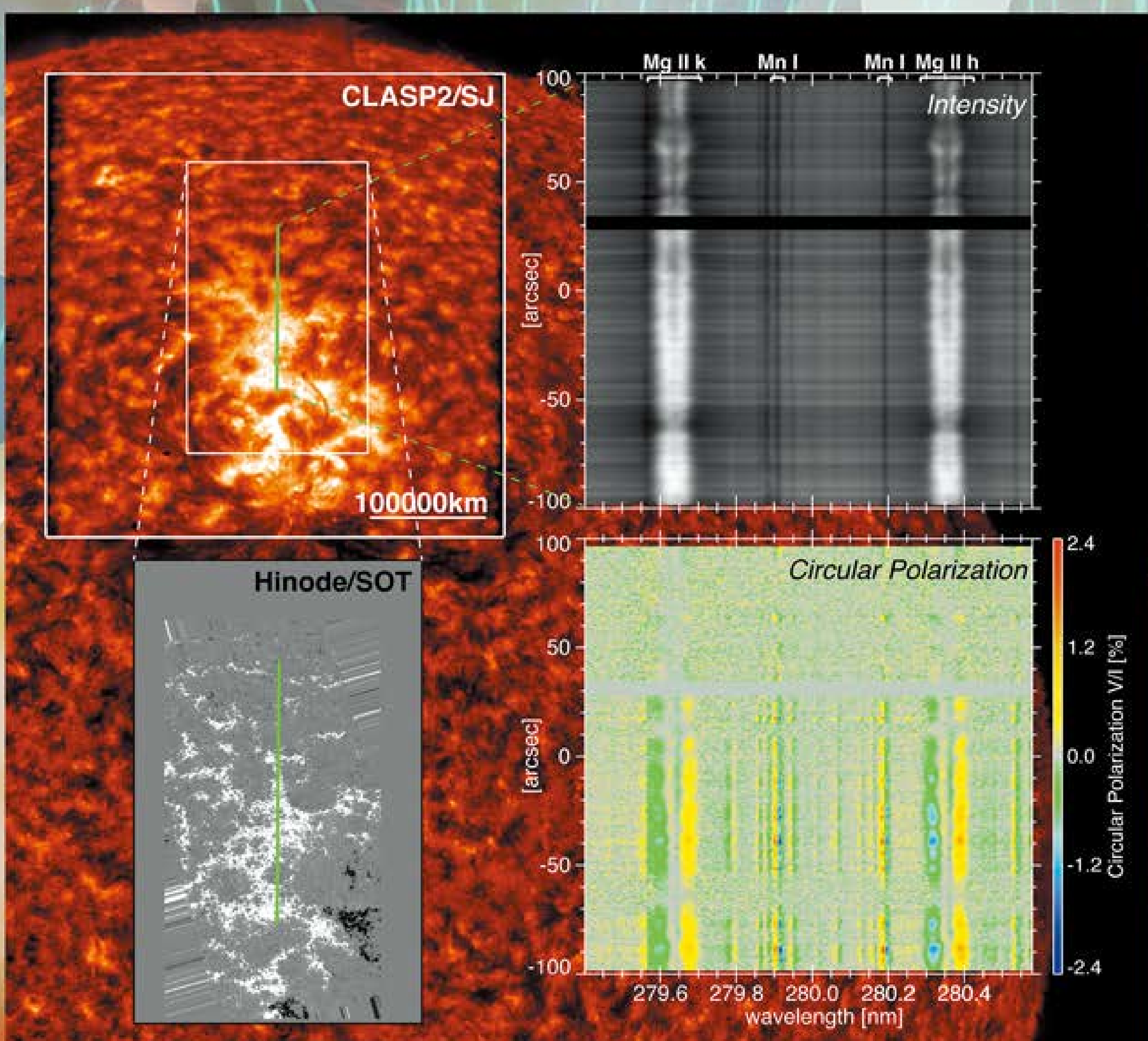
ISSN 1346-1192

Annual Report of the National Astronomical Observatory of Japan

Volume 23 Fiscal 2020



Cover Caption

Magnetic fields from the photosphere to the top of the chromosphere revealed by the coordinated observation between the sounding rocket experiment CLASP2 and the Hinode satellite. CLASP2 measured the magnetic fields at three different heights of bottom, middle and top of the solar chromosphere from the circular polarization spectra in UV.

Credit: NAOJ, IAC, NASA/MSFC, IAS

Postscript

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Annual Report of the National Astronomical Observatory of Japan
Volume 23, Fiscal 2020

PREFACE

Saku TSUNETA
Director General of NAOJ

In 2020, the novel coronavirus had a large impact on people's lives. As a preventative measure against the spread of the infection, the Subaru Telescope and ALMA were forced to temporarily suspend open-use observations, but both were able to resume operations while taking preventative measures in response to the ever changing conditions in accordance with the local regulations in Hawai`i, U.S.A. and Chile where they are located. The 45-m telescope of Nobeyama Radio Observatory, the VERA radio interferometry antenna of the Mizusawa VLBI Observatory, and the Kyoto University Seimei Telescope at the Okayama Branch Office of Subaru Telescope conducted open-use observations as normal.

In these difficult times, there was also good news. Three scientists (English, German, and American) won the Nobel Prize in Physics 2020 for research related to black holes. NAOJ has also been actively pursuing black hole research for a long time. In the 1990's, Nobeyama Radio Observatory's 45-m radio telescope produced an important observational result proving the existence of a super massive black hole in the heart of Galaxy M106. The research recognized this time confirming the existence of a giant black hole at the center of the Milky Way Galaxy is driving the efforts to image a black hole by the Event Horizon Telescope project, in which NAOJ researchers are also participating.

Behind such significant scientific results, you find pioneering work for new technologies to enable advanced research capabilities. Using the facilities of the interferometric gravitational wave antenna TAMA300, NAOJ successfully realized frequency dependent squeezing, a technique to improve sensitivity, at frequencies important for gravitational wave detection. We expect this technique to be used in the next round of upgrades for not only the gravitational wave telescope KAGRA, but also for gravitational wave telescopes around the world.

A team led by Kyoto University created mock-universes through large-scale simulations run on the Center for Computational Astrophysics (CfCA) supercomputer "ATERUI II", and a U.S. team using independent analysis methods was able to extract the cosmological parameters. This is groundbreaking but still preliminary research for developing precision cosmology based on observational results from new instruments on the Subaru Telescope, refining our research methods through an organic combination of observations and simulations. In FY 2020, there were 175 scientific reports based on "ATERUI II" computations. In addition, because a hybrid field of study called "astro-informatics" is emerging, driven by the explosive growth of data accompanying the increase in size and precision of telescopes and instruments, we hired two tenure-track assistant professors and dispatched them to the Institute of Statistical Mathematics for 5 years.

NAOJ realizes the importance of our relationship with our local communities. Through activities like donating masks and other personal protection equipment to local medical organizations, Subaru Telescope did what it could to support medical care in the local area during the COVID emergency. We also cooperate with relevant organizations near the different NAOJ campuses to support the local communities, most notably projects with Mitaka City for the public dissemination of academic knowledge and resources and the promotion of cultural projects. In these ways we engage in symbiotic cooperation to promote comprehensive "personal development" and "community development."

In other ways, NAOJ moved along with society in these changing circumstances; we held many online classes to provide learning opportunities during the COVID emergency and shifted the Special Open House events of NAOJ Mitaka Campus and Nobeyama Radio Observatory to an online format. Indeed, NAOJ had been the first Japanese research organization to start offering online classes when the schools nationwide closed at the end of FY 2019 due to the COVID pandemic. The 188-cm reflector telescope at the Okayama Branch Office of Subaru Telescope, in cooperation with Asakuchi City, conducted the first reserved observations for general citizens. Through projects like these, we created opportunities for the general public to use a telescope which had been exclusively for researchers.

In recent years, the space boom in the private sector has spawned a wave of satellite constellation projects which operate numerous small satellites in orbit. Since these satellites can shine by reflecting sunlight, there are concerns about their potential impact on astronomical observations. Research is underway using the Murikabushi Telescope of Ishigakijima Astronomical Observatory to evaluate the impact of these satellites on astronomy observations. Going forward, we are working to build a future where various measures are in place to allow the space industry and astronomy to coexist in harmony.

Here I would like to summarize the status of NAOJ's various projects in FY 2020. Due to the COVID emergency, the Subaru Telescope suspended observations for almost 2 months. This had a large impact spreading beyond open-use observations; the Subaru Strategic Program scheduled to conclude this fiscal year using the ultra-wide field of view prime focus camera Hyper Suprime-Cam (HSC) was also forced to be delayed. But a number of scientific achievements ranging from the local Universe to the distant Universe were obtained from the HSC Subaru Strategic Program (HSC-SSP), including the discovery of a galaxy forming in the local Universe, multiple proto-clusters of galaxies over 12 billion light-years away, and numerous double quasars in the distant Universe. Of the 169 scientific reports based on Subaru Telescope observations during 2020, approximately one-third came from HSC-SSP results. The importance of wide field of view observations with HSC will only continue to increase. Additionally, in FY 2020, HSC conducted collaborative observations with JAXA's Hayabusa2 project and NASA's New Horizons project, contributing to Solar System exploration.

The COVID situation also affected the development of the ultrawide-field-of-view multi-object Prime Focus Spectrograph (PFS), causing delays. But through the efforts of the development teams in each country, the first of four planned fiber optic cables and a small experimental telescope were installed on the Subaru Telescope in FY 2020. Connecting this fiber to a spectrograph previously installed on the Subaru Telescope, the PFS project succeeded in capturing the spectrum of the Maunakea night sky. The PFS fiber positioner, optical fibers, spectrographs, and detectors are being developed in Taiwan, Brazil, France, and the U.S.A. respectively. We look forward to the first engineering test observations using the Subaru Telescope in FY 2021.

SSP-IRD, the Subaru Strategic Program searching for Earth-like planets with the near Infrared Doppler instrument (IRD), is also proceeding well. Already in FY 2020, results were produced including the characterization of the orbital planes of several Earth-like extrasolar planets. The near infrared high-contrast integral field spectrograph CHARIS discovered a new brown dwarf and characterized its atmosphere. The development, maintenance, and operation of these instruments are proceeding through collaboration between Subaru Telescope and the Astrobiology Center of the National Institutes of Natural Sciences.

At NAOJ we are pursuing the "Subaru Telescope 2.0" plan for greatly improving the capabilities of the telescope with HSC, PFS, and a planned wide-field, high-resolution infrared instrument ULTIMATE using ground layer adaptive optics (GLAO) as the main instruments. Preparation is continuing in order to start in earnest in FY 2022. "Subaru Telescope 2.0" plans to achieve a 50 fold increase in the field of view and a 20 fold increase in the number of simultaneously observable objects for optical spectroscopy; and a 10 fold increase in field of view and a 2 fold increase in angular resolution for infrared observations as compared to the current Subaru Telescope. Subaru Telescope 2.0 was adopted in the Roadmap 2020 of the Ministry of Education, Culture Sports, Science and Technology. Preventative maintenance in response to the aging of the facility is an important issue for the current Subaru Telescope and will be essential for stable operation in the future.

ALMA was forced to suspend observations for about 1 year starting from March 2020 due to the spread of COVID-19 in Chile, but science observations restarted in March 2021. Even during the suspension of observations, the East-Asian ALMA Regional Center (Mitaka Headquarters) and others continued to promote open use and provide user support, primarily through the processing of previously acquired data. The number of scientific papers published based on ALMA data reached 2,264 during the nine-and-a-half-years ending with FY 2020. Japan continued to have the second largest share of published papers after the U.S.A.

As in previous years, in FY 2020, ALMA produced many scientific results. A deep-space survey of unprecedented scale has successfully estimated the amount of molecular gas, which provides the material for stars, down to the small, distant galaxies. In the Solar System, ALMA discovered a belt-like distribution of hydrogen cyanide on the equator of Neptune. In addition, observations of multiple high-density gas clouds in star forming regions in the direction of the constellation Taurus using ALMA's Morita Array became a "census of stellar eggs," clarifying the time required for new stars to be born. Star formation in Taurus is a theme which has been researched by Japanese astronomers since the 1990s through observations with the Nobeyama 45-m Radio Telescope and the Nagoya University 4-m radio telescope. Now this research is being further advanced with ALMA.

In ALMA instrument development, preparation is continuing for first-light observations with the Band 1 receivers (frequency band 35-50 GHz) being developed by a research team led by Academia Sinica Institute of Astronomy and Astrophysics, Taiwan. Also, in cooperation with Osaka Prefecture University, receivers with a bandwidth over 4 times wider than those currently used in ALMA have been installed on the Osaka Prefecture University 1.85-m radio telescope, and successfully received signals from interstellar molecules simultaneously across the wide bandwidth. This is an important milestone in the "ALMA 2.0" plan to improve ALMA's capabilities. The "ALMA 2.0" plan was adopted in the Roadmap 2020 of the Ministry of Education, Culture Sports, Science and Technology.

TMT is a project to build an extremely large telescope with a 30 m diameter being advanced through collaboration between 5 countries: Japan, the United States, Canada, India, and China. NAOJ is responsible for manufacturing vital components of the telescope system such as the telescope structure and primary mirror segments, and development of first-light instruments. Onsite construction is currently on hold due to protests, but TMT International Observatory is considering ways to improve the situation including incrementally relocating its headquarters from Pasadena on the U.S. mainland to Hawai`i and building trust with the local community.

TMT construction is currently on hold, but the partner countries are continuing development on their respective workshares. In Japan, we have worked to address technical issues posing potential risks related to the production of the main body of the telescope. Japan is manufacturing all of the mirror blanks for the primary mirror segments. Aspherical polishing is planned to be conducted by 4 countries. We continued preparation for risk-free mass production of mirror segments. In the Advanced Technology Center, planning and testing is underway for the Infrared Imaging Spectrograph

(IRIS) and Wide Field Optical Spectrograph (WFOS). An NAOJ employee stationed in Pasadena is the project manager leading the development of an additional first-generation instrument MODHIS, a near infrared high-dispersion spectrograph primarily for extrasolar planet research.

In addition, in cooperation with researchers at Japanese universities, we have conducted a detailed investigation of the observing conditions at the alternate TMT construction site on the island of La Palma, Spain. We confirmed that it meets the necessary requirements for most of the scientific goals expected of TMT. We presented these results in an on-line briefing for the astronomy community about the status of the TMT project, as well as at symposiums for not just the optical infrared field, but also including other fields such as radio, high energy, theory, and solar astronomy. Through activities like these we are providing up-to-date information regarding TMT, and promoting the exchange of opinions regarding the situation with the scientific community.

KAGRA, the Large-scale Cryogenic Gravitational Wave Telescope, led by the Institute for Cosmic Ray Research of the University of Tokyo with the participation of NAOJ and the High Energy Accelerator Research Organization KEK, has been overhauling and fine-tuning its equipment with the aim of achieving its first gravitational wave detection for the coming international collaborative observation run O4 (scheduled for after August 2022).

Based on 20 years of results from the VERA project, Mizusawa VLBI Observatory accurately determined the galactic center distance (the distance between the Solar System and the center of the Milky Way Galaxy) to be 25,800 light-years, and found the galactic rotational velocity at the location of the Solar System to be 227 km/s. New discoveries by the Nobeyama 45-m Radio Telescope and ALMA show that collisions between interstellar gas clouds are an important mechanism for the formation of star clusters. There is active discussion about the future operation of Mizusawa VLBI Observatory and Nobeyama Radio Observatory along with efforts to streamline operations at both facilities.

The visual zenith telescope of the closed Latitude Observatory and related buildings, which marked the origin of Mizusawa VLBI Observatory, were recognized in the third (FY 2020) Japan Astronomical Heritage list. Nobeyama Radio Observatory, which always welcomes many visitors, held its Special Open House online. The special lecture which served as the main event had more than 800 simultaneous connections and in the following month amassed over 12,000 views.

The nationwide open-use of Kyoto University's SEIMEI Telescope offered through the Okayama Branch Office of Subaru Telescope produced results including the successful spectroscopic observation of a stellar flare with approximately 20 times the energy of the largest solar flares seen on the Sun. The operation of the 188-cm reflector telescope led by the Tokyo Institute of Technology used 273 nights for automated exoplanet survey and characterization observations.

With the cooperation of NASA and other institutions, the CLASP2 sounding rocket experiment (2019 flight) for high-precision polarimetry was the first in the world to successfully capture information about the magnetic fields in the upper solar chromosphere. Preparation is underway in White Sands U.S.A. for another flight (CLASP2.1) in 2021. In the balloon-borne solar observation mission SUNRISE using a 1-m diameter telescope for high-resolution and high-precision polarimetry, development work in Japan was completed for the Sunrise Chromospheric Infrared spectroPolarimeter (SCIP) for the 2022 flight (SUNRISE-3), and tests combining it with the telescope have started in the Max Planck Institute for Solar System Research. Based on the successful flight of NASA's Focusing Optics X-ray Solar Imager (FOXSI) rocket experiment in 2018, the FOXSI team is planning FOXSI-4 to observe a solar flare in 2024. Japan will provide components vital to the observations including a soft X-ray high speed CMOS camera.

In the Advanced Technology Center (ATC), full-scale operations began using the 5-axis machining center and 3D metal printer, the advanced machining facilities introduced in the latter half of the previous fiscal year. Development and manufacturing continued for the corrugated horns to be installed in ALMA Band 1 receivers and prototypes of structural parts for IRIS, the first TMT instrument. We expect these facilities to become the mainstay for production of instruments for use inside and outside of NAOJ. In the field of detectors, development is progressing on a large-format, high-speed optical CMOS and a near-infrared image sensor with domestic vendors, and high performance has been confirmed for these new detectors. We also considered reorganizing ATC to make it an international bastion for advanced instrumentation. In these ways, NAOJ will continue to contribute to both ground-based facilities and space instrumentation.

The 3,374 papers published during 2016~2020 by members of NAOJ have had an international collaboration rate of 76.3 %; also, 15.4 % of the papers have made it into the Top 10 % of papers published worldwide in terms of citations and 3.3 % have made it into the Top 1 % (according to InCites as of August 2021). While as of August 2021, the 672 Japanese members account for only 5.5 % of the total members of the International Astronomical Union (approximately one quarter the number of United States members), Japan achieved a 9.3 % world share in the number of papers published in astronomy during 2020. This is Japan's highest world share among the 22 fields of study, surpassing physics (7.5 %). In addition, in Fiscal Year 2020, our number of female associate professors increased by 3. As of April 1, 2021, women account for 8.9 % of NAOJ researchers (including Research and Academic Staff and specially appointed teachers) up from 7.4 % in the previous fiscal year.

This concludes my overview of NAOJ's activities in FY 2020. More details can be found in the full report.

I Scientific Highlights

(April 2020 – March 2021)

The −12 mag Dip in the Galaxy Luminosity Function of Hickson Compact Groups

YAMANOI, Hitomi[1], YAGI, Masafumi[2/3], KOMIYAMA, Yutaka[2/4], KODA, Jin[5]

1: Seikei University, 2: NAOJ, 3: Hosei University, 4: Graduate University for Advanced Studies, 5: Stony Brook University

The galaxy luminosity functions (LF) is a powerful tool for probing the environmental dependence of galaxy formation and evolution. Indeed, the LFs of galaxy clusters show a distinct upturn of faint galaxies at $M \sim -18$, which indicates a transition of dominant galaxy population from giant to dwarf galaxies around this luminosity range. However, faint ends ($M > -12$) of the LFs remain relatively unexplored. While a significant dip at $M \sim -12$ was found in a few galaxy clusters [1,2], a large sample in various environments is necessary to confirm it and to understand its origin.

As a new sample of the faint-end LF, we observed the LFs of four Hickson Compact Groups (HCGs) using image data from the Subaru Hyper Suprime-Cam. Their g-band LFs down to $M_g \sim -9$ are shown in Figure 1. All groups show a dip at around $-13 < M_g < -12$. The presence of the −12 mag dip in the LF may have important implications on the process of galaxy formation and evolution. We compared our results with LFs in other environments. In Figure 2, the LFs of the HCGs [3], Coma [2], Centaurus [1], and the field [4] are shown. HCGs, Coma and Centaurus show a significant faint-end dip at $M_g \sim -12$, while the field does not.

We suggest that the physical process that shapes the faint-end dip operates independently from cluster/group mass. Since the ram pressure and the tidal effect are inefficient due to their relatively shallow potential in the compact groups, the presence of the dip in the compact groups implies that frequent galaxy–galaxy interactions in the high density region may cause the dip and the transition of galaxy populations at $M \sim -12$, as well as at $M \sim -18$ in the cluster LFs. A larger sample is required to confirm the key parameter and to quantify its significance.

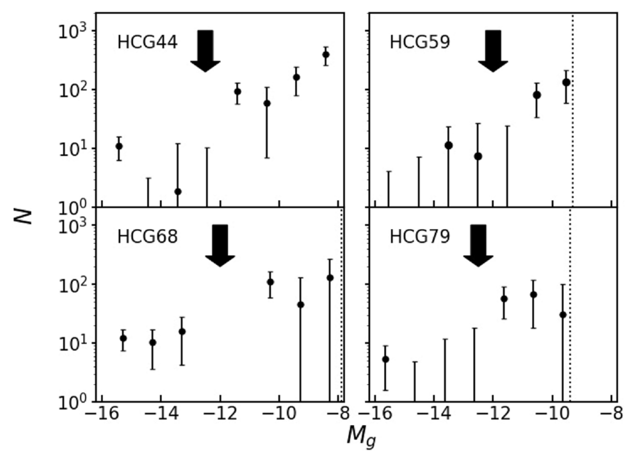

Figure 1: g-band LFs for individual groups of HCG44, HCG59, HCG68, and HCG79. The vertical dotted line indicates the 90% completeness limit for each HCG. The arrows show the locations of the dip around $M_g \sim -12$.

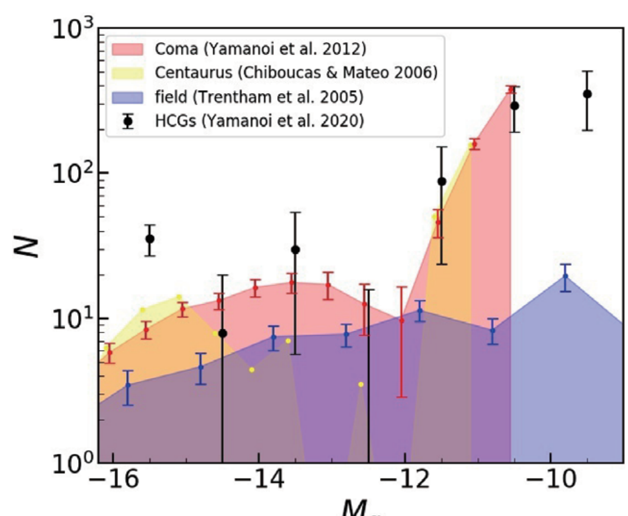

Figure 2: Total LFs of four HCGs and LFs from previous studies. The vertical scale is arbitrary for each LF. The magnitudes are shifted horizontally to adjust to the g band. HCGs, Coma and Centaurus have a significant dip at $M_g \sim -12$.

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Discovery of Radio Jets in the Phoenix Galaxy Cluster Center

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Galaxies are not distributed randomly in space. Through mutual gravitational attraction, galaxies gather together to form galaxy clusters. The space between galaxies is not entirely empty. There is very thin, diffuse gas throughout a cluster which can be detected by X-ray observations. When this intra-cluster gas cooled, it would condense under its own gravity to form stars at the center of the cluster. However, cooled gas and stars are not usually observed in the hearts of nearby clusters, indicating that some mechanism must be heating the intra-cluster gas and preventing star formation. One potential candidate for the heat source is jets of high-speed gas accelerated by a super-massive black hole in the central galaxy.

From the measurement of the SZ effect observed with ALMA, our research team previously found that the gas is exceptionally cooled at the center of Phoenix galaxy cluster (the redshift is 0.596) [1]. The team suspects that this gas cooling is a trigger of massive star formation around the central galaxy. This raises the question, “does the central galaxy have black hole jets as well?”. There was no firm discovery of jets in the past because of a lack of the resolution and the sensitivity of previous radio observations.

Our team proposed an observation with the Australia Telescope Compact Array (ATCA) to search for AGN jets in the Phoenix Galaxy Cluster with the highest resolution to date. We achieved to obtain the highest resolution and the best sensitivity by a deep observation at the frequency (18 GHz) relatively higher than that adopted for imaging an overall structure of radio lobes [2].

As a result, we successfully detected radio emission associated with the central galaxy, and achieved to resolve its structure for the first time ever (Figure 1). Such compact and strong radio sources are likely radio jets. Moreover, we confirmed that the structures detected by ATCA nicely correspond to X-ray cavities of less dense gas, indicating that they are a pair of bipolar jets launched from the AGN of the central galaxy. Therefore, the team discovered the first example, in which intra-cluster gas cooling and AGN jets coexist, in the distant Universe.

The ages of jets are expected to be a few million years, which is very young compared to the evolution timescale of galaxy cluster. The radio lobes exhibit radiatively-inefficient jets from the fact that radio power is about 5 orders of magnitudes smaller than the jet kinetic power estimated previously. These evidence might be hints to understand the reason of co-existence of gas cooling and AGN jets.

Further details of the galaxy and jets could be elucidated through higher-resolution observations with next generation observational facilities, such as the Square Kilometre Array scheduled to start observations in the late 2020s.

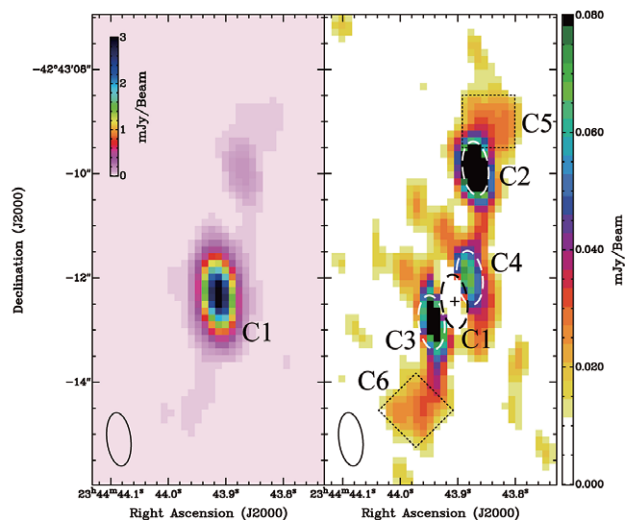

Figure 1: Radio jets observed at the center of the Phoenix cluster. The left panel shows the radio image and the right panel shows the residual image for which the central AGN core emission is subtracted assuming a point-like source.

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SCExAO/CHARIS High-Contrast Imaging of Spirals and Darkening Features in the HD 34700 A Protoplanetary Disk

UYAMA, Taichi[1/2/3], CURRIE, Thayne[4/5/6], CHRISTIAENS, Valentin[7], BAE, Jaehan[8/9], MUTO, Takayuki[10], TAKAHASHI, Sanemichi Z.[3], TAZAKI, Ryo[10], YGOUF, Marie[1], KASDIN, Jeremy N.[11], GROFF, Tyler[12], BRANDT, Timothy D.[13], CHILCOTE, Jeffrey[14], HAYASHI, Masahiko[3], MCELWAIN, Michael W.[12], GUYON, Olivier[5/15/16], LOZI, Julien[5], JOVANOVIC, Nemanja[17], MARTINACHE, Frantz[18], KUDO, Tomoyuki[5], TAMURA, Motohide[19/16/3], AKIYAMA, Eiji[20], BEICHMAN, Charles A.[2/1], GRADY, Carol A.[12/6/21], KNAPP, Gillian R.[11], KWON, Jungmi[19], SITKO, Michael[22], TAKAMI, Michihiro[23], WAGNER, Kevin R.[15/24], WISNIEWSKI, John P.[25], YANG, Yi[19]

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Young stellar objects (YSO, < 10 Myr) often have protoplanetary disks and they are good laboratories for exploring planet formation and disk evolution mechanisms. High-angular resolution observations of these disks have revealed a variety of geometry in the disks – e.g. gaps, rings, and spirals, which are supposed to be relative to planet formation [1]. HD 34700 is one of the most intriguing YSOs with a large cavity and multiple spirals in its disk [2].

In this study we present integral field spectroscopy results of HD 34700 taken with the Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) and the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), details of which are presented in Uyama et al. (2020) [3]. We used the broadband integral field spectroscopy (IFS) mode (1.16–2.37 μm, spectral resolution of $\mathcal{R} \sim 19$, pixel scale = 0.0162″ pixel^{-1}) combined with the Lyot coronagraph (113 milli-arcsec in radius).

We used CHARIS data reduction pipeline [4] to extract pre-processed (dark subtraction, illumination calibration, and wavelength correction) data cubes with 22 uniform spectral channels for HD 34700, the science target, and HR 2466, a point spread function (PSF) reference star. For post-processing, we implemented two reduction techniques to subtract the stellar PSF and instrumental speckles: (1) reference-star differential imaging (RDI) [5] to precisely image the ring morphology (2) combination of angular differential imaging (ADI) and spectral differential imaging (SDI) [6] to investigate outer spirals and potential planetary-mass companions. In both data reductions we used the same data reduction pipelines as presented in Currie et al. (2018, 2019) [6,5].

We were able to detect scattered light from the ring surface in both of the RDI and ADI+SDI results and the spirals in the ADI+SDI result (see Figure 1). We newly confirmed some darkening features (indicated by white arrows in Figure 1) which may be related to shadowing by an inner disk, outer spiral features, and/or scattering profiles at the surface of the ring. However, our data did not reveal any substellar-mass companion candidates. Monnier et al. (2019) [2] suggested that a ~50 M_{Jup} object can induce the asymmetric disk features but our injection test with the CHARIS data could set a robust constraint on the presence of the 50 M_{Jup} object at the expected location.

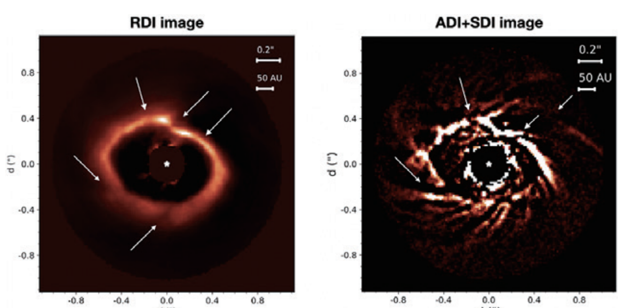

Figure 1: Our RDI (left) and ADI+SDI (right) results of the CHARIS high-contrast imaging of the HD~34700 disk.

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Magnetic Field Structure of Orion Source I

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A radio source I (Source I) in Orion KL is known as the nearest high-mass protostar candidate (400 pc). Previous VLBI and ALMA observations revealed that the millimeter SiO masers and submillimeter SiO thermal lines trace a rotating outflow driven by a magneto-centrifugal disk wind. Thus, Source I has been recognized as the ideal target to study the outflow launching mechanism and the role of the magnetic field in high mass star-formation processes.

We carried out polarization observations of multiple SiO lines in the J = 1–0 (43 GHz) and 2–1 (86 GHz) transitions using JVLA Q-band and ALMA band 3, respectively, toward Orion Source I at resolutions of 50 mas (or 20 au) [1]. The SiO J = 1–0 and 2–1 lines at the vibrationally ground state (v = 0) show NE-SW outflow structure extending toward 800 au scale (Figure 1). Their brightness temperatures exceed 50,000 K, strongly suggesting maser origin. Linearly polarized emission is detected in SiO v = 0 J = 1–0 and 2–1, with the linear polarization fractions of on average ~50–70 % and ~20–50 % for the J = 1–0 and 2–1 lines, respectively. Such a high fractional linear polarization can be explained theoretically by anisotropic pumping or saturated masers.

Overall distributions of polarization vectors in the SiO v = 0 J = 1–0 and 2–1 lines are in good agreement with each other, while some regions show inconsistent polarization angles between two transitions. By using the method applied to the dust polarization data, we estimated the magnetic field strengths from the spatial variation of the SiO maser polarization angles. As a result, we obtained the field strength of about 30 mGauss in the outflow lobes of Source I. The well ordered polarization structures observed in the present study would suggest an important role of the magnetic field in the formation of the outflow driven in Source I.

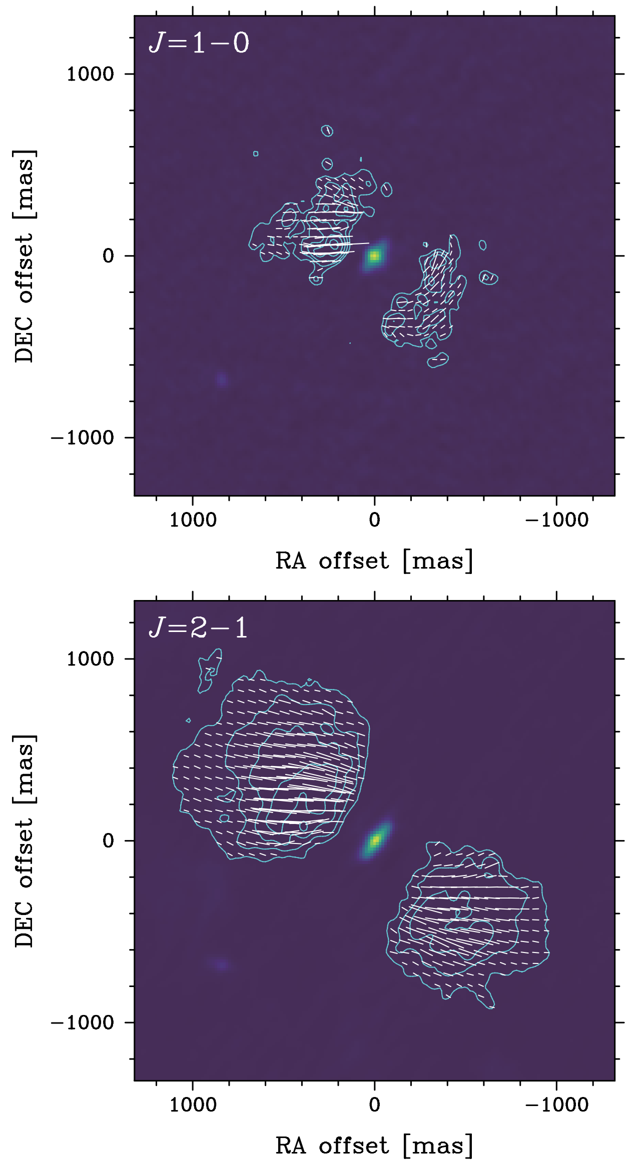

Figure 1: Polarization vector maps of (a) SiO v = 0 J = 1–0 line and the 43 GHz continuum emission observed with JVLA and (b) SiO v = 0 J = 2–1 line and the 96 GHz continuum emission observed with ALMA. Both are averaged over the velocity range from −10 to 20 km s^{-1}. The deconvolved beam size is 0.1″. The contour levels are 4, 8, 16, 32, 64, and 128 times the rms noise levels of 108 mJy beam^{-1} km s^{-1} for SiO v = 0 J = 1–0 and 26 mJy beam^{-1} km s^{-1} for SiO v = 0 J = 2–1. White lines show position angle of the polarization vectors. The length of the polarization vector is proportional to the linear polarization intensity.

Reference

[1] Hirota, T., et al.: 2020, *ApJ*, **896**, 157.

Water Maser Variability in a High-mass YSO Outburst: VERA and ALMA Observations of S255 NIRS 3

HIROTA, Tomoya, BURNS, Ross A., KIM, Jungha, SUNADA, Kazuyoshi
(NAOJ)
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In 2015, a 6.7 GHz methanol maser flare was detected in the high-mass star-forming region S255 NIRS 3, which was caused by a sudden mass accretion event determining an accretion burst. In this study, we carried out astrometric observations of the 22 GHz water masers using VERA, and monitoring with the VERA single-dish 20-m antennas and JVLA [1]. In addition, we also conducted follow-up observations with ALMA in Cycle 5 to image the 321 GHz submillimeter water maser and continuum emission to investigate the dynamical and physical properties and their time variation caused by the accretion burst event [1].

Both VERA and ALMA observations were done in 2017, about 1–2 years after the methanol maser flare. In the VERA observations, we found that the water masers are distributed in the NE-SW outflow (Figure 1). They reveal the SW bow-shock structure as found in previous VLBI observations in 2005 and 2010. The structure of the bow-shock was unchanged, and we successfully measured its dynamical timescale of 60 years through proper motions of the water masers associated with the bow-shock. This suggests that the bow-shock structure is not formed in the current accretion burst event.

On the other hand, the water maser monitoring in 2016–2018 showed that the maser flux are gradually increasing without a sudden flare, unlike the 6.7 GHz methanol masers or the water masers in another accretion burst source NGC 6334I-MM1. The gradually brightening water masers are associated with the newly formed radio jet in the accretion burst event in 2016 in the NE outflow lobe. We found that part of these water maser emission is resolved out even with the JVLA. Our results suggest radiative excitation due to the combined effect of the IR outburst and the expanding jet.

We detected and mapped the 321 GHz water masers with ALMA at Band 7. This is the fourth example of this maser emission in high-mass star-forming regions. The outflow structure is traced by the 321 GHz water masers but the positions and luminosity ratios of the 321 GHz water masers with respect to those at 22 GHz are different from feature to feature (Figure 1). These two water masers probe spatial variation of the physical properties such as temperature and density of the maser emitting regions.

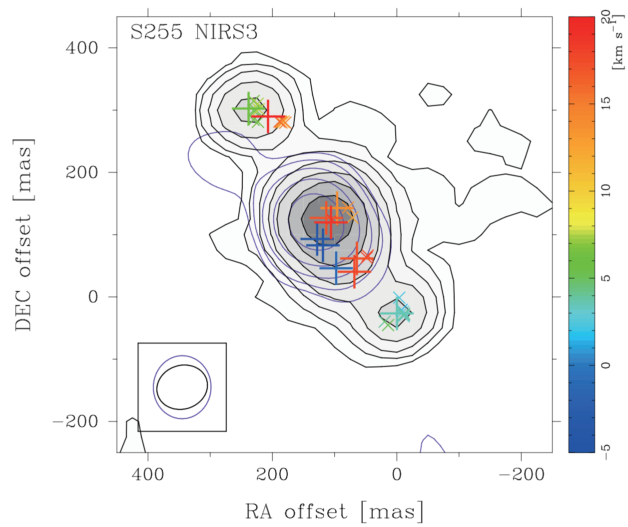

Figure 1: Distributions of the 22 GHz water maser features (colored cross symbols), the 321 GHz water maser features (colored plus symbols and gray scale), and the 22 GHz radio continuum emission (contours) in S255 NIRS 3 observed with VERA, ALMA, and JVLA, respectively. Contour levels are 4, 8, 16, ... times the rms noise level of 0.13 mJy beam^{-1} and 32 mJy beam^{-1} km s^{-1} for the JVLA K-band continuum and the integrated intensity map of the 321 GHz water, respectively. Color symbols indicate their radial velocities.

Reference

[1] Hirota, T., Cesaroni, R., Moscadelli, L., et al.: 2021, *A&A*, **647**, A23.

The First VERA Astrometry Catalog

VERA collaboration, HIROTA, Tomoya[1], NAGAYAMA, Takumi[1], HONMA, Mareki[1], ADACHI, Yuuki[1], BURNS, Ross A.[1], HACHISUKA, Kazuya[1], HADA, Kazuhiro[1], HIRANO, Ken[1], ISHIKAWA, Toshio[1], JIKE, Takaaki[1], KAMEYA, Osamu[1], KIM, Jungha[1], KIM, Mi Kyoung[1], KOBAYASHI, Hideyuki[1], KONO, Yusuke[1], OYAMA, Tomoaki[1], SAKAI, Daisuke[1], SHIBATA, Katsunori M.[1], SHIZUGAMI, Makoto[1], SUNADA, Kazuyoshi[1], SUZUKI, Syunsaku[1], TAKAHASHI, Ken[1], TAMURA, Yoshiaki[1], TAZAKI, Fumie[1], UENO, Yuji[1], YAMASHITA, Kazuyoshi[1], YAMAUCHI, Aya[1], HAMADA, Shota[2], HANDA, Toshihiro[2], HASHIMOTO, Mao[2], HIRATA, Yushi[2], ICHIKAWA, Takanori[2], IMAI, Hiroshi[2], INENAGA, Daichi[2], KASEDA, Daichi[2], MATSUNO, Masako[2], MORITA, Atsushi[2], MURASE, Takeru[2], NAKAGAWA, Akiharu[2], NAKANISHI, Hiroyuki[2], NISHI, Junya[2], OMODAKA, Toshihiro[2], OYADOMARI, Miyako[2], SUDO, Jumpei[2], UNO, Yuri[2], URAGO, Riku[2], WADA, Koji[2], YAMASHITA, Yuto[2], YODA, Akito[2], KIM, Jeong Sook[3], OH, Chung Sik[3], SAKAI, Nobuyuki[3], MOTOGI, Kazuhito[4], NIINUMA, Kotaro[4], SAWADA-SATOH, Satoko[4], CHIBUEZE, James O.[5/6], CHOI, Yoon Kyung[7], HAGIWARA, Yoshiaki[8], KURAYAMA, Tomoharu[9], SUGIYAMA, Koichiro[10], WU, Yuan Wei[11]

1: NAOJ, 2: Kagoshima University, 3: KASI, 4: Yamaguchi University, 5: North-West University, 6: University of Nigeria, 7: MPIfR, 8: Toyo University, 9: Teikyo University of Science, 10: NARIT, 11: National Time Service Center

VERA (VLBI Exploration of Radio Astrometry) is a Japanese VLBI network consisted of four 20-m antennas in Mizusawa, Iriki, Ogasawara, and Ishigakijima in Japan. It is dedicated for the VLBI astrometry of strong Galactic maser sources to construct a 3D map of the Milky Way Galaxy. Construction of VERA was started in 2000 and it is operated under collaboration between Kagoshima University and NAOJ.

In this study, we present the first astrometry catalog from VERA by compiling all the available VLBI astrometry measurements since the first publication in 2007 [1]. In total, 99 maser sources are listed in the VERA catalog and 21 of them are newly reported data.

By combining previously published results from another VLBI project BeSSeL using VLBA and EVN [2], total 224 target sources have been measured by high accuracy VLBI astrometry. Half of these available data are from the VERA catalog. VERA successfully measured the distances toward farther maser sources at 10 kpc (or 32,600 light years), allowing us to more clearly demonstrate the spiral arm structures in the Milky Way Galaxy (Figure 1).

Using the astrometry data of 189 maser sources which are thought to be distributed along the Galactic spiral arms following the Galactic rotation, we constructed a model of the Milky Way Galaxy to estimate the Galactic parameters. As a result, we could determine the distance toward the Galactic center and the Galactic rotation velocity at the location of the Solar system to be 25,800±1,100 light years and 227±11 km s^{-1}, respectively. It should be noted that the latest VERA results increase the number of accurate and reliable measurements, with errors reduced to 5 %, than were previously available. The result of the Galactic center distance is significantly smaller than that of the IAU recommended value in 1985 (27,700 light years). On the other hand, the present results are more consistent with those of recent measurements of stellar orbital motions around the Galactic center Sgr A*, 25,800–26,600 light years. The results imply that Sgr A* is indeed located at the dynamical center of the Milky Way Galaxy.

We also constructed the Galactic rotation curve, the distribution of the rotation velocity as a function of the Galacto-centric distances. We found a so-called flat-rotation curve where the rotation velocity is almost constant regardless of the Galacto-centric distances. As suggested for many other external galaxies, these results confirm that there is significant amount of dark matter outside the Solar orbit of the Milky Way Galaxy.

Further astrometry observations with VERA will be able to advance the studies on models of the Milky Way Galaxy by directly measuring the distance and proper motion of Sgr A*. In addition, we will continue higher accuracy astrometry observations of astronomically important objects, by including newly developed observations with the East Asian VLBI Network (EAVN).

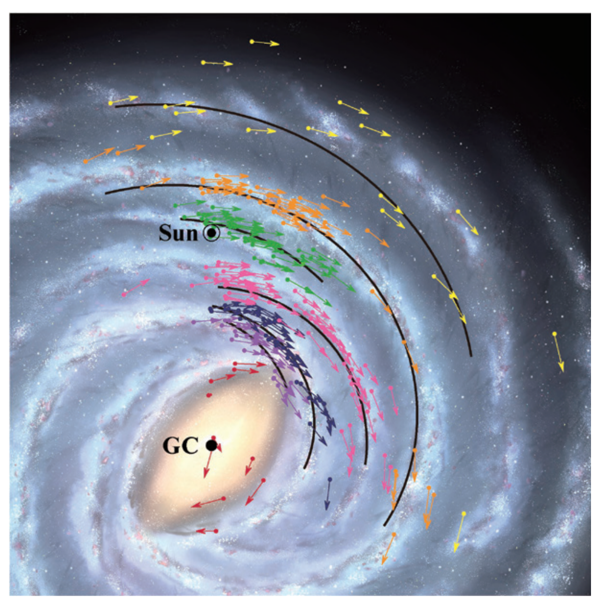

Figure 1: Distribution of the 224 maser sources on the face-on view of the Milky Way Galaxy. Solid lines show the spiral arm structures identified by the BeSSeL results [2].

References

[1] VERA collaboration, Hirota, T., et al.: 2020, *PASJ*, **72**, 50.
[2] Reid, M. J., et al.: 2019, *ApJ*, **885**, 131.

Astrometry of H_2O Masers in the W 48 A (G35.20−01.74) HII Region with VERA: A Compact Disk Outflow inside Core H-2a

CHIBUEZE, James O.[1/2], NAGAYAMA, Takumi[3], OMODAKA, Toshihiro[4], NAGANO, Masayuki[4], WADA, Koji[4], HIRANO, Ken[3]

1: North-West University, 2: University of Nigeria, 3: NAOJ, 4: Kagoshima University

W 48 A core H-2a is one of the young massive protostellar objects in the W 48 region. We conducted multi-epoch astrometric observations of the water (H_2O) masers associated with the W 48 A core H-2a with VLBI Exploration of Radio Astrometry (VERA) [1]. The trigonometric annual parallax of W 48 A core H-2a was measured to be 0.433±0.026 mas, corresponding to a distance of $2.31^{+0.15}_{-0.13}$ kpc. This agrees with the revised parallax of 0.412±0.014 mas by Wu et al. (2019) [2]. We obtained the systemic proper motion and local standard of rest velocity to be $(\mu_\alpha \cos\delta, \mu_\delta)$ = (0.26±0.73, −3.87±0.33) mas yr^{-1} and v_{LSR} = 41.9±0.9 km s^{-1}, respectively.

The distribution of the H_2O masers covers an area of 70 mas×80 mas, corresponding to 160 au×180 au at the distance of 2.31 kpc. The internal proper motions of the H_2O masers trace an east-west bipolar outflow. With the recent absolute position measurement of the 6.7 GHz methanol (CH_3OH) masers and their elliptical distribution, whose major axis is perpendicular to the axis of the bipolar outflow, we suggest the presence of a disk outflow system in core H-2a.

The spectral energy distribution (SED) of the driving source of core H-2a was previously reported to yield a luminosity and envelope mass of 8000±1000 $L_\odot$ and 170±30 $M_\odot$, respectively. Refitting the SED with the new distance, we obtained the luminosity to be 3100±388 $L_\odot$ and derived the zero age main sequence (ZAMS) stellar mass to be 9±1 $M_\odot$. Using our distance measurement, we derived the peculiar motion of W 48 A to be (U_s, V_s, W_s) = (1±4, 5±6, −15±5) km s^{-1}.

References

[1] Chibueze, J. O., Nagayama, T., Omodaka, T., et al: 2020, *PASJ*, **72**, 54.
[2] Wu, Y. W., Reid, M. J., Sakai, N., et al.: 2019, *ApJ*, **874**, 94.

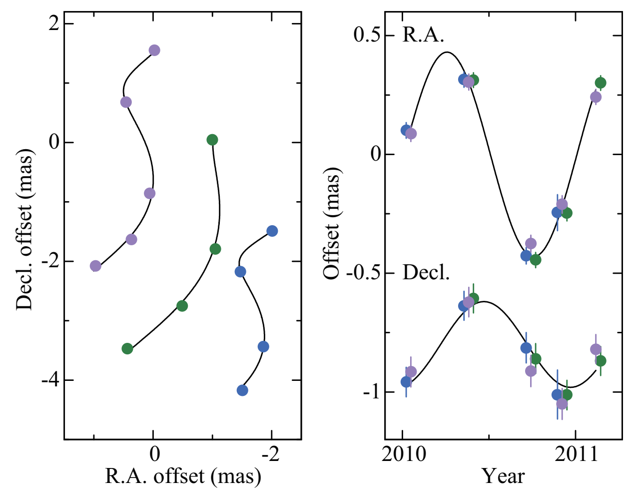

Figure 1: Parallax and proper motion fits of the maser spot at v_{LSR} = 46.4 (purple), 43.9 (green), and 42.0 km s^{-1} (blue). Left panel: Positional variation on the sky. Right panel: Positional variation versus time. The proper motion has been removed, allowing the effects of only the parallax to be seen.

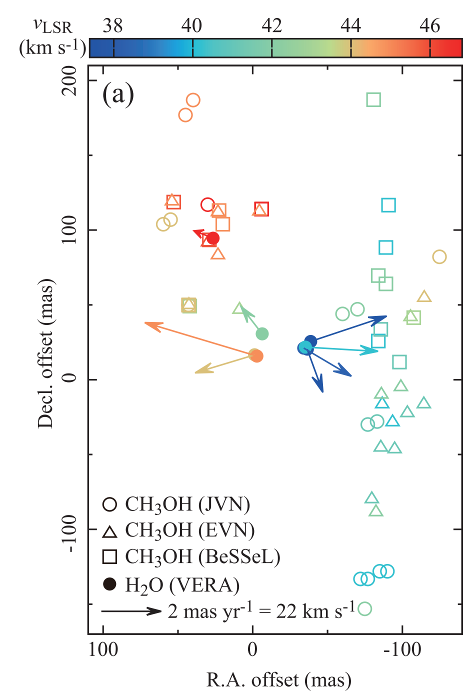

Figure 2: H_2O maser feature distribution with internal motion (filled circles with arrows); 2 mas yr^{-1} corresponds to 22 km s^{-1} at a distance of 2.31 kpc. The open circles, triangles, and squares represent the positions of the 6.7 GHz CH_3OH masers observed by JVN, EVN, and BeSSeL, respectively.

Astrometry and Infrared Observations of the Mira Variable Stars AP Lyncis, V837 Herculis, and BX Camelopardalis: Implications for the Period-luminosity Relation of the Milky Way

CHIBUEZE, James O.[1/2], URAGO, Riku[3], OMODAKA, Toshihiro[3], MORIKAWA, Yuto[3], FUJIMOTO, Masayuki Y.[4], NAKAGAWA, Akiharu[3], NAGAYAMA, Takahiro[3], NAGAYAMA, Takumi[5], HIRANO, Ken[5]

1: North-West University, 2: University of Nigeria, 3: Kagoshima University, 4: Hokkaido University, 5: NAOJ

AP Lyn and V837 Her are long-period Mira variable stars in the Milky Way. We performed VLBI Exploration of Radio Astrometry (VERA) phase-referenced observations towards H_2O masers associated with AP Lyn and V837 Her. The annual parallaxes of AP Lyn and V837 Her were obtained to be 2.008 ± 0.038 mas and 1.090 ± 0.014 mas, corresponding to distances of 498 ± 10 pc and 917 ± 12 pc, respectively.

From our multi-epoch infrared observations using the Kagoshima University 1 m telescope, we derived the mean J-, H-, and K-band magnitudes of AP Lyn, V837 Her, and an additional long-period Mira variable BX Cam, whose parallax is known. We derived their pulsation periods to be 433 ± 1 d, 520 ± 1 d, and 458 ± 1 d, respectively, using the K-band light curves.

The M_K–log P relation of long-period Mira variables seem to be violated by Mira variable stars with larger-than-expected M_K values (like OZ Gem) in the Milky Way because of circumstellar extinction leading to an observed dimming effect. AP Lyn, V837 Her, and BX Cam (like OZ Gem) are dimming from the trend to O-rich stars in the Large Magellanic Cloud. This implies that the high metallicity of the Milky Way galaxy increases the opacity of the Mira-type variable stars and strengthens mass loss.

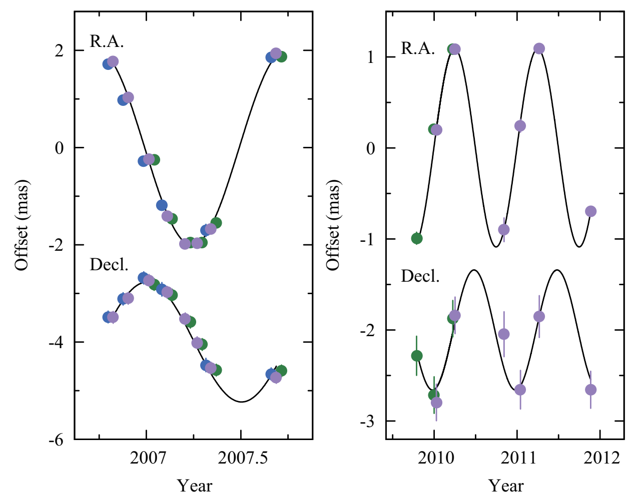

Figure 1: Parallaxes of AP Lyn (left) and V837 Her (right).

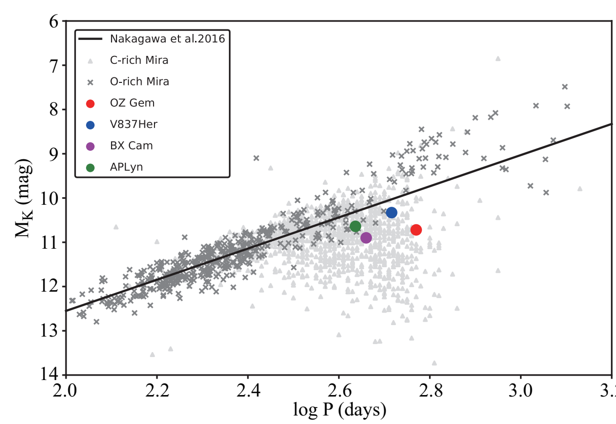

Figure 2: Locations of AP Lyn, V837 Her, BX Cam, and OZ Gem (color circle) on the period–magnitude diagram of Mira variables of the LMC (triangles and crosses denote C-rich and O-rich Miras, respectively). The thick solid line shows the P–L relation of Galactic Miras[4].

References

[1] Chibueze, J. O., et al.: 2020, *PASJ*, **72**, 59.
[2] Matsuno, M., et al.: 2020, *PASJ*, **72**, 56.
[3] Urago, R., et al.: 2020, *PASJ*, **72**, 57.
[4] Nakagawa, A., et al.: 2016, *PASJ*, **68**, 78.

VEDA: VERA Data Analysis Software for VLBI Phase-referencing Astrometry

NAGAYAMA, Takumi[1], HIROTA, Tomoya[1/2], HONMA, Mareki[1/2], KURAYAMA, Tomoharu[3], ADACHI, Yuuki[1], TAMURA, Yoshiaki[1/2], KANYA, Yukitoshi[4]

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We developed the VEra Data Analyzer (VEDA) software package for Very Long Baseline Interferometry (VLBI) phase-referencing observations and parallax measurements [1]. The Japanese VLBI project VLBI Exploration of Radio Astrometry (VERA) provides high-precision astrometric catalog at the 10 micro arcsec (μas) level [2]. To achieve this precision, accurate calibration of the atmospheric phase fluctuation, the instrumental phase, and the source structural effect are required. VEDA specializes in phase-referencing data analysis, including these calibrations.

We demonstrated the performance of VEDA through the data analysis of VERA observations of H_2O maser sources, W3(OH) and Orion KL. The analysis flow and the example of use are also presented in the paper [1]. Figure 1 shows the obtained parallaxes. The parallaxes of W3(OH) and Orion KL could be obtained to be 0.527 ± 0.016 milli arcsec (mas) (the distance of 1.90 ± 0.06 kpc) and 2.459 ± 0.029 mas (407 ± 5 pc), respectively. These are consistent with the parallaxes of the previous measurements by VLBI and Gaia.

We analyzed the VERA archive data of 14 H_2O maser sources using VEDA and the Astronomical Image Processing System (AIPS), and compared the parallaxes as shown in Figure 2. The agreement between VEDA and AIPS is excellent for all sources at the precision of 10 μas level, with the slope of the fitted line consistent with unity and the intercept consistent with zero within 1σ. The slope and the intercept are obtained to be 0.990 ± 0.010 and 0.001 ± 0.011 mas, respectively. Thus, significant systematical differences were not found between VEDA and AIPS. VEDA is available for high-precision parallax measurement of Galactic maser sources.

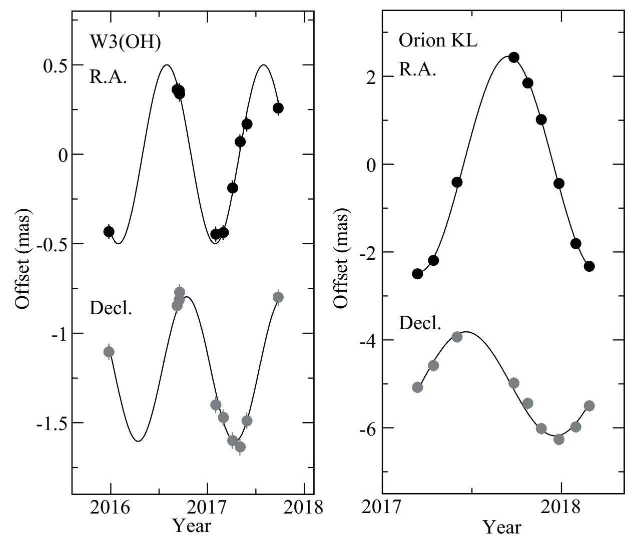

Figure 1: Parallaxes of W3(OH) (left) and Orion KL (right) obtained using VEDA. The black and gray circles show the R.A. and Decl. offsets, respectively. The solid lines shows the best-fit parallaxes of 0.527 ± 0.016 mas for W3OH and 2.459 ± 0.029 mas for Orion KL.

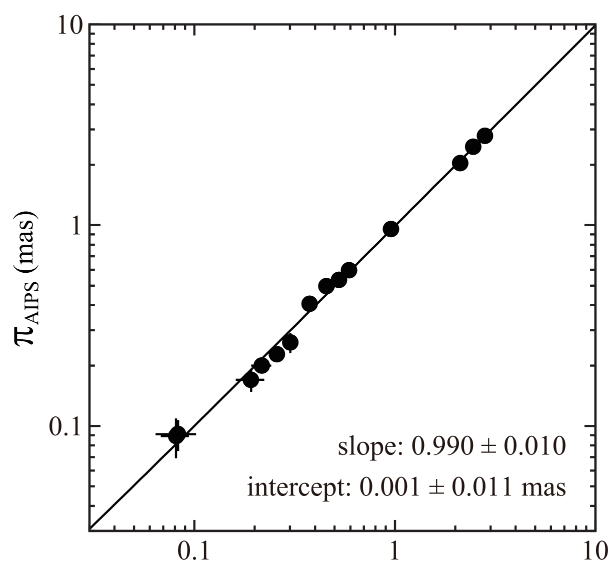

Figure 2: Comparison of the parallaxes obtained by VEDA (π_{VEDA}) and AIPS (π_{AIPS}). The solid line shows the linear fit to $\pi_{AIPS} = 0.990 \cdot \pi_{VEDA} + 0.001$ mas.

References

[1] Nagayama, T., et al.: 2020, *PASJ*, **72**, 51.
[2] VERA Collaboration, Hirota, T., Nagayama, T., et al.: 2020, *PASJ*, **72**, 50.

Performance of VERA in 10 micro-arcsecond Astrometry

NAGAYAMA, Takumi[1], KOBAYASHI, Hideyuki[1], HIROTA, Tomoya[1/2], HONMA, Mareki[1/2], JIKE, Takaaki[1/2], KIM, Mi Kyoung[1], NAKAGAWA, Akiharu[3], OMODAKA, Toshihiro[3], OYAMA, Tomoaki[1], SAKAI, Daisuke[1], SHIBATA, Katsunori M.[1/2], TAMURA, Yoshiaki[1/2]

1: NAOJ, 2: SOKENDAI, 3: Kagoshima University

Very Long Baseline Interferometry (VLBI) astrometry using the phase-referencing technique remains an open issue for the quantitative characterization of the observing conditions to achieve a feasible parallax precision of 10 micro-arcseconds (μas). To address this issue, we evaluated the astrometric performance of the VLBI Exploration of Radio Astrometry (VERA) through the parallax measurements of five distant star-forming regions under good observing conditions of close separations (0.5°–1.3°) and high elevations ($\geq$ 50°). This performance evaluation of VERA was published by Nagayama et al. (2020) [1] in the VERA PASJ special issue including the first VERA astrometry catalog [2].

We observed five H_2O maser sources, G135.28+02.80, G137.07+03.00, G200.08−01.63, G037.50+00.53, and G037.82+00.41, and measured their parallaxes to be 89–200 μas (distances of 5–11 kpc) with an error of 11–20 μas. Figure 1 shows the obtained parallax of G135.28+02.80. We can clearly find the sinusoidal parallax motion with a period of one year.

Furthermore, we investigated the the error budget of the VLBI astrometric position measurement as shown in Figure 2. We concluded that the tropospheric residual contribution is the dominant error source. We also confirmed that the astrometric error propagation strongly depends on the term $\Delta \sec Z$, which stands for the difference between $\sec Z$ of the target and its reference source, where Z is the zenith angle during the observations. We found that for a source pair with a $\Delta \sec Z$ less than 0.01 (for example, a set of a close separation of $\leq$ 0.5° and a high elevation of $\geq$ 50°), we can achieve the parallax precision of 10 μas using a typical monitoring program comprising 10 observing epochs over a span of two years.

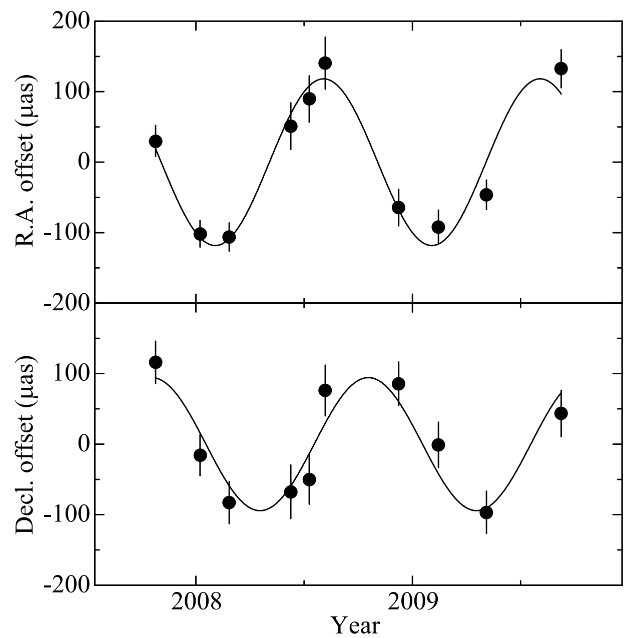

Figure 1: Parallax of G135.28+02.80. The solid line shows the best-fit parallax of 124±11 μas corresponding to the distance of 8.1 $^{+0.8}_{-0.7}$ kpc.

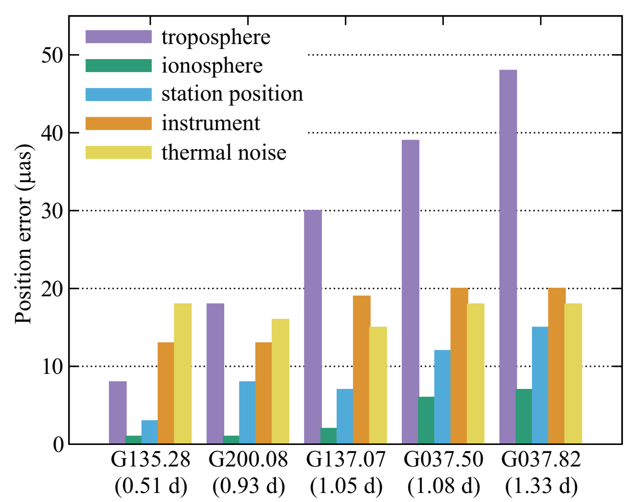

Figure 2: Position error budget of the VLBI astrometry. The value shown in parentheses under the source name is the separation angle between target and reference sources.

References

[1] Nagayama, T., Kobayashi, H., Hirota, T., et al.: 2020, *PASJ*, **72**, 52.

[2] VERA Collaboration, Hirota, T., Nagayama, T., et al.: 2020, *PASJ*, **72**, 50.

Star Formation Rates in the L 1482 Filament of the California Molecular Cloud

OMODAKA, Toshihiro[1], NAGAYAMA, Takumi[2], DOBASHI, Kazuhito[3], CHIBUEZE, James O.[4/5], YAMABI, Akifumi[3], SHIMAJIRI, Yoshito[2], INOUE, Shinnosuke[1], HAMADA, Shota[1], SUNADA, Kazuyoshi[2], UENO, Yuji[2]

1: Kagoshima University 2: NAOJ, 3: Tokyo Gakugei University 4: North-West University, 5: University of Nigeria

We measured the trigonometric parallax of the H_2O maser source associated with the L 1482 molecular filament hosting the most massive young star, LkHα 101, in the California molecular cloud using VLBI Exploration of Radio Astrometry (VERA) [1]. The measured parallax is 1.879 ± 0.096 mas (see Figure 1), corresponding to the distance of 532 ± 28 pc. This parallax is consistent with that of the nearby star cluster LkHα 101, which was recently measured with Gaia DR2 [2]. We found that the L 1482 molecular filament and the LkHα 101 cluster are located at the same distance within 3 ± 30 pc.

We observed the southern parts of L 1482 molecular clouds including the H_2O maser source, which is adjacent to LkHα 101, using the Nobeyama 45 m telescope in the J = 1–0 transitions of both ^{12}CO and ^{13}CO. The peak intensity of the ^{12}CO line revealed the high excitation temperature region (60–70 K) due to heating by UV radiation from LkHα 101. We derived the column density of these molecular clouds assuming local thermodynamic equilibrium (LTE) from the ^{13}CO emission.

Using Dendrogam, we searched for small-scale, dense structures (cores) and identified 337 cores in the ^{13}CO data (see Figure 2). Gravitationally bound cores with a virial mass to LTE mass ratio $\leq$ 1.5 and young stars are concentrated in the high excitation temperature region. The column density in the warm region is five to six times larger than that of the surrounding colder molecular region. This suggests that the warm region has been compressed by a high-pressure wave and successive radiation-driven star formation is in progress in this warm region. In the cold molecular cloud to the north of the warm region, the cores are likely gravitationally unbound, which may be the reason why star formation is not active there.

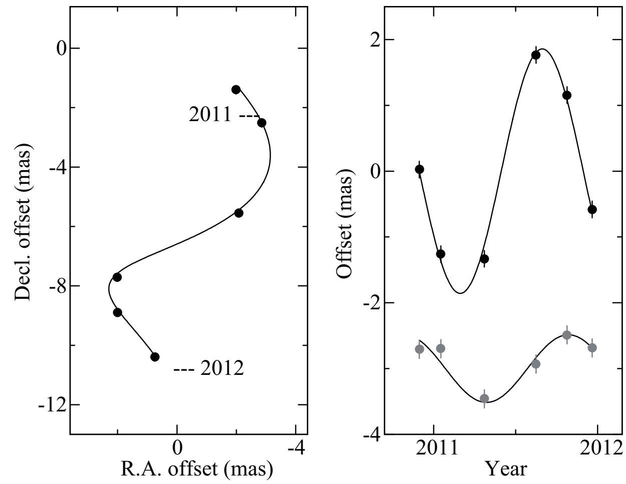

Figure 1: Parallax and proper motion of the H_2O maser spot at in L 1482. Left panel: Positional variation on the sky. Right panel: RA (black circles) and Dec (gray circles) offset versus time. The proper motion has been removed, allowing the effects of only the parallax to be seen.

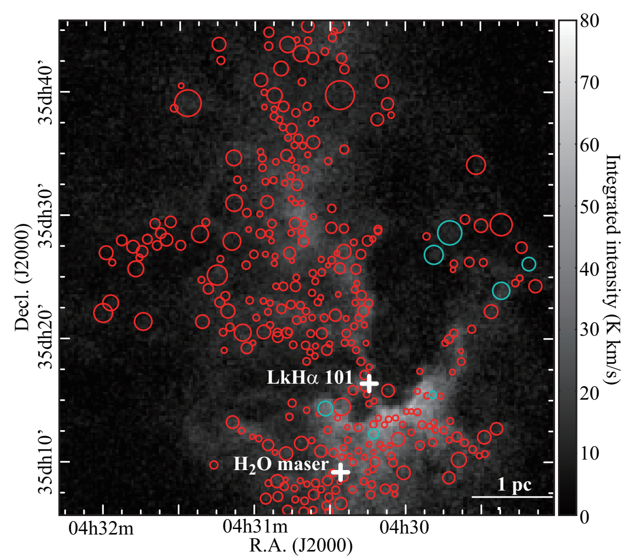

Figure 2: Integrated intensity map of the ^{13}CO(J = 1–0) emission line towards the L 1482 molecular cloud. The circles indicate the locations and diameters of the identified cores.

References

[1] Omodaka, T., Nagayama, T., Dobashi, K., et al.: 2020, *PASJ*, **72**, 55.

[2] Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al.: 2018, *A&A*, **616**, A1.

Trigonometric Parallax of O-rich Mira Variable Star OZ Gem (IRAS 07308+3037): A Confirmation of the Difference between the P-L Relations of the Large Magellanic Cloud and the Milky Way

URAGO, Riku[1], YAMAGUCHI, Ryohei[1], OMODAKA, Toshihiro[1], NAGAYAMA, Takumi[2], CHIBUEZE, James O.[3/4], FUJIMOTO, Masayuki Y.[5], NAGAYAMA, Takahiro[1], NAKAGAWA, Akiharu[1], UENO, Yuji[2], KAWABATA, Miho[6/7], NAKAOKA, Tatsuya[7], TAKAGI, Kengo[7], YAMANAKA, Masayuki[6/7], KAWABATA, Koji[7]

1: Kagoshima University, 2: NAOJ, 3: North-West University, 4: University of Nigeria, 5: Hokkaido University, 6: Kyoto University, 7: Hiroshima University

OZ Geminorum (OZ Gem) is a galactic Mira variable in the Milky Way (MW). We performed the astrometric observations of H_2O masers in OZ Gem with VLBI Exploration of Radio Astrometry (VERA) and measured its annual parallax to be $\pi = 0.806 \pm 0.039$ mas, corresponding to a distance of $D = 1.24 \pm 0.06$ kpc [1].

Based on multi-epoch infrared observations with the Kagoshima University 1 m telescope, we also derived the mean J-, H-, and K'-band magnitudes of OZ Gem to be 5.75 ± 0.47 mag, 4.00 ± 0.16 mag, and 2.65 ± 0.16 mag, respectively. We derived a pulsation period of OZ Gem as 592 ± 1 d from the K'-band lightcurve. From the period-luminosity (P-L) relation and two-color diagram of the Large Magellanic Cloud (LMC), the property of OZ Gem suggests that OZ Gem is assigned among the carbon-rich Mira variables. However, our optical spectroscopic observational results (with the 1.5 m Kanata telescope) confirmed OZ Gem to be an oxygen-rich Mira star with the detection of multiple titanium oxide transition absorption lines.

We suggest that OZ Gem is a low-mass star evolving to an OH/IR star with large mass loss and dust formation. It is predicted that the lower limit to the initial mass of AGB stars for developing the C-rich surface chemistry is larger in the MW than in the LMC because of larger metallicity, and OZ Gem is likely to be the first example to prove this. Our results highlight the necessity of deriving the PL relation of the Milky Way with high accuracy.

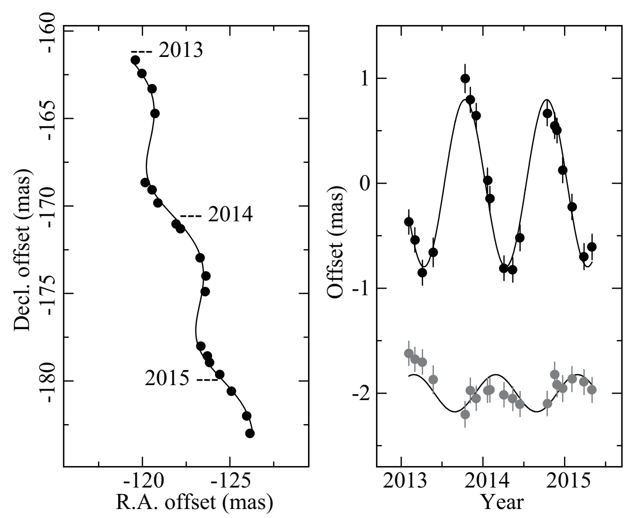

Figure 1: Parallax and proper motion of OZ Gem. The solid line shows the best-fitting results of parallax and proper motion. The black and gray circles show RA and Dec offsets, respectively.

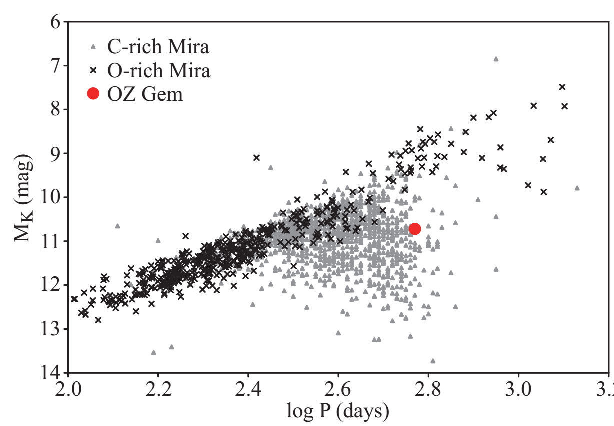

Figure 2: P–L relation of C-rich (gray filled triangles) and O-rich (cross) Mira variables in the LMC. OZ Gem is represented by the black filled circle.

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Couter-rotating Dense Molecular Gas in the NGC 1068 Torus Revealed with ALMA 0.02″ Resolution Observations

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1: NAOJ, 2: Kagoshima University, 3: Toyo University, 4: Kure College, 5: Chalmers University of Technology

An active galactic nucleus (AGN) is an object that shines very brightly at a compact galaxy nucleus, and is believed to be energetically dominated by a mass-accreting supermassive black hole (SMBH). If toroidally distributed dust and dense molecular gas, the so called "dusty molecular torus" is present around the SMBH, many observational results can naturally be explained (the so called AGN unified model). However, since the putative torus is spatially very compact (< 10 pc, or < 0.15″ at 15 Mpc), its observational understanding is still highly incomplete. With the advent of ALMA, detailed studies of the torus has become possible.

NGC 1068 (z = 0.0037, 14 Mpc) is a nearby well-studied AGN and the AGN unified model was originally proposed from observations of NGC 1068. Previous ALMA observations of dense molecular gas tracers, HCN J = 3–2 and HCO^+ J = 3–2 lines, with 0.04″ × 0.07″ resolution, revealed the presence of dense molecular emission that is almost east-west oriented both morphologically and dynamically. These observational results conformed to the expected properties of the torus in NGC 1068 [1]. However, the measured rotation velocity was much slower than Keplerian motion and the rotation direction was opposite to that of inner H_2O maser emission previously detected with centimeter VLBI high-angular-resolution observations [1]. Something very complicated and intriguing must be happening in the NGC 1068 torus.

We have conduced follow-up ALMA 0.02″ resolution observations and revealed that dense molecular gas at < 2 pc shows the same rotation direction as the inner H_2O maser emission, but outer torus dense molecular gas counter-rotates (Figure 1). Torus properties are highly asymmetric between east and west, and are much different from expected ones in the classical torus picture. We infer that a massive compact clump collided into the western torus from a far side, and altered the rotation of the outer torus (Figure 2). In such counter-rotating torus, angular momentum can easily be removed, promoting mass accretion onto the central SMBH and naturally explaining the fact that NGC 1068 is observed as a luminous AGN [2].

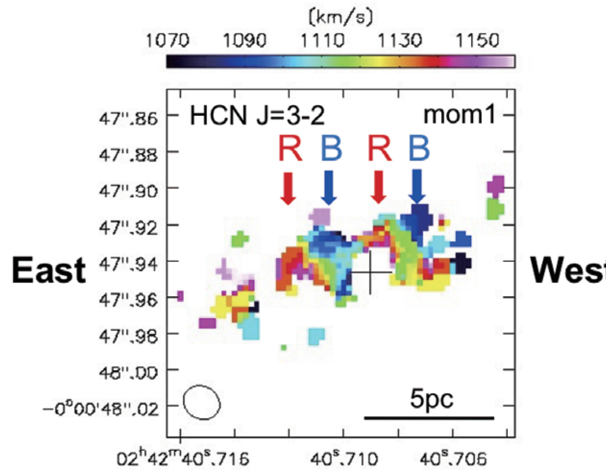

Figure 1: Intensity-weighted mean velocity (moment 1) map of HCN J=3–2 emission line taken with ALMA 0.02″ (~1 pc) resolution observations. In the western torus, inner part is redshifted and outer part is blueshifted. In the eastern torus, inner part is blueshifted and outer part is redshifted. B and R means blueshift and redshift, respectively. Namely, the presence of counter-rotating dense molecular gas components was revealed in the torus [2]. SMBH position is shown as +.

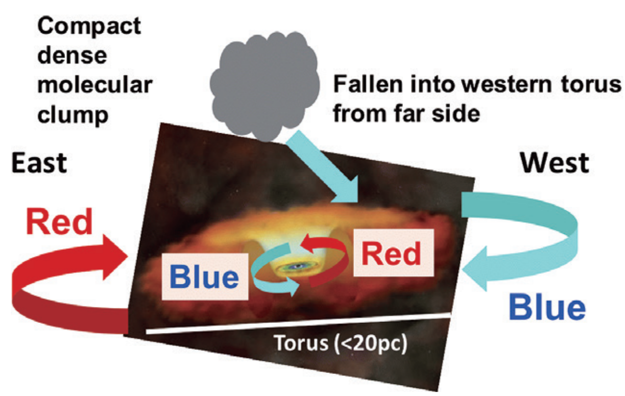

Figure 2: A scenario that can naturally explain the ALMA observational results of NGC1068. We speculate that torus was rotating in such a way that the western side was redshifted and eastern side was blueshifted before. At some point, a compact, dense, massive (~$10^5 M_\odot$) gas clump collided into the western torus from a far side and altered the rotation of outer torus molecular gas to an opposite direction.

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ALMA Detection of Millimeter 183 GHz H_2O Maser Emission in the Merging Superantennae Galaxy

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Water (H_2O) is an abundant molecule in the universe and its rotational energy levels are more complex than simple molecules (e.g., CO, HCN). In warm and dense molecular gas in the vicinity of an AGN (= powered by a mass-accreting supermassive black hole; SMBH), it is theoretically predicted that population inversion can happen for some H_2O transitions and emission can become very luminous through maser amplification. In fact, the 22 GHz (1.4 cm) H_2O maser emission was detected in obscured AGNs. If the H_2O maser emission is sufficiently bright, follow-up VLBI, very-high-angular-resolution observations were possible to probe the dynamics of maser emission and accurately estimate the central SMBH masses. The first very strong evidence for the presence of a SMBH in the universe was obtained through this method [1].

Theories also predict that luminous H_2O maser emission can occur at other transition lines than 22 GHz. It has been expected that by comparing multiple maser emission lines with different excitation energy levels, we can better understand the physical properties of molecular gas illuminated by AGN radiation. H_2O maser emission at (sub)millimeter wavelength (0.8–2 mm) was detected, but only for very nearly (< 20 Mpc) three AGNs.

Using ALMA, we have detected very luminous (> 10^4 solar luminosity) 183 GHz H_2O emission in the merging, AGN-hosting, infrared luminous galaxy, the Superantennae (z = 0.0617). The H_2O emission is brighter than other dense molecular gas tracers, HCN, HCO^+, HNC J=2–1 emission lines (Figure 1) and comes from more compact regions (Figure 2). These observational results can naturally be explained by maser amplification of the 183 GHz H_2O emission line, caused by population inversion, in warm and dense molecular gas in the vicinity of a luminous AGN [2]. We have demonstrated that using highly sensitive ALMA, we can detect the 183 GHz H_2O maser emission as far as ~270 Mpc, far beyond the immediately local universe.

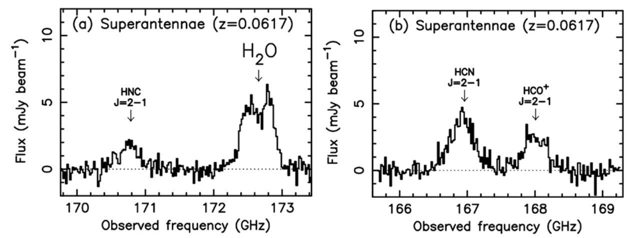

Figure 1: ALMA spectra of the merging infrared luminous galaxy, the Superantennae, at ~170 GHz (~1.8 mm) [2]. The abscissa is observed frequency in GHz and the ordinate is flux density in mJy/beam. The 183 GHz H_2O emission line is much brighter than other dense molecular gas tracers, HCN, HCO^+, and HNC J=2–1 lines.

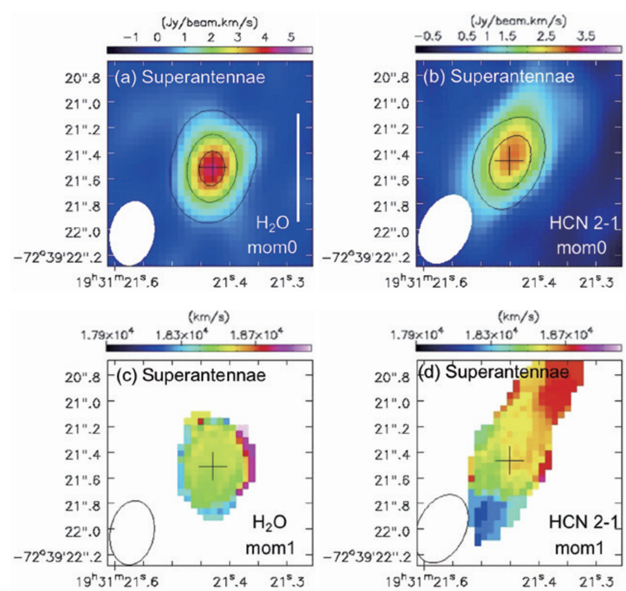

Figure 2: Integrated intensity (moment 0) map (Top) and intensity-weighted mean velocity (moment 1) map (Bottom). (Left): 183 GHz H_2O, (Right): HCN J=2–1. In the top panels, while HCN J=2–1 emission line (b) is spatially extended (> 500 pc), H_2O emission line (a) comes from compact (< 200 pc) regions. The vertical white bar in (a) corresponds to 1kpc. In the bottom panels, HCN J=2–1 emission line (d) shows a rotation pattern with north-western side being redshifted and south-eastern side being blueshifted, suggesting that the emission is spatially resolved. However, H_2O emission line (c) does not show such rotation pattern, which means that the emission is spatially very compact and unresolved [2]. SMBH position is shown as +.

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Millimeter-VLBI Detection and Imaging of the Gravitationally Lensed Gamma-Ray Quasar B0218+357

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The gravitational lensing (GL) effect can occur when a foreground massive object lies close to the line of sight to a background source. As a consequence the background source may be distorted and magnified into multiple lensed images allowing us to reveal objects that would be otherwise impossible to detect with current facilities. Thus observations of GL systems are a powerful approach to study the properties distant galaxies.

B0218+357 is one of the famous GL quasars located at $z = 0.944$, and lensed by a foreground spiral galaxy. The GL effect splits the AGN into two lensed images A and B (Figure 1). In the past, violent flares in high-energy gamma rays were reported from the source, suggesting the presence of a very active supermassive black hole. High-resolution VLBI observations of this source were performed in the past. However, since these VLBI observations were made at long wavelengths, the images were significantly affected by absorption and distortion by the gas in the foreground galaxy. The innermost structure of B0218+357 was therefore not well understood.

In this study, we performed detailed high-frequency VLBI observations of B0218+357 using KaVA 13/7 mm and KVN 3 mm. we revealed the detailed parsec-scale structure of the lensed images, where the ejection of powerful relativistic jets were clearly detected (Figure 2). Based on the radio-mm spectra, we found that the mas-scale source structure at mm wavelengths is less affected by the foreground effect. Moreover, we applied a simple GL model to the observed images and derived the intrinsic morphology of the quasar. We found that the jet extends over 600 light years from the nucleus. Our results provide important insights into the nature of a powerful supermassive black hole in distant universe.

Our KaVA monitoring of the source is still ongoing along with multi-wavelength (optical, X-rays, γ-rays) facilities in the world. This will further allow us to understand the physical properties of the jet in this source.

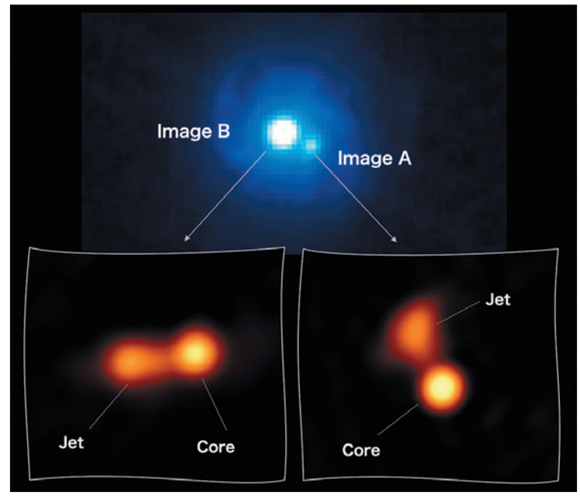

Figure 1: (Top) HST image of B0218+357 (credit: NASA/ESA and the Hubble Legacy Archive). (Bottom) KaVA 7mm images of lensed image A and B.

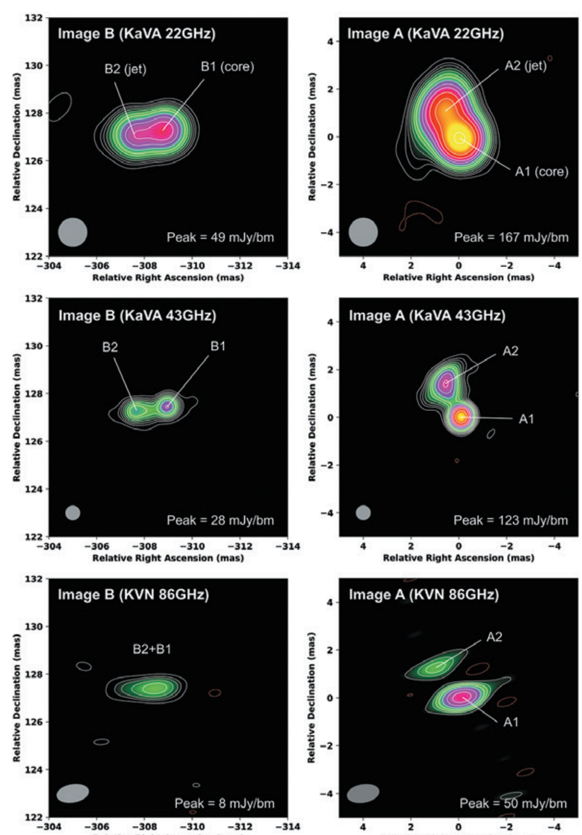

Figure 2: KaVA/KVN imaging of B0218+357 [1]. (Top) KaVA 13mm images. (Middle) KaVA 7 mm images. (Bottom) KVN 3 mm images.

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Spin Parity of Spiral Galaxies III: Evaluation of the Dipole Anistropy of Spin Distribution of Galaxies from SDSS

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Observations of the cosmic microwave background radiation and galaxy distribution brought detailed understanding of the structure and evolution of the universe. In addition to those studies on the scalar field, vector field study might well add additional constraints on the scenario of cosmological evolution. Early studies [1] assumed classical models (Figure 1) on the origin of vortex distribution in the universe.

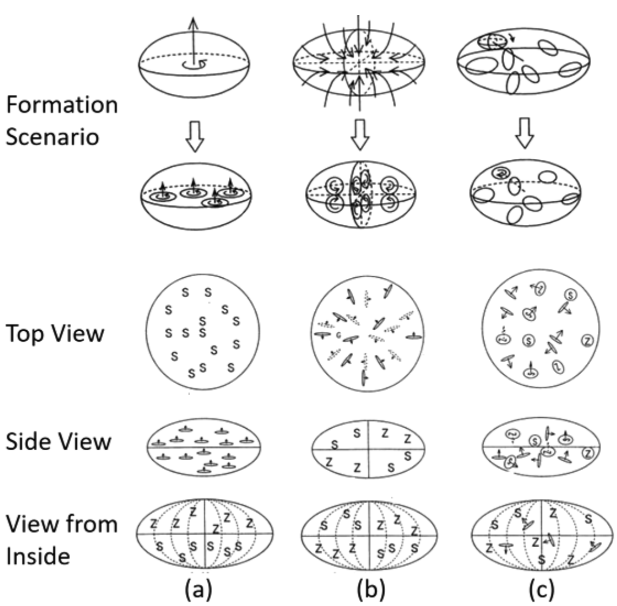

Figure 1: Classic scenarios [1]: (a) Primordial whirl, (b) Pancake shock, (c) Tidal torque.

Iye *et al.* (2019) reassured that the spiral winding direction, S-wise or Z-wise as seen from the Earth, could well be used as a robust measure to judge the sign of the line-of-sight component of the spin angular momentum vector of each galaxy [2]. The standard ΛCDM model of the universe does not predict the existence of any anisotropy in spin distribution in the universe. Shamir (2017) reported, however, finding a significant asymmetry in the spin distribution from his study of 162,516 SDSS galaxies [3].

Let $\mathbf{P}(l_P, b_P)$ be an assumed dipole direction, $h^i = \pm 1$ be the helicity of the i-th galaxy, and θ^i be an angle between the directions of the i-th of N galaxies and $\mathbf{P}$. Then the direction at which the inner product:

$$D(l_P, b_P) = \sum_{i=1}^{N} h^i \mathbf{\Omega}^i \mathbf{P}/N = \sum_{i=1}^{N} h^i \cos\theta^i/N \qquad (1)$$

becomes the largest is the direction of the observed dipole asymmetry $\mathbf{D_{max}}$.

We found that the vector sum of the spin vector randomly assigned for each of the N ensemble of galaxies follows the distribution of 3D random walk problem, called random flight problem. The resultant dipole vector of the system $\mathbf{D_{max}}$ will be an isotropic distribution with its center at zero but with a finite amplitude. The distribution of the amplitude D_{max} follows the χ-distribution with expected mean amplitude expressed by equation (2) and standard deviation by equation (3), respectively.

$$\overline{D}_{max} = \frac{\sqrt{2}\Gamma(2)}{\sqrt{3N}\Gamma(3/2)} \sim \frac{0.921}{\sqrt{N}}. \qquad (2)$$

$$Stddev = \sqrt{\frac{3\pi - 8}{3\pi N}} \sim \frac{0.389}{\sqrt{N}}. \qquad (3)$$

Applying this evaluation method to analyze the distribution of 111,867 spirals at redshift in the range $0.01 \le z \le 0.1$ from Shamir's catalog, we obtained, to our surprise, $D_{max} = 0.00773$, which is 4.00σ times larger than the expected amplitude of 0.00276±0.00126 derived from 50,000 random S/Z assignment simulations.

However, we found that the published catalog of Shamir (2017) contains significant duplication in its entry of galaxies. After cleaning the duplication, the sample number shrunk to 48,089 with measured $D_{max} = 0.00468$, which is only 0.29σ discrepant from the expected mean value of 0.00414±0.00188 [4].

We are conducting a project to AI judge S/Z of spirals from large image collections of SDSS, PanSTARRS, DES and HSC [5] and study their distribution to see if their distribution is really random or not.

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Search for Optically "Dark" Infrared Galaxies in the AKARI NEP Field

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1: Kyoto University, 2: Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), 3: Ehime University, 4: National Tsing Hua University (NTHU), 5: Tokyo University of Science, 6: Laboratoire d'Astrophysique de Marseille (LAM), 7: SOKENDAI, 8: Korea Astronomy and Space Science Institute (KASI), 9: NAOJ, 10: University of California, Los Angeles (UCLA), 11: Kyungpook National University (KNU), 12: ISAS/JAXA, 13: Universidad Nacional Autónoma de México (UNAM), 14: University of Tokyo, 15: Tokushima University, 16: RAL Space, STFC, 17: Japan Space Forum (JSF), 18: Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)

Recently, optically "dark" infrared (IR) galaxies that are undetectable in the optical but very bright in the IR and submillimeter wavelengths have been attracting attention as a key population for galaxy evolution. However, the number of discoveries has been limited due to the small size of the survey area. Hence, we focus on the AKARI North Ecliptic Pole (NEP) field [1], which was intensively observed by AKARI, and conduct a systematic search for optically-dark IR galaxies. As a result, we found 583 candidates of optically dark IR galaxies, which are not detected in the deep optical data taken by the Hyper Suprime-Cam (HSC) [2] acquired by Subaru open-use observations (in 2014–15), but are bright in the IR data of the Spitzer and AKARI [3] (Figure 1).

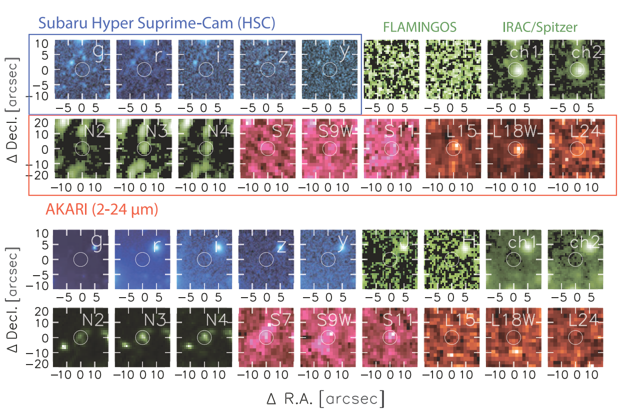

Figure 1: Examples of multiwavelength images for AKARI sources without HSC counterparts. White circles in the images correspond to the coordinates of the AKARI sources.

We then measure the physical quantities of these sources by using a spectral energy distribution (SED) fitting with multiwavelength data from optical to far-IR. By performing SED fitting with the same parameter set as that of the HSC-detected IR galaxies [4], we investigate the difference in physical properties between optically visible and invisible IR galaxies. We found that optically dark IR galaxies tend to have (i) high redshifts and large (ii) dust attenuation of the interstellar medium (ISM), (iii) stellar mass (M_*), and (iv) active galactic nuclei (AGN) activity ($L_{IR}(AGN)/L_{IR}$), and (v) star formation rate (SFR) compared to those of optically visible IR galaxies. Although partly affected by Malmquist bias, these results suggest the importance of optically dark IR galaxies that may be missed in previous surveys [5].

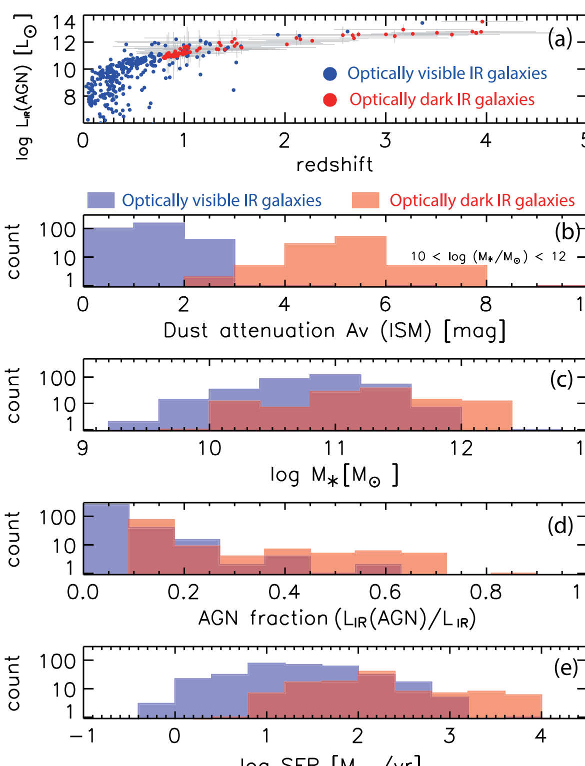

Figure 2: Comparison of optically visible (blue) and dark (red) IR galaxies in terms of (a) redshift and AGN IR luminosity (L_{IR}(AGN)), (b) ISM dust attenuation for stellar mass matched sample, (c) stellar mass (M_*), (d) AGN fraction ($L_{IR}(AGN)/L_{IR}$), and (e) star formation rate (SFR).

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Remarkable Migration of the Sun and Implications for Snowball Earth Events

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Where was our solar system born in the Milky Way? How did the Sun change its orbit to reach its present position? How did the surrounding environments due to the orbital change affect the Earth's surface environment? To answer these fundamental questions concerning our origins, we investigated the birth radius and subsequent orbital migration of the solar system using chemical evolution and orbital calculations [1].

To estimate the birth position of the solar system, we investigated the radius at which [Fe/H] = 0 approximately 4.6 Gyr ago using the chemical evolution of the Milky Way [2]. As a result, we concluded that the sun's birth radius is the Galactocentric radius $R_{\rm birth} < 5$ kpc. In order to investigate how the solar system, which was born at the innermost Galactic disk, migrated to its present position, we performed numerical calculations of the orbital changes of the solar system due to the dynamically evolving bar and spiral arms of the Milky Way. Our results showed that the spiral arms are "dynamic spiral arms" [3] supported by recent *N*-body simulations. Furthermore, we analyzed the changes in the environment around the solar system associated with this orbital motion, and suggested that the solar system experienced quasi-periodic encounters with the spiral arms (Figure 1). The solar system may collide with dense clouds in the spiral arm regions, causing the heliosphere to contract to the au scale. In addition, the solar system may be affected by strong galactic cosmic rays in these regions. These effects may cause the Earth's surface environment to be irradiated by strong galactic cosmic rays, resulting in the formation of large amounts of clouds [4] and the possibility of experiencing long-term cold temperatures (snowball earth events, [5,6]).

The orbital migration of the solar system and the history of the Earth's climate changes may be closely related to the dynamical evolution of the Galactic bar and spiral arms. Further progress in the study of galactic chemical dynamics by the astrometric satellites Gaia (ESA) and JASMINE (NAOJ) is expected.

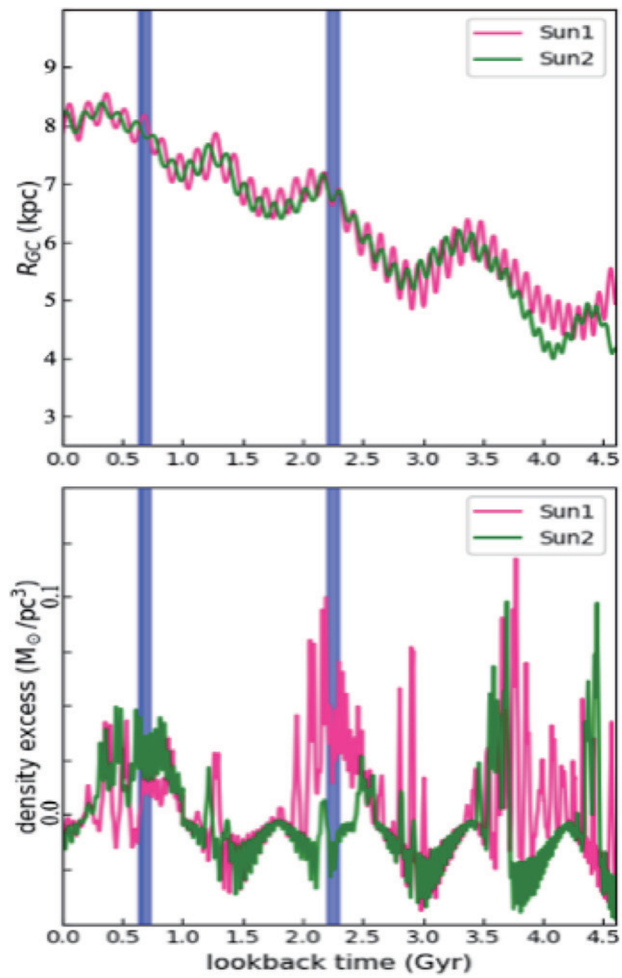

Figure 1: Two examples of temporal changes of the mean orbital radius (upper) and surrounding stellar density (lower). The recorded times of snowball earth events are indicated by the blue vertical zones.

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Completion of a Catalog of Locations for Near-future Star Birth in the Orion Constellation

—Discovery of Mysterious Double-eye Structure toward a Baby Star—

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(NAOJ)

Places to form stars are called "molecular clouds," where molecular gas is accumulated in space. Their densest parts are called "molecular cloud cores," and stars form right there. It is believed that the center of these "cores" further shrink because of gravity, and eventually form baby stars called "protostars." However, not all "cores" necessarily form stars, and also it was not easy to know from which "cores" star will form. We made use of deuterium, which is a special kind of hydrogen, and succeeded to know exact places for near-future star formation, by using a fact that the deuterium percentage reaches its maximum just at the time of star formation.

First, we used the 45 m radio telescope of the Nobeyama Radio Observatory to measure the deuterium percentage in "cores" in the Orion constellation, and completed a catalog of places for near-future star formation.

Next, we observed "cores" having high deuterium percentage with the Morita Array, which is East-Asian constructed part of the world most powerful radio telescope ALMA. As a result, we obtained evidence of the "increasing weight" motion at an exact place before star formation, and also discovered a "mysterious double-eye structure" near a baby star. These results give us an important clue to understand how stars start to form.

The "mysterious double-eye structure" shows a symmetrical distribution of the molecule containing deuterium with respect to the baby star. Future studies will make clear how it was formed, and whether it is a universal phenomenon for the baby star. Observations of deuterium will be a very important tool to scrutinize the sites of star formation. Such observations will definitely advance our understanding of the formation process of baby stars from molecular cloud cores.

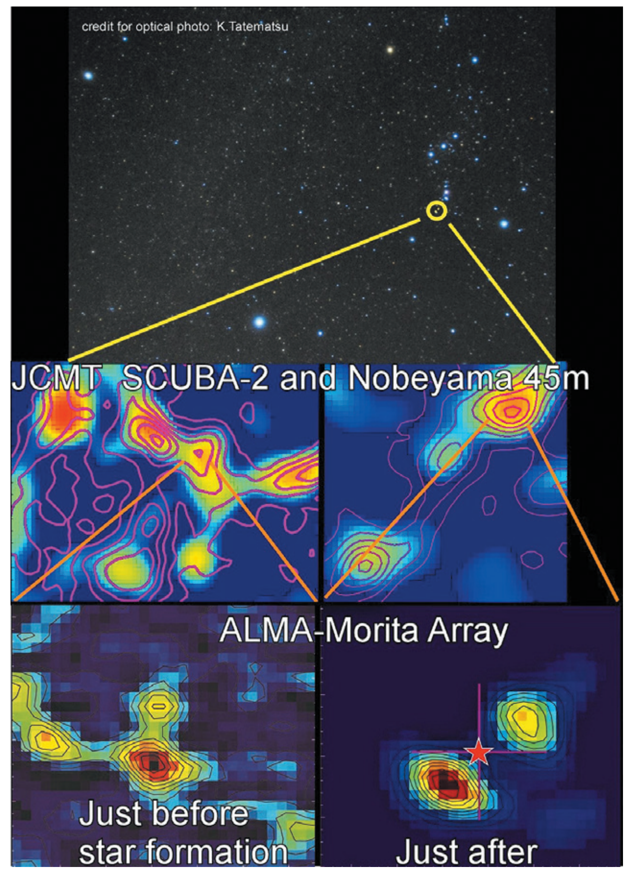

Figure 1: Picture of the Orion constellation and radio maps obtained with the Nobeyama telescope and ALMA-Morita Array. The bottom right panels show the mysterious double-eye structure. Mid row panels show the distribution of a hydrogen-containing molecule, and the bottom row panels show the close-up view obtained with the ALMA-Morita Array using a deuterium-containing molecule.

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A HAWAII-2RG Infrared Camera Operated under Fast Readout Mode for Solar Polarimetry

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1: NAOJ, 2: University of Tokyo

Various energetic phenomena on the Sun are governed by the magnetic field, which can be measured through the polarimetry. The solar polarimetry has been carried out mainly targeting the photosphere, but recently, the magnetic field of solar filaments, which occasionally erupt into the interplanetary space and develop to a flux rope, has been receiving increased attention. The erupted filaments sometimes cause magnetic storms and give harmful effects to the Earth. Therefore, the measurement of the magnetic field of solar filaments is quite important from the point of view of the space weather. However, it has been difficult, because it requires a high-speed, large-format detector covering near-infrared wavelengths.

Thus, we started a development of a new infrared camera for advanced solar polarimetry, employing a high-performance detector, under the support by a Japanese Kakenhi grant, “Project for Solar-Terrestrial Environment Prediction” [1]. The detector is a HAWAII-2RG (H2RG) array by Teledyne, which has 2048×2048 pixels, and we adopted one with the cut-off wavelength of 1.7 μm considering our target wavelengths. It had been difficult to synchronize H2RGs under the fast readout mode with external devices, such as a polarization modulator. We solved this problem by introducing a MACIE card as well as new assembly codes, both provided by Markury Scientific. Thus we succeeded to develop a polarimeter system with a H2RG array, which enables polarization measurements with high frame-rates, such as 29–117 frames per seconds.

We conducted experimental observations of the Sun at the Hida Observatory of Kyoto University using the Domeless Solar Telescope. Experimental arrangement of the H2RG camera system is shown in Figure 1(a). In Figure 1(b), a sample result of polarimetry is shown; the high polarimetric performance of the camera was confirmed.

The technology of this camera system can be widely applied to existing near-infrared solar polarimetry system. Only the addition of a set of a MACIE card and the assembly codes enables the synchronous operation of the H2RG with an external device under the fast readout mode without preparing a new, dedicated camera system.

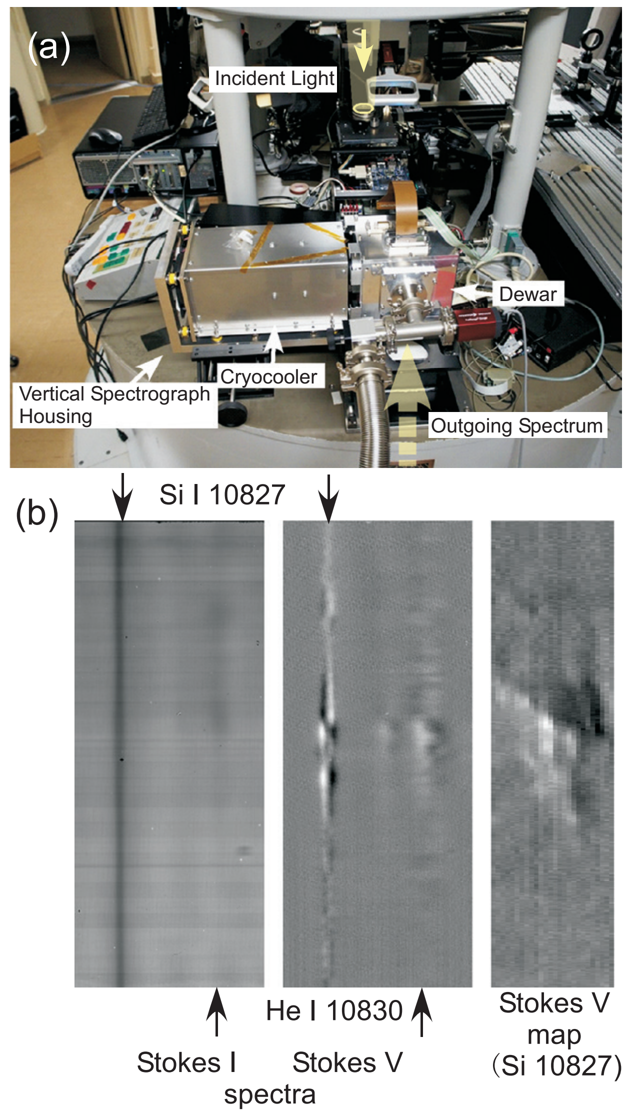

Figure 1: (a) Experimental setup of the H2RG camera system deployed on the top-table of the vertical spectrograph of the Domeless Solar Telescope. (b) Polarimetry data obtained from an experimental observation on 2018 November 20. In the sample Stokes *I* and *V*/*I* spectra including the Si I 1082.7 nm and He I 1083.0 nm lines, the polarization signals produced by the magnetic field can be found. We composed a Stokes *V*/*I* map, taken in the blue wing of the Si I 1082.7 nm line, from the data acquired at 26 slit positions. The map covers a field of view of 3.′7 (along the slit) × 52″ including a plage region NOAA 12727. The solar north is rotated counterclockwise from the top by 6°.

Reference

[1] Hanaoka, Y., et al.: 2020, *Earth, Planets and Space*, **72**, 181.

Internetwork Magnetic Fields Seen in Fe I 1564.8 nm Full-disk Images

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(NAOJ)

The solar surface is filled with magnetic fields. Active regions and supergranulation network boundaries, which have strong magnetic fields, are their dominant components. However, magnetic fields in internetwork regions inside the networks are also an important component despite their weak field strength. So far many researchers have investigated the internetwork magnetic field mainly using large solar telescopes, but some of its properties have not been sufficiently understood yet.

We studied the internetwork magnetic field using polarization data of the Fe I 1564.8 nm line, which were obtained with the spectropolarimeter of the Solar Flare Telescope at NAOJ during 2010–2019 [1]. Contrary to most of the previous studies, we used full-disk data taken with a synoptic instrument. Therefore, our analysis sheds light on the properties of the internetwork field from a quite different angle from those of the previous studies. The Fe I 1564.8 nm line is known to show particularly large Zeeman splitting, and it is suitable to study weak magnetic fields.

Figure 1 shows the full-disk maps of the circular polarization signals of the Fe I 1564.8 nm line, which show the distribution of the longitudinal magnetic field. The maps taken around the solar maximum (2014 May 10) and the solar minimum (2019 Aug 10) are shown. In panels (a) and (b) showing the strong magnetic field (typically 1.1 kG), we can find black and white patches (negative and positive magnetic fields) corresponding to active regions and network boundaries. On the other hand, panels (c) and (d), which present the magnetic field less than 400 G, entirely show grainy appearance. This is the internetwork magnetic field; the small-scale, weak magnetic fields in the internetwork regions spread over the entire solar disk.

Taking a closer look at panels (c) and (d), we can find that the polarization signals increase from the disk center toward the limb. This means that the internetwork magnetic fields are considered to be highly inclined, contrary to the magnetic field of the network boundaries, which are mostly vertical to the solar surface. Although the majority of previous studies derived similar results, they have not been commonly accepted. Our analysis carried out from a quite different viewpoint from the previous ones supports the highly inclined field.

Furthermore, from the analysis of the data during 2010–2019 covering most of solar cycle 24, we found that the properties of internetwork fields do not show notable cycle variation, even though the period includes both the solar maximum and the solar minimum.

To understand the solar magnetic field, it is important to make the properties of the internetwork magnetic field clear. Studies like ours will contribute to revealing still unknown properties of weak magnetic fields, which are different from the strong magnetic fields.

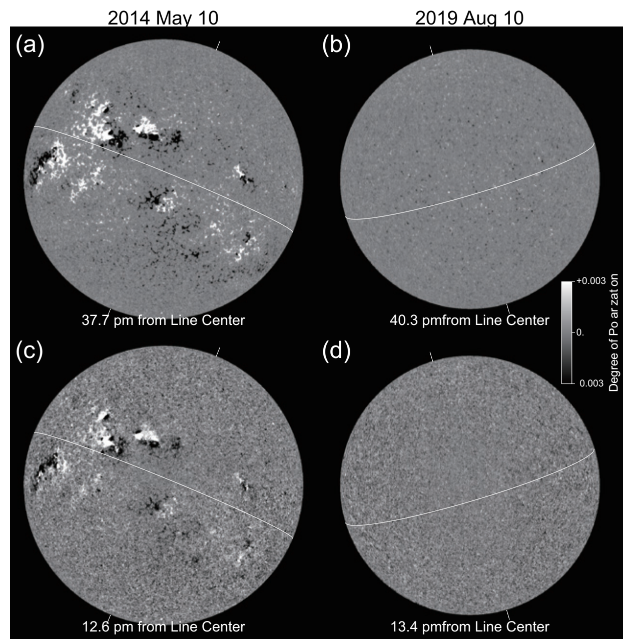

Figure 1: Full-disk circular polarization maps of the Fe I 1564.8 nm line showing the longitudinal magnetic field taken on May 10, 2014 and Aug 10, 2019 with the Solar Flare Telescope. The celestial north is to the top. Black and white represent negative and positive magnetic fields. Panels (a) and (b) are maps of the Stokes *V/I* signals at (a) 37.7 / (b) 40.3 pm offset from the line center; panels (c) and (d) are those at (c) 12.6 / (d) 13.4 pm offset.

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[1] Hanaoka, Y., Sakurai, T.: 2020, *ApJ*, **904**, 63.

Synoptic Solar Observations of the Solar Flare Telescope Focusing on Space Weather

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Synoptic solar observations have contributed to the study of solar activity for long time. Now its contributions to the space weather research are attracting attention. Monitoring flares and eruptive events has been an important role of the synoptic observations, but nowadays, more advanced contributions through the magnetic field measurements of the photosphere and the chromosphere are expected regarding the prediction of space weather events. To track the evolution of solar surface magnetic field is one of them; it is required to predict the eruptive events caused by the magnetic field evolution. To observe the magnetic field of the source region of coronal mass ejections (CMEs) is another one, because such magnetic field may develop into an interplanetary flux rope after their eruption, and the flux rope will cause geomagnetic storms, if it hits the Earth.

Recently the solar group of NAOJ started advanced synoptic solar observations with the Solar Flare Telescope (SFT) [1]. The observations include imaging at H*α*, Ca K, G-band (430 nm), and continuum, and spectropolarimetry at wavelength bands including the He I 1083.0 nm / Si I 1082.7 nm and the Fe I 1564.8 nm lines. In addition to the measurements of the brightness distribution and Doppler signal, magnetic field information of the photosphere and chromosphere is obtained. Figure 1 shows some examples of data obtained with the SFT. H*α* imaging and Doppler observations enable the estimation of three-dimensional velocities of eruptive features in the early phase of CMEs. Polarization measurements at He I 1083.0 nm show the magnetic field structure in filaments, which may develop into CME flux ropes in the interplanetary space and will eventually determine the severity of geomagnetic storms. Particularly the data of the chromosphere taken with the SFT are expected to contribute to space weather research, and this is the uniqueness and advantage of the SFT.

Recently some advanced synoptic telescopes focusing on the space weather research have been proposed in the US and Europe. An infrared spectropolarimeter, which has a similar concept to that of the SFT, is one of the main instruments of them, because the magnetic field measurement of the chromosphere is their primary target. Therefore, the current synoptic observation with the SFT is expected to become a pathfinder for future advanced synoptic instruments. We ourselves are developing a new infrared camera with a large format and high read-out speed detector to realize more advanced observations.

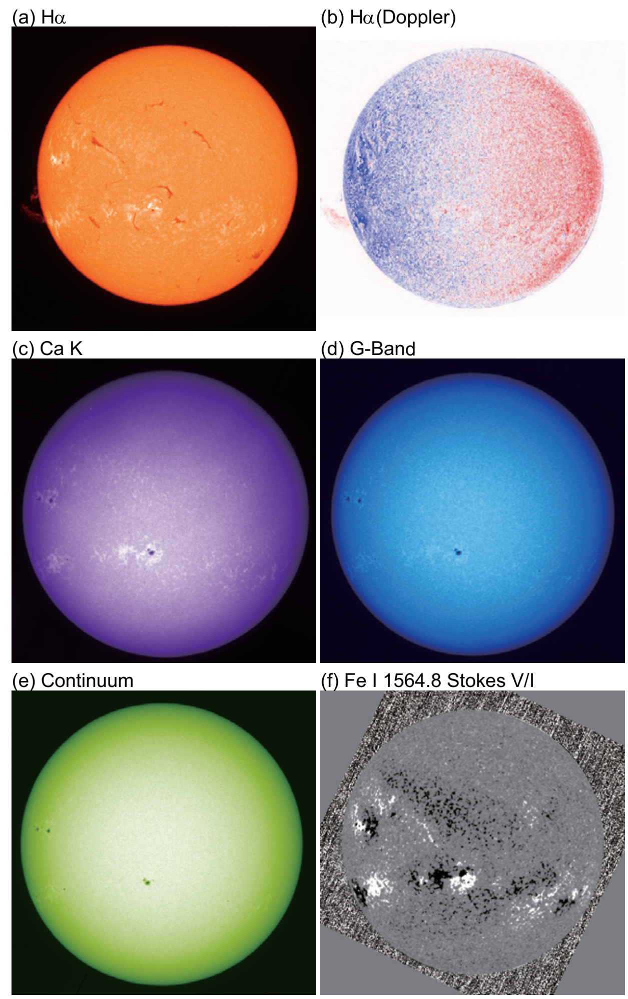

Figure 1: Sample full-disk images of the Sun on October 19, 2015 taken with the SFT. Panels (a)–(b) show an image at the H*α* center and a Dopplergram produced from off-band images. Panels (c)–(e) show images of Ca K, G-band, and continuum. Panel (f) shows a circular polarization (Stokes *V/I*) map using the infrared spectropolarimeter.

Reference

[1] Hanaoka, Y., et al.: 2020, *J. Space Weather and Space Climate*, **226**, 1421.

A Comparison of Properties of Quasars with and without Rapid Broad Absorption Line Variability

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HANAYAMA, Hidekazu[1], KAWAGUCHI, Toshihiro[4]

1: NAOJ, 2: University of Tokyo, 3: Shinshu University, 4: Onomichi City University

Quasar outflows ejected from their accretion disks around the supermassive black holes (SMBHs) are thought to be an element of a feedback from active galactic nuclei (AGNs), since they have following important roles: (i) radiatively and/or magnetically driven winds extract angular momentum from the quasar accretion disk, and (ii) they carry large amounts of energy and metal, then contributing to the chemical evolution of the host galaxy and star formation activities. Quasar outflows are usually detected as quasar absorption lines in rest-frame UV spectra (intrinsic QALs). As one of the intrinsic QALs, broad absorption lines (BALs; FWHM > 2000 km s^{-1}) are provided by quasar outflows, and are known to be variable on its depth, width, and velocity within months to years. However, BAL variability within 10 days are detected in 14 out of 27 BAL quasars [1] frequently observed by the Sloan Digital Sky Survey Reverberation Mapping project (SDSS-RM).

The cause of BAL variability is still being debated. Nowadays, changing ionization states in the outflow clouds due to variability of the quasar continuum emission is prevalent (hereafter, ionization state change). In order to verify the justification of the ionization state change, we investigated the relation between quasar continuum (flux) variability and BAL equivalent width variability, using the 27 quasars [1] which showed short-timescale (< 10 days) BAL variability (hereafter, S1) or not (hereafter S2). The flux variability amplitude decreases with quasar luminosities L_{bol}, increases with black hole masses M_{BH}, and decreases with Eddington ratios as general trends of quasars. If BAL variability is sensitive to quasar flux variability, it is expected that the smaller Eddington ratios (or larger black hole masses) of quasars are, the larger BAL variability becomes. Apart from those parameters, the disk temperature ($T_{\mathrm{AD}} \propto L_{\mathrm{bol}}^{3/8} M_{\mathrm{BH}}^{-3/4}$) is one of the most important physical quantity to characterize the quasar accretion disk. We also examined the correlation between BAL variability and the physical parameters (i.e., luminosity, black hole mass, Eddington ratio, and accretion disk temperature).

Consequently, there is no difference of flux variability amplitude between S1 and S2. On the other hand, our sample quasars show a moderate or strong correlation between flux variability and BAL variability. In addition, BAL variability amplitude and Eddington ratio (Figure 1), accretion disk temperature (or black hole mass) exhibit a strong (or moderate) relation between them. These results support the changing ionization state and suggest that they are closely related to the quasar physical quantities [2]. Moreover, the changing ionization state has an ancillary mechanism to explain short and/or long timescale BAL variability; variations in shielding located at an inner disk gas are proposed. One of the candidates of shielding gas is a warm absorber detected as absorption edges in X-ray spectra [3]. The justification of this ancillary mechanism is verifiable by simultaneous X ray-Optical observations.

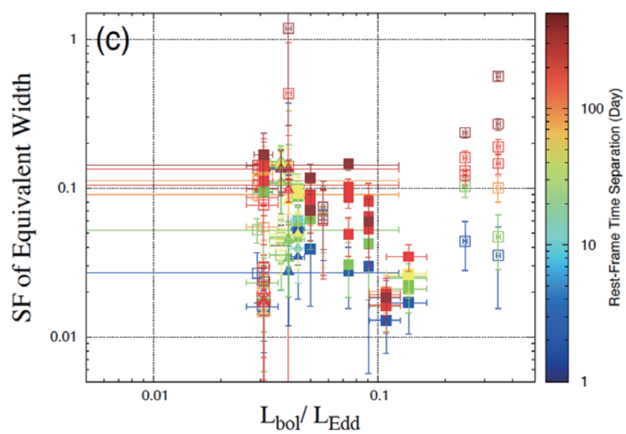

Figure 1: The relation between BAL variability amplitude and Eddington ratio. Colors indicate rest-frame time separation, where redder colors correspond to a larger time lag, as shown in the color bars. Open and filled squares indicate the distribution of S1 and S2 quasars.

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[1] Hemler, Z. S., et al.: 2019, *ApJ*, **872**, 21.
[2] Horiuchi, T., et al.: 2020, *AJ*, **159**, 237.
[3] Gallagher, S. C., et al.: 2002, *ApJ*, **567**, 37.

Simultaneous Multicolor Observations of Starlink's Darksat by the Murikabushi Telescope with MITSuME

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In recent years, satellite mega-constellations are being built for high-speed internet communication services. Especially, SpaceX in the U.S. plans to launch 12,000 Starlink satellites by mid-2020s for the purpose of the internet communication services covering whole world. Moreover in mid-October, 2019 SpaceX announced a plan to add more 30,000 satellites, and the total number becomes 42,000. The first 60 Starlink satellites were launched to low Earth orbit (LEO) on 2019 May 24, and SpaceX has launched about 120 satellites every month since 2020 January. On the other hand, the concern for light pollution caused by these satellites (i.e., the sunlight reflection) is shared by National Astronomical Observatory of Japan and other observatories around the world. In 2019 June, the International Astronomical Union (IAU) expressed a statement concerning its impact on astronomical observations and the pristine appearance of night sky.

In response to the concerns of the IAU, SpaceX developed Darksat (STARLINK-1130) with black paint on its surface to diminish satellite brightness, and launched it on 2020 January. The magnitude measurements for Darksat and one of a normal (unpainted) Starlink satellite (STARLINK-1113) were carried out by a previous study [1], which revealed that (1) Darksat is 0.8 magnitude fainter than STARLINK-1113 in the SDSS g' band, and (2) the impact by these two satellites cannot be ignored in astronomical observations. Furthermore multi-band observations are needed for estimation of magnitudes and reflectivity of satellites, however, such studies have not been reported yet. In this study, we performed a total of four multicolor (g', R_c, I_c bands; Figure 1) observations of Darksat (three times) and STARLINK-1113 (one time), using the largest telescope in the Kyushu-Okinawa area, 1.05 m Murikabushi telescope at the Ishigakijima Astronomical Observatory, with MITSuME system.

From the data analysis for Darksat and STARLINK-1113, we found that (1) the longer the observed wavelength is, the brighter the satellite magnitudes tend to become, (2) there is no clear correlation between solar phase angle (the Sun-satellite-obserber) and orbital altitude-scaled magnitude at 550 km (Figure 2), and (3) the reflectivity (albedo) of Darksat is about half of STARLINK-1113 [2]. Apart from Darksat, SpaceX developed Starlink's Visorsat with a sun visor to reduce the sunlight reflection and launched it on 2020 June 3. In the future, it is important to perform multi-epoch and multicolor (optical-to-NIR) observations for verification of the effect of the sun visor equipped with Visorsat and the phase angle dependence of its magnitude.

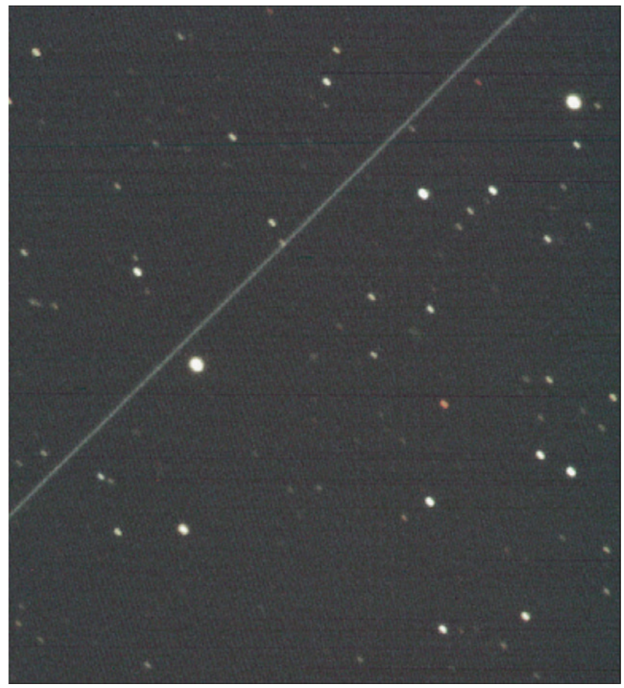

Figure 1: Pseudo color image of a satellite trail from Darksat (©NAOJ).

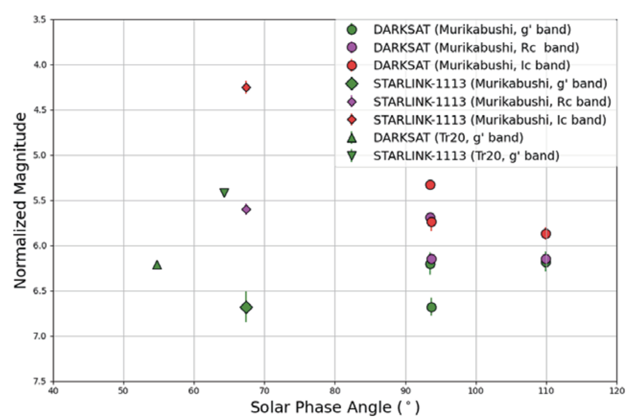

Figure 2: The phase angle dependence of orbital altitude-scaled magnitudes of Darksat and STARLINK-1113. Green, magenta, and red points indicate g'-, R_c-, and I_c-band magnitudes, respectively.

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Extremely Metal-Poor Representatives Explored by the Subaru Survey (EMPRESS). I. A Successful Machine Learning Selection of Metal-poor Galaxies and the Discovery of a Galaxy with $M_\star < 10^6\,M_\odot$ and $0.016\,Z_\odot$

KOJIMA, Takashi[1/2], OUCHI, Masami[3/1/4], RAUCH, Michael[5], ONO, Yoshiaki[1], NAKAJIMA, Kimihiko[3], ISOBE, Yuki[1/2], FUJIMOTO, Seiji[6/7], HARIKANE, Yuichi[3/8/1], HASHIMOTO, Takuya[9], HAYASHI, Masao[3], KOMIYAMA, Yutaka[3], KUSAKABE, Haruka[10], KIM, Ji Hoon[3/11], LEE, Chien-Hsiu[12], MUKAE, Shiro[1/2], NAGAO, Tohru[13], ONODERA, Masato[3/14], SHIBUYA, Takatoshi[15], SUGAHARA, Yuma[16/3/1/2], UMEMURA, Masayuki[9], YABE, Kiyoto[4]

1: ICRR, 2: University of Tokyo, 3: NAOJ, 4: Kavli IPMU, 5: Carnegie Observatories, 6: Cosmic Dawn Center, 7: Niels Bohr Institute, 8: University College London, 9: University of Tukuba, 10: Genève Observatories, 11: Metaspace, 12: NSF's National Optical Infrared Astronomy Research Laboratory, 13: Ehime University, 14: SOKENDAI, 15: Kitami Institute of Tech., 16: Waseda University

The early universe at $z>10$ is expected to be dominated by the large number of young star-formation galaxies with low metallicities (~0.1–1 % $Z_\odot$) and low stellar masses (~10^4–$10^6\,M_\odot$) [1]. The detection of such star-formation galaxies at $z>10$ are challenging, and only few examples are reported to date. On the other hand, low-mass, metal-poor galaxies called extremely metal-poor galaxies (EMPGs) have been discovered at $z\sim0$ (e.g., [2]). The EMPGs are thought to be a key galaxy population to understand the early-phase galaxy evolution. Previous EMPG studies use the photometric and spectroscopic data of Sloan Digital Sky Survey (SDSS), whose photometric limiting magnitude is $i_{\rm limit}\sim$ 21 mag. Due to the shallow data, previous SDSS studies could not reach the very low-metallicity (~0.1–1 % $Z_\odot$) and very low-mass (~10^4–$10^6\,M_\odot$) ranges (e.g., [3]), which star-formation galaxies at $z>10$ are expected to show.

We have initiated a new EMPG survey with deep, wide-field data taken in the HSC Subaru Strategic Program (HSC-SSP), whose limiting magnitudes ($i_{\rm limit}\sim$ 26 mag) is ~5 mag deeper than the SDSS data. Because the HSC-SSP data do not have spectroscopic data like SDSS, we find a large amount of contamination when we use a simple color-color EMPG selection. To overcome the difficulty, we exploit a new EMPG selection based on the machine learning technique. We generate a large number of model spectra of EMPGs, stars, QSOs, and general galaxies, and train our EMPG classifier with the model spectra. Then, the EMPG classifier have successfully chosen 27 EMPG candidates from the HSC-SSP data. We have conducted the spectroscopy for 4 EMPG candidates out of the 27 with Subaru/FOCAS, Magellan/LDSS3+MagE, and Keck/DEIMOS, confirming that the 4 candidates are real metal-poor galaxies. We also find that one of the 4 candidates, HSC J1631+4426 has a metallicity of 1.6 % $Z_\odot$, which is the lowest metallicity reported ever (cf. the previous lowest record was 1.9 % $Z_\odot$, [4]). HSC J1631+4426 also show a very small stellar mass, $10^{5.89}\,M_\odot$, which is comparable to the mass of star clusters. HSC J1631+4426 is expected to be a young star-forming galaxy undergoing an early phase of the galaxy formation. This paper is published from ApJ [5]. Further details are also reported in [6].

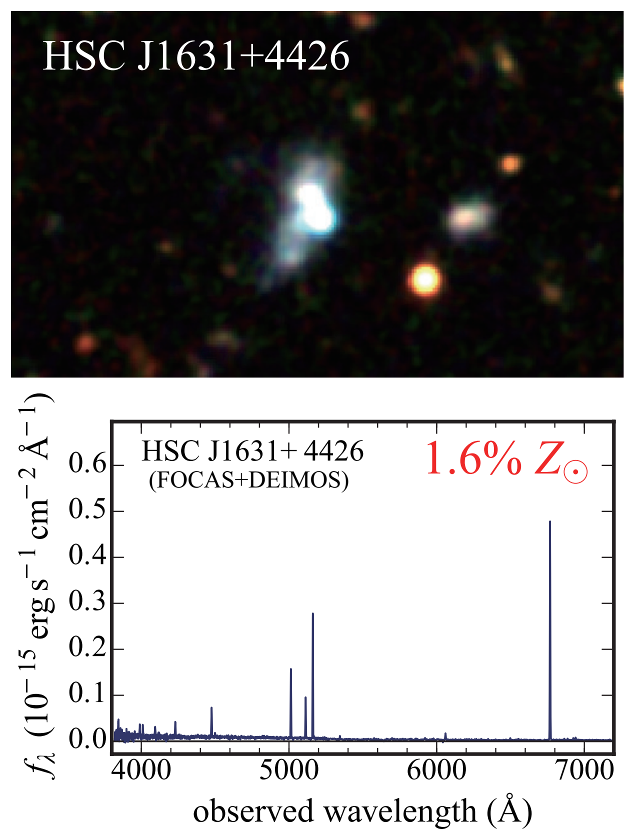

Figure 1: (Top) HSC-SSP image of HSC J1631+4426 (*gri* composite). HSC J1631+4426 is placed at the center. (Bottom) Optical spectrum of HSC J1631+4426 taken with Subaru/FOCAS and Keck/DEIMOS.

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[5] Kojima, T., et al.: 2020, *ApJ*, **898**, 142.
[6] Kojima, T., et al.: 2021, *ApJ*, **913**, 22.

Aurora Light from Comet 21P/Giacobini-Zinner Tells Us about Its Birthplace in the Early Solar System

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TAJITSU, Akito (NAOJ)

Comet 21P/Giacobini-Zinner (hereafter 21P/GZ) is a short-period comet with a period of 6.6 years and is known as the parent comet of the October Draconids meteor shower (historically called the Giacobinids). It has been reported that comet 21P/GZ shows poor abundances of rather simple molecules (carbon-bearing molecules, NH_2, and highly volatile species). Moreover, it has organics materials-rich dust grains. An abnormal negative wavelength gradient of polarization has been also reported in this comet. In the spectroscopic classification of comets, it is classified as the Giacobini-Zinner type, which only involves about 6 % of all comets. Both volatile molecules and dust among them are known to have very unique properties. Previous studies pointed out that comet 21P/GZ may have formed in a special environment different from other comets in the early solar nebula, but the specific formation site is still under debate.

We focused on the difference in sublimation temperature between H_2O, the most abundant element in standard cometary ices, and CO_2, the second most abundant element. We aimed to estimate the formation temperature of cometary nuclei from the abundance ratio of CO_2:H_2O in comets. Since CO_2 is also abundant in the Earth's atmosphere, it has conventionally been observed using space telescopes. On the other hand, we use three forbidden lines (wavelengths of 557.7 nm, 630.0 nm, and 636.4 nm) emitted from oxygen atoms in the coma (Figure 1), which are photodissociation products of solar UV radiation of H_2O and CO_2 in cometary coma because oxygen atoms made from H_2O and CO_2 emit different forbidden lines, the abundance ratio of CO_2:H_2O can be estimated from the intensity ratio of these three forbidden lines.

Observations of comet 21P/GZ were carried out with the High Dispersion Spectrograph (HDS) on the Subaru Telescope in October 2018. It was found that comet 21P/GZ has a small CO_2 abundance ratio, ~1 %, among the comets observed so far (see Figure 2). This low CO_2 abundance ratio and the sublimation temperature of CO_2 in vacuum suggest that comet 21P/GZ may have formed in a temperature environment of ~70 K–150 K, which is higher than those of typical comets ($\lesssim$ 70 K). This result is also consistent with the previous studies of this comet [1].

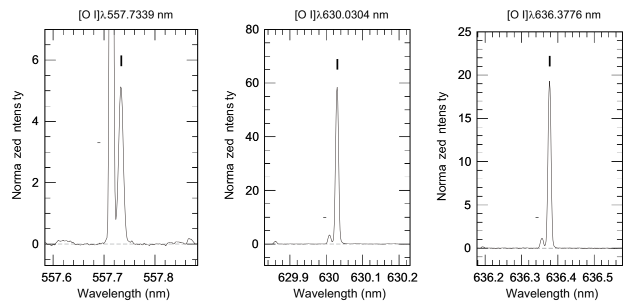

Figure 1: The forbidden oxygen lines in comet 21P/GZ. Vertical tics indicate the [O I] lines of 21P/GZ, and the astrological symbols of Earth (circled "+" marks) located at the shorter wavelength side of each line originated from telluric oxygen.

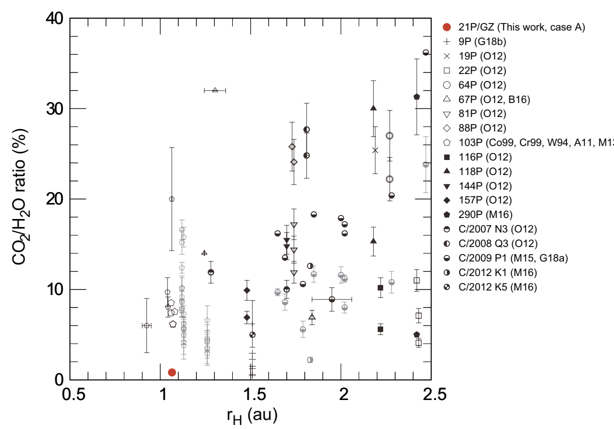

Figure 2: CO_2/H_2O abundance ratios in comets at observed heliocentric distances within 2.5 au. The red filled circle is the CO_2/H_2O abundance ratio of 21P/GZ estimated from the green-to-red line ratio of [O I]. Although the CO_2/H_2O ratios of comets show great variability, comet 21P/GZ has one of the lowest CO_2 abundances of any observed comet.

Reference

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Rapidly Evolving Transients from the HSC SSP Transient Survey

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1: Kyoto Unviersity, 2: Tohoku University, 3: Kavli IPMU, 4: Konan University, 5: NAOJ, 6: Monash University, 7: University of Tokyo, 8: Princeton University

Rapidly evolving transients are characterised by the shorter timescales of the light curves than ordinary supernovae (SNe), while their luminosities are comparable to those of typical SNe. Until now, about 100 rapidly evolving transients have been found by various time-domain surveys [1]. However, the progenitor scenario and explosion mechanism of these transients are not yet understood.

We performed a systematic search for rapidly evolving transients from the 1,824 transients found in the HSC SSP Transient Survey [2]. In order to determine the criteria for rapidly evolving transients, we performed mock observations assuming the observing schedules and conditions of the HSC SSP Transient Survey, and determined the lower limit of timescales of normal thermonuclear and core-collapse supernovae. By selecting the transients whose timescales are shorter than the lower limit of ordinary SNe, we newly confirmed 5 rapidly evolving transients (Figure 1; [3]). Their properties of the light curves are similar to those of the previously found rapidly evolving transients (Figure 2). Our samples have a wide range of redshifts ($0.3 \leq z \leq 1.5$) and peak absolute magnitudes ($-17 \geq M_i \geq -20$). These results demonstrate the high efficiency of {the} HSC SSP Transient Survey to detect high-redshift transients.

Using the rise times from the half of the peak flux to the maximum light in the *i* band and peak luminosities at the *i*-band peaks of our samples, we constrained the explosion scenario of our rapidly evolving transients. Our results show that some of our samples require power source other than the decay of ^{56}Ni, which is a main luminosity source of ordinary SNe. We also found that the event rate of rapidly evolving transients is rather frequent, ~ 4,000 events yr^{-1} Gpc^{-3}, which is is about 1 % of core-collapse SNe.

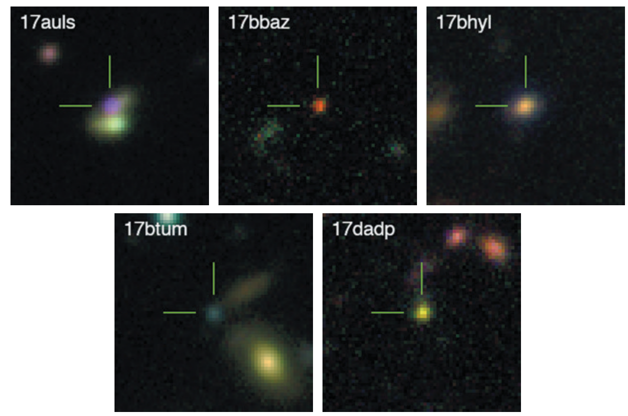

Figure 1: 5 rapidly evolving transients newly found in this work.

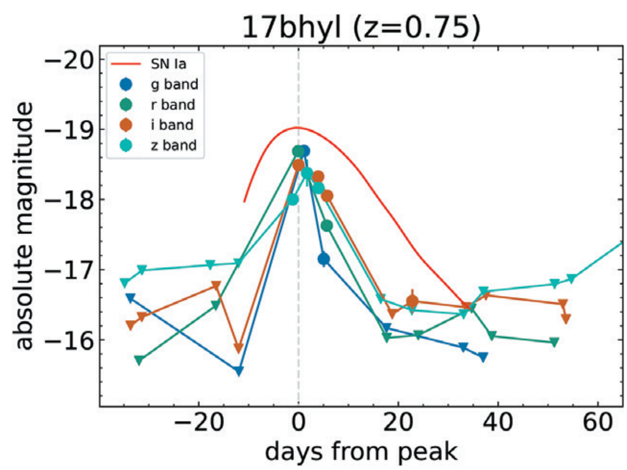

Figure 2: The multi-band and absolute-magnitude light curves of HSC17bhyl. The red line represent the *i*-band light curve of SN Ia generated by the sncosmo package.

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Large Population of ALMA Galaxies at $z>6$ with Very High [OIII] 88 μm to [CII] 158 μm Flux Ratios: Evidence of Extremely High Ionization Parameter or PDR Deficit?

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In this work [1], we present our new ALMA observations targeting [OIII] 88 μm, [CII] 158 μm, [NII] 122 μm, and dust continuum emission for three Lyman break galaxies at z=6.0293–6.2037. The targeted galaxies are identified in the Subaru/Hyper Suprime-Cam (HSC) survey, and spectroscopically confirmed with Lyα using Subaru/FOCAS in the SHELLQs project [2]. The three galaxies were observed during ALMA cycle 5 (ID: #2017.1.00508.S, PI: Y. Harikane) at Bands 6, 7, and 8 for [CII] 158 μm, [NII] 122 μm, and [OIII] 88 μm. We clearly detect [OIII] and [CII] lines from all of the galaxies at 4.3–11.8σ levels (the upper panel of Figure 1), and identify multi-band dust continuum emission in two of the three galaxies.

We plot the [OIII]/[CII] luminosity ratio as a function of the star formation rate (SFR) in the lower panel of Figure 1. In conjunction with previous ALMA observations for six galaxies at $z>6$, we confirm that all the nine z=6–9 galaxies have high [OIII]/[CII] ratios of $L_{\rm [OIII]}/L_{\rm [CII]}\sim 3$–20, ~10 times higher than $z\sim0$ galaxies. We carefully investigate physical origins of the high [OIII]/[CII] ratios at z=6–9 using Cloudy [3], and find that high density of the interstellar medium, low C/O abundance ratio, and the cosmic microwave background attenuation are responsible to only a part of the z=6–9 galaxies. Instead, the observed high [OIII]/[CII] ratios are explained by 10–100 times higher ionization parameters or low photodissociation region (PDR) covering fractions of 0–10 %, both of which are consistent with our [NII] observations. The latter scenario can be reproduced with a density bounded nebula with PDR deficit, which enhance the Lyα, Lyman continuum, and C^+ ionizing photons escape from galaxies, consistent with the [OIII]/[CII]-Lyα EW correlation we find.

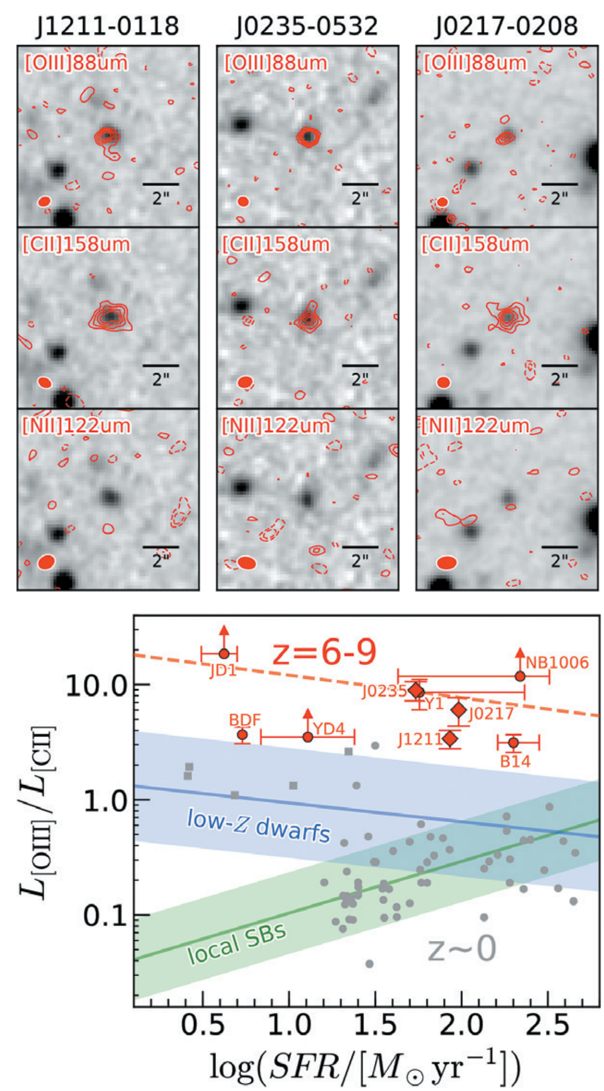

Figure 1: (Upper panel) The red contours are [OIII], [CII], and [NII] emission, and are drawn at 1σ intervals from ±2σ to ±5σ. Positive and negative contours are shown by the solid and dashed lines, respectively. The backgrounds are the Subaru/HSC z-band images. (Lower panel) [OIII]/[CII] ratios as a function of the SFR. The red diamonds represent our targets at $z\sim6$, and the red circles are other z=6–9 galaxies in the literature. The blue and green lines denote relations for $z\sim0$ low-metallicity dwarf galaxies ("low-Z dwarfs") and starburst galaxies ("local SBs"), respectively.

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Enhancement of Lithium Abundances in Red Clump Stars by Neutrino Magnetic Moments

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Among low-mass stars, those in the evolutionary stage where helium burning is occurring in the center are called red clump (RC) stars. Recent surveys have revealed that the lithium abundance on the surface of RC stars is, on average, about 40 times larger than theoretical predictions [1]. This observational fact indicates that the standard theoretical models for low-mass stars are inadequate.

Observations show that there is an excess of lithium abundance in almost all of the RC stars. It implies that the standard stellar model lacks a universal physical process that would work for all stars. In this study [2], we focused on the neutrino magnetic moment (NMM). Neutrinos are electrically neutral particles, but theoretically they can have a magnetic moment. For example, the Standard Model of particle physics predicts a magnetic moment of the order of $10^{-19}\mu_B$ [3], where μ_B is the Bohr magneton. However, some models beyond the Standard Model predict NMMs of much larger values. In this study, we investigate the effect of such large NMMs on the lithium abundance in RC stars.

Figure 1 shows a model of a 1 $M_\odot$ star, calculated by incorporating the effect of the NMMs into a stellar evolution code. The vertical axis is the stellar luminosity and the horizontal axis is the lithium abundance on the surface, where

$$A(\text{Li}) = \log\left(\frac{\text{Li}}{\text{H}}\right) + 12 \qquad (1)$$

The solid line is the standard model and the dotted line is the model with NMMs, where μ_{12} is the NMM normalized by $10^{-12}\mu_B$. The dots represent observations. In particular, the red dots represent RC stars. From this figure, it can be seen that when the NMMs are taken into account, the surface lithium content increases just before the helium flash, mitigating the discrepancy between the observed results and the theoretical prediction.

The mechanism of the increase in lithium content due to the effect of NMMs is as follows. When neutrinos have a magnetic moment greater than $10^{-12}\mu_B$, more neutrinos are produced in the core of the star than in the standard case. These neutrinos escape from the star, taking their energy with them. Therefore, the mass of the helium core just before the helium flash is larger than in the standard model [4]. The density of the hydrogen-burning shell then becomes smaller than usual, and the efficiency of thermohaline mixing in this region becomes higher. The ^{7}Be produced in the hydrogen-burning shell is transported to the convective envelope by this mixing. The ^{7}Be eventually decays to ^{7}Li by electron capture, resulting in an increase in the lithium abundance on the stellar surface just before the helium flash [5].

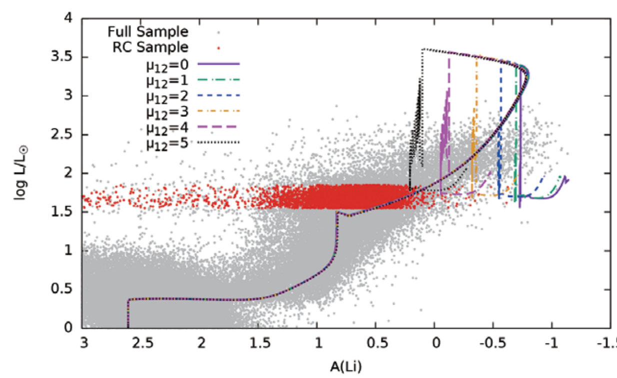

Figure 1: The stellar models with and without NMMs. The solid line is the standard models and the broken lines are the models with NMMs. The dots are observed stars.

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The Screening Effect on Electron Captures and Type Ia Supernova Nucleosynthesis

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Type Ia supernovae are thought to be thermonuclear explosions of white dwarfs, but the nature of their progenitor is not well understood. Theoretical models can be roughly divided into two types. One is called the near-Chandrasekhal mass (near-M_{ch}) model, in which a heavy white dwarf close to the Chandrasekhal mass causes the explosion. The other model is called the sub-Chandrasekhal mass (sub-M_{ch}) model, in which a white dwarf lighter than the Chandrasekhal mass ignites a thermonuclear reaction for some reason, leading to a supernova explosion.

One difference between the two models is the density of the central region: the near-M_{ch} model has a central density of over 10^9 g/cm^3, while the sub-M_{ch} model has a density several orders of magnitude less. In a high-density environment such as the center of the M_{ch} model, neutron-rich nuclei are produced by electron capture reactions. Therefore, the abundance of neutron-rich nuclei produced can be a probe of the nature of the progenitor of type Ia supernovae.

In order to reliably predict the amount of neutron-rich nuclei produced in type Ia supernovae, it is necessary to perform nucleosynthesis calculations using accurate electron capture reaction rates. The electron capture rate in matter is known to be smaller than the value in the laboratory due to the influence of electrons in the plasma. Figure 1 shows the calculated electron capture rate for ^{56}Ni, and it is clear that the reaction rate is indeed suppressed by the electron screening effect.

The effect of this electron screening effect on core-collapse supernovae has been investigated by previous research [1], but has not been studied in detail for type Ia supernovae. In this study [2], we calculated nucleosynthesis of type Ia supernovae using a new electron capture rate that incorporates the electron screening effect. Figure 2 shows the calculated ratio of the nucleation rate with and without the electron shielding effect. This figure shows that the production of neutron-rich nuclei such as ^{50}Ti and ^{54}Cr is suppressed by the electron screening effect.

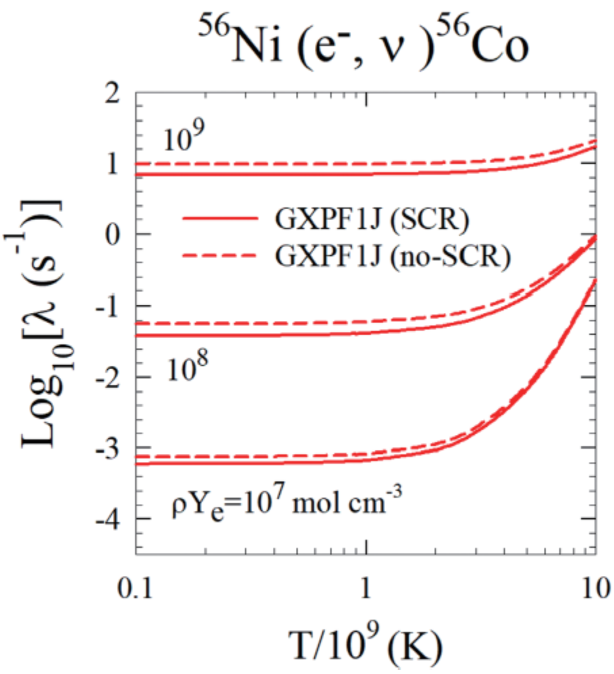

Figure 1: The electron capture rates of ^{56}Ni [2]. The solid (broken) line shows the rate with (without) screening.

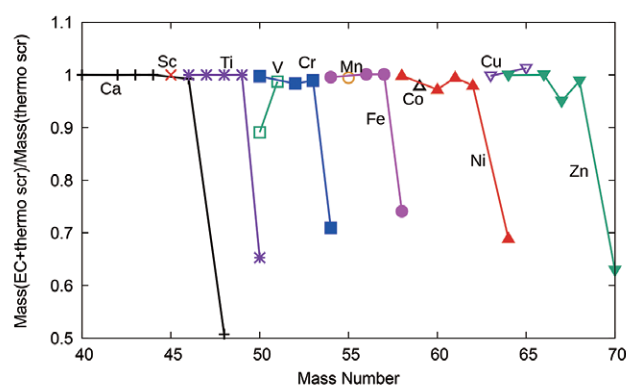

Figure 2: The ratio of the abundances of nuclei [2]. The results with and without screening on electron captures are compared.

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Origin of the Strong Correlation between AGNs and Luminous Galaxies

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It has been revealed that most of galaxies have a Super Massive Black Hole (SMBH) with a mass exceeding $10^6\,M_\odot$ at their center. Theoretical models of the evolution of SMBH have been proposed so far, which introduce gas accretion induced by galaxy mergers, secular evolution caused by gravitational instability inside a galaxy, quiescent accretion of hot halo gas, and so on.

We examined, in the previous study, the dependence of evolution of SMBHs on their environment measured as distribution of galaxies around them in order to investigate effectiveness of the external mechanism due to such as galaxy mergers. The result showed that there is a strong correlation between AGNs, which are galaxies in the rapid evolutional stage of SMBH, and luminous galaxies (LG), which may reflect their higher star formation rate [1]. In order to investigate what is the origin of the strong correlation, we compared the environment around the regions where AGN and LG are found with those of general AGNs and blue galaxies [2].

We used MILLIQUAS catalog for selecting AGNs with a redshift measurement, and six redshift survey catalogs (SDSS, WiggleZ, DEEP2, VVDS, VIPERS, PRIMUS) for selecting galaxy samples (LGs and blue galaxies). The AGN-LG sample was defined as an AGN which has luminous neighbor galaxies with $M_{\lambda 310} < -21$ (absolute magnitude at 310 nm wavelength in the their rest frame) within 4 Mpc projected distance. Two reference samples, AGNs and blue galaxy samples, were also constructed, in which blue galaxies was defined as $D = M_{\lambda 270} - M_{\lambda 380} < 1.4\, M_{\lambda 310} \geq -21$. Then we measured cross-correlation length r_0 with surrounding galaxies, which were extracted from a HSC-SSP S18a catalog, for each sample. The result is shown in Figure 1. The measured r_0 for the AGN-LG sample was the largest ($r_0 = 9.0 \pm 0.4\, h^{-1}$ Mpc) among the three samples, whilst those for AGN and blue galaxy samples were $7.2 \pm 0.2\, h^{-1}$ Mpc and $3.8 \pm 0.3\, h^{-1}$ Mpc, respectively. This indicates that the strong correlation between AGN and LG is related with the environment where they reside.

It is known that galaxies are bound together by gravity and form clusters of galaxies and they are aligned to form a filamentary structure. If the evolution of galaxies and SMBHs are affected by the cluster scale environment, it is expected that the evolution is related with a dynamics of the large scale structure. Thus we examined the distribution of clusters for the three samples [2].

Figure 2 shows the average number of clusters detected around each target source of the three samples. We obtained the highest number 1.94 ± 0.12 for the AGN-LG sample as compared with the numbers 1.58 ± 0.03 and 1.60 ± 0.03 for the AGN and blue galaxy samples, respectively. This indicates that the strong correlation between AGNs and LG is related with the proximity of two or more clusters of galaxies. We thus speculate, as one of the possibilities, that the interaction between clusters triggers the gas accretion in some of the member galaxies and induces star formation and AGN activity, which introduces the strong correlation between AGN and LG at a cluster scale.

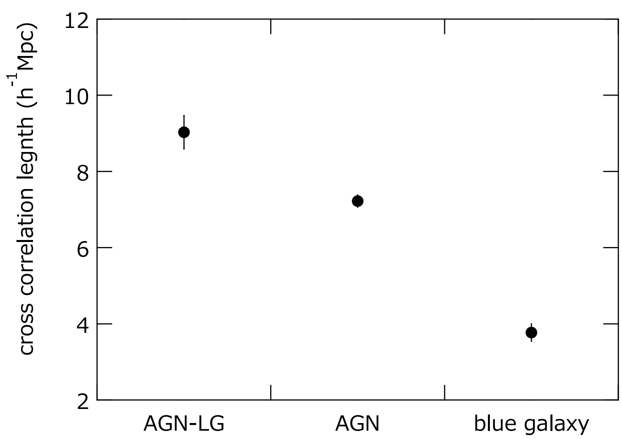

Figure 1: Cross-correlation lengths measured for the three samples (AGN-LG, AGN, blue galaxy).

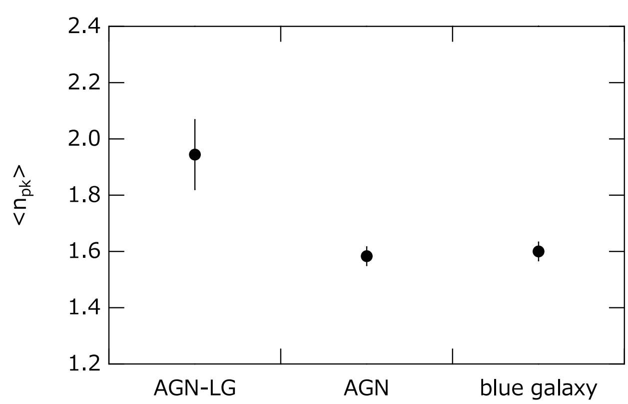

Figure 2: Average numbers of clusters around the target sources for the three samples (AGN-LG, AGN, blue galaxy).

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Discorvery of Long-term Near-infrared Brightening of Non-variable OH/IR Stars

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The asymptotic giant branch (AGB) phase is the late evolutionary stage of small- to medium-mass stars. When an AGB star has lost enough mass, it evolves into the next evolutionary stage, post-AGB phase, and then into the planetary nebula phase. The evolutionary path from the AGB phase to the post-AGB phase, especially the transitional phase between them, is not well understood. A correct understanding of stellar evolution at these phases is an important issue, because it will lead not only to an understanding of stellar evolution, but also to an understanding of the contribution of AGB stars to the chemical enrichment of the universe.

OH/IR stars are considered to be in the AGB to post-AGB phase. OH/IR stars show OH maser emission with a characteristic profile at 1612 MHz and strong infrared emission. Usually, these OH masers show a long-period variability, which is thought to be caused by the long-period pulsation of the central star. However, some objects do not show long-period variability and are called non-variable OH/IR stars. Since the stellar pulsation is expected to cease after the AGB phase, the OH maser is also expected to cease, and thus the non-variable OH/IR stars are considered to be in transition from the AGB phase to the post-AGB phase. Therefore, these objects are thought to be very important for understanding the vailed transitional phase, but their detailed properties are still unknown.

In the conventional picture, non-variable OH/IR stars are considered to have just stopped mass loss, and thus the circumstellar dust is gradually cleared up. If such a change is actually occurring, the extinction and reddening caused by the circumstellar dust would be reduced with time, and the star would become bluer and brighter. We examined whether such a phenomenon actually occurs using near-infrared data from 2MASS, UKIDSS, and OAOWFC. As a result, we obtained time variability data for six of the 16 non-variable OH/IR stars for periods of up to ~20 years, and confirmed brightening for all six (e.g., Figure 1). For one object, the brightening rate is so large that is difficult to explain by circumstellar dust diffusion. In addition, we studied the time evolution of the near-infrared color for three objects (Figure 2), and found that none of them turned blue, but rather red. These results suggest that non-variable OH/IR stars are undergoing time variations that cannot be explained by the diffusion of circumstellar dust alone. In order to explain these phenomena, a change in stellar temperature or an increase in circumstellar dust may be necessary, and a more detailed investigation of the cause of these phenomena is expected to provide new insights into the nature of non-variable OH/IR stars or stellar evolution in the transitional phase from the AGB phase to the post-AGB phase.

These results were published in the *Astrophysical Journal* with the support by the publications committee [1].

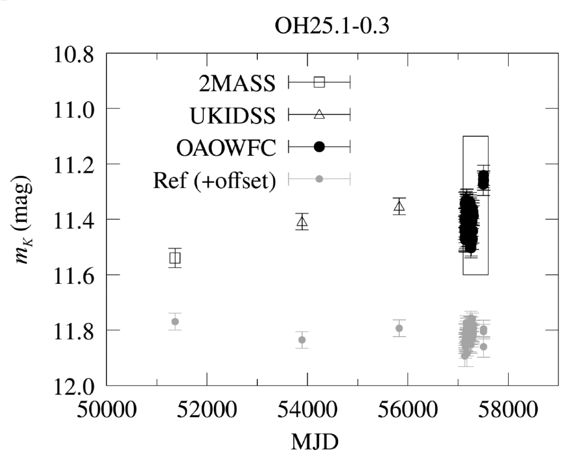

Figure 1: *K*-band light curve of a non-variable OH/IR star obtained by the 2MASS, UKIDSS, and OAOWFC surveys [1]. The black points are the data of OH 25.1–0.3, and the gray points are those of a reference object close to OH 25.1–0.3.

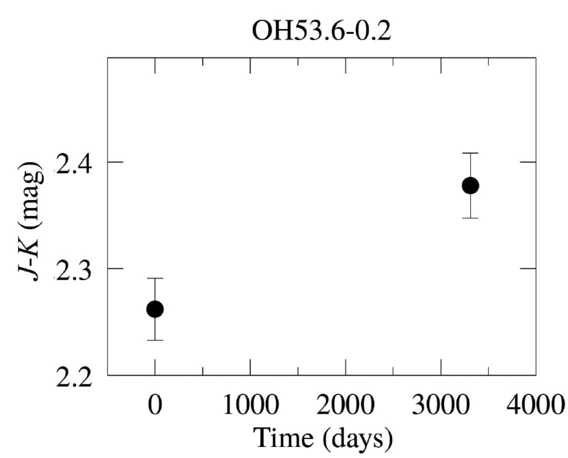

Figure 2: Near-infrared color change of a non-variable OH/IR star, OH 53.6–0.2 [1].

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Limits on the Spin-Orbit Angle and Atmospheric Escape for the 22 Myr Old Planet AU Mic b

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A growing number of "young" transiting exoplanets have been discovered by the dedicated space missions like K2 and TESS these days. Young planets provide a valuable laboratory to test the formation and evolution scenarios of close-in exoplanets; they possess the primordial orbital elements and atmospheres, and therefore investigation of the properties of those young planets allows us to gain insight into the physical processes that are responsible for the current distributions and properties of close-in planets. Specifically, for transiting planets, we can probe the stellar obliquity with respect to the planetary orbital axis as well as exoplanet atmospheres through measurements of the Rossiter-McLaughlin (RM) effect [1] and transmission spectroscopy.

With a goal of investigating the properties of such young exoplanets, we focused on AU Microscopii (AU Mic), which is a ≈ 22 million-year M dwarf in the β Pictoris moving group. Past observations of AU Mic revealed that the star has a nearly edge-on debris disk, and a P = 8.5-day Neptune-sized transiting planet was recently discovered by the TESS mission [2]. Given the brightness of the star (J = 5.4) as well as the relatively deep transit, AU Mic b is a great target to investigate the properties of young close-in planets. For measurements of the RM effect as well as transmission spectroscopy, we conducted high-resolution spectroscopy during a transit of AU Mic b using the InfraRed Doppler (IRD) spectrograph ($R \approx$ 70,000) on the Subaru 8.2-m telescope.

Figure 1 shows the radial velocity (RV) variation of AU Mic obtained by IRD on UT 2019 June 17. The observed pattern of the RV anomaly during the transit (i.e., the redshift during the first half and blueshift during the second half of the transit) is consistent with the "spin-orbit alignment" of the system. To confirm a low stellar obliquity for AU Mic b, we performed an additional analysis, called the "Doppler-shadow" analysis, in which the distortion of the spectral line profile during the transit is modeled and the moving shadow of the planet in the profile is directly analyzed to estimate the stellar obliquity. From this analysis, we obtained the projected stellar obliquity of $\lambda = -4.7^{+6.8}_{-6.4}$ degrees for AU Mic b, implying a good "spin-orbit alignment" of the system [3].

In the past measurements of the RM effect, about two thirds of the exoplanetary systems were shown to have a good spin-orbit alignment, while one third of the systems exhibit a significant misalignment. The low obliquity for such a young exoplanetary system as AU Mic suggests that the observed low obliquity for other older systems has a primordial origin, as opposed to the scenario that the low obliquity was generated by post processes including tidal interactions between the star and planet. Thus, our finding would become an important constraint to discuss the dynamical history of close-in planets.

Using the same IRD spectra, we also investigated if the target exhibits an excess absorption during the transit, to probe the atmosphere of AU Mic b. Specifically, we inspected the Helium triplet line at 1083 nm, which is a good indicator for the atmospheric escape from the upper exoplanet envelop. As a result of analyzing the in-transit and out-of-transit combined spectra, we found no evidence for an excess absorption at the He I triplet. From this measurement, however, we placed a tight constraint on the atmospheric loss from the exoplanet.

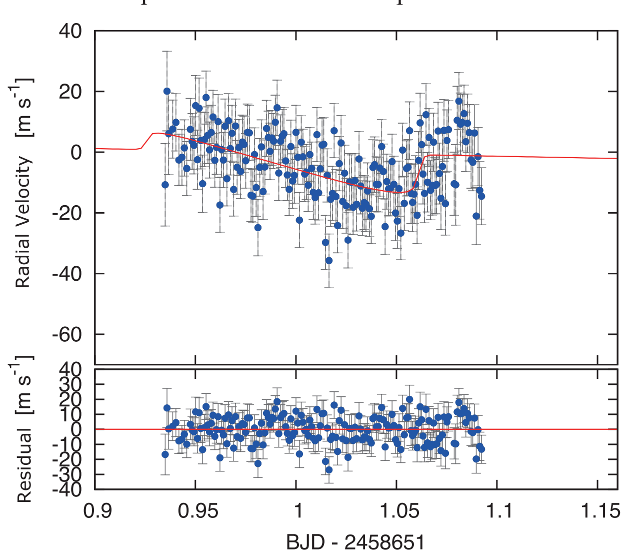

Figure 1: Observed RVs for AU Mic around its transit [3].

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Alignment Determination of Hayabusa2 Laser Altimeter

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Japanese asteroid explorer "Hayabusa2" was launched in 2014, and observed the target asteroid (162173) Ryugu during 2018–2019. The spacecraft is equipped with a laser altimeter called LIDAR for the precise measurement of the distance between the spacecraft and the asteroid, as well as surface topography mapping.

A laser altimeter is an instrument which measures the time of flight of the emitted laser pulses by the optical telescope. In general, the boresight direction of optical instruments aboard spacecraft might be changed due to the shock and the vibration of the launch. As a result, the observed location on the target body could be different from where we assumed. In this study, we detemined the boresight direction of the LIDAR by comparing topography by LIDAR and the camera image data during the asteroid proximity observation [1].

Firstly, we determined the pointing direction of the LIDAR by comparing the LIDAR-derived topography and 147 camera images which were taken at an almost constant altitude. Then, we confirmed the direction with data obtained when the spacecraft flew lower altitude. The Figure shows an example of comparison between the topography of the LIDAR and the camera images. Because Hayabusa2 is not an orbiter but a hoverer, i.e., which stays at a certain altitude above the asteroid, the viewpoints move from the right to the left in the figure due to the asteroid rotation. Upper figure is the topography which is converted from the range data of the LIDAR, assuming the spacecraft trajectory changes smoothly. Many convex topograhic features that are originated from boulders are seen, which are also shown in the bottom image. We focused on two significant time periods, namely 2 to 3 and 9 in the Figure, where images were taken continuously during passage of two boulders (2 to 3), and where a sudden sharp increase of topography was seen (9).

Furthermore, we discussed that the boresight direction had not shifted during the whole proximity observation for one year and half, even though the solar light input changed due to the Sun-spacecraft distance change. Lastly, we estimated the error of the boresight direction, which mainly comes from the pixel-reading error of the images. The trajectory position error in the cross- and along-track direction of the spacecraft were assumed as 0.4 m, 2.1 m, and 8.6 m at the altitude of 1 km, 5 km, and 20 km above the asteroid, respectively. The method we used in this study is simple and thus could be applicable to other spacecraft missions, such as the Martian Moons eXploration (MMX) in the future where a laser altimeter and cameras will be installed.

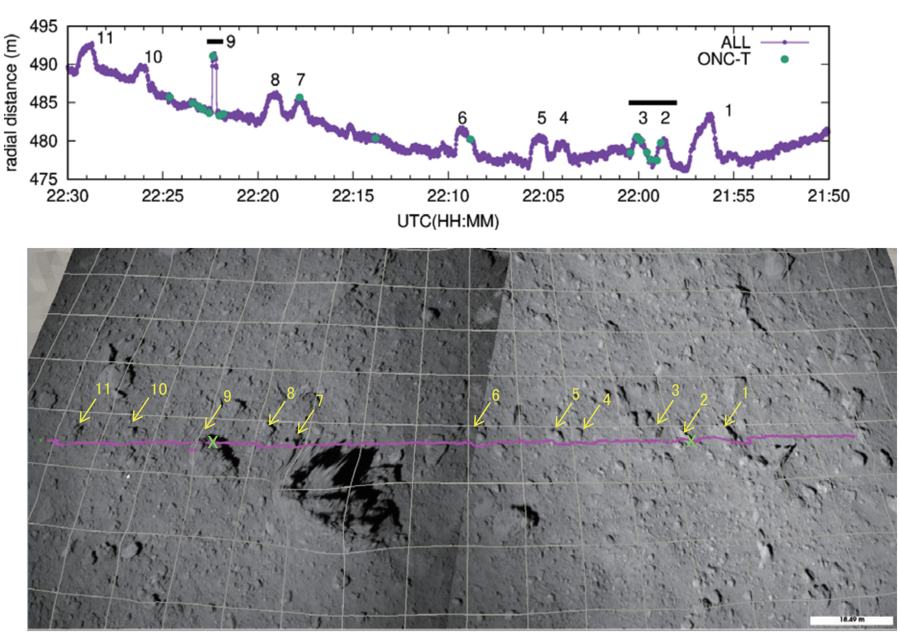

Figure 1: Upper panel shows the topography obtained by the LIDAR, and the bottom is the camera image. The observation points move from the right to the left, according to the asteroid rotation. Quoted from [1].

Reference

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Evolutionary Status of Extremely Li-Enhanced Red Giants

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A mystery in the evolution of solar-like low-mass stars is the existence of red giant stars that show anomalously large abundances of lithium (Li). We have obtained clear evidence, based on measurements of surface chemical abundances and internal structure, that red giants with extremely high Li abundances are at the stage of red clump, where they are burning helium at their centers [1].

When low-mass stars like the Sun have consumed most of the hydrogen at the center, stars evolve to the red giant branch phase where they are supported by hydrogen nuclear burning in the area around the central core. The convection at the surface of these stars becomes more active and mixes the material at the surface with the internal material. Lithium (Li) is a fragile element that is destroyed at the high temperatures found inside of stars, and hence, becomes less abundant at the surface of red giants. However, a small fraction of red giants are known to have orders of magnitude larger Li abundances compared to usual red giants. The frequency of distinctively Li-enhanced stars like those studied in this work is estimated to be about 1 % of all red giants.

Recent observations have suggested that red giants showing anomalously high Li excesses are so-called clump stars, which are in a more evolved stage than red giant branch stars, supported by helium nuclear burning at the center. This could be a useful hint to solve the question about the origin of Li-enhanced stars. However, it is not easy to distinguish the evolutionary status of a red giant, and no definitive conclusion had been obtained. For this purpose, asteroseismology based on long-term precise photometry by space telescopes is very useful.

We have identified a number of red giants that exhibit excess Li from the spectra obtained with the spectroscopic survey telescope LAMOST in China (Figure 1), and distinguished the evolutionary stages of these objects through asteroseismology using the photometry data from the space telescope Kepler. This reveals that most of the Li-enhanced red giants are clump stars. In particular, stars that have extremely high Li abundances are only found in this evolutionary stage. We also obtained high-resolution spectra of 26 Li-rich stars with the Subaru Telescope to derive reliable Li abundances, confirming the above results (Figure 1). Another recent study on Li abundances for a large sample of red giants has also reported Li abundance increases generally found in red clump stars [2].

The existence of Li-enhanced red giants indicates that there remains an essential problem in our understanding of stellar structure and evolution. Although the mechanism that enhances Li in low-mass evolved stars is unknown except for the case of AGB stars, the result that the evolutionary status of such stars has been successfully identified is a big step toward solving the question.

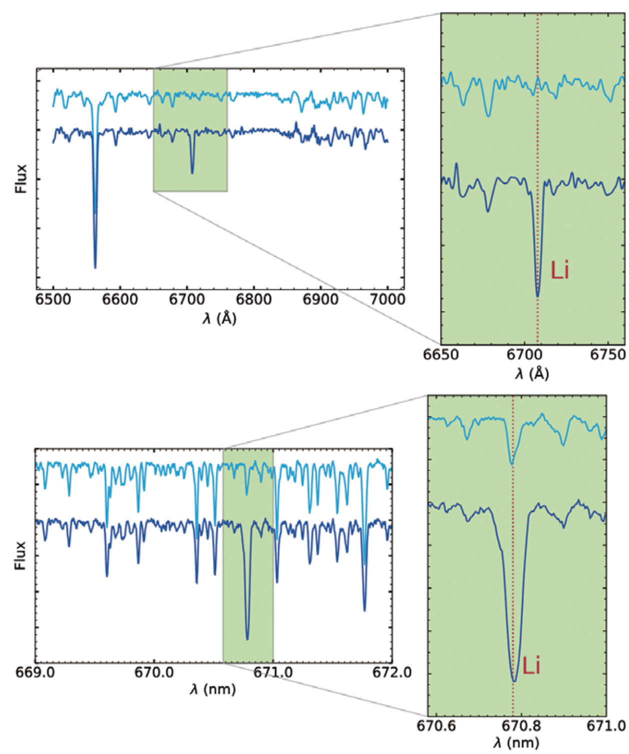

Figure 1: Examples of Li spectral lines observed with LAMOST (top) and the Subaru Telescope (bottom). The two lines in each panel indicate spectra of Li-normal and Li-enhanced stars. 454 Li-rich stars are identified from the LAMOST spectra, and evolutionary stages are determined for 134 stars among them, revealing that 86 % of them are red clump stars.

References

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[2] Kumar, Y. B., et al.: 2020, *Nature Astron.*, **4**, 1059.

Factorization of Antenna Efficiency of Aperture-type Antenna: Beam Coupling and Two Spillovers

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1: NAOJ, 2: University of Tsukuba

Aperture efficiency is one of the most important figures-of-merit of a radio telescope. It is desired to understand the behavier of the aperture efficiency in general case to develop multibeam radio telescopes for the next generation. To this end, we considered general aperture-type antennas with beam waveguides, and found a new factorization of the aperture efficiency into three geometric factors: efficiencies of beam coupling, transmission spillover, and reception spillover [1].

Most radio telescopes are equipped with primary and secondary reflectors, which are sometimes followed by an additional optical system. Such a radio telescope can be modeled with an antenna with two apertures in series (Figure 1). Aperture efficiency[1)] $\eta_{\rm ant}$ is calculated as beam coupling on the first aperture and becomes a product of the taper efficiency and the spillover efficiency $\eta_{\rm sp}$. We can extend it for more general case where the incident beam is not perpendicular to the aperture as follows,

$$\eta_{\rm ant} = \cos\theta \cdot \eta_{{\rm bcp},1} \cdot \eta_{\rm sp} \,. \qquad (1)$$

where θ is the angle between the telescope boresight and the beam axis, $\eta_{\rm bcp,1}$ is an efficiency of beam coupling including mismatch of amplitude, phase, and polarization. The aperture efficiency also can be written as beam coupling on the second aperture, with the beam coupling theorem which states that the coupling of beam is conserved along a beam waveguide. This gives

$$\eta_{\rm ant} = \eta_{{\rm sp},1\to 2} \cdot \eta_{{\rm bcp},2} \cdot \eta_{{\rm sp},2\leftarrow {\rm tx}} \,. \qquad (2)$$

where $\eta_{{\rm sp},1\to 2}$ is the ratio of the power passing through the second aperture to the power passing through the first aperture, $\eta_{\rm bcp,2}$ is the beam coupling efficiency on the second aperture, and $\eta_{{\rm sp},2\leftarrow{\rm tx}}$ is spillover effiency at the second aperture. Factor $\eta_{{\rm sp},1\to 2}$ is a new one which corresponds to a spillover of incoming power and we can call it reception spillover efficiency. Then, we can call $\eta_{{\rm sp},2\leftarrow{\rm tx}}$ transmission spillover efficiency. This factorization is numerically confirmed with an electromagnetic simulation.

The reception spillover corresponds to the rays that reflect at the primary mirror but do not hit the secondary mirror as the example shown in Figure 2.

It is natural to calculate the aperture efficiency factors at a telescope pupil. The abberations can affect the beam coupling efficiency on the pupil, and the beam coupling efficiency can be written by abberation and the receiver beam pattern [2]. These results sharpen theoretical treatment of aperture efficiency and can provide a firm basis for multibeam radio telescope design.

1) The effeiciency is written like this in [1] because the aperture efficiency in radio astronomy is “antenna efficiency” in the IEEE standard.

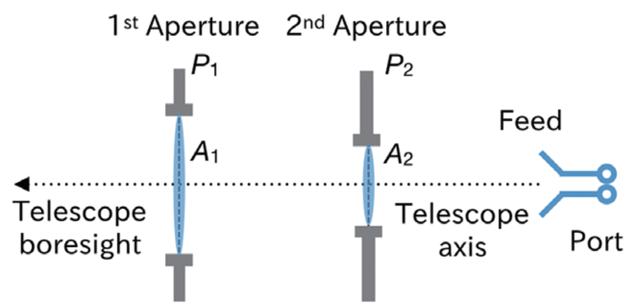

Figure 1: Antenna with two apertures in series.

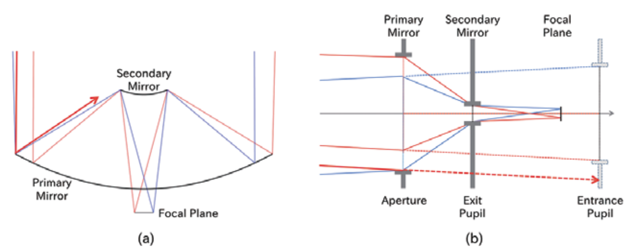

Figure 2: Multibeam Cassegrain telescope whose secondary mirror works as a stop: (a) schematic view and (b) beam propagation. A celestial object sees the secondary mirror reflected in the primary mirror as a pupil.

References

[1] Nagai, M., Imada, H., Okumura, T.: 2020, *IEEE Trans. Antennas Propag. (Early access)*, DOI: 10.1109/TAP.2020.3044381.

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Aberration Theory for a Radio Telescope

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(NAOJ)

Recently, radio telescopes are requested to have a wide field of view or the capability to install multibeam receivers for the improvement of observation efficiency. It is helpful to employ geometrical optics for a radio telescope optical design, as seen in designing an optical/infrared telescope. However, the radio-frequency (RF) community is likely to overlook some essential physical quantities obtained by geometrical optics because of the difference in receiver nature and accordingly because of the different figures of merit. Therefore, geometrical optics is not fully used so far, which makes it difficult for RF people to cancel out aberration effects and drives them to rely on high-cost electromagnetic simulation.

A receiver for a radio telescope generally has strong sensitivity in a specific direction, which is a significant difference from a detector like CCD. The RF people use aperture efficiency as a figure of merit which can account for the receiver sensitivity distribution. It can be factorized into taper efficiency[1)], the ratio of the power getting into the receiver to that of the incident wave, and spillover efficiency, the ratio of the power of the receiver sensitivity coupled with the incident wave to that of the whole receiver sensitivity. On the other hand, geometrical optics provides the optical path length of each ray and aberration. We have successfully constructed a theory to describe the relationship between aberrations and aperture efficiency [1]. The aberration effects appear in taper efficiency[2)], and aperture efficiency can be expressed as a function of aberrations and a receiver sensitivity distribution. As a result, the conditions for canceling out the lowest-order spherical and coma aberrations in an axially symmetric system[3)] are derived for a receiver with a fundamental-mode Gaussian beam. Interestingly, these conditions are qualitatively similar to those derived in geometrical optics but quantitatively different.

Figure 1 shows the aperture efficiency for a spherical mirror. A plane wave comes to it with an incident angle of 1 degree, and a receiver has a fundamental-mode Gaussian beam. The abscissa represents the receiver sensitivity width on the mirror. The right side corresponds to the narrower width with respect to the mirror. This system has spherical, coma, astigmatism aberrations. The blue line shows the aperture efficiency when the Strehl ratio is maximized, and the green line when the derived cancellation conditions are satisfied (red for no aberration, and purple for a Gaussian image point). All the discrete points are obtained from an electromagnetic simulation. The deviations of the green and blue curves from the points are the orders of magnitude of 0.1 %, which indicates the constructed theory works well for a small aberration. Also, maximizing the Strehl ratio does not necessarily mean a maximum aperture efficiency.

We took a receiver model with a Gaussian beam here, but an arbitrary sensitivity distribution is applicable whenever it can be expanded into a series of the Zernike polynomials[4)] employed in our formalism. We will apply our theoretical results to a radio telescope design and extend our formalism to predict a beam pattern and polarization performance with further investigation.

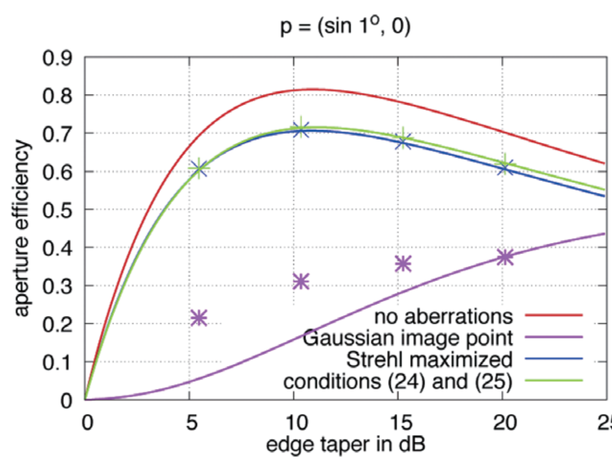

Figure 1: Theoretical curves and electromagnetic simulation results of aperture efficiency. The abscissa represents the width of the receiver sensitivity on the mirror.

References

[1] Imada, H., Nagai, M.: 2020, *Optics Express*, **28**, 23075.
[2] Nagai, M., Imada, H., Okumura, T.: 2020, *IEEE Trans. Antennas Propag. (Early access)*, DOI: 10.1109/TAP.2020.3044381.

1) It is also called aperture illumination efficiency, and so on.
2) To be more precise, taper efficiency is factorized into spillover efficiency of the incident wave and coupling efficiency between the incident wave and the receiver sensitivity [2]. The aberrations affect the coupling efficiency.
3) So-called Seidel aberrations.
4) Orthonormal polynomials.

Circumnuclear Molecular Gas in Low-redshift Quasars and Matched Star-forming Galaxies

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Mass accretion onto a supermassive black hole (SMBH) is widely ascribed to generate the huge amount of energy that is observed as an active galactic nucleus (AGN). Among AGNs, particularly luminous class objects are called as quasars, which often outshines the stellar light of their host galaxies. Quasars are the site of on-going growth of SMBHs, as well as capable of affecting the host galaxy-scale star formation by means of, e.g., intense radiation and massive outflows (negative feedback), making them a key evolutionary phase to investigate the so-called SMBH-galaxy co-evolution [1].

It has been a question under what environment/condition the quasar activity is triggered. Major mergers of gas-rich galaxies is one of the promising process for this [2] as they efficiently remove the angular momentum of gas, then activate mass accretion onto SMBHs. Other rather secular processes have been also proposed thus far. In any case, the available amount of gas at the circumnuclear disk (CND) scale, i.e., if the CND is gravitationally unstable or not, would be the matter.

Considering this, we observed four pairs of $z \sim 0.06$ low redshift quasars and matched (by redshift, stellar mass, and star formation rate/SFR) comparison galaxies by ALMA [3]. These objects were selected from the SDSS catalog (Figure 1). The achieved angular resolution is several 100 pc, which corresponds to the typical spatial scale of CND. We observed redshifted CO(2–1) emission line, which traces bulk of cold molecular gas distribution.

Interestingly, we did not see any significant excess in CO(2–1) surface brightness in quasars that would reflect the gas mass surface density, as compared to the matched normal galaxies (Figure 2). Rather, 3/4 pairs show elevated CO surface density in galaxies. Although this sounds contradictory to the model predictions, there should be a room to reasonably explain this result. For example, we need to further consider (i) quasar-driven outflows, (ii) time delay between the onsets of star formation and quasar, and (iii) X-ray-induced dissociation of cold molecular gas around the quasar nuclei. Further detailed observations are required to test these possibilities.

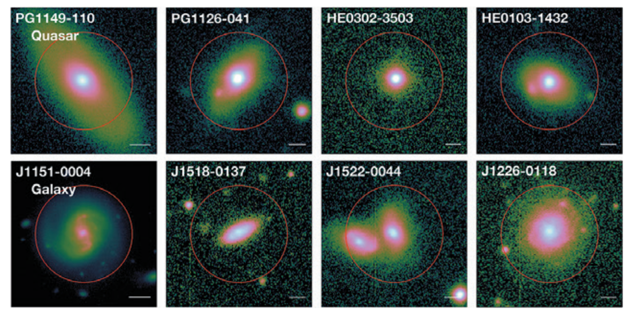

Figure 1: Target objects in this work. (Top) Low-redshift quasars. (Bottom) Matched (by redshift, stellar mass, and SFR) normal galaxies.

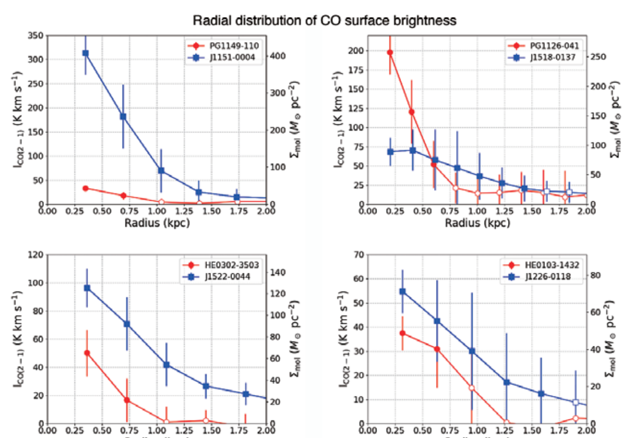

Figure 2: Radial profiles of CO(2–1) surface brightness that would reflect molecular surface density. In only 1/4 pairs we see an excess in a quasar, as compared to the matched galaxy.

References

[1] Kormendy, J., Ho, L. C.: 2013, *Annu. Rev. Astron. Astrophys.*, **51**, 511.
[2] Hopkins, P. H., et al.: 2008, *ApJS*, **175**, 356.
[3] Izumi, T., et al.: 2020, *ApJ*, **898**, 61.

ALMA Observations of Multiple CO and C Lines in NGC 7469

IZUMI, Takuma[1], NGUYEN, Dieu D.[1], IMANISHI, Masatoshi[1], KAWAMURO, Taiki[1], BABA, Shunsuke[1], HARADA, Nanase[1], NAKANISHI, Kouichiro[1], KOHNO Kotaro[2], MATSUSHITA, Satoki[3], HSIEH, Pei-Ying[3], MEIER, David S.[4], TURNER, Jean L.[5], MICHIYAMA, Tomonari[6], MARTÍN, Sergio[7/8], TAKANO, Shuro[9], WIKLIND, Tommy[10], NAKAI, Naomasa[11/12]

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Active galactic nucleus (AGN) is the site of rapid growth of a supermassive black hole (SMBH), while the detailed physical mechanisms for the growth yet remains unknown. Among possible scenarios, the most favored one would be the efficient mass accretion due to major mergers of gas-rich galaxies [1]. However, according to this scheme, it is quite difficult to uncover and study the details of the very early phase of SMBH growth, simply because that SMBH is heavily embedded (obscured) in gas and dust.

We here tried to identify physically and/or chemically unique features in the interstellar medium (ISM) around an AGN, as compared to normal star-forming systems. A key point of our experiment is that the AGN is a much more efficient system to radiate X-rays than starburst. Indeed, theoretical models predict totally different chemical structures in molecular clouds around AGNs as compared to starburst systems [2]. For example, CO molecules will be very efficiently dissociated and/or ionized by X-ray photons in AGNs.

To test this hypothesis, we observed multiple CO (including optically thin ^{13}CO) and atomic C lines toward NGC 7469, a nearby AGN, by ALMA, at ~100 pc high resolutions. We found that CO emissions are distributed over both the central circumnuclear disk (CND) and its surrounding starburst ring (SB ring), whereas [CI] (1–0) emission is clearly concentrated toward the CND. The comparison of some C/CO intensity ratios (including single dish-based line ratios of nearby galaxies) reveals that the line ratios of NGC 7469-AGN (CND) are outstandingly high (Figure 1). Our non local thermodynamic radiative transfer modeling indicates that C/CO abundance ratio around NGC 7469 AGN is ~ 10× higher than that of the SB ring, as well as ~ 5× higher gas temperature in the former. These can be very well explained as the X-ray induced chemical/physical signatures on ISM, i.e., robust evidence of an X-ray dominated region (XDR) confirmed in AGNs for the first time [3]. We will use this unique feature as an indication of AGNs, that is applicable to obscured systems.

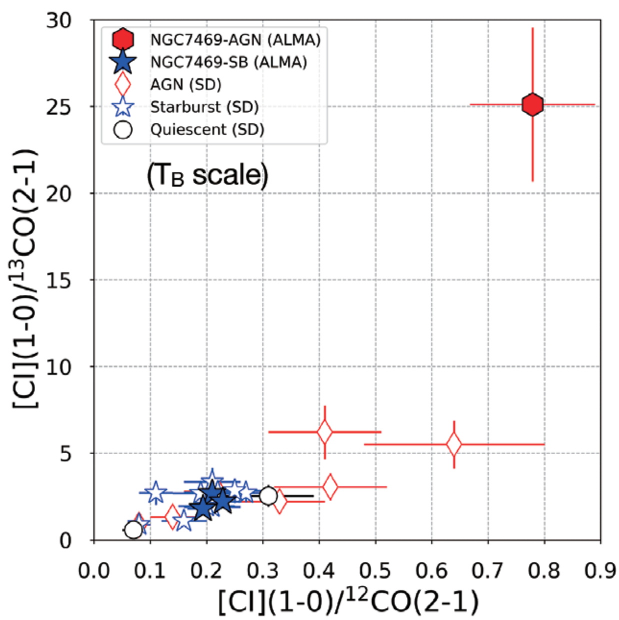

Figure 1: C/CO intensity ratios measured in NGC 7469 (AGN) and its surrounding SB ring. Literature data of single dish-based measurements are also shown. The line ratios of NGC 7469, selectively (spatially resolved) measured by ALMA, are outstandingly high, which will serve as unique features in AGNs.

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[1] Hopkins, P. H., et al.: 2008, *ApJS*, **175**, 356.
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[3] Izumi, T., et al.: 2020, *ApJ*, **898**, 75.

ALMA Observations of Cold Gas toward z = 6.72 Red Quasar

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Quasars, the most luminous population of active galactic nuclei (AGNs, mass-accreting supermassive black holes = SMBHs), have been considered to be a key evolutionary phase of SMBHs, which are also important to discuss the co-evolution with galaxies [1]. Recent theoretical models predict that major mergers of gas-rich galaxies would be a promising trigger of quasars [2]. According to this scheme, an initial phase of SMBH growth is heavily obscured by dense interstellar medium (ISM). Once the central SMBH is switched-on (i.e., AGN), the surrounding ISM is blown out by quasar-driven outflows, making the system visible as normal *blue* quasar. During this transition, the system is reddened by the remaining dust, hence is called as a *red* quasar: this is therefore an important evolutionary phase of SMBHs.

So far, we have searched $z > 6$ red quasars by matching deep optical maps taken by Subaru Hyper Suprime-Cam (HSC) and the WISE satellite, and indeed found the highest redshift record object HSC J1205–0000 [3]. We then observed [CII] line and FIR continuum emission of its host galaxy by ALMA. The [CII] spatial distribution is highly disturbed (Figure 1), indicating recent vigorous activities (mergers, outflows, etc) in the host. The area-integrated [CII] line spectrum clearly deviates from a single Gaussian: at least a double Gaussian function is necessary to better account for the profile. This spectroscopically manifests the existence of multiple components in this host galaxy. Although it is not clear the detailed nature of the components (merger vs outflow, for example), higher resolution ALMA observations and/or direct imaging of stellar light by JWST will shed light on it.

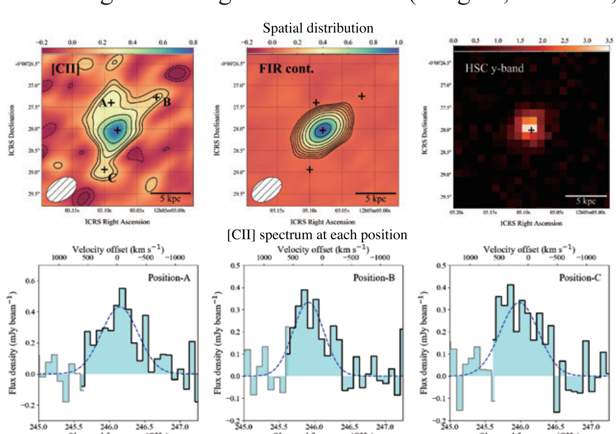

Figure 1: (Top) Spatial distributions of [CII], FIR continuum, and HSC y-band emissions of J1205–0000. The [CII] distribution is disturbed, indicating recent vigorous activities. (Bottom) [CII] spectra taken at three positions of the extended [CII] emission. The signals are significantly detected, confirming the genuine existence of that extended component.

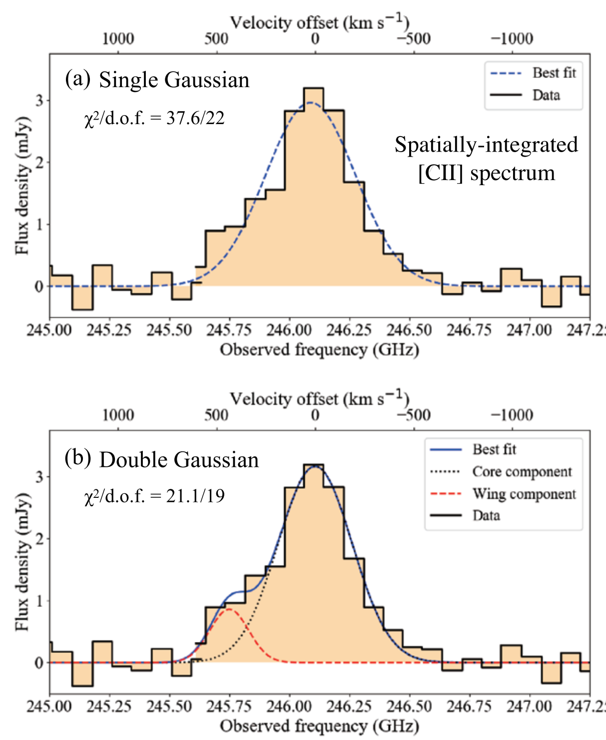

Figure 2: Spatially-integrated [CII] spectrum of J1205–0000. The observed spectrum cannot be well-fitted by a single Gaussian (top). We need to use at least a double Gaussian profile (bottom), which manifests the existence of multiple component in this system spectroscopically.

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[2] Hopkins, P. H., et al.: 2008, *ApJS*, **175**, 356.
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[4] Izumi, T., et al.: 2021, *ApJ*, **908**, 235.

Broadband Selection, Spectroscopic Identification, and Physical Properties of a Population of Extreme Emission-line Galaxies at $3 < z < 3.7$

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We present the selection, spectroscopic identification, and physical properties of extreme emission-line galaxies (EELGs) at $3<z<3.7$, aiming at studying physical properties of an analog population of star-forming galaxies (SFGs) at the epoch of reionization [1]. The sample is selected based on the excess in the observed *Ks* broadband flux relative to the best-fit stellar continuum model flux. By applying a 0.3 mag excess as a primary criterion, we select 240 EELG candidates with intense emission lines and estimated an observed-frame equivalent width (EW) of $\gtrsim 1000$ Å over the UltraVISTA-DR2 ultra-deep stripe in the COSMOS field [2]. We then carried out *HK*-band follow-up spectroscopy for 23 of the candidates with Subaru/MOIRCS, and we find that 19 and 2 of them are at $z > 3$ with intense [O III]λ5007 emission and Hα emitters at $z \simeq 2$, respectively. These spectroscopically identified EELGs at $z \simeq 3.3$ show, on average, higher specific star formation rates than the star-forming main sequence, low dust attenuation of $E(B\text{–}V) \lesssim 0.1$ mag, and high [O III]/[O II] ratios of $\gtrsim 3$. We also find that our EELGs at $z \simeq 3.3$ have higher hydrogen-ionizing photon production efficiencies ($\xi_{\rm ion}$) than the canonical value ($\simeq 10^{25.2}$ erg^{-1} Hz) [3], indicating that they are efficient in ionizing their surrounding interstellar medium. These physical properties suggest that they are low-metallicity galaxies with higher ionizing parameters and harder UV spectra than normal SFGs, which is similar to galaxies with Lyman continuum (LyC) leakage [4,5]. Among our EELGs, those with the largest [O III]/[O II] and EW([O III) values would be the most promising candidates to search for LyC leakage (Figure 1).

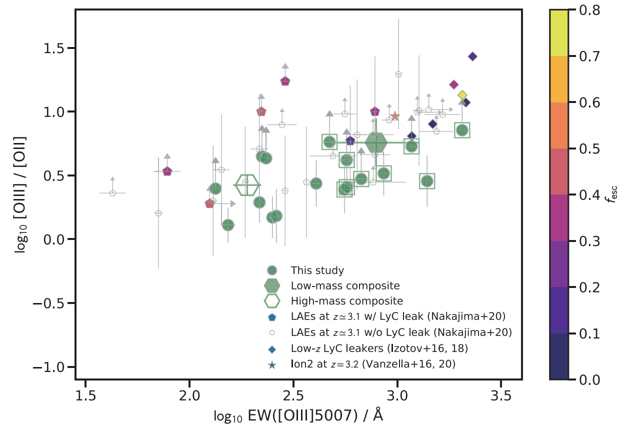

Figure 1: [O III]/[O II] ratios as a function of EW([O III]λ5007). Our EELGs at $z \simeq 3.3$ are shown as filled green circles, with low-mass ($\log M_\star / M_\odot \lesssim 9$) ones indicated by open squares. Stacked measurements are shown with open and filled hexagons for low-mass and high-mass composites, respectively. Filled pentagons, diamonds, a small square, and a star symbol are previously confirmed Lyc leakers from the literature color-coded by LyC escape fraction ($f_{\rm esc}$), corresponding to Lyα emitters at $z \simeq 3.1$ [5], low-redshift galaxies at $z \simeq 0.3$ [4,6] and a high-redshift LyC leaker at $z = 3.2$ [7,8], respectively. Open gray pentagons show Lyα emitters at $z \simeq 3.1$ with no LyC detection [5].

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II Status Reports of Research Activities

01. Subaru Telescope

1. Subaru Telescope Staff

As of the end of FY 2020, the Subaru Telescope staff consisted of 22 dedicated faculty members including seven stationed at Mitaka and two stationed at Okayama, four engineers, one project professor, one project associate professor, five senior specialist, and three administrative staff members. Additional staff members include one project associate professor, three project assistant professors, nine project research staff, twelve senior specialist, and five administration associates, all of whom are stationed at Mitaka. Additional staff members include one project associate professor, and three administration associates, all of whom are stationed at Okayama. Moreover, 17 research/teaching staff members, 14 of whom are stationed at Mitaka and three of whom are stationed at Pasadena, and three engineers, one of whom is stationed at Mitaka, one of whom is stationed at Nobeyama, and one of whom is stationed at Mizusawa are posted concurrently. The project also has 67 local staff members dispatched from the Research Corporation of the University of Hawaii (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 2020, Subaru Telescope produced many outstanding scientific outcomes which were published in major international journals. Below are some examples:

(1) The InfraRed Doppler spectrograph (IRD) observations of two recently discovered young planetary systems revealed that the orbital axis of the planet and the axis of rotation of the star were virtually aligned in both young planetary systems. This is the first time in the world that the orbital inclination has been obtained about a young planet with an age of around 20 million years; this is vital data for understanding the evolution of planetary systems.

(2) Adopting the machine learning method to the wide-field imaging data taken by Hyper Suprime-Cam (HSC), researchers have discovered a galaxy with an extremely low oxygen abundance of 1.6 % solar abundance, breaking the previous record for the lowest oxygen abundance. The measured oxygen abundance suggests that most of the stars in this galaxy formed very recently.

(3) Using the High Dispersion Spectrograph (HDS) to measure the surface chemical abundances and internal structure, the researchers have obtained clear evidence that red giants with extremely high Li abundances are at the stage where they are burning helium at their centers. This result will be a clue to help solve long-standing problems in stellar evolution theories.

(4) The extreme adaptive optics system, Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), coupled with the integral field spectrograph, Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS), has gained its first discovery and demonstrated a new approach to selecting stars with imageable planets and other low-mass companions like brown dwarfs (failed stars). The newly discovered object, a brown dwarf named HD 33632 Ab, orbits a near-twin of the Sun about 86 light-years from the Earth. It joins the few imaged substellar companions orbiting Sun-like stars on Solar System-like scales.

3. Open-use

In S20A, 53 programs (80.2 nights including 13.6 nights for ToO programs) were accepted out of 145 submitted proposals, requesting 330.93 nights in total. In S20B, 34 proposals (63 nights including 6 nights of ToO programs) were accepted out of 145 submitted proposals, requesting 368.5 nights in total. In S20A and S20B, 11.5 nights were used for 4 programs each semester for the continuous intensive programs. Service observations were made for 9 nights. In S20A and S20B, 5 and 2 programs accepted as open-use proposals were by foreign principal investigators, excluding the University of Hawai`i. The number of applicants in submitted proposals was 2379 for Japanese researchers (Japanese astronomers at any institute and non-Japanese astronomers belonging to Japanese institutes) and 974 for foreign researchers. The number of researchers in accepted proposals was 859 for domestic astronomers and 401 for foreign astronomers. In S20A and S20B, the number of open-use visiting observers was 389, of which 58 were foreign astronomers. A total of 169 astronomers observed remotely from Mitaka Campus. In S20A and S20B, 94.5 % of the open use time (including University of Hawai`i time) was used for actual astronomical observations, after excluding weather factor and scheduled maintenance downtime. About 1.23 %, 0.47 %, 3.7 %, and 0.1 % of observing time was lost due to instrument trouble, communication trouble, telescope trouble, and operation trouble, respectively. In S20A and S20B, almost all observations were conducted remotely amid the COVID-19 pandemic. The remote observations from Hilo were conducted for 20 programs with 11.61 nights. On the other hand, remote observations from Mitaka were conducted for 64 nights with 27 programs including HSC and IRD SSPs. Other remote observations utilized the Zoom meeting system. Since S20B, a new Gen2 Extended Remote System (GERS) has been provided to support efficient remote observation for observers. GERS was used 79 nights in S20B. The number of telescope time exchange nights between Subaru Telescope and W.M. Keck Observatory were 7.5 nights in S20A and 4.0 nights in S20B. About those between Subaru Telescope and Gemini, Subaru Telescope users used Gemini time 5.4 nights in S20A and 2.0 nights in S20B (not including 24.3 hours, i.e. ~2.4 nights, of Fast Track programs during both semesters), while Gemini users used Subaru Telescope time 4.4 nights in S20A and 3.6 nights in S20B.

4. Telescope Maintenance and Performance Improvement

The following major repairs, maintenance, and changes were implemented in FY 2020.

(1) Telescope Drive Power amplifier overhaul:

As part of the preventive maintenance work for stable operation of the telescope, the consumable parts of the power amplifier that supplies power to the linear motors for driving the azimuth and elevation axes of the telescope were replaced.

(2) Replacement of the coolant and hydrostatic oil hoses of the azimuth cable wrapper:

A leak was found in the cooling water hoses piping system for cooling the instruments in the azimuth cable wrapper of the telescope. That hose piping in the azimuth cable wrapper mechanism was replaced as an emergency repair.

(3) Primary mirror support actuator repair:

A problem occurred in the actuator that supports the primary mirror of the Subaru Telescope and controls the mirror shape, causing the telescope to stop. The condition of the actuator was such that it could significantly affect observation operations, but we disassembled and replaced some of the components of the actuator and completed the restoration with minimal loss of observation time.

(4) Other activities:

We have been working on the renewal of the primary Uninterruptible Power Supply at the Summit facility and the dome air conditioning unit. In addition, we are accepting new observational instruments, repairing the outer wall of the dome, performing annual maintenance of the mechanical and electrical systems of the telescope and the dome, and repairing sudden failures. In parallel, we initiated the “Telescope Maintenance Group collaboration of NAOJ.” The purpose of this activity is to share know-how and plans for maintenance of the telescopes owned by NAOJ, and to carry out, evaluate, and improve maintenance activities through cooperation among the NAOJ facilities.

5. Instrumentation

After the suspension of operation due to COVID-19 at the end of FY 2019, the instruments and science operation were recovered in May 2020 and the following seven facility instruments were provided for the open-use observations: Hyper Suprime-Cam (HSC), Faint Object Camera And Spectrograph (FOCAS), High Dispersion Spectrograph (HDS), Infrared Camera and Spectrograph (IRCS), Cooled Mid-infrared Camera and Spectrograph (COMICS), Multi-Object Infrared Camera and Spectrograph (MOIRCS), and the 188-elements Adaptive Optics and Laser Guide Star system (AO188/LGS). Among them, the operation of LGS has been temporarily suspended since S19B for its upgrading project. As for the carry-in instruments, the Infrared Doppler spectrograph (IRD), Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS), and Visible Aperture Masking Polarimetric Imager for Resolved Exoplanetary Structures (VAMPIRES) have been offered for the open-use programs.

COMICS was decommissioned after its last operation in S20A. In addition, MOIRCS was hibernated after S20B to prepare for the science operation of the carry-in instrument SWIMS (Simultaneous-color Wide-field Infrared Multi-object Spectrograph) which was developed by the University of Tokyo and has similar capabilities to MOIRCS. The hibernation of MOIRCS and science operation of SWIMS will continue until S22B.

The major upgrade of the laser guide star system is still ongoing, and we started the installation of the subsystems onto the telescope in FY 2020. The installation and test of the TBAD (Transponder-Based Aircraft Detector) system were conducted but the final test with a charter airplane at the end of FY 2020 was postponed due to bad weather conditions. The upgraded grisms of MOIRCS were successfully tested on-sky and provided for open-use observations in S20B. The final design of the Nasmyth Beam Switcher, which enables quickly switching the infrared instruments installed on the infrared side of the Nasmyth platforms and also using multiple instruments at the same time, is ongoing in collaboration with Macquarie University.

6. Computer and Network

Subaru Telescope computing and network systems experienced a dramatic change in administration due to COVID-19. Reliability of the system still remained at a high level, but CDM (Computer and Data Management division) shifted its focus to remote administration of servers and services, critical network services for end user access and keeping a high level of accessibility for end user issues. All this while trying to adapt to full remote work. Although activity was limited during the COVID lockdown, CDM was able to plan for the following projects; VoIP Phone (Summit), Evaluation of Microsoft 365, increasing the capabilities for secure end user access to internal resources, monitoring of systems with notifications, updating the Content Management Systems, and migration of custom web applications.

End user access became the primary focus of CDM during the lockdown period. CDM needed to ensure that access to internal resources was always available. Use of SSL VPN devices on different external network connections allowed for reliable access. VPN access needed to be configured to limit access to particular internal resources. Roles and realms were created to help define network accessibility, this was applied to collaborator groups, such as PFS and SCEXAO. CDM also during this period evaluated and planned a migration scenario from Google Apps to Microsoft 365 provided by Mitaka, requiring much coordination between our current users and Mitaka Network Administrators. Migration is expected to take place within FY 2021. We replaced the unsupported telephone system of the observatory with a VoIP Phone system. This installation was completed with much support from the Summit Daycrew, allowing the observatory to reduce the installation cost significantly.

STN5 contract systems remain the core of Subaru Telescope's computing and network environment. Sub-systems Observatory Management, Virtual Environment, Common Data Analysis, and STARS have been stable and reliable. CDM is constantly investigating ways to increase utilization of equipment, increasing virtual machine deployments, experimenting with different OS technologies. CDM is looking towards the next STN system, which is scheduled to begin in 2023. Evaluation of current systems are ongoing, new deployment strategies and the physical footprint are being studied. Along with STN6, CDM has participated in the study and planning for a high-speed 100 Gpbs network, along with access to 100 Gbps internet connections being provided between Hawai`i and Japan via collaborating academia organizations.

In close collaboration with Hilo and Mitaka personnel, CDM helps support the Mitaka Remote and MASTARS servers. Mitaka Remote is an observation control system nearly identical to the Subaru Summit and Hilo Remote. A joint effort is required by Mitaka, CDM, and OCS administrators to maintain hardware and update critical software, prepare systems for semester observations, and assist observers during observation. MASTARS serves as a data archive identical to STARS. Mitaka staff conducts weekly validation of observation frames, to ensure that all data have replicated properly. Any inconsistency is reported, and updates are quickly completed. In addition, CDM supported various hardware and software components including the Hilo based HSC and PFS analysis clusters and custom web applications such as, Proposal Management System (ProMS) supporting calls for proposals, PRORES, web-based system supporting communication between the Time Allocation Committee and referees of Subaru observation proposals, and online visitor forms supporting visiting on-site or remote observers, engineers, and support contractors for Hilo and Mitaka campuses, in collaboration with other divisions. Subaru Telescope continues support of other web base applications, such as HSCQ (HSC Queue observation) and HSCOBSLOG (HSC Observation Log).

7. Education (Under-graduate and Graduate Courses)

The number of Subaru Telescope staff members in Hilo who were concurrently appointed by SOKENDAI (graduate school) was nine. The number of SOKENDAI students who had primary supervisors affiliated with Subaru Telescope (including those concurrently belonging to Subaru Telescope) was nine, which constituted more than one-third of the total 26 Sokendai students hosted in NAOJ. Of those, seven had supervisors who belonged primarily to Subaru Telescope.

In FY 2020, Subaru Telescope hosted 3 graduate students for long stays in Hilo, of which 2 were SOKENDAI students. On top of that, intensive education activities were seen also in the Subaru Telescope Mitaka office. The numbers of graduate course students in all of Japan who obtained master's degrees and PhD's based on Subaru Telescope data were 16 and 4, respectively, of which one and two were related to the Subaru Telescope Mitaka office.

We also regularly hosted a series of educational programs at Subaru Telescope. We hosted a Subaru Telescope observation training course for two new SOKENDAI students in October 2020. This was done remotely from Mitaka, due to the worldwide spread of COVID-19. In the Hilo and Mitaka offices, we had many official and informal seminars (remotely this year), many of which were jointly organized with other divisions in NAOJ and/or neighboring universities.

8. Public Information and Outreach (PIO)

Subaru Telescope has set up a public relations and outreach office and is developing the following two basic activities.

The first pillar is information dissemination. We have created a web page to widely publicize the scientific results obtained by the Subaru Telescope and the activities of the observatory, and we are conducting information disclosure activities such as providing information to the media and press conferences. This year, we posted 36 observation results (18 in Japanese and 18 in English), and 46 introductions and announcements of the observatory's activities including instrument development (22 in Japanese and 24 in English). Depending on the content, we disseminated information to Japanese media and media in Hawai`i, and also to the global network through the American Astronomical Society. As a result, news about the Subaru Telescope has been featured in Japanese newspapers, local newspapers, and news on the web very often. A total of 67 newspaper articles about the Subaru Telescope were published in the 2020 Japanese fiscal year.

In addition, the number of accesses (page views) to the website of Subaru Telescope, which was completely renewed in March 2020, averaged 19,000 per day. At the same time, we are also focusing on dissemination via social media, which has become very popular in recent years. The number of followers (subscribers) on Twitter exceeds 59,000. Following this, in March 2021, some sites of the Subaru Telescope homepage were made compatible with smartphones. We are focusing on disseminating information through Twitter, Facebook, and YouTube, and creating materials such as photos and videos for this purpose. We continue to respond to interview requests, inquiries from the media (7 cases), and various requests and questions from local educational institutions.

The second pillar is public relations and outreach activities to help local people understand the existence and activities of the Subaru Telescope. This is important for the local acceptance of the Subaru Telescope, including acceptance of the next-generation projects, and stable operation of astronomy institutions. Local outreach events include "Onizuka Science Day" @ University of Hawaii (since 2000), "Astro Day" @ a shopping mall (since 2001), "Tanabata Star Festival" @ Imiloa Astronomy Center (Hilo) (since 2017), and activities such as workshops, exhibitions, and hands-on activities for elementary school students, junior high school students, and high school students were carried out every year. However, many of these local events were canceled due to the impact of the COVID-19 pandemic in FY 2020. Only "Journey Through the Universe" (since 2006) was held and staff from the Maunakea Observatories gave online lessons to students from elementary school to high school. From the Subaru Telescope, 10 staff members participated in more than 50 classes. We participated in the "Inter-University Research Institute Symposium" held in Japan and the "Hawaii Island Career Expo" held in Hawai`i with video lectures and exhibitions using a special website and we received good responses from the participants. At the "Tsukimi no Kai" hosted by the United Japanese Society of Hawaii, the director of Subaru Telescope gave an online lecture on the latest scientific achievements of the observatory. We are also promoting the production and distribution of videos for children. Due to the COVID-19 pandemic, a special tour program for Maunakea observatories which had been held annually for local residents of Hawai`i, was cancelled. The Summit Facility Tour program of Subaru Telescope was also suspended from FY 2020.

02. Nobeyama Radio Observatory

1. Nobeyama 45-m Radio Telescope

(1) Open Use Observations

The 39th open use observations term started on December 1, 2020. The statistics of the successful proposals are as follows, "General Programs": 13 programs were accepted out of 25 submitted proposals including 2 programs from abroad (out of 5 submitted), "GTO (Guaranteed Time Observation) Programs": no proposals were submitted. "Large Program": no proposals were submitted. VLBI open use observations including the 45-m telescope: 4 proposals were accepted out of 8 submitted.

Remote observations were conducted from Mitaka, Iriki, Mizusawa, Kagoshima University, Kyushu University, Osaka Prefecture University, Joetsu University of Education, Kyoto University, Nagoya University, RIKEN, Keio University, Shibaura Institute of Technology, Hokkaido University, and ASIAA (Taiwan).

(2) Improvements and Developments

(a) New Developments

The observatory started design and fabrication of a new focal plane array receiver system for observation at 72–116 GHz. It employs seven beam elements, and allows observations of 2 polarizations and 3 bands. This development was supported by JSPS grant-in-aid KAKENHI Kiban S (PI: K. Tatematsu).

(b) Approved Development Programs

A total of five programs are in progress as follows.

- 3-band simultaneous observing system HINOTORI
- Frequency-modulation local oscillation FMLO
- Band 1 (30–50 GHz) receiver by Taiwan
- Millimetric Adaptive Optics: Development of a Wave-front Sensor
- 100-GHz, 109-element camera

(c) Maintenance and improvements

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

- Regularly scheduled and preventative maintenance were performed.
- The calibration system for continuum observation was replaced.
- The weather warning system (snowfall and strong wind) for the remote observations was developed.
- Development of the data reduction procedure with the CASA pipeline in collaboration with the ALMA-J Project has been completed. Pipelined FITS were released in the Nobeyama-45m Science Data Archive.
- Development of the observation preparation tool for overseas observers is underway.

(3) Scientific Results

A total of 39 refereed journal papers were published on the basis of research using the 45-m radio telescope.

(3-1) 45-m Telescope Large Programs

(a) Nobeyama Planck Project (PI: Ken'ichi Tatematsu)

They investigated how star formation starts through observations of early-type and late-type molecules and deuterated molecules toward Orion and other various environments. The observations with the Nobeyama 45-m Radio Telescope were carried out toward molecular cloud cores in the Planck Galactic Cold Clumps in FY 2017 and FY 2018. The researchers completed a catalog of molecular cloud cores including the deuterium fraction of the molecules, which is an efficient tracer of the chemical evolution toward the onset of star formation. They selected two molecular cloud cores close to the onset of star formation and observed them with the ALMA ACA. They detected mass infall motions toward a starless core, which may be an important mechanism to start star formation. The group published three refereed papers from this project in this fiscal year (Tatematsu et al. 2020; Ge et al. 2020; Kim et al. 2020).

(b) Galactic Center (PI: Shunya Takekawa)

Large-scale imaging observations toward the Central Molecular Zone (CNZ) of our Galaxy in millimeter spectral lines have been conducted by using the 45-m telescope since 2019. The principal objective of this project is to delineate dense and shocked molecular gas distributions over the entire CMZ. In FY 2020, the SiO J = 2–1, $H^{13}CN$ J = 1–0, and CS J = 2–1 observations have been completed and the detailed position-velocity structures of dense/shocked molecular gas in the Galactic center have been successfully revealed. Interestingly, strong SiO emissions associated with expanding shells were detected from the l = 1.3 degree and l = −1.2 degree regions, indicating the presence of supernova explosions in the recent past and hidden massive star clusters. These results were reported in several meetings such as "Nobeyama Science Workshop 2020" and have already been published as a paper in the ApJ (Tsujimoto et al.).

(3-2) Results from Legacy Programs and Open Use General Programs with the 45-m Telescope

Andreani et al. observed galaxies in the local Universe, and derived the molecular mass function, which can be used for studies of the evolution of the molecular mass density. Araki et al. observed absorption lines of CH_3CN toward Sagittarius B2(M), and put constraints on its physical parameters including kinetic temperature. Imai et al. discovered new high-velocity H_2O masers in IRAS 18286−0959. Kinosita et al., Mikito Kohno et al., Nishimura et al., Shimoikura et al., and Tsuboi et al. found observational evidence of cloud-cloud collisions. Yokozuka et al. searched for broad-velocity-width molecular features (BVFs) in the disk part of the Milky Way Galaxy. Morokuma-Matsui et al. statistically studied the molecular gas properties of nearby galaxies. Sofue et al. investigated the CO-to-H_2 conversion factor and radio-quiet supernova remnants, and also cataloged the Atlas of CO-line Shells and Cavities. Tsuboi et al. studied the western part of the Galactic Center Lobe, and concluded that it is a giant HII region in the Galactic disk. Yajima et al. studied ^{12}CO(J = 2–1)/^{12}CO(J = 1–0) line ratios toward nearby galaxies, and found the ratio has good positive correlations with star-formation rate and infrared color, and a negative correlation with molecular gas depletion time. Takemura et al. combined $C^{18}O$ (J = 1–0) data from CARMA and the Nobeyama 45-m Radio Telescope, and identified 692 dense cores toward the Orion Nebula Cluster region, derived the core mass function, and concluded that the cores must gain additional gas from the surroundings to reproduce the current IMF. Kotomi Taniguchi et al. studied carbon-chain chemistry in hot-core regions around the three massive young stellar objects on the basis of the CCH/HC_5N ratio and the ^{13}C isotopic fractionation of HC_3N.

2. Research Support

(1) SPART (Osaka Prefecture University)

Venus has unresolved absorption features in the ultraviolet region, and there is discussion of the possibility that microorganisms may reside in the sulfuric acid cloud layer. Thus, it is crucial to understand material circulation in the Venusian atmosphere in order to understand biosphere environments in planetary atmospheres and the influences of the activities of host stars on surrounding Earth-type planets. In FY 2020, the $^{13}C/^{12}C$ ratio was investigated by observations of ^{13}CO and ^{12}CO spectral lines in the 200 GHz band using SPART (Antenna F of the Nobeyama Millimeter Array) and ALMA, and the altitudinal dependence of mass independent isotope fractionation and the influence of ultraviolet radiation on the Venusian atmosphere were researched. During this season the Sun gradually become active as part of Cycle 25, and with the increase of solar UV radiation the CO mixing ratio at the altitude of 80 km observed by SPART began to decrease, revealing a clear trend of anti-correlation between them. Considering the spatial and temporal variation of SO2 observed by Venus Express (ESA), Akatsuki Satellite (JAXA) and ALMA, the model of material circulation in the Venusian atmosphere induced by (photo)chemical reaction networks such as $CO + O_2 + H_2O + SO_2 + \text{photon} \rightarrow CO_2 + H_2SO_4$ driven by chlorides catalysis and atmospheric dynamics was proposed.

With completion of these successful observations, SPART ended operations in March 2021. However, the heterodyne spectroscopy system established exclusively for the research of planetary atmospheres in the SPART project is currently being examined in Japan as an important candidate for an onboard instrument for the Japanese next-generation Mars missions, the Mars Aqueous-environment and space Climate Orbiter (MACO) and the international Mars Ice Mapper (NASA, JAXA, CSA, ASI). In FY2020, one master's thesis, seven conference presentations related to SPART, two international conference presentations, and one peer-reviewed paper about the polarizer of the heterodyne receiver for the observation of the Martian atmosphere were presented. In the annual Nobeyama Special Open House, the explanation video about SPART was opened to the public through the website.

(2) 1.85-m Radio Telescope (Osaka Prefecture University)

With the 1.85-m radio telescope, we have conducted an extensive survey of molecular clouds along the Galactic plane using the molecular lines of carbon monoxide isotopologues in the 230 GHz band. In FY 2018, we started a new project supported by JSPS (Grant-in-Aid for Scientific Research on Innovative Areas). In this project, we will relocate the telescope to the Atacama site in Chile at an altitude of 2400 m, equipped with an ultra-wideband receiver (230–345 GHz), and carry out an extensive survey of molecular clouds along the Galactic plane and in the Magellanic Clouds in the southern sky. In FY 2019–2020, in preparation for this relocation, we renewed the telescope system and radome, and developed and tested an ultra-wideband receiver in cooperation with ATC in NAOJ Mitaka Campus. We have successfully developed a wideband receiver system using superconducting receivers at 230 and 345 GHz, a horn covering the frequency band (210–375 GHz), and an intermediate frequency (IF) band circuit covering 4–21 GHz. The system can observe six molecular emission lines (^{12}CO, ^{13}CO, and ^{18}O) simultaneously in two frequency bands. It was mounted on the 1.85-m telescope, and we succeeded in the commissioning observations; we successfully mapped the molecular clouds in the six emission lines toward several star-forming regions. In FY 2020, two peer-reviewed papers (Großschedl et al. 2021, Enokiya et al. 2021), which used the archive data obtained by the telescope for the analysis and five SPIE proceedings related to the telescope were published. In addition, three papers on the commissioning observations were submitted to PASJ.

3. Public Outreach

(1) PR activities at Nobeyama Campus

Nobeyama Campus received a cumulative total of 25,971 visitors throughout the year. The open area for visitors is limited to outdoor areas as a precaution against the spread of COVID-19. Moreover, the campus was closed to the public from March 6 to June 17, 2000. During the COVID-19 situation, staff members conducted only two guided tours and granted 17 requests for on-site filming and interviews. Especially, there was no request for Super Science High School (SSH) students and workplace visits for local junior-high schools. The filming and interview requests were mainly about research activities, cooperation with the local government, promotion of the "Nagano Prefecture is Astro-Prefecture," and introducing NRO and its financial difficulties. In particular, the documentary program produced by TV Shinshu Broadcasting which had deeply interviewed NRO members throughout one year, won the 57th (2019) Galaxy Grand Prix for the best program (TV section). We received many responses from the public.

In the visitors' open area, the NINS Nobeyama Exhibition Room was forced to close during the COVID-19 situation. We updated most of the outside panel displays for introducing NRO and its activities to improve the outdoor facilities for the public.

The annual Nobeyama Special Open House was held as an online event. The maximum number of real-time connections for live streaming was about 820 and the total number of views for all content was about 25,000 in the first month.

Moreover, we received and answered about 210 phone calls this year from the public regarding the regular opening of the observatory, observatory events, and general astronomy (including 30 interviews which is more than double a normal year).

(2) Cooperation with Local Communities

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

Moreover, the "Nagano Prefecture is Astro-Prefecture" keyword-rally 2021 was carried out as an online event as a precaution against the spread of COVID-19. It was conducted by the "Nagano Prefecture is Astro-Prefecture" liaison council, which was founded in 2016 through cooperation with Kiso Observatory and other organizations. The fifth meeting was held online and on-site at Kiso Culture Park on February 6 with about 30 participants, who were limited to local residents. Some activity reports and a discussion on future activities were presented. Meanwhile, associated open lectures were also held with about 100 on-site participants limited to people from the Kiso area and 157 online participants (the maximum number for live streaming).

(3) NINS Nobeyama Exhibition Room

Although the NINS Nobeyama Exhibition Room had been opened thorough out the year in cooperation with NINS and other institutes, it was forced to close during the COVID-19 situation. Also, the 4D2U theater could not be presented during this year. However, the 4D2U theater online was tentatively performed twice in March with some participants as monitors from the public.

4. Education

One master-course graduate student from Yamaguchi University 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 the promotion corporation of Minamimaki Village. They had 21 paid group tours and filmings (we received a total of 60 requests including those cancelled due to COVID-19). Moreover, for three months from October 19 to January 18, Minamimaki Village conducted a crowdfunding campaign as a hometown tax donation program to support the observatory. The resultant amount was 7,098,919 yen, which is over twice the target.

(2) Hiring, Transfer (incoming)

Takami, Masaki: Leader of Accounting Section, from Shinshu University

(3) Retirement, Transfer (outgoing)

Takeda, Kiyotake: Leader of Accounting Section, moved to Shinshu University
Kim, Gwanjeong: Project Research Staff, retired
Hamada, Kaname: Senior Specialist, retired
Kikuchi, Tsuyoshi: Administrative Maintenance Staff, retired
Hinata, Shigeto: Administrative Maintenance Staff, retired
Fuji, Shigeru: Administrative Maintenance Staff, retired

(4) NRO Conference Workshops and Users Meeting

- January 5–7, 2021, On-line
  FY 2020 ALMA/45-m/ASTE Users Meeting (Organizing Committee: Hiroshi Nagai, Misato Fukagawa, Daisuke Iono, Alvaro Gonzalez, Ken Tatematsu, Takeshi Kamazaki (NAOJ))

- September 15–16, 2020, On-line
  Nobeyama Science Workshop 2020 (Organizing Committee: Kotomi Taniguchi (Gakushuin University), Shunya Takekawa (Kanagawa University), Fumitaka Nakamura, Ken'ichi Tatematsu (NAOJ), Kazuhito Dobashi (Tokyo Gauge University), Tomomi Shimoikura (Otsuma Women's University), Nario Kuno (Tsukuba University))

03. Mizusawa VLBI Observatory

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

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

1. VERA

(1) Observations and Common-Use Observations

The four stations of VERA were operated by remote control from AOC (Array Operation Center) at NAOJ Mizusawa Campus. In FY 2020, although observation time decreased 20 % compared to the previous year because antenna failure, heavy snow, and several weeks of maintenance during the observation period stopped network operation for a total of about 7 weeks, a total of 241 (1,994 hours) VLBI observations were conducted with VERA; such as VERA project observations; fringe detection observations for maser and reference sources; geodetic observations; and JVN (Japanese VLBI Network) observations. In addition to these, we conducted KaVA (KVN and VERA Array) and EAVN (East Asian VLBI Network) observations, which will be described in the following sections. These VLBI data, except for KaVA and EAVN, were processed at the Mizusawa Correlation Center in NAOJ Mizusawa Campus. The correlated data were sent to each researcher for the case of common-use and JVN observations and to persons in charge of data analyses in the case of project data and geodesy data. VERA common-use calls-for-proposals in FY 2020 were not conducted by VERA alone. This is because almost all observing modes became available in the EAVN common-use, which was released at the same time, and hence, all proposals were submitted to EAVN.

(2) Science Research

In FY 2020, Mizusawa VLBI Observatory published a total of 51 refereed journal papers for scientific achievements. Among them, 9 papers were published by the Observatory staff as a PI and 5 papers were published by graduate students in Kagoshima University and SOKENDAI as a PI. Eleven papers were the results from the VERA astrometry observations, and 1 was the results from the Korea-Japan international collaboration project KaVA (KVN and VERA Array). In addition, Event Horizon Telescope (EHT) results were published in 9 refereed journal papers, and 7 papers were published to report the results from other VLBI projects. In FY 2020, the most remarkable achievement of Mizusawa VLBI Observatory is publication of 10 papers in the VERA special issue of the Publications of the Astronomical Society of Japan (PASJ) in August 2020. In this VERA special issue, all the astrometry measurements of 99 target sources published since the first results from VERA astrometry in 2007 are compiled, including newly measured unpublished 21 sources, as the first VERA catalog. Using these astrometry results, Galactic parameters such as the Galactic center distance of 25,800 light-years and the Galactic rotation velocity of 227 km/s are determined. In the VERA special issue, two papers are directly related to the fundamental studies on VERA astrometry, such as the development of the VERA astrometry data analysis software VEDA and verification of the astrometry accuracy for the distant sources beyond 30,000 light-years. Furthermore, there were 1 paper reporting the study of Galactic structure, 2 for star-formation studies, and 4 for late-type stars, covering various scientific topics originally planned for VERA.

2. The Japanese VLBI Network (JVN)

The University VLBI Collaboration Observation project is carried out as a joint research project between NAOJ and six universities. We organize the radio telescopes of VERA, universities, and research institutes (JAXA/ISAS, NICT) to make the Japanese VLBI Network (JVN), which is operated at three bands of 6.7 GHz, 8 GHz, and 22 GHz. VLBI observations were carried out for 238 hours in total in FY 2020. The main research subjects are thermal emissions of extremely compact HII regions, gamma-ray active galactic nuclei, and methanol masers. In addition, over 4000 hours of single-dish observations were carried out as research related to JVN by Ibaraki University.

In FY 2020, JVN was in the second year of being an A-project of NAOJ. The term of this project is three years, and the purpose of this project is to promote time-domain VLBI astronomy with three research targets as follows: (1) CH_3OH masers with periodic flux variations, (2) Extremely compact HII regions just after the onset of nuclear burning, and (3) Time Domain VLBI astronomy of High-energy Astrophysical Events. The high-sensitivity telescopes larger than 30 m of JVN constitute the key baseline. A survey of extremely compact

HII regions and gamma-ray emitting AGN candidates were examples of the JVN observation in 2020.

In this year, two papers (Tsubono et al. 2020, Okada et al. 2020) led by JVN researchers were published. Researchers of JVN also published some additional papers. The activities of JVN were presented in some international workshops like the 13th East-Asian VLBI Workshop. A joint research seminar, Ibaraki-Yamaguchi Joint Seminar, was held for students of these two universities.

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

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

(1) Observations and Common Use Observations of EAVN

In FY 2020, EAVN (East Asian VLBI Network) observations, utilizing KaVA, the Tianma 65-m, Sheshan 25-m, Nanshan 26-m, Nobeyama 45-m, and Yamguchi/Hitachi/Takahagi 32-m radio telescopes, were conducted for a total of 170 observations (1,135 hours), including common use observation, test, and verification observations. Most of the scheduled observations were successfully conducted without any major issues despite the global pandemic of COVID-19. From 2021A, the new observational band of 6.7 GHz was open for common-use along with the 43 and 22 GHz bands. The Yamaguchi 32-m and Hitachi 32-m antennas operated by the Japanese VLBI Network (JVN) and Sheshan 25 m were newly joined in the EAVN observations at 6.7 GHz. The recorded data were correlated at the Korea-Japan Correlation Center at KASI Daejeon Campus in Korea. EAVN open-use calls for proposals for semesters 2020B and 2021A were made in April and October of 2020, respectively. In total, 37 proposals requesting a total time of 1,287 hours were submitted. Through the evaluations by referees elected from scientists in related fields and the subsequent decision made by the EAVN combined Time Allocation Committee, a total of 31 proposals (1,119 hours) were accepted in 2020B and 2021A.

Regarding global mm-VLBI, EHT observations were not performed during FY 2020 due to the outbreak of COVID-19, and no new data were obtained.

(2) Results of Research

Since the start of open-use observations in FY 2014, various science outcomes based on KaVA data have been constantly produced. In FY 2020, five papers using KaVA data were published in peer-reviewed journals, and substantial contributions from members of Mizusawa VLBI Observatory are included in these papers. First, initial results from the KaVA star formation Large Program were published (Kim et al. 2020), where complex outflow structures were revealed in the high-mass star forming regions G25.82-0.17 by combined observations with KaVA and ALMA. This research was led by a Ph.D. student of Mizusawa VLBI Observatory, and an international press release was also made because of the high scientific importance. KaVA also detected detailed proper motions of water vapor masers in NGC6334I-MM1 that were associated with an outburst (Chibueze et al. 2021). On AGN, two papers were published and one of them revealed the detailed jet structure in a gravitationally lensed distant quasar (Hada et al. 2020). On evolved stars, KaVA successfully mapped the fast velocity maser components that were newly emerged in IRAS 18268-0959 (Imai et al. 2020).

Due to the start of EAVN common-use observations from 2018, many studies currently made with KaVA will be shifted to EAVN. Nevertheless, KaVA will continue to play a key role as a core array of EAVN.

EAVN started open-use observations from late FY 2018, and various science programs are ongoing. In FY 2020 one refereed paper was submitted and accepted based on earlier EAVN commissioning data (EHT Multi-wavelength Science WG et al. 2021 ApJL). This is the result from the multi-wavelength observing campaign of M87 that was coordinated with the EHT-2017 observations. EAVN played an important role in constraining the structure of the jet base during the EHT-2017 period. Staff and students of Mizusawa VLBI Observatory made significant contributions to this international collaboration paper. In addition, one paper on EAVN array performance evaluation was submitted (Cui et al. 2021). Various new experiments were promoted, such as joint observations with the KVAZAR network in Russia and 4 Gbps wideband dual-polarization observations. In March 2021, EAVN Workshop 2021 was held virtually, where collaboration with the Thailand 30 m radio telescope and the roadmap for global-VLBI were actively discussed.

Observational studies of AGNs have been developed from VERA and EAVN to EHT to intensively investigate super-massive black holes in active galactic nuclei (AGNs). In FY 2020, the first polarization measurement was reported by the EHT collaboration to reveal the magnetic field structure in the close vicinity to the SMBH in M87. The results were released on the web and covered by media news.

4. Future Planning for SKA

From 2019, the SKA1 Study Group (SKAJ) was organized under Mizusawa VLBI Observatory. SKAJ conducted a preparatory study for the project proposal to NAOJ and in-kind contribution for SKA1 project itself. SKAJ has been following the progress of the SKA project and has negotiated for future participation with the SKA Organization. The members of SKAJ attended all of the board meetings, council preparatory meetings, and SKA Observatory Council meetings as an observer and explained Japanese constraints for SKA1 commitment like funding process and schedule. And two NAOJ representatives can attend the council as observers. SKAJ has started planning the Japanese SKA1 project plan in order to propose it as a project of NAOJ from 2022. This activity is broken down into work packages as WBS which include planning with required budget, manpower, and timeline. The SKAJ proposal for the NAOJ DG's Fund program was approved. SKAJ submitted a budget request for the Grant-in-Aid for Transformative Research Areas of JSPS with the cooperation of Japan SKA consortium (SKA-JP) as well, which aims to share part of the Japanese contribution for SKA1. And members of SKAJ won external budgets related SKA preparatory works. SKAJ made a survey of the research activities and science interests of the community. Based on them, we have started discussions of science prioritization and strategy and planned the related meeting for July 2021. SKAJ had close communication with stakeholders: SKA Observatory (SKAO), SKA Observatory Council, and SKA-JP. SKAO started to support half of the manpower cost for a researcher, strengthening communication and cooperation between SKAO and NAOJ. In every month, SKAJ has joined the executive meeting of SKA-JP to build a mutual understanding and discuss status and future work. The members of SKAJ contributed to a SKA-JP webinar to introduce the SKA project including science goals, system design, and schedule to the Japanese science community, which had more than a hundred attendees.

SKAJ has had close collaboration with SKA-JP for science preparation. The members of SKAJ have attended monthly videoconferences of 10 science working groups in SKA-JP. This is to encourage the development of science use cases and science strategies (key science projects and PI projects). The outcomes are 9 science use cases for LOW-VLBI, 8 science use cases for SKA-ALMA synergy, proposals for JSPS grants (two Science Research class B, one Transformative Research area, etc), as well as a Key Science Program strategy with science priority aspects, PI based Proposal scope report, and SKA Development Program (SDP) request report. Also, a series of journal papers about Japanese SKA science is in preparation. As for Science Regional Center (SRC) development, SKAJ has organized the SRC Task Force meetings with SKA-JP. They gathered the SRC user requests and started planning the Japanese SRC concept. SKAJ had a busy week during March 8-12, 2021 to address EoR technical problems such as RFI mitigation and foreground removal. A graduate student at Kumamoto University was invited to NAOJ with our travel support. The student successfully shared the knowledge of RFI flagging and their idea of subtracting non-Gaussian components from the data. They also had an on-line meeting with experts at the Institute of Statistical Mathematics and got useful comments and suggestions. SKAJ purchased a workstation and GPUs to develop an efficient pipeline for LOW EoR science. The workstation was placed at Kumamoto University and most of the major applications such as CASA, COTTER, and TIPS were successfully installed. SKAJ participated in the MWA project to access the MWA-Pulsar pipeline and data. This allowed us to release a risk assessment report about SKA-LOW pulsar science. SKAJ and Japan SKA consortium members attended the SKA science conference held online on February 15-19, 2021. Three oral presentations were made by Japanese researchers including one SKAJ member.

SKAJ has committed to the AIV project of SKA. We have contributed to the prototype testing of the LOW telescope in Sidney and to the planning of the system integration test facility of the MID telescope. The test equipment for the test facility is being designed. The ethernet data in the test will be captured by 100 GbE transceivers. One of the transceivers is being tested in a server computer in Japan before shipping to the site. SKAJ conducted an international test observation of the LOW VLBI with Iitate Station of Tohoku University. The VLBI system is being developed introducing an A/D converter with 8-bit quantization, which is effective to avoid spurious RFI signals at low frequency. And the software correlator at Mizusawa has been upgraded to adapt for the standard VDIF format and operations of the 32 stations for SKA AIV. SKAJ has been carrying out UHF-band RFI measurements on Japanese radio telescopes. Osaka prefecture University and SKAJ have developed prototypes of a quad ridge wave guide and coaxial transducer as a part of the receiver feed. A reasonable transmission loss is obtained as expected by the electromagnetic simulation. SKAJ members attended several engineering meetings related to SKA such as WS on Future Trends in Radio Astronomy Instrumentation in September 2020. And SKAJ has committed to the SKA-Japan consortium engineering working group as well.

5. Geodesy and Geophysics

In order to monitor the position and shape of the VERA network, regular geodetic observations were conducted 2-3 times a month. VERA internal geodetic observation sessions using K band were conducted once or twice a month including joint observation with KVN. Mizusawa Station conducted IVS sessions (IVS-T2 and AOV) using S- and X-bands once every one or two months. In AOV and IVS-T2P, wideband observations using OCTAD-OCTADISK2 have become regular programs.

In FY 2020, VERA internal geodetic observation was conducted 13 times, including joint observation with KVN, and we participated in IVS sessions 7 times. The final estimates of the station positions of VERA and KVN were reconstructed based on ITRF2014 and supplied to the astrometric analysis performed by VERA and EAVN.

At the station position estimated from VLBI, displacements of 58 mm to the southeast direction and 3 mm in the upward direction were confirmed during FY 2020 as the post-seismic creeping of Mizusawa after "The 2011 off the Pacific coast of Tohoku Earthquake" (Mw 9.0), the annual amount of displacement is gradually decreasing. In addition, temporal fluctuations of the displacement velocity vector were confirmed in Iriki, Ogasawara, and Ishigakijima.

We carried out continuous GPS observations at VERA stations in order to monitor short term coordinate variations and to estimate atmospheric propagation delays. The propagation delays (excess pass delays) vary irregularly in time. We produce essential correction data for accurate VERA astrometry through GPS observations. At Iriki station, we operated a water vaper radiometer experimentally. We compared its result with the GPS observation result. The positioning result of GPS at Mizusawa shows a post-seismic motion to the East-Southeast direction even though 10 years have passed since the occurrence of the 2011 off the Pacific coast of Tohoku Earthquake. The gravity change observation at Ishigakijima continued through joint work with the Earthquake Research Institute, the University of Tokyo; and Geological Survey of Japan, AIST. That observation contributes to the study of ground water behavior. The strain and tilts observation data obtained at the Esashi Earth Tides Station are distributed in real time to several institutes based on the research agreement between the Earthquake Research Institute and Mizusawa VLBI Observatory.

6. System Development

As a development group, we are currently developing the dual-polarization and dual-frequency (K, Q) receiver system with a rate of 32 Gbps for VERA in accordance with the next EAVN broad-band observing mode. In 2020, we developed the RF and IF integrated switches with 16 inputs and 4 outputs for dual polarizations of five bands (Q, K, C, S, L) in-house and installed them at Iriki and Ishigakijima Stations, and the integrated switch in Ogasawara station, which was installed last year, was refurbished. In addition, we upgraded the down converters for right polarization to install an input and output port for a direct RF (K-band) left polarization signal. After that, we reinstalled the new down converters at all VERA stations. As a result, it is now possible to perform two-beam ultra-wideband and simultaneous dual-frequency (K, Q) observations with dual polarizations.

In 2019, we developed and installed the new L-band receivers and patch antennas at Mizusawa and Ishigakijima Stations. We evaluated and investigated this system, and as a result, it was revealed that the system noise temperature could be halved. This system will be refurbished and reinstalled at Mizusawa and Ishigakijima Stations in 2021.

The GPU correlator, which is under test operation at the Mizusawa correlation center, was upgraded for EAVN, SKA-AIV, and VLBI. In a result, the GPU correlator now supports VDIF (VLBI Data Interchange Format), which is the world standard recording format, and process up to 32 stations.

7. Timekeeping Office Operations

The Time Keeping Office operates four cesium atomic clocks together with a hydrogen maser atomic clock at Mizusawa VERA Station, and sets Japan “Central Standard Time.” The facilities contribute to the determination of UTC (Coordinated Universal Time) by BIPM (Bureau International des Poids et Mesures) through international time comparison. The NTP (Network Time Protocol) server at the Time Keeping Office provides standard time on a network. This service has been in great demand; about 20 million daily visits have been recorded.

8. Public Relations (PR) and Awareness Promotion Activities

(1) Open House Events

In 2020, we canceled all open house events to prevent the spread of the novel coronavirus.

(2) Regular Public Visiting

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 New Year’s.

The numbers of visitors to each facility are as follows,

a) Mizusawa VLBI Observatory (VERA Mizusawa Station) 9,995

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.

Mizusawa VLBI Observatory suspended access to the visitors area from March 3, 2020 to May 12, 2020 to prevent the spread of the novel coronavirus. The Kimura Hisashi Memorial Museum continues to be closed.

b) VERA Iriki Station 1,226
c) VERA Ogasawara Station 4,450
d) VERA Ishigakijima Station 2,131

(3) Cooperation with Local Communities

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

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

· Special exhibitions

Dec. 2, 2020 (Wed.)–Dec. 13, 2020 (Sun.) Hiraizumi Municipal Library

Dec. 16, 2020 (Wed.)–Dec. 22, 2020 (Tue.) Mizusawa Library of Oshu City Libraries

Dec. 25, 2020 (Fri.)–Jan. 27, 2021 (Wed.) Ichinoseki Library of Ichinoseki Public Libraries

Jan. 15, 2021 (Fri.)–Jan. 21, 2021 (Thu.) Central Library of Kitakami City Libraries

Jan. 30, 2021 (Sat.)–Feb. 7, 2021 (Sun.) Kanegasaki Municipal Library

Feb. 2, 2021 (Tue.)–Feb. 7, 2021 (Sun.) Tono City Library

Feb. 12, 2021 (Thu.)–Feb. 22, 2021 (Mon.) Hanamaki Library of Hanamaki City Libraries

Mar. 3, 2021 (Wed.)–Mar. 7, 2021 (Sun.) Nishiwaga-cho Culture Creation Hall (Galaxy Hall)

· Lectures and Workshops

Jan. 23, 2021 (Sat.) Ichinoseki Civic Center / Ichinoseki Science Cafe “From Iwate to BlackHole, Galactic Railroad Trip”

Feb. 6, 2021 (Sat.) Hanamaki City Culture Hall / Hanamaki Library Workshop “Let’s make a spinning top like galaxy!”

Feb. 6, 2021 (Sat.) Hanamaki City Culture Hall / Hanamaki Library Literature Lecture “The first blackhole seen by humankind”

The Iwate Marugoto Science Museum is held under the initiative of Iwate Prefecture. It is held at two locations, in Morioka City and the coastal area every year, but this year it was held online to prevent the spread of the new coronavirus. With Oshu City, an on-site lesson for elementary and junior high schools in the city, “Kirari ☆ Oshu City Astronomical Class,” is held every year, but it was canceled in 2020 to prevent the spread of the novel coronavirus.

9. Education

(1) University and Post-Graduate Education

Regarding postgraduate education, Mizusawa VLBI Observatory assisted 2 doctor and 2 master course graduate students from the University of Tokyo, and 2 doctor course graduate students from SOKENDAI with their research. Three of them were from foreign countries. One of the SOKENDI students got her Ph.D. degree and graduated in September 2020. In addition, staff members of Mizusawa VLBI Observatory give lectures at the University of Tokyo, Kyoto University, and Tohoku University as visiting professors.

(2) Research Experience for High School Students

From September 19 to 20, 2020, the VERA Ishigakijima Station and Ishigakijima Astronomical Observatory held “The Churaboshi Research Team Workshop” with the support of JSPS. From FY 2020, Ishigakijima Astronomical Observatory belongs to the Public Relations Center of NAOJ, and hence, the event was co-organized by the Public Relations Center and Mizusawa VLBI Observatory. Due to the situation of COVID-19, the event was held online, and 22 high school students in 11 prefectures from Hokkaido to Okinawa attended. The local staff in Ishigakijima presented the online lecture, broadcast a virtual tour, and demonstrated remote observations. The attendees joined the online discussion via zoom.

04. Solar Science Observatory (SOL)

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

1. Hinode Space Observatory

The scientific satellite Hinode is an earth-orbiting satellite that was launched on September 23, 2006, by ISAS/JAXA, as Japan's third solar observational satellite following Hinotori (1981) and Yohkoh (1991). Hinode is equipped with three telescopes: the solar optical telescope (SOT), the X-ray telescope (XRT), and the extreme ultraviolet imaging spectrometer (EIS). In addition to observations of the detailed magnetic field and velocity field of the solar photosphere, it carries out simultaneous observations of the radiance and velocity field from the chromosphere to the corona. The telescopes equipped on the Hinode satellite were developed through international collaboration with the US NASA and the UK STFC under the cooperation of ISAS/JAXA and NAOJ, and the European Space Agency ESA and the Norwegian Space Center NSC join its scientific operations. NAOJ played a central role in the development of the science payload in Japan and has been making a significant contribution to the science operation and the data analysis since the launch. The data acquired with Hinode are released to everyone as soon as the data are ready for analysis.

The Hinode Science Working Group (SWG), composed of representatives from the international teams, offers support in scientific operation and data analysis. It has a total of 17 members, including four from SOL: Y. Katsukawa as a secretary, Y. Suematsu as SOT PI, H. Hara as EIS PI, and T. Sakurai, professor emeritus, as a project scientist. The Science Schedule Coordinators (SSC) have been organized to leverage the open-use observation system. Two Japanese members from SOL (T. Sekii for SOT and T. Watanabe, professor emeritus, for EIS) join the SSC activity. The SSC serves as a contact point for observation proposals from world solar physics researchers to use Hinode and promotes joint observations between Hinode and the other science satellites and ground-based observatories. The Hinode science payload has been steadily observing the Sun from space, except for the SOT filtergraph instrument which was terminated in February 2016. New science results have been obtained via joint observations with SDO, IRIS, and ALMA as well as long-term standalone observations by Hinode. The number of Hinode-related refereed papers published in FY 2020 is about 60, and further achievements are expected in the coming years.

FY 2020 corresponds to the final year of the third mission extension period (FY 2017 to FY 2020) of the Hinode science operation. During this period, the emphasis is placed on the evolution of the magnetic field at the site of solar flares; observations of the locations of magnetic reconnection; long-term observation of general magnetic fields in the photosphere of the polar regions during the declining activity phase; and joint observations with ALMA and other ground-based observatories. The fourth mission extension was proposed to ISAS/JAXA and was approved for the period from FY 2021 to FY 2023. The scientific motivation in the coming period is to continuously observe rising activity toward the solar maximum using techniques such as observations of magnetic fields in the polar regions and full-disk mosaic observations, as well as to promote research combined with inner heliosphere observations by new satellites such as Solar Orbiter. Another aim is to conduct collaborative observations with DKIST, a large aperture ground-based telescope described below.

Solar Data Analysis System (SDAS) in the Astronomy Data Center (ADC), which developed from the open-use data analysis system of the Hinode Science Center and NSRO (Nobeyama Solar Radio Observatory) in addition to the data archive/public release system of the former Solar Observatory, fulfilled the roles of data analysis and data distribution, and it finally completed its task at the end of FY 2017. The data analysis functionality was integrated into the ADC Multi-wavelength Data Analysis System (MDAS), and the new SDAS: Solar Data Archive System, has started since FY 2018 for the archiving and public release of the solar data. SOL is jointly operating SDAS with ADC and the open-use data analysis system of Hinode data is maintained under MDAS. The SOL project is jointly operating HINODE Science Center at the Institute for Space-Earth Environmental Research, Nagoya University, where value-added Hinode data are maintained such as a flare catalog and magnetic field data in the solar polar regions. Joint research is ongoing for a comparative study between radiative magnetohydrodynamic numerical simulations and Hinode observations.

2. Ground-based Observations at Mitaka Campus

The SOL project continues to conduct observations at Mitaka Campus to obtain basic data for solar research and to help satisfy the public demand for monitoring possible influence on the global environment. The primary observation is an infrared spectro-polarimeter for magnetography with the Solar Flare Telescope (SFT). The others include full-disk Hα, Ca K, continuum, and G-band imaging observations, and relative sunspot number measurements as a proxy of long-term solar magnetic activity. In order to ensure stable operation, we are replacing aging parts of the instruments and continuously upgrading a data server to accommodate the increasing amount of data. The solar activity has been gradually increasing since 2019 after the solar minimum, and useful data such as active regions and flares have been obtained in the new cycle. The observation data are available at a data analysis server of

ADC and on the web page of this project. Now FITS data are available for data analysis by researchers.

The magnetic field observations that were conducted with SFT starting from 1992 have provided vector magnetic fields in the photosphere with a field of view covering active regions by observing an absorption line in the visible wavelength range. It has been replaced with near-infrared Stokes polarimetric observations since 2010 for higher precision measurements of magnetic fields both in the photosphere at 1.565 microns and in the chromosphere at 1.083 microns. Long-term variation (2010–2019) of the magnetic fields on the solar surface was analyzed using the data taken by the near-infrared Stokes polarimetric observations (Y. Hanaoka et al.). Factors that limit the efficiency and precision of magnetic field measurements are the imaging pixel format and the read-out noise of the infrared cameras. Toward having a large-format detector and low read-out noise performance, an imaging camera with an H2RG sensor has been developed in the Program of the Solar-Terrestrial Environment Prediction (PSTEP), Grant-in-Aid for Scientific Research on Innovative Areas. The camera has been demonstrated for application in the polarimetric observations.

The sunspot observation that started in 1929 continues, although it was upgraded to imaging observation using a digital camera in 1998. The sunspot data are also reported to SILSO World Data Center of the Royal Observatory of Belgium. NAOJ has long-term solar observation data in the form of films, photographic plates, and sketches acquired since the time of its predecessor, Tokyo Astronomical Observatory. The data are being digitized for a study of long-term variations in solar activity, and a paper has been published using the high-precision redigitized data of Ca II K-line images.

3. Nobeyama Solar Radio Polarimeters

Nobeyama Radio Polarimeters (NoRP) monitor the microwave radiation from the Sun, especially at seven frequencies (1, 2, 3.75, 9.4, 17, 34, and 80 GHz), and measure its circular polarization to study solar cycle activity and particle acceleration phenomena associated with solar flares. Although the Nobeyama Solar Radio Observatory (NSRO) was closed at the end of FY 2014, the observation of intensity and circular polarization at the seven frequencies, conducted over a half century, continues because of its importance in monitoring long-term solar activity.

Nobeyama Radio Observatory carries out the operation and maintenance of the automated radio polarimeter system, and SOL leads the scientific verification and calibration of the data with solar researchers in universities and the National Institute of Information and Communications Technology. Since FY 2019, SOL started to take responsibility for the operation and maintenance for the radio polarimeter in cooperation with NRO. Thanks to the sequential replacement of the origin sensors for telescope pointing, which were developed in FY 2019, observations at five frequencies of 1, 2, 3.75, 9.4, and 17 GHz, which are important for a study of the solar activity cycle, have been more stably continued in FY 2020.

4. Rocket and Balloon Experiments

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

The CLASP project is an observational sounding rocket experiment aiming to measure solar magnetic fields in the chromosphere and transition region through polarization observation in the ultraviolet wavelengths. Following the successful spectro-polarimetric observation using the hydrogen Lyman alpha line (λ121.6 nm) in 2015, the second flight experiment CLASP2 (Japanese PI: R. Ishikawa, launched in April 2019) succeeded in an observation of the Mg II h & k line (λ280 nm) of ionized magnesium with high precision spectro-polarimetry. In addition to the linearly polarized light of these emission lines produced by the scattering polarization, we have been able to obtain clear circularly polarization due to the Zeeman effect in an active region and obtained information on the magnetic field at the top of the chromosphere for the first time in the world (R. Ishikawa et al.). The CLASP2 data are available at the Virtual Solar Observatory in the US. We proposed the CLASP2 re-flight experiment (CLASP2.1) to NASA, a further observation rocket experiment using the CLASP2 instrument, and it will be flown in the fall of 2021. The CLASP2.1 experiment plans to perform a three-dimensional (two-dimensional space plus height) tomographic diagnosis of the magnetic field from the photosphere to the top of the chromosphere using the ionized magnesium lines by performing a slit scan.

SUNRISE-3 is the third flight of the international balloon project SUNRISE, led by Germany, and is scheduled to be flown in the summer of 2022. In this project, we are in charge of the near-infrared spectro-polarimeter instrument SCIP to be installed in SUNRISE-3 (Japanese PI: Y. Katsukawa) and have been working with the Advanced Technology Center and ISAS/JAXA to design the instrument and to develop flight products. For the observational control of SCIP during the flight, it is necessary to synchronize the control electronics and the camera developed in cooperation with Spain with the polarization modulator and the scan mirror mechanism developed in Japan. The synchronization performance has been demonstrated in a ground test. A thermal vacuum test simulating the vacuum temperature environment during the flight was conducted to verify the thermal and optical performance. After the final test in Japan, the instrument will be transported to Germany in the summer of 2021, where it will be installed and connected with the telescope for flight in 2022. The technologies for high precision spectro-polarimetry obtained through the development of SCIP were published in conference proceedings, etc. In parallel with the instrument development, we are studying methods for analyzing high-precision polarization data of the chromosphere together with domestic and international researchers and are working on the application of these methods not only to balloon observations but also to chromosphere observations with large solar telescopes such as DKIST.

The Focusing Optics X-ray Solar Imager (FOXSI) is a joint Japan-US sounding rocket experiment to observe X-rays emitted from the solar corona by 2D focused imaging and spectroscopy. The two flights in 2012 and 2014 achieved observations in the hard X-ray band (5 keV–15 keV), and the third flight (FOXSI-3) in 2018 successfully observed the soft X-ray band (0.5 keV–5 keV). The FOXSI-3 data were calibrated and are used for scientific analysis. The fourth flight FOXSI-4 proposed to NASA in 2019 was approved (Japanese PI: N. Narukage) in 2020. In November 2020, a kick-off meeting was held online between the US and Japanese FOXSI teams, and the project was launched.

5. Cooperation with SOLAR-C Project

The Solar-C_EUVST Science Task Team hosted an online seminar to discuss the scientific achievements and future challenges to refine an observation plan. SOL project members (Y. Katsukawa, T. Matsumoto) gave talks in the seminar. We are promoting research to simulate spectroscopic observations of key processes in atmospheric heating using numerical simulations. The target is to simulate not only the visible and near-infrared spectra observed by SUNRISE-3 balloon observations, but also the ultraviolet spectra observed by CLASP and Solar-C. The SOL project is collaborating on a study of critical techniques for the development of the Solar-C instruments.

6. Education

The SOL project accepted and supervised three Ph.D. students from Sokendai and three contract graduate students from the University of Tokyo. One received a Ph.D. degree at Sokendai. One undergraduate student was accepted in a summer student program of Sokendai and was supervised online. The project participated in the Tour of Solar Research Frontiers (March 2021, online) and introduced solar research at NAOJ to undergraduate students.

7. Public Outreach (PO) Activity

The SOL project has been conducting various public outreach activities for education and delivering the results obtained through the scientific research of the Sun to the public: press releases, web releases, cooperation for exhibition activity at science museums, media appearances by responding to requests for media interviews and providing materials to the media, etc. The NHK TV program Science ZERO, broadcasted in November 2020, featured results of solar observations with the Hinode satellite and the Solar Flare Telescope, as well as an introduction of development for cutting-edge solar observations.

8. Science and Community Meetings

The international Hinode Science Meetings have been regularly held to advance the solar physics research with the Hinode satellite. The 14th Hinode Science Meeting was originally scheduled to be held in July 2020, but was postponed to October 2021 due to COVID-19. A meeting of the Hinode Science Working Group was held online on July 27, 2020, to discuss ways to continuously generate scientific results from Hinode and to share the status of mission extension in participating countries. The Japan Solar Physics Community Symposium was held online on December 21–22, 2020, where the latest research results from domestic instruments and foreign space- and ground-based observations were presented, and future plans for Solar-C and beyond were discussed.

9. Others

The Daniel K. Inouye Solar Telescope (DKIST), a 4-meter aperture solar telescope being built by the US on Haleakala in Hawai‘i, obtained its first light images in January 2020. One member of SOL (Y. Katsukawa) is a member of the Science Working Group and helped to develop the Critical Science Plan for the initial observations of DKIST, which was published as a paper. The first call for observations with DKIST (Operation Commissioning Phase 1, OCP1) was issued in May 2020. We encouraged solar researchers in Japan to submit a proposal. OCP1 received about 100 submissions from around the world, and of the eight proposals made by researchers in Japan, five were accepted, which was the third largest number after the US and UK. A grant for enhancing collaborative research with DKIST has been approved (co-I: M. Kubo), and we will conduct numerical simulation studies until we obtain DKIST observation data. We are working on the basic development of the DKIST focal plane instrument and have applied for a grant for instrument development.

In Europe, another 4-m solar telescope (EST) is now in the planning stage. SOL is participating in the SOLARNET project (January 2019 to December 2022) of the European solar community to develop a prototype IFU for the EST-prototype GREGOR solar telescope. An image slicer unit for the IFU was designed and fabricated with a Grant-in-Aid for Scientific Research. In the next-generation global network solar observation project (ngGONG), which is led by NSO in the US, the SOL project has expressed our intention to cooperate with NSO for its realization based on the scientific and technological heritage obtained through near-infrared spectro-polarimetry with SFT at Mitaka Campus.

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

05. ALMA Project, NAOJ Chile, and ASTE Project

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

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

The mission of the NAOJ ALMA Project is to: implement the functions of the East Asian ALMA Regional Center, which provides support for users in East Asia; coordinate international project activities based on global partnership; formulate future project plans; and make budget requests. On the other hand, the mission of the NAOJ Chile is to manage and oversee the NAOJ researchers assigned to the Joint ALMA Observatory (JAO) and to facilitate the on-site operations of ALMA in Chile. Under the 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 2019, under the umbrella of the ALMA project. The ngVLA Study Group has been assessing, together with the Community, scientific opportunities of a possible future contribution from Japan to ngVLA; and has initiated development studies which allow NAOJ to contribute timely to construction if supported by the Japanese scientific community and budget processes.

1. Progress of the ALMA Project

Due to the outbreak of the novel coronavirus (COVID-19) in Chile, ALMA temporarily closed the Array Operations Site (AOS) and Operations Support Facility (OSF) on March 22, 2020 in order to protect the observatory staff and prevent the spread of the infection in Chile. After the shutdown, a small number of staff members, including Norikazu Mizuno of NAOJ (an international staff member of the JAO who serves as the head of the ALMA Department of Engineering), worked in shifts for facility maintenance and safety control. With the improvement of the COVID-19 situation in Chile, ALMA restarted operations of the site from October 1, 2020 following a gradual recovery plan based on gate reviews and careful monitoring of the pandemic evolution in Chile (including vaccination status of the general population and staff), and strictly enforced COVID-19 protocols. Scientific observations resumed on March 17, 2021 after test observations with a smaller number of antennas than usual. After the resumption of scientific observations, the JAO is cautiously proceeding with the return to stable operations in accordance with the gradual recovery plan. From the beginning of April 2020, most of the staff involved in ALMA at NAOJ Mitaka Campus had to work from home due to the development of the COVID-19 pandemic in Japan, but ALMA offsite operations continued mostly as usual without interruption, including user support.

2. ALMA Open-Use and Scientific Observations

The call for proposals for Cycle 8, the ninth round of ALMA open-use observations, was issued in March 2021. Cycle 8 is scheduled to start from October 2021. The main capabilities of Cycle 8 include: interferometric observations using at least forty-three 12-m antennas; Atacama Compact Array (ACA) observations (interferometric observation with at least ten 7-m antennas and single-dish observation with at least three 12-m antennas); eight frequency bands (Bands 3, 4, 5, 6, 7, 8, 9, and 10); and maximum baselines of 8.5 km. From Cycle 8, Band 5 will be available for solar observations, and Bands 9 and 10 will be available for stand-alone 7-m Array observations. In addition to these, Cycle 8 will provide spectral scan observations with the 7-m Array, mosaicking of continuum linear polarization observations in Bands 3 to 7 with the 12-m Array, and VLBI observation modes. The Cycle 8 call for proposals was closed at 24:00 on April 21, 2021 Japan time, after receiving the largest number of requests for ALMA observation time ever.

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.

A research team led by Kazuki Tokuda, a researcher at Osaka Prefecture University and NAOJ, observed 32 high-density gas clouds (molecular cloud cores) in the constellation Taurus using ALMA. This observation revealed a process in which a molecular cloud core contracts due to its own gravity and rapidly grows into a star, as well as a gas stream peculiar to the protostar in one of the observed cores. Since the age of this gas stream is estimated to be several thousand years, it is assumed that the protostar was discovered shortly after its birth. In addition, the team found that the evolution time scale from the molecular cloud core to the protostar is about 100,000 years.

A research team led by Yuhei Iwata, a third-year Ph.D. student at Keio University, examined the observation data obtained by continuously observing radio emissions from the area around the supermassive black hole Sagittarius (Sgr) A* in the center of the Milky Way galaxy with ALMA and discovered that the radio-wave intensity changes slowly over an hour or more and occasionally shows short periodic variations of about 30 minutes. Such periodic blinks are interpreted as being caused by a "hot spot" that orbits around the supermassive black hole with a very close orbital radius of 0.2 astronomical unit. It is expected that this discovery will be key to unveiling the phenomenon occurring around the supermassive black hole.

A research team led by Takahiro Iino, a project associate professor at the University of Tokyo, observed Neptune with ALMA and detected hydrogen cyanide, which is a type of poisonous gas contained in the atmosphere. It has been known from past observations that hydrogen cyanide exists in the stratosphere, but it was revealed by this observation for the first time ever that hydrogen cyanide is distributed in a band in the stratosphere on the equator. This is an important achievement in understanding the atmospheric circulation structure of Neptune. This study also shows that it is possible to observe in detail even a small quantity of molecular gas contained in a distant planet such as Neptune by using a large-scale ground-based telescope.

In addition, there is a steadily increasing number of press releases based on ALMA large-scale observation data.

An international research team, including Hanae Inami of Hiroshima University, carried out high-sensitivity observations of the Hubble Ultra Deep Field, the deepest region of the Universe explored by the Hubble Space Telescope, with ALMA and succeeded in accurately measuring the quantities of molecular gas and dust, which are the ingredients of stars, in many galaxies in the era about 10 billion years ago when star formation was taking place most intensely in the history of the Universe. By making comprehensive observations of galaxies including even small galaxies about 1/10th of the size of the Milky Way galaxy, the team revealed that there is a difference in the mass ratio of dust and gas between small galaxies and large galaxies, and that the formation process may differ depending on the size of the galaxy.

3. Educational Activities and Internships

The NAOJ ALMA Project is collaborating with the Joint ALMA Observatory to create a Japanese version of ALMA Kids, a website for children, with the aim of providing opportunities for more people to learn about the technology of ALMA and its scientific results in a fun way. ALMA Kids provides up-to-date content for kids introducing various announcements on the latest observation results. In addition, the Project has also developed educational content, mainly targeting elementary school students, called "Why ALMA Workshop" which explains the basics of radio astronomy by combining videos and worksheets. This content has been released on the Project website.

Furthermore, in collaboration with the Space Education Center, Japan Aerospace Exploration Agency (JAXA), the NAOJ ALMA Project held an educational event for elementary school students titled "JAXA x NAOJ Cosmic College: Astronomy Session—The Mysteries of the Universe Explored by Radio Waves" on February 27, 2021. In addition, the Project held a seminar to explain how to use educational materials on astronomy for the organizers of Cosmic College (local government staff and local educators).

4. Public Outreach Activities

In FY 2020, ALMA scientific observation results were covered by over 97 newspaper/journal articles, and the ALMA telescope was featured by 4 television/radio programs. The NAOJ ALMA website posted 44 news articles and 6 press releases. Mailing-list-based newsletters have been issued on a monthly basis with approximately 2,200 subscribers. Day-to-day information is posted in a timely manner on Twitter (@ALMA_Japan) with nearly 57,500 followers as of the end of FY 2020.

In FY 2020, twelve lectures were given for the general public and most of them were held online to prevent the spread of COVID-19 infections. These events served as good opportunities to share the current status of ALMA with many participants through dialogues and increase interest in ALMA and its observation results. In FY 2020, four viewer-participation events were held using Twitter in combination with YouTube lectures. The NAOJ ALMA Project called for entries for haiku and tanka (traditional Japanese poems) on Twitter in connection with astronomy events that are of general interest, such as Tanabata and the harvest moon, and introduced some of the entries in the YouTube lectures while explaining the seasonal starry sky in relation to ongoing research with ALMA. In March 2021, the NAOJ Public Talk/25th ALMA Public Talk titled “Stars Formed in Dark Clouds — Delving into the ALMA Observations from the Forefront of the Operations to the Latest Observation Results” was held in the form of YouTube live streaming and viewed by 1,377 people on the Internet in real time. The video recording of the event was posted on YouTube, and the number of views is increasing even after the event. In July 2020, the NAOJ ALMA Project exhibited a booth for ALMA at the Japan Geoscience Union Meeting (held online).

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

5. International Collaboration (Committees, etc.)

For the international ALMA project, meetings are held frequently by various committees. In FY 2020, all face-to-face meetings were replaced by online meetings, due to the COVID-19 pandemic. The ALMA Board and the ALMA Scientific Advisory Committee (ASAC) held online meetings as often as usual years, while the ALMA East Asian Science Advisory Committee (EASAC) held online meetings semiannually. Meetings were held more frequently by groups in charge of specific tasks to implement the international project in close cooperation.

6. Workshops

- May 25, 2020: ngVLA SWG1 meeting held online
- May 25, 2020: ngVLA SWG4 meeting held online
- May 28, 2020: ngVLA SWG5 meeting held online
- June 2, 2020: ngVLA SWG3 meeting held online
- June 11, 2020: ngVLA SWG2 meeting held online
- July 28, 2020: ngVLA SWG3 meeting held online
- Aug. 12, 2020: ngVLA SWG1 meeting held online
- Sep. 1, 2020: ngVLA SWG2 meeting held online
- Sep. 3, 2020: ngVLA SWG4 meeting held online
- Oct. 14–16, 2020: The ALMA 2030 Vision Design considerations for Digitizers, Backend and Data Transmission System held online
- Dec. 1, 2020: ngVLA solar meeting held online
- Dec. 4, 2020: ngVLA galactic meeting held online
- Dec. 8 and 15, 2020: ALMA Grant Fellow Symposium held online
- Dec. 18, 2020: ngVLA extra-galactic meeting held online
- Jan. 15, 2021: ngVLA SWG joint meeting held online
- Feb. 17–19, 2021: East Asian ALMA Science Workshop 2021 held online
- Jan. 5–7, 2021: ALMA/45m/ASTE Users Meeting 2020 held online
- Mar. 22–23, 2021: ALMA Cycle 8 2021 Proposal Preparation Meeting held online

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

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

8. Changes in Specially Appointed Research Staff

(1) Hired
- James Miley: Specially Appointed Research Staff
- Satoko Sorahana: Specially Appointed Research Staff
- Yuki Kudoh: Specially Appointed Research Staff (secondment to Kagoshima University)
- Hiroyuki Kaneko: Specially Appointed Research Staff (secondment to Joetsu University of Education)
- Yuma Sugahara: Specially Appointed Research Staff (secondment to Waseda University)
- Yoshinobu Fudamoto: Specially Appointed Research Staff (secondment to Waseda University)

(2) Departed or transferred
- Daniel Walker: Specially Appointed Research Staff
- Nguyen Duc Dieu: Specially Appointed Research Staff
- Andrea Silva: Specially Appointed Research Staff
- Benjamin Wu: Specially Appointed Research Staff
- Takanobu Shimoda: Specially Appointed Research Staff
- Tao Wang: Specially Appointed Research Staff
- Yuichi Higuchi: Specially Appointed Research Staff
- Tomoko Suzuki: Specially Appointed Research Staff

9. Main Visitors

- Aug. 6, 2020
  Koichi Hagiuda, Minister of Education, Culture, Sports, Science and Technology (MEXT) visited NAOJ Mitaka Campus.

10. Progress of the ASTE Telescope

In FY 2020, the ASTE telescope was shut down for a long time due to the outbreak of COVID-19 that began to spread worldwide from February 2020 at the end of FY 2019. Under the initial plan, it was foreseen to stop the operation in late March 2020 after regular maintenance, and to resume activities in April or later for the preparation of the open-use observations scheduled for July to August of the same year. However, considering the increase in the number of COVID-19 cases in Japan and Chile and the temporary closure of the ALMA facility which manages the ASTE telescope area and access roads, it was finally decided to suspend open-use observations and carry over all of the accepted seven observation proposals to FY 2021, and such notification was given to the proposers. The ASTE telescope site was reopened only for a short term in December 2020 to check the status of the site and equipment and in March 2021 for minimal antenna maintenance. Except for these periods, operations were suspended in FY 2020.

As for new observational instruments, two development projects were carried out with Grants-in-Aid for Scientific Research: (1) the development of a wide intermediate-frequency bandwidth for the Band 8 (387–498 GHz band) receiver, and (2) the development of a new spectrometer together with a frequency converter that converts the receiver signal for the spectrometer. In the development of the Band 8 receiver, steady progress was seen in the design, manufacturing, and purchasing of new parts required for the wideband, as well as in the evaluation of each unit. The new spectrometer and its frequency converter were designed according to the discussion on the required observing modes, and their prototyping and evaluation made steady progress, too. The goal is to install both instruments in the telescope in the latter half of 2021. The Band 10 receiver (790 - 940 GHz band) developed with Grants-in-Aid for Scientific Research also continued to be evaluated. Although no observations were conducted with the receiver in FY 2020, we continued performance evaluation and data reduction using data taken in FY 2019. The results were reported online in an international workshop (SPIE Astronomical Telescopes + Instrumentation 2020).

In FY 2020, five peer-reviewed papers were published, including three papers written by domestic researchers (outside NAOJ) and two by overseas researchers. Although the decrease in the number of papers published was unavoidable due to the equipment failure in FY 2018 and the suspension of scientific observations due to the COVID-19 pandemic in FY 2020, it is worth noting that a paper based on the demo science data of the Band 8 receiver, which was intended to promote submillimeter observation using ALMA, was published in the Publications of the Astronomical Society of Japan.

06. Center for Computational Astrophysics (CfCA)

1. Overview

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

2. Open Use of Computers

(1) General Status

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

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

Computational resources of the XC50, GRAPE's including GPU, and smaller PC clusters are allocated in accordance with a formal review process. The statistics of applications and approvals for this year are listed in the next subsection. Our center conducted a survey on the number of peer-reviewed papers published in English in this fiscal year on studies that involved the project's open-use computers. It turned out that 166 refereed papers (written in English) were published in this fiscal year.

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

(2) Operation Stats for Each of the Facilities

Cray XC50

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

GRAPE/GPU system

- Number of users
  9 (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: 531,778
  Annual core operation ratio by users' PBS jobs: 89 % (a ballpark figure)
- Number of users
  69 (at the end of the fiscal year)

(3) Tutorials and Users Meeting

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

- Tutorial sessions for iSALE (WebEx + Slack)
  Lecture and hands-on training on the basics of the iSALE shock physics code
  June 2 – July 3, 2020
  22 attendees

- Cray XC50 workshop for novice users (zoom)
  Introduction to the basic usage of XC50 for novice users

September 29, 2020
13 attendees

• Cray XC50 workshop for intermediate users (zoom)
Introduction to debugging, performance analysis, and optimization of XC50 for intermediate users
September 30, 2020
15 attendees

• CfCA Users' Meeting (zoom + Slack)
Presentation of research results using the open-use facilities in this department, and discussion of the operation of the equipment
January 19–20, 2021
95 attendees (January 19), 70 attendees (January 20)

• Early spring school for N-body numerical simulations (zoom + Slack)
Lectures on N-body simulations, and programming practice using GRAPE/GPU
February 16–19, 2021
20 attendees (for hands-on training and lectures), 8 attendees (for lectures only)

• Numerical simulation school for hydrodynamics (zoom + Slack)
Lecture and practice for MHD numerical simulations using the public code Athena++
March 10–12 and 22–23, 2021
65 attendees

3. PR Activity

In FY 2020, the following press releases were issued from the center:

• "Large Simulation Finds New Origin of Supermassive Black Holes"
June 2, 2020, Sunmyon Chon (Tohoku University) et al.
• "That Must've Hurt: Ganymede Covered by Giant Crater"
July 27, 2020, Naoyuki Hirata (Kobe University), Ryo Suetsugu (the National Institute of Technology, Oshima College) et al.
• "Compressive Fluctuations Heat Ions in Space Plasma"
December 11, 2020, Yohei Kawazura (Tohoku University) et al.
• "Supercomputer Turns Back Cosmic Clock"
February 16, 2021, Masato Shirasaki (NAOJ/the Institute of Statistical Mathematics) et al.
• "American Astronomers Find Secrets of Japanese Universes"
March 3, 2021, Takahiro Nishimichi (Kyoto University) et al.
In addition, the following research results and news appeared on the CfCA website:
• "CfCA Member Wins NINS Young Researcher Award"
June 12, 2020, Takashi Moriya (CfCA)
• "Munehito Shoda Wins International Astronomical Union PhD Prize"
July 11, 2020, Munehito Shoda (JSPS Research Fellow at the Solar Science Observatory of NAOJ)
• "Research using the supercomputer "ATERUI" wins the 2019 PASJ Excellent Paper Award"
September 11, 2020, Masaomi Tanaka (Tohoku University) et al.
• "Second Alignment Plane of Solar System Discovered"
September 29, 2020, Arika Higuchi (University of Occupational and Environmental Health Japan)

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

4. 4D2U Project

In FY 2019, the 4D2U project continued to develop and provide movie content and software.

Two simulation movies were released on the 4D2U website; "Formation of a Multiple-Star System" (simulation: Tomoaki Matsumoto/Hosei University, visualization: Takaaki Takeda) in August 2020 and "Asteroid Collisions and Shape Evolution" (simulation: Keisuke Sugiura/Tokyo Institute of Technology, visualization: Satoki Hasegawa) in March 2021. In addition, a fluid simulation visualization movie "Gas Disk around a Black Hole" (simulation: Hiroyuki Takahashi/Komazawa University and Ken Ohsuga/University of Tsukuba, visualization: Hirotaka Nakayama) was released on the 4D2U YouTube Channel.

The updated version 1.6.0b of the four-dimensional digital universe viewer, "Mitaka," was released in May 2020. In this version, several bugs have been fixed and the manual has been revised. Online workshops on how to use the command execution feature in version 1.6.0 and later were held by the Mitaka Working Group of the Japan Society for the Promotion of Astronomy Education in September 2020 and February 2021.

Four members of the 4D2U Project have received the Award for Science and Technology (Public Understanding Promotion Category) of the 2020 Commendations for Science and Technology by MEXT. The award winners are: Eiichiro Kokubo, Tsunehiko Kato, Hirotaka Nakayama (all CfCA), and Takaaki Takeda (PRC). This award recognizes their contribution to "promoting public awareness of the latest views of the Universe through stereoscopic visualization of astronomy data."

4D2U content was provided both domestically and internationally for TV programs, planetarium programs, lecture presentations, books, and so on. Particularly in FY 2020, due to the request to refrain from going out to prevent the spread of COVID-19, there was an increase in the number of requests to use 4D2U content on services such as YouTube and zoom.

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

5. External Activities

(1) Joint Institute for Computational Fundamental Science

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

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

Representing CfCA, Professor Eiichiro Kokubo and Assistant 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 JICFuS-led HPCI Strategic Program Field 5 as well as Priority Issue 9 to be tackled using the K Computer as mentioned in Section 5.1, the activity in the HPCI consortium is basically independent from them. 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," is about to be put into full-scale service, and there is a lot of scientific discussion on how the user community should make the best use of this equipment.

6. Staff Transfers

(1) Staff members hired in this FY
(Research Supporter) Makiko Ban
(Administrative Supporter) Mami Masuyama

(2) Staff members who departed in this FY
(Project Research Staff) Yukari Ohtani
(Administrative Supporter) Kyoko Mashiko

07. Gravitational Wave Science Project

In the third obervation run (O3) of gravitational waves (GW), which started in 2019, there were 39 GW events observed in the first half of the period, and gravitational wave astronomy made remarkable progress. However, follow-up observations with optical telescopes like the Subaru Telescope have been reported in only one case in the second run, O2. So improvement of the GW event localization has become strongly desired. To this aim, Japan's KAGRA (large-scale cryogenic gravitational wave telescope) needs to participate in the International Gravitational Wave Observation Network.

The Gravitational Wave Science Project (GWSP) in the National Astronomical Observatory of Japan (NAOJ) assertively promotes hardware improvements and operation of the KAGRA. And the GWSP also leads GW reaserches in Japan by developing advanced technology for GW detectors with TAMA300 and the ATC laboratory in NAOJ Mitaka Campus.

1. Gravitational Wave Telescope, KAGRA

The GWSP in NAOJ has taken a critical role in the operation and management of KAGRA as a sub-host institute based on the “Memorandum of Understanding on Promotion of Gravitational Wave Astronomy Using the Large-scale Cryogenic Gravitational Wave Telescope, KAGRA” with the Institute for Cosmic Ray Research, University of Tokyo and the High Energy Accelerator Research Organization.

In particular, the GWSP has consistently led the construction of the low-frequency vibration isolation system, auxiliary optics, and main interferometer as well as mirror evaluation, and has contributed to the management by assigning members to the Executive Office, System Engineering Office, etc. In February 2020, KAGRA was put into operation for the first time and ultimately achieved a sensitivity of 1 Mpc for the range of binary neutron star coallescense detection. This barely met the requirements for participation in the O3 conducted by LIGO-Virgo. Unfortunately, KAGRA could not join because O3 was discontinued due to the worldwide spread of COVID-19. On the other hand, international joint observation (O3GK) was conducted with the GEO600 in Germany, which continued observation in April, and collaborative data analysis is underway.

Since then, KAGRA has been refurbished for O4 observation (scheduled after June 2022). The main tasks are as follows.

(1) **Vibration Isolation Systems**

To isolate the interferometer mirrors and some optics from ground vibration, KAGRA uses four different types of vibration isolation systems (Type-A, Type-B, Type-Bp, Type-C). Improvements and renovations were carried out on all of these. Especially for the Type-A system at the Y-end, the filters were retuned and reinstalled. We also developed an accelerometer that improves the sensitivity of the inertial sensor used to control the inverted pendulum by about an order of magnitude at 0.1 Hz.

(2) **Auxiliary Optics**

The GWSP is responsible for all-optical equipment such as optical baffles for stray light countermeasures, optical angle sensors, beam reducing telescope (BRT), cameras for beam monitors, and viewport windows. We designed baffles and beam dumps to address issues from O3. Also, a new actuator mechanism was prototyped to improve the operability of the BRT anti-vibration table. These were carried out in collaboration with the Advanced Technology Center (ATC).

The above renovations are scheduled to continue until 2021.

2. R&D in TAMA300 and ATC

In the GWSP, TAMA300, a first-generation interferometric GW detector constructed in the 1990s, has been effectively utilized to drive next-generation gravitational wave telescope technology development. In addition, the ATC has also been conducting technology development on a tabletop experiment and actual KAGRA equipment assemblies. In 2020, significant progress was made, especially in the following three outcomes.

(1) **Development of Frequency-dependent Squeezing Technology in TAMA300**

Frequency-dependent squeezing is a quantum optics technology that can reduce the quantum noise of a GW telescope in a wide band, and competitive development is taking place all over the world. In the GWSP, we have been conducting this development research using TAMA300, and in 2020 we succeeded in demonstrating it in the practical frequency band of 100 Hz for the first time in the world. This achievement was published in the April 28 issue of “Physical Review Letters” and was selected as the “Featured in Physics” and “Editor's Suggestion”. In this research, the assistant professor of the GWSP received the Young Researcher Award of the National Institute of Natural Sciences, and the SOKENDAI student received the SOKENDAI Award. After that, we continued the experiment to generate stable frequency-dependent squeezing and started the study to introduce it in KAGRA.

(2) **Ultra-high Performance Mirror Development**

KAGRA sapphire mirrors are known to have three issues to improve, 1. light absorption, 2. reflectance asymmetry, and 3. birefringence. We are solving these problems in cooperation with the manufacturers and research institutes inside and outside of Japan. In particular, the GWSP led the mirror evaluation using an optical absorption coefficient and birefringence measuring device and found a correlation between the optical absorption and birefringence of the sapphire crystalline structure. This result has been fed back to the crystal maker, and efforts are being made toward better sapphire crystal production.

(3) **Study of Residual Gas Adsorption Phenomenon of Low-temperature Mirrors at ATC**

In an interferometer using low-temperature mirrors such as KAGRA, residual gas is adsorbed on the mirror surface and forms a molecular layer. We have developed a method to measure the film thickness ellipso-metrically and succeeded in obtaining the absorption coefficient of the molecular layer. From the obtained values, it was found that optical absorption will become a problem in the next-generation interferometers unless measures are taken to suppress the formation of molecular layers.

3. Education

Three students, two SOKENDAI graduate students and one University of Tokyo graduate student, who had been researching at TAMA300 and the ATC laboratory, obtained doctoral degrees. Among them, one student of SOKENDAI, received high praise such as the SOKENDAI Award.

As for graduate school/university education, in addition to the guidance for the above students, our staff gave lectures at the University of Tokyo Graduate School, SOKENDAI, and Hosei University. In addition, lectures at the Asahi Culture Center, Educational Academia Course, Chuo Ward College Course, Okazaki Kita High School, Astronomy Pub, Hikari Association Monthly Seminar, and Tama City Third Elementary School were presented, and other activities in social education were conducted enthusiastically.

4. Outreach

In collaboration with the Public Relation Center in NAOJ, we produced a video to publicize the GWSP. The GWSP homepage has also been revised, and a new faculty introduction page has been established, especially for students aiming to enter graduate school. In addition, we gave interviews for the 10th serial article of Kyodo News, “Galactic Travel from National Astronomical Observatory of Japan”, NHK science program “Science ZERO”, Asahi Shimbun, etc. We cooperated with the Mitaka City walking tour and contributed to the Bungeishunju opinion.

5. International Collaboration and Visitors

Under the restrictions of the COVID-19 situation, we had eight visitors, which is a smaller number than usual. On the other hand, international cooperation has been actively carried out, and joint research with CNRS / APC (France), iLM (France), National Tsing Hua University (Taiwan), Myongji University (Korea), KASI (Korea), etc. has progressed.

6. Publications, Presentations, and Workshop Organization

The GWSP members were authors of 9 refereed publications in international journals. There were 7 non-refereed publications in European languages and 2 in Japanese. There were 24 presentations at international conferences and 38 presentations in domestic conferences. In addition in print publications, there were 9 reports in European languages and 1 in Japanese.

7. Acquisition of External Funds

In FY 2020, no external funds other than scientific research funds were obtained.

8. Staff

(1) Hired
- Dan Chen: Project Research Staff
- Yuhang Zhao: Project Research Staff
- Michael page: JSPS Postdoctoral Fellow
- Marc Eisenmann: JSPS Postdoctoral Fellow
- Satoru Ikeda: Senior Specialist
- Mie Ueda: Administrative Expert
- Atsumi Sawagaki: Administrative Supporter

(2) Transfer / Retirement
- Ayaka Shoda: Project Assistant Professor (transferred to private enterprise)
- Eleonora Capocasa: JSPS Postdoctoral Fellow (transferred to APS, Maite de conferences, France)
- Chihiro Kozakai: JSPS Postdoctoral Fellow (transferred to private enterprise)
- Yuhang Zhao: Project Research Staff (transferred to ICRR, Institute for Cosmic Ray Research, University of Tokyo)

08. Thirty Meter Telescope Project

The Thirty Meter Telescope (TMT) Project is a project to build an extremely large 30-meter telescope under the collaboration of research institutes in five countries: Japan, the United States, Canada, China, and India (Figure 1). For Japan's part, the National Institutes of Natural Sciences (NINS) is the ultimately responsible body, and NAOJ is the executing institute. In 2014, an agreement was executed among the participating organizations to found the TMT International Observatory (TIO) for the purpose of the construction and operation of the observatory; the construction was subsequently commenced. Japan is responsible for the 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 Conservation District Use Permit (CDUP) for TMT construction on Maunakea in 2017, on-site construction was planned to restart in FY 2019. However, demonstrations and a road blockade by those opposed to TMT on Maunakea prevented construction work at the summit region. Currently, as a TIO member, NAOJ provides assistance for TIO's continued efforts for consensus building in Hawai‘i together with relevant organizations. TIO, NAOJ, and the other members are focused on essential activities in the overall process and minimizing their expenditures, while these efforts are being made. In the meanwhile, the NAOJ TMT Project evaluated in detail feasibility of the alternative site and its conditions for astronomical observation, in case construction in Hawai‘i becomes infeasible. Also, it commenced discussion of a science operations plan with a view to open use during the operation phase.

1. TMT Project Progress and Status of the Construction Site

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

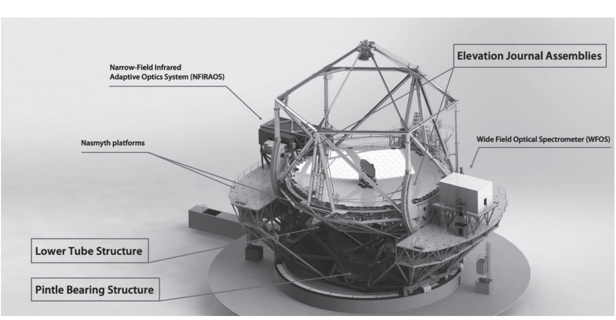

Figure 1: Rendering of the latest design for the TMT structure (Credit: TIO).

TIO, operated according to deliberations and decisions made in meetings of the TMT Board of Governors, is overseeing the construction work performed in each country as well as developing the on-site infrastructure. The board meetings are attended by three representatives from Japan, Director General Tsuneta, Vice-Director General Iguchi, and NAOJ TMT Project Manager Usuda. Regularly held on a quarterly basis, the Board of Governors was convened eight times in FY 2020 to discuss activities for the future participation of NSF, the on-site construction issues, and other matters. Different working groups were created under the board to engage in efforts for construction in Hawai‘i, as well as to discuss issues of the project operation, by holding meetings frequently. The Members' meeting was also held once in FY 2020, attended by NINS President for Japan, to discuss pivotal issues of the project. These meetings were held online due to COVID-19 restrictions.

In the United States, the Decadal Survey, which decennially evaluates and identifies the most compelling challenges in the field of astronomy, is in progress and scheduled to be announced in 2021. A joint program called the U.S. Extremely Large Telescope Program (US-ELT Program) was proposed to the Decadal Survey, which will allow all-sky observation by working in concert with TMT and the Giant Magellan Telescope (GMT, a telescope with an aperture of 24 m currently under construction in Chile). Additionally, TIO submitted a planning and design proposal of this program to NSF in May 2020 together with NSF's National Optical-Infrared Astronomy Research Laboratory (NSF's NOIRLab) and GMT to plan a potential partnership. Considering that U.S. federal investment in the TMT project through NSF is essential for the project's success, TIO is presently working for NSF's preliminary design review scheduled for FY 2021. The final decision on the federal funding to the project will be made by the U.S. Congress. NSF has been actively making informal outreach efforts with stakeholders in Hawai‘i since 2020 in a move to help the agency to determine its participation in the project.

As for the situation in Hawai‘i, a CDUP was approved for the TMT planned site on Maunakea in September 2017. Several parties appealed this decision, but in October 2018, the State Supreme Court found that due process was followed for issuance of the CDUP, which completed all the legal process for TMT. However, those opposed to TMT on Maunakea staged demonstrations, including some sit-ins on the access road to the summit region, preventing the planned construction from commencing in July 2019. The road was cleared for traffic after a while, but on-site construction has not been resumed as of the end of FY 2020. A forum for discussion was created later in FY 2019, where the NAOJ Director General and others from TIO participated in a dialogue with leaders of the movement and other relevant parties. Reflecting on the past activities that should have engaged more with the Hawai‘i community, the board decided on phased relocation of the TIO headquarters to Hawai‘i. Along with this, the project manager is planning to move to the Island of Hawai‘i in the first half of FY 2021 to work more closely with the community. In March 2021, the House of Representatives of the Hawai‘i State Legislature determined to form a working group that includes individuals nominated by Native Hawaiian groups and communities, and to task the working group with restructuring the management of Maunakea. Membership selection began, with a view to producing a report by the end of 2021. Since this may affect the TMT project, its development is closely monitored.

As for the alternative site on the island of La Palma of the Canary Islands in Spain selected in 2016, the process for all permits needed for construction was completed in November 2019, including an environment impact assessment. In FY 2020, working together with researchers at universities in Japan, NAOJ’s TMT Project thoroughly examined observation conditions in La Palma, and concluded that although Maunakea is superior, La Palma meets many of the scientific needs expected for TMT. This result was reported to the astronomy community at meetings. NAOJ expresses its support for relocation to La Palma in case construction in Hawai‘i becomes infeasible, as long as the project is expected to be federally funded in the U.S.

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

For the construction of TMT, Japan is responsible for many essential components of the telescope: the design and fabrication of the telescope structure and its control system; and the manufacturing of the primary mirror, in accordance with the executed agreements. It also takes part in production of a portion of the science instruments which are developed through international partnerships. While the restart of on-site construction is halted, in FY 2020, Japan has worked on designs and preparation for production, concentrating its efforts on essential work for the overall process instead of production. In FY 2020, the progress below was made.

(1) Manufacturing of the Primary Mirror Segments

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

Of these processes, the plan calls for Japan to fabricate all the mirror blanks and to perform spherical grinding on all 574 segment mirrors. With the share of work for the processes beginning from aspherical grinding and polishing and ending with mounting of the mirror segment on a support assembly distributed among four countries, Japan is leading this work for 175 of the mirror segments. In FY 2020, the primary mirror team examined and identified the necessary work in an effort to facilitate production of the primary mirror when full-fledged manufacturing of the mirror segments is resumed, without affecting the entire process. It confirmed the ability to deliver high precision of the position and angle for adhesion of parts by improving the accuracy of tools to be used for mounting support assemblies. Since the total number of bonding components required for production of the 175 segments will exceed 10,000, the team developed a procedure to remove adhered parts safely in case the requirements are not met. In addition, a measure to protect the mirror surface during the hexagonal shaping was examined. The highlights of FY 2020 included the start of TIO’s review of segments that were aspherically polished by FY 2019 to confirm that they meet the technical conformance criteria before being cut into their hexagonal shape (Figure 2).

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

Japan is responsible for the design and production of the telescope structure, as well as its control system, which functions as a mount for the optics systems, such as the primary mirror, and the science instruments, and points

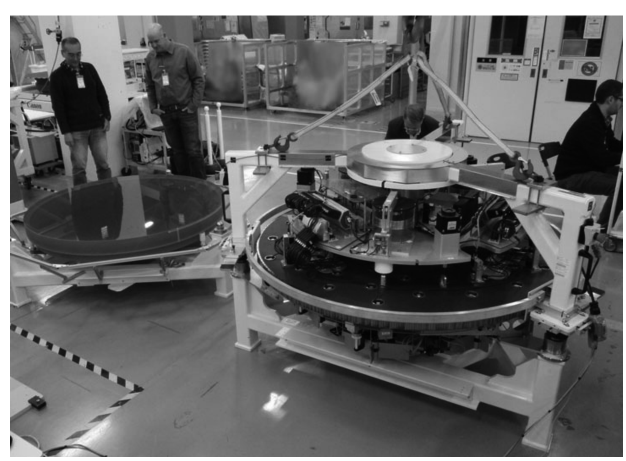

Figure 2: TIO inspected Japan’s mirror polishing and measurement processes. In December 2020, the first quality review was conducted for a segment mirror that underwent the aspherical polishing process. This mirror, which was one of the mirrors polished in FY 2019, successfully passed the review, and will be cut into a hexagonal shape in the next step.

them in the direction of a target astronomical object. Following the baseline and detailed designs developed by FY 2016 and preparation for fabrication in FY 2017, FY 2018 saw the launch of the fabrication process for the telescope structure. In FY 2020, continuing on from the previous fiscal year, the work was focused on determination of the interfaces and development of drawings for production, with an eye toward a production readiness review scheduled before full-scale production. In particular, given the great relevance of the telescope structure to the piping and wiring subsystems that were reviewed for the final designs by TIO, the structure team provided assistance in definitions of interfaces and other matters. It also scrutinized high-risk technical issues, which will pave the way for future production.

(3) Science Instruments

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

One of them is IRIS that stands for an InfraRed Imaging Spectrograph. Being in charge of its imager, Japan currently engages in development that includes designing and prototyping in cooperation with the Advanced Technology Center. IRIS has been in the detailed design phase since FY 2017. Following the work in FY 2019, it further developed and completed the optical design of the imager. Progress was also made in detailed mechanical designs of elements of the imager, including the cold stop, the filter wheels, the atmospheric dispersion compensator, the detector's mount, and the pick-off mirror unit for the slicer spectrometer, as well as the corresponding analysis of stray light. The prototype test was carried out along with improvement of the bearing lifetime test and the surface figure measurement of a large mirror in a cryogenic environment, both of which had begun by the previous fiscal year. A NAOJ staff member, based at the NAOJ California Office, Pasadena, serves as a system engineer for all of IRIS, playing a leading role in determination of the interfaces within IRIS and with the Narrow Field InfraRed Adaptive Optics System (NFIRAOS), as well as in examining on-site assembly and verification.

A Wide Field Optical Spectrometer or WFOS, underwent an interim conceptual design review in May 2020, where the instrument's progress to date was reported with regard to the conceptual design of the mask exchange system, the camera lens barrels, and the integral field unit, followed by the cost evaluation based on the review. The conceptual design is being further explored for the mask exchange system and the integral field unit.

Adopted as one of the first light instruments is a Multi-Object Diffraction-limited High-Resolution Infrared Spectrograph or MODHIS, which will target exoplanets. A NAOJ staff member based in Pasadena, leads its development as the MODHIS project manager, and is currently developing a conceptual design jointly with TIO and the California Institute of Technology. A contribution plan for development of the exoplanet instrument is being sketched out with the Astrobiology Center.

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

TIO's Science Advisory Committee, consisting of researchers from the participating countries and institutions, discusses science programs and instrumentation envisioned with TMT. In FY 2020, meetings were held online on an almost monthly basis, attended by four university researchers and NAOJ TMT Project Manager Usuda on behalf of Japan. In view of the preliminary design review scheduled for 2021 for potential participation of NSF, TIO's committee primarily discussed development of instruments through international partnerships and a science operations plan once the telescope is completed, as well as holding joint science meetings with GMT.

The TMT Science Advisory Committee, which is a domestic committee consisting of 12 researchers from universities and other institutes, reviewed issues of science programs, instrumentation, and operations. Its efforts extended to international activities, including the opportunity to learn about views directly from a TMT supporters' group of Native Hawaiians, and a joint meeting with Canada's science advisory committee. With respect to NAOJ's funding program for research and development of TMT science instruments, which did not call for applications due to budgetary restrictions in FY 2020, the committee discussed the important role that the funding program plays in the development of TMT science instruments and underlying technology, and focused on issues for its resumption in FY 2021. Seeing a science operations plan being developed rapidly in the U.S. as part of planning by the US-ELT Program toward possible participation of NSF, the TMT Science Advisory Committee created a working group under the committee to commence examination of science operations, and to exchange opinions at meetings with AURA and TIO.

More meetings for larger communities of astronomy in Japan were organized to explain the status of the project and engage in discussions. In addition to an online session in May 2020 to provide the project details, the TMT Project held meetings for a wide range of researcher communities, including radio astronomy, theoretical astronomy, and solar physics, as well as optical and infrared astronomy. The NAOJ Director General provided the latest information on the TMT project for the astronomy and astrophysics subcommittee of the Science Council of Japan.

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. 66 through 69 were delivered.

Many in-person lectures and exhibitions, which had been actively held throughout Japan, were called off due to the COVID-19 pandemic. In the meantime, online lectures were capitalized on, and allowed a greater reach to schools worldwide, as well as nationwide, through a program of NAOJ called FUREAI (Friendly) Astronomy, which offers children opportunities to learn about astronomy directly from astronomers. There was a total of 43 sessions of lectures for the public and classes on demand, including online opportunities.

The NAOJ TMT Project participated as on-demand lecturers in a science/technology education and PR event in Hawaiʻi, where TMT is to be constructed, called "Journey Through the Universe," which was held online in March 2021.

In October 2020, it was afforded another opportunity at NAOJ's event for reporters and writers to illustrate the science merits expected for collaboration between TMT and the Subaru Telescope, and to provide up-to-date information on the project.

5. Organization

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

With the aim of strengthening the close partnership with TIO, six members are assigned to the NAOJ California Office in Pasadena. There are two members in Hawaiʻi working for TMT, one of whom is from the Office of International Relations.

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

09. JASMINE Project

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

(1) Overview

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

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

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

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

Small-JASMINE was selected by ISAS/JAXA in May 2019 as the unique candidate for the JAXA Competitive Middle-Class Science Missions No.3. At the present, according to the progress schedule in the Space Basic Plan, the launch of Small-JASMINE is scheduled for 2028. We are promoting the Small-JASMINE Project with the aim of gradually improving the development stage at JAXA. Small-JASMINE has the following three primary scientific goals.

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

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

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

The mission objective of the Small-JASMINE Project is to use a three-mirror optical system telescope with a primary mirror aperture of 30 cm to perform infrared astrometric observations (Hw band: 1.1–1.7 μm) (to be determined in detail). A mission goal is to measure as the highest precision annual parallaxes at a precision of less than or equal to 25 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 degrees of the Galactic nuclear bulge and in the directions of a number of specific astronomical objects of interest in order to create a catalogue of the positions and movements of stars within these regions. The project is unique in that unlike the optical space astrometry mission, "Gaia Project," operated by the European Space Agency (ESA), the same astronomical object can be observed frequently, and observation will be performed in the near-infrared band, in which the effect of absorption by dust is weak. This project will help to achieve revolutionary breakthroughs in astronomy and basic physics, including the formation history of the Galactic nuclear bulge (Galactic Center Archeology); Galacto-seismology; the supermassive black hole at the Galactic Center; the gravitational field in the Galactic Nuclear Bulge; the activity around the Galactic Center; formation of star clusters; the orbital elements of X-ray binary stars and the identification of the compact object in an X-ray binary; the physics of fixed stars; star formation; planetary systems; and gravitational lensing. Such data will allow for the compilation of a more meaningful catalog when combined with data from terrestrial observations of the line-of-sight velocities and chemical compositions of stars in the bulge.

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

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

(2) Major Progress in FY 2020

1) Organization of the office

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

2) Overview of planning and developing the Small-JASMINE Project

NAOJ established a Small-JASMINE Working Group (WG) in August 2019, and the activities of the working group continued until June 2020. The purpose of the WG was to "work as a management advice body on a wide range of items related to the Small-JASMINE Project." The WG was composed of seven members from inside and outside of NAOJ. The WG discussed the scientific goals of Small-JASMINE, including their merits and technical feasibility. As a result, the WG concluded that NAOJ can support JASMINE to proceed through JAXA's review process to the next development stage. The JASMINE Project established a JASMINE consortium consisting of researchers. The purposes of the consortium are to conduct the science study, and to prepare a data analysis team, data validation team, and outreach team. At present, about 50 domestic members are participating. In November 2020, a consortium meeting was held online, which also served as an open science workshop for Small-JASMINE.

Regarding the development of observation instruments, the infrared detector to be installed on the JASMINE mission was conventionally planned to use a detector made in the United States. However, due to circumstances, we decided to shift its focus to mounting an infrared detector developed by the NAOJ Advanced Technology Center for ground based astronomy, and started developing this domestic detector for space use. Furthermore, with the installation of a domestic infrared detector, we confirmed the feasibility of the mission according to the characteristics of the detector. The JASMINE team examined the specifications of the observation instruments (primary mirror aperture, detector array, etc.), and entrusted the investigation of the specifications to satellite manufacturer company candidates. For the satellite system as a whole, the risks that should be resolved at this point were identified in cooperation with multiple satellite manufacturer company candidates. Regarding data analysis, with the addition of new development members (about 15 people in total) a group has been organized to develop and carry out simulations of stellar image creation and a series of end-to-end simulations from estimations of stellar image centers to deriving astrometric parameters such as annual parallaxes. The group carried out pipeline verification and correction work. In international cooperation, we proceeded with preparations for analysis of astrometric data with researchers at Heidelberg University.

3) Progress of the Nano-JASMINE Project

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

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

1. Project Overview

In FY 2020, the RISE Project investigated the operation plans of Martian Moons eXploration (MMX) and introduced new software as the MMX Geodesy sub science team (G-SST). (i) In order to collect information regarding orbit/gravity field estimation software produced by CNES in France, we held an online meeting in August. Then we clarified the modifications necessary to apply the software to MMX and our rights and obligations for the usage and amendment. G-SST members, including those of the RISE Project, attended this meeting from Japan. (ii) As for the stereophotoclinometry shape-modelling software (SPC), we negotiated with the Planetary Science Institute (PSI) who developed the SPC, and were finally allowed by the US Department of Commerce to import from PSI. At the same time, (iii) we investigated plans for imaging to model the shape of Phobos. A tool developed in the Hayabusa2 mission to plan the timing to take images was applied to MMX. In addition, (iv) the attitude of the MMX spacecraft which enables observations of poles and high-latitude regions from three-dimensional Quasi-Satellite Orbit (3D-QSO) was studied; (v) constraints on the densities of two-layer interior modeling based on tracking data for orbits ascending from and descending onto the landing sites on Phobos were considered. (vi) Upon request of the MMX data processing working team (DPWT), information necessary for development of the data analysis/archiving system, including a reformatter, was discussed and provided; (vii) we attended development meetings helping to develop the Engineering Model of the laser altimeter (LIDAR); (viii) and we began a series of seminars to review recent research of Phobos's internal structure.

Second, we manufactured data products to be published and wrote related documents such as the Software Interface Specification (SIS) document. The data products and a draft of the SIS were prepared by the Hayabusa2 LIDAR team by August. However, they are still being revised because there were requests to publicize not only level 2, but also level 0/1 data products. As scientific outcomes, two papers were published in an international journal regarding precise position estimates of the spacecraft as well as a method to determine the alignment of LIDAR in orbit. Also, a paper to study the efficiency of resurfacing on asteroids was published in an international journal based on an impact experiment of Hayabusa2 that revealed little to no movement of rocks on Ryugu. At the time of Hayabusa2's return to the Earth, we conducted a laser link experiment jointly with the Institute of Space and Aeronautics Science and National Institute of Information and Communications Technology. RISE Project members attended the operation of LIDAR on December 7 to 11, 14, 16, 18, and 21 to 23.

Third, an application for a new A project for development and preparation for operation of MMX was submitted in May, and was approved as the "RISE Project" which will continue until FY 2022. The "Project Goals and Missions" summary of the new project was submitted in August and was approved. Also, we proposed the establishment of a Planetary Science Working Group under the Science Strategy Committee together with a recommendation for 8 working group members. The proposal and members were approved by the Director General. Then the first and second working group meetings were held online on February 15 and March 17.

2. Educational Activities

One RISE member served as a part-time lecturer at the University of Tokyo for half a semester for an undergraduate class. Another member accepted and educated a graduate student of the University of Tokyo.

3. Outreach/PR

In FY 2020, the Project members volunteered for Kirari Oshu City Astronomy School as well as five times for FUREAI (Friendly) Astronomy classes. In addition, RISE members provided three special lectures for the public.

11. SOLAR-C Project

1. SOLAR-C Project Overview

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

(1) Formation mechanism of the hot solar atmosphere and solar wind

(2) Energy release mechanism of solar explosions

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

The SOLAR-C project was proposed as the Solar-C_EUVST small satellite project in the JAXA public small satellite solicitation opportunity in January 2018. This proposal was nominated as a candidate for Publicly Offered Small Satellites 3 or 4 in July 2018, and the plan has moved to the Mission Definition Phase (Pre-Phase-A2) in 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. In terms of international cooperation, NASA's participation in this project was confirmed in December 2020 based on NASA's Phase A study that had been underway since 2019, followed by the participation of European space agencies.

2. Progress of the SOLAR-C Project Activity in FY 2020

In FY 2020, the following aspects of the telescope section and satellite bus, which Japan is responsible for, were studied using the JAXA front-loading expenses: (1) The design study of the primary mirror assembly with tip-tilt and focusing mechanisms, (2) the redesign and refinement of the structure model, (3) the on-orbit temperature prediction and thermal deformation prediction by the thermal mathematical model, (4) the study of mechanical interface conditions between the satellite and the observation equipment and those within the science payload, (5) the examination of requirements for the small satellite standard bus, (6) the performance evaluation of the prototype model of the Ultra Fine Sun Sensor, and (7) the investigation of outgassing characteristics of candidate adhesives and the prediction of their impact using a simple contamination mathematical model. 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.

3. SUNRISE-3 Project Support

While the short-term experiment projects have been handled by the Solar Science Observatory (SSO) since this fiscal year, most SOLAR-C Project members continue to contribute to developing the science payload for the balloon project SUNRISE-3. Refer to the report of the Solar Science Observatory for details.

4. Project Budget

While NAOJ reimbursed the SOLAR-C Project for its general operation and contingencies, a large part of the expenses for supporting the project preparation was funded by other external sources such as JAXA's study-acceleration and basic development fund.

From the viewpoint of smoothing out the administrative work volume of SOLAR-C and SSO, the expense processes for the short-term experiment projects were conducted by this project.

5. Staff

J. Sugimoto: Administrative Supporter; transferred from SSO in Apr

R. Kano: Associate Professor; move to JASMINE Project in Sep

Y. Suematsu: Associate Professor; retired from Project Director in Sep

H. Hara: Associate Professor; Project Director starting in Oct

T. Kawate; NIFS Assistant Professor, concurrent post starting in Nov

Y. Suematsu: Associate Professor; retired in Mar 2021

12. The Subaru Prime Focus Spectrograph (PFS) Project

1. Overview of the PFS project

Prime Focus Spectrograph (PFS) is a next generation large-scale facility instrument of the Subaru Telescope. PFS will enable us to obtain spectra of ~2400 objects simultaneously at wavelengths ranging from 0.38 μm to 1.26 μm with a spectral resolution of R ~ 2000–4000. It is expected to start open-use observation from FY 2022.

PFS has been developed under 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 (6 institutions, USA), Brazilian consortium, LAM (France), MPE/MPA (Germany), and Chinese PFS Participation Consortium (6 institutions, China). The subsystems of the PFS instrument have been developed at designated institutions, and NAOJ is responsible for modifying the telescope/dome, preparing a temperature-controlled clean room for the spectrograph system, and operation of the instrument. NAOJ is also committed to its commissioning, data pipeline, and science database.

NAOJ approved these activities as an A-project from FY 2019. The mission of the A-project is to complete on-site assembly and installation into the Subaru Telescope and then verification to meet its system requirements, and to execute science commissioning and verification within the period of this project.

2. Progress in FY 2020

Due to the untimely death of the Project Director, who was also the only member of this project, during the compiling of the manuscript for the annual report, the report for this fiscal year has been postponed until next year.

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

1. Project Overview

The Subaru Ground Layer Adaptive Optics (GLAO) project aims to realize near-infrared survey observations at the Subaru Telescope with unprecedented depth and field of view, and with high-spatial resolution comparable to the Hubble Space Telescope by developing and implementing a GLAO, 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 the project is to reveal the history of galaxy formation and evolution by an unprecedented near-infrared survey of the distant universe.

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

2. Staff

The GLAO project team mainly consists of members of Subaru Telescope. At the end of FY 2020 there were one dedicated associate professor, 4 assistant professors, and 7 RCUH employees (4 research staff and 3 engineering staff) appointed concurrently. In addition, the GLAO project received support from the instrument division technicians, day crews, and administration staff at Subaru Telescope. The total FTE of the persons working for the GLAO project in FY 2020 was 6.96.

3. Major Progress in FY 2020

The GLAO science team plays a crucial role in establishing the strategy of our optical/infrared astronomy community toward the 2030s (TMT era). During the Subaru User's Meeting held in March 2021, we reported the project status and the progress of the science case development for the primary science goal as well as extended science goals recently discussed among domestic and international scientists. In FY 2020, we summarized science requirements derived from the primary and extended science goals and analyzed their flow down to the system requirements for the GLAO system and its science instruments.

The GLAO preliminary design has been conducted for its main subsystems: the adaptive secondary mirror (ASM), the laser guide star facility (LGSF), and the wavefront sensor system (WFS) based on the GLAO system requirements. In FY 2020, we completed a preliminary design of the ASM in collaboration with the AdOptica consortium in Italy and started its detailed design by considering the interface with the Subaru telescope. We also started preliminary designs of the WFS and the LGSF by organizing a development team and identifying the system requirements including the interface between the telescope and the science instruments. Our plans for the science instruments are to reuse the existing wide-field near-infrared imager and spectrograph (MOIRCS) at the Nasmyth IR focus and to develop a new wide-field imager (WFI) at the Cassegrain focus. In FY 2020, we developed a conceptual design of MOIRCS and identified the interface with the GLAO system at the Nasmyth IR platform. A conceptual design review for MOIRCS and WFI will be held in June, 2021.

A new LGSF for the existing AO system (AO188) and four laser Shack-Hartmann WFSs for tomographic wavefront reconstruction (LTAO) are being developed at Subaru Telescope and Tohoku University to demonstrate their performance and technical feasibility for the future GLAO system. In FY 2020, we completed all of the design and the production for the new LGSF and installed a new TOPTICA fiber laser system and its diagnostic optics at the Subaru Telescope. Installation of the relay system which transfers the laser beam from the TOPTICA laser to the laser launching telescope behind the secondary mirror of the Subaru Telescope is planned for the first half of FY 2021. We are aiming to start the operation of the new LGSF in FY 2022. The LTAO has completed its design and production phase in FY 2020. Currently, the LTAO is being assembled and tested at Tohoku University. The LTAO will be delivered to the Subaru Telescope by the end of FY 2021 and will start its commissioning operation.

4. 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 web site (https://ultimate.naoj.org).

5. International Collaboration

The GLAO project has been closely collaborating with the Australian National University (ANU) and the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) for the preliminary study of the GLAO system. In FY 2020, we conducted the preliminary design study of the WFS and the LGSF in collaboration with ANU, and conducted conceptual design studies for the Nasmyth IR relay optics and instrument rotator in collaboration with ASIAA.

In FY 2020, the GLAO project science team led the application for a core-to-core program at the Japan Society for the Promotion of Science (JSPS) and submitted a proposal entitled "International research network toward the era of deep and wide near-infrared surveys of the Universe with space and ground-based telescopes". The proposal was successfully accepted at the end of FY 2020. The program is started from FY 2021. This program is aiming to accelerate the international collaboration among the USA, France, Australia, Taiwan, and Japan with the basis of synergetic observations by US/European next generation space telescopes and the Subaru Telescope, including collaborative development for the GLAO system.

14. Astronomy Data Center

1. Introduction

The Astronomy Data Center (ADC) archives astronomical data permanently and opens them to the public for easy and comprehensive use by operating several archive computer systems. ADC also operates data analysis computer systems to utilize those astronomical data for various research. These activities are conducted by the DB/DA project team, JVO project team, HSC data analysis and archiving software development project team, and open-use computer systems and services team.

2. DB/DA Project

The DB/DA project conducts research and development on astronomical Databases and Data Analysis. SMOKA (http://smoka.nao.ac.jp/) is the core of the DB/DA project and opens archival data of Subaru Telescope, Okayama 188-cm telescope, Kiso 105-cm Schmidt telescope (the University of Tokyo), two MITSuME 50-cm telescopes (Tokyo Institute of Technology), KANATA 150-cm telescope (Hiroshima University), NAYUTA 2-m telescope (University of Hyogo), and Seimei Telescope (Kyoto University). The total amount of opened raw observational data is about 30 million frames (265 TB) as of May 2021. SMOKA contributes to many astronomical publications. The total number of refereed papers using SMOKA data is 262 including 12 new publications as of March 2021.

Data taken with the observing instruments MIMIZUKU attached to the Subaru Telescope, KOOLS-IFS on the Seimei Telescope, and HIDES-F on the Okayama 188-cm telescope were newly opened in JFY 2020. The information on astrometric calibration of Kiso KWFC was also opened. Development of new functionalities requested from users and improvements for efficient operation were also conducted.

3. JVO Project

All the Subaru-Telescope/Suprime-Cam data were reduced and made publicly available for the quick-look function. Those data are also distributed through the VO standard HiPS protocol and they are visible on the Aladin desktop application developed by CDS, Strasbourg astronomical Data Center in France. The procedure of the data reduction and the data search GUI for those data were presented at ADASS 2020.

ALMA ARI-L (The Additional Representative Images for Legacy) data were registered and made available at the JVO ALMA FITS archive. We have started updating the FITS WebQL, which is a quick-look viewer for 3D data cubes in FITS format, to accommodate large ALMA data with a size exceeding 300 GB. Since it takes more than several minutes to display such large data with the current FITS WebQL, an upgrade is starting to decrease the waiting time through distributed processing.

Gaia EDR3 catalogs were made available at the JVO portal. Gaia WebQL, which enables users to make plots from the Gaia source catalog on their web browsers, was released.

VO crawler database was updated to include survey catalogs taken by ground-based telescopes, in addition to the originally created database from space mission data. The metadata of JAXA's radio astronomy satellite, HALCA, was registered in the JVO system and has now became available through the VO interface.

Total access count for the JVO services was 13.5 million and the download size was 11 TB in total in JFY 2020.

4. HSC Data Analysis/Archiving Software Development Project

This project, started in January 2009, primarily develops the data analysis pipeline and data archiving software for Hyper Suprime-Cam (HSC). Our main subject is to implement the software for efficient and accurate data analysis and archiving. In the Subaru Strategic Program (SSP) with HSC (March 2014-), we perform data analysis with the developed pipeline, and produce databases for the processed results for researchers. We made the 9th data release (S20A) to the SSP team collaborators in August 2020, which covers roughly 520 degree^2 of quality areas, with a total of 520 TB of files. The catalog database includes about 860 million objects. We have continued developing various user interface software for providing images and catalog products. The next internal data release for SSP collaborators (June 2021) and the 3rd public data release (PDR3; August 2021) are also being prepared. The PDR service has over 1500 registered users. We have also been supporting the on-site data evaluation for HSC observations. We have continued development of a fast catalog query system with a next-generation database for huge HSC catalogs.

Commissioning of the metrology camera system and spectrographs for the next-generation multi-object spectrograph PFS is underway. We have been involved in discussions of data formats based on engineering data, and development of science data archives which are to be combined with the HSC products, in cooperation with Subaru Telescope.

5. Open-use Computer Systems and Services

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

The system consists of "Multi-Wavelength data analysis subsystem (MDAS)", "Large data archive and service subsystem (MASTARS, SMOKA, HSC science, ALMA, VERA, NRO, Okayama, and Solar data archives)", "JVO subsystem", "Data analysis subsystem in Mizusawa campus", “Development subsystem”, and “Open-use terminals and printers in Mitaka campus”.

We have been constructing the “Large-scale data analysis system (LSC)” for analyzing the big astronomical observational data such as HSC. The LSC system has been in operation for general HSC observers since September 2019. A major upgrade of the LSC system to add several computing nodes with another 1,500 CPU cores was completed. Starting in October 2020, the LSC system became available for HSC archival data users.

As part of the tasks as an Inter-University Research Institute, several workshops and hands-on tutorials were held to demonstrate to users how to use the specific software, applications, and the open-use systems. All workshops in JFY 2020 were held online due to the COVID-19 situation. The dates and numbers of participants in JFY 2020 were as follows.

1. PyRAF mini school (1st), September 29, 2020, 12 users
2. PyRAF mini school (2nd), October 28–29, 2020, 11 users
3. ALMA data analysis school for beginners (Co-host), November 17–18, 2020, 12 users

The total number of participants in the workshops and tutorials in JFY 2020 was 35 users. The number of workshops held in JFY 2020 was smaller than usual because some workshops were difficult to hold remotely.

6. Others

As part of outreach and promotion activities, 92 issues of “ADC News” were published from No. 963 to No. 1054 and 26 of announcement for LSC users were published from No. 14 to No. 39 in JFY 2020. These articles were distributed to users by E-mail and posted on the ADC public web pages.

15. Advanced Technology Center

1. Summary of Activities in ATC

The Advanced Technology Center (ATC) is the core research organization of the technological development at the National Astronomical Observatory of Japan (NAOJ), and is the research and development (R&D) center for advanced astronomical observation instruments, from radio waves to visible and ultraviolet light, both on the ground and in space. From the beginning of Fiscal Year (FY) 2020, most ATC staff members were forced to work from home due to the declaration of a state of emergency in relation to COVID-19, a situation which had never been experienced before. However, some staff members had difficulty continuing to work from home because of the manufacturing nature of ATC's work. So, our activities in ATC have been gradually restarted while taking countermeasures against COVID-19 by ourselves. Thanks to ATC Facility Management Unit's prompt actions such as placing alcohol bottles for disinfection at the entrances of all rooms in ATC, taking measures to avoid crowding, introducing a non-contact thermometer, and so on, we were quickly able to offer an environment to work safely. In addition, we have prepared our own COVID-19 control manual with the cooperation of Subaru Telescope, and updated it according to the situation. By sharing the manual with ATC staff, users inside and outside NAOJ, and visitors, the measures against COVID-19 have been thoroughly implemented. Through these efforts, we successfully minimized delays in work in "Workshops and Development Support Facilities," NAOJ project work such as "Prioritized Area Developments," and the development/manufacturing of other instruments and related technology for projects inside and outside of NAOJ.

The restructuring of the current organization to develop the instruments more systematically, which has been considered since FY 2019, is expected to be implemented in FY 2021. Although the number of visitors was significantly smaller than usual due to the COVID-19 situation, we were able to stress the importance of ATC in NAOJ for visitors from MEXT such as the Minister, Director of Scientific Research Institutes Division, and Director of the Department of Facilities Planning and Disaster Prevention, and so on. We also provided ATC tours for visitors from private companies and online tours for students. It should be highlighted that in FY 2020 operation of the 5-axis machining center and metal 3D printer introduced in FY 2019 has been fully launched for production of prototype parts for TMT/IRIS and for mass-production of corrugated horns to be used in the ALMA Band 1 receivers. In addition, the results of ATC's joint research with universities have contributed to the conclusions of comprehensive research collaboration agreements between NAOJ and the University of Electro-Communications, and Osaka Prefecture University. Details are described below.

2. Workshops and Development Support Facilities

(1) Mechanical Engineering Shop (ME Shop)

The ME shop engages in a comprehensive manufacturing process to fabricate experimental and observational instruments, from design to fabrication and verification. All four teams (Design team, Additive Manufacturing team, Machining team, and Measurement team) cooperate with each other to meet the various needs from NAOJ projects and other institutions by leveraging their expertise.

1) Design Team

As in the previous fiscal year, the design team has worked on mechanical design and related measurement and equipment installation for TMT/IRIS, KAGRA, TMT/WFOS, and SUNRISE-3.

TMT/IRIS: As the second year of the two years of the final design phase, the design team continued to work on the detailed design of each subsystem comprising the IRIS Imager. Specifically, A) detailed stress and modal analysis of the subsystems, B) creation of simplified models based on the results of the detailed analyses, C) creation of the imager global finite element model for global vibration analysis, D) detailed design of the slicer pickoff mirror mechanism; collimator and camera TMA optical bench; and PV mechanism were performed. Prototype tests under a 77 K environment were also executed as follows: a) an additional durability test of the 4-inch bearing, b) a repeated bending test of the thermal link, and c) a surface profile measurement of the TMA mirror and an estimation of wavefront error using finite element analysis.

TMT/WFOS: The design team proceeded with the conceptual design and initial phase manufacturing and labor cost estimates of the Slit Mask Exchanger (SMX), Slit Mask Fabrication Facility (SMF), and Integral Field Unit (IFU) based on the WPA of CoDP-2. And we participated in the Tier-C review in May and Costing review in September. For SMX, 1) formulation of the design specifications, 2) function analysis, 3) discussion of interfaces with peripheral subsystems, and 4) investigation of the operation sequence were done and the L2 Design Review Document (DRD) and Detailed Design Document (DDD) were prepared. SMF is a new item to be considered from this fiscal year, we performed i) formulation of the design specifications and ii) function analysis, and in addition iii) selection of a laser cutting machine that can meet the requirements was also completed with the support of Tokyo Metropolitan Industrial Technology Research Institute. For IFU, a) discussion of the optical layout, b) the optical designing, and c) the preparation of the DDD were done.

KAGRA: The design of the mirror holders for the Narrow Angle Baffles was updated.

SUNRISE-3: We proceeded with 1) mechanical and optical alignments, 2) designing and manufacturing of opt mechanical parts, and 3) opt-structural analysis for the design verification for shipment by the end of the fiscal year. For the mechanical and optical alignments, we were in charge of 3D measurement and position correction of optical components. For the designing and manufacturing of opt mechanical parts, a flight product of a metal spring for removing heat from optical elements was manufactured in cooperation with the ATC ultra-precision section. For opt-structural analysis for the design verification, we completed i) estimation of wavefront error in collaboration with the ATC optical design team, and ii) soundness check to shock load when the balloon was mounted and in a non-operating temperature environment. This result was reported at SPIE.

2) Additive Manufacturing (AM) Team

Continuing from last fiscal year, the AM team have continued to learn about basic AM techniques including operation of the 3D printer and peripheral equipment, and modeling design. FY 2020 was the first year of initial operation for AM team, and the first 12-month maintenance was conducted on our 3D printing machine. This major maintenance affected the production condition, and we could learn the impact of adjustments on fabrication. In parallel, the development and manufacturing of the corrugated horns for the ALMA Band 1 receivers, which were the most important initial development item, proceeded in collaboration with the Development team of the NAOJ ALMA project. As a part of Band 1 horn development, some material property tests (mechanical properties, e.g., tensile strength, hardness, density, etc., thermal and electrical conductivity, and outgassing) were conducted at room temperature and cryogenic temperature in cooperation with Japan Advanced Institute of Science and Technology (JAIST) and High Energy Accelerator Research Organization (KEK). In addition, initial studies requested from the KAGRA project and some groups in the Institute of Space and Astronautical Science (ISAS), JAXA were implemented aiming for future collaboration development. As for the Resin 3D printer which was introduced for metal modeling practice, besides using it for the original purpose of support design study, it has also been used for the fabrication of practical products, such as acrylic partition stands to prevent the spread of COVID-19, and astronomical models (Moon and Mars) for publicity.

3) Machining Team

The machining team has responded to fabrication consultations and fabrication requests from a range of groups including major NAOJ projects, groups at ATC, and open-use users. And, for users who wanted to work on their own, we provided guidance as needed. For the 5-axis machining center, the machine performance was checked after installation (to be continued in the next fiscal year), and basic data for improving machining accuracy was obtained. In addition, we are preparing for regular operation.

The main requests were as follows:

a. Regarding TMT/IRIS, fabrication of parts for element tests being conducted by design team.
b. Manufacturing of the mask frame which will be used for the near infra-red multi-object spectrograph SWIMS (to be continued in the next fiscal year).
c. Flight components production for SUNRISE-3.
d. Post-processing for the metal 3D printer products.

As for fabrication by the Ultra-Precision Section, we have completed the fabrication of metal springs for heat exhaust for SUNRISE-3 as flight parts, which had been ongoing since last year.

4) Measurement Team

The measurement team carried out measurement requests using large 3D measurement machines through open use, as well as accuracy verification and precision confirmation for fabrication requests contracted by the machining team. And we provided consultation and technical advice on measurement as needed.

The main requests were as follows:

a. Measurement of corrugation roundness of a Band 1 horn made by metal 3D printer.
b. For airborne instrumentation, position measurement of optics for SUNRISE-3.
c. Tool adjustment and product measurement of metal springs for heat exhaust in ultra-precision machining.

5) Future Technology Development

From a long-term perspective, the ME shop has been developing the underlying technologies that will be needed for the future, based on the technology demands from the various projects. However, due to the COVID-19 situation, the development of the cryogenic applicable non-optical contactless linear encoder to use for positioning mechanisms in radio and infrared instruments started in FY 2019 was suspended in this fiscal year.

(2) Optical Design and Development

For the Optical Design and Development, an engineer dedicated to optics is involved in multiple projects and provides cross-project optical development functions, such as optical design, optical performance analysis, measurement, specification development, and procurement. In FY 2020,

Table 1: The requests in FY 2020.

From FY 2019	4
ATC	8
TMT/IRIS	6
ALMA	8
KAGRA	4
SUNRISE-3	9
Public Relations Center	3
Other	1
External Organizations	
Univ. of Tokyo	3
Univ. of Tsukuba	1
Total	43
To FY 2021	6

regarding NAOJ projects, the engineer was responsible for the optical design and the development of CLASP2, SUNRISE-3, Solar-C_EUVST, TMT/WFOS, and KAGRA. As open-use and joint research projects, he was responsible for the optical design of the focal plane instruments of two submillimeter-wave telescopes, which are being developed by the University of Tsukuba and the University of Tokyo. In addition to this, he performed tolerance analysis of an instrument for the TAO telescope and a feasibility study for an extremely large space telescope realized using numerous small satellites.

In addition, in order to introduce optical equipment that can be used for current and future development within a limited budget, he makes proposals based on development experience with several projects. In FY 2020, three pieces of equipment (a high-precision Fizeau interferometer, its expansion options, and a hexapod), which were proposed to and approved for introduction by the NAOJ Leadership program, were procured.

(3) Thin Film Processing Unit

Fundamental experiments were continued to design and to develop the concrete processes of coating, taking into account the application and expected performance of using inhomogeneous multilayers. Various data on the correlation between status of the coater and the film characteristics were obtained. And improvements of the power source, modifications for the control software, and optimization of the geometrics of electrodes of the ion source, have been implemented experimentally.

(4) Space Chamber and Space Optics Shop

As project support, we have participated in the development activities of the balloon experiment SUNRISE-3. We contributed to the preparation and operation of equipment for the thermal vacuum optical test of the SUNRISE Chromospheric Infrared Polarimeter (SCIP) using a large vacuum chamber in a clean room. We have also assisted a low temperature test and outgassing measurements of SCIP components. In addition, thermal-fluid coupled analysis using software was conducted to estimate the temperature of the Subaru Prime Focus Spectrograph (PFS) through simulations.

In terms of equipment development and management, the development of a telemetry system started in the last fiscal year is almost completed, and the system has been put into operation to remotely monitor the measurement of experiments, operate equipment, and watch the environment in clean rooms. We will continue to add functions and maintain the hardware and software for the system. In terms of equipment, a sequencer was updated to solve the problem of a control system of the medium-sized vacuum chamber. In response to the Solar-C_EUVST project's request, the interlock settings of bakeout heaters in the large and medium vacuum chambers were changed to support low vacuum bakeout of satellite components.

(5) 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.

a) Repairing and upgrading for measurement systems
• Accuracy Calibration for LEGEX 910 (MITUTOYO)
• Inspection for GPI-XP (ZYGO)

b) Open use
• The number of annual users: 229
  NAOJ: 201 (including 123 from ATC)
  External organizations: 28
• Use of LEGEX910 (large-scale 3-D measurement machine): 20
  Number of operating days: 28
• Technical consulting for users: 17

(6) Optical and Infrared Detector Group

High performance near infrared image sensors for astronomical observation were only supplied from a manufacturer in US so far. They were extremely expensive, and it took a great deal of time to purchase them. We have succeeded in developing a near infrared image sensor in cooperation with a domestic manufacturer. In this year, we successfully evaluated a readout IC for another near infrared image sensor sensitive to a longer wavelength in cooperation with Kagoshima University.

(7) Terahertz Experimental Group

The terahertz experiment group supports development in superconducting detectors, cryogenic electronics, and cryogenic systems. Especially, the submillimeter-wave Fourier transform spectrometer (FTS) is operated for optical evaluation of instruments in terahertz frequencies. For the development of the MKID camera in collaboration with Tsukuba University, the MKID camera for the Nobeyama 45-m Radio Telescope was evaluated using the FTS, and shows good band-pass performance matched with the 100 GHz atmospheric window. For the development of terahertz photon detectors in collaboration with AIST, electromagnetic simulation tools, HFSS and FEKO, were used for a new design of SIS photon detectors for higher quantum efficiencies. For the development of 0.8 K sorption coolers, design modifications for the pressure vessel and an orifice for super-fluid helium results in stable performance of 0.71 K for 3 hours for multiple models.

(8) Facility Management Unit

Facilities Management (Unit) is responsible for all operational management of the buildings, electrical equipment, daily inspections and use of the Cold Evaporator (CE) in accordance with laws and regulations, laboratory equipment including clean rooms, as well as leading construction work, chemicals and hazardous substances management, and laboratory planning. As usual, the circulating cooling water system was inspected and overhauled, and wash treatment was also performed to reduce the effects of water quality deterioration due to aging of the cooling tower and pipes. In ATC Building No. 3 (TMT building), we have done the demonstration experiment using a side flow unit in a large space, which is expected to consume less power and achieve higher cleanliness, instead of the conventional vertical flow system. We have confirmed its usefulness. Furthermore, in order to implement maximum prevention of COVID-19 infection and to maintain our work, we have implemented measures such as formulating a countermeasure manual, preparing disinfectant alcohol, installing a non-contact thermometer and deep-UV locker at the entrance of the building, CFD analysis for effective ventilation, and putting up an informational poster in a conspicuous place.

3. Prioritized Area Developments

(1) TMT

1) IRIS

The near-infrared imaging spectrograph, IRIS, has been in the detailed design phase since the middle of FY 2017. In the detailed design phase, NAOJ is responsible for leading the system engineering of IRIS, contributing to the software design team, and the overall development of the IRIS imager. The ATC is in charge of optomechanical design, analysis, and prototype testing of IRIS. The major progress in FY 2020 is as follows: completion of optical tolerance analysis and stray light analysis; measurement and analysis of large-scale mirror surface deformation during cryogenic cooling; execution of prototype test of the durability of moving mechanisms; finishing the mechanical design and analysis of IRIS imager subsystems: cold stop assembly; ADC assembly; filter wheel assembly; bench assemblies for collimator and camera mirror optics; and detector assembly with IFS pick-off mirrors and shutter. ATC's ME shop played a central role in prototype tests and mechanical design and analysis.

2) WFOS

The development phase of Conceptual Design (Phase 2) ended in May 2020, and the instrument concept has been almost fixed. After that, Conceptual Design (Phase 3) has started, and details of the concept have been designed to complete the conceptual design. The WFOS-Japan team estimated the costs of the mask exchange system, the science camera lens barrels, and the integral field unit based on their concepts developed in Conceptual Design (Phase 2). To adapt to the design change of the WFOS structure, we have modified the design of the mask exchange system to avoid physical interference with other subsystems (calibration light system, auto-guider system, and M4 system). In the modification, operational safety was considered. Since Conceptual Design (Phase 3), we have studied the mask fabrication system. For the integral field unit, we have investigated solutions to resolve the physical interference caused by the design change of the auto-guider system. In addition, we have analyzed stray light and vignetting caused by an image slicer which is a special optical device with a complex structure, and derived an optimum design. We have also contributed revisions to the Level 2 Design Requirements Document (DRD) in which instrument requirements are summarized.

3) MODHIS

MODHIS is a diffraction-limited, single-mode fiber (SMF) feed, high-resolution infrared spectrometer. We have been developing and operating the REACH instrument, which combines the Extreme-Adaptive Optics SCExAO and the high-resolution infrared spectrometer IRD at the Subaru Telescope, as a test-bed to realize MODHIS. MODHIS requires fiber switching to inject object light, wavelength calibration light, and a light source for alignment during/before/after observations. We have developed a remote fiber switching instrument for REACH and demonstrated that high connection efficiency, > 95 %, is possible at the summit of Maunakea, and this instrument is being used for open-use observations of REACH. We also plan to provide high-precision dichroic mirrors and off-axis parabola mirrors for MODHIS. We recently developed dichroic and off-axis parabola mirrors for YJH and K bands, which have 3.9 nm and 16 nm RMS surface figure errors respectively, for REACH. Such a small surface figure error is critical to realize high coupling efficiency to SMF. We also built a large vacuum chamber for a high-resolution infrared spectrometer for the South Africa telescope, SAND, to realize an extremely temperature stable spectrometer similar to MODHIS, with a goal of better than a few milli-Kelvin temperature stability.

(2) ALMA

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

NAOJ is in charge of the maintenance of the cold cartridge assemblies (CCAs) for three receiver bands - Band 4 (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 have developed and manufactured at NAOJ, or 73 units including 7 spares for each band, were shipped to the ALMA site. Most of the receivers have been installed and operated in the ALMA antennas for scientific observation. At ATC, the ALMA receiver maintenance team has been repairing the receiver cartridges that failed during operation since FY 2014. In FY 2020, one Band 10 receiver was repaired and delivered to ALMA Operations Support Facility in Chile. This failure was caused by degradation of the mixer performance. The receiver was repaired by replacing the mixer block, and then replacing the cold amplifier, isolator, and their interconnecting cables, and the mirror block including multiplier for optimization of the overall performance. In addition, two Band 4 receivers on the antennas had high receiver noise temperature and bias failure. For these Band 4 receivers, the phenomenon resembled the ones caused by CCA failure during the production phase, and we asked JAO to return the CCAs for repair via the issue tracking and management tool. They will be removed from the receiver systems in the course of regular maintenance, and will be returned for repair in the next fiscal year or later.

This fiscal year, the operation of ALMA was suspended for 9 months due to the influence of COVID-19, and it was expected that the number of failures would increase due to the storage situation during the suspension period and the restart of the telescope system. In the three months after return to normal operation of the telescope, there have been no receiver failures despite the long-term outages. The number of repairs has recently decreased to three or less per year, and initial failures have decreased. Although the frequency of repairs caused by aging failure is currently kept low, an increase of the failure rate cannot be denied when the wear failure period begins according to the bath-tub curve. In order to continue stable operation of ALMA, it is important to maintain a maintenance system in ATC that can quickly respond to ALMA receiver failures.

The inventory of maintenance parts is managed according to the current average number of repairs over several years. However, for long-term operation, spare parts, materials for assembly, instruments for receiver evaluation systems, operating environment of the software for the evaluation systems, etc. will become obsolete, and it is necessary to conduct surveys and analyses, such as impact evaluations, to secure alternative parts and materials in response to the discontinuation of the products by manufactures. Some of the obsolescence may be overcome by development projects such as the wide IF Band 8 receiver project. Continuing the maintenance work over the long term is an issue, which will be addressed in the next fiscal year.

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

2) Future development

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

2-1) Receiver development for Bands 1 and 2

The Band 1 project (Radio Frequency (RF): 35–50 GHz, best effort to 52 GHz) led by ASIAA (Academia Sinica Institute of Astronomy and Astrophysics) as a contribution to East Asia ALMA has gone into production phase. We are contributing the testing and production of corrugated horns, the support for cryogenic maintenance of cryocoolers at ASIAA, and support for procurement and shipping of several important components in cooperation with the NAOJ ALMA project. We have completed the procurement and delivery of the warm lenses under the collaboration agreement with the University of Chile (UdC), and procurement of the cryogenic amplifiers and photomixers for ASIAA. Under a collaboration agreement, we also tested several dozens of the corrugated horns, which were fabricated by traditional techniques at the University of Chile, and shipped them to ASIAA. As part of NAOJ’s work share, corrugated horns have been fabricated with the metal 3D printer and evaluated in close collaboration with Mechanical Engineering shop. Several corrugated horns with good room-temperature performance have been sent to ASIAA, and the cryogenic testing will be performed on Band 1 cartridges to confirm that they are suitable for production.

We have contributed to the Band 2 project (RF: 67–116 GHz) led by ESO (European Organization for Astronomical Research in the Southern Hemisphere) with the design, fabrication, and testing of waveguide components and receiver optics based on a dielectric lens. Band 2 receiver preproduction (first 6 receivers) was approved by the ALMA Board in April 2019. NAOJ has manufactured optics component including a corrugated horn, circular-square waveguide transition, and waveguide orthogonal mode transducer; and their RF characterization has been performed at room temperature. We also redesigned and manufactured a dielectric lens based on characterization results of the material with a material characterization system established at NAOJ. Furthermore, to improve the receiver noise temperature, low loss dielectric materials and alternative optics configurations are under investigation.

2-2) Development for the next generation projects

Ultra-wideband receivers are being developed for future ALMA receiver upgrades. A double sideband (DSB) mixer developed at ATC has showed quantum-limited performance in the 275–500 GHz RF range across 3–22 GHz Intermediate Frequency (IF). Based on this DSB mixer, we have performed experimental studies to demonstrate a wideband sideband separating (2SB) receiver. The measured receiver noise temperature and image rejection ratio showed reasonably good performance. In addition, we have collaborated with external institutes and universities on wideband receiver development. Osaka Prefecture University (OPU) has proceeded with the development of a Band 6+7 (211–373 GHz) receiver in collaboration with NAOJ. Based on the wideband DSB mixer developed at NAOJ, OPU installed the receiver into the 1.85-m telescope located in Nobeyama Radio Observatory, and then succeeded in simultaneously observing 6 spectral lines of CO molecular isotopes in the 230 GHz and 345 GHz bands. These activities demonstrate future prospects for implementation in ALMA. Furthermore, NAOJ has produced and tested ALMA Band 8 receiver (385–500 GHz) components with wide IF bandwidth in collaboration with several domestic universities in order to demonstrate astronomical observations. In this fiscal year, we procured components necessary for DSB mixer assemblies and completed RF performance testing of several DSB mixers to be installed on telescopes in next fiscal year or later.

The terahertz (Band 10) receiver technologies have been developed for 2SB receivers for which a compact 2SB mixer block integrated with RF waveguide components, mixer chip slots, and 4–12 GHz IF planar circuits were assembled and tested at the Band 10 frequencies. We confirmed reasonable performances.

Connected to the work remaining from the previous year, we fully assessed a Band 4 (125–163 GHz) 2 x 2 prototype SIS array receiver, which was developed by implementing the hybrid planar integration (HPI) scheme. The measurement results conclusively proved the innovative approach by showing uniform LO distribution and low crosstalk between pixels. Simultaneously, we designed, fabricated, and tested silicon based monolithic microwave integrated circuits (MMICs) for 2SB mixing. Preliminary results demonstrated 2SB mixing.

We continued the investigation of Nb/Al/AlN$_x$/Al/Nb junction fabrication with unusually high critical current density, which is the crucial requirement for broadband SIS receivers. Excellent reproducibility and a record in critical current density of up to 60 kA/cm^2 were achieved. We also proceeded with the fabrication of MMIC-type SIS mixers implemented with the HPI scheme. In addition, we continued the study on fabricating anti-reflection layers on silicon with the deep reactive etching process by successfully fabricating double layer anti-reflection surfaces. The measured performance is nearly consistent with theoretical expectations. With these micro-machined surfaces, highly transparent vacuum windows fabricated with wafer bonding techniques are under investigation.

(3) KAGRA

In collaboration with the Gravitational Wave Project, we are developing the vibration isolation system (VIS) and the auxiliary optics system (AOS) of KAGRA, and preparing instruments for evaluating the performance of the mirrors. Here the AOS means the optical devices required for the construction of the KAGRA interferometer, such as optical baffles to mitigate stray light effects, optical angle sensors, beam reducing telescope (BRT) optics, cameras for beam monitoring, and viewport windows. For both AOS and VIS, we had completed the required works for the construction of KAGRA by the last fiscal year, and so KAGRA was able to do its observational operation (called O3GK) in early FY 2020. So far, many instruments essential for the observational operation of KAGRA have been delivered, and so ATC's contribution is one of the largest in terms of both quality and quantity within the KAGRA collaboration.

In the international network of gravitational wave observation involving LIGO, Virgo, and KAGRA, the next fourth observation phase (O4) is scheduled to start sometime after June 2022. In this fiscal year, we designed various modifications to the AOS that were planned for O4 (such as the adjustment mechanism of the BRT vibration isolator, the cover of the optical angle sensor, and optical filter holders), as well as the mirror performance evaluation system. We also started the planning of the VIS refurbishment in anticipation of the next observation operation (O5).

4. Advanced Technology Developments

(1) CLASP2/SUNRISE-3/SOLAR-C

ATC has cooperated with the SOLAR-C Project to develop space-/balloon-borne instruments in the advanced technology development program. The ATC team members in the CLASP2 project received the Group Achievement Honor Award from NASA Marshall Space Flight Center for their contributions to the successful launch experiment in April 2019. The team also has a re-flight opportunity in Fall 2021 and has started preparing CLASP2.1 for the flight. In the development of the spectro-polarimeter SCIP for the balloon experiment SUNRISE-3, the adjustment of optical components and the assembly of the whole system were completed in the ATC cleanroom. After the performance test in the atmospheric conditions, the instrument performance was examined under the pressure and thermal conditions for the flight environment in the largest ATC vacuum chamber.

The SCIP will be shipped to Germany in mid-2021 for the flight experiment in June 2022. ATC has contributed to the optical design study of the Solar-C_EUVST project, which was selected in May 2020 as the fourth JAXA small-satellite mission. The preparation for functional improvements of the ATC vacuum chambers to be used has started for the coming development activity phase of this satellite project.

5. Open-Use Programs, Joint research and Development

We categorize open use programs as facility use programs or collaboration programs depending on the ATC facilities used and the commitment of ATC members. In FY 2020, we made calls for open use programs twice, accepting applications for 15 collaboration programs and 14 facility use programs. The effect of COVID-19 limited the operation of common use programs. With countermeasures against the infectious disease, common use programs have been started according to their urgency. Applicant names and program titles are listed in the section “Open Use Programs, etc.” The results of the programs can be found on the ATC homepage.

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. Until FY 2019, the Center was comprised of the following sections: 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), and the General Affairs Office. However, in this fiscal year, Ishigakijima Astronomical Observatory was separated from Mizusawa VLBI Observatory and incorporated into the Public Relations Center, so it is now comprised of 7 offices, 1 unit, and 1 observatory.

2. Personnel

In FY 2020, the Public Relations Center was composed of Acting Director Junichi Watanabe and the following staff members: 1 professor, 1 project professor, 2 associate professors, 2 assistant professors (each holds concurrent posts), 1 research engineer, 1 engineer, 1 section leader, 6 senior specialists, 2 project research staff members, 2 research experts, 1 technical expert, 2 administrative experts, 2 research supporters, 1 technical support staff member, 15 public outreach staff members, and 2 re-employment staff members.

On April 1, public outreach staff Mikiya Sato arrived in the Outreach and Education Office; and project research staff Hidekazu Hanayama, project research staff Takashi Horiuchi, technical expert Kanae Shimada, administrative expert Kanae Endo, and technical supporter Satoru Konishi at Ishigakijima Astronomical Observatory/VERA Ishigakijima Station changed their affiliations to Public Relations Center.

On June 30, research supporter Junko Tsuneyama resigned (Spectrum Management Office).

On October 1, research supporter Maki Ozaki arrived in the Spectrum Management Office.

On March 31, technical expert Kanae Shimada and technical supporter Satoru Konishi changed their affiliations from the Public Relations Center because of an internal reorganization.

3. Public Relations Office

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

(1) Online-Based Information Sharing

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

The Office opened Twitter, Facebook, and Instagram accounts in both Japanese and English sequentially from 2010, actively disseminating information on social networking services. Our office disseminates information on the status of various NAOJ projects such as public visits, regular stargazing parties at Mitaka Campus, and position openings, both in English and Japanese. As of the end of March 2021, the number of twitter followers of our Japanese language account is approaching 230,000, and that of our English language account exceeds 7,800. Information dissemination via the English version of Twitter, as well as the release of visual images on Instagram have been conducted continuously this year.

NAOJ e-mail newsletters No.215–226 were issued, introducing research results and NAOJ hosted events.

We continued to produce videos explaining astronomical phenomena and research results, and videos introducing outreach activities. Including English versions, 25 original videos were produced. The videos are uploaded mainly on YouTube.

Month	Access counts	Month	Access counts	Month	Access counts
April 2020	649,092	August 2020	1,805,833	December 2020	1,373,250
May 2020	734,099	September 2020	666,985	January 2021	694,513
June 2020	1,447,258	October 2020	921,413	February 2021	559,245
July 2020	1,114,619	November 2020	775,608	March 2021	496,508
Total: 11,238,423					

Table 1: Monthly website access statistics for the Public Relations Office website, NAOJ Public Relations Center (April 2020–March 2021).

Starry Sky Information Movies (June 2020 to March 2021, uploaded monthly, totaling 12 videos)	Japanese Version
NAOJ Introduces Metal 3D Printer!	Japanese Version
NAOJ Introduces 5-axis Machining Center!	Japanese Version
Classifying Galaxies with Artificial Intelligence	Japanese/English Versions
6-m Millimeter-Wave Radio Telescope at NAOJ Mitaka Campus	Japanese Version
Unraveling a Spiral Stream of Dusty Embers from a Massive Binary Stellar Forge (Subaru Telescope Channel)	Japanese/English Versions
How to Assemble the NAOJ Telescope Kit	Japanese Version
Take Me to The Moon	Japanese Version
Cosmic Tours with the Subaru Telescope (Inter-University Research Institute Corporation Symposium 2020) (Subaru Telescope Channel)	Japanese Version
Virtual tour of the Subaru Telescope's Base Facility (Subaru Telescope Channel)	Japanese Version
50-cm Telescope for Public Outreach at NAOJ Mitaka Campus Captures Hayabusa2	Japanese Version

Table 2: Summary of Produced Videos.

As of the end of March 2021, these videos have accumulated a total of 2,390,576.4 hours of play time (473,123 hours in FY2019) and 3,745,638 views (1,117,295 views in FY2019). We received positive feedback for our live stream of celestial bodies with the 50-cm Telescope for Public Outreach, and of a partial solar eclipse, which was observed simultaneously from three locations: Mitaka Campus, Ishigakijima Astronomical Observatory, and Nayoro City Astronomical Observatory. Related to this, we have been approved as an official program by DWANGO Co., Ltd., which manages niconico Live, a video streaming service, and our viewers are increasing. There were 425,128 views of the solar eclipse in real time on YouTube live, and additional views of the archive. This increase is likely a result of people staying at home due to the novel coronavirus (COVID-19) crisis. On April 28, we live streamed a special lecture program for high school students, and starting from November 2020, we provide an online mini-lecture for elementary school students once a month. Mitaka Open House Day and Special Open House Day for Nobeyama Radio Observatory were both held online, and we focused on creating live stream programs.

(2) Research Result PR

There were 30 research result announcements (compared to 33 in FY 2019 and 26 in FY 2018). We released 29 of them in both English and Japanese. For domestic audiences, we have continued to organize press conferences, as well as mail press releases to an original media list. For press releases aimed towards overseas audiences, we have continued to use the delivery services of the American Astronomical Society (until October 2020), AlphaGalileo, and EurekAlert! from AAAS, and mail press releases to an original media list.

We held two sessions of “Astronomy Lecture for Science Journalists.” One was held as the 26th lecture in cooperation with the TMT Project on October 28 with the theme of “The Universe Revealed by TMT and Current Status of the Plan.” The other was held as the 27th lecture on December 15 with the theme of “GALAXY CRUISE: Citizens helping to unlock the secrets of galaxies,” introducing the citizen astronomy project “Galaxy Cruise.” Both were held online. There were 28 participants (17 media companies) and 14 participants (13 media companies) respectively.

(3) Activities as NAOJ’s Public Relations Center

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

The Public Relations Office organized lectures with research projects. On March 6, 2021, the NAOJ lecture meeting/25th ALMA public lecture “Stars born from dark clouds — from the observation site to the latest results” was held with 418 simultaneous connections. As of March 31, the video of this lecture has accumulated over 25,000 views.

To raise NAOJ’s international profile, we regularly hold booths at international meetings where the press, researchers, and educational officials gather. This fiscal year, we held a booth and a sponsored workshop at the 2021 AAAS Annual Meeting (AAAS2021, held online from February 8–11) jointly with four other institutes, and our online booth attracted a total of 203 visitors. With the cooperation of the Foreign Press Center Japan (FPCJ), we held an online seminar titled “The Seven Samurai of Science -Confronting Global Challenges-” jointly with five other institutes on February 18, 2021, mainly targeting foreign media based in Japan. This seminar was attended by eight foreign media representatives, four domestic media representatives, and 13 people involved in public relations.

To support outreach efforts of other projects, we contributed to launching new websites for the 4D2U Project (website creation), the Office of International Relations (website creation and translation), and the NAOJ Gender Equality Promotion Committee (translation).

(4) New Astronomical Objects

Four staff members, including one full-time and three contract employees, handled reports of new astronomical objects and other communications submitted to NAOJ. In this fiscal year, there were a total of 34 reports including confirmation requests for new celestial object candidates

April 28, 2020	TAMA300 Blazes Trail for Improved Gravitational Wave Astronomy
May 14, 2020	TRAPPIST-1 Planetary Orbits not Misaligned: First Scientific Result by the New Spectrograph on the Subaru Telescope
May 22, 2020	ALMA Spots Twinkling Heart of Milky Way
June 2, 2020	Large Simulation Finds New Origin of Supermassive Black Holes
June 11, 2020	New Method to Study Barred Spiral Galaxies
July 10, 2020	The Lion's Roar: New Telescope Spots Superflare in Leo
July 15, 2020	Subaru Telescope and New Horizons Explore the Outer Solar System
August 11, 2020	Classifying Galaxies with Artificial Intelligence
August 13, 2020	That Must've Hurt: Ganymede Covered by Giant Crater
August 27, 2020	Rare encounters between cosmic heavyweights
September 4, 2020	Misaligned Planet-Forming Rings around Triple Young Stars
September 15, 2020	Phosphine on Venus – A step forward to understand biomarker molecule
September 16, 2020	Unraveling a Spiral Stream of Dusty Embers from a Massive Binary Stellar Forge
September 25, 2020	Pair of Massive Baby Stars Swaddled in Salty Water Vapor
September 29, 2020	Second Alignment Plane of Solar System Discovered
October 12, 2020	Studying the Sun as a Star to Understand Stellar Flares and Exoplanets
October 28, 2020	Galaxies in the Infant Universe were Surprisingly Mature
December 8, 2020	Study Confirms Dark Coating Can Reduce Satellite Reflectivity
December 18, 2020	Compressive Fluctuations Heat Ions in Space Plasma
December 18, 2020	The Subaru Telescope Photographs the Next Target Asteroid for Hayabusa2
January 26, 2021	When galaxies collide—Models suggest galactic collisions can starve massive black holes
February 16, 2021	Supercomputer Turns Back Cosmic Clock
February 20, 2021	Sounding Rocket CLASP2 Elucidates Solar Magnetic Field
May 10, 2021	Star Formation Triggered by Cloud–Cloud Collisions
March 19, 2021	American Astronomers Find Secrets of Japanese Universes
March 29, 2021	Stellar Eggs near Galactic Center Hatching into Baby Stars

Table 3: Web Releases.

August 1, 2020	Machine Learning Finds a Surprising Early Galaxy—Breaking the Lowest Oxygen Abundance Record
August 7, 2020	Stellar Egg Hunt with ALMA—Tracing Evolution from Embryo to Baby Star
August 31, 2020	Can Black Hole Fire Up Cold Heart of the Phoenix?
November 26, 2020	Earth Faster, Closer to Black Hole in New Map of Galaxy

Table 4: Press Conferences.

and other reports. The contents were: 22 novae/supernovae, 3 comets/cometary objects, 1 star, 3 asteroids, 1 fireball, 2 luminous objects, 1 moving celestial object, and 1 other. Among the many examples of reporting a known asteroid or ghosts as a new object, the report of an object in July 2020 was communicated through NAOJ to the IAU Central Bureau for Astronomical Telegrams (CBAT) and was recognized as the discovery of the nova V6568 Sgr. Furthermore, the two reports of objects in March 2021 were communicated through NAOJ to CBAT as well and were recognized as a discovery of the nova V1405 Cas and an independent discovery of the nova V6594 Sgr.

(5) Citizen Astronomy (Shimin Tenmongaku)

Together with Subaru Telescope, we jointly developed the GALAXY CRUISE website, through which citizens participate in galaxy classification. Both Japanese and English versions were released last fiscal year. This fiscal year, we implemented campaigns in August and the end of the year, which steadily increased the number of both participants and classified galaxies. As of March 1, 2021, there are 6,407 registered participants from 81 countries and regions, and the total classification results exceed 1,340,000. This project appeared in news coverage on TV and in newspapers repeatedly, and we received many invitations to speak at international conferences and seminars.

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

4. Outreach and Education Office

In FY 2020, the COVID-19 pandemic forced us to suspend, scale down, or restructure many of our outreach and education activities.

	Solar Ephemeris	Lunar Ephemeris	Ephemeris	Time	Solar System	Universe	Astronomy	Other	Total
April–June	135	33	8	4	68	34	28	172	482
July–September	96	62	19	3	285	95	72	337	969
October–December	114	124	30	5	369	104	66	341	1153
January–March	85	55	174	14	100	86	52	224	790
Total	430	274	231	26	822	319	218	1074	3394

Table 5: Telephone inquiries made to the Outreach and Education Office of the NAOJ Public Relations Center (April 2020–March 2021).

(1) Public Visits

A total of 6,237 people participated in Mitaka Campus Public Visits (former name was Visitors' Area) in FY 2020. In addition, the group tours in 2020 consisted of 8 general tours (355 guests), for a total of 6,592 guests visiting Mitaka Campus. Public visits scheduled for April 1–June 14, 2020 and January 9–March 21, 2021 were all canceled to prevent the potential spread of COVID-19. Even after the public visits program resumed, we implemented preventive measures, restricting public access to within the outdoor areas, and canceling the acceptance of general group tours.

Regular stargazing parties, which are usually held twice a month (the day before the 2nd Saturday and the 4th Saturday) with the 50-cm Telescope for Public Outreach, were canceled in FY 2020 due to the COVID-19 pandemic. Instead of on-site stargazing parties, we held "online stargazing parties" on YouTube Live every fourth Saturday (excluding October due to Mitaka Open House Day) starting from August, which have taken place seven times and accumulated 12,891 views as of April 7, 2021. Using the 50-cm telescope, we also photographed the re-entry capsule of Hayabusa2 and the great conjunction of Jupiter and Saturn, sharing these photos on social media.

Because of a reduction in staff, the number of days reserved for regular public screenings at the 4D2U Dome Theater was reduced from four times a month to three times a month (1st, 3rd Saturday and the day before the 2nd Saturday). Additionally, a reduced number of actual screening days (35 days to 7 days) and capacity (from 40 seats to 14 seats) due to the COVID-19 pandemic resulted in only 255 visitors being able to participate in the screening events. "Astronomers' Talks," mini-lecture events, and private screening for groups were canceled. In addition, 21 group tours (140 people) were organized and a total of 395 guests watched the 4D2U stereoscopic movies.

(2) Telephone Inquiries

Because of a reduction in workforce, the number of staff assigned to handle telephone inquiries on a given day was reduced from two to one.

Different from previous years, we accepted inquiries only from the media and public agencies from April 1 to May 31 as a protective measure against COVID-19.

The office received inquiries and letters from the media, government offices, and the general public. The Outreach and Education Office responded to 3,394 inquiries (594 of which were from the media) (Table 5) and 91 letters, 28 of which were official documents.

(3) Media Reception

We received 151 interview and filming requests from various media. Among these, we dealt with 140 requests. The contents were: 52 news-paper articles; 52 TV programs (25 news programs, 8 science programs, 1 drama, 18 others); 16 publications (6 magazines, 4 books, 6 others); 9 website contents; 5 exhibitions; 1 radio program; 2 animated movies; and 3 others. In FY 2019, we started to charge a fee for commercial filming and photography in the campus. This fiscal year, we received 1 filming request from a drama.

(4) Educational and Outreach Activities

The "FUREAI (Friendly) Astronomy" project, now in its 11th year, started to provide online lectures via a video conferencing system this fiscal year to prevent the spread of COVID-19. On-site lectures were also delivered as in previous years, when the situation allowed. Lectures were also provided for schools for the deaf, special-needs schools, and evening junior high schools, as well as Japanese and supplementary schools around the world. Our lectures were delivered at a total of 99 schools (69 in Japan and 30 overseas), with a total of 6,529 participating children and students, ranging from 2 to 370 in each lecture, and with 64 lecturers. In 11 years, 72,960 students in total have attended the lectures in 783 schools inside and outside Japan.

"Mitaka Open House Day" was held online this year, and we participated as part of the secretariat under the direction of the steering committee, and contributed to some pieces of the content. This event was held with the theme of "The Unknown Dark Universe" under the auspices of NAOJ; the Astrobiology Center; the Institute of Astronomy, the University of Tokyo; the Department of Astronomical Science, SOKENDAI, and with the cooperation of the TV Asahi program "GARIBEN GIRL V." The online event was held on October 24, 2020 (Saturday), consisting of the main live program and seven special content programs live-streamed on YouTube and niconico Live. This series of programs was designed to follow the storyline through seven sections, from the Solar System to the outer reaches of the Milky Way Galaxy, with researchers providing lectures in each section. Videos introducing technical and administrative staff and their activities and question-and-answer sessions were also included in these programs. The event lasted over eight hours, garnering 11,220 views on YouTube and 17,701 viewers on niconico Live.

(5) Community Activities

The “Mitaka Picture Book House in the Astronomical Observatory Forest” welcomed 12,166 visitors in FY 2020. The Office supervised an exhibition “Universe and Life” (July 2020 to June 2021). We were able to have a conversation between the Director General and the mayor for its opening anniversary, but unfortunately COVID-19 precautions did not allow us to host traditional Tanabata and moon viewing 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 5 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 canceled due to the COVID-19 pandemic. Instead of this event, an online event titled “Mitaka TAIYOKEI walk will not stop” was held with the cooperation of NAOJ and interested staff members.

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

The “Information Space of Astronomy and Science,” which is jointly operated by Mitaka City, Mitaka NETWORK University Organization, and Mitaka Town Management Organization, marked the sixth anniversary since its foundation in September 2015. In FY 2020, a total of six exhibitions were held at this space, of which one was planned and held by the Public Relations Center. Also, the office offered outreach videos and monthly astronomical information images through largescale information displays. This fiscal year saw approximately 5,170 visitors. The number dropped by almost 10,000 compared to an average year most likely because operating days and hours had to be reduced given the continuing COVID-19 pandemic. However, the space has accumulated over 84,000 visitors since its foundation, and is now recognized as a place where the public can get to know more about science in an urban environment.

(6) Merchandizing Business

The “You are Galileo!” project was launched in 2008 aiming to provide more opportunities for the world’s children to observe the sky through astronomical telescopes. In FY 2020, the project advanced the development, production, and sale of a telescope kit. The kit was originally named the “NAOJ Telescope Kit,” but the IAU calls it the “Kaifu-NAOJ Telescope Kit.” These 5-cm aperture telescopes, with eyepieces of 16x and 66x magnification, started to be sold and distributed in July 2019, and approximately 4,000 kits were sold in this fiscal year.

As for web content, we created “Astronomy Information” to provide monthly star charts, planetary phenomena, and other remarkable astronomical phenomena information. We also created a web page to provide information about when and where Comet C/2020 F3 (NEOWISE), which became bright in July 2020, could be seen. We revised seven items, by updating or adding more information, on the “Frequently Asked Questions” page, where frequently asked inquiries and their answers are aggregated.

5. Spectrum Management Office

This is the second year since the establishment of the Spectrum Management Office. Its start-up phase is almost over, and we have entered into a normal operation state. The Office currently consists of three members, of which two are dedicated members (Head and a research supporter) and one who holds a concurrent post. One research supporter left the office in late June due to expiration of the employment contract, and the successor was appointed on October 1. Our scope of activities is broad, including both domestic and international affairs. At the time of establishment, our focus was the protection of the radio astronomy environment, but the rise of issues surrounding mega-constellations has suddenly forced us to address light pollution concerns as well. This fiscal year, we participated in one international meeting and 22 domestic meetings. In addition to these, we also participated in e-mail discussions and video conferences as needed.

(1) International Meetings

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

The WP7D meeting was held online from September 14 through 18, 2020, because of the temporary closure of the ITU headquarters and travel restrictions between Japan and Europe due to the COVID-19 pandemic. The major items discussed included: allocation of frequency bands for expanding mobile phone use; mobile phone communication via high altitude platforms; and new allocation in the 22 GHz band, where water maser emissions are observed. The discussion was still in the early stages, so the main part of our activities was sending protection criteria of radio astronomy observations to other working parties responsible for consideration. It was agreed to create a new report under the name of ITU-R to make the importance of geodetic VLBI known to a wider audience.

We also held online meetings as needed to exchange opinions and strengthen ties with people involved in 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) Regulations Imposed on Mega-constellations: Mega-constellations, such as Starlink and OneWeb, aim to deploy large swarms of satellites to provide global internet access. There are concerns that such satellites constellations could

interfere with radio astronomy because they are designed to operate in the frequency bands adjacent to the 10.6–10.7 GHz radio astronomy band. It was agreed to impose restrictions on the 10.7–10.95 GHz emissions from Starlink satellites as in the case of OneWeb, which was considered first.

2) Outdoor Use of UWB Systems: It was agreed that the unwanted emission levels from ultra-wideband radio (UWB) systems would be reduced so that they would not interfere with the 6.7 GHz CH_3OH maser emissions, and that the general users would be informed not to use UWB systems near radio astronomy observatories.

3) Wireless power transmission (WPT) systems use the 920 MHz, 2.4 GHz, and 5.7 GHz bands to transfer electric power, and thus they should adversely affect not only ratio astronomy observations but also various radio communication systems. To avoid any interference, it was decided to register radio observatories in a database and avoid using WPT systems around these observatories.

4) Other Matters Considered Include: reconciliation to protect radio astronomy observations from the interference from satellite communication systems that are operated by universities and operate in the 1.6 GHz band; reconciliation to prevent synthetic aperture radar systems that operate in the 9 GHz band from adversely affecting radio astronomy observations; and reconciliation to prevent obstacle detection radar systems installed at airport runways from adversely affecting radio astronomy observations.

(3) Designation of Receiving Equipment

Designation of receiving equipment should be conducted based on the Radio Law, Article 56. Once it is approved, a radio station must be operated in such a way as not to cause interference or any other obstruction that impairs the operation of radio astronomy stations or equipment designated by the Ministry of Internal Affairs and Communications. This fiscal year, we renewed the designation of four VERA stations, whose designated periods expired in December 2020, and successfully obtained approval.

(4) Light Pollution

1) Light Pollution Caused by Mega-constellations (such as Starlink)

The IAU and NAOJ have issued statements that express concerns over the possible impacts of mega-constellations, such as Starlink and OneWeb, which aim to deploy large swarms of satellites to provide internet access around the world. Considering the efforts of mega-constellation operators to reduce the reflectivity of their satellites, together with Ishigakijima Astronomical Observatory we measured the brightness of Darksat, a Starlink satellite treated with a dark coating. The satellite was observed simultaneously in three bands (g', Rc, and Ic), and the results were published in The Astrophysical Journal (ApJ) in December 2020. These observations allowed us to quantitatively evaluate how much dark coating can reduce satellite reflectivity, and the results were shared with SpaceX. This research has attracted much attention from the media, and we have received many inquiries from both inside and outside Japan.

2) Addition of a New Webpage

We added a new page for light pollution to our website to raise awareness of light pollution issues among a wider audience. (https://prc.nao.ac.jp/freqras/light%20pollution.html)

6. Ephemeris Computation Office

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

(1) ECO published the “Calendar and Ephemeris 2021” and compiled the Ephemeris section of the “Rika Nenpyo 2021” (Chronological Scientific Tables). ECO also posted the “Reki Yoko 2022” in the official gazette on February 1, 2021. In addition to those paper-oriented products, ECO maintains web versions of “Calendar and Ephemeris” and “Reki Yoko” and updated their data simultaneously with the release of “Reki Yoko.” The publication of the “Calendar and Ephemeris” was delayed due to the COVID-19 pandemic. ECO temporary released the pdf edition without tidal data on May 1, then released another pdf edition including tidal data on June 19, and finally the paper edition in August. Because of the changes in the holidays in 2021 caused by the postponement of the Tokyo Olympic and Paralympic Games, ECO revised the web version of “Reki Yoko 2021,” posted a topic on the website, and

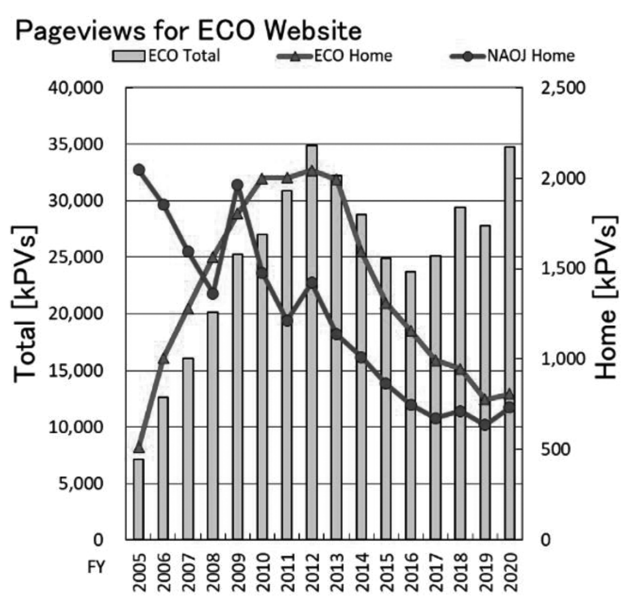

Figure 1: Pageviews for ECO Website.

released an article in the official gazette on December 28 jointly with the Cabinet Secretariat and Cabinet Office.

(2) ECO made the website compatible with dark mode and released long term versions of Koyomi Station and Celestial Phenomena. Despite the end of the astronomical phenomena awareness campaigns, ECO displayed the radiant points of the Perseid and Geminid showers and the place of Comet NEOWISE in the Sky Viewer. In FY 2020, there were about 34 million page views for the ECO website.
https://eco.mtk.nao.ac.jp/koyomi/index.html.en

(3) The COVID-19 pandemic forced the Japan Association for Calendars and Culture Promotion, hereafter JACCP, to cancel Mini Forum and its 10th General Meeting. Instead, JACCP released videos of lectures and a panel discussion looking back on its 10-year history. The annual Calendar Presentation Ceremony was held with a limited number of people. The research materials collected by the late Dr. Yoshiro Okada, the Supreme Academic Advisor of JACCP, were donated to NAOJ by his family. They are now partially available at the Yoshiro Okada collection site.
https://library.nao.ac.jp/kichou/okada.html

(4) ECO usually holds a regular exhibition presenting NAOJ's invaluable collection of historical archives of Japanese and Chinese books in collaboration with the Library. However, in FY 2020, it was suspended the due to the COVID-19 pandemic. Past exhibitions, including the dormant 59th exhibition "Promotional Calendars from the Yoshiro Okada Collection," are available at the Rare Materials Exhibition website.
https://eco.mtk.nao.ac.jp/koyomi/exhibition/

7. Library Unit

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

The library was originally open to those outside NAOJ on weekdays, but due to the COVID-19 pandemic, it suspended public access to library materials since last fiscal year, and throughout this fiscal year. But even in this situation, we continued to lend or provide photocopies of materials that are not available at other libraries. These materials were provided to the general users through public libraries, and to researchers and students belonging to other institutions through the libraries of their institutions. A total of 55 materials were provided this fiscal year including both original materials and photocopies.

We also provided a remote service to NAOJ members off-campus.

Important documents, especially those originating from the Edo Era Tenmonkata (Shogunate Astronomer), are preserved while taking into account the environment of a specialized library. Images of some of the important documents are available to the public on the Library Unit homepage, and were exhibited at the National Museum of Nature Science. We also lent our documents to history and art museums for exhibitions. These items have appeared in various external publications.

For the 2020 Special Open House Day, which was held online in October, we created a special web page that lists books and other materials housed in our library. We also featured photos of the reading room on the first floor, allowing people to virtually stroll through 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 PR and promotions. The following periodicals were also published this year:

- Annual Report of the National Astronomical Observatory of JAPAN Volume 32 Fiscal 2019 (Japanese)
- Annual Report of the National Astronomical Observatory of JAPAN Volume 22 Fiscal 2019 (English)
- NAOJ Pamphlet (Japanese)
- NAOJ News, No. 321–No. 332 (April 2020 – March 2021)
- NAOJ Calendar (The 16th in the series)

In FY 2019, the office revised the NAOJ pamphlet (Japanese), and published the Annual Report of the NAOJ (Japanese/English versions) and the 21st Report of the National Astronomical Observatory of Japan. In the systematic production of special editions with the goal of developing project outreach support in NAOJ News, we produced "Subaru Telescope 2020 Special Editions" (Part 1 September, Part 2 November). In the current situation where there is concern about the impact on astronomy observations from satellite constellations to establish global high-speed communication (mega-constellations), the Research Topics in the May 2020 and March 2021 editions focused on this subject. Other than periodicals, the 2021 calendar "Scenes from NAOJ Telescopes 2021" (the 16th since 2005) was created. As in other years, editing support was also given to the publication of the "Rika Nenpyo 2020 (Chronological Scientific Tables, Astronomy section)." In addition, the office continued to support the English production and editing of releases, publications, and web content both inside and outside of NAOJ.

9. IAU Office for Astronomy Outreach (OAO)

The IAU Office for Astronomy Outreach (OAO) is a joint venture between the IAU and the National Astronomical Observatory of Japan (NAOJ). The OAO is primarily responsible for managing the IAU's communication and accessibility initiatives and supporting the international network of IAU Outreach National Coordinators (NOCs) in 136 countries and regions.

During the Fiscal Year of 2020–2021, we highlight the implementation of the OAO External Review 2020 that led to the successful signing of the new OAO Agreement between the IAU and NAOJ. We also note the significant adjustments that needed to be carried out in our annual planning due to the impact of the COVID-19 pandemic in order to better support our communities.

Among the key relevant activities carried by the office, we highlight the NOCs management and engagement, leading to an increase in representation to 136 countries and regions, 14 more than the previous FY, the conclusion of the NOCs Funding Scheme 2020 with 4 projects funded in 2020 and the implementation of the second edition in 2021 that involved 24 proposals, involving 46 NOCs and collaboration with the SKAO outreach network that increased the budget for this funding.

We also highlight the publication of Issues #28 and #29 of the Communicating Astronomy with the Public (CAP) Journal. Issue #28 was a special on the IAU 100 years celebrations with 10 articles and 49 contributors published in November. Issue #29 was a regular issue with 7 articles and 22 contributors published in March 2021. Additionally, the OAO launched a call for a special issue of CAPjournal seeking articles on Astronomy Communication in a Time of Confinement that received nearly 60 submissions from around the world.

Regarding IAU communication channels, we have successfully generated a 9 % growth in our IAU Facebook channel with 18,000+ followers. On IAU Twitter we had a 20 % growth rate, reaching 12,700 followers. In our OAO channels, we have successfully generated a 32 % growth in our OAO Facebook channel with 7,500+ followers. On OAO Twitter, we had a 27 % growth rate, reaching 3,500+ followers. The office also delivered 160+ astronomy outreach/education news items through 23 issues of the IAU Astronomy Outreach Newsletter to 4,500+ subscribers worldwide, translated into six different languages by volunteers.

With the COVID-19 pandemic strongly affecting our daily lives and the lives of the members of our networks of outreach practitioners, many of our annual plans changed to adapt to the circumstances and better serve and support our communities.

From these activities, we highlight the direct engagement of 34 countries with Telescopes for All 2020 that included a digital camera to support online sharing of the observations; the Astronomy@Home Awards with over 240 reports from 59 countries and regions; launching our annual event calendar with over 390 activities registered; the Meet the IAU Astronomers! program and a hybrid version of the IAU Outreach Visitors program.

Emphasis on online communication channels, sharing online activities and resources through the IAU and OAO media platforms, recognizing the inspirational examples of the community, and providing access to professional astronomers are some of the examples of how the office worked to support the community. In parallel, and not neglecting those who have little to no internet accessibility, we have tried to incorporate safe alternative actions for our community. It is our commitment to identify the needs and provide solutions that can mitigate the negative impact in the communities we serve.

10. Ishigakijima Astronomical Observatory

In FY 2020, public access was canceled for almost the entire year as a result of protective measures against the COVID-19 pandemic and the partial closure of Maesedake Rindo, the road leading to the observatory. In public outreach, the facilities were open to the public only during parts of April and July for an annual total of approximately 100 visitors. On the other hand, the observatory was involved in many online activities, such as broadcasts of astronomical phenomena and website planning. In education, we visited junior high and high schools to give lectures and conducted online observations, and in September, Minister Haguida of Education, Culture, Sports, Science and Technology became the first minister to visit the facility. In research, 3 refereed papers were published on topics including observations of Starlink satellites, bringing the total number of papers published based on data from Ishigakijima Astronomical Observatory to 29.

(1) Public Outreach Activities

[Guided Tours, 4D2U Theater, Stargazing Sessions]

Stargazing sessions and screenings at the 4D2U Theater were canceled as protective measures against the COVID-19 pandemic. In response to the declared state of emergency, on April 10 the facilities closed entirely to the public, including guided tours. After that, when sufficient preventative measures against the COVID-19 pandemic had been implemented in accordance with the guidelines of NAOJ and Ishigaki City, on July 3 the facilities were partially reopened to the public. But Maesedake Rindo, the road leading to the observatory, was partially closed due to fear of a retaining wall collapse, forcing the facilities to reclose. The total number of visitors for the year was 117.

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

In June we participated in the online event “Observatory Meridian Relay All Japan” (4,352 views on YouTube) and presented the sight of a sundial during culmination. On the 21st of the same month, an internet broadcast of a partial solar eclipse covering 90 % of the solar disk was conducted from 3 locations, Ishigaki, Mitaka, and Nayoro, accumulating a record setting more than 500,000 views on YouTube. In August, the “Southern Island Star Festival” was held online, accumulating 8,295 views on YouTube.

In addition to photographs of Comet NEOWISE taken for use as public outreach images, photographs of nebulae, star clusters, galaxies, etc. taken with the Murikabushi Telescope were released. The Southern Cross Monitor had its lens replaced between summer and autumn, and it has been active as a Milky Way monitor. For the second year in a row, entries from observatory employees received Excellence Awards in the “2019 ‘Local’ Star View Photo Contest (GOTO INC).” In addition, together with Nayoro Observatory we conducted an alternative stamp rally (watching videos and answering a quiz to apply for the prizes).

(2) Educational Activities

The Chura-boshi Research Team Workshop for high school students was held online in September with 22 participants from across Japan. In the same month, Minister Hagiuda of Education, Culture, Sports, Science and Technology came for a tour; NAOJ Director General Tsuneta and NINS President Komori showed him around and explained the facility. In October, a lecture was held at the Ishigaki Youth House as part of the Ishigaki training (12 participants) of Koyo High School. In December, classroom visits and lectures were conducted for seniors at Ishigaki Junior High School (173 participants). And from October to December, we conducted cooperative lectures for “Certification of Astronomy Guides” (55 participants) of the University of the Ryukyus.

(3) Research Activities

Three refereed papers (supernova SN 2019ein, Starlink satellites, dwarf nova ASASSN-18aan) were published in western journals in FY 2020. The total number of papers including results based on Ishigakijima Astronomical Observatory observational data reached 29. There were 5 presentations at domestic and international conferences. Great successes were produced, in particular, one refereed report about quasars by project research staff member Horiuchi as primary author, and one refereed report about Starlink satellites as primary author. We observed 80 celestial objects over the course of 86 nights. Collaborative observations with OISTER, etc. observed 27 objects over 27 nights. Research fellow observations consisted of 29 objects over 71 nights. Public outreach observations consisted of 24 objects over 33 nights.

17. Division of Science

1. Overview

It has been two years since the Division of Science was established. The vision of the Division of Science was re-defined as follows and the research is being conducted accordingly.

- To advance the world class cutting-edge astronomy research, develope important research fields, and cultivate creative seed studies for new research fields.
- To facilitate the fusion between theoretical and observational research and advance multi-wavelength and multi-messenger astronomy.
- To promote internationalization as a national center.
- To contribute to future projects of the National Astronomical Observatory of Japan (NAOJ) based on free ideas.
- To cooperate with other projects of NAOJ and other domestic and international researchers to create new science.
- To nurture young researchers through education at graduate school and other opportunities.

The division handles a wide variety of themes in astronomy research, addressing a diversity of hierarchical structure of the Universe in terms of formation and evolution processes, dynamics, and physical state of matter, covering a span from the early Universe to galaxies, stars, planet formation and evolution, activities of compact objects, and plasma phenomena in astronomy and astrophysics; joint research with theoretical and observational astronomy using observational facilities of various frequency bands such as the Subaru Telescope, ALMA, and Nobeyama radio telescope; neutrino astrophysics; gravitational wave astronomy; and interdisciplinary research on the physics of elementary particles and atomic nuclei. The division members are also actively participating in developing the science for future observational projects.

The Division of Science like its predecessor, the Division of Theoretical Astronomy, aims to promote interaction with researchers at universities and other research institutes. However, face-to-face communications have been severely restricted in FY 2020 due to COVID-19. Instead, the division has been actively inviting domestic and international researchers to the division's online colloquia and seminars to promote discussions. It also provides the online opportunities to facilitate the communication among the division members, including lunch meetings and informal gatherings.

2. Current Members and Transfers

In FY 2020, the dedicated faculties of the Division of Science included four professors, one project professor, three associate professors, and seven assistant professors in addition to one adjunct professor and one adjunct assistant professor who concurrently held a primary position at the Center for Computation Astrophysics. They include four new members, who enhance the research activities of the division on exoplanets, magnetohydrodynamics, gamma ray bursts, and astrochemistry. In addition to these research and educational members, the division was served by eight project assistant professors, one project research staff member, one EACOA fellow, four special researchers of Japan Society for the Promotion of Science, one research supporter, and in addition three administrative supporters who gave full support to all activities of the division.

3. Research Results

The refereed research papers published by the division members as authors are more than 142 in number. Some of the research results are presented as the research highlights listed at the beginning of this report. The following highlights include research in which the division members took leading roles:

- Search for Extremely Metal-Poor Galaxies with Subaru HSC-SSP Data I: Development of the Machine-Learning Technique and the Discovery of a Galaxy with the Lowest Metallicity Found to Date (KOJIMA, Takashi, OUCHI, Masami, et al.)
- Enhancement of lithium abundances in red clump stars by neutrino magnetic moments (MORI, Kanji, KAJINO, Toshitaka, et al.)
- The screening effect on electron captures and type Ia supernova nucleosynthesis (MORI, Kanji, KAJINO, Toshitaka, et al.)
- Comparison between Core Mass Function and Stellar Initial Mass Function in Orion Nebula Cluster Region (TAKEMURA, Hideaki, NAKAMURA, Fumitaka, KAWABE, Ryohei, et al.)
- Star Formation Triggered by Cloud-Cloud Collisions in Orion A and M17 IRDC (KINOSHITA, Shinichi, NAKAMURA, Fumitaka, et al.)
- Invited review on observations of the Lyman-α Universe (OUCHI, Masami, et al.)
- Detectability of atmospheric signatures of habitable planets using future mid-infrared high-resolution spectroscopy from space. (FUJII, Yuka, et al.)

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

- A prediction of neutrino oscillations in electron capture supernovae (SASAKI, Hirokazu, TAKIWAKI, Tomoya, et al.)
- Systematic radiation-hydrodynamic simulations of transients powered by circum-stellar interaction (SUZUKI, Akihiro, MORIYA, Takashi, and TAKIWAKI, Tomoya)

4. International and Domestic Collaborations and Cooperations

Due to COVID-19, international conferences were severely limited in FY 2020. The international conferences that the members of the division organized or co-organized are as follows.

- The 9th Observational Cosmology Workshop
(2020/11/10~2020/11/12, online)

Other collaborations and cooperation are as follows:
Toshitaka Kajino was the chair of the Japan Forum of Nuclear Astrophysics, a member of the sigma committee of the Atomic Energy Society of Japan, a reviewer of the Yamada Science Foundation, a reviewer of JSPS, a member of the International Friends Committee of the American Physical Society, an Associate member of the European Center for Theoretical Studies in Nuclear Physics and related Areas (ECT*), an International Associate member of ChETEC-INFRA (Chemical Elements as Tracers for the Evolution of the Cosmos, INFRASTRUCTURES for Nuclear Astrophysics in Europe), a member of the International Editorial Advisory Board of the Uzbek Journal of Physics, and an Editorial Board member of Chinese Physics. Masani Ouchi chaired the Future Projects Study Group of the Group of Optical and Infrared Astronomers (GOPIRA), co-chaired the Galaxy Evolution Study Group with PFS of Subaru Telescope, co-chaired the ALMA Lensing Cluster Survey, and worked as the project leader of Extremely Metal-Poor Representatives Explored by the Subaru Survey for 3D. Hideko Nomura was the vice-chair of SPICA Research Promotion Committee and the Science Study Group. Yuka Fujii, Kenji Furuya, and Sota Arakawa worked as members of the SPICA Science Study Group and contributed to the writing of the final report. Bochao Hu, Takahiro Ueda, and Kenji Furuya wrote the ngVLA-J memo series. Mami Machida and Yuka Fujii led the ISM and Planets Sub-Working Groups, respectively, of the SKA-JP Science Working Group. Masami Ouchi, Takashi Moriya, and Kimihiko Nakajima were the members of NASA's Roman Space Telescope Science Investigation Team. Takashi Moriya was also a member of the Subaru Advisory Committee. Eiichiro Kokubo was a member of the Subaru IRD project and the project to search for exoplanets around G-type giants with Okayama Astrophysical Observatory. Hideko Nomura and Takashi Tsukagoshi served as reviewers for Subaru Telescope proposals. Fumitaka Nakamura was the vice-chair of the millimeter/submillimeter subcomittee as well as the Japanese representative for the public data release of CO (carbon monoxide) from the CARMA-NRO Orion Survey. Maria Dianotti was an affiliated member of the Fermi-LAT collaboration.

5. Educational and Outreach Activities

The members of the Division of Science engaged in education of both graduate and undergraduate students at many universities. Takashi Tsukagoshi supervised a graduate student of Japan Women's University. Maria Dainotti supervised PhD students and undergraduate students from the following Universities: Stanford University (US mainland), Jagiellonian University (Poland), the University of Federico II of Naples (Italy), Tufts University (US mainland) and the Scientific Caribbean Foundation in Puerto Rico (US territory).

6. Awards

The paper that Takashi Tsukagoshi co-authored entitled "Mass constraint for a planet in a protoplanetary disk from the gap width" and the paper that Takashi Hamana co-authored entitled "Cosmology from cosmic shear power spectra with Subaru Hyper Suprime-Cam first-year data" won the PASJ Excellent Paper Award 2020.

Kenji Furuya won the Best Researcher Award 2019 of the Japanese Society of Planetary Science.

Takashi Moriya won the NINS Young Researcher Award.

Eiichiro Kokubo et al. won the 2020 MEXT Commendation for Science and Technology for their contribution to promoting public awareness of the latest views of the Universe through stereoscopic visualization of astronomy data.

Hideaki Takemura, Yuta Yamazaki, and Misako Tatsuuma won the oral award of the 50th Summer School on Astronomy and Astrophysics.

7. Visitors from Overseas

While the division usually strives to fulfill its roles as a center of excellence in Japan for the studies in astronomy and astrophysics by hosting many domestic and international researchers, the division did not have visitors from abroad in FY 2020 in order to prevent the spread of COVID-19.

18. Office of International Relations

The Office of International Relations strives to promote research activities by planning and implementing strategies for NAOJ's international research efforts. It maintains an environment where multi-cultural researchers and students can engage cooperatively in research and educational activities. Specifically, the Office's main activities include supporting international collaborative projects; liaising with overseas astronomical research organizations; gathering and providing information on international activities; offering support for hosting international conferences, workshops, and seminars; providing support for visiting international researchers and students; and assisting Japanese research organizations for international partnerships.

1. Support for International Collaborative Projects

The Office of International Relations, with the other 3 institutions forming the East Asian Core Observatories Association (EACOA) including NAOC (China), KASI (Republic of Korea), and ASIAA (Taiwan), assisted with recruitment and selection of the EACOA/EAO postdoctoral fellowship program recipients. From April 2020, the Research Promotion Group of the Administration Department took charge of export security control for the export of goods or transfer of technology. The Office of International Relations continues to conduct preliminary reviews for legal documentation and handling administrative coordination in the approval processes to sign agreements and memoranda for international collaborations.

2. Liaison Work for Overseas Astronomical Research Organizations

SPIE Astronomical Telescopes + Instrumentation 2020, planned in Yokohama, Japan, during June 14 – 19, 2020 and the Asia-Pacific Regional IAU Meeting (APRIM) in Parth, Australia, during July 6 – 10, 2020 were not held, due to the COVID-19 pandemic. Therefore, we cancelled our exhibitions at those conferences. However, as our first time in a virtual exhibition booth, we did participate in the 237th American Astronomical Society (AAS) meeting, which was held as an online meeting during January 10 – 15, 2021. We presented NAOJ's research activities and the information on the foreigner invitation program.

Also, same as last year, the Office of International Relations was in charge of activities related to the recruitment of overseas researchers.

3. Support for Hosting International Staff and Students

The Office enhanced its framework for offering organizational support for research, education, and living arrangements for international staff and students. The NAOJ Office of International Relations Support Desk ("SD") offers a broad range of services to help international staff and students overcome their difficulties in living in Japan.

To provide better services, the SD has been operated under a 2 staff × 3 days shift since October 2017. Thus, on Thursdays, when both of the SD staff are at the office, meetings are held between the SD staff and the other office members to ensure the smooth transfer of on-going issues, as well as sharing of information.

During the state of emergency, to prevent the spread of COVID-19, the SD staff work from their homes via e-mails, the internet, and telephone calls. The SD staff members work at the office one day per week, though commute when requested, handling consultation meetings and escorting outings.

The Office provided online Japanese language lessons, helping the international members of NAOJ acquire beginner level capability. To provide a better service to suit the students, a new lessons provider was selected.

The Office has also been working on a new website for the Office of International Relations, whose main purpose is to provide information to foreigners. It will be completed in the first half of 2021.

III Organization

1. Organization

- Advisory Committee for Research and Management
- Director General
  - Vice-Director General (on General Affairs)
  - Vice-Director General (on Program)
  - Director of Engineering
  - Director of Research Coordination
  - Executive Advisors to the Director General
  - Projects
    - (C Projects)
      - Subaru Telescope
      - Nobeyama Radio Observatory
      - Mizusawa VLBI Observatory
      - Solar Science Observatory
      - ALMA Project
      - NAOJ Chile
      - Center for Computational Astrophysics
    - (B Projects)
      - Gravitational Wave Science Project
      - Thirty Meter Telescope (TMT) Project
    - (A Projects)
      - JASMINE Project
      - RISE Project
      - SOLAR-C Project
      - Subaru Prime Focus Spectrograph (PFS) Project
      - Subaru Ground Layer Adaptive Optics (GLAO) Project
      - ASTE Project
  - Centers
    - Astronomy Data Center
    - Advanced Technology Center
    - Public Relations Center
  - Division of Science
  - Collaborative Projects
    - Inter-university Collaboration: Optical and Infrared Synergetic Telescopes for Education and Research (OISTER)
    - Inter-university Collaboration: Japanese VLBI Network (JVN)
  - Research Enhancement Strategy Office
    - Research Assessment Support Office
    - Industry Liaison Office
  - Office of International Relations
  - Human Resources Planning Office
  - Safety and Health Management Office
  - Engineering Promotion Office
  - IT Security Office
  - Administration Department

2. Number of Staff Members

(2021/3/31)

Director General		1
Research and Academic Staff		146
	Professor	26
	Executive Engineer	0
	Associate Professor	37
	Senior Research Engineer	10
	Associate Professor (Senior Lecturer)	4
	Associate Senior Research Engineer	1
	Assistant Professor	55
	Research Associate	0
	Research Engineer	13
Engineering Staff		37
Administrative Staff		57
Research Administrator Staff		6
Employees on Annual Salary System		151
Research Administrator Staff Transferring to the Mandatory Retirement System		1
Employees on Annual Salary System Transferring to the Mandatory Retirement System		2
Full-time Contract Employees		35
Full-time Contract Employees Transferring to the Mandatory Retirement System		2
Part-time Contract Employees		80
Part-time Contract Employees Transferring to the Mandatory Retirement System		18

3. Executives

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

4. Research Departments

Projects

C Projects

Subaru Telescope

Director	Yoshida, Michitoshi
Vice-Director	Takami, Hideki
Vice-Director	Yamamiya, Osamu
Professor	Takato, Naruhisa
Professor	Yoshida , Michitoshi
Project Professor	Takami, Hideki
Project Professor*	Tamura, Motohide
Associate Professor	Minowa, Yosuke
Associate Professor	Tanaka, Masayuki
Project Associate Professor	Kanbe, Eiji
Project Associate Professor	Oya, Shin
Senior Research Engineer	Iwashita, Hiroyuki
Senior Research Engineer	Kumura, Yoshinori
Assistant Professor*	Hirano, Teruyuki
Assistant Professor	Imanishi, Masatoshi
Assistant Professor	Ishigaki, Miho
Assistant Professor	Komiyama, Yutaka
Assistant Professor	Kotani, Takayuki
Assistant Professor	Koyama, Yusei
Assistant Professor*	Nakajima, Tadashi
Assistant Professor	Okamoto, Sakurako
Assistant Professor	Okita, Hirofumi
Assistant Professor	Onodera, Masato
Assistant Professor	Ono, Yoshito
Assistant Professor	Pyo, Tae-Soo
Assistant Professor*	Suto, Hiroshi
Assistant Professor	Yagi, Masafumi
Assistant Professor	Yanagisawa, Kenshi
Project Assistant Professor	Hayashi, Masao
Project Assistant Professor*	Hori, Yasunori
Project Assistant Professor	Izumi, Takuma
Project Assistant Professor*	Kuzuhara, Masayuki
Project Assistant Professor*	Hashimoto, Jun
Project Assistant Professor	Shimakawa, Rizumu
Research Engineer	Bando, Takamasa
Research Engineer	Omiya, Jun
Engineer (Gishi)	Namikawa, Kazuhito
Engineer (Shunin Gijyutuin)	Sato, Tatsuhiro
Engineer (Gijyutsuin)	Miura, Takuya
Engineer (Gijyutsuin)	Tsutsui, Hironori
Project Research Staff	Hamano, Satoshi
Project Research Staff	He, Wanqiu
Project Research Staff	Kawanomoto, Satoshi
Project Research Staff*	Komatsu, Yu
Project Research Staff*	Kosugi, Makiko
Project Research Staff	Koyama, Shuhei
Project Research Staff	Murata, Kazumi
Project Research Staff	Nakata, Fumiaki
Project Research Staff	Nashimoto, Masashi
Project Research Staff*	Nugroho, Stevanus Kristianto
Project Research Staff*	Omiya, Masashi
Project Research Staff*	Suzuki, Taiki
Project Research Staff*	Takahashi, Aoi
Project Research Staff*	Takarada, Takuya
Project Research Staff	Uchiyama, Hisakazu
Project Research Staff	Yamashita, Takuji
Senior Specialist (Tokuninsenmonin)	Fujinawa, Toshiyuki
Senior Specialist (Tokuninsenmonin)	Harasawa, Sumiko
Senior Specialist (Tokuninsenmonin)	Ishiduka, Yuki
Senior Specialist (Tokuninsenmonin)	Ishii, Miki
Senior Specialist (Tokuninsenmonin)	Katakura, Junichi
Senior Specialist (Tokuninsenmonin)	Koike, Michitaro
Senior Specialist (Tokuninsenmonin)*	Kusakabe, Nobuhiko
Senior Specialist (Tokuninsenmonin)	Mineo, Sogo
Senior Specialist (Tokuninsenmonin)	Morishima, Takahiro
Senior Specialist (Tokuninsenmonin)	Nakajima, Masayo
Senior Specialist (Tokuninsenmonin)	Oka, Shinji
Senior Specialist (Tokuninsenmonin)	Okura, Yuki
Senior Specialist (Tokuninsenmonin)	Shindo, Miwa
Senior Specialist (Tokuninsenmonin)	Tanaka, Mitsuhiro
Senior Specialist (Tokuninsenmonin)	Yamamiya, Osamu
Administrative Expert	1
Re-employment Staff	2
Administrative Supporters	3
Research Assistant Staff	1

Senior Specialist (Tokumeisenmonin)	1

*concurrently appointed in NINS

Administration Department

Manager	Seto, Yoji
General Affairs Unit	
Staff	Tamura, Makoto
Accounting Unit	
Leader	Sugawara, Satoshi

RCUH

RCUH Staff	67

Okayama Branch Office

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

Nobeyama Radio Observatory

Director	Tatematsu, Kenichi
Professor	Tatematsu, Kenichi
Assistant Professor	Ishiduki, Sumio
Assistant Professor	Umemoto, Tomofumi
Engineer (Gishi)	Handa, Kazuyuki
Engineer (Gishi)	Kurakami, Tomio
Engineer (Gishi)	Miyazawa, Chieko
Engineer (Gishi)	Miyazawa, Kazuhiko
Engineer (Gishi)	Takahashi, Toshikazu
Senior Specialist (Tokuninsenmonin)	Hamada, Kaname
Senior Specialist (Tokuninsenmonin)	Kinugasa, Kenzou
Senior Specialist (Tokuninsenmonin)	Takahashi, Shigeru
Technical Experts	2
Administrative Expert	1
Research Supporter	1
Administrative Maintenance Staff	3

Administration Office

Deputy Manager	Otsuka, Tomoyoshi
General Affairs Unit	
Administrative Supporters	2
Accounting Unit	
Leader	Takami, Masaki
Senior Staff	Uchiyama, Yoshifumi
Administrative Supporters	3

Mizusawa VLBI Observatory

Director	Honma, Mareki
Professor	Honma, Mareki
Project Professor	Kobayashi, Hideyuki
Assistant Professor	Hada , Kazuhiro
Assistant Professor	Hirota, Tomoya
Assistant Professor	Jike, Takaaki
Assistant Professor	Kameya, Osamu
Assistant Professor	Kono, Yusuke
Assistant Professor	Sunada, Kazuyoshi
Assistant Professor	Tamura, Yoshiaki
Engineer (Shunin Gijyutuin)	Ueno, Yuji
Engineer (Gijyutsuin)	Hirano, Ken
Project Research Staff	Akahori, Takuya
Project Research Staff	Sakai, Daisuke
Senior Specialist (Tokuninsenmonin)	Nagayama, Takumi
Senior Specialist (Tokuninsenmonin)	Oyama, Tomoaki
Senior Specialist (Tokuninsenmonin)	Ozawa, Tomohiko
Technical Experts	6
Research Supporter	1
Administrative Supporters	2
Research Assistant Staff	1
Senior Specialist (Tokumeisenmonin)	1

Administration Office

Deputy Manager	Onuma, Toru
General Affairs Unit	
Leader	Onuma, Toru
Re-employment Staff	1
Administrative Supporters	3
Accounting Unit	
Leader	Yamaguchi, Shinichi
Administrative Supporters	2

Time Keeping Office

Director	Tamura, Yoshiaki

Solar Science Observatory

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

ALMA Project

Director	Gonzalez Garcia, Alvaro
Professor	Fukagawa, Misato
Professor	Iguchi, Satoru
Professor	Sakamoto, Seiichi
Project Professor	Hasegawa, Tetsuo
Project Professor	Kiuchi, Hitoshi
Associate Professor	Gonzalez Garcia, Alvaro
Associate Professor	Iono, Daisuke
Associate Professor	Kosugi, George
Associate Professor	Shimojo, Masumi
Project Associate Professor	Ishii, Shun
Project Associate Professor	Nagai, Hiroshi
Project Associate Professor	Nakanishi, Koichiro
Project Associate Professor	Shimajiri, Yoshito
Senior Research Engineer	Kikuchi, Kenichi
Senior Research Engineer	Sugimoto, Kanako
Senior Research Engineer	Watanabe, Manabu
Assistant Professor	Ezawa, Hajime
Assistant Professor	Hiramatsu, Masaaki
Assistant Professor	Kamazaki, Takeshi
Assistant Professor	Matsuda, Yuichi
Project Assistant Professor	Imada, Hiroaki
Project Assistant Professor	Miyamoto, Yusuke
Project Assistant Professor	Okamoto, Joten
Project Assistant Professor	Saigo, Kazuya
Project Assistant Professor	Sanhueza Nunez, Patricio Andres
Project Assistant Professor	Tadaki, Kenichi
Project Assistant Professor	Ueda, Junko
Research Engineer	Ashitagawa, Kyoko
Research Engineer	Nakazato, Takeshi
Research Engineer	Yamada, Masumi
Engineer (Gishi)	Kato, Yoshihiro
Engineer (Gishi)	Nakamura, Kyoko
Engineer (Shunin Gijyutuin)	Nishitani, Hiroyuki
Engineer (Gijyutsuin)	Shizugami, Makoto
Project Research Staff	Bakx, Tom Johannes Lucinde Cyrillus
Project Research Staff	Cataldi, Gianni
Project Research Staff	Chen, Xiaoyang
Project Research Staff	Fudamoto, Yoshinobu
Project Research Staff	Guzman Fernandez, Andres Ernesto
Project Research Staff	Inoue, Shigeki
Project Research Staff	Kaneko, Hiroyuki
Project Research Staff	Kudo, Yuki
Project Research Staff	Lee, Seokho
Project Research Staff	Lu, Xing
Project Research Staff	Nishimura, Yuri
Project Research Staff	Shimoda, Takanobu
Project Research Staff	Sorahana, Satoko
Project Research Staff	Sugahara, Yuma
Project Research Staff	Suzuki, Tomoko
Project Research Staff	Tokuda, Kazuki
Project Research Staff	Wu, Yu-Ting
Project Research Staff	Yan, Yi
Project Research Staff	Zahorecz, Sarolta
Senior Specialist (Tokuninsenmonin)	Curotto Molina, Franco Andreas
Senior Specialist (Tokuninsenmonin)	Fujimoto, Yasuhiro
Senior Specialist (Tokuninsenmonin)	Fukui, Hideharu
Senior Specialist (Tokuninsenmonin)	Hayashi, Yohei
Senior Specialist (Tokuninsenmonin)	Ikeda, Emi
Senior Specialist (Tokuninsenmonin)	Kawasaki, Wataru
Senior Specialist (Tokuninsenmonin)	Miel, Renaud Jean Christophe
Senior Specialist (Tokuninsenmonin)	Miyata, Keiko
Senior Specialist (Tokuninsenmonin)	Morita, Eisuke
Senior Specialist (Tokuninsenmonin)	Nakanishi, Takashi
Senior Specialist (Tokuninsenmonin)	Nakayama, Susumu
Senior Specialist (Tokuninsenmonin)	Nishie, Suminori
Senior Specialist (Tokuninsenmonin)	Nishikawa, Tomoko
Senior Specialist (Tokuninsenmonin)	Otawara, Kazushige
Senior Specialist (Tokuninsenmonin)	So, Ryoken
Senior Specialist (Tokuninsenmonin)	Uemizu, Kazunori
Senior Specialist (Tokuninsenmonin)	Yoshino, Akira
Re-employment Staff	1
Technical Expert	1
Administrative Expert	1
Research Supporter	1
Administrative Supporters	3

NAOJ Chile

Acting Director	Gonzalez Garcia, Alvaro
Vice-Director	Mizuno, Norikazu

Professor	Kameno, Seiji
Professor	Mizuno, Norikazu
Associate Professor	Asaki, Yoshiharu
Associate Professor	Minamidani, Tetsuhiro
Associate Professor	Okuda, Takeshi
Associate Professor	Sawada, Tsuyoshi
Associate Professor	Takahashi, Satoko
Assistant Professor	Hirota, Akihiko
Project Assistant Professor	Hull, Charles Lindsay Hopkins
Engineer (Gishi)	Kobiki, Toshihiko
Engineer (Shunin Gijyutuin)	Ito, Tetsuya
Project Research Staff	Miley, James Maxwell

Chile Employees

Chile Employees	6

Administration Department

Deputy Manager	Watanabe, Teruyuki

General Affairs Unit

Staff	Isozaki, Yuka

Accounting Unit

Staff	Yamafuji, Yasuto

Center for Computational Astrophysics

Director	Kokubo, Eiichirou
Professor	Kokubo, Eiichirou
Associate Professor (Senior Lecturer)	Ito, Takashi
Assistant Professor	Iwasaki, Kazunari
Project Research Staff	Ishikawa, Shogo
Project Research Staff	Taki, Tetsuo
Senior Specialist (Tokuninsenmonin)	Fukushi, Hinako
Senior Specialist (Tokuninsenmonin)	Hohokabe, Hirotaka
Senior Specialist (Tokuninsenmonin)	Kato, Tsunehiko
Research Expert	1
Research Supporters	3
Administrative Supporters	2

B Projects

Gravitational Wave Science Project

Director	Tomaru, Takayuki
Professor	Tomaru, Takayuki
Associate Professor	Aso, Yoichi
Assistant Professor	Leonardi, Matteo
Assistant Professor	Takahashi, Ryutaro
Research Engineer	Ishizaki, Hideharu
Engineer (Shunin Gijyutuin)	Tanaka, Nobuyuki
Project Research Staff	Zhao, Yuhang
Senior Specialist (Tokuninsenmonin)	Hirata, Naoatsu
Administrative Expert	1
Administrative Supporter	1

Kamioka Branch

Professor	Tomaru, Takayuki
Assistant Professor	Akutsu, Tomotada
Project Research Staff	Chen, Dan
Senior Specialist (Tokuninsenmonin)	Ikeda, Satoru
Administrative Supporter	1

Thirty Meter Telescope (TMT) Project

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

NAOJ Monrovia Office

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

A Projects

JASMINE Project

Director	Gouda, Naoteru
Professor	Gouda, Naoteru
Professor	Kano, Ryouhei
Assistant Professor	Miyoshi, Makoto
Assistant Professor	Tatsumi, Daisuke
Assistant Professor	Tsujimoto, Takuji
Assistant Professor	Ueda, Akitoshi
Assistant Professor	Yano, Taihei
Project Assistant Professor	Baba, Junichi
Technical Supporter	1

RISE Project

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

SOLAR-C Project

Director	Hara, Hirohisa
Associate Professor	Hara, Hirohisa
Assistant Professor	Ishikawa, Ryoko
Assistant Professor	Kubo, Masahito
Engineer (Gishi)	Shinoda, Kazuya
Project Research Staff	Kawabata, Yusuke
Senior Specialist (Tokuninsenmonin)	Nodomi, Yoshifumi

Subaru Prime Focus Spectrograph (PFS) Project

Director	Takato, Naruhisa

Subaru Ground Layer Adaptive Optics (GLAO) Project

Director	Minowa, Yosuke

ASTE Project

Acting Director	Kamazaki, Takeshi

Centers

Astronomy Data Center

Director	Kosugi, George
Associate Professor	Ichikawa, Shinichi
Associate Professor	Takata, Tadafumi
Assistant Professor	Furusawa, Hisanori
Assistant Professor	Shirasaki, Yuji
Project Research Staff	Furusawa, Junko
Project Research Staff	Higuchi, Aya
Project Research Staff	Kakuwa, Jun
Project Research Staff	Otsubo, Takafumi
Senior Specialist (Tokuninsenmonin)	Isogai, Mizuki
Senior Specialist (Tokuninsenmonin)	Kamegai, Kazuhisa
Senior Specialist (Tokuninsenmonin)	Makiuchi, Shinichiro
Senior Specialist (Tokuninsenmonin)	Nakajima, Yasushi
Senior Specialist (Tokuninsenmonin)	Ozawa, Takeaki
Senior Specialist (Tokuninsenmonin)	Tanaka, Nobuhiro
Senior Specialist (Tokuninsenmonin)	Yamane, Satoru
Senior Specialist (Tokuninsenmonin)	Zapart, Christopher Andrew
Re-employment Staff	1

Advanced Technology Center

Director	Uzawa, Yoshinori
Vice-Director	Hayano, Yutaka
Professor	Miyazaki, Satoshi
Professor	Motohara, Kentarou
Professor	Uzawa, Yoshinori
Project Professor	Mitsuda, Kazuhisa
Associate Professor	Hayano, Yutaka
Associate Professor	Kojima, Takafumi
Associate Professor	Makise, Kazumasa
Associate Professor	Matsuo, Hiroshi
Associate Professor	Shan, Wenlei
Senior Research Engineer	Fujii, Yasunori
Senior Research Engineer	Fukushima, Mitsuhiro
Senior Research Engineer	Kanzawa, Tomio
Senior Research Engineer	Okada, Norio
Associate Professor (Senior Lecturer)	Nakaya, Hidehiko
Associate Professor (Senior Lecturer)	Ozaki, Shinobu
Associate Senior Research Engineer	Obuchi, Yoshiyuki
Assistant Professor	Oshima, Tai
Project Assistant Professor	Hattori, Masayuki

Research Engineer	Ezaki, Shohei
Research Engineer	Sato, Naohisa
Research Engineer	Tsuduki, Toshihiro
Engineer (Gishi)	Kamata, Yukiko
Engineer (Gishi)	Kubo, Koichi
Engineer (Gishi)	Omata, Koji
Engineer (Gishi)	Tamura, Tomonori
Engineer (Gishi)	Uraguchi, Fumihiro
Engineer (Shunin Gijyutuin)	Fukuda, Takeo
Engineer (Shunin Gijyutuin)	Ikenoue, Bungo
Engineer (Shunin Gijyutuin)	Inata, Motoko
Engineer (Shunin Gijyutuin)	Iwashita, Hikaru
Engineer (Shunin Gijyutuin)	Kaneko, Keiko
Engineer (Shunin Gijyutuin)	Mitsui, Kenji
Engineer (Shunin Gijyutuin)	Miyachi, Akihira
Engineer (Shunin Gijyutuin)	Waseda, Koichi
Engineer (Gijyutsuin)	Sakai, Ryo
Engineer (Gijyutsuin)	Shimizu, Risa
Project Research Staff	Nagai, Makoto
Senior Specialist (Tokuninsenmonin)	Kusumoto, Hiroshi
Senior Specialist (Tokuninsenmonin)	Saito, Sakae
Technical Experts	1
Research Supporter	1
Administrative Supporters	3

Public Relations Center

Acting Director	Watanabe, Junichi
Professor	Watanabe, Junichi
Project Professor	Oishi, Masatoshi
Associate Professor	Agata, Hidehiko
Associate Professor	Yamaoka, Hitoshi
Research Engineer	Katayama, Masato
Engineer (Shunin Gijyutuin)	Nagayama, Shogo
Project Research Staff	Hanayama, Hidekazu
Project Research Staff	Horiuchi, Takashi
Senior Specialist (Tokuninsenmonin)	Hansen, Izumi Ka Hoku Hula O Kekai
Senior Specialist (Tokuninsenmonin)	Ishikawa, Naomi
Senior Specialist (Tokuninsenmonin)	Lundock, Ramsey Guy
Senior Specialist (Tokuninsenmonin)	Pires Canas, Lina Isabel
Senior Specialist (Tokuninsenmonin)	Tsuduki, Hiroko
Senior Specialist (Tokuninsenmonin)	Usuda-Sato, Kumiko
Research Experts	2
Technical Expert	1
Administrative Experts	2
Re-employment Staff	2
Research Supporter	1
Technical Supporter	1
Public Outreach Staff	15

Public Relations Office

Director	Yamaoka, Hitoshi

Outreach and Education Office

Director	Agata, Hidehiko

Ephemeris Computation Office

Director	Katayama, Masato

Spectrum Management Office

Director	Oishi, Masatoshi

Library

Leader	Tamefusa, Mizuho

Publications Office

Director	Yamaoka, Hitoshi

The Office for Astronomy Outreach of the IAU

Director	Agata, Hidehiko

Administration Office

Director	Matsuda, Ko

Ishigakijima Astronomical Observatory

Director	Hanayama, Hidekazu

Division of Science

Division Head	Nomura, Hideko
Professor	Kawabe , Ryohei
Professor	Nomura, Hideko
Professor	Ouchi, Masami
Professor	Tomisaka, Koji
Project Professor	Kajino, Toshitaka
Associate Professor	Fujii, Yuka
Associate Professor	Machida, Mami
Associate Professor	Nakamura, Fumitaka
Assistant Professor	Dainotti, Giovanna
Assistant Professor	Hamana, Takashi
Assistant Professor	Harada, Nanase
Assistant Professor	Kataoka , Akimasa
Assistant Professor	Morino, Junichi
Assistant Professor	Moriya, Takashi
Assistant Professor	Takiwaki, Tomoya
Project Assistant Professor	Furuya, Kenji
Project Assistant Professor	Nakajima, Kimihiko
Project Assistant Professor	Ogihara, Masahiro
Project Assistant Professor	Sano, Hidetoshi
Project Assistant Professor	Sugiyama, Naonori
Project Assistant Professor	Suzuki, Akihiro
Project Assistant Professor	Takahashi, Sanemichi
Project Assistant Professor	Tsukagoshi, Takashi
Project Research Staff	Nozawa, Takaya
Administrative Experts	2
Research Supporter	1
Research Assistant Staff	3

5. Research Support Departments

Research Enhancement Strategy Office

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

Research Assessment Support Office

Director	Saito, Masao
Senior Specialist (Tokuninsenmonin)	Hori, Kuniko

Industry Liaison Office

Director	Hayano, Yutaka

Office of International Relations

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

Support Desk

Research Supporters	2

Human Resources Planning Office

Director	Noda, Noboru

Safety and Health Management Office

Director	Okamoto, Koichi
Technical Experts	1

Engineering Promotion Office

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

IT Security Office

Director	Iguchi, Satoru
Vice Director	Oe, Masafumi
Senior Research Engineer	Nakamura, Kohji
Associate Professor (Senior Lecturer)	Oe, Masafumi
Engineer (Gijyutsuin)	Matsushita, Sayaka
Administrative Experts	1

Administration Department

General Manager	Sasagawa, Hikaru
Senior Specialist (Tokuninsenmonin)	Harada, Eiichiro

General Affairs Group

Manager	Nagata, Yuki
Deputy Manager	Furuhata, Tomoyuki
Senior Specialist	Yamanouchi, Mika
Specialist (Information Technology)	Kawashima, Ryota
Senior Specialist (Tokuninsenmonin)	Ito, Yuko
Senior Specialist (Tokuninsenmonin)	Murakami, Sachiko
Senior Specialist (Tokuninsenmonin)	Yamamoto, Chieko

General Affairs Unit

Leader	Kawashima, Ryota
Staff	Matsukura, Koji
Staff	Saito, Masahiro
Re-employment Staff	2
Administrative Experts	1
Administrative Supporters	1

Personnel Unit

Leader	Yamanouchi, Mika
Staff	Iwasaki, Yumi
Staff	Okawa, Makoto
Staff	Ouchi, Kaori
Staff	Sakamoto, Misato
Administrative Experts	1

Payroll Unit

Leader	Furukawa, Shinichiro
Staff	Kayamori, Shinji
Staff	Takada, Miyuki
Staff	Takahashi, Sachiko
Administrative Supporters	3

Employee Affairs Unit

Leader	Yamaura, Mari
Staff	Manabe, Yuta
Staff	Tanaka, Masashi
Administrative Experts	1

Research Promotion Group

Manager	Hosoya, Akio
Senior Specialist (International Relations)	Onishi, Tomoyuki
Senior Specialist (Tokuninsenmonin)	Baba, Takashi

Research Support Unit	
Leader	Goto, Michiru
Administrative Experts	1
Administrative Supporters	1
External Funding Unit	
Specialist (External Funding)	Ihara, Yuko
Staff	Nakagawa, Yukie
Administrative Supporters	2
Graduate Student Affairs Unit	
Leader	Kitabayashi, Kaya
Administrative Experts	1
Administrative Supporters	1
International Academic Affairs Unit	
Leader	Sato, Yoko
Financial Affairs Group	
Manager	Honda, Daisuke
Deputy Manager	Iwashita, Kanefumi
Specialist (Audit)	Tsukano, Satomi
General Affairs Unit	
Leader	Chiba, Yoko
Staff	Naraoka, Aone
Administrative Supporters	1
Budget Unit	
Leader	Yamamoto, Shinichi
Senior Staff	Yoshimura, Tetsuya
Administrative Supporters	1
Asset Management Unit	
Leader	Kikkawa, Hiroko
Staff	Okubo, Kazuhiko
Receiving Unit	
Leader	Kikkawa, Hiroko
Administrative Supporters	4
Accounting Group	
Manager	Tahara, Yuji
Specialist (Contracts)	Miura, Susumu
Accounting Unit	
Leader	Akeno, Aya
Administrative Supporters	3
Procurement Unit	
Leader	Sato, Kanako
Staff	Morita, Akitsugu
Staff	Sugimoto, Naomi
Administrative Experts	1
Administrative Supporters	1
Facilities Group	
Manager	Ogihara, Masanobu
Deputy Manager	Murakami, Kazuhiro
General Affairs Unit	
Leader	Ishikawa, Junya
Staff	Hiramatsu, Naoya
Administrative Supporters	1
Facilities Direction Unit	
Leader	Murakami, Kazuhiro
Administrative Supporters	2
Maintenance Unit	
Leader	Narisawa, Hiroyuki
Senior Staff	Kurose, Takahiro
Staff	Hayashi, Yuki

6. Personnel Change

Research and Academic Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2020/4/1	Motohara, Kentaro	Hired	Advanced Technology Center, Professor	(The University of Tokyo Graduate School of Science Institute of Astronomy, Associate Professor)
2020/4/1	Fujii, Yuka	Hired	Division of Science, Associate Professor	(Tokyo Institute of Technology Earth-Life Science Institute, Specially Appointed Associate Professor)
2020/4/1	Machida, Mami	Hired	Division of Science, Associate Professor	(Kyushu University Faculty of Science Department of Physics, Assistant Professor)
2020/5/1	Ishigaki, Miho	Hired	Subaru Telescope, Assistant Professor	(Tohoku University Graduate School of Science Astronomical Institute, Project Assistant Professor)
2020/7/1	Harada, Nanase	Hired	Division of Science, Assistant Professor	(Academia Sinica Institute of Astronomy and Astrophysics, Project Researcher)
2020/9/1	Hattori, Kohei	Hired	Research Enhancement Strategy Office, Assistant Professor	(Carnegie Mellon University Department of Physics, Research Associate)
2020/10/1	Shirasaki, Masato	Hired	Research Enhancement Strategy Office, Assistant Professor	(Division of Science, Project Assistant Professor)
2021/1/1	Makise, Kazumasa	Hired	Advanced Technology Center, Associate Professor	(National Institute of Advanced Industrial Science and Technology Research Center for Emerging Computing Technologies, Senior Researcher)
2021/1/1	Ozaki, Shinobu	Hired	Advanced Technology Center, Associate Professor (Senior Lecturer)	(Subaru Telescope, Project Research Staff)
2021/1/1	Dainotti, Maria Giovanna	Hired	Division of Science, Assistant Professor	(Jagiellonian University, Adjunct Professor)

2020/11/30	Asayama, Shin'ichiro	Resigned	(SKA Organisation, SKA System Scientist)	NAOJ Chile, Associate Professor
2020/12/31	Kiuchi, Hitoshi	Resigned	(Advanced Technology Center, Project Professor)	ALMA Project, Associate Professor
2021/3/31	Watanabe, Junichi	Resigned	(Public Relations Center, Project Professor (Distinguished Professor))	Public Relations Center, Professor

2021/3/31	Tomisaka, Koji	Retired		Division of Science, Professor
2021/3/31	Suematsu, Yoshinori	Retired		Solar Science Observatory, Associate Professor

2020/9/1	Kano, Ryohei	Promoted	JASMINE Project, Professor	SOLAR-C Project, Associate Professor
2020/9/1	Obuchi, Yoshiyuki	Promoted	Advanced Technology Center, Associate Senior Research Engineer	Advanced Technology Center, Research Engineer
2020/12/1	Nakaya, Hidehiko	Promoted	Advanced Technology Center, Associate Professor (Senior Lecturer)	Advanced Technology Center, Assistant Professor
2020/12/1	Oe, Masafumi	Promoted	IT Security Office, Associate Professor (Senior Lecturer)	IT Security Office, Assistant Professor
2021/3/1	Ito, Takashi	Promoted	Center for Computational Astrophysics, Associate Professor (Senior Lecturer)	Astronomy Data Center, Assistant Professor

Engineering Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2020/4/1	Miyachi, Akihira	Hired	Advanced Technology Center, Engineer	(ALMA Project, Senior Specialist)
2020/7/12	Kon'no, Yusuke	Resigned		Subaru Telescope, Engineer

Administrative Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2020/4/1	Nagata, Yuki	Hired	Administration Department General Affairs Group, Manager	(Fukushima University)
2020/4/1	Tahara, Yuji	Hired	Administration Department Accounting Group, Manager	(Research Organization of Information and Systems)
2020/4/1	Ogihara, Masanobu	Hired	Administration Department Facilities Group, Manager	(Niigata University)
2020/4/1	Kitabayashi, Kaya	Hired	Administration Department Research Promotion Group Graduate Student Affairs Unit, Leader	(The University of Tokyo)
2020/4/1	Sato, Yoko	Hired	Administration Department Research Promotion Group International Academic Affairs Unit, Leader	(Tokyo Medical and Dental University)
2020/4/1	Yoshimura, Tetsuya	Hired	Administration Department Financial Affairs Group Budget Unit, Senior Staff	(The University of Tokyo)
2020/4/1	Okawa, Makoto	Hired	Administration Department General Affairs Group Personnel Unit, Staff	
2020/8/1	Takami, Masaki	Hired	Nobeyama Radio Observatory Administration Office Accounting Unit, Leader	(Shinshu University)
2020/10/1	Ihara, Hiroko	Hired	Administration Department Research Promotion Group, Specialist (External Funding)	(Japan Society for the Promotion of Science)
2020/10/1	Manabe, Yuta	Hired	Administration Department General Affairs Group Employee Affairs Unit, Staff	
2020/7/31	Takeda, Kiyotaka	Resigned	(Shinshu University)	Nobeyama Radio Observatory Administration Office Accounting Unit, Leader
2021/3/31	Sasagawa, Hikaru	Resigned	(Research Organization of Information and Systems)	Administration Department, General Manager
2021/3/31	Honda, Daisuke	Resigned	(Ministry of Education, Culture, Sports, Science and Technology-Japan)	Administration Department Financial Affairs Group, Manager
2021/3/31	Ogihara, Masanobu	Resigned	(Niigata University)	Administration Department Facilities Group, Manager
2021/3/31	Narisawa, Hiroyuki	Resigned	(National Museum of Nature and Science)	Administration Department Facilities Group Maintenance Unit, Leader
2021/3/31	Kurose, Takahiro	Resigned	(The University of Tokyo)	Administration Department Facilities Group Maintenance Unit, Senior Staff
2020/4/1	Murakami, Kazuhiro	Promoted	Administration Department Facilities Group, Deputy Manager, and Facilities Direction Unit, Leader	Administration Department Facilities Group Facilities Direction Unit, Leader
2020/4/1	Furukawa, Shin'ichiro	Promoted	Administration Department General Affairs Group Payroll Unit, Leader	Administration Department General Affairs Group Payroll Unit, Senior Staff

2020/4/1	Kurose, Takahiro	Promoted	Administration Department Facilities Group Maintenace Unit, Senior Staff	Administration Department Facilities Group Maintenace Unit, Staff

2020/4/1	Tanaka, Masaru	Reassigned	National Institutes of Natural Sciences Administrative Bureau Liaison and Planning Division, Manager	Administration Department Accounting Group, Manager
2020/4/1	Miura, Susumu	Reassigned	Administration Department Accounting Group, Specialist (Contracts)	National Institutes of Natural Sciences Administrative Bureau Liaison and Planning Division, Specialist
2020/4/1	Iida, Naoto	Reassigned	National Institutes of Natural Sciences Administrative Bureau General Affairs Division, Staff (Ministry of Education, Culture, Sports, Science and Technology-Japan, Administrative Intern Trainee)	Administration Department General Affairs Group Personnel Unit, Senior Staff
2020/4/1	Saito, Keisuke	Reassigned	National Institutes of Natural Sciences Administrative Bureau Liaison and Planning Division Planning Coordination Section, Staff	Administration Department Financial Affairs Group General Affairs Unit, Staff

Employee on Annual Salary System

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2020/4/1	Mitsuda, Kazuhisa	Hired	Advanced Technology Center, Project Professor	
2020/4/1	Ishii, Shun	Hired	ALMA Project, Project Associate Professor	(NAOJ Chile, Assistant Professor)
2020/4/1	Shimakawa, Rizumu	Hired	Subaru Telescope, Project Assistant Professor	
2020/4/1	Tadaki, Ken'ichi	Hired	ALMA Project, Project Assistant Professor	
2020/4/1	Baba, Jun'ichi	Hired	JASMINE Project, Project Assistant Professor	(JASMINE Project, Project Research Staff)
2020/4/1	Sano, Hidetoshi	Hired	Division of Science, Project Assistant Professor	
2020/4/1	Furuya, Kenji	Hired	Division of Science, Project Assistant Professor	
2020/4/1	Kawanomoto, Satoshi	Hired	Subaru Telescope, Project Research Staff	
2020/4/1	Chen, Xiaoyang	Hired	ALMA Project, Project Research Staff	
2020/4/1	Sugahara, Yuma	Hired	ALMA Project, Project Research Staff	
2020/4/1	Kaneko, Hiroyuki	Hired	ALMA Project, Project Research Staff	
2020/4/1	Kudo, Yuki	Hired	ALMA Project, Project Research Staff	
2020/4/1	Otsubo, Takafumi	Hired	Astronomy Data Center, Project Research Staff	
2020/4/1	Nagai, Makoto	Hired	Advanced Technology Center, Project Research Staff	(Advanced Technology Center, Project Research Staff)
2020/4/1	Ishizuka, Yuki	Hired	Subaru Telescope, Senior Specialist	
2020/4/1	Uemizu, Kazunori	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2020/4/1	Otawara, Kazushige	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2020/4/1	Nakayama, Susumu	Hired	ALMA Project, Senior Specialist	
2020/4/1	Harada, Eiichiro	Hired	Administration Department, Senior Specialist	(Administration Department General Affairs Group, Manager)
2020/5/1	Chen, Dan	Hired	Gravitational Wave Science Project, Project Research Staff	
2020/6/1	Miel, Renaud Jean Christophe	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)

2020/7/1	Nakanishi, Koichiro	Hired	ALMA Project, Project Associate Professor	(ALMA Project, Project Associate Professor)
2020/8/1	Takahashi, Sanemichi	Hired	Division of Science, Project Assistant Professor	(Division of Science, Project Research Staff)
2020/8/1	Koyama, Shuhei	Hired	Subaru Telescope, Project Research Staff	
2020/8/1	Murata, Kazumi	Hired	Subaru Telescope, Project Research Staff	
2020/8/1	Harasawa, Sumiko	Hired	Subaru Telescope, Senior Specialist	
2020/8/1	Morishima, Takahiro	Hired	Subaru Telescope, Senior Specialist	
2020/8/1	Yamaguchi, Takahiro	Hired	NAOJ Chile, Senior Specialist	
2020/9/1	Nashimoto, Masashi	Hired	Subaru Telescope, Project Research Staff	
2020/9/1	Oka, Shinji	Hired	Subaru Telescope, Senior Specialist	
2020/9/1	Katakura, Jun'ichi	Hired	Subaru Telescope, Senior Specialist	
2020/9/1	Ikeda, Satoru	Hired	Gravitational Wave Science Project, Senior Specialist	
2020/10/1	Oya, Shin	Hired	Subaru Telescope, Project Associate Professor	(Subaru Telescope, Project Associate Professor)
2020/10/1	Imada, Hiroaki	Hired	ALMA Project, Project Assistant Professor	
2020/10/1	Akahori, Takuya	Hired	Mizusawa VLBI Observatory, Project Research Staff	(Mizusawa VLBI Observatory, Project Research Staff)
2020/10/1	Miley, James Maxwell	Hired	NAOJ Chile, Project Research Staff	
2020/10/1	Fudamoto, Yoshinobu	Hired	ALMA Project, Project Research Staff	
2020/10/1	Zhao, Yuhang	Hired	Gravitational Wave Science Project, Project Research Staff	
2020/11/1	He, Wanqiu	Hired	Subaru Telescope, Project Research Staff	
2020/11/1	Baba, Takashi	Hired	Administration Department Research Promotion Group, Senior Specialist	
2020/12/15	Curotto Molina, Franco Andreas	Hired	ALMA Project, Senior Specialist	
2020/12/20	Tajitsu, Akito	Hired	Subaru Telescope, Project Associate Professor	
2021/1/1	Kiuchi, Hitoshi	Hired	Advanced Technology Center, Project Professor	(ALMA Project, Associate Professor)
2021/1/1	Ikeda, Emi	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2021/1/1	Yoshino, Akira	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2021/2/1	Watanabe, Teruyuki	Hired	NAOJ Chile, Senior Specialist	
2021/3/1	Nakata, Fumiaki	Hired	Subaru Telescope, Project Research Staff	
2021/3/1	Fujinawa, Toshiyuki	Hired	Subaru Telescope, Senior Specialist	

2020/4/30	Walker, Daniel Lewis	Resigned		NAOJ Chile, Project Research Staff
2020/4/30	Nomura, Reiko	Resigned		RISE Project, Project Research Staff
2020/4/30	Yamanoi, Hitomi	Resigned		Subaru Telescope, Senior Specialist
2020/6/30	Higuchi, Arika	Resigned		RISE Project, Project Research Staff
2020/6/30	Takita, Satoshi	Resigned		Subaru Telescope, Senior Specialist
2020/7/31	Takahashi, Sanemichi	Resigned	(Division of Science, Project Assistant Professor)	Division of Science, Project Research Staff
2020/9/4	Indriolo, Nicholas	Resigned		ALMA Project, Project Assistant Professor
2020/9/7	Wu, Benjamin	Resigned		ALMA Project, Project Research Staff
2020/9/30	Shirasaki, Masato	Resigned	(Research Enhancement Strategy Office, Assistant Professor)	Division of Science, Project Assistant Professor
2020/10/31	Shoda, Ayaka	Resigned		Gravitational Wave Science Project, Project Assistant Professor

2020/10/31	Rusu, Cristian Eduard	Resigned		Subaru Telescope, Project Research Staff
2020/11/30	Higuchi, Yuichi	Resigned		ALMA Project, Project Research Staff
2020/12/31	Ozaki, Shinobu	Resigned	(Advanced Technology Center, Associate Professor (Senior Lecturer))	Subaru Telescope, Project Research Staff
2020/12/31	Wang, Tao	Resigned		ALMA Project, Project Research Staff
2021/3/24	Nguyen, Duc Dieu	Resigned		ALMA Project, Project Research Staff
2021/3/31	Koyama, Shuhei	Resigned		Subaru Telescope, Project Research Staff
2021/3/31	Uchiyama, Hisakazu	Resigned		Subaru Telescope, Project Research Staff
2021/3/31	Higuchi, Aya	Resigned		Astronomy Data Center, Project Research Staff
2021/3/31	Nagayama, Takumi	Resigned		Mizusawa VLBI Observatory, Senior Specialist
2021/3/31	Miyata, Keiko	Resigned		ALMA Project, Senior Specialist

2020/7/7	Otani, Yukari	Quit		Center for Computational Astrophysics, Project Research Staff

2020/4/30	Adachi, Yuki	Contract Expired		Mizusawa VLBI Observatory, Senior Specialist
2020/5/31	Miel, Renaud Jean Christophe	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2020/6/30	Nakanishi, Koichiro	Contract Expired	(ALMA Project, Project Associate Professor)	ALMA Project, Project Associate Professor
2020/7/31	Haruki, Mutsumi	Contract Expired		Office of International Relations, Senior Specialist
2020/9/30	Oya, Shin	Contract Expired	(Subaru Telescope, Project Associate Professor)	Subaru Telescope, Project Associate Professor
2020/9/30	Akahori, Takuya	Contract Expired	(Mizusawa VLBI Observatory, Project Research Staff)	Mizusawa VLBI Observatory, Project Research Staff
2020/10/31	Kim, Gwanjeong	Contract Expired		Nobeyama Radio Observatory, Project Research Staff
2020/11/30	Endo, Tatsuki	Contract Expired		Subaru Telescope, Senior Specialist
2020/12/31	Tanaka, Kei	Contract Expired		ALMA Project, Project Research Staff
2020/12/31	Ikeda, Emi	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2020/12/31	Yamaguchi, Takahiro	Contract Expired		NAOJ Chile, Senior Specialist
2020/12/31	Yoshino, Akira	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2021/1/31	Silva Bustamante, Andrea Ludovina	Contract Expired		NAOJ Chile, Project Research Staff
2021/2/28	Takahashi, Hidehiro	Contract Expired		Administration Department General Affairs Group, Senior Specialist
2021/3/31	Hasegawa, Tetsuo	Contract Expired		ALMA Project, Project Professor (Distinguished Professor)
2021/3/31	Kajino, Toshitaka	Contract Expired		Division of Science, Project Professor
2021/3/31	Hayashi, Masao	Contract Expired		Subaru Telescope, Project Assistant Professor
2021/3/31	Okamoto, Takenori	Contract Expired		ALMA Project, Project Assistant Professor

2021/3/31	Ogihara, Masahiro	Contract Expired		Division of Science, Project Assistant Professor
2021/3/31	Sakai, Daisuke	Contract Expired		Mizusawa VLBI Observatory, Project Research Staff
2021/3/31	Shimoda, Takanobu	Contract Expired		ALMA Project, Project Research Staff
2021/3/31	Suzuki, Tomoko	Contract Expired		ALMA Project, Project Research Staff
2021/3/31	Zhao, Yuhang	Contract Expired		Gravitational Wave Science Project, Project Research Staff
2021/3/31	Yamamoto, Keiko	Contract Expired	(RISE Project, Project Research Staff)	RISE Project, Project Research Staff
2021/3/31	Hamada, Kaname	Contract Expired		Nobeyama Radio Observatory, Senior Specialist
2021/3/31	Yamamiya, Osamu	Contract Expired		Subaru Telescope, Senior Specialist
2021/3/31	Kamegai, Kazuhisa	Contract Expired		Astronomy Data Center, Senior Specialist
2021/3/31	Ozawa, Takeaki	Contract Expired	(Astronomy Data Center, Senior Specialist)	Astronomy Data Center, Senior Specialist
2021/3/31	Makiuchi, Shin'ichiro	Contract Expired	(Astronomy Data Center, Senior Specialist)	Astronomy Data Center, Senior Specialist
2021/3/31	Kusumoto, Hiroshi	Contract Expired	(Advanced Technology Center, Senior Specialist)	Advanced Technology Center, Senior Specialist

Employee on Annual Salary System Transferring to the Mandatory Retirement System

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2021/3/31	Yamamoto, Chieko	Retired		Administration Department General Affairs Group, Senior Specialist

Foreign Visiting Researcher

Not applicable, due to the effects of the novel coronavirus

7. Advisory Committee for Research and Management

Members

From universities and related institutes

○ Doi, Mamoru	Professor at the Graduate School of Science, University of Tokyo
Fujisawa, Kenta	Professor at the Research Institute for Time Studies, Yamagichi University
Inutsuka, Shuichiro	Professor at the Graduate School of Science, Nagoya University
Kawakita, Hideyo	Professor at the Faculty of Science, Kyoto Sangyo University
Kodama, Tadayuki	Professor at the Graduate School of Science, Tohoku University
Kusano, Kanya	Professor at the Institute for Space-Earth Environmental Research, Nagoya University
Ohashi, Masatake	Professor at the Institute for Cosmic Ray Research, University of Tokyo
Sakai, Nami	Chief Scientist at the RIKEN
Takada, 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

From NAOJ

Fukagawa, Misato	Professor in NAOJ ALMA Project
Iguchi, Satoru	Vice-Director General (on Program)
Kobayashi, Hideyuki	Project Professor in the Mizusawa VLBI Observatory
Kokubo, Eiichiro	Professor in the Center for Computational Astrophysics
Mitsuda, Kazuhisa	Director of Engineering
Nomura, Hideko	Professor in the Division of Science
Saito, Masao	Director of Research Coordination
Uzawa, Yoshinori	Professor in the Advanced Technology Center
● Watanabe, Junichi	Vice-Director General (on General Affairs)
Yoshida, Michitoshi	Professor at Subaru Telescope

● Chairperson ○ Vise-Chairperson
Period: June 18, 2020 – March 31, 2022

8. Professors Emeriti

Professors Emeriti (NAOJ)

Arimoto, Nobuo
Ando, Hiroyasu
Chikada, Yoshihiro
Fujimoto, Masakatsu
Fukushima, Toshio
Hayashi, Masahiko
Hiei, Eijiro
Hirayama, Tadashi
Inoe, Makoto
Ishiguro, Masato
Iye, Masanori
Karoji, Hiroshi
Kawaguchi, Noriyuki
Kawano, Nobuyuki
Kinoshita, Hiroshi
Kobayashi, Yukiyasu
Kodaira, Keiichi
Manabe, Seiji
Miyama, Shiyoken
Miyamoto, Masanori
Mizumoto, Yoshihiko
Nakano, Takenori
Nariai, Kyoji
Nishimura, Shiro
Nishimura, Tetsuo
Noguchi, Kunio
Noguchi, Takashi
Oe, Masatsugu
Ogasawara, Ryusuke
Okamoto, Isao
Sakurai, Takashi
Shibasaki, Kiyoto
Watanabe, Tetsuya
Yamashita, Yasumasa
Yoshida, Haruo

IV Finance

Revenue and Expenses (FY 2020)

(Unit: ¥1,000)

Revenue	Budget	Final Account	Budget − Final Account
Management Expenses Grants	9,405,177	9,425,942	−20,765
Facilities Maintenance Grants	1,666,655	668,382	998,273
Subsidy Income	1,448,613	1,450,541	−1,928
Miscellaneous Income	40,848	57,461	−16,613
Industry-Academia Research Income and Donation Income	376,741	665,989	−289,248
Reversals of Reserves for Specific Purposes	0	0	0
Total	12,938,034	12,268,315	669,719
Expenses	Budget	Final Account	Budget − Final Account
Management Expenses	9,446,025	8,369,621	1,076,404
Employee Personnel Expenses	3,687,882	3,549,115	138,767
Operating Expenses	5,758,143	4,820,506	937,637
Facilities Maintenance Expenses	1,666,655	668,382	998,273
Subsidy Expenses	1,448,613	1,450,541	−1,928
Industry-Academia Research Expenses and Donation Expenses	376,741	377,252	−511
Total	12,938,034	10,865,796	2,072,238
Revenue-Expenses	Budget	Final Account	Budget − Final Account
	0	1,402,519	−1,402,519

V KAKENHI (Grants-in-Aid for Scientific Research)

1. Series of Single-year Grants for FY 2020

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)	9	61,800	18,540	80,340
Transformative Research Areas (A)	2	41,300	12,390	53,690
Scientific Research (S)	2	131,900	39,570	171,470
Scientific Research (A)	10	70,200	21,060	91,260
Scientific Research (B)	12	45,700	13,710	59,410
Young Scientists (A)	1	1,100	330	1,430
JSPS Research Fellows	8	8,700	2,610	11,310
JSPS International Research Fellows	3	1,400	0	1,400
Publication of Scientific Research Results	2	1,190	0	1,190
Total	49	363,290	108,210	471,500

2. Series of Multi-year Funds for FY 2020

Research Categories	Number of Selected Projects	Budget (Unit: ¥1,000)		
		Direct Funding	Indirect Funding	Total
Scientific Research (C)	30	30,100	9,030	39,130
Early-Career Scientists	23	19,900	6,210	26,110
Challenging Research (Pioneering)	2	9,200	2,760	11,960
Challenging Research (Exploratory)	1	1,000	300	1,300
Research Activity Start-up	3	3,300	990	4,290
Promotion of Joint International Research	3	6,100	1,830	7,930
Total	62	69,600	21,120	90,720

VI Research Collaboration

1. Open Use

Type	Project/Center	Category	Number of Accepted Proposals	Total Number of Researchers	Note
Open Use at Project/Center	Subaru Telescope	Subaru Telescope	87	389 (74)	48 Institutes, 11 Countries
	Subaru Telescope Okayama Branch	SEIMEI Telescope	29	120 (1)	9 Institutes, 1 Country
	Solar Science Observatory	Ground-based Solar Observatory	*	*	*
		Sun-observing satellite “Hinode”	**	**	**
	Nobeyama Radio Observatory	45-m telescope (Regular Program)	13	168 (77)	63 Institutes, 17 Countries
	Mizusawa VLBI Observatory	VERA	30	106 (76)	41 Institutes, 17 Countries
	Astronomy Data Center		336	336 (22)	75 Institutes, 15 Countries
	Center for Computational Astrophysics		325	325 (21)	69 Institutes, 7 Countries
	Advanced Technology Center	Facility Use	14	36	8 Institutes, 0 Countries
		Joint Research and Development	14	55	7 Institutes, 0 Countries
	ALMA Project	ALMA (Cycle7)	***	***	***
		ASTE	****	****	****
	RISE Project		2	5	3 Institutes, 0 Countries
Joint Development Research			6		6 Institutes, 0 Countries
Research Assembly			10		6 Institutes, 0 Countries
NAOJ Symposium			0		

The number of researchers at foreign institutes shown in brackets ( ) is included in the total.

The country count does not include Japan.

* The observation data is open to the public on the web. No application is needed to use the data.

** Since the function of the Hinode Science Center has shifted to the Astronomy Data Center, there is no procedure for application and adoption of projects for “Hinode.”

*** The period of ALMA (Cycle7) was started in October 2019 and is ongoing as of March 31, 2021 with a period of interruption due to the spread of COVID-19.

**** Observations with ASTE in FY 2020 were postponed due to the spread of COVID-19.

2. Commissioned Research Fellows

Visiting Scholars (Domestic)

Name	Position at NAOJ	Affiliated Institute	Period	Host Project/Center/ Division
Hayashi, Yoshi-Yuki	Visiting Professor	Faculty of Science, Kobe University	2020/4/1-2021/3/31	Center for Computational Astrophysics
Takahashi, Keitaro	Visiting Associate Professor	Faculty of Advanced Science and Technology, Kumamoto University	2020/4/1-2021/3/31	Mizusawa VLBI Observatory
Kawaguchi, Toshihiro	Visiting Associate Professor	Faculty of Economics, Management and Information Science, Onomichi City University	2020/4/1-2021/3/31	Advanced Technology Center

JSPS (Japan Society for the Promotion of Science) Postdoctoral Research Fellows

Name	Research Subject	Acceptance Period	Host Researcher
Arakawa, Sota	The birth environment of the Solar System unraveled by the thermal history of small bodies	2020/4/1–2023/3/31	Kokubo, Eiichiro
Matsushita, Yuko	A unified understanding of the star formation process in low to high mass stars	2020/4/1–2021/3/31	Tomisaka, Koji
Sasaki, Hirokazu	Influence of nonstandard interactions on supernova neutrinos	2020/4/1–2021/2/21	Nakamura, Fumitaka
Shoda, Munehito	Simulation and observation study of the solar wind acceleration	2019/4/1–2022/3/31	Katsukawa, Yukio
Baba, Shunsuke	Study of a link between AGN torus formation and circum-nuclear starbursts	2019/4/1–2022/3/31	Imanishi, Masatoshi
Harikane, Yuichi	Chemical Evolution of High Redshift Galaxies Revealed with Multi-wavelength Spectroscopy	2019/4/1–2020/5/31	Matsuda, Yuichi
Ueda, Takahiro	Probing rocky and icy planetesimal formation through two-dimensional simulations of gas and dust co-evolution	2019/4/1–2022/3/31	Kataoka, Akimasa
Washimi, Tatsuki	Evaluation of the glitch noise for burst gravitational wave detection	2019/4/1–2022/3/31	Tomaru, Takayuki
Kozakai, Chihiro	Development and installation of low frequency calibration method in KAGRA	2018/4/1–2021/3/31	Tomaru, Takayuki

JSPS (Japan Society for the Promotion of Science) Foreign Research Fellows

Name	Period	Host Researcher
Capocasa, Eleonora	2018/9/30–2020/8/31	Flaminio, Raffaele
Page, Michael Anthony	2020/11/30–2022/11/29	Aso, Yoichi
Eisenmann, Marc	2020/11/30–2022/11/29	Leonardi, Matteo

VII Graduate Education

1. Department of Astronomical Science, School of Physical Sciences, SOKENDAI (The Graduate University for Advanced Studies)

SOKENDAI (The Graduate University for Advanced Studies) was established in 1988 as an independent graduate university without undergraduate courses via partnerships with inter-university research institutes for the purpose of advancing graduate education.

There used to be four schools – Cultural and Social Studies, Mathematical and Physical Sciences, Life Science, and Advanced Sciences before the reorganization of School of Mathematical and Physical Sciences into the schools of Physical Sciences, High Energy Accelerator Science, and Multidisciplinary Sciences in April 2004. Now the total of six schools are offering doctoral education and research opportunities.

NAOJ has been accepting three-year doctoral-course students since FY 1992 and five-year- course students since FY 2006 for Department of Astronomical Science, School of Physical Sciences.

(1) Objective of Department of Astronomical Science

Department of Astronomical Science aims to train students, through observational, theoretical, or instrument development research in astronomy or in related fields, in an environment with the most advanced observational instruments and supercomputers, to be researchers who work at the forefront of world-class research; experts who carry out development of advanced technology; and specialists who endeavor in education and public outreach activities equipped with advanced and specialized knowledge.

Numbers of students to be admitted annually:
Two (for the five-year doctoral course)
Three (for the three-year doctoral course)
Degree: Doctor of Philosophy (Doctor of Science, or Doctor of Engineering, depending on the topic of Doctoral thesis)

(2) Admission Policy

Department of Astronomical Sciences seeks students with a strong interest in astronomy and the universe; a passion for unraveling scientific questions through theoretical, observational, and instrument-development research; and who have not only basic academic skills, but also the logical and creative aptitude required for advanced research.

(3) Department Details (Course Offerings)

Optical and 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 department 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 Supports

In order to provide the students economical basis upon which they can develop into young researchers skilled in conducting research effectively, the department has set up the Associate Researcher program in addition to Research Assistant system. In addition, the department has introduced the 'NAOJ Junior Fellow' system from FY 2020 to create an environment in which outstanding students can devote themselves more to their studies and research, and to further improve the standards of researchers produced by the department.

In FY2020 there were 6 NAOJ Junior Fellows, 17 Associate Researchers, and 3 Research Assistants.

To further improve the research environment for the students, the department provides Oversea Travel Fund, to encourage the students to participate in international conferences to give English talks, conduct observations at various oversea observational facilities and so on, and Research Fund to help them pursue their own original ideas to plan and carry out research, experiments, etc.

In FY2020, one research project was supported by this research fund.

(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 Department of Astronomical Science. Admission Guidance also targets undergraduate students.

In FY 2020, 19 students participated in the SOKENDAI Summer Students program. The Asian Winter School, conducted online, received 325 applications from 16 countries, and of these, 247 students participated in the program. In addition, 27 students participated in the Spring School, which was also conducted online.

(7) Number of Affiliated Staff (2021/3/31)

Chair of the Department of Astronomical Science	1
Optical and Near Infrared Astronomy Course	
Professors	10
Associate Professors	10
Assistant Professors	10
Radio Astronomy Course	
Professors	9
Associate Professors	11
Assistant Professors	18
General Astronomy and Astrophysics Course	
Professors	7
Associate Professors	17
Assistant Professors	20
Total	113

(8) Graduate Students (30 students)

1st year (6 student)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ishihara, Kousuke	Saito, Masao	Nakamura, Fumitaka	An observational study of star-forming regions
Sasaki, Shunsuke	Takiwaki, Tomoya	Machida, Mami	Explosion Mechanism of Core-Collapse Supernovae
Sugimori, Kanako	Tanaka, Masayuki	Iwata, Ikuru	Formation and evolution of galaxies in the early Universe
Tada, Shotaro	Kotani, Takayuki	Hayano, Yutaka Minowa, Yosuke	Development of a new type of high resolution spectrometer for an exoplanet survey and characterization
Doi, Kiyoaki	Kataoka, Akimasa	Nomura, Hideko Fukagawa, Misato	Unveiling planet formation via protoplanetary disk observations
Abdurrahman, Naufal	Tanaka, Masayuki	Koyama, Yusei	Morphological Evolution of Galaxies across Cosmic Environment

2nd year (5 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Kasagi, Yui	Kotani, Takayuki	Hayashi, Saeko Aoki, Wako	Study of Earth-like planets around M-dwarfs via near-infrared radial velocity method
Kashiwagi, Raiga	Tomisaka, Kohji	Takiwaki, Tomoya	Simulation Study of Star Formation Process
Kobayashi, Umi	Tanaka, Masayuki	Nakanishi, Koichiro	Influence of galaxy interactions and mergers on AGN activities
Nakano, Suzuka	Imanishi, Masatoshi	Nakanishi, Koichiro	The interplay and co-evolution between galaxies and active supermassive blackholes
Masai, Takaho	Gonzalez, Alvaro	Uzawa, Yoshinori Kojima, Takafumi	Development of (sub-)mm-wave optics and waveguide components for radio astronomy receivers

3rd year (3 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Takemura, Hideaki	Nakamura, Fumitaka	Hirota, Tomoya	Study of the star formation processes focusing on the CMF
Nishiumi, Taku	Hori, Yasunori	Aoki, Wako Izumiura, Hideyuki	Characterization of extrasolar planets with high photometric precision observations using space telescopes and MuSCAT series
Bilinskyi, Illia	Nomura, Hideko	Kokubo, Eiichiro	Theoretical Study on Formation of Planetary Systems

4th year (6 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ito, Kei	Tanaka, Masayuki	Matsuda, Yuichi	The systematical study of protoclusters based on the Subaru wide field survey
Shishido, Takaharu	Tomaru, Takayuki	Aso, Yoichi	Study of Pendulum-Thermal-Noise Reduction for Cryogenic Gravitational Wave Telescope KAGRA
Tsukui, Takafumi	Iguchi, Satoru	Nagai, Hiroshi	Formation and evolution of galactic structures using gas and stellar kinematics.
Namiki, Shigeru	Koyama, Yusei	Tanaka, Masayuki	Multi-wavelength study of galactic-scale gas inflow/outflow and their chemical evolution
Ishikawa, Ryohtaroh	Suematsu, Yoshinori	Katsukawa, Yukio	Study of turbulence-magnetic field interaction in the solar photosphere using spectro-polarimetric observations
Liang, Yongming	Tanaka, Masayuki	Matsuda, Yuichi	Correlation between galaxy and IGM at $z \approx 2$ based on MAMMOTH overdensities mapped by Subaru/HSC

5th year (10 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ishikawa, Hiroyuki	Aoki, Wako	Hayashi, Saeko	Study of atmospheric compositions and physical parameters of M-dwarfs
Tanioka, Satoshi	Aso, Yoichi	Takahashi, Ryutaro	A feasibility study for a cryogenic gravitational-wave detector
Hatta, Yoshiki	Sekii, Takashi	Hara, Hirohisa	Asteroseismic measurements of internal rotation of stars via solving inverse problems
Watanabe, Noriharu	Hori, Yasunori	Takami, Hideki Aoki, Wako	Research for giant planets around hot stars
Kambara, Nagaaki	Tomisaka, Kohji	Hara, Hirohisa	Spectroscopic diagnostics of highly ionized astrophysical plasma
Cui, Yuzhu	Honma, Mareki	Nagai, Hiroshi	Observational study of jets in active galactic nuclei with the East Asian VLBI Network
Fukagawa, Nao	Aoki, Wako	Iono, Daisuke	Contribution of rotating massive stars to the chemical enrichment in the low-metallicity environments of dwarf galaxies
Sahoo, Ananya	Minowa, Yosuke	Takato, Naruhisa	Advanced wavefront control in adaptive optics for exoplanet imaging and spectroscopy
Zhao, Yuhang	Leonardi, Matteo	Aso, Yoichi	Frequency dependent squeezing for gravitational wave detectors
Kim, Jungha	Honma, Mareki	Kobayashi, Hideyuki	Understanding the circumstellar structure of high-mass young stellar objects based on KaVA and ALMA observations

2. Education and Research Collaboration with Graduate Schools

Name	Affiliated Institute	Supervisor	Title of Research Project
Adachi, Hiroaki	The University of Tokyo	Fukagawa, Misato	Observational Research on Planetary-system Formation around Young Stars
Ogawa, Takuma	The University of Tokyo	Goda, Naoteru	Study on the Galactic dynamics by the use of astrometric data
Ono, Kyohei	The University of Tokyo	Kokubo, Eiichiro	Theoritical Study on Formation of Planetary Systems
Kofuji, Yutaro	The University of Tokyo	Honma, Mareki	Imaging super-massive black holes with mm VLBI
Chen, Nuo	The University of Tokyo	Motohara, Kentaro	Observational Study of Galaxy Formation and Evolution in the ZFOURGE-COSMOS Field
Honda, Yuichi	The University of Tokyo	Sakamoto, Seiichi	Study of triggering mechanisms for massive star formation
Morii, Kaho	The University of Tokyo	Nakamura, Fumitaka	Understanding of the role of stellar feedback in the process of star cluster formation
Moritsuka, Akie	The University of Tokyo	Katsukawa, Yukio	Study of magneto-convection on the solar surface with spectro-polarim observations
Ono, Nozomi	The University of Tokyo	Hara, Hirohisa	Study on EUV Spectra at the initial phase of Solar Flares
Kinoshita, Shinichi	The University of Tokyo	Nakamura, Fumitaka	Elucidation of star formation process using numerical simulation
Huang, Shuo	The University of Tokyo	Okuda, Takeshi	Study of Bulge Formation in High-z Submillimeter galaxies
Goto, Koki	The University of Tokyo	Fukagawa, Misato	Observational Study of Planetary-system Formation
Takamura, Mieko	The University of Tokyo	Honma, Mareki	Observational research of AGN jet in the Narrow-line Seifer 1 Galaxy 1HO323+342
Nakatsuno, Naoki	The University of Tokyo	Goda, Naoteru	Effects of inner bar on co-evolution of the Milky Way Galaxy and super massive black hole
Nakamura, Hiroki	The University of Tokyo	Motohara, Kentaro	Spatially-resolved Study of Nearby Luminous Infrared Galaxies
Hasegawa, Ryuto	The University of Tokyo	Fukagawa, Misato	Planet Formation in Protostellar Disks and Protoplanetary Disks
Mitsuhashi, Ikki	The University of Tokyo	Sakamoto, Seiichi	Study of distant galaxies using ALMA
Yoshida, Yuki	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study on Formation of Planetary Systems
Kawakami, Tomohiro	The University of Tokyo	Fukagawa, Misato	Revealing Circumstellar Structure of Protostars with Radio Observations
Okino, Hiroki	The University of Tokyo	Honma, Mareki	Observational study of AGN jets with Global VLBI
Kushibili, Kosuke	The University of Tokyo	Motohara, Kentaro	Development of an Integral Field Unit SWIMS-IFU and an Observational Study of Nearby LIRGs
Hoshino, Haruka	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study on Formation of Planetary Systems
Yamazaki, Yuta	The University of Tokyo	Nakamura, Fumitaka	The Cosmic-time Evolution of Elements
Guo, Kangrou	The University of Tokyo	Kokubo, Eiichiro	Planetesimal Dynamics in the Presence of a Massive Companion
Lee, Sujin	The University of Tokyo	Honma, Mareki	Observational study of pulsars/magnetars in the radio band
Ishizuka, Noriyoshi	The University of Tokyo	Hara, Hirohisa	Study on Magnetic Reconnection Site in Solar Flares
Luo, Yudong	The University of Tokyo	Nakamura, Fumitaka	Primordial Magnetic field fluctuation and its impact on the Big Bang Nucleosynthesis
Tatsuuma, Misako	The University of Tokyo	Kokubo, Eiichiro	Planetesimal formation process investigated by material strength calculation of small bodies in our Solar System
Mori, Kanji	The University of Tokyo	Nakamura, Fumitaka	Exploring x-ray bursts with numerical simulations, nuclear experiments, and astronomical observations

3. Commissioned Graduate Students

Doctoral Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Aritomi, Naoki	The University of Tokyo	2020/4/1–2021/3/31	Aso, Yoichi	Frequency dependent squeezing for gravitational wave detectors
Yamaguchi, Masayuki	The University of Tokyo	2020/4/1–2021/3/31	Kawabe, Ryohei	Diversity of Planet Formation Explored by ALMA Using Super-resolution Imaging
Kozuki, Yuto	University of Electro-Communications	2019/10/1–2020/9/30	Uzawa, Yoshinori	Study on SIS frequency up-converters
Kang, Haoran	The University of Tokyo	2019/10/1–2021/9/30	Alvaro, Gonzalez	Study of array receivers in millimeter/submillimeter waves
Murayama, Yosuke	University of Tsukuba	2020/4/1–2020/11/30	Shan, Wenlei	Development of large-format focal plane array using microwave kinetic inductance detectors

Master's Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Ishimura, Shuhei	Ibaraki University	2019/10/1–2020/9/30	Watanabe, Junichi	Ham-band Radio meteor observation
Uno, Shinsuke	The University of Tokyo	2020/4/1–2021/3/31	Uzawa, Yoshinori	Development of kinetic inductance detectors (KIDs) for multichroic continuum camera
Omae, Rikuto	Kyushu University	2020/10/1–2021/3/31	Machida, Mami	Investigation of polarization properties by type of radio source
Ogami, Itsuki	Hosei University	2020/10/1–2021/9/30	Aoki, Wako	The Structure of the Andromeda Galaxy's Stellar Halo using Subaru/Hyper Suprime-Cam NB515
Kumaki, Kosuke	Nihon University	2020/4/1–2021/3/31	Aoki, Wako	High-contrast imaging methods for direct observations of exoplanets
Hu, Bochao	Tokyo Institute of Technology	2020/4/1–2021/3/31	Nomura, Hideko	Modelling gas and dust emission from circumplanetary disks
Koyama, Sao	Niigata University	2020/4/1–2021/3/31	Iono, Daisuke	Research on star formation and galaxy evolution of submillimeter galaxies using ALMA data
Saito, Yoshiharu	Nagoya University	2020/4/1–2021/3/31	Uzawa, Yoshinori	Development of high dynamic range series-connected SIS junction mixer
Tashima, Yuta	Kyushu University	2020/10/1–2021/3/31	Machida, Mami	Simulated radio band observation of the galactic disk
Tsutsumi, Toshihisa	Yamaguchi University	2020/4/1–2021/3/31	Tatematsu, Ken'ichi	Construction of simultaneous triple band VLBI system for Nobeyama 45-m Radio Telescope
Nishiyama, Gaku	The University of Tokyo	2020/4/1–2021/3/31	Matsumoto, Koji	Investigation on subsurface structure of mascon basins on the Moon using lunar gravity field data

4. Degrees Achieved with NAOJ Facilities

Name	Degree	Title of Research Project
Kim, Jungha	Doctor of Philosophy, SOKENDAI	Understanding the Circumstellar Structure of High-Mass Young Stellar Objects Based on Interferometric Observations
Sahoo,Ananya	Doctor of Philosophy, SOKENDAI	Precision Photometric and Astrometric Calibration for Exoplanet Imaging
Zhao, Yuhang	Doctor of Philosophy, SOKENDAI	Development of a frequency dependent squeezed vacuum source for broadband quantum noise reduction in advanced gravitational-wave detectors
Ishikawa, Hiroyuki	Doctor of Philosophy, SOKENDAI	Measurement of Spin-orbit Obliquity of WASP-33b by Doppler Tomography and Transit Photometry
Tanioka, Satoshi	Doctor of Philosophy, SOKENDAI	Optical Loss Study of Molecular Layers Using a Cryogenic Folded Cavity for Future Gravitational-wave Detectors
Hatta, Yoshiki	Doctor of Philosophy, SOKENDAI	Asteroseismology of a Possible Blue Straggler Star KIC11145123
Watanabe, Noriharu	Doctor of Philosophy, SOKENDAI	Detailed Characterization of Nearby M Dwarfs with High-Resolution Near-Infrared Spectroscopy

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 (147 days in total): April 1–June 14 and January 9–March 21 (due to COVID-19), and November 14 (due to equipment inspection)

Visitors: 6,592 (Including 355 in group tours)

As a measure against the COVID-19 pandemic, we suspended all group activities, except for those recognized as school activities.

Open Observatory History Museum (65-cm Telescope Dome), 20-cm Telescope Dome, Solar Tower Telescope, Exhibit Room, Repsold Transit Instrument Building (Transit Instrument Museum), Astronomical Instruments Museum, Gautier Meridian Circle Building, Old Library, 6-m Millimeter-Wave Radio Telescope.

As a measure against the COVID-19 pandemic, only the building exteriors were open to the public.

[Regular Star Gazing Party]

Dates: (On-site) Friday before second Saturday; fourth Saturday

(Online) Fourth Saturday

Visitors: 0 (23 events planned and 0 events held)

Viewers: 13,634 (As of March 31, 2021)

(held 7 times during August–September and November–March)

All on-site events were canceled due to the COVID-19 pandemic. Online events were held about once a month since August (live streamed through YouTube).

[4D2U Theater Showings]

Dates: Friday before second Saturday; first and third Saturdays

Visitors: 255 (35 events planned and 7 events held)

The showings scheduled for April to June, August 7 and 15, September, October, and December to March (28 events in total) were canceled as a protective measure against COVID-19.

[Special Open-House Event] Mitaka Open House Day

Dates: October 23 (Fri), 2020, 14:00–19:00 (Canceled)

October 24 (Sat), 2020, 10:00–19:00 (Held online)

Topic: The Unknown Dark Universe

Same-day Views: YouTube 11,220 (Maximum simultaneous connections: 1,265), niconico Live 17,006

Total Views: YouTube 28,773 (as of March 31, 2021)

niconico Live 19,207 (as of April 7, 2021)

This event is jointly sponsored by NAOJ, the University of Tokyo Graduate School of Science Institute of Astronomy, the SOKENDAI Department of Astronomical Science, and the NINS Astrobiology Center. In FY 2020, instead of being held on-site at Mitaka Campus, Mitaka Open House Day was held online only on Saturday (live streamed through YouTube and niconico Live).

*As a measure against COVID-19, we had to reduce public access to Mitaka Campus during this fiscal year.

Ishigaki Island: Ishigakijima Astronomical Observatory

[Open year-round]

Dates: April to March (closed except for April 1–9 and July 4–9 in FY 2020*)

Open Hours: Wednesdays through Sundays (except for the New Year's season; when Monday is a national holiday, it is opened and closed on the following Tuesday-Wednesday), 10:00–17:00

Stargazing Sessions: Evenings on Saturdays, Sundays, and Holidays, (20:00–22:00), two 30-minute sessions per evening

4D2U Theater: from 15:00 to 15:30 every day when the Observatory is open

Visitors: 117

Open Facilities: Murikabushi 105-cm optical/infrared telescope, Hoshizora Manabi no Heya (Starry Sky Study Room) (featuring the 4D2U "four-dimensional digital universe"), interior of observation dome, and corridors (including exhibits of astronomical images)

*Closed from April 10–July 3 due to the COVID-19 pandemic, and since July 10 due to a partial closure of the road leading to the observatory (Maesedake Rindo).

[Special Open Day]

[Southern Island Star Festival 2020] (co-sponsored and held online)

Dates: August 28 (Saturday), 2020

Venue: Ishigakijima Hoshinoumi Planetarium (live streamed with no audience on site)

Views: 8,295 (YouTube)

2. Mizusawa Campus

[Open year-round]

Dates: April to March (except for New Year's season), 9:00–17:00 daily

Visitors: 9,995

Open Facilities: Kimura Hisashi Memorial Museum, VERA 20-m antenna, 10-m VLBI antenna

The open house event is held at the campus with the cooperation of the Oshu Space and Astronomy Museum (OSAM: Yugakukan) located in the campus.
However, in order to prevent the spread of the novel coronavirus infection, the Kimura Hisashi Memorial Museum has been temporarily closed during the following periods.
April 1 to June 2 and August 2 to the foreseeable future

[Special Open Day]
In light of the fact that novel coronavirus infections have not yet ended, we consulted with Oshu City and the Oshu Space and Astronomy Museum (OSAM: Yugakukan), and decided to cancel this event in consideration of the health and safety of the participants and related people, and to prevent the spread of the infection.

Iriki: VERA Iriki Station

[Open year-round]

Dates: April to March (except for New Year's season)

Visitors: 1,226

[Special Open Day]
The special open house is usually held as the "Yaeyama Highland Star Festival" organized by the executive committee led by Satsuma-sendai city hall and Kagoshima University. This year, in light of the measures to prevent the spread of the novel coronavirus, it was expected that the situation would continue to require that events be cancelled or infection prevention measures be taken to avoid crowding during the event period, and even if the event period was postponed, it would be difficult to implement. After consultation with the main committee members, it was decided to cancel the conference.

Ogasawara: VERA Ogasawara Station

[Open year-round]

Dates: April to March (except for the New Year's season)

Visitors: 4,450

[Special Open Day]
In view of the fact that novel coronavirus infections have not yet ended, we decided to cancel this event in order to protect the health and safety of the participants and related people and to prevent the spread of the infection.

Ishigaki Island: VERA Ishigaki-jima Station

[Open year-round]

Dates: April to March (except for 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: 2,131

[Special Open day]
In view of the fact that novel coronavirus infections have not yet ended, we decided to cancel this event in order to protect the health and safety of the participants and related people and to prevent the spread of the infection.

3. Nobeyama Campus

[Regular Open]

Open Time: 8:30–17:00 (every day except around New Year's Day (December 29 to January 3), especially, open until 18:00 during the summer (July 20 to August 31))

However, we were forced to close from April1 to June17 for prevention measures against the spread of COVID-19.

Visitors: 25,971

Open Facilities: 45-m Radio Telescope, Nobeyama Millimeter Array, Nobeyama Radioheliograph, etc. (just viewing)

[Open House Day] (held online only)

Date: August 29 (Saturday), 2020, 9:30–16:00 (available for access after the day)

Participants: 827 (Maximum simultaneous connections for live stream) about 23,000 (total number of views for all contents in about the first 15 days)

Nobeyama Open Campus Day 2020 was held online as a precaution against the spread of COVID-19. The theme was just "Open Campus at home in this year." We had a special lecture, which attracts a large audience every year. It was held online with the title "Observations of the Universe urge international collaborations – diversity is the foundation of resilience in society" by Associate Prof. Hayashi, Saeko (TMT project/ NAOJ California Office). The number of concurrent connections for this live streaming reached over 800. Moreover, the total number of views in the first 15 days was more than 10 thousand. We also proceeded with online streaming content such as a 4D2U theater, mini lectures led by the ALMA project, demonstration of the 45-m radio telescope, and a live broadcast from Nobeyama Campus. We prepared many movie contents including an introduction to our research, a tour inside the 45-m radio telescope, antenna origami, a road to becoming astronomers, and introductions of ALMA, the 10-m antenna, and Osaka Prefecture University's 1.85-m telescope and so on. Moreover, we had a "keyword rally," event for communicating with participants. The participants look for and collect keywords in some movies and fill in the answers in a form to get NRO original goods. The result was that the number of participants was more than that of on-site Open Campus events to date.

[Jimoto Kansha Day (Thanks Day for the locals)]

This event could not be held due to prevention measures against the spread of COVID-19.

4. Subaru Telescope

[Summit Facility Tour]

Public tours have been suspended due to various factors since 2020

Special tours were not held in FY 2020 due to the COVID-19 pandemic

[Base Facility Tour]

Special tours were not held in FY 2020 due to the COVID-19 pandemic

[Public information]

○ Primary means of public information is posting at the official website https://subarutelescope.org

- Science results from the Subaru Telescope – 19 Japanese and 19 English articles
- Depicting special activities or making announcements on Call for Proposals, recruitment – 22 Japanese and 24 English articles.

○ Web postings are supplemented by social media via the official account

- Twitter accounts – SubaruTelescope (for Japanese), SubaruTel_Eng (for English)
- Facebook pages – 国立天文台(for Japanese), National Astronomical Observatory of Japan, and Subaru Telescope Hawaii Outreach (for English)
- YouTube channels – SubaruTelescopeNAOJ (for Japanese), SubaruTelescopeNAOJe (for English)

[Outreach]

1. Lectures, workshops, etc. at nearby facilities: 1 case, 1000 people in total

2. Others: 5 exhibitions and outreach activities, able to interact remotely with about 3,000 people.

Breakdown as follows:

- Journey Through The Universe: held remotely due to the COVID-19 pandemic and 10 staff members from the Subaru Telescope participated and gave 50 remote lectures to local students.
- “Tsukimi no Kai” hosted by the United Japanese Society of Hawaii : The director of the Subaru Telescope gave an online lecture on the latest scientific achievements of the observatory.
- Hawaii Island Career Expo: The staff of the telescope gave video lectures.
- Inter-University Research Institute Symposium: The staff of the telescope presented video lectures and exhibitions using a special website.

The following local annual events were canceled due to the COVID-19 pandemic:

- The Mary Monarch Parade
- Astro Day
- Astro Day West
- The Tanabata Hoshimatsuri Festival
- Hawaii Explorations Expo
- Onizuka Science Day

3. Media Interview/Filming: 7 cases, 67 articles were featured in Japanese newspapers

IX Overseas Travel

Research and Academic Staff Overseas Travel

(Including employees on annual salary system.)

country/area \ category	Business Trip	Training	Total
South Korea	0	0	0
China	0	0	0
Thailand	0	0	0
Taiwan	1	0	1
Hong Kong	0	0	0
Singapore	0	0	0
Indonesia	0	0	0
Philippines	0	0	0
Other areas in Asia	0	0	0
Hawai`i	3	0	3
U.S.A.	0	0	0
Australia	0	0	0
Italy	0	0	0
U.K.	0	0	0
France	0	0	0
Canada	0	0	0
Guam, Saipan	0	0	0
Germany	0	0	0
Other areas in Europe and Oceania	1	0	1
Mexico	0	0	0
Brazil	0	0	0
Africa	0	0	0
Other areas in South and Central America *	0	0	0
Total	5	0	5

* The number of business trips this year decreased significantly due to COVID-19.
In typical years, most travelers to South and Central America go to Chile.

X Award Winners

Award Recipients	Affiliated Division	Job Title	Award	Date
Kokubo, Eiichiro; Kato, Tsunehiko; Nakayama, Hirotaka; Takeda, Takaaki	Center for Computational Astrophysics/ Center for Computational Astrophysics/ Center for Computational Astrophysics/ Public Relations Center	Professor/ Senior Specialist/ Research Expert/ Public Outreach Staff	The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Prizes for Science and Technology (Public Understanding Promotion Category) FY 2020	2020/4/7
Moriya, Takashi	Division of Science	Assistant Professor	The 9th NINS Young Researcher's Prize	2020/6/14
Zhao, Yuhang	SOKENDAI	Student	The 5th SOKENDAI Award	2020/9/28
Furuya, Kenji	Division of Science	Project Assistant Professor	the Best Researcher Award 2019 of the Japanese Society of Planetary Science	2020/11/14
International outreach project IAU100 (including Lina Canas)	Public Relations Center	Senior Specialist	The first Communication Award by the Dutch Research Council (NWO)	2020/12/1
Aritomi, Naoki	The University of Tokyo	Student	The 26th KAGRA Face-to-Face meeting Best Poster Award	2020/12/18
Hull, Charles L. H.	NAOJ Chile	Project Assistant Professor	2020 NAOJ Young Researchers Award	2021/1/5
EHT Collaboration (Including Honma, Mareki; Nagai, Hiroshi; Hada, Kazuhiro; Kawashima, Tomohisa; Tazaki; Fumie, Oyama, Tomoaki; Kono, Yusuke; Cui, Yuzhu; Tsuda, Shuichiro; Okino, Hiroki; Hirota, Akihiko)			2021 Royal Astronomical Society Group Achievement Award	2021/1/6
Chromospheric LAyer Spectro-Polarimeter-2 Team (Including Ishikawa, Ryoko; Kano, Ryohei; Song, Donguk; Yoshida, Masaki; Okamoto Jyoten; Uraguchi, Fumihiro; Kubo, Masahito; Shinoda, Kazuya; Suematsu, Yoshinori; Tsuduki, Toshihiro; Narukage, Noriyuki; Hara, Hirohisa)			(MSFC) Group Achievement Honor Award	2021/1/18
Hamana, Takashi; Komiyama, Yutaka; Mineo, Sogo; Miyazaki, Satoshi; Shirasaki, Masato; Tanaka, Masayuki; Yamada, Yoshihiko	Division of Science/Subaru Telescope/Subaru Telescope/ Advanced Technology Center/ Research Enhancement Strategy Office/Subaru Telescope/Subaru Telescope	Assistant Professor/ Assistant Professor/ Senior Specialist/ Professor/Assistant Professor/Associate Professor/Research Affiliate	PASJ Excellent Paper Award Recipients	2021/3/18
Honma, Mareki	Mizusawa VLBI Observatory	Professor	the 2020 Hayashi Chushiro Prize from the Astronomical Society of Japan (ASJ)	2021/3/18
Okada, Norio	Advanced Technology Center	Senior Research Engineer	Letter of appreciation from JAXA	2021/3/31
Aritomi, Naoki	The University of Tokyo	Student	Student Presentation Award of the Physical Society of Japan	2021/3/18

XI Library, Publications

1. Library

Number of books in each library (2021/3/31)

	Japanese Books	Foreign Books	Total
Mitaka	18,157	47,990	66,147
Nobeyama	1,128	5,891	7,019
Mizusawa	4,986	18,113	23,099
Hawai`i	1,699	4,683	6,382
Total	25,970	76,677	102,647

Number of journal titles in each library (2021/3/31)

	Japanese Journals	Foreign Journals	Total
Mitaka	371	1,675	2,046
Nobeyama	16	82	98
Mizusawa	659	828	1,487
Hawai`i	15	12	27
Total	1,061	2,597	3,658

2. Publication

Here we list continuing publications produced by NAOJ in FY 2020.

(Mitaka)
01) Report of the National Astronomical Observatory of Japan, Vol. 21: 1 issue (Digital Publication Only)
02) Annual Report of the National Astronomical Observatory of Japan (Japanese), No. 32 Fiscal Year 2019: 1 issue
03) Annual Report of the National Astronomical Observatory of Japan (English), Vol. 22 Fiscal Year 2019: 1 issue
04) Calendar and Ephemeris, 2021: 1 issue
05) NAOJ News, No. 321–332: 12 issues
06) NAOJ Pamphlet (Japanese): 1 issue
07) Rika Nenpyo (Chronological Scientific Tables), 2021: 1 issue
08) Publication of the National Astronomical Observatory of Japan, Vol. 15: 1 issue (Digital Publication Only)

3. Publication Support

In FY 2020, the NAOJ Reprints were replaced by publication support.

National Astronomical Observatory publication support, No. 3334–3478: 145 issues

XII Important Dates

April 1, 2020 – March 31, 2021

2020	
April 7	Kazunori Akiyama, a Research Affiliate at the NAOJ Mizusawa VLBI Observatory and a Jansky Fellow at the National Radio Astronomy Observatory of the United States (NAOJ), received the Young Scientist Prize of the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology in 2020.
April 8	The Subaru Telescope announced that in response to the shortage of masks and other protective equipment at medical facilities on the Island of Hawai'i due to the spread of COVID-19, the Subaru Telescope had donated masks, shoes covers, and gowns to Hilo Medical Center. They were originally prepared for telescope maintenance. The telescope said that it is putting the safety of its staff and the local community as its top priority.
April 30	Content released for creating space themed cards, with a focus on black holes, for the karuta game.
April	The VERA Ishigaki-jima Station and Ishigakijima Astronomical Observatory appeared in the final climax of the January-March 2021 anime broadcast of manga artist Quro's "Asteroid in Love."
May 11~15	The 3rd Event Horizon Telescope Imaging Workshop was held online with more than 100 participants from around the world. The workshop covered the short and long term directions of the project as a whole, reports on the activities of each working group, future plans, and issues to be discussed.
May 18	The Subaru Telescope suspended its operation and astronomical observation temporarily from March 25, 2020 due to the global spread of COVID-19, but resumed its open-use observations following the COVID-19 countermeasure guidelines.
June 18	Regular Opening of Nobeyama Campus, which had been closed to help prevent the spread of COVID-19, was restarted, limited to just the outside areas.
June 21	An online broadcast of the partial solar eclipse was held connecting Mitaka Solar Flare Telescope, Ishigakijima Astronomical Observatory, and Nayoro Observatory. There were 750,000 views on Youtube, including overseas access, and 37,843 views on niconico Live.
July 14	The Subaru Telescope announced that collaborative observations with NASA's New Horizons mission had started at the Subaru Telescope since May 2020. Hyper Suprime-Cam (HSC), the wide field camera mounted on the prime focus of the Subaru Telescope, was used for the observations to search for target candidates for New Horizons' next observations.
July 30	Some of the photos that were restored from the glass dry plates of the latitude observatory were opened to the public on the website of Kimura Memorial Hall (Mizusawa VLBI Observatory, NAOJ).
July 30	COMICS, the Cooled Mid-Infrared Camera and Spectrometer at the Cassegrain focus of the Subaru Telescope, had its final night of observation, after more than 20 years since its first observation in 1999 as one of the 1st generation instruments at the Subaru Telescope. COMICS' unique capability to detect the longest wavelengths (8–25 microns) in the infrared observable from the ground led to wide-ranging scientific accomplishments such as uncovering complex organic molecules in a comet and new insights into the nature of building blocks of planets.
August 1	A press conference "Surprisingly Young Galaxy Breaks Low-Oxygen Record" was held online. The organizers who co-hosted the conference with NAOJ were the Institute for Cosmic Ray Research, University of Tokyo and W.M. Keck Observatory in the USA. The conference was attended by 17 participants from 15 media companies.
August 7	A press conference "Stellar Egg Hunt with ALMA—Tracing Evolution from Embryo to Baby Star" was held online. The organizers who co-hosted the conference with NAOJ were Osaka Prefecture University and Nagoya University. The conference was attended by 14 participants from 13 media companies.
August 28	The Southern Island Star Festival 2020 (cohosted by Ishigakijima Astronomical Observatory and Yaeyama Hosinokai) was held online on YouTube.
August 29	Open House day of Nobeyama Radio Observatory was held online. The maximum number of concurrent connection for live streaming reached about 820, and the total number of views for all contents for about the first 15 days was about 23,000.
August 31	A press conference "Can Black Hole Fire Up Cold Heart of the Phoenix?" was held online. The organizers who co-hosted the conference with NAOJ were the School of Science, University of Tokyo; Institute of Astronomy and Astrophysics, Academia Sinica, ASIAA; and Toho University. The conference was attended by 13 participants from 12 media companies.

September 8	The 6-m Millimeter-Wave Radio Telescope was added to the Japan Astronomical Heritage List.
September 15~16	“Nobeyama Science Workshop 2020” was held online on the latest results and the future plan of the 45-m radio telescope. There were about 130 registrations, mainly young researchers.
September 19~20	Chura-boshi Research Team workshop for high school students was held at VERA Ishigaki-jima Station and Ishigakijima Astronomical Observatory for the first time during the four consecutive holidays in September. In addition to 5 students from Ishigaki Island and 1 student from Okinawa Island, there were 4 students from Tokyo, 2 students each from Aichi, Niigata, and Kanagawa Prefectures, and 1 student each from Osaka, Nara, Kyoto, Shizuoka, Chiba, and Hokkaido Prefectures. This time, we tried to include remote lectures, but since all the lectures were delivered via Zoom, we could not operate the telescopes and observe and analyze on site, so it was difficult to create a sense of realism through these simulated experiences. In the observation experience using the Murikabushi Telescope, we explored unknown small Solar System objects. As a result, the observation data obtained on the day of the Chura-boshi Research did not show any new celestial body candidates, but the preliminary observation data of the day before showed two new celestial body candidates, and the discovery with the Murikabushi Telescope was the first in four years since the 2016 Chura-boshi Research.
September 24~25	“The 18th Mizusawa VLBI Observatory Users Meeting” was held online for the first time this year due to concerns about the spread of the novel coronavirus infection, and it became a substantial meeting where 67 people participated. There was spirited discussion of Japanese, East Asian, and world VLBI programs.
September 29	Mr. Koichi Hagiuda, Minister of Education, Culture, Sports, Science and Technology, visited the VERA Ishigaki-jima Station and Ishigakijima Astronomical Observatory in Ishigaki City, Okinawa Prefecture. At the VERA Ishigaki-jima Station, Mareki Homma, Director of Mizusawa VLBI, explained about VERA and its observation system and research results. At the same time, he was presented with the black hole photos taken by the Event Horizon Telescope, in which members of the station also participated. He also met local high school students who are supporting the long-term continuation of VERA, and listened attentively to the voices of the Ishigaki citizens in support of astronomy.
October 1	Prof. Michitoshi Yoshida, the Director of Subaru Telescope, joined “Tsukimi No Kai” (moon-viewing party) hosted by the United Japanese Society of Hawaii, and gave a video lecture. He firstly introduced the Subaru Telescope and its latest research results, and then presented new findings related to moons, such as the origin of the Earth’s moon, and satellites of other planets of the Solar System.
October 6	The three scientists involved in black hole research were awarded the 2020 Nobel Prize in Physics, and Mareki Homma, Director of Mizusawa VLBI and head of the Japanese research team for the Event Horizon Telescope, gave a congratulatory speech.
October 14~16	The ALMA2030 Vision: Design considerations for Digitizers, Backend and Data Transmission System was held online.
October 17~18	The Subaru Telescope joined the online event in Japan “Inter-University Research Institute Corporation Symposium 2020” by giving a video lecture and holding an exhibition using a special website. In the video lecture, Dr. Sakurako Okamoto, an astronomer of Subaru Telescope, became a guide and gave a virtual tour of the observatory’s Base Facility, which is crucial for the daily operation of the Subaru Telescope. She also introduced the latest results about her own research on galaxies and looked forward to further discoveries that will be made with the next generation of instruments of the telescope.
October 24	“Mitaka Open House Day” was held online (on YouTube and niconico Live) with the theme of “The Unknown Dark Universe.”
October 28	“The 26th NAOJ Lecture for the Science Media” titled “The Universe Revealed by TMT and Current Status of the Plan” was held with 28 participants from the media in attendance.
October 30	East Asia ALMA Community Gathering was held online.
November 16~20	Local staff of the Subaru Telescope gave video lectures to local students on the Big Island of Hawaiʻi in “Hawaii Island Virtual Career Expo,” and spoke about occupations needed in the operation of the Subaru Telescope as well as the necessary skills and how to be prepared for those positions.
November 19~30	In order for visitors to the Mizusawa VLBI Observatory to enjoy the observatory as much as possible, we have cooperated with the Ihatov Space Action Center / the Oshu Space and Astronomy Museum (OSAM: Yugakukan) to hold an event titled “Solving the mystery 2020! You are the one who can solve the space crisis!”
November 20	The Subaru Telescope captured Hayabusa2 on its way back to Earth after exploring the asteroid (162173) Ryugu. The image was featured in many media outlets.
November 25	A press conference “Earth Faster, Closer to Black Hole in New Map of Galaxy” was held simultaniously in Mizusawa, Kaoshima, and online. The confernce was co-hosted with Kagoshima University. The conference was attended by 22 participants from 17 media companies.

December 2	In collaboration with the Iwate Prefectural Government's Kenan Regional Promotion Bureau, we held a special exhibition at libraries and other venues in the Kenan area until March 7, 2021.
December 3	Agreement signed with Mitaka City for increased cooperation.
December 6	Professor Seiichi Sakamoto, Assistant Professor Masaaki Hiramatsu, and Project Assistant Professor Andres Guzman participated as lecturers in the online event organized by Mitaka City to celebrate that Mitaka City has become the "Host Town" and "Host Town for Symbiotic Society" of Chile for the Tokyo 2020 Games.
Desember 8, 15	ALMA Grant Fellow Symposium 2020 was held online.
December 10	1998 KY26 was photographed by the Subaru Telescope in the direction of the constellation Gemini as a 25.4-magnitude point of light with a measurement uncertainty of 0.7 mag. The positional data collected during these observations will be used to improve the accuracy of the orbital elements of the asteroid.
December 13	Associate Professor Yoshiharu Asaki gave an online lecture on the solar eclipse for Japanese living in Chile.
December 15	"The 27th NAOJ Lecture for the Science Media" titled "GALAXY CRUISE: Citizens helping to unlock the secrets of galaxies" was held with 14 participants from the media in attendance.
December 30	The Subaru Telescope received a letter of appreciation from the Hayabusa2 Project of the Institute for Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), for the Subaru Telescope's observations of the asteroid 1998 KY26, the target of Hayabusa2's extended mission.

2021

January 5~7	ALMA/45m/ASTE users meeting 2020 was held online.
January 11	Mareki Homma, Director of Mizusawa VLBI, was awarded the 25th Hayashi Chushiro Prize, which is given for original and significant contributions to the field of astronomy.
January 14	The Subaru Telescope has launched a new science archive that delivers processed, high quality data from Hyper Suprime-Cam (HSC) . The archive will accelerate scientific explorations of HSC data and hopefully lead to new discoveries.
February 6	The Fifth "Nagano is a Astro-Prefecture" meeting and Open Lectures were held online and at Kiso Cultural Park by "Nagano Prefecture is Astro-Prefecture" liaison council, which consists of Nobeyama Radio Observatory, Kiso Observatory of the University of Tokyo, and so on. There were about 60 participants in the meeting and about 280 (125 on-site and about 150 online) in the open lectures.
February 8~11	NAOJ (in collaboration with 4 other institutes) hosted an exhibit at the 2021 AAAS Annual Meeting held online.
February 17~19	East Asian ALMA Science Workshop 2021 was held online.
February 18	NAOJ and 5 other institutes, in cooperation with the Foreign Press Center Japan, presented online science lectures for overseas media representatives stationed in Japan.
March 1	An agreement was signed with Osaka Prefecture University for comprehensive research cooperation.
March 1~5	10 staff members of the Subaru Telescope participated in "Journey Through the Universe" — which started in 2006 and was carried out entirely online for the first time in 2021 due to the COVID-19 pandemic — and shared the wonders of the Universe and the possibilities of a career in science and technology. They interacted with approximately 1000 school students on Hawai‘i Island.
March 3~5	An annual Subaru Users Meeting FY 2020 was held online and intensive discussions were made on new Subaru instruments, changes in the operational modes in the COVID-19 pandemic, and on the Subaru future strategy.
March 6	NAOJ Public Talk/25th ALMA Public Talk "Stars born from dark clouds - from the observation site to the latest results" was held online with a maximum of 418 simultaneous connections.
March 18	The Mizusawa VLBI Observatory's Visual Zenith Telescope 1, the Visual Zenith Telescope Building, and the Meridian Mark were recognized in the 3rd Japanese Astronomical Heritage list of historical sites and things of historical significance from the viewpoint of astronomy (including calendar science) in Japan.
March 22~23	ALMA Cycle 8 2021 Proposal Preparation Meeting was held online.
March 24	East Asia ALMA Community Gathering in March 2021 was held online.
March 30	The Subaru Telescope website was redesigned to make it easier to see on smartphones.
March 31	The Subaru Telescope announced that the research paper on observational cosmology based on observations with Subaru Hyper Suprime-Cam (HSC) earned the PASJ Excellent Paper Award for the most outstanding paper published in the Publications of the Astronomical Society of Japan (ASJ) and the award ceremony was held in the ASJ Annual Spring meeting in March. This research revealed the amount and distributions of dark matter using the weak lensing effect by large-scale structure appearing on images of more distant galaxies, and quickly drew worldwide attention.

Throughout the year	A special summit facility tour for local residents, “Kamaaina Observatory Experience” has been held every year for a long time by the observatories on Maunakea and the Subaru Telescope usually holds this special summit facility tour for local residents once every three months each year. However due to the COVID-19 pandemic, the whole tour program was cancelled in FY 2020. Since it was difficult to hold face-to-face events due to the COVID-19 pandemic, the Subaru Telescope developed outreach activities using visual materials such as images. The telescope also promoted the production and distribution of video works for children, and promoted outreach activities in a new style originating from Hawai‘i. The Subaru Telescope also focused on social media, and the number of followers (subscribers) on Twitter exceeded 59,000. The telescope focused on disseminating information using relatively new methods such as Facebook and YouTube, and creating materials such as photos and videos for this purpose.

XIII Publications, Presentations

1. Refereed Publications

Abbott, B. P., et al. including **Akutsu, T.**, **Barton, M. A.**, **Capocasa, E.**, **Flaminio, R.**, **Hirata, N.**, **Leonardi, M.**, **Marchio, M.**, **Nakamura, K.**, **Shoda, A.**, **Takahashi, R.**, **Tanioka, S.**, **Tapia San Martin, E. N.**, **Zeidler, S.**, **Zhao, Y.**, KAGRA Collaboration, LIGO Scientific Collaboration, Virgo Collaboration: 2020, Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA, *Living Rev. Relativ.*, **23**, 3.

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Akahori, T., Kitayama, T., Ueda, S., **Izumi, T.**, Lee, K., **Kawabe, R.**, Kohno, K., Oguri, M., Takizawa, M.: 2020, Discovery of radio jets in the Phoenix galaxy cluster center, *PASJ*, **72**, 62.

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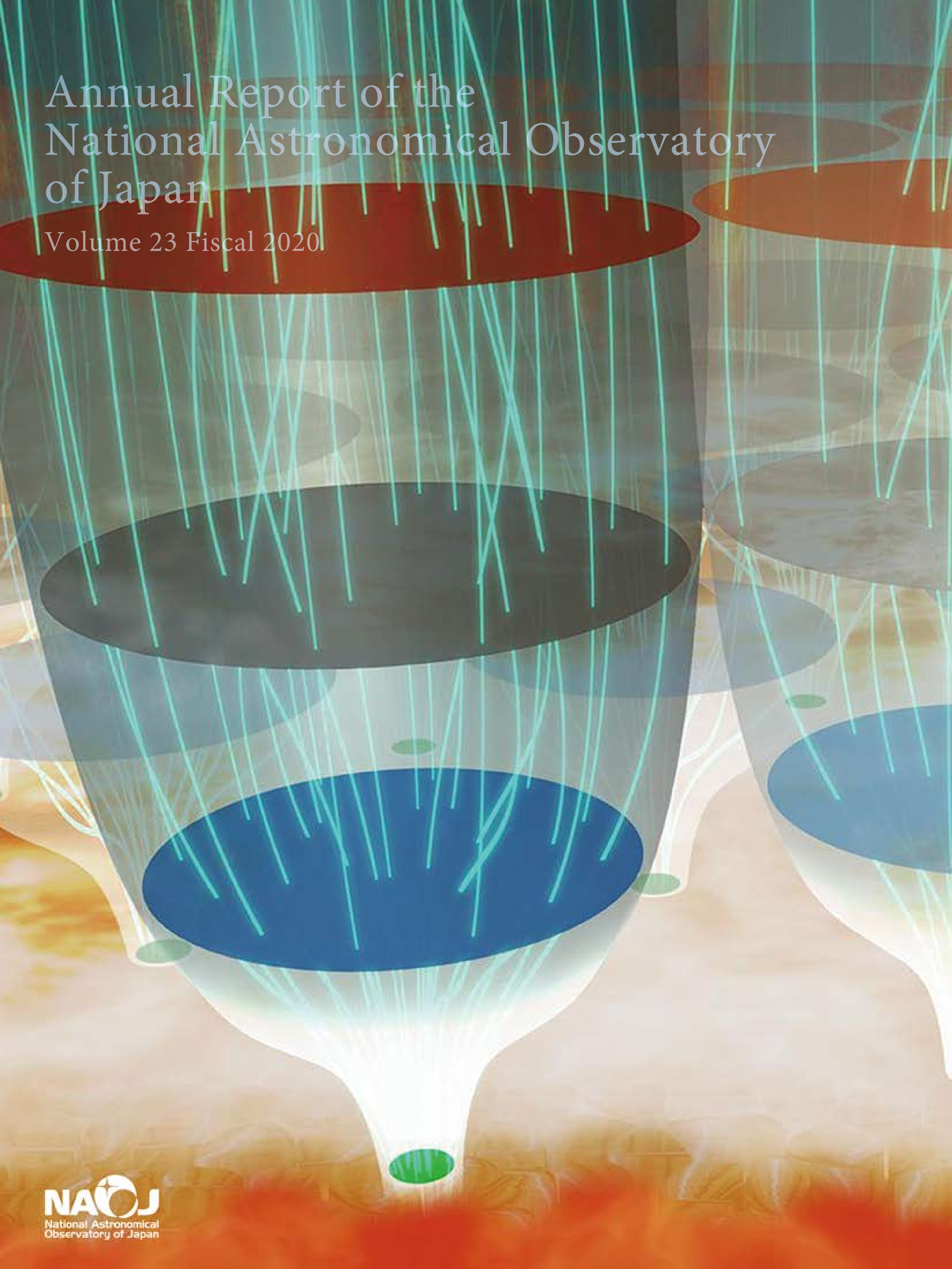

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