports international researchers and students with daily life in Japan, has seen a significant increase in the number of accompaniment requests for various municipal procedures and general inquiries compared to recent years. The "NAOJ Support Desk Registration Form," first introduced in FY 2021, is now fully established, streamlining the process for SD staff to gather information from incoming international visitors and ensuring prompt assistance for a smooth and swift stabilization of their lives in Japan.

Since launching its website in July 2021, the OIR has maintained the website to provide information to international researchers and students and their NAOJ hosts. The website offers bilingual support, providing practical information on immigration procedures, accommodations, campus neighborhoods, daily life, and reference information in both Japanese and English. In FY 2023, the information posted on the website continued to be updated. At the same time, active efforts to publicize the website have helped promote its use among researchers within and outside NAOJ.

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. Both the beginner and intermediate courses offer lessons that have been developed 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 responsiveness, students were given the freedom to study at their convenience. The courses were well received by the students, who remained highly motivated to learn.

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. In FY 2023, the OIR engaged in the active dissemination of information to approximately 320 visitors to the NAOJ booth at the Asia-Pacific Regional IAU Meeting 2023 (APRIM2023) held in Koriyama, Fukushima Prefecture, Japan in August 2023, and approximately 630 visitors to the NAOJ booth at the 243rd American Astronomical Society Meeting (243rd AAS Meeting) held in New Orleans, USA in January 2024.

At APRIM2023, the OIR served as a member of the local organizing committee, handling support tasks for welcoming keynote speakers, presenters, and participants.

4. Others

In addition to the above-mentioned regular duties, the OIR undertook the following tasks in FY 2023: In October, the office played a key role in supporting the NAOJ External Review 2023 (ER2023). This included providing assistance with the arrival and reception of the overseas experts on the External Review Panel. The OIR also served as a contact point for each panel member and facilitated the preparation of meeting minutes and the English translations of relevant materials.

Furthermore, the office took part in preparing the English translation of the handover documentation authored by the Director General prior to the completion of his term in office.

22. Human Resources Planning Office

The Human Resources Planning Office works closely with the Directorate to formulate and implement the organization's overall human resources strategy and is expected to make the best use of the organization's human resources and contribute to the continuity and development of business at the National Astronomical Observatory of Japan (NAOJ). Specifically, the scope of its work includes the operation of the Objective Sharing and Talent Development System, planning and implementation of the management training program, management of fixed-term employees, improvement of the work environment including harassment prevention, and handling individual labor matters and consultations from employees. Through these, we strive to strategically and effectively promote human resource strategies to achieve organizational goals.

In January 2023, the Vice-Director General (on General Affairs) concurrently served as the Director of the Human Resources Planning Office, and a newly hired Senior Specialist was assigned as a Human Resources Manager, creating a structure for smoother business operation and more practical contribution.

In October-November 2023, a total of 66 leadership-level staff members participated in face-to-face management training conducted by outside instructors for the first time in five years, partly due to the designation of the novel coronavirus as a category 5 virus.

1. Objective Sharing and Talent Development System

The Objective Sharing and Talent Development System was operated for Research and Academic Staff, Research Engineer Staff, Engineering Staff, and Employees on Annual Salary System/URA Staff (Specially Appointed Teachers, Project Researchers, and Senior Specialists), with the overall flow of setting annual objectives, mid-term review, and review at the end of the year. The evaluation results were reflected in the bonuses (June and December) and January salary increases for Research and Academic Staff and Engineering Staff, and in the annual salary amount from April for Employees on Annual Salary System. In each process, the transfer of related documents was conducted using SharePoint, to enhance security and efficiency as well as convenience for the staff involved. Also, the operation guide was revised for the first time in eight years. In addition, the process of exchanging evaluations with other institutions for cross-appointment staff, the number of which is on the increase, was reviewed and a basic flow was created, then announced to all concerned parties.

2. General Employment Management for Fixed-term Staff

Appropriate employment measures (e.g., operation of the Fixed-Term Employee Review Committee, operation of employment measures for employees transitioning to the mandatory retirement system, etc.) were implemented for fixed-term contract employees with various employment statuses, including Employees on Annual Salary System. Particular attention was paid to employment management for fixed-term employees, including procedures for transitioning to the mandatory retirement system. Sufficient time was taken to inform all parties concerned of the eligible employees, conditions, and procedural schedule for transitioning to the mandatory retirement system. Effective employment management that meets the needs of the organization is being practiced.

3. Management Training

In FY 2023, a total of three face-to-face training session including two types of programs were conducted for management level staff. “Training for Evaluators and Handling Labor Issues” (half-day course) was held on October 24 (22 participants) and November 13 (20 participants). On November 1, “Internal Communication Program for Management” (full-day course) was conducted by an external instructor with 24 participants. The internal communication program was rich in content, including the basics and importance of internal communication, psychological safety, listening, unconscious bias, assertive communication, coaching, conflict management, and other topics. With the cooperation of the Directorate, the training was also structured in an interactive manner, including the creation of a unique case study at NAOJ and the implementation of group work and role-playing. The face-to-face training, the first in a long time, provided an opportunity for staff members to interact with each other across departmental and professional boundaries, and many positive comments and opinions were received in the post-training questionnaire.

4. Handling of Harassment, Mental Health, and Individual Labor Issues

We responded promptly and courteously to consultations regarding harassment (consultations with the external consultation service, internal counselors, or the Human Resources Planning Office), and took appropriate measures based on the fact-finding process. In addition, measures to prevent harassment (e.g., implementation of e-learning training and recommendations to use external contact points) were undertaken in cooperation with the Employee Affairs Unit of the Administration Department and the external consultation service vendor.

5. Contribution to International Projects

The Human Resources Manager participated in the ALMA HR AG (Human Resource Advisory Group) as a member of NAOJ, and actively built relationships and exchanged opinions at the meeting held in Chile in July 2023. In addition, we proceeded with a series of recruitment processes for the International Staff

Members (ISM) of the Joint ALMA Observatory (JAO) in cooperation with the relevant departments. In 2023, NAOJ staff members were hired for two key positions (Deputy Director of Operation and Deputy Director of Development) at JAO, and we coordinated among the parties involved and responded to various questions and requests in the process.

6. Others

Various data and trends are analyzed and provided to the Directorate as reference materials for organizational management. In December 2022, personnel requests from each department were compiled and progress reports are regularly shared with the Directorate. This information is used to deliberate on the appropriate recruitment and assignment of human resources.

23. Safety and Health Management Office

The mission of the Safety and Health Management Office is to prevent accidents through appropriate management and operation of NAOJ facilities, equipment, and devices and to promote the creation of a comfortable work environment by maintaining the safety, health, and well-being of employees. Specifically, the office holds Safety and Health Committee meetings and promotes information sharing, conducts periodic safety and health patrols and work environment measurements, provides safety and health education, implements healthcare and safety and health training programs, and develops rules and manuals on workplace safety and health.

In FY 2023, one of the two health officers (Safety and Health Management Office Staff) was replaced by an inexperienced young person from another section, and the other veteran officer would retire at the end of April 2024, so it was necessary to replace him with a new certified person within FY 2023. Because of this turnover in the officers, efforts were made to ensure longer handover time and to systematically take over operations in order to mitigate the impact of these changes as much as possible.

1. Holding Safety and Health Committee Meetings and Promoting Information Sharing

The Safety and Health Committee promotes safety and health activities through the committees that are organized at each work site, namely the Mitaka (including the Okayama Branch, Kamioka Branch, and Thirty Meter Telescope (TMT) Project / California Office), Nobeyama, Mizusawa, Hawai`i, and Chile districts. The activities of each committee are reported and shared on a monthly basis. In addition to the monthly reports, committee members and observers from each district and branch participate in a quarterly all-hands meeting to share information. The month following a quarterly meeting, important matters are reported at the Project Director Committee, which is attended by all staff at the management level, including the Director General, Vice-Director Generals, and Directors of Projects and Centers.

In FY 2023, the committee successfully promoted the planned activities and achieved the following results.

2. Periodic Patrols and Environmental Measurements

The health officer (Safety and Health Management Office Staff) conducted regular weekly patrols at each workplace in the Mitaka district and left comments for improvement upon noticing any problems or points of concern. During the patrols, environmental measurements (illuminance, room temperature, humidity, discomfort index, Carbon Dioxide concentration, formaldehyde, and suspended particulate matter PM10) were conducted using a digital illuminance meter and Air Quality Monitor, and quantitative data were used to check the workplace environment in more detail, which enabled the office to gain further insights into the areas for improvement.

In addition, at the middle of October 2023, Mizusawa VLBI Observatory hosted a special joint patrol program on safety management with the National Institutes of Natural Sciences. Furthermore, as a part of the voluntary safety and health routine inspections, the office conducted patrols at Mizusawa VLBI Observatory in early July 2023, Subaru Telescope / Okayama Branch in early September 2023, Mizusawa VLBI Observatory / VERA Ogasawara Station in early November 2023, Nobeyama Radio Observatory in late November 2023 and identified the status of maintenance and improvement measures for preventing the recurrence of accidents in each district.

3. Safety and Health Education

As in previous years, a safety and health workshop (special education for workers who transferred jobs or are engaged in hazardous operations) was held on May 29, 2023.

Course Content:

□ New Occupational Safety and Health Laws and Regulations (New chemical substance management)
□ Chemical substance manager
□ Protective equipment wearing manager
□ Industrial accident cases
□ Hazardous risks
□ High pressure gas safety act

Participants who completed this course were certified as hazardous materials practitioners for handling “coolants, high-pressure gases, cold evaporators (CE), organic solvents, and specified chemical substances.”

Number of certificates issued: 82 (29 for NAOJ staff, 53 for students / external staff, etc.)

Other: Noone participated in CE handling practical training.

In addition, in cooperation with the Engineering Promotion Office, “System Safety (Exercises)” as a part of Safety & Product Assurance Training were held on December 8, 2023.

Course Content:

□ Exercise 1 [The conditions of hazard identification] The information regarding the circular saw is limited and there are no rules regarding the framework and analytical method.
□ Exercise 2 [The conditions of hazard identification] The information regarding the circular saw is specified and no rules regarding the framework and analytical method are specified.
□ Exercise 3 [The conditions of hazard identification] The information regarding the circular saw is specified and the rules regarding the framework and analytical method are specified.
□ Exercise 4 [The conditions of hazard identification] The information regarding the circular saw is shared and the rules regarding the framework and analytical method are shared.
□ Exercise 5: Risk estimation and risk assessment
□ Database utilization, Documentation and Summary

Number of Participants: 33 (including those who viewed the recorded session at later dates)

4. Healthcare and Safety and Health Training

In fulfilling the responsibilities of a health officer, the office assisted in promoting the following tasks.

□ Health Examination
□ Influenza Vaccination
□ Stress Check
□ Health Consultation with Occupational Physicians in the Mitaka district
□ General Lifesaving Course

5. Development of Rules and Manuals

The following guideline, in accordance with the partial revision of the industrial safety and health acts etc., is prepared and requires business operators to establish and operate a system to appropriately implement exposure control measures based on the results of risk assessment, mainly for hazardous chemical substances.

□ Handling Guidelines for Chemicals at NAOJ (Mitaka Campus)

24. Engineering Promotion Office

1. Outline

The Engineering Promotion Office (EPO) aims to improve the overall level of NAOJ's engineering capability and facility operation by coordinating the skill development of engineering staff. Specifically, EPO acts mainly on "assigning engineering staff", "engineering staff human resource development", and "other areas needed to improve the engineering capabilities."

2. Assignment of Engineering Staff

The engineering staff which consists of executive engineers, senior research engineers, associate senior research engineers, and research engineers, work on NAOJ's engineering issues with advanced expertise and a high sense of responsibility.

EPO considers the balance between a long-term plan of human resource and technological capability development and the efficient completion of individual technology projects. Then, EPO considers the balance of the engineering staff members' years of experience and assignment of personnel needed to ensure the continuation of technological expertise in each field of engineering to make medium- and long-term personnel promotion and hiring proposals.

In FY 2023, we cooperated in the recruitment or promotion of three Associate Senior Research Engineers, two Research Engineers, and five Engineers.

3. Engineering Staff Human Resource Development

Human resource development for engineering staff is being conducted based on the documents compiled for that purpose in FY 2020. The commercial human resource evaluation system launched in FY 2022 was temporarily suspended as a result of cost-effectiveness considerations, and goals were set and evaluated using the conventional method.

As for training, 5 engineering staff members participated in an e-learning English training course and 2 engineering staff members participated in a lecture-style English language training program sponsored by the Administration Department. Eleven applicants were invited to take the commercial business e-learning course, and evaluations of the lecture content are being collected to study its effectiveness.

As for the systems engineering training that has been conducted since FY 2020, a preparatory meeting for the next training was discussed by NAOJ staff, from which a review meeting for past lectures and a new study group were formed to establish the training within NAOJ. The systems engineering course given by lecturers was held with 43 participants from NAOJ. Systems safety training was conducted by NAOJ staff with 21 participants from NAOJ.

The 43rd Symposium on Engineering in Astronomy 2023 was held without a hitch, entrusting the management of the symposium to the engineering staff. The symposium was attended by more than 90 engineers and researchers from NAOJ and elsewhere. The symposium aimed to provide a forum for engineers and researchers involved in astronomy to exchange technical information on the design, development, improvement, and daily operations, and to contribute to technological development in the field of astronomy.

4. Other Areas Needed to Improve the Engineering Capabilities

As for safety and product development assurance in NAOJ, a Safety and Product Assurance (S&PA) Liaison Committee was established, to share the information with concerned parties.

25. Graduate Education Office

The Graduate Education Office was established in April 2022 to lay a basis for the sustainable and developing management of graduate education at NAOJ by systematically managing the efforts for graduate education related to the Graduate University for Advanced Studies (SOKENDAI), cooperative graduate schools, NAOJ Special Inter-Institutional Research Fellows, and others.

With the establishment of the Graduate Education Office, it is expected that the future leaders of graduate education at NAOJ will have the opportunity to accumulate experience in the management of graduate education under the auspices of an organizationally recognized effort. The Graduate Education Office also acts as a window for cooperation between NAOJ and other universities or research institutions.

The Graduate Education Office also oversees the Graduate Education Committee and the Committee of the Astronomical Science Program, the Graduate Institute for Advanced Studies at SOKENDAI. In FY 2023, which is the first year after SOKENDAI's reorganization, the Graduate Education Office worked with particular care on a smooth transition. For graduate students, as in FY 2022, individual meetings between SOKENDAI students and members of the Graduate Education Office were arranged for all students to further enhance support for graduate students.

For further information, refer to section VII “Graduate Education.”

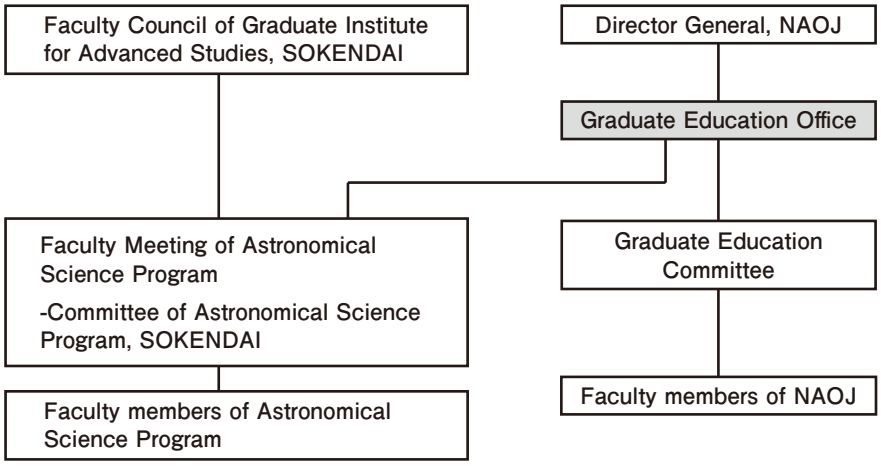
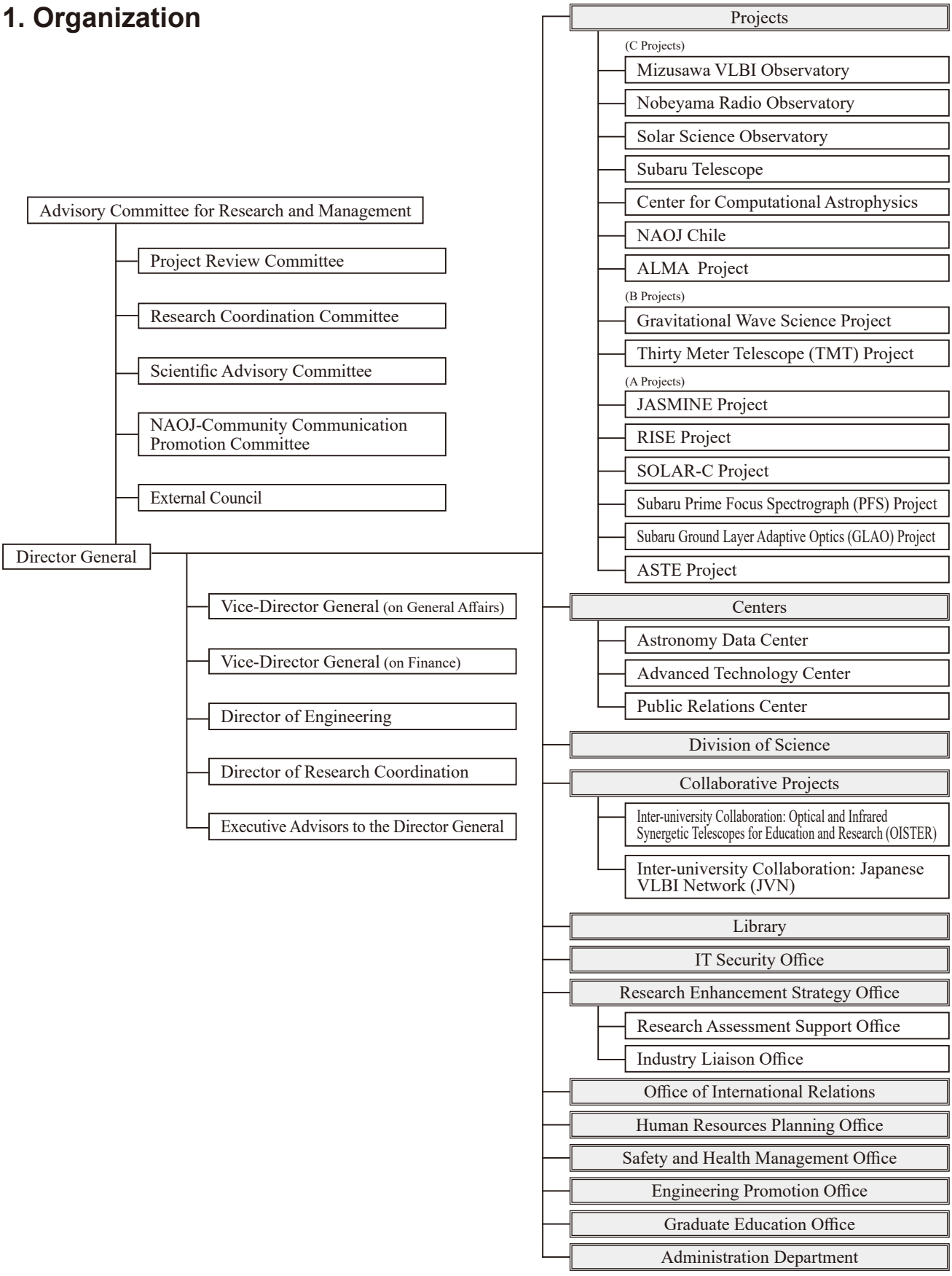


Figure 1: Organizational chart showing the position of the Graduate Education Office within NAOJ.

III Organization

1. Organization



2. Number of Staff Members

(2024/3/31)

Director General	1
Research and Academic Staff	156
Professor	29
Executive Engineer	1
Associate Professor	41
Senior Research Engineer	8
Associate Professor (Senior Lecturer)	6
Associate Senior Research Engineer	5
Assistant Professor	53
Research Associate	0
Research Engineer	13
Engineering Staff	39
Administrative Staff	58
Research Administrator Staff	2
Employees on Annual Salary System	135
Research Administrator Staff Transferring to the Mandatory Retirement System	1
Employees on Annual Salary System Transferring to the Mandatory Retirement System	13
Full-time Contract Employees	31
Full-time Contract Employees Transferring to the Mandatory Retirement System	3
Part-time Contract Employees	85
Part-time Contract Employees Transferring to the Mandatory Retirement System	13

3. Executives

Director General	Tsuneta, Saku
Vice-Director General	
on General Affairs	Yoshida, Michitoshi
on Finance	Saito, Masao
Director of Engineering	Uzawa, Yoshinori
Director of Research Coordination	Motohara, Kentaro
Executive Advisor to the Director General	Hiramatsu, Masaaki
Executive Advisor to the Director General	Kurasaki, Takaaki

4. Research Departments

Projects

C Projects

Mizusawa VLBI Observatory

Director	Honma, Mareki
Professor	Honma, Mareki
Project Professor	Kobayashi, Hideyuki
Associate Professor	Hirota, Tomoya
Assistant Professor	Hada, Kazuhiro
Assistant Professor	Jike, Takaaki
Assistant Professor	Kouno, Yusuke
Assistant Professor	Sunada, Kazuyoshi
Project Assistant Professor	Sakai, Daisuke
Engineer (Gishi)	1
Engineer (Shunin Gijutsuin)	1
Engineer (Gijutsuin)	1
Project Researcher	Akahori, Takuya
Project Researcher	Kurahara, Kohei
Senior Specialist (Tokuninsenmonin)	3
Technical Experts	3
Research Supporters	2
Administrative Supporters	2

Administration Office

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

Nobeyama Radio Observatory

Director	Tatematsu, Kenichi
Professor	Tatematsu, Kenichi
Project Associate Professor	Nishimura, Atsushi
Senior Engineer	1
Engineers (Gishi)	3
Re-employment Staff	1

Administration Office

Head of Administration Office	Tatematsu, Kenichi
General Affairs Unit	
Senior Staff	1
Re-employment Staff	1
Administrative Supporters	2
Accounting Unit	
Senior Staff	1
Administrative Supporters	2

Solar Science Observatory

Director	Katsukawa, Yukio
Professor	Katsukawa, Yukio
Associate Professor	Hanaoka, Yoichiro
Associate Professor	Ishikawa, Ryoko
Assistant Professor	Narukage, Noriyuki
Project Assistant Professor	Benomar, Othman Michel
Project Researcher	Ishikawa, Ryohtaroh
Senior Specialist (Tokuninsenmonin)	Morita, Satoshi
Re-employment Staff	1
Research Supporter	1
Administrative Supporter	1

Subaru Telescope

Director	Miyazaki, Satoshi
Vice-Director	Hayano, Yutaka
Professor	Hayano, Yutaka
Professor	Miyazaki, Satoshi
Project Professor	Yoshida Michitoshi
Project Professor *	Tamura, Motohide
Associate Professor *	Hirano, Teruyuki
Associate Professor	Koyama, Yusei
Associate Professor	Minowa, Yosuke
Associate Professor	Tanaka, Masayuki
Project Associate Professor	Kambe, Eiji
Senior Research Engineer	Iwashita, Hiroyuki
Senior Research Engineer	Kumura, Yoshinori
Associate Professor (Senior Lecturer) *	Nakajima, Tadashi
Assistant Professor	Imanishi, Masatoshi
Assistant Professor	Ishigaki, Miho
Assistant Professor	Moritani, Yuki
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 *	Kuzuhara, Masayuki
Project Assistant Professor *	Livingston, John Henry
Project Assistant Professor	Toba, Yoshiki

Research Engineer	Bando, Takamasa
Research Engineer	Omiya, Jun
Senior Engineer	1
Engineer (Shunin Gijutsuin)	4
Project Researcher	Ando, Makoto
Project Researcher	Fitriana, Itsna Khoirul
Project Researcher	He, Wanqiu
Project Researcher	Kawanomoto, Satoshi
Project Researcher *	Komatsu, Yu
Project Researcher	Nakata, Fumiaki
Project Researcher *	Nugroho, Stevanus Kristianto
Project Researcher *	Omiya, Masashi
Project Researcher *	Takahashi, Aoi
Project Researcher *	Takarada, Takuya
Project Researcher *	Urago, Riku
Senior Specialist (Tokuninsenmonin)	13
Postdoctoral Researcher	Taniguchi, Daisuke
Re-employment Staff	1
Administrative Expert	1
Research Supporter	1
Public Outreach Staff	1
Administrative Supporters	6

*concurrently appointed in NINS

Administration Department

Manager	Furuhata, Tomoyuki
General Affairs Unit	
Staff	1
Accounting Unit	
Leader	1

RCUH

RCUH Staff Members	68

Okayama Branch Office

Director	Tajitsu, Akito
Associate Professor	Izumiura, Hideyuki
Project Associate Professor	Tajitsu, Akito
Assistant Professor	Maehara, Hiroyuki
Administrative Supporters	2

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 Researcher	Ideguchi, Shinsuke
Project Researcher	Keszthelyi, Zsolt
Project Researcher	Matsumoto, Yuji
Project Researcher	Misugi, Yoshiaki
Senior Specialist (Tokuninsenmonin)	2
Research Expert	1
Administrative Expert	1
Research Supporters	3

NAOJ Chile

Director	Watanabe Teruyuki
Vice-Director	Mizuno, Norikazu
Associate Professor	Minamidani, Tetsuhiro
Engineer (Shunin Gijutsuin)	1
Senior Specialist (Tokuninsenmonin)	1
Re-employment Staff	1
Chile Employee	
Chile Employees	6

Administration Department

Manager	Seto, Yoji
General Affairs Unit	
Staff	1
Accounting Unit	
Senior Staff	1

ALMA Project

Director	Iguchi, Satoru
Professor	Fukagawa, Misato
Professor	Iguchi, Satoru
Professor	Kameno, Seiji
Professor	Mizuno, Norikazu
Professor	Sakamoto, Seiichi
Associate Professor	Asaki, Yoshiharu
Associate Professor	Hatsukade, Bunyo
Associate Professor	Izumi, Takuma
Associate Professor	Nagai, Hiroshi
Associate Professor	Okuda, Takeshi
Associate Professor	Sawada, Tsuyoshi
Associate Professor	Shimojo, Masumi
Associate Professor	Takahashi, Satoko
Project Associate Professor	Ishii, Shun
Project Associate Professor	Nakanishi, Kouichiro
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	Hsieh, Pei-Ying
Assistant Professor	Kamazaki, Takeshi
Assistant Professor	Matsuda, Yuichi
Project Assistant Professor	Cataldi, Gianni
Project Assistant Professor	Imada, Hiroaki
Project Assistant Professor	Sanhueza Nunez, Patricio Andres
Project Assistant Professor	Tokuda, Kazuki

Project Assistant Professor	Wu, Yu-Ting
Project Assistant Professor	Zavala Solano, Jorge Armando
Research Engineer	Nakazato, Takeshi
Research Engineer	Yamada, Masumi
Engineers (Gishi)	2
Engineer (Shunin Gijutsuin)	1
Engineer (Gijutsuin)	1
Project Researcher	Algera, Hiddo Sunny Bouwe
Project Researcher	Chen, Xiaoyang
Project Researcher	Cheng, Yu
Project Researcher	Feeney-Johansson, Anton Fiachra George
Project Researcher	Kawanaka, Norita
Project Researcher	Lee, Kianhong
Project Researcher	Liu, Junhao
Project Researcher	Mallick, Kshitiz Kumar
Project Researcher	Saha, Piyali
Project Researcher	Shibaike, Yuhito
Project Researcher	Silva Bustamante, Andrea Ludovina
Project Researcher	Sugahara, Yuma
Project Researcher	Takahashi, Sanemichi
Project Researcher	1
Senior Specialist (Tokuninsenmonin)	21
Re-employment Staff	1
Technical Expert	1
Administrative Experts	2
Research Supporter	1
Public Outreach Staff	1
Technical Supporters	3
Administrative Supporters	3

B Projects

Gravitational Wave Science Project

Director	Tomaru, Takayuki
Professor	Tomaru, Takayuki
Associate Professor	Aso, Yoichi
Assistant Professor	Akutsu, Tomotada
Assistant Professor	Takahashi, Ryutaro
Engineer (Shunin Gijutsuin)	1
Project Researcher	Eisenmann, Marc
Project Researcher	Page, Michael Anthony
Administrative Expert	1
Administrative Supporter	1

Kamioka Branch Office

Director	Tomaru, Takayuki
Assistant Professor	Chen, Dan
Project Assistant Professor	Washimi, Tatsuki
Senior Specialist (Tokuninsenmonin)	1
Administrative Supporter	1

Thirty Meter Telescope (TMT) Project

Director	Usuda, Tomonori
Vice-Director	Aoki, Wako
Professor	Aoki, Wako
Professor	Saito, Masao
Professor	Usuda, Tomonori
Professor	Yamashita, Takuya
Project Professor	Kurasaki, Takaaki
Associate Professor	Hayashi, Saeko
Associate Professor	Iono, Daisuke
Associate Professor	Noumaru, Junichi
Associate Professor	Sugimoto, Masahiro
Associate Professor	Suzuki, Ryuji
Associate Professor	Terada, Hiroshi
Assistant Professor	Nishikawa, Jun
Assistant Professor	Yasui, Chikako
Research Engineer	Tazawa, Seiichi
Senior Specialist (Tokuninsenmonin)	1
Research Supporter	1
Senior Specialist (Tokumeisenmonin)	1

NAOJ California Office

Research Engineer	Nakamoto, Takashi

A Projects

JASMINE Project

Director	Gouda, Naoteru
Professor	Gouda, Naoteru
Professor	Kano, Ryouhei
Associate Professsor	Wada, Takehiko
Project Associate Professor	Kataza, Hirokazu
Assistant Professor	Miyoshi, Makoto
Assistant Professor	Ohsawa, Ryou
Assistant Professor	Tatsumi, Daisuke
Assistant Professor	Tsujimoto, Takuji
Assistant Professor	Ueda, Akitoshi
Assistant Professor	Yano, Taihei
Project Researcher	Miyakawa, Kohei
Project Researcher	Ramos Ramirez, Pau

RISE Project

Director	Namiki, Noriyuki
Professor	Namiki, Noriyuki
Associate Professor	Matsumoto, Koji
Assistant Professor	Araki, Hiroshi
Assistant Professor	Kikuchi, Shota
Assistant Professor	Noda, Hirotomo
Project Researcher	Yamamoto, Keiko
Re-employment Staff	1

Public Outreach Staff	1

SOLAR-C Project

Director	Hara, Hirohisa
Professor	Hara, Hirohisa
Assistant Professor	Kawabata, Yusuke
Assistant Professor	Kubo, Masahito
Assistant Professor	Okamoto, Takenori
Engineer (Gishi)	1
Senior Specialist (Tokuninsenmonin)	1
Administrative Supporter	1

Subaru Prime Focus Spectrograph (PFS) Project

Director	Rousselle, Julien

Subaru Ground Layer Adaptive Optics (GLAO) Project

Director	Minowa, Yosuke

ASTE Project

Director	Minamidani, Tetsuhiro

Centers

Astronomy Data Center

Director	Kosugi, George
Associate Professor	Furusawa, Hisanori
Associate Professor	Ichikawa, Shinichi
Associate Professor	Kosugi, George
Associate Professor	Takata, Tadafumi
Associate Senior Research Engineer	Morita, Eisuke
Assistant Professor	Shirasaki, Yuji
Assistant Professor	Yagi, Masafumi
Research Engineer	Koike, Michitaro
Research Engineer	Mineo, Sogo
Research Engineer	Shizugami, Makoto
Project Researcher	Kasuga, Toshihiro
Project Researcher	Uchiyama, Hisakazu
Senior Specialist (Tokuninsenmonin)	8
Re-employment Staff	1
Administrative Supporter	1

Advanced Technology Center

Director	Hirabayashi, Masayuki
Vice-Director	Fukushima, Mitsuhiro
Vice-Director	Ozaki, Shinobu
Professor	Ozaki, Masanobu
Professor	Uzawa, Yoshinori
Professor	Motohara, Kentaro
Project Professor	Mitsuda, Kazuhisa
Project Professor	Yamamori, Hirotake
Executive Engineer	Hirabayashi, Masayuki
Associate Professor	Fujieda, Miho
Associate Professor	Kojima, Takafumi
Associate Professor	Makise, Kazumasa
Associate Professor	Matsuo, Hiroshi
Associate Professor	Oya, Shin
Associate Professor	Shan, Wenlei
Senior Research Engineer	Fukushima, Mitsuhiro
Senior Research Engineer	Kanzawa, Tomio
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
Research Engineer	Ezaki, Shohei
Research Engineer	Sato, Naohisa
Research Engineer	Tokoku, Chihiro
Research Engineer	Tsuzuki, Toshihiro
Engineer (Gishi)	7
Engineer (Shunin Gijutsuin)	8
Engineer (Gijutsuin)	3
Project Researcher	Kang, Haoran
Project Researcher	Masui, Sho
Project Researcher	Murayama, Yosuke
Project Researcher	Nagai, Makoto
Project Researcher	Yoneta, Kenta
Senior Specialist (Tokuninsenmonin)	2
Re-employment Staff	1
Technical Experts	2
Administrative Expert	1
Technical Supporter	1
Administrative Supporters	2
Research Assistants	1
Senior Specialist (Tokumeisenmonin)	1

Public Relations Center

Director	Yamaoka, Hitoshi
Project Professor	Watanabe, Junichi
Associate Professor	Agata, Hidehiko
Associate Professor	Yamaoka, Hitoshi
Associate Professor (Senior Lecturer)	Hanayama, Hidekazu
Associate Professor (Senior Lecturer)	Hiramatsu, Masaaki
Associate Senior Research Engineer	Fuse, Tetsuharu
Associate Senior Research Engineer	Katayama, Masato

Assistant Professor	Umemoto, Tomofumi
Engineer (Shunin Gijutsuin)	1
Project Researcher	Hayatsu, Natsuki
Project Researcher	Shibata, Takashi
Senior Specialist (Tokuninsenmonin)	4
Re-employment Staff Members	3
Research Experts	2
Administrative Experts	2
Research Supporters	2
Public Outreach Staff Members	14
Senior Specialist (Tokumeisenmonin)	1
Public Relations Office	
Director	Yamaoka, Hitoshi
Outreach and Education Office	
Director	Umemoto, Tomofumi
Ephemeris Computation Office	
Director	Katayama, Masato
Spectrum Management Office	
Director	Hiramatsu, Masaaki
Library	
Leader	1
Publications Office	
Director	Yamaoka, Hitoshi
The Office for Astronomy Outreach of the IAU	
Director	Blumenthal, Kelly Anne
Administration Office	
Director	1
Ishigakijima Astronomical Observatory	
Director	Hanayama, Hidekazu
Time Keeping Office	
Director	Fuse, Tetsuharu

Division of Science

Division Head	Ikoma, Masahiro
Professor	Ikoma, Masahiro
Professor	Kohri, Kazunori
Professor	Nomura, Hideko
Professor	Ouchi, Masami
Professor	Tominaga, Nozomu
Associate Professor	Fujii, Yuka
Associate Professor	Machida, Mami
Associate Professor	Nakamura, Fumitaka
Project Associate Professor	Baba, Junichi
Assistant Professor	Dainotti, Maria Giovanna
Assistant Professor	Hamana, Takashi
Assistant Professor	Harada, Nanase
Assistant Professor	Kataoka, Akimasa
Assistant Professor	Takahashi, Koh
Assistant Professor	Morino, Junichi
Assistant Professor	Moriya, Takashi
Project Assistant Professor	Arzoumanian, Doris
Project Assistant Professor	Furuya, Kenji
Project Assistant Professor	Kashino, Daichi
Project Assistant Professor	Kokubo, Mitsuru
Project Assistant Professor	Nagakura, Hiroki
Project Assistant Professor	Nakajima, Kimihiko
Project Assistant Professor	Sugiyama, Naonori
Project Assistant Professor	Taniguchi, Kotomi
Project Researcher	Behroozi, Peter Spalding
Project Researcher	Dorozsmai, Andras
Project Researcher	Ito, Yuichi
Project Researcher	Iwata, Yuhei
Project Researcher	Kikuta, Satoshi
Project Researcher	Ohno, Kazumasa
Project Researcher	Zhang, Haibin
Postdoctoral Researcher	Kusakabe, Haruka
Postdoctoral Researcher	Mori, Masamitsu
Administrative Expert	1
Research Supporters	2
Administrative Supporter	1
Research Assistants	3

5. Research Support Departments

IT Security Office

Director	Yoshida, Michitoshi
Vice Director	Oe, Masafumi
Associate Professor (Senior Lecturer)	Oe, Masafumi
Associate Senior Research Engineer	Tomine, Takashi
Engineer (Gijutsuin)	1
Senior Specialist (Tokuninsenmonin)	1
Re-employment Staff	1

Research Enhancement Strategy Office

Director	Saito, Masao
Assistant Professor	Hattori, Kohei
Assistant Professor	Ishizuki, Sumio
Assistant Professor	Shirasaki, Masato
Senior Specialist (Tokuninsenmonin)	3

Research Assessment Support Office

Director	Saito, Masao
Assistant Professor	Ishizuki, Sumio
Senior Specialist (Tokuninsenmonin)	1

Industry Liaison Office

Director	Hiramatsu, Masaaki

Office of International Relations

Director	Chapman, Junko
Senior Specialist (Tokuninsenmonin)	2
Research Supporter	1

Support Desk

Research Supporters	2

Human Resources Planning Office

Director	Yoshida, Michitoshi
Senior Specialist (Tokuninsenmonin)	1

Safety and Health Management Office

Director	Mori, Yasushi
Senior Specialist (Tokuninsenmonin)	2
Technical Expert	1

Engineering Promotion Office

Director	Uzawa, Yoshinori
Senior Research Engineer	Fujii, Yasunori

Graduate Education Office

Director	Sekii, Takashi
Project Professor	Sekii, Takashi

Administration Department

General Manager	Fujita, Hisashi
Senior Specialist (Tokuninsenmonin)	1

General Affairs Group

Manager	Tanaka, Aiko
Deputy Manager	2
Specialist (Information Technology)	1
Specialist (Personnel Relations)	1
Senior Specialist (Tokuninsenmonin)	3
Re-employment Staff	1
General Affairs Unit	
Leader	1
Senior Staff	1
Staff	1
Administrative Expert	1
Administrative Supporters	2
Personnel Unit	
Leader	1
Staff Members	3
Administrative Expert	1
Payroll Unit	
Leader	1
Senior Staff	1
Staff Members	2
Administrative Supporter	1
Employee Affairs Unit	
Leader	1
Staff Members	2
Administrative Expert	1

Research Promotion Group

Manager	Kaneko, Osamu
Senior Specialist (International Relations)	1
Senior Specialist (Tokuninsenmonin)	1
Administrative Supporter	1
Research Support Unit	
Leader	1
Administrative Expert	1
Administrative Supporters	2
External Funding Unit	
Specialist (External Funding)	1
Staff	1
Administrative Expert	1
Graduate Student Affairs Unit	
Leader	1
Administrative Expert	1
International Academic Affairs Unit	
Leader	1

Financial Affairs Group

Manager	Kawazu, Hironori
Deputy Manager	1
Specialist (Audit)	1
Re-employment Staff	1
General Affairs Unit	
Leader	1
Senior Staff	1
Administrative Supporter	1
Budget Unit	
Leader	1
Senior Staff Members	3
Administrative Supporter	1
Asset Management Unit	
Leader	1
Receiving Unit	
Leader	1
Administrative Supporters	3

Accounting Group

Manager	Hosoya, Akio
Specialist	1
Accounting Unit	
Leader	1
Administrative Supporters	3
Procurement Unit	
Leader	1
Senior Staff	1
Staff Members	2
Administrative Expert	1
Administrative Supporter	1

Facilities Group

Manager	Kataoka, Toru
Deputy Manager	1
Senior Specialist	1
General Affairs Unit	
Leader	1
Administrative Supporter	1
Facilities Direction Unit	
Leader	1
Administrative Supporters	2
Maintenance Unit	
Leader	1
Staff Members	2

6. Advisory Committee for Research and Management

Members

From universities and related institutes

	Arai, Tomoko	Director of the Planetary Exploration Research Center, Chiba Institute of Technology
	Kodama, Tadayuki	Professor at the Graduate School of Science, Tohoku University
○	Ohashi, Masatake	Professor at the Institute for Cosmic Ray Research, University of Tokyo
	Omukai, Kazuyuki	Professor at the Graduate School of Science, Tohoku University
	Sakai, Nami	Chief Scientist at RIKEN
	Sumi, Takahiro	Professor at the Graduate School of Science, Osaka University
	Takada, Masahiro	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
	Yokoyama, Takaaki	Professor at the Astronomical Observatory, Graduate School of Science, Kyoto University
	Yonekura, Masanori	Professor at the Center for Astronomy, Ibaraki University
	Yonekura, Masanori	Professor at the Center for Astronomy, Ibaraki University

From NAOJ

	Fukagawa, Misato	Professor at ALMA Project
	Kokubo, Eiichiro	Professor at the Center for Computational Astrophysics
	Kobayashi, Hideyuki	Project Professor at the Mizusawa VLBI Observatory
	Miyazaki, Satoshi	Professor at Subaru Telescope
	Motohara, Kentaro	Director of Research Coordination
	Nomura, Hideko	Professor at the Division of Science
	Saito, Masao	Vice-Director General(on Finance)
	Uzawa, Yoshinori	Director of Engineering
	Watanabe, Junichi	Project Professor at Public Relations Center
●	Yoshida, Michitoshi	Vice-Director General(on General Affairs)

● Chairperson ○ Vise-Chairperson

Period: April 1, 2022 – March 31, 2024

IV Finance

Revenue and Expenses (FY 2023)

(Unit: ¥1,000)

Revenue	Budget	Final Account	Budget − Final Account
Management Expenses Grants	8,588,192	9,326,643	−738,451
Facilities Maintenance Grants	2,564,154	1,852,144	712,010
Subsidy Income	1,411,780	1,424,229	−12,449
Miscellaneous Income	16,491	441,234	−424,743
Industry-Academia Research Income and Donation Income	305,537	667,030	−361,493
Reversals of Reserves for Specific Purposes	0	0	0
Total	12,886,154	13,711,280	−825,126
Expenses	Budget	Final Account	Budget − Final Account
Management Expenses	8,604,683	8,739,673	−134,990
Employee Personnel Expenses	3,856,763	3,736,193	120,570
Operating Expenses	4,747,920	5,003,480	−255,560
Facilities Maintenance Expenses	2,564,154	1,852,144	712,010
Subsidy Expenses	1,411,780	1,424,229	−12,449
Industry-Academia Research Expenses and Donation Expenses	305,537	560,401	−254,864
Total	12,886,154	12,576,466	309,708
Revenue − Expenses	Budget	Final Account	Budget − Final Account
	0	1,134,834	−1,134,834

V KAKENHI (Grants-in-Aid for Scientific Research)

1. Series of Single-year Grants for FY 2023

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)	1	2,500	750	3,250
Transformative Research Areas (A)	3	70,100	21,030	91,130
Scientific Research (S)	5	204,500	61,350	265,850
Scientific Research (A)	10	59,800	17,940	77,740
Scientific Research (B)	23	97,200	29,160	126,360
Publication of Scientific Research Results	1	490	0	490
Total	43	434,590	130,230	564,820

2. Series of Multi-year Funds for FY 2023

Research Categories	Number of Selected Projects	Budget (Unit: ¥1,000)		
		Direct Funding	Indirect Funding	Total
Scientific Research (C)	17	18,200	5,460	23,660
Early-Career Scientists	16	14,800	4,440	19,240
Challenging Research Exploratory	2	2,900	870	3,770
Research Activity Start-up	6	5,700	1,710	7,410
Fund for the Promotion of Joint International Research (International Leading Research)	1	245,440	73,632	319,072
Fund for the Promotion of Joint International Research (Fostering Joint International Research (B))	2	6,800	2,040	8,840
JSPS Research Fellows	13	23,100	6,930	30,030
JSPS International Research Fellows	3	2,000	0	2,000
Total	60	318,940	95,082	414,022

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	100	1407 (444)	46 Institutes, 6 Countries
	Subaru Telescope Okayama Branch	SEIMEI Telescope	52	155	17 Institutes
	Solar Science Observatory	Ground-based Solar Observatory	*	*	*
		Sun-observing satellite “Hinode”	**	**	**
	Mizusawa VLBI Observatory	VERA	29	107 (68)	53 Institutes, 15 Countries
	Astronomy Data Center		346	346(24)	91 Institutes, 13 Countries
	Center for Computational Astrophysics		360	360 (35)	81 Institutes, 10 Countries
	Advanced Technology Center	Facility Use	25	88	25 Institutes
		Joint Research and Development	14	95	18 Institutes
	ALMA Project	ALMA (Cycle 9)	285	3819 (3393)	362 Institutes, 37 Countries
		ASTE	***	***	***
Paid Telescope Time System	Nobeyama Radio Observatory	45-m telescope	35	-	–
Large-scale Collaborative-Observation Program	Mizusawa VLBI Observatory	VERA	17	74 (7)	27 Institutes, 4 Countries
Joint Development Research			5		4 Institutes, 0 Countries
Research Assembly			14		11 Institutes, 0 Countries
NAOJ Symposium			1		1 Institutes, 0 Countries

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 9) is from October 2022 to September 2023.

* The observation data are open to the public on the web. No application is needed to use the data.
** Since the operation of the Hinode Science Center has shifted to the Astronomical Data center, there is no procedure of application and adoption as “Hinode.”
*** ASTE has cancelled the joint-use observations scheduled for FY 2023 due to the malfunctions of the sub-reflector. 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
Tsuchiya, Fuminori	Visiting Professor	Tohoku University	May 1, 2023 – March 31, 2024	Mizusawa VLBI Observatory
Shimoikura, Tomomi	Visiting Associate Professor	Otsuma Women's University	April 1, 2023 – March 31, 2024	Division of Science
Nakanishi, Hiroyuki	Visiting Associate Professor	Kagoshima University	April 1, 2023 – March 31, 2024	Mizusawa VLBI Observatory
Tsuchiya, Fuminori	Visiting Associate Professor	Tohoku University	April 1, 2023 – April 30, 2023	Mizusawa VLBI Observatory
Furuya, Rei	Visiting Associate Professor	Tokushima University	April 1, 2023 – March 31, 2024	Center for Computational Astrophysics
Higuchi, Aya	Visiting Research Fellow	Tokyo Denki University	April 1, 2023 – March 31, 2024	Astronomy Data Center

Visiting Scholars (Foreign)

Name	Position at NAOJ	Affiliated Institute	Period	Host Project/Center/ Division
Turner, Edwin	Visiting Professor	Princeton University	July 11, 2023 – August 25, 2023 September 6, 2023 – October 21, 2023	Subaru Telescope
Lunardini, Cecilia	Visiting Professor	Arizona State University	September 17, 2023 – Desember 14, 2023	Center for Computational Astrophysics

JSPS (Japan Society for the Promotion of Science) Postdoctoral Research Fellows

Name	Research Subject	Acceptance Period	Host Researcher
Zhang, Yechi	Formation and Evolution of Supermassive Black Holes Probed by High-Redshift Active Galactic Nuclei	2023/10/1 – 2025/3/31	Ouchi, Masami
Mori, Kanji	Investigating Signatures of Axions from Core-collapse Supernova Events with Three-dimensional Simulations	2023/4/1 – 2026/3/31	Takiwaki, Tomoya
Kusakabe, Haruka	Kinematics and ionization state of the circumgalactic medium around extremely-metal poor galaxies investigated with wide-field integral field spectroscopy	2023/4/1 – 2026/3/31	Ouchi, Masami
Taniguchi, Daisuke	Metallicity distribution and formation history of nearby galaxies investigated using red supergiants	2023/4/1 – 2026/3/31	Ishigaki, Miho
Mori, Masamitsu	Calculation of black holes from supernovae for the multi-messenger astronomy	2023/4/1 – 2026/3/31	Takiwaki, Tomoya
Cooray, Suchetha	A Physically Consistent Machine Learning Model of Galaxy Formation	2023/4/1 – 2024/3/31	Ouchi, Masami
Kimura, Tadahiro	Development of primordial atmospheric formation model including water production for the prediction of water contents of terrestrial exoplanets	2023/4/1 – 2024/3/31	Ikoma, Masahiro
Tei, Akiko	Exploring the nature of the solar chromosphere jets with high-resolution spectroscopic observations	2023/4/1 – 2026/3/31	Katsukawa, Yukio
Okuya, Ayaka	Revealing planet formation around intermediate-mass stars from planetary remnants accreting on white dwarfs	2022/4/1 – 2025/3/31	Ikoma, Masahiro
Uyama, Taichi	Developing exoplanetary science by high-contrast imaging	2021/4/1 – 2023/11/5	Fujii, Yuka
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

JSPS (Japan Society for the Promotion of Science) Foreign Research Fellows

Name	Period	Host Researcher
Bajpai, Rishabh	2023/5/1 – 2025/4/30	Tomaru, Takayuki
Kuzma, Pete Bryson	2023/10/17 – 2025/10/16	Ishigaki, Miho
Chaudhuri, Arnab	2023/11/14 – 2025/11/13	Kohri, Kazunori

VII Graduate Education

1. Astronomical Science Program, Graduate Institute for Advanced Studies, SOKENDAI (The Graduate University for Advanced Studies)

The Graduate University for Advanced Studies, SOKENDAI was established in 1988 via partnerships with inter-university research institutes for the purpose of advancing graduate education. Starting from FY 2004 SOKENDAI had six schools: Cultural and Social Studies, Physical Sciences, High Energy Accelerator Science, Multidisciplinary Sciences, Life Science, and Advanced Sciences, offering doctoral education and research opportunities.

NAOJ accepted three-year doctoral-course students starting from FY 1992 and five-year- course students from FY 2006 for Department of Astronomical Science, School of Physical Sciences.

SOKENDAI reorganized its six graduate schools into the Graduate Institute for Advanced Studies to offer a 20-program system starting from April 2023. In accordance with this reorganization, Department of Astronomical Science has been reorganized into Astronomical Science Program.

(1) Astronomical Science Program

Astronomical Science Program 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 accepted annually:
Around 5 (for the five-year doctoral course)
Around 1 (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

Astronomical Science Program 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) Program Details

Optical and Near 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 program consists of the Optical Near-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 the 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 Support

In order to provide the students economical basis upon which they can develop into young researchers skilled in conducting research effectively, the program has set up the Associate Researcher program in addition to Research Assistant system. In addition, the program 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 program.

In FY 2023 there were 10 NAOJ Junior Fellows, 12 Associate Researchers, and 4 Research Assistants.

To further improve the research environment for the students, the program 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 SOKENDAI Summer Students Program, Spring School, and Asian Winter School to offer chances to experience research at the Astronomical Science Program. Admission Guidance also targets undergraduate students.

In FY 2023, 25 students participated in the SOKENDAI Summer Students program. The Asian Winter School, conducted online, received 258 applications from 14 countries, and of these, 148 students participated in the program. In addition, 34 students participated in the Spring School, which was held onsite in Mitaka Campus.

(7) Number of Affiliated Staff (2024/3/31)

Optical and Infrared Astronomy	
Professors	9
Associate Professors	11
Associate Professors (Senior Lecturers)	1
Assistant Professors	12
Radio Astronomy	
Professors	9
Associate Professors	13
Associate Professors (Senior Lecturers)	1
Assistant Professors	13
General Astronomy and Astrophysics	
Professors	12
Associate Professors	15
Associate Professors (Senior Lecturers)	2
Assistant Professors	20
Total	118

(8) Graduate Students (31 students)

1st year (4 student)

Name	Principal Supervisor	Supervisor	Title of Research Project
Imai, Seiya	Tanaka, Masayuki	Koyama, Yusei	Galaxy formation and evolution in the distant Universe
Tan, Miho	Machida, Mami	Takiwaki, Tomoya	Clarifying the Collimation Mechanism of Astrophysical Jets
Hatami, Ryota	Tominaga, Nozomu	Takiwaki, Tomoya	Supernova nucleosynthesis
Watanabe, Kazuki	Uzawa, Yoshinori	Kojima, Takafumi	Development of a sub-THz MKID Camera for Deep Space Observation

2nd year (5 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Kakimoto, Takumi	Tanaka, Masayuki	Iono, daisuke	The formation mechanism of massive elliptical galaxies
Sato, Yoshiaki	Narukage, Noriyuki	Shimojo, Masumi/ Sekii, Takashi	Study of High-Energy Phenomena in the Solar Corona Tackled with X-ray Imaging-Spectroscopy
Naito, Yoshihiro	Hara, Hirohisa	Ishikawa, Ryoko	Spectroscopic study of Alfvenic waves in the source region of high-speed solar winds
Hatano, Shun	Ouchi, Masami	Koyama, Yusei	Ionizing Sources of Early Galaxies and Cosmic Reionization Studied by Deep Spectroscopy
Watanabe, Kuria	Ouchi, Masami	Tominaga, Nozomu	Origin of Elements in Early Galaxies Studied by Deep Spectroscopy

3rd year (5 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ikeda, Ryota	Iono, Daisuke	Tanaka, Masayuki	Observational Studies of Distant Galaxies using ALMA
Ishigami, Shun	Hara, Hirohisa	Katsukawa, Yukio	Spectroscopic study at the site of coronal heating
Ichimura, Ryota	Nomura, Hideko	Kataoka, Akimasa	Research on Chemical Evolution from Star- and Planet-Forming Regions to Planetary Systems by Chemical Reaction Network Calculations
Nishigaki, Moka	Ouchi, Masami	Takata, Tadafumi	Exploring the early phase of galaxy formation with large optical datasets
Yoshida, Tomohiro	Nomura, Hideko	Fukagawa, Misato	Research on Physical and Chemical Structure of Planet-Forming Regions by ALMA Observations of Molecular Lines

4th year (8 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ishihara, Kousuke	Saito, Masao	Nakamura, Fumitaka	Study of high-mass star formation process, focusing on hierarchical fragmentation
Ogami, Itsuki	Aoki, Wako	Furusawa, Hisanori	The Nature of the Andromeda Stellar Halo and Substructures Explored with Subaru Telescope
Sasaki, Shunsuke	Takiwaki, Tomoya	Machida, Mami	Turbulent-driven mechanism of core-collapse supernovae
Sato, Masato	Tominaga, Nozomu	Takiwaki, Tomoya	Supernova light curve and observation
Tada, Shotaro	Kotani, Takayuki	Hayano, Yutaka/ Minowa, Yosuke	Development of a novel method to realize ultra-precision detector characterization for exoplanet and astrometric observation in space
Doi, Kiyoaki	Kataoka, Akimasa	Nomura, Hideko/ Fukagawa, Misato	Unveiling planet formation by observations of protoplanetary disks
Naufal, Abdurrahman	Koyama, Yusei	Tanaka, Masayuki	Morphological Evolution of Galaxies across Cosmic Environment
Bhardwaj, Shubham	Dainotti, Maria Giovanna	Tominaga, Nozomu	The Multiwavelength analysis of Gamma-Ray Bursts via machine learning

5th year (9 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Omae, Rikuto	Machida, Mami	Ouchi, Masami	Probing the Magnetic Fields of Distant Galaxies to Unravel the Evolution of Galactic Magnetic Fields
Kasagi, Yui	Kotani, Takayuki	Hayashi, Saeko/Aoki, Wako	Search for extra-solar planets around young to late stars, and brown dwarfs for understanding planet formation at various evolutionary stages
Kashiwagi, Raiga	Iwasaki, Kazunari	Takiwaki, Tomoya	Study on star formation process induced by collisions between filamentary molecular clouds
Kobayashi, Umi	Tanaka, Masayuki	Nakanishi, Koichiro	Influence of galaxy interactions and mergers on AGN activities
Seo, Chanoul	Fujii, Yuka	Nomura, Hideko/ Ikoma, Masahiro	Modeling atmospheres of super-Earth/sub-Neptune-sized planets in contact with magma ocean
Tashima, Yuta	Machida, Mami	Nakamura, Fumitaka/ Takiwaki, Tomoya	Elucidating galactic magnetic fields using MHD simulation and polarization pseudo-observations
Nakano, Suzuka	Nakanishi, Koichiro	Sekii, Takashi	The interplay and co-evolution between galaxies and active supermassive blackholes
Hosokawa, Kou	Kotani, Takayuki	Minowa, Yosuke/ Fujii, Yuka	Development of high-contrast and high-spectral resolution spectrometer for the Subaru Telescope and characterization of exoplanet atmospheres
Masai, Takaho	Uzawa, Yoshinori	Kojima, Takafumi	Study of the effect of aberrations on aperture efficiency in radio telescopes towards high-performance multi-beam receivers at sub-mm wavelengths

2. Education and Research Collaboration with Graduate Schools

Name	Affiliated Institute	Supervisor	Title of Research Project
Otsuka, Munetake	The University of Tokyo	Tomaru, Takayuki	Study of Gravitational Wave Detection
Kitamura, Ryota	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study of Planet Formation
Sawamura, Mahoshi	The University of Tokyo	Okuda, Takeshi	Observational Studies on Nearby Galaxies
Zhuang, Rui	The University of Tokyo	Fukagawa, Misato	Observational Study on Exoplanet Formation
Fujimori, Arisa	The University of Tokyo	Katsukawa, Yukio	Study of magentic structures in the solar polar regions
Masaoka, Hiroto	The University of Tokyo	Honma, Mareki	Exploring the sources and mechanisms of FRBs through the expansion of domestic radio telescopes to the low-frequency band
Matsumura, Akifumi	The University of Tokyo	Ikoma, Masahiro	Theoretical research on the formation and evolution of exoplanet atmospheres
Yukino, Tomoya	The University of Tokyo	Motohara, Kentaro	Development of a NIR spectrograph NINJA and observational study of nearby LIRGs
Yoshino, Aoto	The University of Tokyo	Nakamura, Fumitaka	Fluid simulation of star formation
Li, Xinru	The University of Tokyo	Sakamoto, Seiichi	Observational study of the structural evolution of Galactic molecular clouds
Oki, Aika	The University of Tokyo	Honma, Mareki	Measure potential heat content of galaxy clusters and devise a galaxy cluster evolution map based on observations of AGN using VLBI
Ozawa, Yoshiki	The University of Tokyo	Fukagawa, Misato	Observational Study on Exoplanet Formation
Kambara, Yuki	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study of Planet Formation
Cha, Chaenae	The University of Tokyo	Motohara, Kentaro	Development of a NIR spectrograph NINJA and observational study of kilonova
Narita, Kanako	The University of Tokyo	Sakamoto, Seiichi	Observational Study of Material Evolution in Interstellar Space
Mitsuhashi, Kohei	The University of Tokyo	Tomaru, Takayuki	Study of Low-Frequency Vibration Isolation System for Gravitational Wave Telescope
Moritsuka, Akie	The University of Tokyo	Katsukawa, Yukio	Study of magneto-convection on the solar surface with spectro-polarimetric observations
Nishino, Yohei	The University of Tokyo	Tomaru, Takayuki	Development of Speedmeter Type Gravitational Wave Detector
Hafieduddin, Mohammad	The University of Tokyo	Honma, Mareki	Observational Studies of High-mass Star Formation using VLBI
Fariyanto, Elika Prameswari	The University of Tokyo	Honma, Mareki	The Jet Collimation Profile Analysis and Core-Shift Measurement of M84
Yun, Jeung	The University of Tokyo	Motohara, Kentaro	Spectroscopic Study of H-alpha Emitters at z~2 and development of SWIMS
Adachi, Hiroaki	The University of Tokyo	Fukagawa, Misato	Observational Research on Planetary-system Formation around Young Stars
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
Morii, Kaho	The University of Tokyo	Nakamura, Fumitaka	Statistical study of molecular cloud core embedded in infrared-dark cloud
Kinoshita, Shinichi	The University of Tokyo	Nakamura, Fumitaka	MHD simulation of cluster-forming clumps: The effect of the parental clump's environment on the dense core
Takamura, Mieko	The University of Tokyo	Honma, Mareki	Probing the pc-scale environment of Narrow line Seyfert 1 galaxy with VLBI
Nishiyama, Gaku	The University of Tokyo	Namiki, Noriyuki	Relational study of subsurface dyke and surface topography on the Moon
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 of Planet Formation

3. Commissioned Graduate Students

Doctoral Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Abe, Homare	Tokyo Institute of Technology	2023/4/1–2023/9/30	Aso, Yoichi	Measurement of birefringence in a sapphire mirror for the gravitational-wave telescope KAGRA
Uno, Shinsuke	The University of Tokyo	2023/4/1–2024/3/31	Uzawa, Yoshinori	Development of detector circuits for a submillimeter multichroic camera
Okada, Hiroko	University of Hyogo	2023/5/1–2024/3/31	Tominaga, Nozomu	Study of metal-poor stars
Katsuki, Riku	The University of Electro-Communications	2023/11/1–2024/3/31	Tomaru, Takayuki	Real-time imaging of cell traction force with 3D birefringence measurement
Koseki, Tomohiro	University of Tsukuba	2023/4/1–2024/3/31	Matsuo, Hiroshi	Realizing Synthesis Imaging Using Intensity Interferometry
Suzuki, Yoshihisa	Tohoku University	2023/10/1–2024/3/31	Aoki, Wako	Exploration of metal-poor stars using Subaru HSC narrow-band filters
Naganuma, Toyo	The University of Electro-Communications	2023/4/1–2023/7/31	Uzawa, Yoshinori	Development of the multi-chroic mm/submm wave camera
Niwa, Ayako	University of Tsukuba	2023/4/1–2024/3/31	Matsuo, Hiroshi	Development of 1.5 THz Photon Detectors for Antarctic Terahertz Intensity Interferometry
Matsui, Sena	Nagoya University	2023/4/1–2024/3/31	Aoki, Wako	Galactic archaeology of the Milky way and satellite galaxies
Miyato, Ken	The University of Electro-Communications	2023/4/1–2024/3/31	Nishimura, Atsushi	Study on distribution of molecular clouds in the Galaxy
Yamasaki, Yasumasa	Osaka Metropolitan University	2023/4/1–2024/3/31	Kojima, Takafumi	Development of wideband optical system for radio telescope
Watanabe, Yumi	Fukushima University	2023/10/1–2024/3/31	Nakanishi, Koichiro	Study of dense molecular cases using HCN(J=1-0)/CO(J=1-0) intensity ratios in the nearby Seyfert galaxy NGC 1068

Master's Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Inoue, Shuhei	The University of Tokyo	2023/4/1–2024/3/31	Uzawa, Yoshinori	Development of planar Magic-T for wideband millimeter/submillimeter wave detectors
Okami, Junpei	Shizuoka University	2023/10/1–2024/3/31	Kojima, Takafumi	Study on microwave cryogenic low-noise amplifier with ultra-low-power consumption
Sato, Kyosuke	Hosei University	2023/4/1–2024/3/31	Tanaka, Masayuki	Spatial dependency of the star formation history of the Ursa Minor dwarf spheroidal galaxy
Kameyama, Akira	Osaka Metropolitan University	2023/10/1–2024/3/31	Honma, Mareki	Development of low noise and wideband receiver for VERA
Kondo, Shoki	Osaka Metropolitan University	2023/10/1–2024/3/31	Honma, Mareki	86 GHz band observation using VERA telescope
Nagashima, Yuzuki	Fukushima University	2023/10/1–2024/3/31	Nakanishi, Koichiro	A Study of the Star Formation Distribution in the Nearby Spiral Galaxy NGC 1068
Nishikawa, Yuma	Osaka Metropolitan University	2023/10/1–2024/3/31	Kojima, Takafumi	Development of wideband optics for radio telescope
Yamamura, Ryosuke	The University of Electro-Communications	2023/4/1–2024/3/31	Uzawa, Yoshinori	Development of MKID for multi-color camera

4. Degrees Achieved with NAOJ Facilities

Name	Degree	Title of Research Project
Kasagi, Yui	Doctor of Philosophy, SOKENDAI	Unveiling Atmospheric Features of Faint Substellar Companions from High-Resolution Near-Infrared Spectra
Kashiwagi, Raiga	Doctor of Philosophy, SOKENDAI	Instability and Evolution of Shocked Clouds Formed by Collisions between Filamentary Molecular Clouds
Masai, Takaho	Doctor of Philosophy, SOKENDAI	A Study on the Design of Receiver Optics and Waveguide Components Towards High-Performance (Sub)Millimeter Wave Multibeam Receivers
Omae, Rikuto	Doctor of Philosophy, SOKENDAI	Probing the Magnetic Fields of Distant Galaxies to Unravel the Evolution of Galactic Magnetic Fields

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 (4 days in total): October 28 (for Mitaka Open House Day, open to participants only), November 11 (due to equipment inspection), and February 11–12 (due to snowfall).

Visitors: 18,228 (of which 2,720 were in groups)

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

The Exhibit Room and Astronomical Instruments Museum reopened on May 8, and the Theater Room reponed on August 26.

[Regular Star Gazing Party]

Dates: (Online) Friday before second Saturday
(On-site) fourth Saturday

(Online): Held 9 times
Maximum number of simultaneous connections: 909
Total Views: 10,429 (As of March 31, 2024)

(On-site): Held 11 times
Total Visitors: 749 guests

Online events were broadcasted via Zoom to YouTube Live.

[4D2U Theater Showings]

Dates: Friday before second Saturday; first and third Saturdays

Capacity: 120 people per day

Visitors: 5,354 (36 events planned and 35 events held, with additional special group tours)

[Special Open-House Event] Mitaka Open House Day

Dates: October 28 (Saturday), 2023, 10:00–17:00

Topic: The Universe Explored by Supercomputers and AI

Onsite Attendees: 1,114 (advance registration required)

NAOJ Main Lectures: 2

Total YouTube Maximum Simultaneous Connections: 1,169

Total Views on YouTube: 14,945 (in the first 3 weeks)

Total Views on niconico Live: 261

This event is jointly sponsored by NAOJ, the University of Tokyo Graduate School of Science Institute of Astronomy; Astronomical Science Program at the Department of Advanced Studies; and the NINS Astrobiology Center. In FY 2023, taking preventative measures against the COVID-19 pandemic into consideration, the event was held in an onsite (limited capacity, advanced reservations required) format. The main lectures were held onsite and also broadcast through niconico Live streaming.

Ishigaki Island: Ishigakijima Astronomical Observatory

[Open year-round]

Dates: April to March

Open Hours: Wednesdays through Sundays and Holidays, 10:00–15:30 (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, (20:00–21:00), one 45-minute session per evening

Space Theater: 15:30–16:15, from Wednesdays to Sundays and on Holidays

Visitors: 5,435

Open Murikabushi 105-cm optical/infrared telescope, Hoshizora Manabi no Heya (Starry Sky Study Room) (featuring exhibits of astronomical images, screenings of celestial body videos and 4D2U "four-dimensional digital universe," and stargazing sessions with the 40-cm telescope), interior of observation dome, and corridors (including exhibits of astronomical images)

[Special Open Day]

[Southern Island Star Festival 2023] (co-sponsored)

Dates: August 19 (Saturday) – 27 (Sunday), 2023

Cool Evening Live Performance & Stargazing Party: Held on August 19 (Saturday) at Painuhama-machi Green Park with 2,000 onsite guests in attendance

Memorial Lecture and "Asteroid in Love" KiraKira [Sparkling] Talk Show: Held on August 20 (Sunday) at Ishigaki City Hall with 100 visitors

Total for Star Festival Week: August 19 (Saturday) – 27 (Sunday), Ishigakijima Astronomical Observatory, Total Guests: 434

2. Mizusawa Campus

[Open year-round]
Dates: April to March (except for New Year's season), 9:00–17:00 daily
Visitors: 12,845
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.

[Special Open Day] Held as Part of Iwate Galaxy Festival 2023
Dates: August 26 (Saturday), 2023
Visitors: total 690
In light of the fact that novel coronavirus infections have not yet ended, since national policy no longer uniformly requires basic infection control measures in everyday life we consulted with Oshu City and the Oshu Space and Astronomy Museum (OSAM: Yugakukan), and this year, the event was held normally for the first time in four years, since 2019.

Iriki: VERA Iriki Station
[Open year-round]
Dates: April to March (except for New Year's season)
Visitors: 1,140

[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, although the national policy no longer uniformly calls for basic infection control measures in daily life, the new coronavirus infection has not yet ended, and the "three densities" are expected at the event, so there is concern about the spread of infection. After consultation with the main committee members, it was decided to cancel the event.

Ogasawara: VERA Ogasawara Station
[Open year-round]
Dates: April to March (except for New Year's season)
Visitors: 6,360

[Special Open Day]
Dates: February 27 (Saturday), 2024
Visitors:194
In view of the fact that novel coronavirus infections have not yet ended, since national policy no longer uniformly requires basic infection control measures in everyday life the event was held normally for the first time in four years, since 2019.

Ishigaki Island: VERA Ishigaki-jima Station
[Open year-round]
Dates: April to March (except for the 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: 2,310

[Special Open day] The Special Open Day was held as a part of the Southern Island Star Festival.
Dates: August 20 (Sunday), 2023
Visitors: 248

In view of the fact that novel coronavirus infections have not yet ended, since national policy no longer uniformly requires basic infection control measures in everyday life the event was held normally for the first time in four years, since 2019.

3. Nobeyama Campus

[Regular Open]

Open Time: 8:30–17:00 (every day except around New Year's Day, December 29 to January 3)

Visitors: 39,217

Open Facilities: 45-m Radio Telescope, Nobeyama Millimeter Array, Nobeyama Radioheliograph, etc. (just viewing)

[Open House Day]

(Online)

Date: July 22 (Saturday), 2023, 10:00–16:00 (available for video access after the day)

Participants:

Public lectures:

- maximum viewers for live streaming ~430 (am), ~400 (pm)
- ~35,000 (total number of views as of 2024/4/10)

Virtual space (poster session): ~100

(On-site)

Date: August 26 (Saturday), 2023, 9:30–16:00

Participants: 1,353

Nobeyama Open Campus Day 2023 was held onsite and online. Nine observatory users gave public online lectures regarding their research topics such as Ph.D. researcher Haruka Sakemi (Kagoshima University) and Ph.D. researcher Shinji Fujita (University of Tokyo). The number of views for this live streaming reached over 400, and the total number of views was more than 35,000 as of April 2024. We also held a poster session using virtual space where 13 posters of individual research and 19 posters of laboratory introduction were presented for the about 100 participants who gathered. For on-site Open House Day, several events were conducted such as the 45-m antenna-touch; DIY of paper-fan-antenna by observatory alumni; exhibition booths by the ALMA project, Solar Science Observatory, Spectrum Management Office, and Osaka Metropolitan University; and public lectures by observatory users (six talks and ten posters were presented). In total 1,353 people attended.

4. Subaru Telescope

[Summit Facility Tour]
- The public tour program officially ended due to various circumstances.
- Special tours: 50 groups, 151 visitors

[Base Facility Tour]
- Special tours visitors: 20 groups, 737 visitors

* This number includes 7 school field trips (667 visitors)

[Public Information]
- Primary means of public information is posting at the official website https://subarutelescope.org
- Science results from the Subaru Telescope – 12 Japanese and 12 English articles
- Announcements and topics of special activities and events – 32 Japanese and 32 English articles
- Social media official accounts
  - X (formerly known as Twitter) accounts – SubaruTelescope (Japanese), SubaruTel_Eng (English)
  - Facebook accounts – 国立天文台 (Japanese), National Astronomical Observatory of Japan, and Subaru Telescope Hawaii Outreach (English)
  - Instagram account – subaru_telescope (English)
  - YouTube channels – SubaruTelescopeNAOJ (Japanese), SubaruTelescopeNAOJe (English), subarutel_starcamadmin (bilingual subchannel)
- Press releases to the local media of Hawai‘i – 10 English releases (including 2 joint release with other observatories)

[Outreach]

1. Lectures, Workshops, etc., at Nearby Facilities:
46 cases, about 1,900 people in total

(Main Activities)
- Judges at a series of VEX robotics competitions for elementary, intermediate, and high school teams
- Classroom visits through the annual Journey Through The Universe program
- Lecture at the Tanabata Japanese Star Festival
- Lectures at the After Dark in the Park program at Hawai‘i Volcanoes National Park
- Panel discussion about the A Hua He Inoa program to propose Hawaiian names for exoplanets

2. Other Activities, including Outreach Events

1) In person Activities:
18 events, able to interact over 11,000 people.

(Main Activities)
- Merrie Monarch Parade
- AstroDay
- AstroDay West
- Tanabata Japanese Star Festival (co-hosted with ‘Imiloa Astronomy Center)
- Career events (Career Fair, Career EXPO) for high school students
- Family Science events at elementary schools
- Stargazing party at Mo‘okini Heiau, a part of Kohala Historical Sites State Monument
- Stargazing at Lili‘uokalani Gardens
- Christmas in the Park at Lili‘uokalani Gardens (as a member of Maunakea Observatories)
- Maunakea Coin Contest (as a member of Maunakea Astronomy Outreach Committee)

2) Online Activities:
3 events, able to interact with 29 people.

(Activity)
- Remote presentations for Japanese high school students

3. YouTube Live Streaming:
27 cases, about 2.16 million views

(Main Activities)
- Live streaming of the NAOJ citizen science project GALAXY CRUISE
- Live streaming of Lyrids meteor shower (*)
- Live streaming of Perseids meteor shower (*)
- Live streaming of Geminids meteor shower (*)

(*) Streamed from the Asahi Shimbun Astro LIVE YouTube Channel (20 out of 27 cases)

In addition, a 24/7 live stream from the Subaru-Asahi Star Camera is offered through cooperation with The Asahi Shimbun Company.

4. Volunteer Activities: 2 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

5. Media Interview/Filming: 27 cases (26 Japanese, 1 English)
- 71 articles were published in newspapers in Japan
- 5 news clips and programs were aired on terrestrial television in Japan
- 27 articles were published in media in Hawai‘i (including newspapers and online news websites)

IX Overseas Travel

Research and Academic Staff Overseas Travel

(Including employees on annual salary system.)

category / country/area	Business Trip	Training	Total
South Korea	23	0	23
China	10	0	10
Thailand	6	0	6
Taiwan	18	0	18
Hong Kong	0	0	0
Singapore	1	0	1
Indonesia	0	0	0
Philippines	0	0	0
Other areas in Asia	14	0	14
Hawai`i	33	0	33
U.S.A.	73	0	73
Australia	5	0	5
Italy	23	0	23
U.K.	12	0	12
France	10	0	10
Canada	8	0	8
Guam, Saipan	0	0	0
Germany	23	0	23
Other areas in Europe and Oceania	44	0	44
Mexico	1	0	1
Brazil	0	0	0
Africa	5	0	5
Other areas in South and Central America *	44	0	44
Total	353	0	353

* In typical years, most travelers to South and Central America go to Chile.

X Award Winners

Award Recipients	Affiliated Division	Job Title	Award	Date
Masui, Sho	Advanced Technology Center	Project Researcher	The IEICE Electronics Society Student Award	2023/9/12
Masui, Sho	Advanced Technology Center	Project Researcher	The JSAP Young Scientist Presentation Award	2023/9/19
Jike, Takaaki	Mizusawa VLBI Observatory	Assistant Professor	FY 2023 The Tsuboi Prize of the Geodetic Society of Japan (Group Prize)	2023/10/12
Behroozi, Peter	Division of Science	Project Researcher	Clarivate Highly Cited Researcher 2023	2023/11/15
Narukage, Noriyuki	Solar Science Observatory	Assistant Professor	The 2023 Shoichiro Yoshida Memorial/ Nikon Astronomy Achievement Award	2024/1/31
Hiramatsu, Masaaki	Public Relations Center	Associate Professor (Lecturer)	FY 2023 The ASJ Award for Education and Public Outreach in Astronomy	2024/3/11
Namekata, Kosuke, Maehara, Hiroyuki	ALMA Project; Okayama Branch Office, Subaru Telescope	JSPS Postdoctoral Fellow; Assistant Professor	FY 2023 PASJ Excellent Paper Award	2024/3/12
Hamana, Takashi, Shirasaki, Masato, Miyazaki, Satoshi, Tanaka Masayuki	Division of Science; Research Enhancement Strategy Office; Subaru Telescope	Assistant Professor; Professor; Associate Professor	FY 2023 PASJ Excellent Paper Award	2024/3/12

XI Library, Publications

1. Library

Number of books in each library (2024/3/31)

	Japanese Books	Foreign Books	Total
Mitaka	19,148	50,399	69,547
Nobeyama	1,128	5,891	7,019
Mizusawa	4,986	18,113	23,099
Hawai`i	1,699	4,683	6,382
Total	26,961	79,086	106,047

Number of journal titles in each library (2024/3/31)

	Japanese Journals	Foreign Journals	Total
Mitaka	371	1,675	2,046
Nobeyama	16	82	98
Mizusawa	659	828	1,487
Hawai`i	15	9	24
Total	1,061	2,594	3,655

2. Publication

Here we list continuing publications produced by NAOJ in FY 2023.

(Mitaka)
01) Report of the National Astronomical Observatory of Japan, Vol. 24: 1 issue (Digital Publication Only).
02) Annual Report of the National Astronomical Observatory of Japan (Japanese), no. 35, Fiscal Year 2022: 1 issue
03) Annual Report of the National Astronomical Observatory of Japan (English), vol. 25 Fiscal Year 2022: 1 issue
04) Calendar and Ephemeris, 2024: 1 issue
05) NAOJ News, No. 340–342: 3 issues
06) NAOJ Pamphlet 2024 (Japanese): 1 issue
07) Rika Nenpyo (Chronological Scientific Tables), 2024: 1 issue
08) Kankyo Nenpyo (Chronological Environmental Tables), 2023–2024; 1 issue

3. Publication Support

In FY 2023, the NAOJ Reprints were replaced by publication support.
National Astronomical Observatory publication support, No. 3685–3743: 59 issues.

XII Important Dates

April 1, 2023 – March 31, 2024

2023	
2023/4/6	As a part of the Subaru Stars program, Subaru Telescope invited grades K-1 students of Na‘alehu Elementary School to the Hilo Base Facility for an immersive field trip.
2023/4/15	Subaru Telescope and TMT Project participated in Merrie Monarch Parade held in Hilo, the Island of Hawai‘i, as Maunakea Observatories members.
2023/4/17	Vice Minister of Education, Culture, Sports, Science and Technology Yousei Ide visited Mitaka Campus.
2023/4/18	ALMA Cycle 10 Proposal Preparation Meeting was held at Mitaka Campus and online.
2023/4/19, 2023/4/21	Subaru Telescope live streamed the Lyrids meteor shower from Maunakea, Hawai‘i with the cooperation of The Asahi Shimbun Company.
2023/4/19	Two astronomers received the Young Scientists' Award of the 2023 Commendations for Science and Technology by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for their observational research using the Subaru Telescope.
2023/4/19 –2023/4/21	TMT Project set up the NAOJ booth at OPIE SPACE & ASTRONOMICAL OPTICS EXPO 2023 held at Pacifico Yokohama and showcased TMT, Gravitational Wave Science Project, Industry Liaison Office, and Mizusawa VLBI Observatory.
2023/4/20	Live streaming of the partial solar eclipse from Ishigakijima Astronomical Observatory.
2023/4/25	Kimura Hisashi Memorial Museum opened a new special exhibition (researcher's own notes) for a short period of time until mid-July.
2023/5/1	Vice Minister of Cabinet Office Tsuyoshi Hoshino visited Mitaka Campus.
2023/5/6	Subaru Telescope, its internal citizen science project PANOPTES, and TMT Project participated in the annual AstroDay event, in Hilo, the Island of Hawai‘i, and provided fun science activities at their booths to the local community.
2023/5/8	The National Institutes for Natural Sciences (NINS) and the NAOJ presented David Yutaka Ige, former governer of Hawai‘i, with a certificate of appreciation.
2023/5/11	The Churaboshi Research Team Workshop, abbreviated as “Churaken,” issued a call for participants in the Churaboshi Research Team Workshop to be held on Ishigaki Island (August 21 (Monday) to August 23 (Wednesday), 2023).
2023/5/17	ALMA 10th Anniversary Celebration held at Hitotsubashi Hall.
2023/5/18	As a part of the Subaru Stars program, Subaru Telescope invited grade 2 students of Na‘alehu Elementary School to the Hilo Base Facility for an immersive field trip.
2023/5/21 –2023/5/26	TMT Project set up the NAOJ booth at the hybrid Japan Geoscience Union (JpGU) Meeting 2023 at Makuhari Messe and showcased TMT and ALMA.
2023/5/29 –2023/6/2	NINS (National Institutes of Natural Sciences) President Kawai visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile and made courtesy visits to Ministry of Foreign Affairs and others in Chile.
2023/7/1	COIAS, an application that searches for small Solar System bodies (SSSBs, including asteroids, comets, and trans-Neptunian objects) based on images taken by the Subaru Telescope, was released.
2023/7/12 –2023/7/14	ALMA Data Reduction Workshop was held at Mitaka Campus .
2023/7/20	Kimura Hisashi Memorial Museum opened a new special exhibition (41 years of observation field books) until around the time of the first snowfall.
2023/7/20	IRAM Dr. Reinhard Genzel visited Mitaka Campus.
2023/7/22	Open House Day of Nobeyama Radio Observatory was held on-line.
2023/8/1	Announcement that Iwate Galaxy Festival 2023 (date August 26 (Saturday)) will be held normally for the first time in four years, since 2019.
2023/8/3	45-m telescope painting event was held under the joint organization of Nobeyama Radio Observatory and 45 Supporters Club (voluntary group).
2023/8/7 –2023/8/11	The Office of International Relations, in collaboration with relevant NAOJ departments, hosted an NAOJ booth at the Asia-Pacific Regional IAU Meeting 2023 (APRIM 2023) in Koriyama, Fukushima Prefecture. Exhibits from the Subaru Telescope, TMT, and ALMA Projects were also featured at the booth.
2023/8/8	Four Undergraduate interns of the Akamai Workforce Initiative program, supervised by Subaru Telescope mentors, presented at the Akamai Internship Symposium held at University of Hawai‘i at Hilo.

2023/8/11 –2023/8/13	Subaru Telescope live streamed the Perseids meteor shower from Maunakea, Hawai'i, for three consecutive nights with the cooperation of The Asahi Shimbun Company.
2023/8/16	Satoshi Miyazaki, Director of Subaru Telescope, sent message to the Maui community affected by the wildfires.
2023/8/19	Subaru Telescope co-hosted the Tanabata Japanese Star Festival with 'Imiloa Astronomy Center.
2023/8/19 –2023/8/27	The "Southern Island Star Festival" was held for the 22st time this year, featuring evening live performances & star lectures/viewing sessions, commemorative lectures, and a special opening of the VERA Ishigakijima Station.
2023/8/26	Open House Day of Nobeyama Radio Observatory was held on-site.
2023/8/26	The "Iwate Galaxy Festival 2023," announced on August 1, was held.
2023/8/30	Kazuhisa Shibuya, Ambassador of Japan in Chile, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
2022/9/1	Undergraduate students of the SOKENDAI Summer Student program gave hybrid (in-person and online) presentations about their study results.
2023/9/3 –2023/9/4	"Starry Sky Protection Research Conference" held in hybrid format on-site at NAOJ Mitaka Campus and online.
2023/9/7	World-wide online APRSAF-29 stargazing party.
2023/9/12	GALAXY CRUISE, NAOJ citizen science project, started the 2023 Special Campaign, classifying simulated galaxies.
2024/9/15	Subaru Telescope suspended night observations and started thoroughly investigating the causes and effects of the telescope's troubles.
2023/9/20	Subaru Telescope posted the first report about suspension of night observations on the website.
2023/9/28	Subaru Telescope posted the second report about suspension of night observations on the website.
2023/9/30 –2024/1/20	Subaru Telescope staff members contributed to a series of VEX robotics competitions as judges for elementary, intermediate, and high school teams.
2023/10/5 –2023/10/6	NAOJ External Review in research, development, operations, etc. was conducted at Mitaka Campus.
2023/10/7	Subaru Telescope, its internal citizen science project PANOPTES, and TMT Project participated in the annual AstroDay West event at a shopping center in Kailua-Kona, the Island of Hawai'i, and provided fun science activities at their booths to the local community.
2023/10/12	"GGOS Japan" was awarded the Tsuboi Prize (group prize) of the Geodetic Society of Japan for 2023 at the 140th Conference of the Geodetic Society of Japan. The National Astronomical Observatory of Japan (NAOJ), which includes Mizusawa VLBI Observatory, is one of the member institutions of GGOS Japan.
2024/10/16	Subaru Telescope posted the third report about suspension of night observations on the website.
2023/10/19	Hak-Jae Kim, Ambassador of Republic of Korea in Chile, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
2023/10/28	Mitaka Open House Day held. Some events such as main lectures were also provided online.
2023/11/3	The 8th "Nagano Prefecture is Astro-Prefecture" meeting was held by "Nagano Prefecture is Astro-Prefecture" liaison council, which consists of Nobeyama Radio Observatory, Kiso Observatory of the University of Tokyo, and so on.
2023/11/13 –2023/11/17	ALMA Data Processing Pipeline Developer Group Meeting was held at Mitaka Campus and online.
2023/11/13 –2023/11/22	Director General Tsuneta made courtesy visits to Ministry of Foreign Affairs and others in Chile.
2023/11/15	ALMA achieved the highest resolution ever, 5 milli-arcsec.
2023/11/17	Subaru Telescope and its internal citizen science project PANOPTES participated in Career EXPO for high school students in Hilo and its vicinity, and introduced various jobs and career paths.
2023/11/23	Subaru Telescope posted the fourth report about suspension of night observations on the website.
2023/12/4 –2023/12/8	ALMA at 10 years: Past, Present, and Future was held in Chile.
2023/12/4 –2023/12/12	NAOJ ALMA Project selected five young astronomers who have achieved outstanding scientific results using ALMA to commemorate the 10th anniversary. They attended the conference "ALMA at 10 years" and visted the ALMA site.
2023/12/11 –2024/2/10	The Maunakea Coin Contest, open to K-12 students on the Island of Hawai'i, was held by the Maunakea Astronomy Outreach Committee. Subaru Telescope staff led the contest.
2023/12/12	ALMA science workshop between Chile and Japan was held at the Santiago office of the Joint ALMA Observatory.
2023/12/13 –2023/12/14	Subaru Telescope live streamed the Geminids meteor shower from Maunakea, Hawai'i, for two consecutive nights with the cooperation of The Asahi Shimbun Company.
2023/12/20	Kimura Hisashi Memorial Museum opened a new special exhibition (World of Numbers) until around spring 2024.
2023/12/20	ALMA Grant Fellow Symposium 2023 was held at Mitaka Campus and online.

2023/12/21 –2023/12/22	ALMA/45m/ASTE Users Meeting 2023 was held at Mitaka Campus and online.
2023/12/23 –2023/12/24	Subaru Telescope participated in Christmas in the Park at Lili‘uokalani Gardens event as a member of Maunakea Observatories.
2023/12/25	Subaru Telescope posted the fifth report about suspension of night observations on the website.

2024

2024/1/3	Ricardo G. Rojas, Ambassador of Chile in Japan, visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
2024/1/5	Annoucement that “Star Island 20” (date January 27 (Saturday)) will be held normally for the first time in four years, since 2019.
2024/1/7 –2024/1/11	The Office of International Relations, in cooperation with the Subaru Telescope and other relevant departments at NAOJ, exhibited an NAOJ booth at the 243rd Meeting of the American Astronomical Society (243rd AAS Meeting) held in New Orleans, USA.
2024/1/16 –2024/1/18	ALMA Workshop 2023a was held in Ishigakijima Astronomical Observatory and Nobumoto Ohama Memorial Hall.
2024/1/18	As a part of the Subaru Stars program, Subaru Telescope invited grade 5 students of Kea‘au Elementary School to the Hilo Base Facility for an immersive field trip.
2024/1/23	As a part of the Subaru Stars program, Subaru Telescope invited grade 3 students of Kea‘au Elementary School to the Hilo Base Facility for an immersive field trip.
2024/1/23 –2024/1/25	The annual Subaru Users Meeting FY 2023 was held in a hybrid style of on-site and online.
2024/1/27	The “Star Island 20,” announced on January 5, was held.
2024/1/28	Latin America and Caribbean Affairs Bureau Manager of Ministry of Foreign Affairs of Japan Tsukamoto visited the operation site facilities and the observatory close to San Pedro de Atacama in Chile.
2024/2/5 –2024/2/9	Subaru Telescope and TMT Project staff members participated in the annual educational program Journey Through the Universe and delivered interactive presentations at classrooms of public elementary, intermediate, and high schools in Hilo, Hawai‘i.
2024/2/13	As a part of the Subaru Stars program, Subaru Telescope invited grade 2 students of Kea‘au Elementary School to the Hilo Base Facility for an immersive field trip.
2024/2/15	Subaru Telescope posted the sixth report about suspension of night observations on the website.
2024/2/15 –2024/2/17	Co-Hosted an onsite booth with 10 other organizations at the American Association for the Advancement of Science Annual Meeting (AAAS2024 held in hybrid format).
2024/3/3	The Subaru Telescope resumed night observations.
2024/3/4	Subaru Telescope posted the last report about the suspension of night observations on the website.
2024/3/4 –2024/3/8	Dense GAS in Nearby Galaxies – ALMA Workshop was held at Osaka University Nakanoshima Center.
2024/3/5	Takako Ito, Ambassador of Japan in Chile, visited NAOJ Mitaka Campus.
2024/3/7 –2024/3/8	As part of the FY 2023 NAOJ project evaluation, an international evaluation of Mizusawa VLBI Observatory was conducted at Mizusawa Campus.
2024/3/8 –2024/3/17	Engineering observations were conducted for the first time with all four spectrographs of the Prime Focus Spectrograph (PFS) mounted on the Subaru Telescope.
2024/3/12	Satoshi Miyazaki, Director of Subaru Telescope, received the Japan Academy Prize.
2024/3/21	“ALMA Data Reduction Practice (Advanced Level)” held at Mitakat Campus and online.
2024/3/21 –2024/3/22	As part of the FY 2023 NAOJ project evaluation, an international evaluation of Nobeyama Radio Observatory was conducted at Nobeyama Campus.
2024/3/22	“ALMA Cycle 11 Proposal Preparation Meeting” held at Mitakat Campus and online.
2024/3/25 –2024/3/26	As part of the FY 2023 NAOJ project evaluation, an international evaluation of the ASTE Project was conducted at Mitaka Campus.

Throughout the year

	Subaru Telescope provides the 24/7 live streaming from Maunakea, Hawai‘i with the Subaru-Asahi Star Camera in collaboration with The Asahi Shimbun Company.

XIII Publications, Presentations

1. Refereed Publications

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