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Cover Caption

The shadow of the supermassive black hole in the elliptical galaxy M87 captured by the Event Horizon Telescope (EHT) Collaboration through millimeter-wave VLBI observations.

Credit: EHT Collaboration

Postscript

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Annual Report of the National Astronomical Observatory of Japan

Volume 22, Fiscal 2019

PREFACE

Saku TSUNETA
Director General of NAOJ

In 2019, astronomy received several prestigious awards, attracting the world's attention. The Nobel Prize in Physics went to three scientists for the discovery of an exoplanet orbiting a solar-type star and for contributions to our understanding of the evolution of the Universe. The themes of the award are the hottest topics in modern astronomy. At NAOJ, a new observation instrument to search for exoplanets, IRD, is being developed through collaboration with the NINS Astrobiology Center, and is being offered for collaborative use on the Subaru Telescope. NAOJ is also contributing to our understanding of the structure and history of the Universe, through results like the discovery by the Subaru Telescope of the most distant galaxy proto-cluster ever observed and the discovery by ALMA of a giant galaxy in the early Universe.

In April 2019, the Event Horizon Telescope (EHT), in which NAOJ researchers participate, announced that it had succeeded in direct imaging of the shadow of the supermassive black hole in the heart of Galaxy M87, attracting attention in society worldwide. It was decided to award the Breakthrough Prize in Fundamental Physics for this achievement. Among the 347 recipients, 11 researchers belonged to NAOJ. ALMA, operated through an international collaboration including NAOJ, achieved the highest sensitivity among the telescopes participating in the EHT observations, a vital contribution to this success.

In order to achieve successes like these, the scale of the astronomical facilities and the complexity of the international collaborations developing them are both increasing. At NAOJ, to examine the role NAOJ should play in future large-scale international projects, we established the SKA1 (Square Kilometer Array) and ngVLA (next generation Very Large Array) Investigation Groups. In addition to scientific contributions, we will consider the contributions we can make on the technical side, where NAOJ is strong. From the technology development standpoint, in December 2019 NAOJ and the National Research and Development Agency of the National Institute of Information and Communications Technology (NICT) concluded an agreement establishing a framework for collaboration between the two institutes.

On the other hand, domestic cooperation is also important. We are pursuing OISTER (Optical and Infrared Synergetic Telescopes for Education and Research) and JVN (Japanese VLBI Network) linking optical-infrared and radio telescopes respectively located at various universities to function as observation networks through NAOJ-led collaborative projects. With these collaborations as hubs, we expect to contribute to graduate-student education and advance "spicy hot science."

Also in 2019, the previous four Divisions (Theoretical Astronomy; Optical and Infrared Astronomy; Radio Astronomy; and Solar and Plasma Astrophysics) were combined to form the new Division of Science. We hope that while pursuing topics like the fusion of theory and observations; multi-wavelength astronomy; and multi-messenger astronomy, the Division of Science will contribute to decision making and future planning at NAOJ, and the development of young researchers.

The Center for Computational Astrophysics (CfCA) has been operating a system of open-use computers centered around the massive parallel supercomputer ATERUI II (theoretical peak performance 3 Pflops) upgraded in Fiscal Year 2018. Operation of a GPU cluster started on a trial basis since FY 2019. Approximately 140 papers were published in FY 2019. Activities include the creation of training data needed for cosmological research utilizing artificial intelligence and black hole shadow research by the Event Horizon Telescope.

The Japan Virtual Observatory, being developed by the Astronomy Data Center, an organization supporting multi-wavelength and multi-messenger astronomy, continued to advance with a strong awareness of the end-users' experience. It has been recognized internationally as a Japan-made tool for opening observational data from ALMA and the Subaru Telescope to the world and enabling these data to be used in concert with data collected by other telescopes located throughout the world.

Projects have also started to help people develop a more familiar relationship with astronomy. The Citizen Astronomy project "GALAXY CRUISE," in which researchers and ordinary citizens work together to solve the mysteries of galaxies, is a new effort at NAOJ. Using data acquired by the Subaru Telescope's ultrawide-field-of-view prime-focus camera, participants classify the shapes of colliding galaxies by hand, with the goal of researchers and citizens working together to produce scientific results.

Here I would like to summarize the status of NAOJ's major projects in FY 2019.

Subaru Telescope

In FY 2019 the Subaru Strategic Program utilizing the ultrawide-field-of-view prime-focus camera Hyper Suprime-Cam (HSC) has moved forward, issuing its second data release in May. Through ultrawide field-of-view observations with HSC, 83 supermassive black holes were discovered in the distant Universe 13 billion light-years from Earth. This important result is the first time it has been shown that supermassive black holes are common in the distant cosmos and provides new insight into the cause of the cosmic reionization which occurred in the early stages of the Universe. In addition, follow up observations using the Keck and Gemini observatories of galaxy candidates discovered 13 billion light-years away by the Subaru Telescope revealed a protocluster consisting of 12 galaxies. This is the farthest example among the currently known protoclusters. This important result shows that protoclusters were growing while

actively forming stars very early on, when the Universe was only 800 million years old (less than 6% of its current age). Furthermore, a survey for gravitational lensing events caused by primordial black holes with masses less than that of the Moon (and sizes beneath 0.1 millimeter) used HSC to watch for small changes in the brightness of as many as 900 million stars in the Andromeda Galaxy. The results of this survey showed observationally for the first time that it is highly unlikely that such primordial black holes contribute significantly to the composition of dark matter. These findings show a glimpse of the rich results from HSC.

Development of the next facility instrument after HSC, the Prime Focus Spectrograph (PFS), is advancing through an international collaboration of seven countries and regions led by KAVLI IPMU at the University of Tokyo. PFS is a revolutionary instrument that arrays approximately 2,400 fibers across an area almost as wide as HSC's field of view and conducts simultaneous spectroscopy. Development is continuing at each institute, aiming to start science observations in 2023. In FY 2019, the first spectrograph tests at the summit facility went well. When PFS is completed, it will enable us to obtain accurate distances, speeds, and chemical compositions for the multitude of unknown objects captured by HSC. We hope that while helping to understand the nature of dark energy, it will also clarify how galaxies formed throughout the long history of the Universe.

Making best use of the high-performance velocity measurements at infrared wavelengths by IRD (InfraRed Doppler instrument), a strategic program has started in order to search for Earth-like planets in the habitable zones around red dwarf stars, which are lighter than the Sun. Also, various collaborative observation projects are continuing, such as follow-up observations of planet candidates discovered by NASA's TESS satellite. Open-use of SCExAO (Subaru Coronagraphic Extreme Adaptive Optics) for the direct observation of exoplanets and the near infrared CHARIS (Coronagraphic High Angular Resolution Imaging Spectrograph) is proceeding well. The development, maintenance, and operation of these instruments are conducted through cooperation between the NINS Astrobiology Center, Subaru Telescope, and other organizations.

At NAOJ we are pursuing a plan "Subaru Telescope 2" to greatly upgrade the Subaru Telescope, with HSC, PFS, and ULTIMATE (Ultra-wide Laser Tomographic Imager and MOS with AO for Transcendent Exploration) using GLAO (Ground Layer Adaptive Optics) as the primary instruments. "Subaru Telescope 2" plans to achieve a 50-fold increase in field of view and a 20-fold increase in the number of targets which can be observed simultaneously in visible spectroscopy observations; and a 10-fold increase in field of view and a 2-fold increase in resolution as compared to the current Subaru Telescope in infrared observations. This plan was selected as one of the high-priority projects in the Master Plan 2020 initiative of the Science Council of Japan in January 2020.

On the operations side, in the summer of FY 2019, existing observatories in the summit region of Maunakea were not accessible due to the protests against TMT. Subaru Telescope lost close to 50 nights of observing time.

More than 20 years have passed since the start of open-use observations at the Subaru Telescope and the effects of aging are starting to appear in the basic facilities and equipment. Repairs were conducted on the secondary mirror and observational instruments damaged by hurricanes or the 2018 earthquake. In FY 2019 repair work was conducted on the dome main shutter which had been an outstanding problem. To support the activities of the Subaru Telescope, it will be necessary to continue investment in response to aging.

ALMA

The 8th round of ALMA open-use observations commenced in October 2019 as Cycle 7. There were submissions of 1,773 proposals from all over the world. In addition, there were 249 proposals in response to the Atacama Compact Array stand-alone Supplemental Call for Proposals. The enhancement of the observational capabilities continued, including the start of Band 7 observations with the maximum baseline of 16.2 km, which will provide the highest spatial resolution ever of about 10 milli-arcsec. The number of papers published using ALMA data in the approximately eight and a half years up through 2019 reached 1,822. Japan continued to hold on to second place, behind the United States, in terms of number of papers published.

In FY 2019, there were several big results in research related to galaxies in the earliest eras of the Universe. Myriads of galaxies unobservable with the Hubble Space Telescope were discovered in the ancient Universe 11 billion years ago. These galaxies are thought to evolve into giant elliptical galaxies like those seen in the modern Universe. These objects had not been predicted by theoretical galaxy formation research; this result upends our understanding of galaxy evolution in the early Universe.

In addition, the detection of molecules including phosphorus in star forming regions attracted attention. Phosphorus is an important element for life, being included in DNA. Because molecules containing phosphorus have also been discovered in comets, this is a hint to decipher the story connected to the origin of life of how the materials related to life were transported via comets to planets from the molecular cloud stage of stellar formation. There is also active utilization of the data available in the archive, producing results.

In receiver development, Band 1 (observational wavelength band 35-50 GHz) receiver development led by ASIAA (Academia Sinica Institute of Astronomy and Astrophysics) with contributions from NAOJ and other institutes has entered the mass production phase. NAOJ contributed the design and production of the corrugated horns, one of the essential components. Mass production of the horns is planned using the 3D metal printer introduced in the Advanced Technology Center (ATC) in August 2019.

Looking ahead to the next 10 years, we are preparing the "ALMA 2" plan to greatly enhance the capabilities of ALMA. Under this new ALMA 2 plan, international cooperative observations will continue while setting new science goals and upgrading the sensitivity, angular resolution, and the simultaneously observable wavelength bands. This plan was also selected as one of the high-priority projects in the Master Plan 2020 initiative of the Science Council of Japan in January 2020.

TMT

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 project such as the telescope structure and primary mirror segments. Onsite construction is currently

on hold due to protests, but TMT International Observatory has opened a dialog with representatives of the opposition groups, and the United States federal government has started preparations to participate through the National Science Foundation (NSF).

In FY 2019 planning and development have progressed steadily in Japan and the other countries on their respective workshares. In work related to the telescope structure for which Japan is responsible, we have used the delay caused by the suspension of onsite construction to increase the design maturity and decrease risk through measures such as tests to ensure that the seismic isolation system can withstand even a once-in-a-millennium scale earthquake, the first time this has been done for a large telescope. Japan is manufacturing all of the mirror blanks for the primary mirror segments. Aspherical polishing is planned to be conducted by 4 countries, and Japan has already commenced its aspherical polishing. In the Advanced Technology Center (ATC), the planning and testing of observational instruments is proceeding. Starting from FY 2019, six members of the NAOJ TMT Project, most notably the Project Director, have been resident at TIO, helping to strengthen personnel support.

KAGRA

KAGRA, the Large-scale Cryogenic Gravitational Wave Telescope advancing through collaboration led by the Institute for Cosmic Ray Research of the University of Tokyo and including NAOJ and the High Energy Accelerator Research Organization KEK, has finished the construction phase after 10 years of work and started observations in February 2020. It has achieved a sensitivity allowing it to detect binary neutron star mergers out to a distance of 1 Mpc. KAGRA's planned participation in joint observations with the American LIGO and the European Virgo as part of the O3 (Observation-3) run was postponed due to COVID-19. Ever though we weren't able to participate this time, looking ahead to O4 (Observation-4) we undertook efforts to increase the sensitivity, including improvements to the high performance vibration isolation system and optical baffles developed at NAOJ, with the aim of improving the sensitivity enough to be able to detect binary neutron star mergers out to a distance of 25 Mpc. KAGRA's participation in O4 will make it easier to pinpoint the location of gravitational wave sources for follow-up observations by the Subaru Telescope and other telescopes. So we can look forward to great advances in multi-messenger astronomy.

Other Activities

Efforts to improve the efficiency of open-use at Mizusawa VLBI Observatory and Nobeyama Radio Observatory continue, and we have started a dialog about future science goals with the community. This year, 2019, marked the 120th anniversary since the establishment of the International Latitude Observatory of Mizusawa, the precursor of Mizusawa VLBI Observatory. In the imaging of the black hole shadow by EHT, the Japanese research team centered around The Institute of Statistical Mathematics of the Research Organization of Information and Systems and Mizusawa introduced a new data processing technique and succeeded in independently imaging the black hole shadow from the data. In addition, combining the data of the Nobeyama 45-m Radio Telescope and CARMA radio interferometer in the United States enabled the creation of an unprecedentedly detailed radio map of nearby star forming regions.

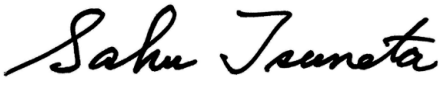
On the other hand, the Nobeyama Radio Heliograph, which has been operated by a consortium composed primarily of universities since the closure of the Nobeyama Solar Radio Observatory, ceased observations at the end of FY 2019. If there are observatories which have finished their roles, then there is also the opportunity to develop new observatories. In this way, we can say astronomy continues to be dynamic.

Nationwide open-use of Kyoto University's Seimei Telescope is on the right track, thanks to the Okayama Branch Office of Subaru Telescope established in FY 2018. Through the efforts of Kyoto University, control of the segmented primary mirror is stable, and the telescope is satisfactorily demonstrating its power as a 4-m class telescope. The Okayama 188-cm Reflector Telescope, which has been operated by the Tokyo Institute of Technology since FY 2018, has aggressively pursued an automated exoplanet survey, observing for more than 300 nights during FY 2019. Cooperation is also advancing with Asakuchi City for education and outreach activities such as using the facility for concerts or lending it to astronomy fans.

In ATC, through cooperation with a domestic company we have succeeded in the development of an InGaAs image sensor which surpasses the near infrared image sensors for low-noise astronomical observations that have been available from only a single company in the United States. We hope the sensor will be used not just for astronomy but also for other applications, such as observations of the Earth from space. The large clean room in Development Building 3 for assembly and adjustment of TMT observational instruments has been completed. With this, we look forward to not only the development of TMT observational instruments but also in the future the development of observational instruments to be flown on JAXA satellites.

We can say that it has been a fruitful time at NAOJ because in addition to the status of our major projects as summarized above, the 3,191 papers published during 2015~19 by members of NAOJ, including young researchers, have had an international collaboration rate of 75 %; also, 14 % of the papers have made it into the Top10% of papers published worldwide in terms of citations and 2.9 % have made it into the Top1% (according to InCites as of August 2020). While as of August 2020, 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 9.0 % world share in the number of papers published in astronomy during 2019. This is Japan's highest world share among the 22 fields of study, surpassing even physics. In addition, in the 2018 and 2019 Fiscal Years, we have welcomed our first 2 female professors. As of April 1, 2020, women account for 7.4 % of NAOJ researchers (including Research and Academic Staff and Specially Appointed Teachers).

Finally, during this Fiscal Year former NAOJ Director General Norio Kaifu passed away. Since the era of Tokyo Astronomical Observatory, Dr. Kaifu played a crucial role in the establishment of the Nobeyama 45-m Radio Telescope, Subaru Telescope, and ALMA. We pray that his soul may rest in peace.



I Scientific Highlights

(April 2019 – March 2020)

Age Dating the Galactic Bar with the Nuclear Stellar Disc

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KAWATA, Daisuke
(MSSL/UCL)

Revealing the formation history and structure of the bar in the Milky Way is a long-standing challenge in Galactic astronomy. Early infrared observations revealed that the Galactic bulge shows the boxy shape and is believed to be a bar. Recent surveys towards the Galactic bulge, such as BRAVA and VVV, shows a clear inner boxy/peanut-shaped bulge connected to the long thinner Galactic bar as long as ~5 kpc [1]. Using kinematic data of the bar/bulge stars, recent studies suggest that the current pattern speed of the Galactic bar is ~40 km s^{-1} kpc^{-1} [2]. Another unknown property of the Galactic bar is the formation time. The Galactic bar impacts the dynamics and star formation of the Galactic disc significantly, and identifying the formation epoch of the bar is one of the key questions to understand the formation and evolution history of the Milky Way. However, it should be noted that the age of stars in a bar does not equal the 'dynamical' age of the bar.

In this study [3], we demonstrate that the gas funneling and starburst in the central sub-kpc region can be used to identify the formation epoch of the Galactic bar, using an *N*-body/SPH simulation of an isolated Milky Way-like galaxy. Our simulation shows that the bar formation triggers an intense star formation for ~1 Gyr in the central region and forms an NSD (Fig. 1), as observations [4]. As a result, the oldest age limit of the NSD is relatively sharp, and the oldest population becomes similar to the age of the bar (Fig. 2). Therefore, the age distribution of the NSD tells us the formation epoch of the bar. We also demonstrate that because the NSD is kinematically colder than the other stellar populations in the Galactic central region, the NSD population can be kinematically distinguished from the other stellar populations. Hence, the accurate measurements of the transverse velocities of stars are necessary, and the near-infrared space astrometry mission, *Small-JASMINE*, would play a crucial role to identify the formation epoch of the Galactic bar.

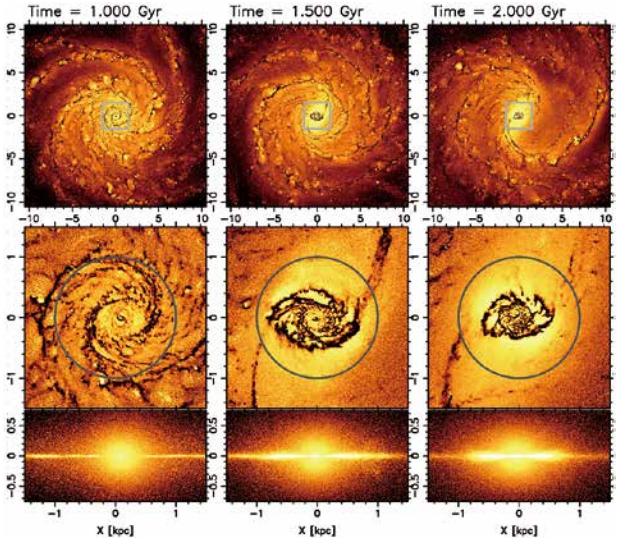

Figure 1: Morphological evolution of the simulated barred spiral galaxy. Colours indicate surface density of stars in logarithmic scale. After the bar formed ($t \simeq 1.5$ Gyr), the major axis of the bar is set to be the direction to 25° from the *y*-axis. The simulation was performed on the ATERUI-II (CfCA/NAOJ).

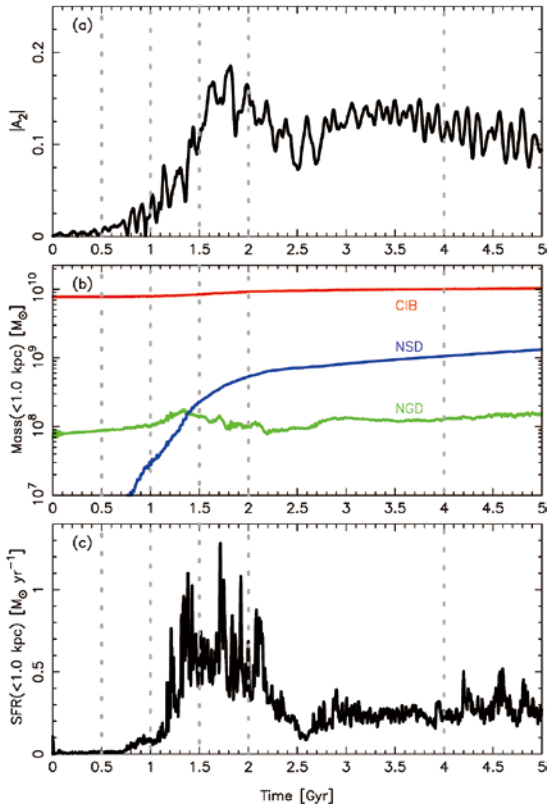

Figure 2: Time evolution of (a) the bar amplitude, (b) the include masses, and (c) in-situ SFR in the central 1 kpc region.

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Stellar Overdensity in the Local Arm in Gaia DR2

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Revealing the shapes of spiral arms in the Milky Way is a long-standing challenge in Galactic astronomy. The first successful identification of spiral arms in the Milky Way was made by Morgan et al. (1952) [1] from distributions of ionized hydrogen in the solar neighborhood. Since then, many studies have reported the characteristics of spiral arms in the Milky Way. The well-known spiral arms within a few kiloparsecs of the Sun are the Sagittarius–Carina arm and the Perseus arm. There is another spiral arm between the Sagittarius–Carina and Perseus arms, called the 'Local Arm' or the 'Orion Arm' [2]. The Local Arm is often considered to be a spur which bridges between the Sagittarius–Carina arm and the Perseus arm. However, recent studies suggest that a large number of HMSFRs are observed in the Local Arm, and the overall length (> 5 kpc) identified with HMSFRs is substantial, which led to a recent debate that the Local Arm may be a major spiral arm [3].

In this study [4], using the cross-matched data of Gaia DR2 and the 2MASS Point Source Catalog, we investigated the surface density distribution of stars aged ~1 Gyr in the thin disk in the range of $90° < l < 270°$. The selected sample shows an arm-like overdensity at $90° < l < 190°$, which is located close to the Local Arm traced by the HMSFRs but its pitch angle is slightly larger than that of the HMSFR-defined arm. This overdensity structure poses questions concerning both of the competing scenarios of spiral arms. The offset between the arms traced by stars and HMSFRs is difficult to explain using the dynamic arm scenario. On the other hand, the pitch angle of the stellar Local Arm, if confirmed, is larger than that of the Perseus arm, and is difficult to explain using the density-wave scenario [5]. The dynamic arm scenario [6] can explain the pitch angle of the stellar Local Arm, if the Local Arm is in a growing up phase, while the Perseus arm is in a disrupting phase [7]. Our result provide a new and complex picture of the Galactic spiral arms, and encourages further studies.

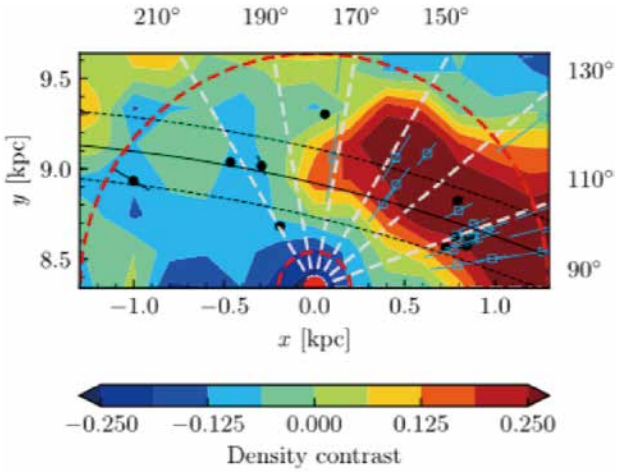

Figure 1: The smoothed density distribution of our selected stars as 1 Gyr stellar populations after division by an exponential profile. The Sun is located at $(x, y) = (0, 8.34)$ kpc. The x-axis is the direction of the Galactic rotation, and the y-axis is the direction from the Galactic center to the Sun. The location of the Local Arm defined with HMSFRs is highlighted by a solid black line and the dashed black lines indicate the width.

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* (NAOJ) as of the publication date

ALMA Spatially Resolved Dense Molecular Gas Survey of Nearby Infrared Luminous Galaxies - Census of Mass-accreting Supermassive Black Holes -

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Ultraluminous infrared galaxies (ULIRGs) radiate very large infrared luminosity of $L_{IR} > 10^{12} L_{\odot}$, due to dust thermal radiation heated by hidden energy sources, and are usually found to be gas-rich galaxy mergers. The hidden energy sources can be either star-formation (nuclear fusion inside stars) and/or an active galactic nucleus (AGN; a mass-accreting supermassive black hole [SMBH]). Distinguishing these kinds of activity in ULIRGs is indispensable to understand how stars are formed and SMBHs grow in mass during gas-rich galaxy merger in the universe. However, AGNs are spatially very compact and so can be easily buried deep inside dust and gas, and become elusive. Observations at wavelengths of small dust extinction effects, such as (sub) millimeter, are necessary.

Since energy generation mechanism is different between star-formation and an AGN, their physical/chemical effects to the surrounding molecular gas should be different. It is expected that (sub)millimeter molecular rotational J-transition line flux ratios are different, depending on primary energy sources. We conducted ALMA high-spatial-resolution (0.1–0.2″) observations of 26 ULIRGs (infrared-flux-limited complete sample), using tracers of nuclear-mass-dominating dense molecular gas, and obtained the following results [1].

(1) In the majority of ULIRGs, dense molecular emission was spatially resolved and elevated HCN/HCO$^+$ J=3–2 flux ratios were seen at galaxy nuclei where putative luminous AGNs reside, compared to spatially-extended star-forming regions (Figure 1). Since such high HCN/HCO$^+$ J=3–2 flux ratios are usually seen in optically-identified luminous AGNs, we interpret that the high flux ratios seen in ULIRG's nuclei are caused by luminous buried AGNs.

(2) Not only ULIRGs with infrared-identified luminous AGNs, but also ULIRGs without such infrared AGN signatures display high HCN/HCO$^+$ J=3–2 flux ratios (>1) as expected for luminous AGNs (Figure 2). These sources may be extremely deeply buried AGNs which are detectable only at (sub) millimeter, but elusive in other wavelengths.

We argue that (sub)millimeter dense molecular line observations can be a very effective way to scrutinize mass-accreting SMBHs in dusty merging galaxies, due to negligible dust extinction effects.

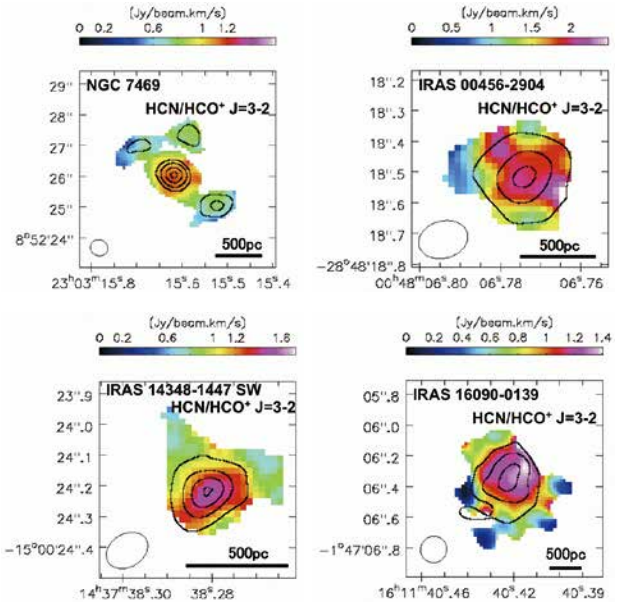

Figure 1: Examples of the spatial variation of HCN/HCO$^+$ J=3–2 flux ratio (shown as color). Contours indicate continuum emission. The flux ratio is high (red colored) at galaxy nuclei (defined as a continuum peak).

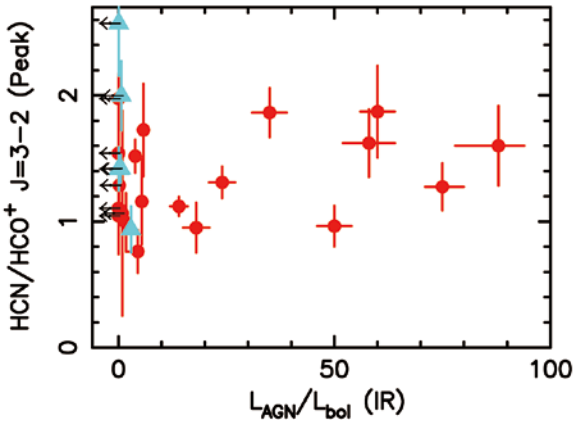

Figure 2: Abscissa: Infrared-estimated AGN's bolometric contribution [2]. Ordinate: HCN/HCO$^+$ J=3–2 flux ratio at galaxy nuclei within beam size. Objects observed with large beam sizes are shown in thin blue.

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Subaru Infrared High-spatial-resolution Imaging Search for Luminous Dual AGNs in Nearby Infrared Luminous Merging Galaxies

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According to the standard cold-dark-matter-based galaxy formation scenario, small gas-rich galaxies with a supermassive black hole (SMBH) in each nucleus, collide and merge, and then evolve into more massive galaxies. If more than one SMBH is present and becomes active in such gas-rich galaxy mergers, many dual AGNs are expected to be detected. However, a dual AGN detection rate in previous optical observations is much smaller than that theoretically expected. It is possible that luminous AGNs deeply buried in a large amount of dust and gas at merging galaxy's nuclei were overlooked.

We have conducted infrared K'-band (2.1 μm) and L'-band (3.8 μm) adaptive-optics-assisted high-spatial-resolution (< 0.3″) imaging observations of 40 nearby infrared-luminous merging galaxies using Subaru IRCS. This is because (1) dust extinction effects are much smaller in the infrared than the optical, and (2) a luminous AGN is very bright in the L'-band, due to AGN-heated hot (> 100 K) dust emission, shows a very red K'–L' color, and so is distinguishable from star-formation. We have obtained the following results [1].

(1) We detected dual AGNs in 5 merging galaxies (Figure 1), but the detected dual AGN fraction is still < 20 % even in the infrared.

(2) We derived the activation of SMBHs in individual merging galaxy nuclei, in the form of SMBH-mass-normalized AGN luminosity. The AGN luminosity ratio among multiple nuclei is estimated from the L'-band luminosity ratio. The SMBH mass ratio is inferred from stellar-origin K'-band luminosity ratio. We found that SMBHs are more active in more massive SMBHs than in less massive SMBHs (Figure 2), as predicted by numerical simulations of gas-rich galaxy mergers. Less-active, less-massive SMBHs are faint in the L'-band, which may be a reason for the low infrared-detected dual AGN fraction.

(3) In a few sources, our independent ALMA millimeter observations suggested that intrinsically more luminous AGNs are present in infrared fainter galaxy nuclei. The presence of such even infrared-elusive extremely deeply buried AGNs may also lower the infrared dual AGN detection rate.

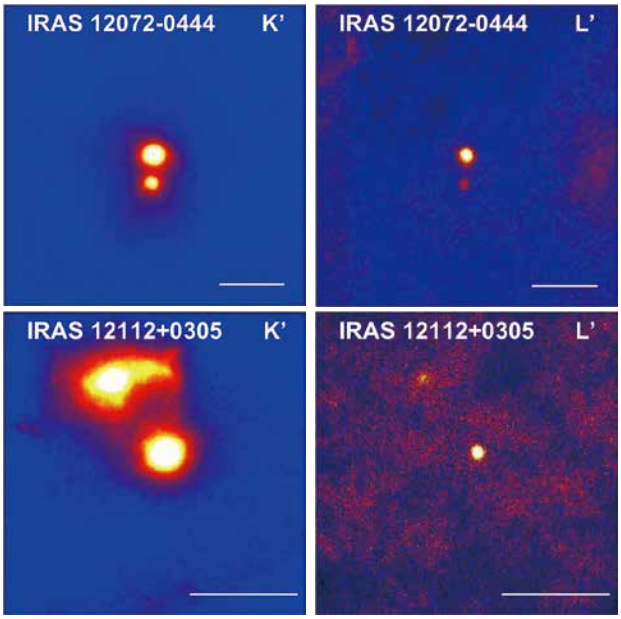

Figure 1: Examples of merging galaxies which show dual red K'–L' (> 1.0 mag) nuclei (i.e., dual AGN candidates). (Left) : K'-band. (Right) : L'-band. The horizontal solid line at the lower-right side indicates 5 kpc.

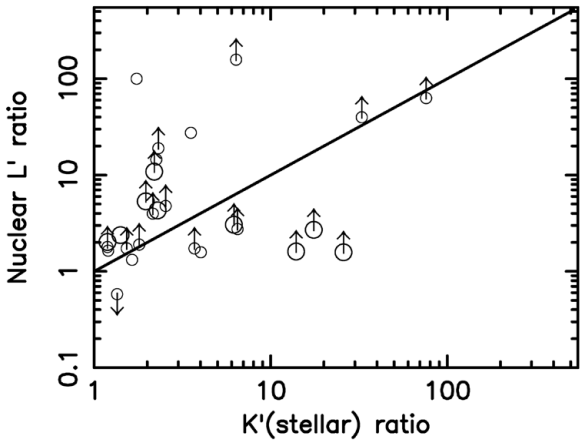

Figure 2: Abscissa: K'-band luminosity ratio. Ordinate: L'-band luminosity ratio. Values at K'-band brighter galaxy nuclei are divided by those at K'-band fainter nuclei. The abscissa and ordinate is an approximate of SMBH-mass ratio and AGN luminosity ratio, respectively. Sources located at the upper-left side of the thick solid line indicate that more massive SMBHs are more actively mass-accreting with higher SMBH-mass-normalized AGN luminosity than less massive SMBHs. Almost all sources show this trend. Small open circles are from our previously published results, and our new results are displayed with large open circles.

Reference

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A Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS). II. Physical Properties Derived from the SED Fitting with Optical, Infrared, and Radio Data

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Radio galaxies (RGs) observed as a strong radio source are sub-class of Active Galactic Nuclei (AGNs). Investigating the cosmological evolution of RGs provides insight into understanding the (i) the co-evolution of galaxy and supermassive black hole, (ii) the structure formation, and (iii) the AGN feedback phenomenon. However, previous RG surveys with optical data seem to be not enough either for survey area and depth, and thus we may miss a RG population in a certain evolutionary stage.

Therefore, we have launched a new project called "Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS: [1])" in which we use deep and wide optical imaging data taken by the Subaru Hyper Suprime-Cam (HSC) Strategic Program [2] and radio (1.4 GHz) data taken by a Very Large Array legacy project (FIRST: [3]). As a result, we have successfully identified the optical counterpart of ~3600 RGs.

In this work [4], we performed the Spectral Energy Distribution (SED) fitting for RGs in order to investigate the physical properties of host galaxy and SMBH. The sample is 1056 RGs at $0 < z < 1.7$ that have a uniform multi-wavelength data and have reliable redshift.

Figure 1 shows the the color excess ($E(B-V)_*$), stellar mass (M_*), star formation rate (SFR), and AGN luminosity of RGs as a function of redshift. We found that optically faint RGs that are newly discovered by our RG survey tend to be high redshift and to have a large dust extinction, low stellar mass, high SFR, and high AGN luminosity compared with optically bright ones (e.g., the SDSS). Those physical properties seem to differ from local RGs, suggesting that our WERGS project may explore a new parameter space of the RG survey.

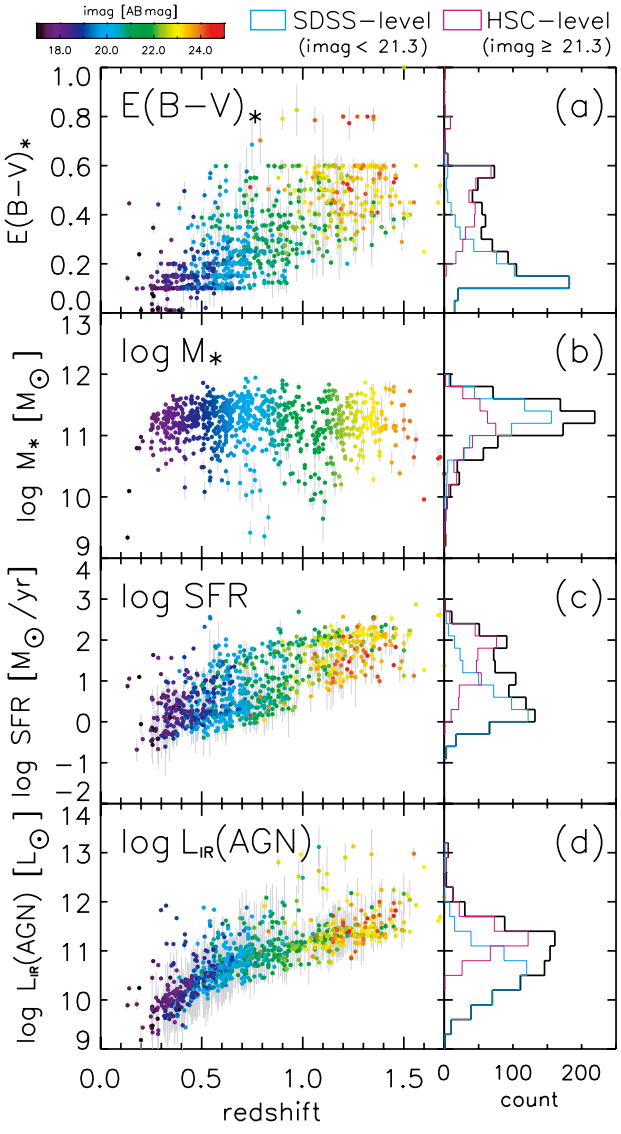

Figure 1: (a) The color excess ($E(B-V)_*$), (b) stellar mass, (c) SFR, and (d) AGN luminosity of our RG sample as a function of redshift. The color code is i-band magnitude. The histograms show the SDSS-level (cyan), HSC-level (magenta), and total (black) objects.

References

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Estimating the Temperature and Density of a Spicule from 100 GHz Data Obtained with ALMA

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A spicule is one of the building blocks of the solar atmosphere and a key-phenomenon for understanding the heating of the corona and chromosphere. It is believed that spicules provide the energy and mass for forming the hot atmospheric layers and solar wind. On the other hand, it is hard to derive physical parameters of the spicules from theses chromospheric lines because of deviating from the local thermodynamic equilibrium (LTE) for these lines. Some authors determined the temperature and density of spicules and their distribution. However, the results of them depend on the complicated forward modeling of the radiation from non-LTE medium.

Since the millimeter waves emitted from the chromospheric plasma satisfies the LTE condition, it is relatively easier than other chromospheric lines to derive the physical parameters. We obtained the observing time in ALMA Cycle 4 and succeeded in observing two large spicules with ALMA as well as the Interface Region Imaging Spectrograph (IRIS), and the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory simultaneously.

One is a spicule seen in the IRIS Mg II slit-jaw images and AIA 304 Å images (MgII/304 Å spicule). The other one is a spicule seen in the 100 GHz images obtained with ALMA (100 GHz spicule). Although the 100 GHz spicule overlapped with the MgII/304 Å spicule in the early phase, it did not show any corresponding structures in the IRIS Mg II and AIA 304 Å images after the early phase. It suggests that the spicules are individual events and do not have a physical relationship. To obtain the physical parameters of the 100 GHz spicule, we estimate the optical depths as a function of temperature and density using two different methods. One is using the observed brightness temperature by assuming a filling factor, and the other is using an emission model for the optical depth. As a result of comparing them, the kinetic temperature of the plasma and the number density of ionized hydrogens in the 100 GHz spicule are ~6800 K and 2.2×10^{10} cm^{-3}. The estimated values can explain the absorbing structure in the 193 Å image, which appear as a counterpart of the 100 GHz spicule. These results suggest that the 100 GHz spicule presented in this paper is classified as a macrospicule without a hot sheath in former terminology [1].

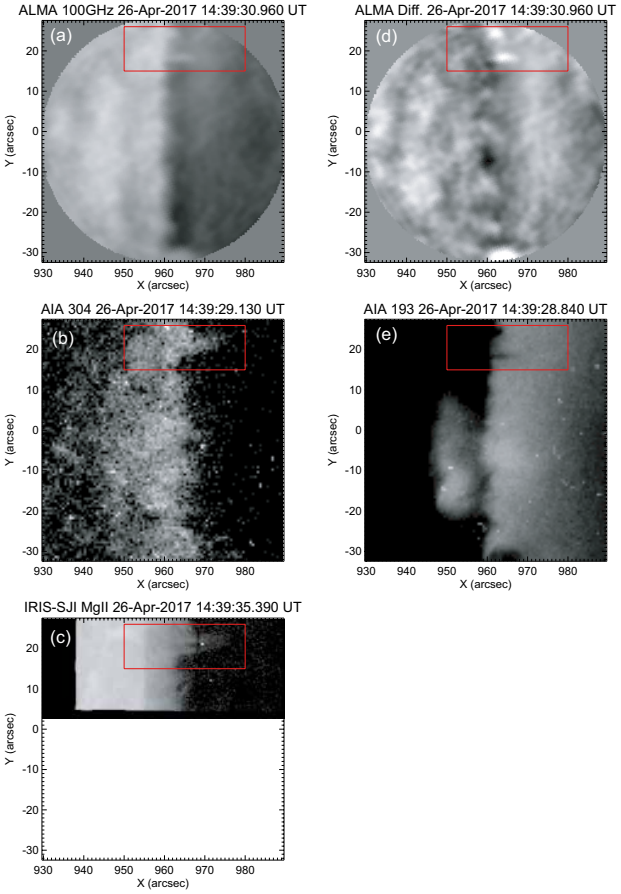

Figure 1: Joint observations with ALMA, IRIS, and AIA/SDO. Left column, from top: (a) ALMA 100 GHz, (b) AIA 304 Å band and (c) IRIS slit-jaw image at Mg II 2796 Å band. Right column, from top: (d) ALMA the 100 GHz image subtracted the averaged image created from the images obtain within 1.5 hours (ALMA difference image), and (e) AIA 193 Å band. The red boxes in the panels indicate the location of the spicule investigated in the paper. The X and Y in the panels present the heliocentric coordinates (SOL-X/Y).

Reference

[1] Shimojo, M., et al.: 2020, *ApJL*, **888**, L28.

X-Ray Spectral Model from Clumpy Torus and Its Application to the Circinus Galaxy

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Recent studies suggested that in an active galactic nucleus (AGN) obscuring matter composed of gas and dust surrounds the supermassive black hole (SMBH). This torus plays a key role in AGN feeding, serving as a mass reservoir linking the SMBH and host galaxy. Hence elucidating the torus structure is essential for understanding the mechanisms of the SMBH and galaxy co-evolution. Nevertheless, many of basic properties of AGN tori still remain unclear.

In this study [1], we construct an X-ray spectral model from the clumpy torus in an active galactic nucleus (AGN), designated as "XCLUMPY", utilizing the Monte Carlo simulation for Astrophysics and Cosmology code (MONACO) [2]. We assume that the torus geometry is the same as that in [3], who assume a power law distribution of clumps in the radial direction and the Gaussian distribution in the elevation direction (Figure 1).

Then, we also present the results applied to the broadband X-ray spectra of the Circinus galaxy observed with *XMM-Newton*, *Suzaku*, and *NuSTAR* (Figure 2). Our model well reproduces the broadband X-ray spectra and we obtain a hydrogen column density along the equatorial plane $N_{\rm H}^{\rm Equ} = 9.08^{-0.08}_{+0.14} \times 10^{24}\,{\rm cm}^{-2}$, a torus angular width $\sigma = 14.7^{-0.39}_{+0.44}$ degree, and a 2–10 keV luminosity $\log L_{2-10}/{\rm erg\,s^{-1}} = 42.5$.

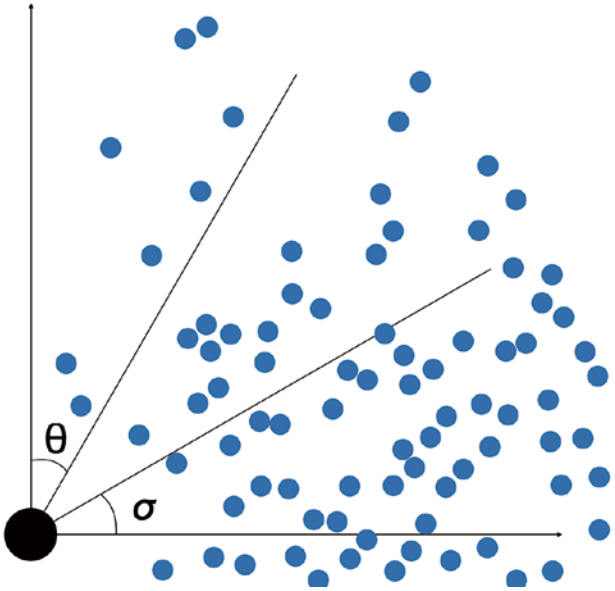

Figure 1: Cross section view of the torus. We assume a power law distribution of clumps in the radial direction and the Gaussian distribution in the elevation direction.

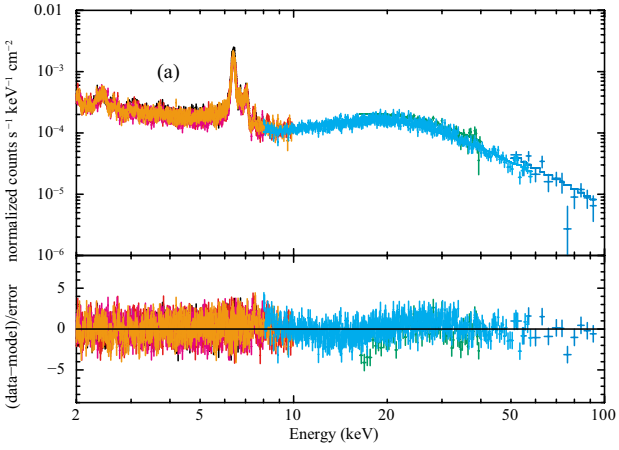

Figure 2: Folded X-ray spectra fitted with the XCLUMPY model. Black crosses: *Suzaku*/BIXIS. Red crosses: *Suzaku*/FIXIS. Green crosses: *Suzaku*/PIN. Blue crosses: *Suzaku*/GSO. Pink crosses: *XMM-Newton*/EPN. Orange crosses: *XMM-Newton*/MOS. Light Blue crosses: *NuSTAR*/FPMs.

References

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NuSTAR Discovery of a Compton-thick, Dust-obscured Galaxy: WISE J0825+3002

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NAGAO, Tohru[5], WANG, Wei-Hao[2], TANIMOTO, Atsushi[1], KAWAMURO, Taiki[6]

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Active Galactic Nuclei (AGNs) with line-of-sight hydrogen column density ($N_{\rm H}$) greater than $10^{24}\,{\rm cm}^{-2}$ are termed as Compton-thick (CT) AGNs. In the framework of co-evolution of galaxy and supermassive black hole (SMBH) caused by a galaxy merger, AGNs with the highest accretion rate are expected to be surrounded by a large amount of gas and dust (e.g., [1]). Therefore, CT-AGNs could be a key population to understand a full picture of galaxy–SMBH co-evolution.

In this work [2], we performed a joint X-ray spectral analysis of a candidate of CT-AGN, WISEJ082501.48+300257.2 (hereafter WISE0825) in which X-ray data were taken from an archival data of XMM-Newton and were obtained by NuSTAR (PI: Y.Toba). The candidate was drawn from our infrared (IR)-bright dust-obscured galaxy (DOG) sample ([3]) with SDSS (optical) and WISE (mid-IR) data.

We analyzed the X-ray spectrum (Figure 1) by using XCLUMPY model ([4]) and derived absorption-corrected X-ray luminosity in the 2–10 keV band and $N_{\rm H}$. The resultant X-ray luminosity and $N_{\rm H}$ are $L_{\rm X}$ (2–10 keV) $= 4.2^{-2.8}_{+1.6} \times 10^{44}\,{\rm erg\,s^{-1}}$ and $N_{\rm H} = 1.0^{-0.8}_{+0.4} \times 10^{24}\,{\rm cm^{-2}}$, respectively, indicating that WISE0825 is a CT AGN. The estimated Eddington ratio based on the Spectral Energy Distribution (SED) fitting is $\lambda_{\rm Edd} = 0.70$.

Figure 2 shows the absorption-corrected hard X-ray luminosity and $N_{\rm H}$ of WISE0825 and other dusty star-forming galaxies and AGNs. Given an identical $N_{\rm H}$, the X-ray luminosity of WISE0825 is intermediate between IR-faint DOGs and Hot DOGs, suggesting that they are evolutionally linked.

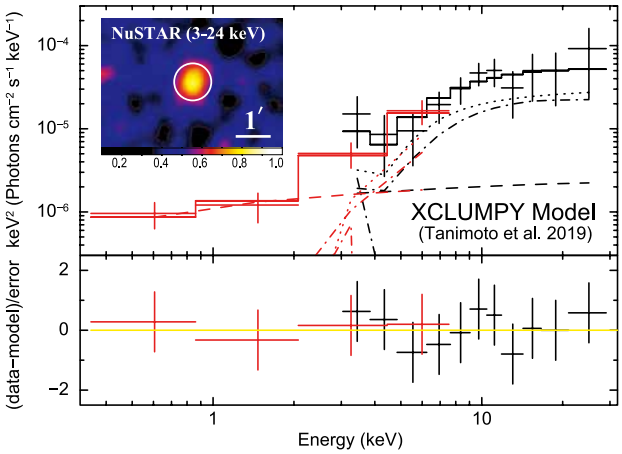

Figure 1: The X-ray spectrum of WISE0825 fitted with XCLUMPY ([4]). The solid, dotted, dashed, and dotted-dashed lines correspond to the total, cutoff power-law component, scattered component, and reflection component, respectively. The bottom panels show the residuals. The inserted figure shows NuSTAR 3–24 keV image.

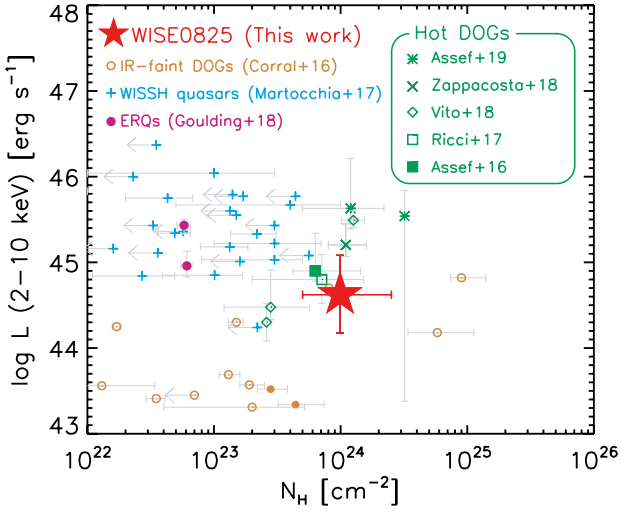

Figure 2: Hard X-ray luminosity in the rest-frame 2–10 keV band as a function of hydrogen column density ($N_{\rm H}$) for WISE0825, IR-faint DOGs, Hot DOGs, Extremely red quasars (ERQs), and WISSH quasars.

References

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[4] Tanimoto, A., et al.: 2019, *ApJ*, **877**, 95.

Nobeyama 45-m Cygnus X CO Survey: II. Physical Properties of $C^{18}O$ Clumps

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YAMAGISHI, Mitsuyoshi[7], MATSUO, Mitsuhiro[5], OHASHI, Satoshi[8], TOKUDA, Kazuki[4/9]
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1: The University of Tokyo, 2: UEC Tokyo, 3: Nagoya University, 4: Osaka Prefecture University, 5: NRO/NAOJ, 6: University of Virginia, 7: ISAS/JAXA, 8: RIKEN, 9: NAOJ, 10: SOKENDAI

Understanding the physical and chemical properties of dense cores and clumps is one of the most important astrophysical topics in regard to the star formation process connecting a molecular cloud and protostar, mechanism to determine the initial stellar mass function (IMF), and enrichment of interstellar molecules. Cygnus X is one of the most massive complexes of GMCs in our galaxy. Its environment is characterized by the current extremely active star formation, and a unrivaled close distance of 1.4 kpc [1] provides an unique opportunity to investigate the cluster formation process and ISM affected by strong stellar UV feedback by high-mass stars.

We conducted the multi-line CO survey that covers the 9 deg^2 field of the north and south regions of Cygnus X [2] using the FOREST receiver operated on the Nobeyema 45-m radio telescope [3]. The obtained image is shown in Figure 1. From the $C^{18}O$ cube data, we identified 174 $C^{18}O$ clumps using the dendrogram method. Ninety eight out of the 133 objects, except for the objects that were located at the map edge or in the DR13 S region, were accompanied by one or more protostars. The physical properties of identifed clumps were estimated and show radii of 0.2–1 pc, velocity dispersions of < 2.2 km s^{-1}, gas masses of 30–3000 $M_\odot$, and H_2 densities of (0.2–5.5) $\times 10^4$ cm^{-3}. The average virial ratio of 0.3 supports that these clumps are gravitationally bound and the clumps presumed to be evolved to the formation sites of stars.

We investigated the differences of physical properties regarding to the region (north and south) and star formation activity. The $C^{18}O$ clumps in the north region show significantly higher H_2 density than those in the south region, supporting the existence of a difference in the evolution stage between the regions, and this is consistent with the actual star formation activity of these regions. The difference in the clump properties of the star-forming and starless clumps is also confirmed by the radius, velocity dispersion, gas mass, and H_2 density. This tendency is consistent with the result for $C^{18}O$ cores in the nearby low-mass star-forming regions unveiled by the NANTEN surveys [4].

We also invesitage the clump/core mass function (CMF), which is pointed out the similarity to the stellar IMF. The IMF and CMF are defined in a form $dN(>M)/dM \propto M^{\alpha}$. Using the clump samples, we found two spectral index components, $\alpha = -1.4$ in 55–140 $M_\odot$ and $\alpha = -2.1$ in > 140 $M_\odot$. These induces were consistent with the low- and intermediate-mass parts of the Kroupa's initial mass function [5]. The spectral index in the star-forming clumps in > 140 $M_\odot$ was consistent with that of the starless clumps in 55–140 $M_\odot$, suggesting that the latter will evolve into star-forming clumps. Assuming a typical star formation efficiency of molecular clumps (10 %), about ten $C^{18}O$ clumps having a gas mass of $> 10^3$ $M_\odot$ will evolve into open clusters containing one or more OB stars at least.

This result was published in the Astrophysical Journal [6].

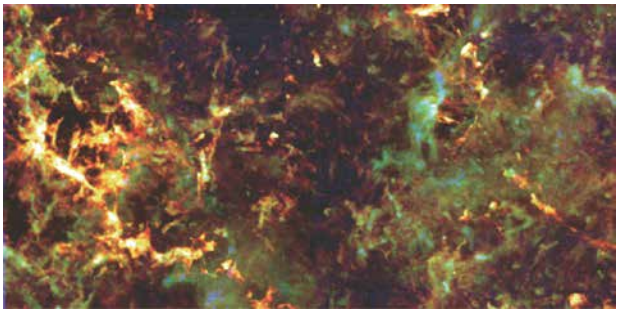

Figure 1: The three-color false image of the Cygnus X region obtaiend by the Nobeyama 45-m telescope. The red, green, and blue colors corresponds to the ^{12}CO, ^{13}CO, and $C^{18}O$ intensity.

References

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Roof of a Giant Gas Planet: Exploring the Jovian Atmosphere Connected to Outer Space

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Planets do not have their roofs. Their atmospheres are unstable area connected to outer space. This report introduces two recent Subaru observations around this region on Jupiter.

(1) Emission from the thermosphere: Jupiter's intense magnetic field captures electrons and ions with orders of magnitude and energy higher than Earth. These enter into the thermosphere (altitude: ~200–1000s km), hit and heat the dilute atmosphere, producing strong aurora emissions. On the dayside seen from the earth, this emission is buried in the cloud reflection light. However, in UV and near IR light, the reflection light is suppressed by the CH_4 absorption in the stratosphere (altitude: $\lesssim$ 200 km), and thermospheric emission can be seen. In near IR, H_3^+ emission is evident. This emission was discovered by T. Oka and is bright in interstellar molecular clouds with energetic particles. Jovian thermosphere has a similar environment.

The distribution of this emission was observed by Subaru/IRCS (Fig. 1). Using Galilean satellites for AO188, we achieved the spatial resolution of ~250 km (0.1″). The strong emission spreads in an altitude of 500–1,000 km and the temperature reaches ~1,000 K or more. The atmosphere in higher altitude has a non-equilibrium state and is easier for escape.

The spatial distribution was slightly strange. The H_3^+ emission is maximum in the UV aurora oval, which is consistent with H_3^+ molecule formations enhanced by energetic electrons. On the other hand, H_2 emission fills the polar cap. This region is not bright in UV, but is known for X-ray emission by higher energy particles. This region is connected to the solar wind boundary region by a magnetic field, and the generation mechanism of high-energy particles here is one of the main targets of NASA Juno mission.

(2) Variation of hydrocarbons in the stratosphere, High-energy particles that produce H_2 emission in the polar cap can penetrate into the stratosphere. Up to this region, CH_4 rises from the lower layer, and high-energy particles create more complex hydrocarbon molecules. These C_xH_y molecules have a lot of absorption and emission in the mid IR.

The distribution and variations of these molecular emission was observed by Subaru/COMICS (Fig. 2). Large sized aperture is important for the spatial decomposition. Other capability is only provided by the VLT. The stop of COMICS operation in July 2020 is disappointing. (We will be the final observer.)

In Jan and May 2017, we observed the distribution and variation of CH_4 emissions covering the entire polar region as well as near IR H_2 emission. It is shown that the precipitating high-energy particles can fluctuate the atmospheric temperature even in a short time scale, about one day, and progress to the production of complex hydrocarbons. It was also found that this fluctuation correlates with the solar wind pressure. It suggests that the influence of outer space can reach below than the thermosphere.

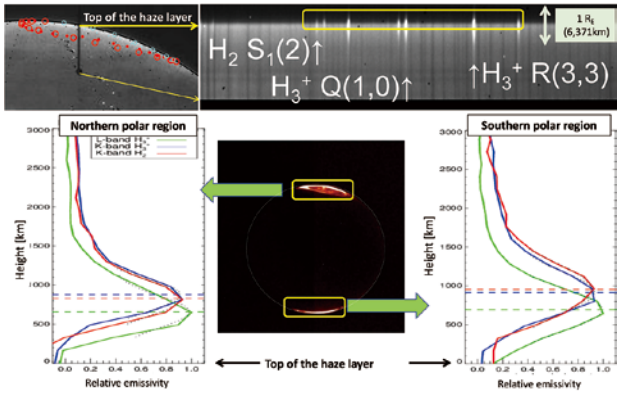

Figure 1: Altitude distribution of Jovian H_3^+ and H_2 thermospheric emissions observed by Subaru/IRCS [1].

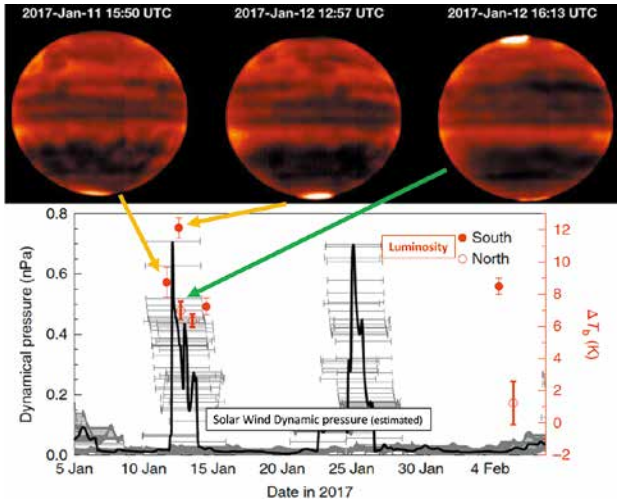

Figure 2: Variation of Jovian stratospheric CH_4 emissions observed by Subaru/COMICS [2].

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[1] Kita, H., et al.: 2018, *Icarus*, **313**, 93-106.
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Discovery of High-Redshift Superluminous Supernovae by the Subaru Hyper Suprime-Cam

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(NAOJ)

Subaru Telescope Hyper Suprime-Cam Transient Science Team

Hyper Suprime-Cam on the Subaru telescope has an incredible field-of-view among the 8m-class telescopes. The Hyper Suprime-Cam enables us to conduct a survey for very faint transients. Indeed, a transient survey has been performed for a half year from November 2016 at the COSMOS field in the sky as a part of the Hyper Suprime-Cam Subaru Strategic Program. Using the data acquired during the half-year survey, we searched for high-redshift superluminous supernovae.

Superluminous supernovae are extremely luminous supernovae that are recently recognized. Using Hyper Suprime-Cam, we can in principle observe superluminous supernovae up to redshifts of around 5. We searched for high-redshift superluminous supernova candidates using Hyper Suprime-Cam and conducted spectroscopic follow-up observations using the Keck telescope in order to determine the redshifts of the candidates.

With these observations, we succeeded in discovering high-redshift superluminous supernovae at the redshifts of 2.40, 1.97, and 1.85 [1,2]. Figure 1 shows these superluminous supernovae. Although we could not renew the highest-redshift supernova discovery record at z=3.9, HSC16adga at the redshift of 2.40 has become the second most distant supernovae ever discovered (Figure 2).

We also succeeded in estimating the superluminous supernova event rate at redshifts around 2 based on the high-redshift superluminous supernovae discovered by Hyper Suprime-Cam. We found that the superluminous supernova event rate at around redshifts 2 is not so different from those estimated by extraporating the local superluminous supernova event rate based on the cosmic star formation history. This result indicates that the progenitors of superluminous supernovae in the local Universe and those at redshifts around 2 are not so different.

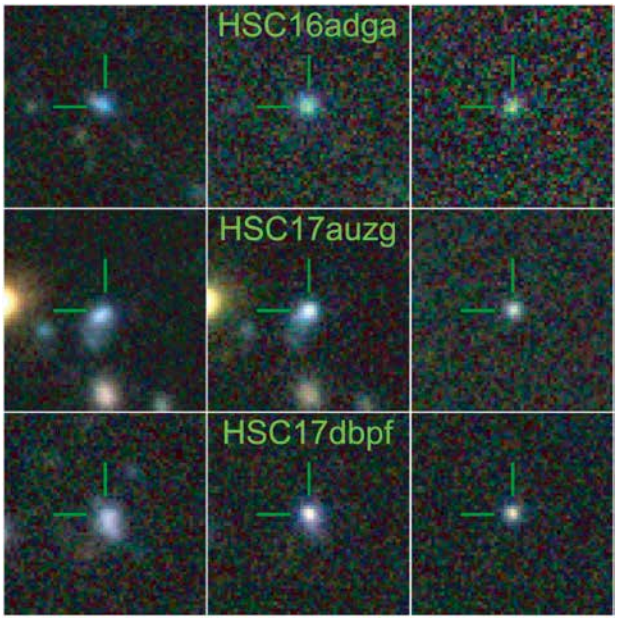

Figure 1: High-redshift superluminous supernovae discovered by the transient survey conducted with Hyper Suprime-Cam. The left panels show the images before the explosion, the middle panels show those after the explosion, and the right panels show the subtracted images. The spectroscopic observations by the Keck telescope confirmed that HSC16adga is at z=2.40, HSC17auzg is at z=1.97, and HSC17dbpf is at z=1.85.

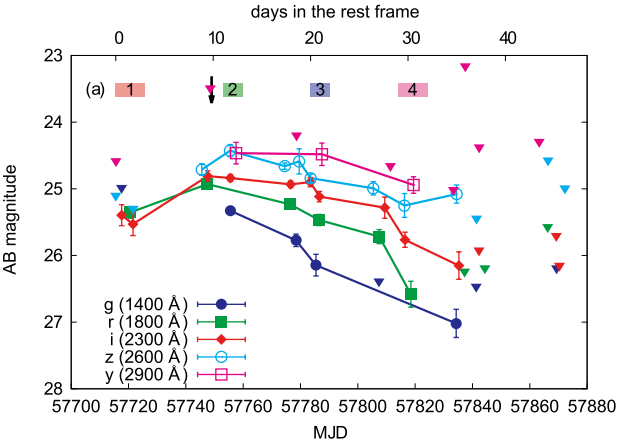

Figure 2: Light curve of HSC16adga at the redshift of 2.40.

References

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2D Radiation-hydrodynamic Simulations of Supernova Colliding with a Disk-like Circumstellar Medium

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Supernovae (SNe) are violent explosions of stars at their final evolutionary stages. Among them, the so-called type IIn SNe are known to show observational evidence of SN ejecta colliding with dense surrounding media (circum-stellar media or CSM in short). The CSM is thought to be produced prior to the death of the progenitor stars. However, when and how exactly such dense materials are ejected from dying stars are still debated. Some type IIn SNe show spectral and polarization properties indicating non-spherical photosphere. This implies that asphericity may play a role in those events.

In this work [1], we performed 2D radiation-hydrodynamics simulations of SN ejecta colliding with non-spherical CSM by using the numerical code developed by one of the authors [2]. In the simulations, we assume $10\,M_\odot$ spherical SN ejecta freely expanding with a kinetic energy of 10^{51} erg. We consider spherical and disk-like CSMs with opening angles of 10° and 20°. The CSM mass is assumed to be 0.1, 1.0 and $10\,M_\odot$. In total, we calculated 9 models. Figure 1 shows the result of a simulation. The CSM around the equatorial plane prevents the ejecta from expanding freely, resulting in the bipolar density structure (upper panel of Figure 1). The flux distribution (lower penal) highlights the different ways of radiative transfer along the equatorial and polar directions. The power source of the thermal emission is the interface between the ejecta and the CSM disk as demonstrated by the region with the highest radiative flux (reddish region in the lower panel of Figure 1). The diffusion velocity of radiation along the equatorial plane is much slower than that in the SN ejecta due to the high density, making the radiative flux small. On the other hand, along the polar direction, the radiation can be transported more efficiently.

The different ways of the radiative transfer along the equatorial and polar directions indicate a significant viewing angle dependence of the light curve. The simulation results certainly exhibit viewing-angle dependent bolometric light curves, which can be compared with observations of type IIn SNe.

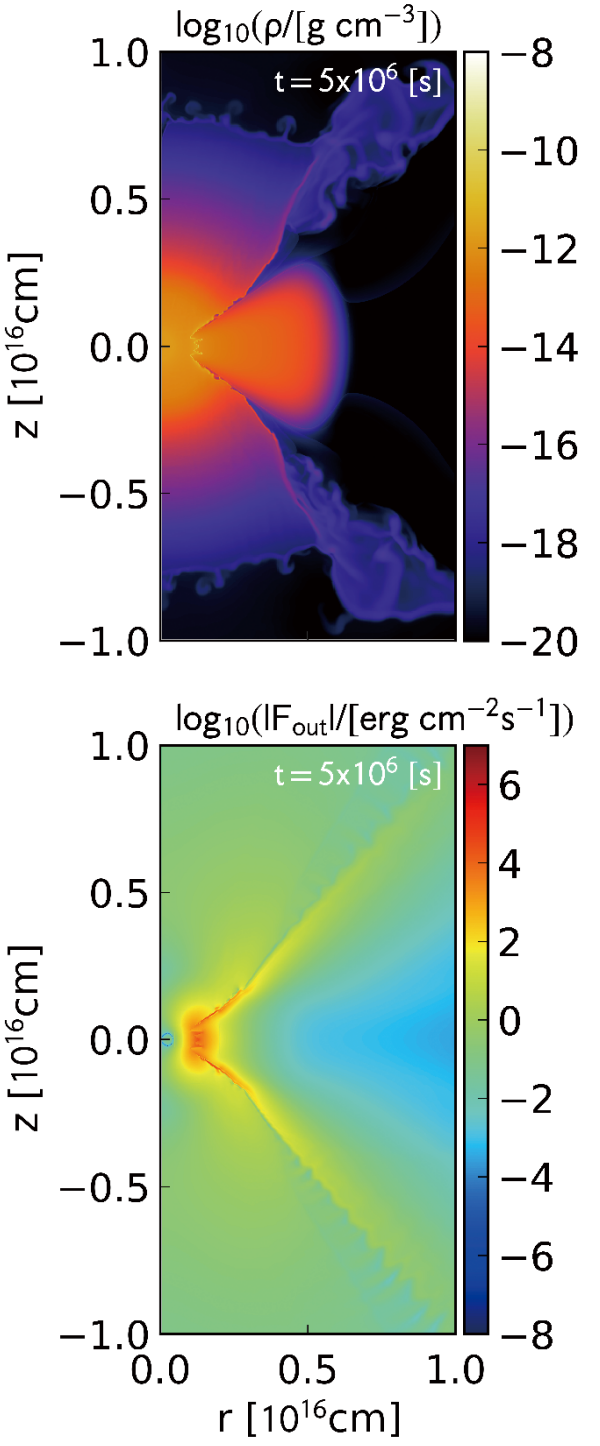

Figure 1: Results of the 2D radiation-hydrodynamic simulation. The spatial distributions of the density (upper panel) and outgoing flux (lower panel).

References

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[2] Suzuki, A., Maeda, K., Shigeyama, T.: 2016, *ApJ*, **825**, 92.

Q-type Asteroids: Possibility of Elder Weathered Surfaces without Fine Particles

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Analysis of Itokawa particles, which are samples from the S-complex near-earth asteroid 25143 Itokawa [e.g., 1] by the Hayabusa spacecraft, proved that the parent bodies of the ordinary chondrite meteorite are S-complex asteroids [e.g., 2]. In addition, a new discovery revealed that the exposure age of space weathering on the surface of Itokawa is several thousand years [e.g., 3]. Conventionally, Q-type asteroids have been considered to have a fresh surface [e.g., 4]. However, the time scale of space weathering from results of Itokawa particles is about three orders of magnitude smaller than the time scale of space weathering [e.g., 5]. Surface renewal process of Q-type asteroids cannot explain with conventional proposals [e.g., 6] in terms of timescale. In this study, we proposed a new model for the surface of the Q-type asteroid: the Q-type asteroid has elder weathered surface without fine particles.

To verify this theory, we first calculated the orbit of known Q-type asteroids, and confirmed that most of the Q-type asteroids had no close encounter of the planets in thousands of years. This result show it difficult to reset of the surface on the Q-type asteroids in thousands of years. Next, space weathering simulation experiments to ordinary chondrite meteorites were performed for observing the change in those spectra. Spectral analysis revealed that spectra of weathered chondrite meteorites consistent with those of Q-type asteroids in case of particles size are larger than 100 μm in size (Fig. 1, 2). This suggests that Q-type asteroids are more likely to be elder and weathered surfaces [7].

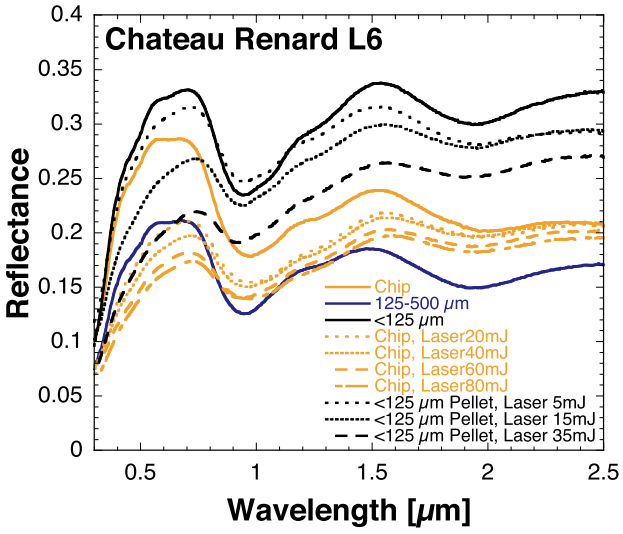

Figure 1: Spectra of Chateau Renard L6 ordinary chondrite.

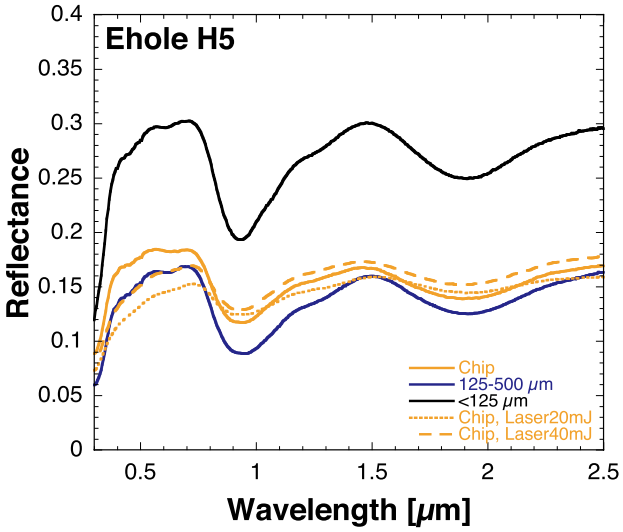

Figure 2: Spectra of Ehole H5 ordinary chondrite.

References

[1] Hasegawa, S., et al.: 2018, *PASJ*, **70**, 114.
[2] Nakamura, T., et al.: 2011, *Science*, **333**, 1113.
[3] Noguchi, T., et al.: 2014, *Meteorit. Planet. Sci.*, **49**, 188.
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Discovery of The Most Distant Protocluster with Subaru/HSC

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SHIBUYA, Takatoshi[5], FAISST, Andreas L.[6], GOTO, Tomotsugu[7], HATSUKADE, Bunyo[2]
KASHIKAWA, Nobunari[2], KOHNO, Kotaro[2], HASHIMOTO, Takuya[1/8], HIGUCHI, Ryo[2], INOUE, Akio K.[8]
LIN, Yen-Ting[9], MARTIN, Crystal L.[10], OVERZIER, Roderik[11/12], SMAIL, Ian1[3], TOSHIKAWA, Jun[2]
UMEHATA, Hideki1[4/2], AO, Yiping[15], CHAPMAN, Scott[16], CLEMENTS, David L.[17], IM, Myungshin[18]
JING, Yipeng[19], KAWAGUCHI, Toshihiro[20], LEE, Chien-Hsiu[1], LEE, Minju M.[21/1], LIN, Lihwai1[3]
MATSUOKA, Yoshiki[22], MARINELLO, Murilo1[7], NAGAO, Tohru[22]
ONODERA, Masato[1], TOFT, Sune[23], WANG, Wei-Hao[9]

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In this work [1], we discovered the most distant protocluster observed so far, at $z = 6.6$, with Subaru/Hyper Suprime-Cam (HSC).

In the present universe, fully-formed clusters of galaxies contain hundreds or thousands of member galaxies. These clusters are the most massive astronomical objects in the Universe, and are connected with each other into a huge network of galaxies called the large-scale structure. Thus studying the formation of clusters is important for understanding structure formation and galaxy formation in the universe.

In the distant universe, several observations found ancestors of clusters, called protoclusters. A protocluster is a dense system of ~10 distant galaxies that is expected to grow into a cluster by the ΛCDM model and/or theoretical simulations. The previous record of the most distant protocluster is a protocluster found by the Subaru telescope in 2012 [2].

We selected Lyα emitters at $z = 6.6$ using the narrow-band data taken with Subaru/HSC, and found a group of galaxies, z66OD, whose number density of galaxies is 15 times higher than the normal field. Follow-up spectroscopic observations with Keck and Gemini telescopes confirmed Lyα emission lines from 12 galaxies. Comparison with theoretical simulations [3] indicated that z66OD is a protocluster that will grow into a cluster scale halo at $z = 0$. We also found that star formation rates of galaxies in z66OD are five times higher than normal galaxies, indicating active star formation in the protocluster.

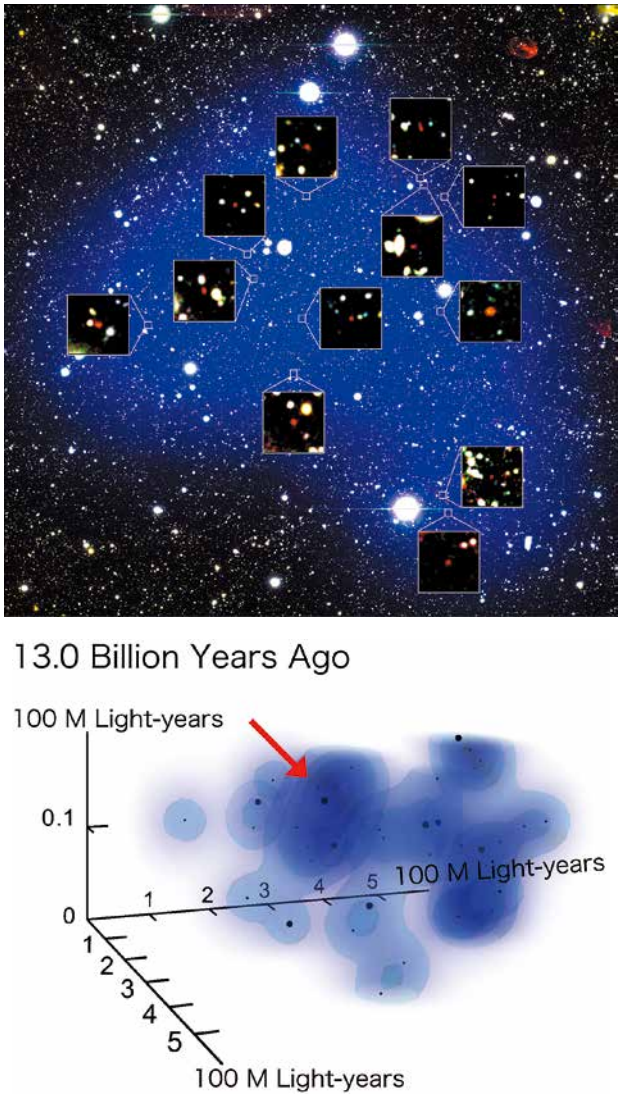

Figure 1: (Upper panel) The most distant protocluster discovered in this work. The bluer color indicates higher density of galaxies in the protocluster. The red objects in zoom-in figures are the 12 galaxies found in it. (Lower panel) Three-dimensional map of galaxies obtained in this work. The black points indicate locations of galaxies.

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[1] Harikane, Y., et al.: 2019, *ApJ*, **883**, 142.
[2] Toshikawa, J., et al.: 2012, *ApJ*, **750**, 137.
[3] Inoue, A. K., et al.: 2018, *PASJ*, **70**, 55.

Cosmological Constraints from Cosmic Shear Two-point Correlation Functions with HSC Survey First-year Data

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We have presented a cosmological analysis of the cosmic shear TPCFs measured from the HSC first year data, covering 136.9 deg^2 and including 9 million galaxies to $i \sim 24.5$ AB mag [1]. We used the HSC first year shape catalog. Photometric redshifts derived from the HSC five-band photometry are adopted to divide galaxies into four tomographic redshift bins ranging from $z = 0.3$ to 1.5 with equal widths of $\Delta z = 0.3$. The unweighted galaxy number densities for each tomographic bin are (from the lowest to highest redshift) 5.9, 5.9, 4.3, and 2.4 arcmin^{-2}.

In addition to the HSC data set, we utilized HSC mock shape catalogs constructed based on full-sky gravitational lensing ray-tracing simulations. The mock catalogs have the same survey geometry and shape noise properties as the real data. We derived the covariance matrix adopted in our cosmological analysis from 2268 mock realizations.

Ten combinations of auto and cross tomographic TPCFs were measured with high signal-to-noise ratio over a wide angular range. The total signal-to-noise ratio computed over the angular ranges that we adopted in our cosmological analysis ($7' < \theta < 56'$ for ξ_+ and $28' < \theta < 178'$ for ξ_-) was $S/N = 18.7$. We also examined the E/B-mode decomposition of the cosmic shear TPCFs to test our assumption in the cosmological analysis that the cosmic shear field is B-mode free. We evaluated the standard χ^2 value for B-mode TPCFs with the shape noise covariance, and found $\chi^2 = 86.9$ for $N_d = 90$. We thus conclude that no evidence of significant B-mode shear is found.

We performed a standard Bayesian likelihood analysis for the cosmological inference of the measured cosmic shear TPCFs. Our fiducial ΛCDM model consists of five cosmological parameters and includes contributions from intrinsic alignment of galaxies as well as seven nuisance parameters (2 for PSF errors, 1 for shear calibration error, and 4 for source redshift distribution errors). We found that our model fits the measured TPCFs very well with a minimum χ^2 of 162.3 for 167 effective degrees-of-freedom. Marginalized one-dimensional constraints are (mean and 68 % confidence interval) $S_8 = \sigma_8\sqrt{\Omega_m/0.3} = 0.804^{-0.029}_{+0.032}$, $\Omega_m = 0.346^{-0.100}_{+0.052}$, and $\sigma_8 = 0.766^{-0.098}_{+0.110}$ (see Fig. 1).

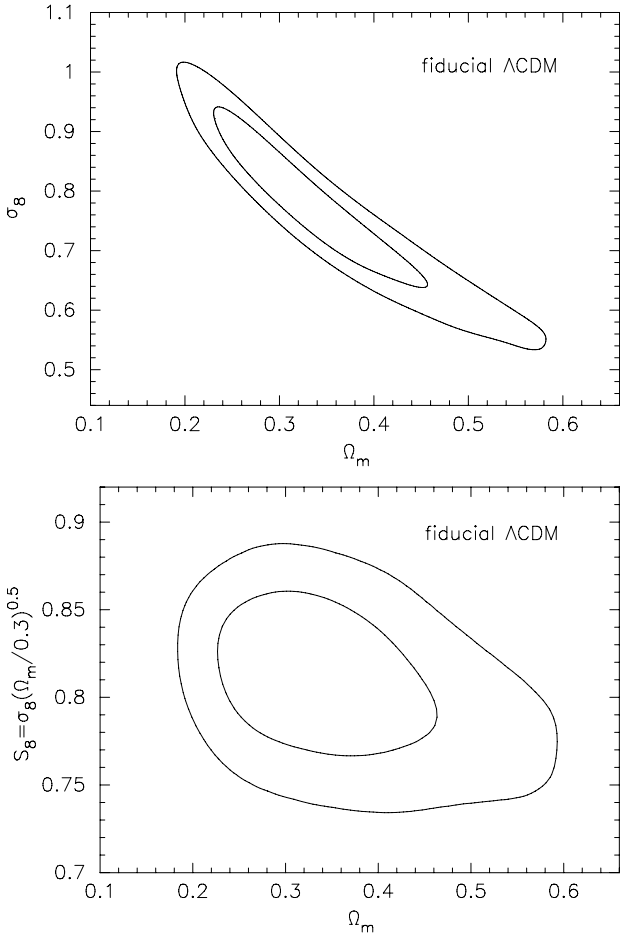

Figure 1: Marginalized posterior contours (68 % and 95 % confidence levels) in the Ω_m-σ_8 plane (top panel) and in the Ω_m-S_8 plane (bottom panel), where $S_8 = \sigma_8\sqrt{\Omega_m/0.3}$ in the fiducial flat ΛCDM model.

Reference

[1] Hamana, T., et al.: 2020, *PASJ*, **72**, 16H.

The Whole Picture of the Large-scale Structure of the CL1604 Supercluster at $z \sim 0.9$

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MIYAZAKI, Satoshi[1], SHIMAKAWA, Rhythm[1], SUZUKI, L. Tomoko[2], TANAKA, Ichi[1]
YAMAMOTO, Moegi[4], YAMAMOTO, Naoaki[2]

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We reveal the whole picture of the CL1604 supercluster at $z \sim 0.9$ by using deep wide-field imaging data available from the Subaru Strategic Program (SSP) with Hyper Suprime-Cam (HSC) on the Subaru telescope [1]. The CL1604 supercluster has been known as a large-scale structure over ~26 comoving Mpc consisting of three galaxy clusters and at least five galaxy groups [2], namely one of the largest structures at such a high redshift. In this study, we find that the already-known CL1604 supercluster is a mere part of larger-scale structures and, so to speak, the tip of the iceberg. As shown in Figure 1, the distribution of the galaxies selected with photometric redshifts of $z \sim 0.9$ is more extended to the north and south over more than 50 comoving Mpc scale than what we have ever known. Our follow-up spectroscopic observations confirm the redshifts of 55 red-sequence galaxies and 82 star-forming galaxies in total, demonstrating that the overdensity regions we discovered in both the northern and southern side are indeed associated with the CL1604 supercluster at $z \sim 0.9$. Revealing the whole picture of the supercluster allows us to better understand how galaxies have evolved along with the evolution of large-scale structures.

We use the spectra of the red-sequence galaxies (i.e., mature galaxies) to investigate stellar population of the galaxies by measuring strength of 4000 Å break, D_n4000, and equivalent width of Balmer Hδ absorption line, EW(Hδ), as shown in Figure 2. The red-sequence galaxies located in different galaxy clusters, even if they are >50 Mpc apart from each other, tend to have similar stellar population with age of $\gtrsim 2$ Gyr, but a large variation in the star formation history. It is likely that galaxies associated with the large-scale structures at 50 Mpc scale formed at almost the same time, have assembled into the denser regions, and then evolved along the hierarchical growth of the cosmic web.

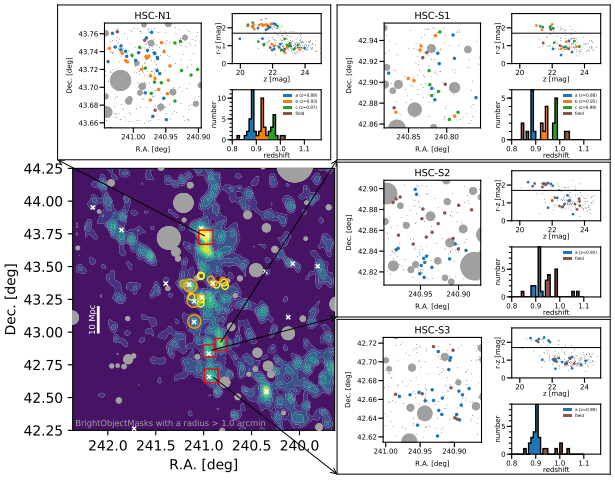

Figure 1: The lower left panel shows the large-scale structures revealed by this study. In each regions (red squares) spectroscopically confirmed, zoom-up view of the spatial distribution of the galaxies, the color--magnitude diagram, and the redshift distribution are shown. The orange and yellow circles show the already-known galaxy clusters and groups [2]. See also figure 5 of [1] for more details.

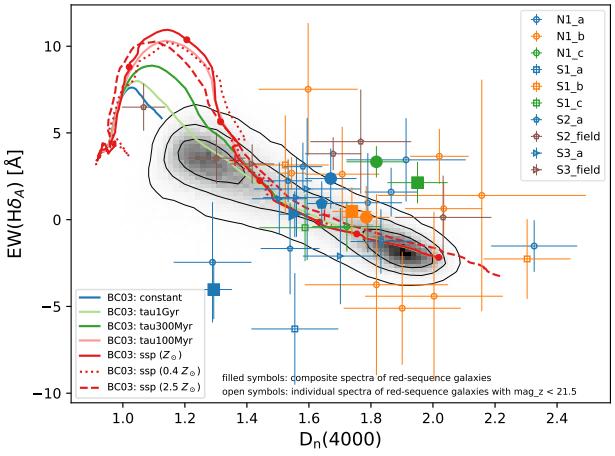

Figure 2: Strength of Balmer Hδ absorption line as a function of strength of 4000 Å break for red-sequence galaxies. The different symbols and colors mean the different positions and redshifts (the color coding is the same as Figure 1). The open symbols show the measurement for the individual galaxies, while the filled symbols show the measurement for the composite spectra. The solid lines are model tracks of stellar population synthesis with different star formation histories. The gray-scale histogram shows the distribution of the galaxies at $z = 0.04$–0.1. See also figure 7 of [1] for more details.

References

[1] Hayashi, M., et al.: 2019, *PASJ*, **71**, 112.
[2] Lemaux, B. C., et al.: 2012, *ApJ*, **745**, 106.

Detection of A New Methylamine (CH_3NH_2) Source: Candidate for Future Glycine Surveys

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SUZUKI, Taiki (SOKENDAI)

It has been a long-standing issue to discover interstellar glycine (NH_2CH_2COOH), the simplest amino acid, in studying a possible relation between the Universe and origin of life. In the last about 40 years all surveys of glycine failed, and it would be an alternative strategy to search for precursor(s) to glycine. Such studies of precursors would be crucial prior to conducting sensitive surveys by ALMA. Laboratory studies have suggested that CH_3NH_2 is a possible precursor to glycine on grain surfaces. CH_3NH_2 may be formed from HCN adsorbed onto the grain surfaces through hydrogenation (addition of the Hydrogen atom): HCN → CH_2NH → CH_3NH_2. Further theoretical study also suggested that the CH_2NH_2 radical that can be formed from CH_3NH_2 through photodissociation can be a good precursor to glycine.

We observed CH_3NH_2 towards several hot core sources by using the Nobeyama 45 m radio telescope, and succeeded in finding a new CH_3NH_2 source, G10.47+0.03 through seven transitions between 79 and 89 GHz (see Figure 1). We derived the excitation temperature to be 46 ± 21 K by using the rotation diagram method. The value is significantly lower than the desorption temperature (200 K) adopted in the literature [1]. The source-averaged column density of CH_3NH_2 is $4.0 \pm 2.8 \times 10^{15}$ cm^{-2}, which corresponds to the fractional abundance of CH_3NH_2 towards G10.47+0.03 to be $1.5 \pm 1.1 \times 10^{-8}$. At the time of writing, G10.47+0.03 is the most abundant source of CH_3NH_2 ever known. We found that the observed abundance of CH_3NH_2 agrees fairly well with the theoretically predicted value [1]. We were not able to detect CH_3NH_2 towards three other hot core sources, NGC6334F, G31.41+0.31 and W51 e1/e2.

Since CH_3NH_2 is regarded a plausible precursor to glycine, we discussed detectability of interstellar glycine. We found that it is highly possible to detect interstellar glycine towards G10.47+0.03 by using ALMA, however, we also found it would be very difficult to detect interstellar glycine by single dish radio telescopes.

Towards the future it is suggested to conduct survey observations of CH_3NH_2 not only in hot core/ hot corino sources but in protoplanetary disks and comets in studying incorporation of interstellar prebiotic molecules such as glycine into planetary forming regions.

This work was published in August, 2019 [3].

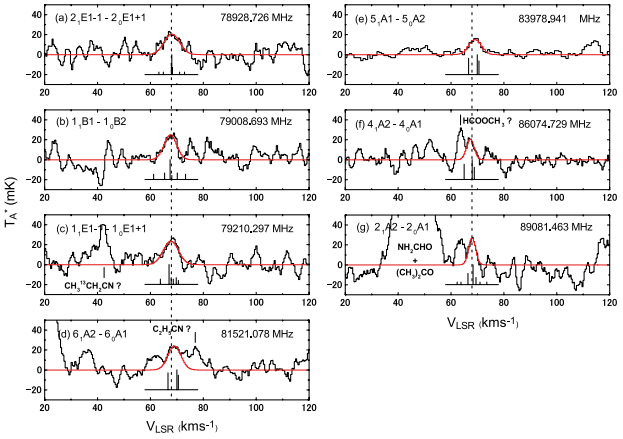

Figure 1: CH_3NH_2 spectra detected towards G10.47+0.03. The abscissa is the radial velocity, and the ordinate is the antenna temperature. The vertical dashed lines correspond to the systemic radial velocity of G10.47+0.03, 68 km s^{-1}. The red curves show results of the Gaussian fitting to the observed spectra. On each panel the transition is shown on the top-left, and the reference frequency which was used in calculating the radial velocity is shown on the top-right. We adopted the calculated transition frequencies without hyperfine splitting (hfs), taken from [2], as the reference frequencies. For each transition, we also plot relative positions of the hfs components with respect to the adopted rest frequency which is free from the hfs splittings, as well as their intensities relative to the strongest hfs component. Note that the relative intensities do not scale among the seven panels. We have omitted the *F* quantum numbers so as not to make each panel too busy. It is noted that the figure was taken from [3].

References

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[3] Ohishi, M., et al.: 2019, *PASJ*, **71**, 86.

Cosmology from Cosmic Shear Power Spectra Using Subaru HSC Data

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The Λ Cold Dark Matter (ΛCDM) model has been established as the standard cosmological model to describe the expansion history and the growth of the large-scale structure of the Universe. However, we are challenged by a fundamental lack of physical understanding of the main components of the Universe, dark matter and cosmological constant Λ or more generally dark energy. Coherent distorted pattern of distant galaxy images by gravitational lensing of large-scale structure, commonly referred to as the cosmic shear signal, is a unique probe of the total matter distribution in the Universe including dark matter. Cosmic shear is especially sensitive to the combination of the matter density parameter Ωm and the amplitude parameter of matter fluctuations σ_8, i.e., $S_8(\alpha) \equiv \sigma_8(\Omega_m/0.3)^\alpha$ with $\alpha \sim 0.5$.

We measure cosmic shear power spectra with the Subaru Hyper Suprime-Cam (HSC) survey first-year shear catalog covering 137 deg^2 of the sky. The HSC survey has a unique combination of its depth (5σ point-source depth of the Wide layer of $i \sim 26$) and excellent image quality (typical i-band seeing of $\sim 0''.58$), which enables us to measure cosmic shear signals up to higher redshifts with lower shape noise than current lensing survey such as KiDS and DES. Thanks to the high effective galaxy number density of 16.5 arcmin^{-2} even after conservative cuts such as magnitude cut of $i < 24.5$ and photometric redshift cut of $0.3 \leq z \leq 1.5$, we obtain a high significance measurement of the cosmic shear power spectra in 4 tomographic redshift bins, achieving a total signal-to-noise ratio of 16 in the multipole range $300 \leq \ell \leq 1900$.

In order to obtain robust cosmological constraints from cosmic shear measurements, we perform a blind analysis to avoid confirmation biases affecting our results. We carefully account for various uncertainties in our analysis including the intrinsic alignment of galaxies, scatters and biases in photometric redshifts, residual uncertainties in the shear measurement, and modeling of the matter power spectrum. The accuracy of our power spectrum measurement method as well as our analytic model of the covariance matrix are tested against realistic mock shear catalogs.

For a flat ΛCDM model, we find $S_8 \equiv \sigma_8(\Omega_m/0.3)^\alpha = 0.800^{+0.029}_{-0.028}$ for α=0.45 from our HSC tomographic cosmic shear analysis alone (Fig. 1). We find that the effect of possible additional systematic errors can shift the best-fit values of S_8 by up to $\sim 0.6\sigma$. In comparison with *Planck* cosmic microwave background constraints, our results prefer slightly lower values of S_8, as shown in Figure 1. Such lower best-fit values of S_8 and Ω_m are also found in other recent weak lensing analyses including KiDS and DES. Although our consistency analysis based on the Bayesian evidence ratio test indicates that these lower values could just be a statistical fluctuation, there is a possibility that these lower values originate from systematic effects that are unaccounted for in our current cosmic shear analysis, or more interestingly, from a possible failure of our fiducial ΛCDM model. The full HSC survey data will contain several times more area, and will lead to significantly improved cosmological constraints.

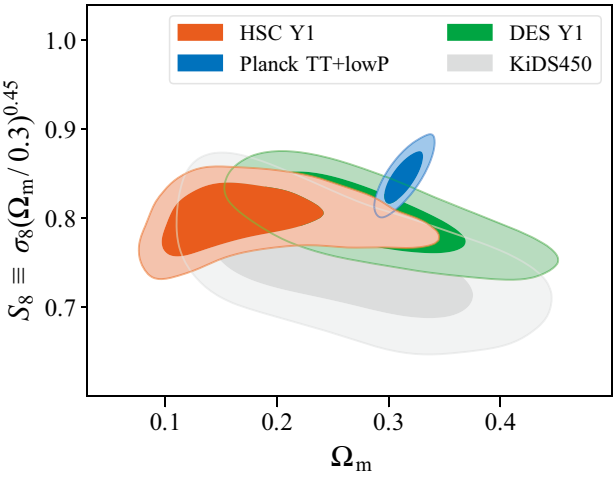

Figure 1: Marginalized posterior contours in the Ω_m-$S_8(\alpha=0.45)$ plane, where $S_8(\alpha) \equiv \sigma_8(\Omega_m/0.3)^\alpha$, in the fiducial ΛCDM model [1]. Both 68 % and 95 % credible levels are shown. For comparison, we plot cosmic shear results from KiDS-450, DES Y1, as well as *Planck* 2015 CMB constraints without CMB lensing.

Reference

[1] Hikage, C., et al.: 2019, *PASJ*, **71**, 43.

Discovery of an Au-scale Excess in Millimeter Emission from the Protoplanetary Disk around TW Hya

TSUKAGOSHI, Takashi[1], MUTO, Takayuki[2], NOMURA, Hideko[1], KAWABE, Ryohei[1], KANAGAWA, Kazuhiro[3], OKUZUMI, Satoshi[4], IDA, Shigeru[4], WALSH, Catherine[5], MILLAR, Tom[6], TAKAHASHI, Sanemichi[1], HASHIMOTO, Jun[7], UYAMA, Taichi[8], TAMURA, Motohide[3]

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It is widely accepted that protoplanetary disks (PPDs) are the birthplace of planets. Obtaining observational evidence of a forming planet in PPDs is crucial for understanding of the formation and diversity of (exo-) planets. Recent high-resolution observations using the Atacama Large Millimeter/submillimeter Array (ALMA) have revealed complex disk substructures that are likely related to the planet formation process [1]. However, the direct evidence of a small-scale substructure, such as a circumplanetary disk surrounding a forming planet, has not been reported yet.

TW Hya is a young low-mass star and is surrounded by the closest PPD to us (d = 59.5 pc). So far, high-resolution observations with ALMA have resolved multiple axisymmetric gaps and inner hole [2,3]. No evidence for a small-scale substructure, e.g., a circumplanetary disk, has been reported for the PPD around TW Hya.

We carried out high-resolution and high-sensitivity observations in continuum emission at 1.3 mm using ALMA [4]. The spatial resolution of the final image was 2–3 au. The sensitivity of the image was achieved to be 3 times better than that of our previous study [4].

The known axisymmetric features, gaps and inner hole, are resolved more clearly, as shown in Figure 1. The remarkable finding is that in the southwest part of the PPD, the resolved excess of emission is discovered at a radius of 52 au. The size of this excess emission is measured to be as small as 4 and 1 au for the major and minor axes, respectively.

The origin of the excess emission is still unclear. There are two expected scenarios that can be responsible for such a small-scale substructure, and both are supposed to be a key structure for understanding the planet formation process.

One is dust accumulation at a localized small-scale gas vortex. The aspect ratio of stable gas vortices theoretically investigated to be of several [5], which is consistent with the observed shape of the excess emission. However, it is inconsistent with the fact that the gas disk may be full of such "weak vortices" if the PPD is moderately turbulent.

An alternative scenario is the existence of a circumplanetary disk surrounding a forming planet embedded in the PPD [6]. In this case, we can roughly estimate the planetary mass to be the mass of Neptune from the observed size of the emission feature. Although some observational evidence prefers such a lower mass planet [7], the total flux density of the observed emission feature may not be fully accounted for by emission from a CPD.

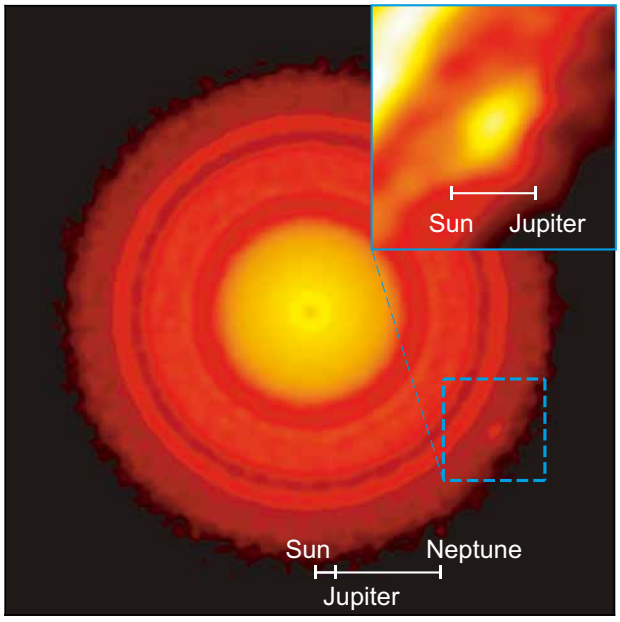

Figure 1: 1.3 mm continuum map of the protoplanetary disk around TW Hya. The inset at the top-right corner shows the zoom-up view around the millimeter blob we found. For reference, the distances between the Sun, Jupiter and Neptune are shown by the white lines.

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Identification of Absorption Lines of Heavy Metals in the Wavelength Range 0.97–1.32 μm

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Stellar absorption lines of heavy elements can give us various insights into the chemical evolution of our Galaxy and other nearby galaxies. Recently developed spectrographs for the near-infrared wavelengths are becoming more and more powerful at producing a large number of high-quality spectra, but identification and characterization of the absorption lines in the infrared range remain to be fulfilled.

We searched for lines of elements heavier than the iron group, i.e., those heavier than Ni, in the *Y* (9760–11100 Å) and *J* (11600–13200 Å) bands [1]. We considered the lines in three catalogs, i.e., the Vienna Atomic Line Database [2], the compilation by R. Kurucz [3], and the list published in 1999 by Meléndez & Barbuy [4]. We here investigate the absorption lines that appear in near-infrared spectra of FGK-type stars, in particular, supergiants. We have two main reasons for considering supergiants: (i) many absorption lines are expected to be strong in stars with low surface gravity as we see below, and (ii) their high luminosities are advantageous as stellar tracers of the Galaxy and nearby galaxies. In particular, Cepheid variable stars are supergiants within the range of FGK types, aged at 10–300 Myr, and they are useful for studying the Galactic disk because their distances and ages can be accurately estimated. Based on synthetic spectra for the ($T_{\rm eff}$, $\log g$) range covering the FGK-type stars, we selected 108 candidate lines of 14 species that were expected to be visible.

We used near-infrared high-resolution spectra of 13 giants and supergiants within FGK spectral types (spanning 4000–7200 K in the effective temperature) which were collected with the WINERED spectrograph. WINERED is a high-resolution echelle spectrograph covering the wavelength range of 0.90–1.35 μm with the resolving power of 28000 or higher [5,6].

Finally, we detected 23 lines of Zn I, Sr II, Y II, Zr I, Ba II, Sm II, Eu II, and Dy II, in the order of atomic number. Although the number of the detected lines is small, they are potentially useful diagnostic lines of the Galactic chemical evolution, especially in those regions for which interstellar extinction hampers detailed chemical analyses with spectra in shorter wavelengths. In contrast, 85 candidate lines were not confirmed. Although some of them may still be present but weak, the current lists did include lines that were wrontly predicted (at least their oscillator strengths are wrong). In addition, in comparing the observed and synthetic spectra of the 13 objects, we found dozens of absorption lines which are well visible in the observed spectra but not predicted in the synthetic ones. They need to be identified in future research.

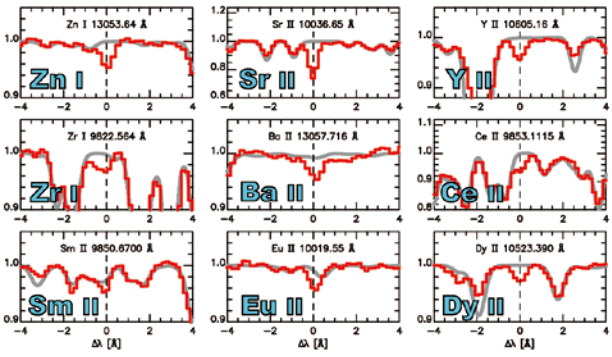

Figure 1: Examples of absorption lines for the nine elements whose lines are detected in our study. Red curves indicate observed spectra while gray curves indicate theoretical spectra synthesized without the target lines included.

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Origin of Titan

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Titan is the largest satellite around Saturn, which is about 50 times more massive than the second largest satellite, Rhea. That is, Titan is the only giant satellite in the Saturnian satellite system. No previous study has succeeded in explaining the reason why no giant moons except for Titan exist in the Saturnian system.

Similar to planet formation in a protoplanetary disk, regular satellites such as Titan would have formed in a circumplanetary disk (CPD). According to previous studies on satellite formation, Satellites that grow in the CPD keep orbital distances with neighboring satellites ($\simeq$ 10 Hill radii), and multiple satellites remain at the end, which is inconsistent with the orbital configuration of the Saturnian system.

To address this issue, several researchers have investigated the role of orbital migration. Satellites exchange angular momentum with the surrounding CPD and exhibit orbital migration (type I migration). As a result of inward orbital migration, it has been shown that satellites can be lost to the planet [1]. However, it has also been demonstrated that all giant satellites undergo inward migration, and no satellites left at the end [2].

In this study, we adopt a new CPD model in which the thermal and density structures are calculated much more accurately than previous models of CPD [3]. We perform *N*-body simulations of satellite formation that take into account the new CPD model. As a result of *N*-body simulation, we find that the direction of orbital migration depends on the local thermal and density structures of CPD. We also find that there exists a safety zone near the current orbit of Titan, which keeps the satellite from falling into the planet. Even when multiple satellites grow in the CPD, one satellite can escape into the safety zone while other satellites fall into the planet. Thus, only one moon remain after the CPD dissipates (Figure 1). In summary, we succeed in forming only one giant satellite like Titan for the first time [4].

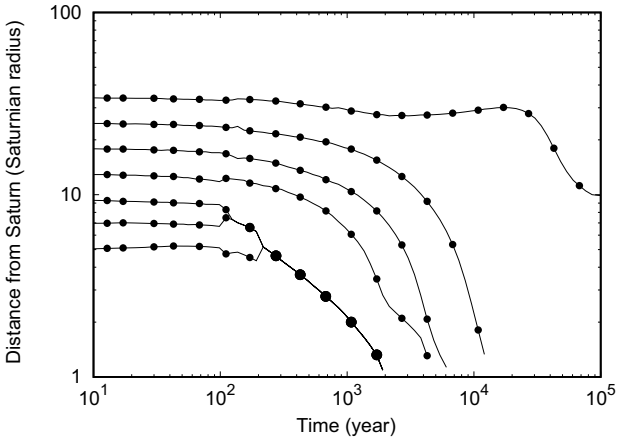

Figure 1: Example of orbital evolution of satellite system. The simulation is started with seven satellites with typical orbital separations. The outermost satellite escapes into the safety zone and avoid inward migration, while other satellites undergo inward migration and fall into the planets.

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Neutrino-^{13}C Cross Sections at Supernova Neutrino Energies

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Neutrino capture reaction on ^{13}C are studied at supernova energies, up to 50 MeV [1]. Partial cross sections for various particle and gamma emission channels are evaluated by Hauser-Feshbach method for both charged and neutral current reactions. Coherent elastic neutrino scattering cross section is also calculated.

^{13}C is naturally present (1.07 % abundance) in carbon-based scintillators, and neutrino-induced reactions on ^{13}C, which have low threshold energies compared with the ^{12}C target, were proposed for detection of solar and reactor neutrinos [2,3]. Here, we extend our study of neutrino-^{13}C reactions at reactor energies [3] to supernova energies, relevant to supernova observation and experiments at the spallation neutron sourses. Shell-model calculations have been done with the SFO Hamiltonian [4], which can describe spin degree's of freedom in *p*-shell nuclei quite well.

For charged-current reactions, proton emission channel (the transition to the ground state of ^{13}N) is dominant at neutrino energies above (below) 10 MeV.

In case of neutral-current reactions, the largest contributions come from coherent elastic scatttering, where the neutron density distribution in the nucleus is probed. This reaction was experimentally observed for the first time only recently using a CsI scintillator [5]. Comparing total elastic scattering cross sections for ^{13}C and ^{12}C, even a single extra neutron is found to appreciably enhance the cross section. An expansion of nuclear form factor in powers of momentum transfer is given, and the importance of including nuclear structure effects is pointed out when one is exploring the decrease of the cross section due to possible non-standard physical effects such as production of sterile neutrinos [1].

Neutron emission channels give considerable contributions for neutral-current neutrino reactions on ^{13}C. The total neutron emission cross section has several components which can help analysis of data from supernova and neutron-spallation sources. They are compared in Fig. 1. Among them the cross section for the transition to the 0^+ ground state, $\nu + {}^{13}\mathrm{C} \rightarrow \nu + \mathrm{n} + {}^{12}\mathrm{C}$ (g.s.), is the dominant one. The cross section for the transition to the 2^+ state in ^{12}C at 4.44 MeV followed by decay into the ^{12}C ground state, $\nu + {}^{13}\mathrm{C} \rightarrow \nu + \mathrm{n} + {}^{12}\mathrm{C}\ (2^+)$ and ${}^{12}\mathrm{C}\ (2^+) \rightarrow {}^{12}\mathrm{C}$ (g.s.) + γ (4.44 MeV), is also shown in Fig. 1. A shape distortion in the 5–7 MeV range is identified in the measured spectrum in short-baseline reactor neutrino experiments [6]. A recent proposal suggests a beyond the Standard Model solution to resolve this issue by assuming that the prompt γ (4.44 MeV) emission process above would mimic the spectral distortion [7]. However, the cross section obtained here in the Standard Model is quite small to support this non-standard solution.

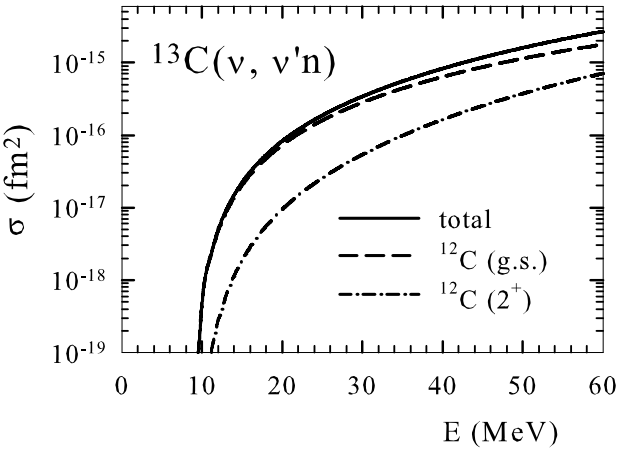

Figure 1: Neutron emission cross sections for neutral-current neutrino scattering on ^{13}C. The total cross section, cross section for the transition to ^{12}C (g.s.), and one for the transition to ^{12}C (2^+) followed by emission of γ (4.44 MeV) are denoted by solid, dashed and dot-dashed curves, respectively. Adapted from Ref. [1].

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Identification of Hermit Gaussian Photon with Compton Scattering [1]

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Photon vortices caring orbital angular momentum (OAM) [2] with a wave function of Laguerre Gaussian (LG) wave and Bessel wave are one of most interesting topics in various fields of physics. It is expected to create in astronomical systems such as black holes [3] and neutron-stars.

Gamma-ray bursts (GRBs) are one of the most energetic explosive phenomena in the universe. One of remarkable features for observed rays is a fact that high linear (circular) polarization was observed for some γ-rays in the energy region of several hundred keV.

We have suggested a possibility that Hermite Gaussian (HG) wave photons are generated by the high-harmonic radiations in GRBs [1] The HG wave function is one of higher-order Gaussian modes of the electromagnetic field, and its form is the same as the wave fucntion of the two-dimensional hramonic oscillator with the orthogonal coodinate. However, there is a critical question, how to identify these γ-rays in astronomical observation and laboratory experiments. We have proposed a new method to identify the wave function of these non-plane wave photons using Compton scattering [3,4].

The HG wave γ rays propagating along the z-direction have quantum numbers of nodes of n_x and n_y in the x- and y-directions, respectively. We calculate the differential cross sections for Compton scattering of photons described by HG wave function in the framework of relativistic quantum mechanics.

In Fig. 1 we show the calculated differential cross sections as functions of the azimuthal angles φ_q for polar angles $\theta_q = 0.1\,\pi$ and $0.5\,\pi$ and node numbers of $n_x = 1$ and $n_y = 0$, and $n_x = 2$ and $n_y = 0$ when the initial photon energy is 500 keV. In the case of standard Compton scattering of a plane wave photon, the scattered photon energy, E_0, is uniquely determined when the scattered angle is fixed because of the conservation law of energy and momentum. In contrast, the scattered photon energy for the incident HG wave photon may shift from that for the standard Compton scattering. Thus, we present the differential cross sections for various energy differences between the HG photon energy E_q and the plane wave photon energy ($\Delta E = E_q - E_0$).

The present results indicate that one can identify HG wave photons and their node numbers of n_x and n_y by measuring the azimuthal angle dependence of the scattering cross sections for a fixed ΔE. In near future, it is expected that HG γ rays are measured by the next generation of satellite polarimeters.

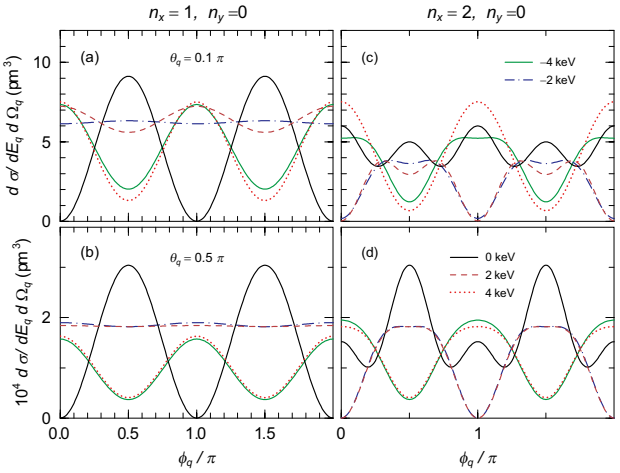

Figure 1: The differential cross sections of Compton scattering with HG wave function photons for $n_x = 1$ and $n_y = 0$ (a, b), and $n_x = 2$ and $n_y = 0$ (c, d). The scattered polar angles are $\theta_q = 0.1\,\pi$ (a, c) and $\theta_q = 0.5\,\pi$ (b, d). The solid, dashed, dot, dot-dashed, two-dot-dashed lines indicate the cross sections for $\Delta E = 0$ keV, 2 keV, 4 keV, −2 keV, −4 keV, respectively.

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Stellar Velocity Dispersion of a Massive Quenching Galaxy at $z = 4.01$

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Galaxies can be broadly classified into two types; star-forming late-type galaxies and quiescent early-type galaxies. Quiescent galaxies tend to be massive galaxies, and roughly a half of massive galaxies at $z \sim 2$ are known to be quiescent. But, physical mechanisms to suppress star formation activities in massive galaxies remain unclear. This is one of the biggest unresolved questions in the extragalactic astronomy today.

In order to address the question, we are exploring quiescent galaxies in the distant Universe. Recent work has revealed that quiescent galaxies already emerged even at $z > 3$. However, most of the previous studies are based on photometric data and spectroscopic confirmations of such galaxies are still very limited.

In the SXDS field, where there are a lot of deep multi-wavelength data, we carried out deep near-IR spectroscopic observations using MOSFIRE on Keck. We targeted a massive quiescent galaxy at $z \sim 4$ selected on the basis of photometric redshifts and detailed spectral energy distribution (SED) analysis. Figure 1 shows the spectrum [1]. There are prominent Hydrogen absorption lines, which yields $z = 4.01$. There are no emission lines in the spectra, confirming the quiescent nature of the galaxy. This is the most distant quiescent galaxy known to date.

Thanks to the high quality of the spectra, we are able to measure its stellar velocity dispersion; $\sigma = 268 \pm 59\,\mathrm{km\,s^{-1}}$. This is quite similar to typical massive galaxies today, which indicates that the core of massive quiescent galaxies has already nearly fully formed as early as $z = 4$. Detailed analyses of its star formation history suggests that the galaxy experienced an intense burst of star formation in a short period of time, followed by rapid quenching [2]. The physical process(es) that drives such a fast evolution still remains unclear, but very powerful energy feedback is necessarily for rapid quenching. These results motivate us to perform further follow-up observations of distant quiescent galaxies.

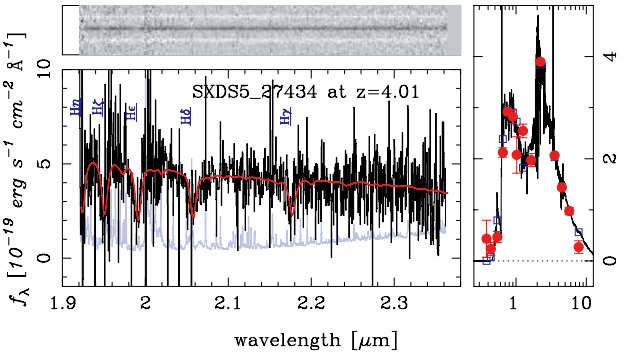

Figure 1: Spectrum of the $z = 4.01$ galaxy obtained with MOSFIRE. The top-left and bottom-left panels show the 2D and 1D spectra, respectively. In the bottom-left panel, the black, blue, and red spectra are object, noise and best-fitting model spectra, respectively. The absorption lines identified are indicated with labels. The right panel shows the overall SED based on the photometric data. The red and blue points are the observed and model photometry. The black spectrum is the best-fitting model spectrum.

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Structural Growth of Star-forming Galaxies in a Proto-cluster at $z = 2.53$

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How the structural diversity of galaxies in the Universe is established is one of the important questions to understand the scenario of galaxy formation and evolution. Many previous studies discussed the structural growth of galaxies by investigating the stellar structural properties of galaxies at different redshifts [1]. Observing the spatial distribution of on-going star formation as well as the stellar component enables us to directly investigate how galaxies are building-up their structures by star formation [2].

We conducted high angular resolution imaging observations for star-forming galaxies at $z = 2$–2.5 in different density environments with the near-infrared instrument (IRCS) and the Adaptive Optics system (AO188) mounted on the Subaru telescope. We aim to investigate the internal structures of star-forming galaxies around the peak epoch of the global star-forming activity in the Universe and to investigate the environmental impacts on the structural growth of galaxies at the peak epoch. With the AO system, we can achieve an angular resolution of 0.1–0.2 arcsec from the ground. In this project, we combine AO188 and narrow-band (NB) filters of IRCS to map out the star-forming regions traced by Hα emission line within the targets.

Here we report our results for star-forming galaxies residing in a proto-cluster at $z = 2.53$ [3]. We conducted the AO-assisted K'-band and NB imaging observations targeting 11 Hα emitters in the densest region in this proto-cluster. The K'-band images correspond to the underlying stellar continuum and the NB images correspond to the Hα emitting region. By dividing 11 galaxies into two groups according to their stellar masses, we conducted the stacking analysis to obtain the averaged images of the stellar continuum and Hα emitting region.

We then converted the stellar continuum and Hα emission line images to the stellar mass and star formation rate (SFR) maps, respectively. Figure 1 shows the comparison between the average radial profiles of the stellar mass and SFR surface density for the massive star-forming galaxies ($\log(M_\star/M_\odot) = 10$–$11.1$) in the proto-cluster. We find that the star-forming region is further extended than the underlying stellar component, which means that the massive star-forming galaxies in the high density environment grow their structures by adding new stars in their outskirts, i.e., inside-out growth.

We compare the spatial extent of the star-forming region for the proto-cluster galaxies with that for the field galaxies at similar redshifts obtained with the same observational technique. We find no clear environmental dependence of the spatial extent of the star-forming region for the star-forming galaxies at $z = 2$–2.5. This suggests that the structural growth of massive star-forming galaxies at $z = 2$–2.5 is dominated by the internal secular processes rather than the external processes irrespective of their surrounding environments.

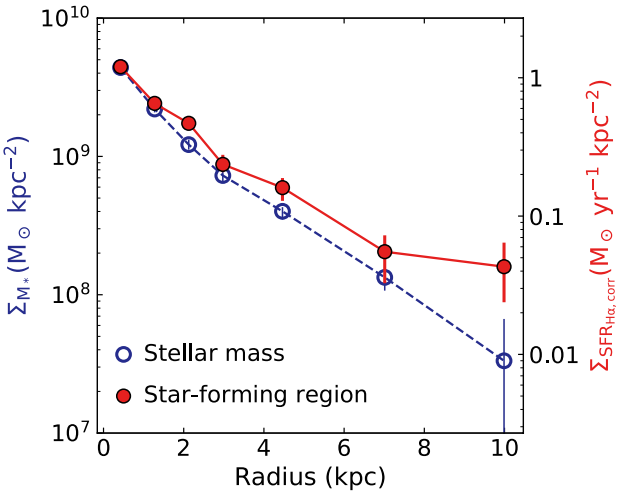

Figure 1: The averaged radial profiles of the stellar mass surface density (dashed line) and the SFR surface density (solid line) for the massive star-forming galaxies in the proto-cluster at $z = 2.53$. The star-forming region is further extended than the underlying stellar component [3].

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A Fireball and Binary Near-Earth Asteroid 2003 YT_1: The Potentially Hazardousness

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A fireball was detected in the night sky over Kyoto, Japan on UT 2017 April 28 at $15^h58^m19^s$ by the SonotaCo Network (Figure 1). Radiant point, geocentric velocity and orbital elements of fireball are determined. The similarity to asteroid 2003 YT_1 with D-criterions (D_{SH} = 0.0079) gives an order of smaller values than the significant threshold, indicating a parental association [1]. Absolute visual magnitude is $M_v = -4.10 \pm 0.42$ mag. Light curves give the meteoroid mass $m = 29 \pm 1$ g which corresponds to the size $a_s = 2.7 \pm 0.1$ cm with the density 2700 kg m^{-3}. Meteor luminous model comprising time derivative of momentum in drag equation is suggested to employ a velocity-dependent ablation coefficient, as determined by $\sigma v^2 < 1$. The 2003 YT_1 binary could be rotationally disrupted asteroids with mass shedding, consistent with Pravec & Harris (2007). The YORP spin-up timescale is $\tau_Y \sim 2$ Myr, shortly induces rotational instability. The resulting end-state is a breakup/fission if it is the rubble-piled body held by weak cohesive strength $S_c \sim 240$ N m^{-2}. Micrometeorite impactors with $\simeq$ 1 mm in size sufficiently produce the cm-sized dust particles, given populated near the 2003 YT_1 orbit. Radiation pressure may sweep out the mm-sized particles from 2003 YT_1, could be source of faint meteors with apparent magnitude of ~ +5 mag. The cm-sized particles are too large to be removed. The other dust production mechanisms are unprovable or pending.

The feasibility in the parental aspect of 2003 YT_1 is somewhat reconciled with the fireball observation, yielding an insight into how we approach potentially hazardous objects.

The particular fireball was not a threat to Earth, as it was estimated to only be a few centimeters in size. Something so small would burn up before it reached the surface. The 2017 fireball and its parent asteroid gave us a behind-the-scenes look at meteors. Next, we plan to further research predictions for potentially hazardous objects approaching the Earth. Meteor science can be a powerful asset for taking advanced steps towards planetary defense.

References

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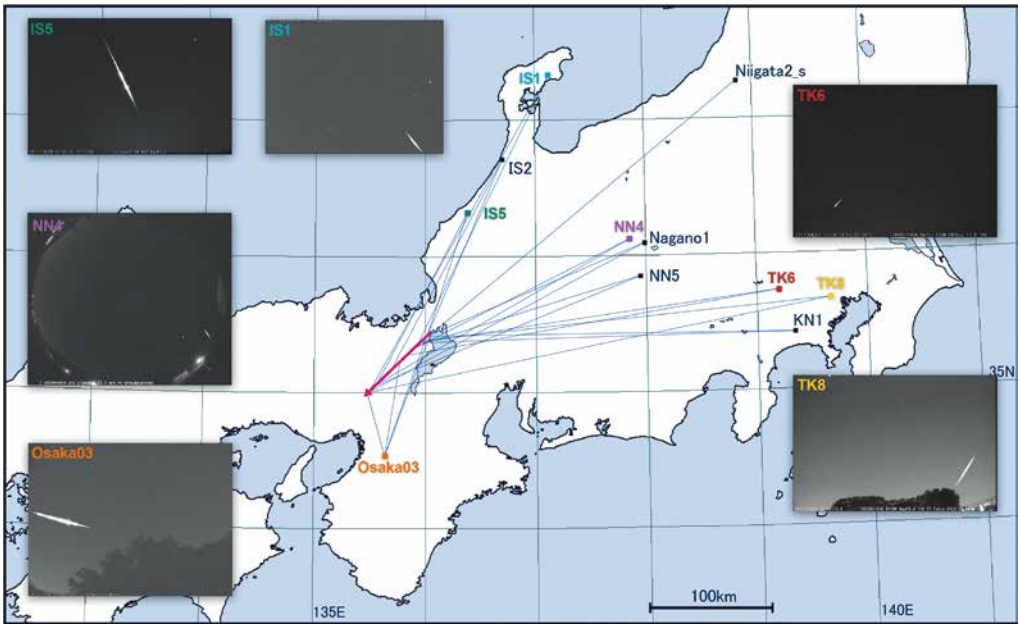

Figure 1: The 2017 fireball images captured in different angles and a map showing where the cameras were located [2] (NAOJ Press Release (January 15, 2020)).

Optical Properties of Infrared-bright Dust-obscured Galaxies Viewed with Subaru Hyper Suprime-Cam

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In Noboriguchi et al. (2019) [1], we reported the optical properties of infrared (IR)-bright dust-obscured galaxies (DOGs [2], defined as $(i\text{-}[22])_{\rm AB} \geq 7.0$ [3]). Because supermassive black holes (SMBHs) in IR-bright DOGs are expected to be rapidly growing in the major-merger scenario, they provide useful clues for understanding the co-evolution of SMBHs and their host galaxies (e.g., [4]). However, the optical properties of IR-bright DOGs remain unclear due to their optical faintness.

By combining multi-wavelength catalogs in a 105 deg^2 field, Subaru Hyper Suprime-Cam (HSC, [5]), VISTA VIKING, and WISE, we have selected 571 IR-bright DOGs (their photometric redshift is about 1.2). We found that IR-bright DOGs show a redder $(g\text{-}z)_{\rm AB}$ color than other populations of dusty galaxies, such as ultraluminous IR galaxies (ULIRGs) at a similar redshift, with a significantly large dispersion. Then we classified the IR-bright DOGs into star formation (SF)-dominated DOGs (bump DOGs), active galactic nucleus (AGN)-dominated DOGs (PL DOGs), and unclassified DOGs, based on their near-IR and mid-IR colors. The bump DOGs show a redder color even in optical than PL DOGs (see Figure 1). If the PL DOGs are AGNs in a late merger stage evolving from the bump DOGs, this result is consistent with the idea where the relative AGN contribution in the optical emission becomes more significant at a later stage in the major-merger scenario. More interestingly, we discovered eight IR-bright DOGs showing a significant blue excess in the blue side of HSC bands (BluDOGs). This blue excess can be interpreted as a leaked AGN emission that is either a directly leaking or a scattered AGN emission, as proposed for some blue-excess Hot DOGs in earlier studies ([6]). The origin of this blue-excess will be becoming clearly to execute the spectroscopic observation of these spectra.

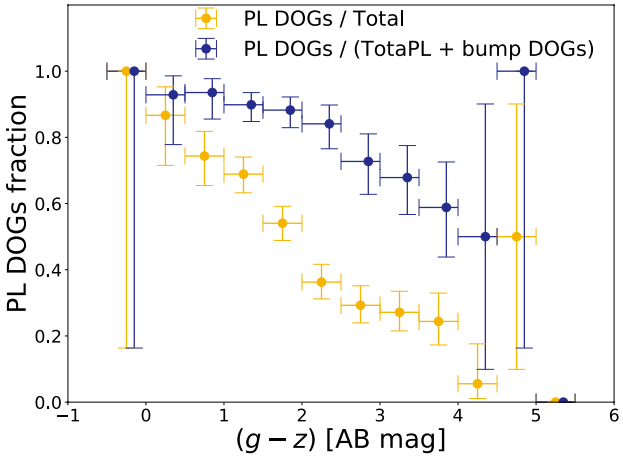

Figure 1: The PL DOGs fraction as a function of the HSC $(g\text{-}z)_{\rm AB}$ color. The orange and the blue circles represent the PL DOGs fraction among total (i.e., including unclassified DOGs) and PL DOGs + bump DOGs (i.e., without unclassified DOGs), respectively. The error bar is given based on the bimodal statistics (see [7]). The green circles are shifted to $(g\text{-}z)_{\rm AB}$ + 0.1 for clarity.

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[7] Gehrels, N.: 1986, *ApJ*, **303**, 336.

Okayama Astrophysical Observatory Wide-Field Camera

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TSUTSUI, Hironori[1], IZUMIURA, Hideyuki[1], YOSHIDA, Michitoshi[1], OHTA, Kouji[3]
KAWAI, Nobuyuki[4], NAKADA, Yoshikazu[5], YAMAMURO, Tomoyasu[6]

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Classical Cepheid variable stars are one of the most suitable objects for studying the arm structure of the Milky Way galaxy because of their brightness (M_K = −5 – −6.5 mag) and relatively young age (20 – 100 Myr). However, their distribution in the inner Galaxy is still unknown because they are located behind the Galactic plane of strong absorption. To investigate the distribution of Cepheids, we need to conduct monitoring observation with a near-infrared wide-field camera. Therefore we remodeled the 91 cm reflector telescope (Classical Cassegrain, f/13, [1]) at the Okayama Astrophysical Observatory (now the Okayama Branch Office of the Subaru Telescope) to a wide-field near-infrared camera and started unmanned autonomous observations in 2015 [2] (see Figure 1). This camera was named the Okayama Astrophysical Observatory Wide-Field Camera (OAOWFC).

OAOWFC has a hybrid optics consisting of forward Cassegrain optics and quasi-Schmidt optics. The focal ratio is f/2.5, which is the fastest in the near-infrared imagers in the world. A HAWAII-1 (engineering grade) array is placed on the focal plane, which can image a field of view of 0.°48 × 0.°48 at a time at a scale of 1.″7 pixel^{-1} (see Figure 2). The field of view is almost the same as that of the UKIRT WFCAM after the ESO VISTA.

OAOWFC is a robotic camera. The control elements that make up the facility, such as telescope, mount, dome, infrared camera, etc., have been updated with distributed control in mind, and multiple daemons realize cooperative operation of these elements. The core of the distributed control is a single-chip microcomputer PIO board developed in-house, and the cooperative operation is implemented with Rinda/Ruby. Unmanned observation obeys a simple decision sequence, mainly realized by three daemons. The shutter daemon judges the weather based on the output of the mid-infrared cloud monitor and opens and closes the dome shutter. If the dome shutter is open, the scheduler daemon orders to take images according to a given schedule. The focus adjustment daemon measures the out of focus every few minutes and moves the secondary mirror to the appropriate position. The autofocus functions well as expected, and a moderate image size of about 2.5 pixels FWHM is obtained.

We have demonstrated photometric reproducibility of 2 % in the densest field ($l \sim 26°$) of the northern Galactic plane, and have successfully discovered previously unreported variable stars to date. At present, we regularly monitor the Galactic plane in the K_S band and search for the optical counterpart of gravitational waves as targets of opportunity observation.

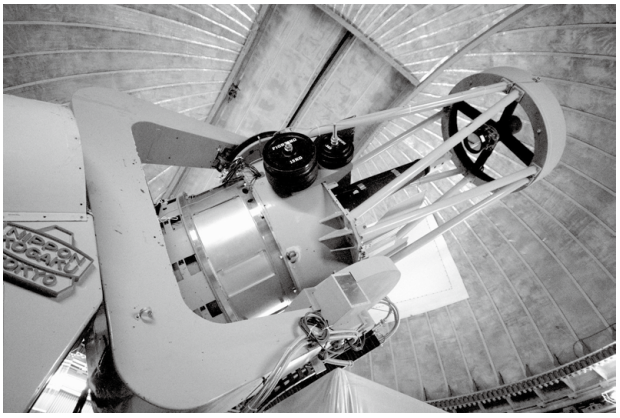

Figure 1: The appearance of OAOWFC.

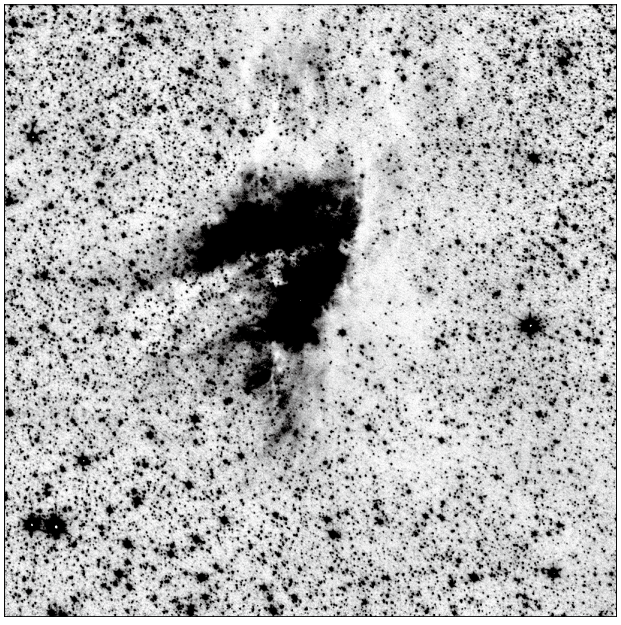

Figure 2: A K_S image of M17 field taken by OAOWFC with an exposure time of 80 seconds. The field of view is 0.48 × 0.48 square degrees.

References

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Do Galaxy Morphologies Really Affect the Efficiency of Star Formation during the Phase of Galaxy Transition?

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NAKAGAWA, Takao[3], NAMIKI, Shigeru V.[4], SUZUKI, Tomoko L.[2/5], FUKAGAWA, Nao[4], KODAMA, Tadayuki[5]
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It is believed that star-forming galaxies evolve into the passive galaxies by quenching their star formation, accompanying morphological transformation. However, it is still unclear what triggers this transition event. One of the scenario proposed for that is the so-called "morphological quenching" scenario, where galaxy morphologies themselves control their star formation activity. Recent simulations predict that the presence of stellar bulge suppress the efficiency of star formation in early-type galaxies.

In this study, in order to discuss the net effect of galaxy morphologies on the star formation efficiency (SFE) during the phase of galaxy transition, we focused on green-valley galaxies, which are expected to be in the star formation quenching phase. We observed CO(J=1–0) line of 13 "disk-dominated" and 15 "bulge-dominated" green-valley galaxies with the Nobeyama 45m Radio Telescope, supplemented by 1 disk- and 6 bulge-dominated galaxies from the xCOLD GASS data. By using a total of 35 green-valley galaxies, we revealed that the distribution of SFE of green-valley galaxies do not change with their morphologies, suggesting little impact of galaxy morphologies on their SFE (The blue and red symbols in Figure 1). Furthermore, interestingly this result is also valid for normal star-forming galaxies selected from the xCOLD GASS data, i.e. the average SFE on the star-forming main sequence (MS) does not vary with their morphologies at a fixed stellar mass (The cyan and orange symbols in Figure 1). Finally, we confirmed that there is a significant decrease of the mean SFEs from the main sequence to the green-valley, regardless of their morphologies. Our results suggest that the presence of stellar bulge does not decrease the efficiency of on-going star formation, in contrast to the prediction of the morphological quenching scenario, and the quenching mechanism equally affects the SFE of galaxies regardless of their morphological properties.

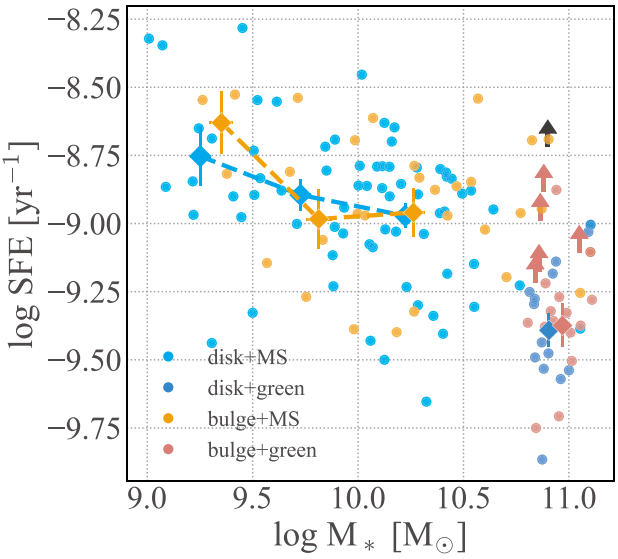

Figure 1: Distribution of galaxies on the M_*–SFE plane for the disk-dominated MS (disk+MS, cyan), disk-dominated green-valley (disk+green, blue), bulge-dominated MS (bulge+MS, orange), and bulge-dominated green-valley galaxies (bulge+green, red). Diamonds and their error bars show the mean and standard deviation for M_* and SFE, where the MS galaxies are divided into three M_* bins (log ($M_*/M_\odot$) = 9.0–9.5, 9.5–10.0 and 10.0–10.5). The red and black arrows show the lower limits of SFE for CO-undetected bulge+green galaxies and their stacking result, respectively [1].

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A Non-corotating Gas Component in an Extreme Starburst at z=4.3

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Bright submillimeter galaxies (SMGs) are intensively forming stars with a rate of 1000 $M_\odot$ yr^{-1}, except for strongly-lensed objects. The dust continuum emission is compact with a half-light radius of ~1 kpc, which corresponds to the size of a bulge in massive quiescent galaxies at z~2 and giant elliptical galaxies at z=0. These findings suggest an evolutionary link between bright SMGs and compact quiescent galaxies at z~2 although it is not necessarily the case in faint SMGs. The star formation rate surface density in the central 1–2 kpc region exceeds 100 $M_\odot$ yr^{-1} kpc^{-2}. Understanding the physical mechanism triggering such an extreme starburst in early Universe is a main topic in this research field.

Minor mergers with a mass ratio of 1:10 are expected to happen frequently and contribute to enhancements in star formation activity. The accretion of small satellites onto massive galaxies could also affect the dynamical condition and cause compaction of the gas disk if the gas fractions of the companions are high. However, late-stage minor mergers are poorly explored in observations of high-redshift SMGs because it is difficult to identify small companions at a distance of less than 10 kpc (< 1.5 arcsec) due to limitations of sensitivity and spatial resolution in submillimeter/millimeter observations.

We have made Atacama Large Millimeter/submillimeter Array (ALMA) 0.17 arcsec resolution observations of [CII] emission line in a bright unlensed submillimeter galaxy at z=4.3, COSMOS-AzTEC-1 [2]. The ALMA data clearly demonstrates that the gas kinematics is characterized by an ordered rotation. After subtracting the best-fit model of a rotating disk, we kinematically identify two residual components in the channel maps. Both observing simulations and analysis of dirty images confirm that these two subcomponents are not artificially created by noise fluctuations and beam deconvolution. One of the two has a velocity offset of 200 km s^{-1} and a physical separation of 2 kpc from the primary disk and is located along the kinematic minor axis of disk rotation (Figure 1). We conclude that this gas component is falling into the galaxy from a direction perpendicular to the disk rotation. The accretion of such small non-corotating gas components could stimulate violent disk instability, driving radial gas inflows into the center of galaxies and leading to formation of in-situ clumps such as identified in dust continuum and CO [2]. We require more theoretical studies on high gas fraction mergers with mass ratio of 1: >10 to verify this process.

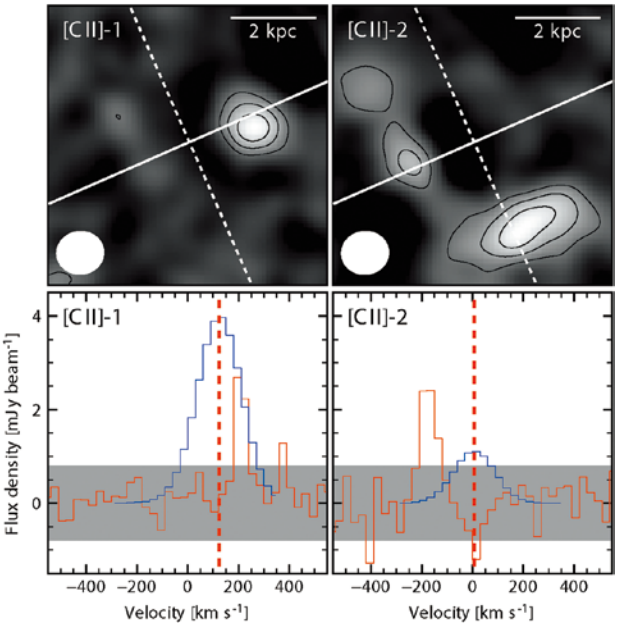

Figure 1: Spectra at the position of [CII] subcomponents, extracted from the low-resolution cube. Blue and red lines indicate the best-fit model as the primary disk component and the residuals between the data and the model, respectively. Gray shaded regions denote the 2σ level. Red vertical lines show the coherent velocity of the disk component at the position of subcomponents. The velocity-integrated residual maps are shown in the top panels. The image size is 1 arcsec × 1 arcsec. Contours are plotted every 2σ from 3σ. White solid and dashed lines show the kinematic major and minor axis of disk rotation, respectively.

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Planck Far-infrared Detection of Hyper Suprime-Cam Protoclusters at $z \sim 4$: Hidden AGN and Star Formation Activity

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UCHIYAMA, Hisakazu[1/8], CLEMENTS, David L.[9], ALEXANDER, David M.[10], MATSUDA, Yuichi[1/8]
KODAMA, Tadayuki[11], GOTO, Tomotsugu[12], CHENG, Tai-An[9], ITO, Kei[8]

1: NAOJ, 2: ICRR The University of Tokyo, 3: Bath University, 4: The University of Tokyo, 5: JHU, 6: Observatório Nacional, 7: University of São Paulo, 8: Graduate University for Advanced Studies, 9: Imperial College London, 10: Durham University, 11: Tohoku University, 12: NTU

Overdense regions at high redshift known as protoclusters are plausible progenitors of clusters of galaxies today and thus important targets probe the formation history of galaxy clusters. Excess dusty starburst in protoclusters have been reported by deep observations in the infrared (IR) (e.g., Umehata et al. 2018 [1]) however the statistical properties are not yet been known well. To study the properties of protoclusters hidden by dust statistically, we perform a stacking analysis of *Planck*, *AKARI*, Infrared Astronomical Satellite (*IRAS*), Wide-field Infrared Survey Explorer (*WISE*), and *Herschel* images at the locations of the largest number of (candidate) protoclusters at $z \sim 3.8$ selected from the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP; [2]). Stacking the images of the 179 candidate protoclusters [3], the combined infrared (IR) emission of the protocluster galaxies in the observed 12–850 μm wavelength range is successfully detected with $> 5\sigma$ significance (at *Planck*, Fig. 1 and 2). This is the first time to derive the average IR spectral energy distribution (SED) of a protocluster at $z \sim 4$.

The observed IR SEDs of the protoclusters exhibit significant excess emission in the mid-IR compared to that expected from typical star-forming galaxies (SFGs). They are reproduced well using SED models of intense starburst galaxies with warm/hot dust heated by young stars, or by a population of active galactic nuclei (AGN)/SFG composites. For the pure star-forming model, a total IR (from 8 to 1000 μm) luminosity of $19.3^{+0.6}_{-4.2} \times 10^{13}\,L_\odot$ and a star formation rate (SFR) of $16.3^{+1.0}_{-7.8} \times 10^{3}\,M_\odot\,\mathrm{yr}^{-1}$ are found whereas for the AGN/SFG composite model, $5.1^{+2.5}_{-2.5} \times 10^{13}\,L_\odot$ and $2.1^{+6.3}_{-1.7} \times 10^{3}\,M_\odot\,\mathrm{yr}^{-1}$ are found. Meanwhile, no significant IR flux excess is observed around optically selected QSOs at similar redshifts, consistent with Uchiyama et al. (2018) [4], who showed that typical quasars at $z \sim 4$ are not found in protoclusters. Our results suggest that the $z \sim 4$ protoclusters trace dense, intensely star-forming environments that also with significant contributions from obscured star-formation and AGNs missed by the selection in the optical.

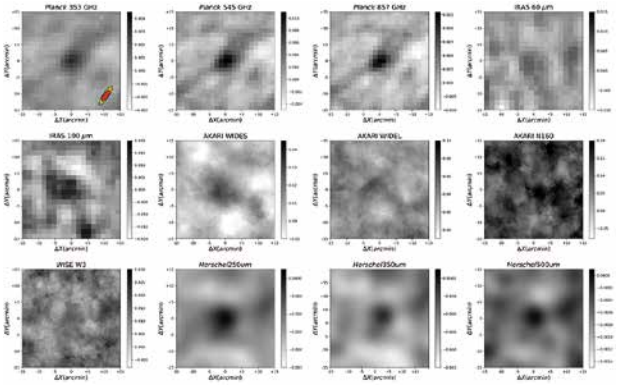

Figure 1: Stacked images of protoclusters in data from the archival IR images [5].

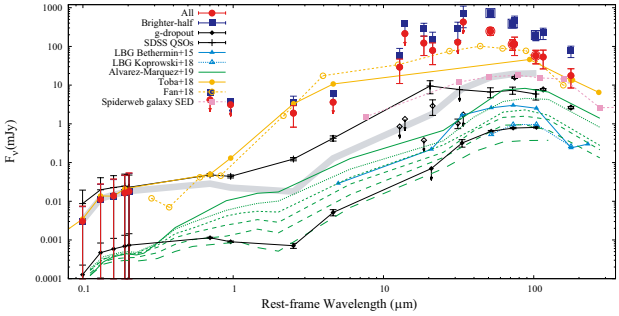

Figure 2: Red circles show the fluxes of a typical protocluster at $z \sim 4$ found by our analysis. Gray thick curve shows the flux of a protocluster expected from the overdensities of galaxies selected in the optical [5].

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Possible Progression of Mass-flow Processes around Young Intermediate-mass Stars Based on High-resolution Near-infrared Spectroscopy. I. Taurus

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WATASE, Ayaka[2], TANIGUCHI, Daisuke[3], MIZUMOTO, Misaki[5], IZUMI, Natsuko[6], KOBAYASHI, Naoto[3]

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We used the WINERED spectrograph [1] to perform near-infrared high-resolution spectroscopy (resolving power R = 28,000) of 13 young intermediate-mass stars in the Taurus star-forming region. Based on the presence of near- and mid-infrared continuum emission, young intermediate-mass stars can be classified into three different evolutionary stages: Phases I, II, and III in the order of evolution [2]. Our obtained spectra (λ = 0.91–1.35 μm) depict He I λ10830 and Pβ lines that are sensitive to magnetospheric accretion and winds. We also investigate five sources each for Pβ and He I lines that were obtained from previous studies along with our targets. We observe that the Pβ profile morphologies in Phases I and II corresponded to an extensive variety of emission features; however, these features are not detected in Phase III. We also observe that the He I profile morphologies are mostly broad subcontinuum absorption lines in Phase I, narrow subcontinuum absorption lines in Phase II, and centered subcontinuum absorption features in Phase III. Our results indicate that the profile morphologies exhibit a progression of the dominant mass-flow processes: stellar wind and probably magnetospheric accretion in the very early stage, magnetospheric accretion and disk wind in the subsequent stage, and no activities in the final stage. These interpretations further suggest that opacity in protoplanetary disks plays an important role in mass-flow processes. Results also indicate that He I absorption features in Phase III sources, associated with chromospheric activities even in such young phases, are characteristics of intermediate-mass stars [3].

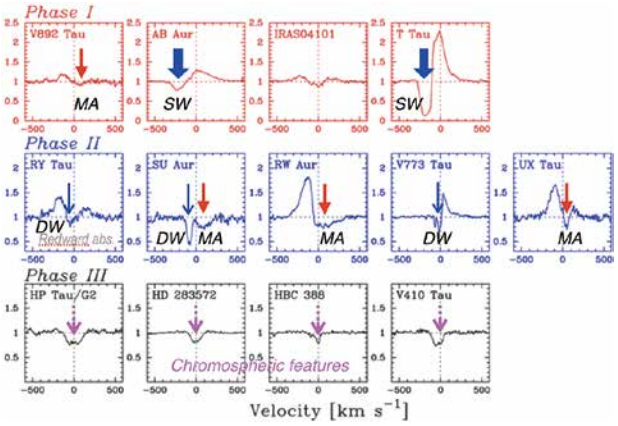

Figure 1: Residual He I profiles. Velocities are relative to the stellar rest velocities. Spectra for Phase I, II, and III sources are shown in top, middle, and bottom panels, respectively.

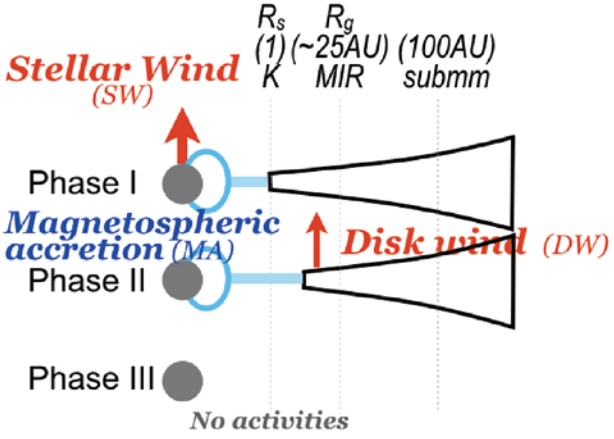

Figure 2: Schematic picture of proposed progression of the dominant mass processes.

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Resonance Spectra of Coplanar Waveguide MKIDs Obtained Using Frequency Sweeping Scheme

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We are developing a detector array for astronomical observations in the 100-GHz band using microwave kinetic inductance detectors (MKIDs) and its readout system [1]. MKIDs are resonators of superconducting film with an intrinsic capability of frequency-domain multiplexing, suitable for large detector arrays. Power deposition into the resonator film results in changes in the resonance parameters: the resonance frequency and quality factor. There are certain methods available for the readout of MKIDs which use the amplitude or phase of the transmission coefficient S_{21} at a single frequency in the resonance. In contrast, we employed a scheme that can obtain S_{21} at many frequency points for a resonance, based on the fast Fourier transform spectrometer (FFTS) [2], with the frequency sweeping scheme [3]. This scheme has a dynamic range higher than the standard scheme; the probe tones can trace their target resonance even when the optical loading moves the resonance frequency significantly. Moreover, the derived resonance frequencies are not affected by changes in the gain or delay in the transmission line. Though the scheme has these advantages, the resonance profile measured can be distorted by frequency sweeping. Thus, evaluating the effect of frequency sweeping on apparent resonance spectrum is indispensable. We made measurements using the scheme with several frequency-sweep velocities (Fig. 1) and checked its effect on the resonance frequency and the quality factor (Fig. 2). A slow frequency sweep causes only small differences in the resonance spectrum compared to an ideal profile, and hence, is suitable for astronomical applications.

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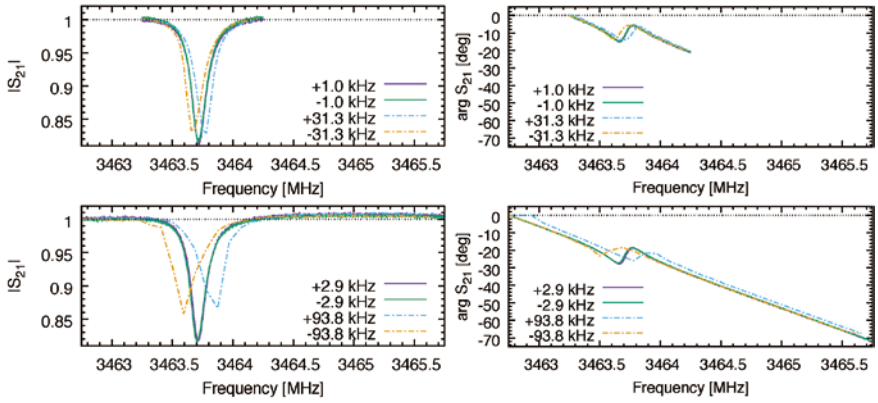

Figure 1: Example of spectra obtained with frequency sweeping scheme of a resonance. (*Left*) amplitude of S_{21}. (*Right*) phase of S_{21}. Modulation widths are 1 MHz (*top*) and 3 MHz (*bottom*). Spectra with the slowest and fastest sweep are shown. The legend indicates the frequency sweep step.

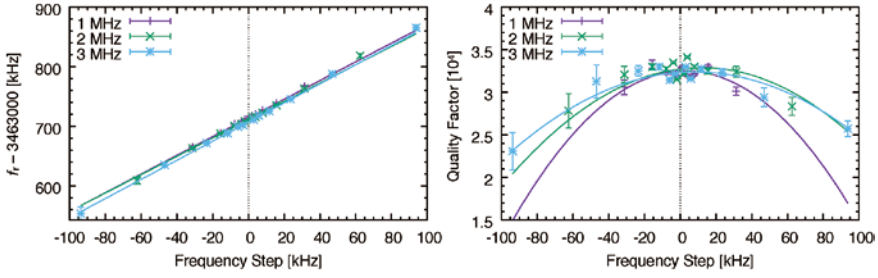

Figure 2: Apparent resonance parameters of a symmetric resonance. (*Left*) resonance frequency. (*Right*) resonance quality factor. The legend indicates the modulation width. Fitted polynomial curve (linear for resonance frequency and quadratic for quality factor) are also shown.

Fe I Lines in 0.91–1.33 μm Spectra of Red Giants for Measuring the Microturbulence and Metallicities

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KOBAYASHI, Naoto[1], SAMESHIMA, Hiroaki[1], HAMANO, Satoshi[4], ARAI, Akira[2], KAWAKITA, Hideyo[2]
YASUI, Chikako[4], IZUMI, Natsuko[5], MIZUMOTO, Misaki[6], OTSUBO, Shogo[2], TAKENAKA, Keiichi[2]
WATASE, Ayaka[2], ASANO, Akira[2], YOSHIKAWA, Tomohiro[7], TSUJIMOTO, Takuji[4]

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For a detailed analysis of stellar chemical abundances, high-resolution spectra in the optical have mainly been used, while the development of near-infrared (NIR) spectrograph has opened new wavelength windows. It is essential both to identify lines to utilize and to verity the methods to determine abundances with NIR wavelength range.

On the basis of two different lists of lines in 0.19–1.33 μm, the Vienna Atomic Line Database (VALD) [1] and the catalog published by Meléndez & Barbuy 1999 (MB99) [2], we selected lines that are not severely blended and compiled lists with 107 Fe I lines in total (97 and 75 lines from VALD and MB99, respectively). Combining our lists with spectra of two prototype red giants: Arcturus and μ Leo obtained with high-resolution ($\lambda/\Delta\lambda$ = 28,000) and high signal-to-noise (>500) spectra taken with WINERED [3], we estimated $\log \epsilon_{\rm Fe}$ from individual Fe I lines using MPFIT [4].

The basic assumption of the method is that the $\log \epsilon_{\rm Fe}$ values should be independent of line strength, as is often assumed in the classical method of abundance analysis. We used a bootstrap method for determining the microturbulence and abundance together with their errors. With the MB99 list, we obtained ξ = 1.20 ± 0.11 kms and $\log \epsilon_{\rm Fe}$ = 7.01 ± 0.05 dex for Arcturus, and ξ = 1.54 ± 0.17 kms and $\log \epsilon_{\rm Fe}$ = 7.73 ± 0.07 dex for μ Leo. These final values show better agreements with previous values in the literature than the corresponding values we obtained with VALD (Figure 1).

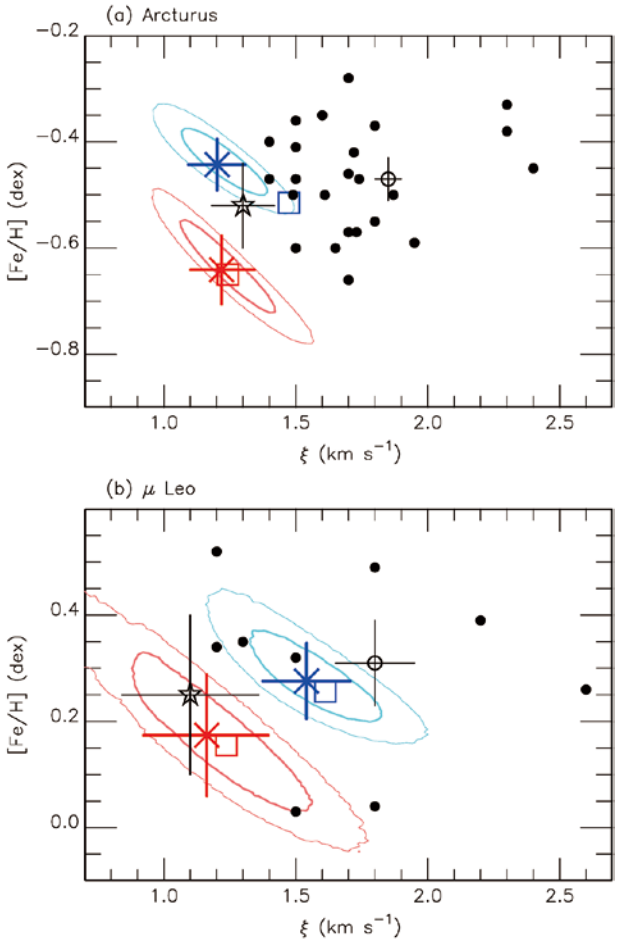

Figure 1: Comparison of our estimates of ξ and [Fe/H] with previous estimates. The results for VALD and MB99 are illustrated in red and blue, respectively [5]. The inner and outer contours show the ranges that include 68.26 % (1σ) and 95.44 % (2σ) of the 1,000,000 bootstrap samples. The cross symbol indicates the best estimates, and the open square indicates the estimates obtained with very strong lines, which were rejected because these lines are likely to introduce problems into a chemical abundance analysis. The total errors are added to the crosses. Two recent results in the literature are shown with error bars: Smith et al. (2013) [6] and Jofré et al. (2014) [7] indicated by an open circle and a star symbol, respectively. The filled circles indicate the other previous estimates that we compiled except those without the microturbulence explicitly given.

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Accretion Origin of Halo Stars with an Extreme r-process Enhancement

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The Milky Way Galaxy has a sparse structure of old stars, called halo, around the disk. This has been formed in the early phase of the Galaxy formation, and includes stars formed in gas clouds in the growing large galaxy and also those formed in small stellar systems that have accreted onto the Galaxy. Such a scenario is predicted by computer simulation of galaxy formation assuming cold dark matter. The small stellar systems accreted onto the Galaxy would be similar to dwarf galaxies found in the current universe. Though they should have already been disintegrated in the space, individual stars should preserve the orbital motion in the Galaxy and their chemical abundance ratios that were determined before the accretion. The focus of current studies in this field is to find evidence for such a scenario of galaxy formation by observations of individual stars in the Milky Way.

The star formation in dwarf galaxies is relatively slow compared to larger galaxies, resulting in difference in chemical abundance ratios recorded in stars. For instance, the magnesium to iron (Mg/Fe) ratios in stars of dwarf galaxies currently found show clear difference from those of the bulk of Milky Way stars.

We have been investigating chemical abundances of halo stars since 2014 using the spectroscopic survey telescope LAMOST in China and the High Dispersion Spectrograph (HDS) on the Subaru Telescope. We have obtained chemical abundances for more than 400 stars, among which we found one object, J1124+4535, to have remarkable abundance features with extremely high abundance ratios of elements heavier than iron, as well as a quite low Mg/Fe ratio (Figure 1) [1]. The abundance pattern of these heavy elements is well explained by the r-process. Whereas the abundance ratios of Fe/H and Mg/H are 1/20 and 1/40 of the solar ones, respectively, the abundance ratio of europium (Eu), which is a good indicator of the r-process, is as high as the solar value.

Such extreme abundance ratios are discovered for the first time among Milky Way stars. On the other hand, several examples of stars having similar abundance ratios are known in dwarf galaxies. This result suggests that this star has formed in a dwarf galaxy, and has accreted onto the Milky Way in the process of galaxy formation. The abundance ratios of this star provide the clearest signature of merger events of dwarf galaxies in stellar chemical abundances known to date.

Interestingly, this star is similar to relatively metal-rich stars found in stars of dwarf galaxies. This indicates that the accreted dwarf galaxy had already chemically evolved at the time of accretion, suggesting that the merging events of dwarf galaxies in the formation of the halo structure continued with timescale comparable to dwarf galaxy evolution. This result supports the current galaxy formation scenario predicted by simulation.

The formation mechanism of such an extreme object is still a mystery. Merger of binary neutron stars could produce large amounts of heavy elements. However, material ejected from the merging event would be diluted by a large amount of surrounding material because the event is very explosive, which makes it difficult to form next-generation stars having such extreme chemical abundance ratios. Solving this problem is important for understanding of star formation in the environment of dwarf galaxies.

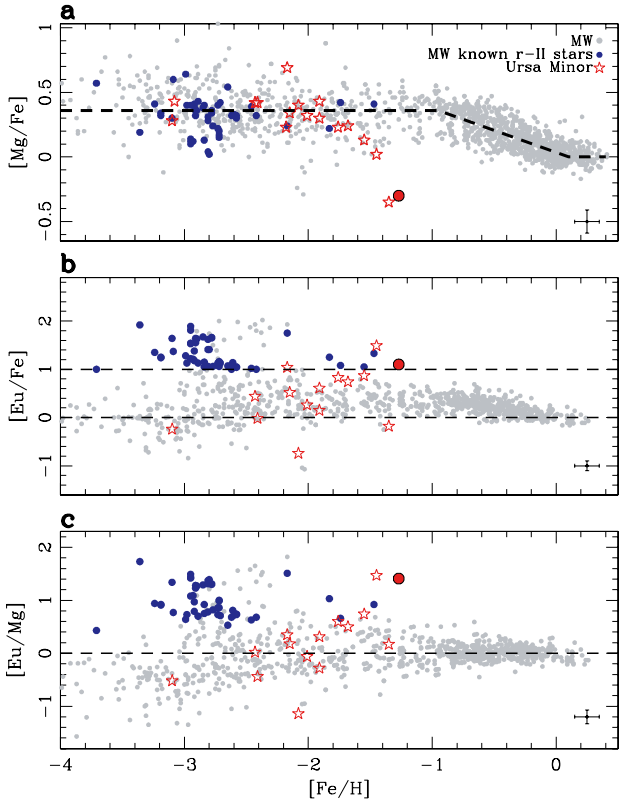

Figure 1: Chemical abundance ratios of J1124+4535 measured with Subaru/HDS: (a. Mg/Fe, b. Eu/Fe, c: Eu/Mg; Eu represents elements produced by the r-process). Asterisks indicate stars in the Ursa Minor dwarf galaxy, whereas others mean stars in the Milky Way. The values indicate ratios of number density of atoms of elements normalized to solar-system values.

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Improving Hayabusa2 Trajectory by Combining LIDAR Data and a Shape Model

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HIRATA, Naru[5], HIRATA, Naoyuki[6], NAMIKI, Noriyuki[1/2], OTSUBO, Toshimichi[7], HIGUCHI, Arika[1]
WATANABE, Sei-ichiro[8], IKEDA, Hitoshi[9], MIZUNO, Takahide[9], YAMADA Ryuhei[5], ARAKI, Hiroshi[1]
ABE, Shinsuke[10], YOSHIDA, Fumi[4], SASAKI, Sho[11], OSHIGAMI, Shoko[1], TSURUTA, Seiitsu[1]
ASARI, Kazuyoshi[1], SHIZUGAMI, Makoto[1], YAMAMOTO, Yukio[9/2], OGAWA, Naoko[9], KIKUCHI, Shota[9]
SAIKI, Takanao[9], TSUDA, Yuichi[9/2], YOSHIKAWA, Makoto[9/2], TANAKA, Satoshi[9/2], TERUI, Fuyuto[9]
NAKAZAWA, Satoru[9], YAMAGUCHI, Tomohiro[9], TAKEI, Yuto[9], TAKEUCHI, Hiroshi[9/2], OKADA, Tatsuaki[9]
YAMADA, Manabu[4], SHIMAKI, Yuri[9], SHIRAI, Kei[9], OGAWA, Kazunori[6], IIJIMA, Yuichi[9]

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Precise information of spacecraft position with respect to target body is of importance in terms of scientific interpretation of remote sensing data. In case of Hayabusa2, such information is also necessary for landing site selection activity. We propose a quick method [1] to improve the spacecraft trajectory when LIDAR [2] measurements and a shape model [3] are provided together with crude initial trajectory, spacecraft attitude information, and asteroid spin information. We compared topographic features contained in the altimeter data with those expressed by the reference shape model, and estimated long-period trajectory correction so that discrepancy between the two topographic profiles was minimized. We take two-step procedure, i.e., (step-1) simple polynomial fit and (step-2) MCMC parameter search. The residual with the initial trajectory exceeding 100 m is reduced down to an order of several meters with the step-2 correction (Fig. 1).

Near global topography of Ryugu can be depicted by LIDAR observations scanning in latitudinal direction (Fig. 2). In order to make regional and local topographic features more visible, we represent a reference shape by even zonal harmonics. We found that there is a depression near the antipode of the center of Ryugu's western bulge [4], which invokes the possibility of impact-induced formation of the western bulge.

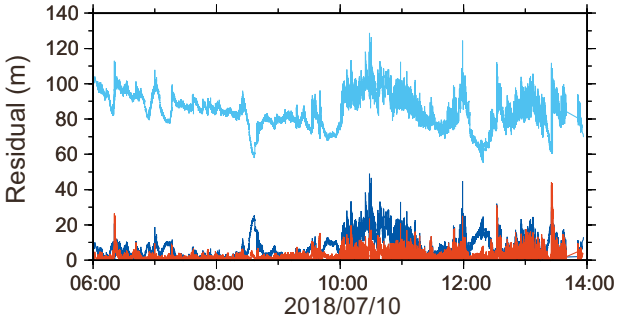

Figure 1: Residual time series on 10 July 2018. Residuals calculated with three trajectories, i.e., initial trajectory, trajectory after simple polynomial fit (step-1), and trajectory after MCMC search (step-2), are indicated by light-blue, blue, and red.

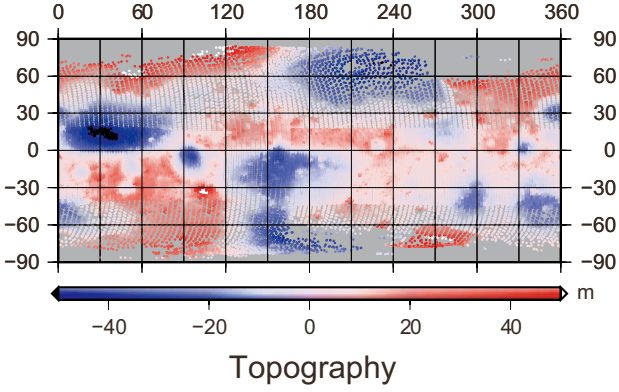

Figure 2: Ryugu's shape obtained by LIDAR scan observation and the corrected trajectory of this study.

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The Photospheric Dynamics Studied with the Spectral Line Broadening and Asymmetry

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The photosphere is filled with convection cells called granules. Recent magnetohydrodynamic simulations have focused on motions on scales smaller than the granules, but the spatial resolution of the current equipment is not sufficient to resolve them.

In this study, we estimated the unresolved velocity structure by analyzing the asymmetry and broadening of the photospheric spectral lines using the spectropolarimetric data observed by the Solar Optical Telescope onboard the Hinode satellite. It has been pointed out in previous studies that the spectral line broadening is caused not only by the velocity structure on the scales smaller than the spatial resolution but also by the Doppler velocity gradient along the line-of-sight (LOS). By applying bisector analysis, we estimated the Doppler velocities in the lower and upper photosphere, and defined the difference of the Doppler velocities (Δv) as an index of the line-of-sight gradient of the Doppler velocities. We used the FWHM of the spectral line profile as an index of the spectral line width.

We investigated the correlation between Δv and FWHM (Figure 1). The velocity gradient tended to be positive around the center of the granules and negative in the intergranular lanes. This is because that the upward velocity is faster in upper layer above the granules, and the downward velocity is faster in lower layer in the intergranular lanes. These signs of Δv are consistent with the convection. On the other hand, the relationship between the granulation and the spatial distribution of FWHM is not so clear. For example, FWHM is small around the center of a large granule at (x,y) = (2″, 2.″5), while FWHM is large around a small graunle at (x,y) = (2.″5, 7″).

We investigated the correlation between the intensity, Δv, and FWHM, and found that the some regions with average intensity has large FWHM. We found that there are the two types of region with large FWHM: (1) region with negative Δv and strong magnetic flux, and (2) region with positive Δv and very small magnetic flux (Figure 2). Such strong positive Δv has not been pointed out by both numerical and observational studies. To investigate the origin of this positive Δv, we analyzed the temporal evolutions of granules.

We found that the Δv becomes large positive and the FWHM increases when a granule fades out. Figure 3 shows the temporal evolution of the fading granules on the Δv-FWHM diagram. It it important that the FWHM is still large even when the Δv is near 0. This implies that the increase of FWHM cannot be explained only by the velocity gradient. If we explain the FWHM at Δv=0 with microturbulence, microturbulence of 0.9 km/s is required.

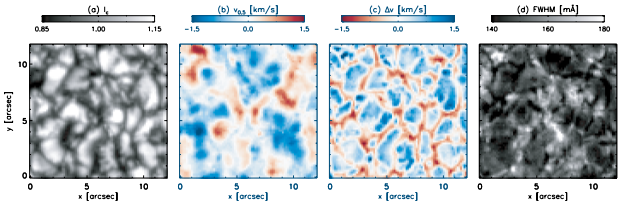

Figure 1: The spatial distributions of intensity (a), Doppler velocity (b), Δv (c), and FWHM (d).

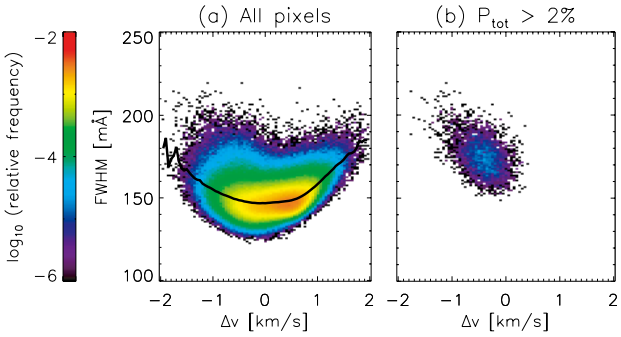

Figure 2: The 2-D histogram of Δv and FWHM with the all pixels (a) and with strongly magnetized pixels (b).

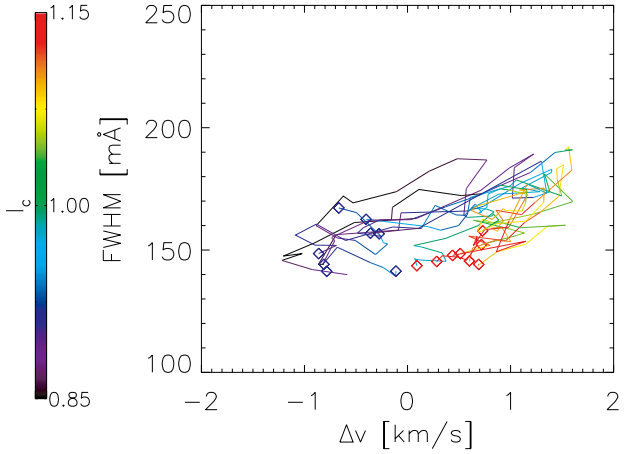

Figure 3: The temporal evolution of 8 fading granules on the Δv-FWHM diagram.

Reference

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Astrometry of IRAS 01123+6430 and cloud-cloud Collision Scenario

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We carried out VLBI astrometry observation towards the star-forming region IRAS 01123+6430 using VLBI Exploration of Radio Astrometry (VERA), as part of Outer Rotation Curve project [1].

Figure 1 shows a result of parallax fitting of identified H_2O maser spots. The annual parallax was measured to be 0.151 ± 0.042 mas, which corresponds to the trigonometric distance of $6.61^{+2.55}_{-1.44}$ kpc. Based on the newly determined more accurate distance, the bolometric luminosity of the YSO was derived to be $L_{\rm Bol} = (3.11 \pm 2.86) \times 10^3\, L_\odot$, which corresponds to spectral type B1–B2.

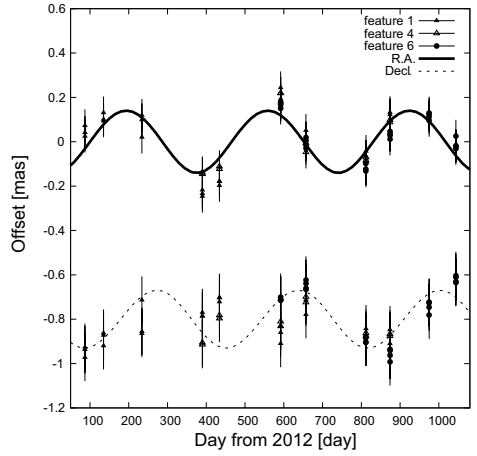

Figure 1: Time variation of right ascension and declination after subtracting the proper motions.

The proper motions were measured to be $(\mu_\alpha \cos\delta, \mu_\delta) = (-1.44 \pm 0.15, -0.27 \pm 0.16)$ mas yr^{-1}. If Galactic constants $(R_0, \Theta_0) = (8.05 \pm 0.45$ kpc, 238 ± 14 km s$^{-1})$ are adopted, the Galactocentric distance and rotation velocity were derived to be $(R, \Theta) = (13.04 \pm 2.24$ kpc, 239 ± 22 km s$^{-1})$, which is consistent with the flat rotation curve.

In addition, we analyzed distribution of molecular gas associated with IRAS 01123+6430 using the ^{12}CO (J = 1–0) survey data obtained with the Five College Radio Astronomical Observatory (FCRAO) 14 m telescope [2]. We found that the cloud consists of arc-like and linear components as shown in Figure 2. This molecular distribution well matches the result of numerical simulation of the cloud-cloud collision (CCC) phenomenon as shown in Figure 3 [3]. Particularly the existence of linear component suggests that collisional speed was 3–5 km s^{-1}, which meets the criteria of massive

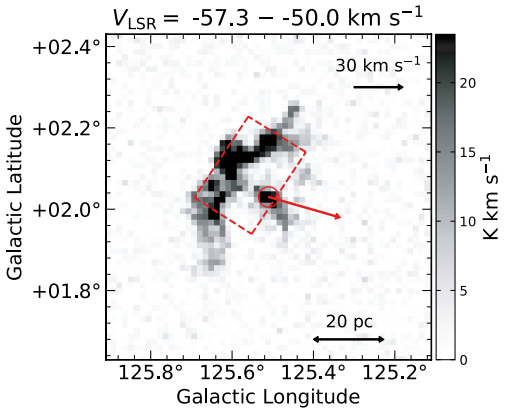

Figure 2: Distribution of molecular gas associated with IRAS01123+6430 traced by the FCRAO 14 m telescope.

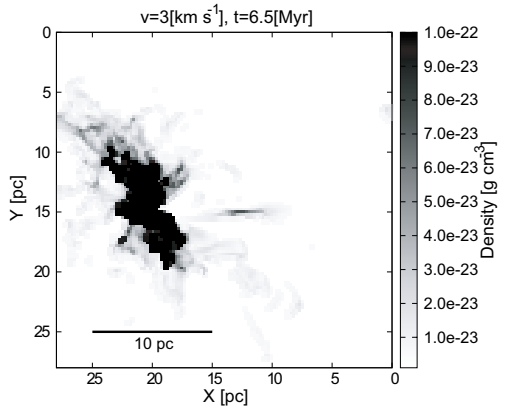

Figure 3: Distribution of molecular gas obtained by a numerical simulation of cloud-cloud collision [3].

star formation according to the CCC simulation. It is consistent with actual observational fact that spectral type of IRAS01123+6430 was B1–B2. If we assume that distance between arc-like and linear components increases with the collisional speed 3–5 km s^{-1}, it would suggest that CCC occurred 2.6–4.4 Myrs ago, which is consistent with time scale of massive star formation. Our analysis supports the scenario that slow collisional speed is more important in massive star formation suggested by a former work [3].

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HSC-SSP Transient Survey at COSMOS Region

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MAEDA, Keiichi[5], SAKO, Masao[6], IKEDA, Shiro[7], KIMURA, Akisato[8], MORII, Mikio[7], UEDA, Naonori[8]
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A supernova is the name given to an exploding star that has reached the end of its life. Supernova classified as Type Ia is useful because its constant maximum brightness allows us to measure its luminosity distance. Using this characteristics the accelerated expansion of the Universe has been discovered [1,2] and more distant supernovae are being observed to understand the nature of dark energy.

In order to discover supernova effectively and measure the light curve of them, we need to monitor wide area of the sky for a long time. High quality and wide field image of Hyper Suprime-Cam (HSC) mounted on the Subaru telescope with large aperture mirror is the best tool in the world for this kind of the observation.

We have conducted a deep transient survey at COSMOS region (7.5 square degree ~ 5 pointings of HSC) in Sextant as a part of HSC-SSP from November 2016 to April 2017 with a cadence of 2 epoch per lunation per filter [3]. The limiting magnitudes per epoch are as follows: 26.4, 26.3, 26.0, 25.6, and 24.6 mag in the *g*-, *r*-, *i*-, *z*-, and *y*-band, respectively. The dataset obtained is one of the deepest wide-field transient surveys attempted to date. We have recorded about 65,000 transients. After excluding objects having light curves dominated by negative fluxes and objects whose host looks like stars, we have visually checked them and identified about 1,800 supernova (Figure 1 and Figure 2). For the detection of the transients, machine learning methods are also applied.

By template fitting to multi-color light curves, about 400 supernovae are classified as Type Ia. Among them, spectroscopic redshift or photometric redshift using 30-band photometry ranging from UV to IR are available for 129 supernovae. In particular, 58 supernovae are located at $z > 1$. In comparison, Hubble Space Telescope took about 10 years to discover a total of 50 supernovae located at $z > 1$. This fact demonstrates the very high survey power of Subaru telescope and HSC. In addition, we have identified 5 super luminous supernovae at $z > 2$ and a event rate at these redshifts has been measured [4].

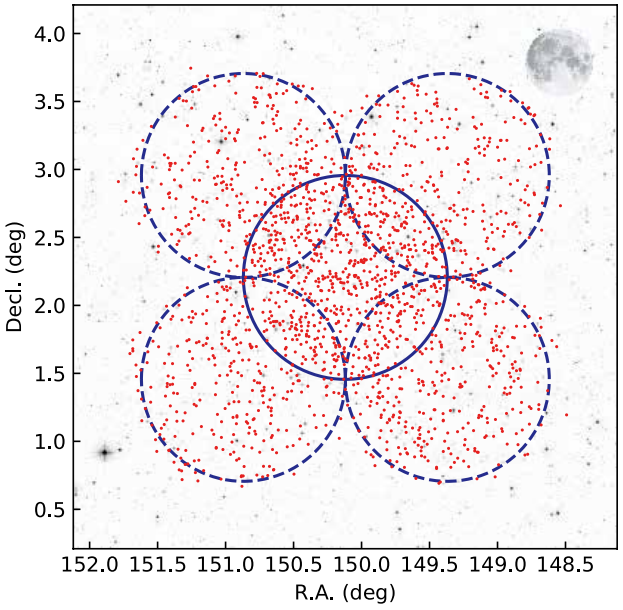

Figure 1: A map showing all of the supernovae (in red) discovered in this study. The blue circles indicate the areas Hyper Suprime-Cam was able to capture in one shot. The background is an image taken by the Sloan Digital Sky Survey. An image of the moon has been added to understand the area of night sky Hyper Suprime-Cam can capture.

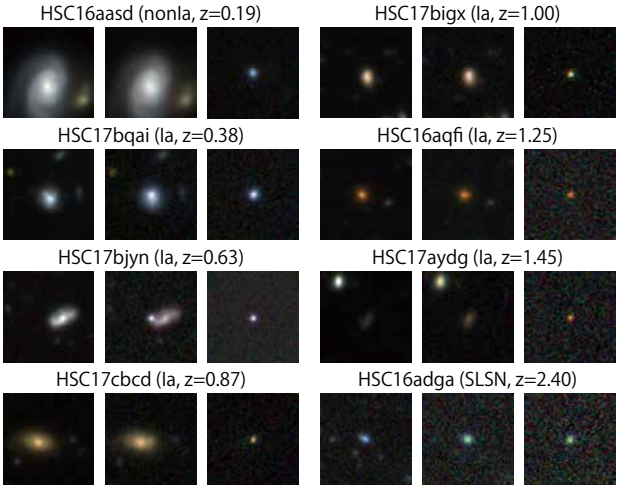

Figure 2: Some supernovae discovered in this study. There are three images for each supernova for before it exploded (left), after it exploded (middle), and supernovae itself (difference of the first two images).

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Gas Filaments of the Cosmic Web Located around Active Galaxies in a Protocluster

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How galaxies obtain gas and subsequently form stars and grow super massive black holes (SMBHs) is a major, open problem. Models of cosmological structure formation in a cold dark matter universe predict that the matter in the intergalactic medium (IGM) form a "cosmic web" of sheets and filaments, and the intersection of these structures would mark cradles in which galaxies form and thrive. Streams of cold gas flowing along the IGM filaments can provide fuel for the growth of galaxies and SMBHs through the circumgalactic medium Unfortunately, although most baryons are in these filaments, their low density, low temperatures and low metal abundance make them notoriously hard to observe.

The SSA22 proto-cluster at $z = 3.1$ is a remarkable cosmic structure with an extent of 30 comoving Mpc, which provides a unique laboratory to investigate the co-evolution of galaxies and large-scale structures. The volume density of dusty starbursts (so-called submillimeter galaxies or SMGs) and X-ray AGNs in a $2' \times 3'$ region of the core is 2–3 orders greater than the field [1]. This suggests that we are witnessing violent growth phase of galaxies and SMBHs in the proto-cluster. Such a vigorous activity must be associated with high level of gas accretion from the cosmic web, as predicted by cosmological simulation.

An intensive search using Subaru/Suprime-Cam and VLT/MUSE has indeed produced groundbreaking results. As shown in Figure 1, very extended Lyα filaments (≥ 1 projected physical Mpc) with surface brightness down to $\mu \sim 0.3 \times 10^{-18}$ erg s^{-1} cm^{-2} arcsec^{-2} have been detected. All SMGs and X-ray AGNs at $z_{\rm spec} \simeq 3.09$ are embedded in these Lyα filaments and also associated in the velocity space. Given that the characteristic size of this emission far exceeds the scale of the dark matter halo of SMGs (a virial radii of ~100 kpc, for $10^{12.5}$ M$_\odot$ halo at $z \sim 3$), the Lyα emission clearly originates from gas in between galaxies, which has been ionized by the copious amount of photons produced by rapidly growing galaxies and AGNs [2].

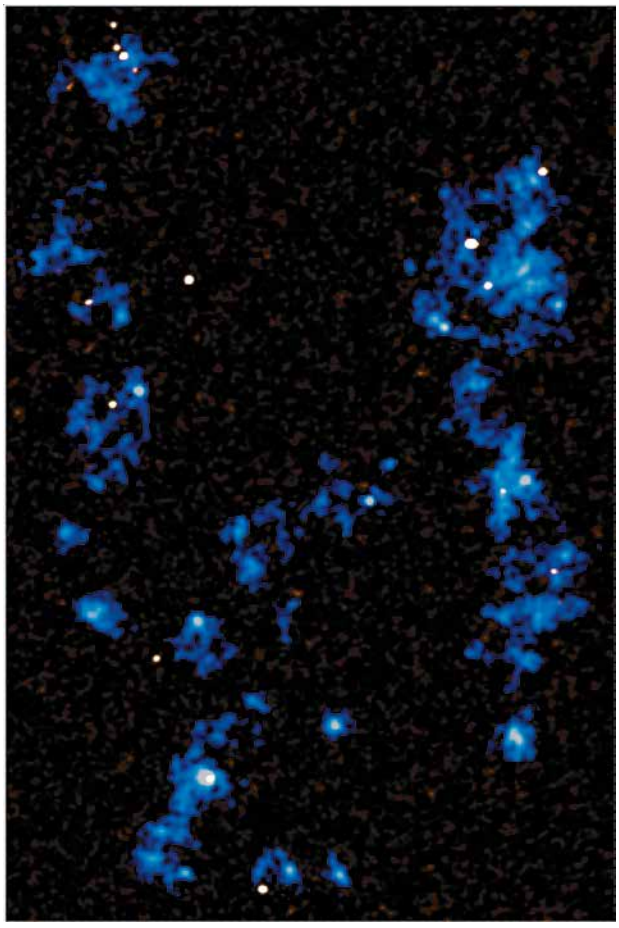

Figure 1: Cosmic web filaments found in this work. Extended Lyα emission are shown across the panel (0.9×1.3 Mpc at $z \approx 3.1$ in size). Background image is the 1.1 mm map taken with ALMA. SMGs ubiquitously distribute along the filaments, which suggests that cosmic web fuels such active galaxy growth.

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Mid-infrared Emission Band from Complex Organic Molecules in Comet 21P/Giacobini-Zinner

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Comet 21P/Giacobini-Zinner (21P/G-Z) is a Jupiter-family comet with an orbital period of about 6.6 years and is thought to be the parent body of the October Draconids meteor shower. Comet 21P/G-Z is categorized as "G-Z type" (~6 % of surveyed comets) [1] because it is peculiar in terms of its volatile content (depleted in carbon-chain molecules, highly volatile species, etc.) and the properties of its dust grains compared to other comets. A negative trend of linear polarization in the optical wavelength region is also reported for the dust continuum of comet 21P/G-Z. It is suggested that this trend might be explained by a higher content of organic materials in the dust grains of 21P/G-Z. Based on previous studies, it was proposed that comet 21P/G-Z originated in a different region than other comets, but we did not have any information about the specific region in the protoplanetary disk.

If complex organic molecules like amino acids are enriched in comet 21P/G-Z and in the meteoroids of the October Draconids, this meteor shower might have delivered complex organic materials to the ancient Earth. However, complex high-molecular-weight organic molecules have never been detected clearly in comets, except in comet 67P/Churyumov-Gerasimenko by the in-situ measurements of the Rosetta spacecraft [2].

We conducted mid-infrared spectroscopic and imaging observations of comet 21P/G-Z using COMICS on UT July 5, 2005 [3]. The obtained spectrum of comet 21P/G-Z shows emission peaks of crystalline silicate grains, which are usually also seen in many other comets. In addition to these silicate features, we found that the spectrum of comet 21P/G-Z exhibits unidentified infrared emission features, which could be attributed to a mixture of aliphatic and aromatic hydrocarbons (such as polycyclic aromatic hydrocarbons or hydrogenated amorphous carbons contaminated by N- or O-atoms).

The presence of these complex organic molecules suggests that comet 21P/G-Z originated from a warmer region in the protoplanetary disk than the typical comet-forming region. Considering that the derived mass fraction of crystalline silicates in comet 21P/G-Z is typical of comets, we propose that the comet originated from the circumplanetary disk of a giant planet (like Jupiter or Saturn) where it was warmer than the typical comet-forming region (5–30 au from the Sun) and was suitable for the formation of complex organic molecules. Comets from circumplanetary disks might be enriched in complex organic molecules, similar to comet 21P/G-Z, and may have provided pre-biotic molecules to ancient Earth by direct impact or meteor showers.

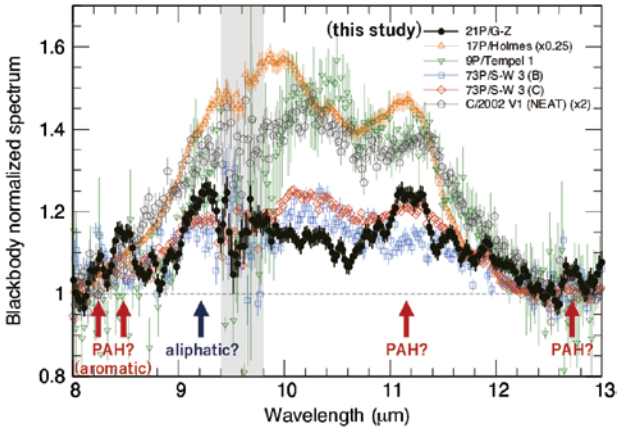

Figure 1: Blackbody normalized mid-IR spectra of comets. The spectrum of comet 21P/G-Z (black filled circles) is different from other comets, and exhibits unidentified infrared emission features at ~8.2, ~8.5, ~9.2, ~11.2, and ~12.7 μm (cf. [3]).

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The Brightest UV-selected Galaxies in Protoclusters at $z \sim 4$: Ancestors of Brightest Cluster Galaxies?

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Brightest Cluster Galaxies (BCGs) are the most massive and optically luminous galaxies in a galaxy cluster. In the local universe, they have different properties compared to other galaxies, so investigating the formation process of them, especially from the observational studies, is important for understanding the origin of the environmental effect of galaxies.

The statistical studies of them had been difficult since the number density of progenitors of galaxy clusters (i.e., protoclusters) is quite small, and we only had ~20 sample at $z \geq 3$ so far. In this situation, we have selected 179 protocluster candidates at $z \sim 4$ from Lyman break galaxies in Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) [1]. This protocluster sample is the largest one so far and we can conduct statistical studies of protocluster galaxies.

In this study, we select the rest-UV brightest protocluster galaxies which is 1.1 mag brighter than the fifth brightest galaxies as candidates of progenitor of BCGs (proto-BCGs). We compare the rest-UV properties of them with those of the field galaxies with the same luminosity [2].

We first compare *i*-*z* color, which is the rest-UV color of galaxies at $z \sim 4$. We find that proto-BCG candidates have redder color than the field galaxies, which implies that they are dustier. This difference is confirmed to be significant from the Anderson-Darling test.

We also compare the average rest-UV surface brightness profile of proto-BCG candidates with that of field galaxies by stacking *i* band images of HSC-SSP. Both profile estimated in this study is more extended than the PSF, and we find that proto-BCGs are more larger than field galaxies.

These two results show that even at $z \sim 4$, at lest the UV-brightest galaxies in protoclusters have different properties to those of field galaxies. Also, since the amount of the dust is correlated to the star formation history of galaxies, proto-BCGs are expected to have different star formation history.

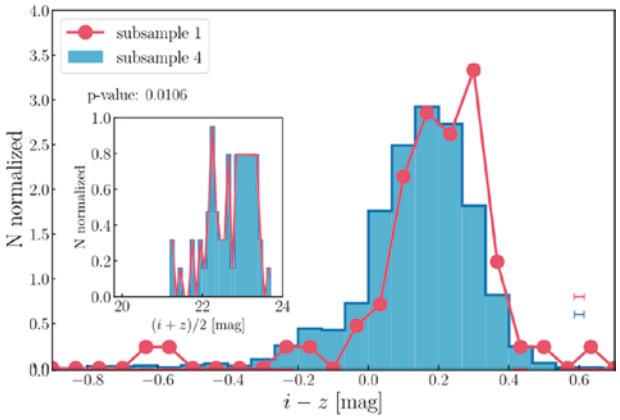

Figure 1: The *i*-*z* color distribution of proto-BCG candidates (red) and field galaxies (blue).

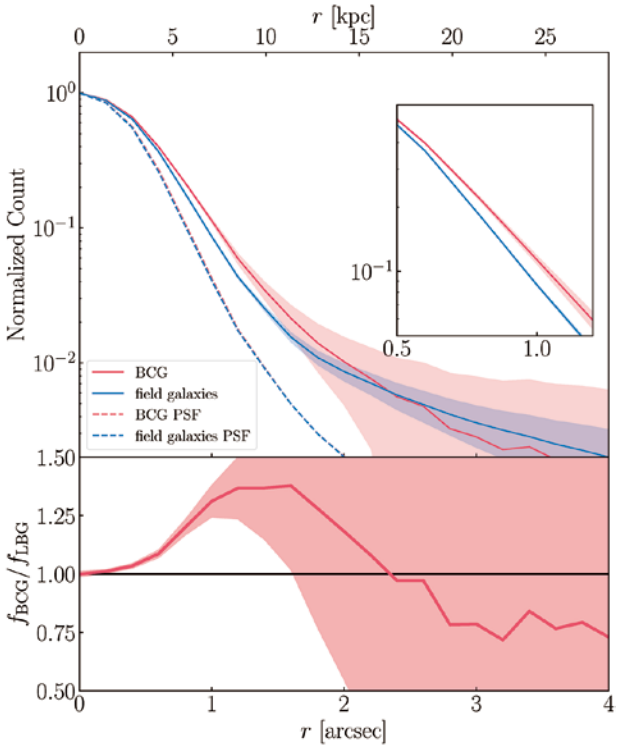

Figure 2: The rest-UV surface brightness profile of proto-BCG candidates (red) and that of field galaxies (blue).

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A *Chandra* and ALMA Study of X-ray-irradiated Gas in the Central ~100 pc of the Circinus Galaxy

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Mass-accreting supermassive black holes, or active galactic nuclei (AGN), have potential to strongly affect the growth of their host galaxies in various forms. Among them, X-ray irradiation is ubiquitous one, given that the AGN is usually luminous in the X-ray band. Particularly, a region whose physical and chemical conditions is determined by X-ray emission is referred to as the X-ray-dominated region (XDR). Theoretically, X-rays are expected to dissociate molecules via high-energy electrons produced by photo-ionization. Given an observed positive correlation between the molecular gas and star-formation rate surface densities, it can be considered that the X-ray dissociation of molecules consequently leads to suppression of star-formation activity.

The aim of this work is to investigate X-ray-irradiated gas in a nearby AGN host galaxy of the Circinus galaxy (hereafter, Circinus) at 4.2 Mpc with a particular focus on X-ray-dissociation of molecules [1]. For this purpose, we used *Chandra* and ALMA. Their spatial resolutions down to sub-arcsec enable us to resolve structures on scales of ~10 pc. *Chandra* is crucial particularly to unveil regions irradiated by X-ray emission, whereas ALMA with high sensitivity at submm/mm wavelengths enables us to not only map molecular gas emission in detail but also constrain physical and chemical properties of the gas based on detections of various molecular emission lines.

Analyzing *Chandra* imaging data, we mapped the Fe-Kα fluorescent line at 6.4 keV to identify X-ray-irradiated gas. The line is produced through photo-ionization of Fe by X-rays with energies above 7.1 keV, corresponding to the K-edge of neutral iron. Thus, the Fe line can trace the gas irradiated by the hard X-rays from the AGN, and it is irrelevant whether the gas is in the molecular phase or the atomic one. Also, to reveal a spatial distribution of molecular gas, we mapped $HCO^+(J = 4–3)$ emission at ≈0.6 arcsec by using ALMA data.

Figure 1 shows the spatial distributions of a proxy of the 6.4 keV Fe-Kα equivalent width (6.2–6.5 keV/3.0–6.0 keV ratio) and the $HCO^+(J = 4–3)$ intensity at ~0.5 arcsec (≈10 pc) resolution. The most interesting feature is the spatial anti-correlation between the two emission lines. The $HCO^+(J = 4–3)$ line may become luminous in dense gas regions if abundant molecular gas is available, but is faint in regions with bright Fe-Kα line emission. The molecular emission seems to be brighter rather in the outer side. This anti-correlation is consistent with that molecules are dissociated into atoms in the proximity of the AGN due to the harsh X-ray radiation. Then, the outer surfaces of the regions may correspond to the atomic-to-molecular gas transition boundary within which photoelectrons produced by X-rays can greatly dissociate molecules.

To quantitatively discuss the above interpretation, we calculated effective ionization parameters along with the XDR model by Maloney et al. [2]. We found that the ionization parameters in the regions with bright Fe-Kα emission but faint $HCO^+(J = 4–3)$ emission were log $\xi_{\rm eff}$ ~ −3. This is high enough to suggest that a large fraction of molecules are dissociated into atoms.

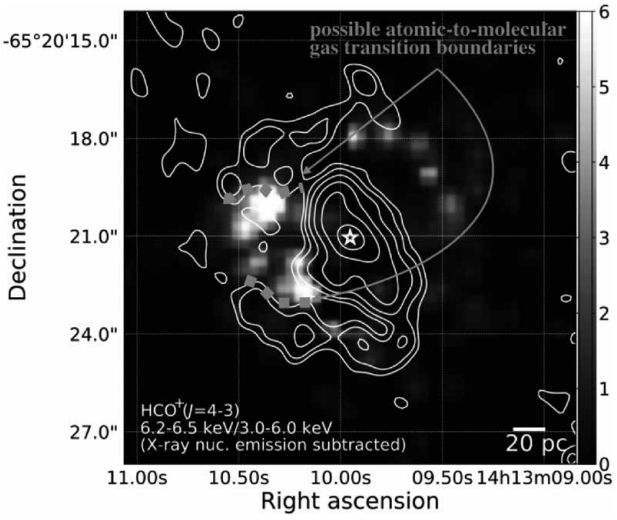

Figure 1: Spatial comparison between a proxy of the Fe-Kα equivalent width (6.2–6.5 keV/3.0–6.0 keV ratio) and the $HCO^+(J = 4–3)$ intensity (white contour) in the central ~100 pc of Circinus. An interesting feature is the spatial anti-correlation between the two emission lines.

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A *NuSTAR* and *XMM-Newton* Study of the Two Most Actively Star-forming Green Pea Galaxies

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It is suggested that the fraction of low-stellar mass galaxies ($< 10^{10}\,M_{\rm sun}$) having central black holes (BHs) gives insights into BH seed formation mechanisms. A rough way to estimate the fraction is to first constrain the AGN fraction and then assume a fraction of BHs being AGNs regardless of the galaxy mass. Thus, a complete AGN census has been crucial for the discussion.

Hard X-ray observations are important to perform a census of AGNs as completely as possible. Compared with soft X-ray ones often used, they can detect heavily absorbed systems due to the higher penetrating power. Also, little contamination from stellar phenomena is another advantage. Indeed, while mid-infrared (MIR) observations are raised as good options less biased against absorption, they can struggle with distinguishing between actively star-forming low-mass galaxies and AGNs.

In this study [1], we discussed the presence of AGNs in two low-mass galaxies SDSS J074936.77+333716.3 and SDSS J082247.66+224144.0 (hereafter, J0749+3337 and J0822+2241), which have infrared properties consistent with containing AGNs. The targets were categorized as Green Pea galaxies (GPs), found in the Galaxy Zoo project and known to have low-stellar masses ($10^{8.5–10}\,M_{\rm sun}$). Also, we note our targets have the two highest star formation rates (SFRs) among all GPs, and were selected because they were expected to have X-ray luminous AGNs given a positive correlation with SFR if AGNs are present.

We observed J0749+3337 and J0822+2241 with the hard X-ray observatory *NuSTAR*. Figure 1 shows the obtained spectrum and the background contribution for J0822+2241. As is clear, no significant emission was found from J0822+2241. This is true also for J0749+3337. Thus, there may be no AGNs in the galaxies. Otherwise, there are heavily obscured AGNs. Regarding the latter case, we investigated how large absorbing column densities are needed to be consistent with the nondetection if there are AGNs with $\log(L_{2-10\,\rm keV}/{\rm erg\,s^{-1}}) \approx 44.3$, expected from MIR luminosities. Based on an AGN torus model, we found that absorbing column densities ($N_{\rm H}^{\rm eq}$) in the the equatorial plane must be larger than $2\times10^{24}\,{\rm cm^{-2}}$ for J0749+3337 and $5\times10^{24}\,{\rm cm^{-2}}$ for J0822+2241.

Complementarily, we also analyzed soft X-ray data taken by *XMM-Newton*, and detected significant emission in J0749+3337 and J0822+2241 (Figure 1). From spectral analyses, we estimated 0.5–8 keV luminosities of J0749+3337 and J0822+2241 to be $\sim 1\times10^{42}\,{\rm erg\,s^{-1}}$. Unfortunately, the luminosities could be however explained only by the active star formation, and therefore we could not found clear AGN signatures.

As no robust evidence was obtained from the X-ray bands, a possibility remains that no AGNs exist. In this case, the infrared properties must be interpreted as the result of stellar phenomena, and young Class I young stellar objects would be one of the main contributors, given their MIR colors similar to those of AGNs.

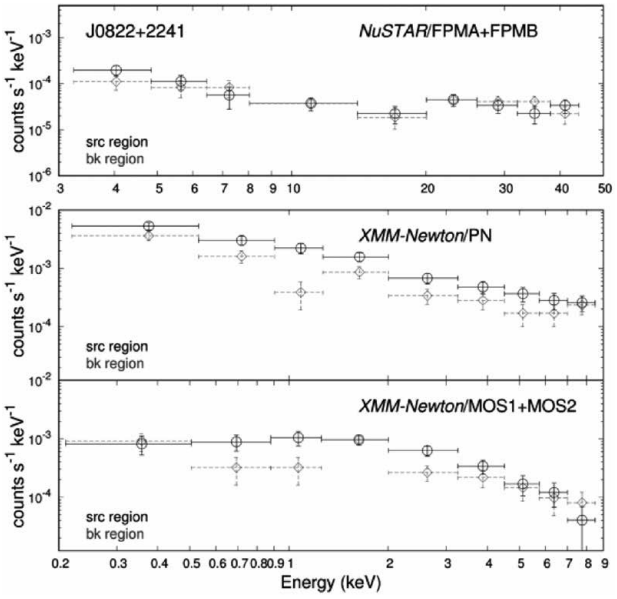

Figure 1: *NuSTAR* 3–50 keV and *XMM-Newton* 0.2–9 keV spectra of J0822+2241 taken from the source (black crosses with circles) and background (blue dashed crosses with diamonds) regions (see [1] for J0749+3337).

Reference

[1] Kawamuro, T., et al.: 2019, *PASJ*, **71**, 68.

First Detection of *A–X* (0,0) Bands of Interstellar C_2 and CN

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C_2 and CN are important not only for understanding the chemical evolution of the translucent clouds but also for probing the physical properties of interstellar clouds. Because pure rotational electric dipole transitions of C_2 are forbidden because of the lack of permanent electric dipole moments, C_2 can be rotationally excited to higher levels by collisions with atoms and molecules, as well as through electronic transitions by the interstellar radiation field. By comparing with the C_2 excitation model, the kinetic temperature and density of the cloud can be constrained from the observed rotational distribution of C_2. CN has been used for estimating the temperature of cosmic microwave background.

We reported the first detection of C_2 and CN *A–X* (0,0) bands in the interstellar medium [1]. The detection was made using the near-infrared (NIR) high-resolution spectra of Cyg OB2 No. 12 collected with the WINERED spectrograph mounted on the Araki telescope. We demonstrated that the C_2 *A–X* (0,0) band in the NIR region could be detected with higher accuracy compared with the previous optical observations of Cyg OB2 No. 12 because of the larger oscillator strength of the NIR band, and the column densities of high rotational levels $J'' > 20$ could be measured (Figure 1). As a result, by comparing the observed rotational distributions with the C_2 excitation model, the kinetic temperatures and densities of the two velocity components of Cyg OB2 No.12 were estimated with the unprecedented accuracy (Figure 2). These results suggest that the observation of these molecules with NIR absorption bands are robust, and these new tools enable the C_2 and CN observations in the strong-extinction regions, where the optical observations were difficult. In addition, we could detect the absorption band of $^{12}C^{13}C$ marginally. If it is true, this is the first detection of $^{12}C^{13}C$ in the interstellar medium. The carbon isotope ratio of C_2 can contribute to the further understanding of the formation and destruction processes of C_2 in the interstellar medium.

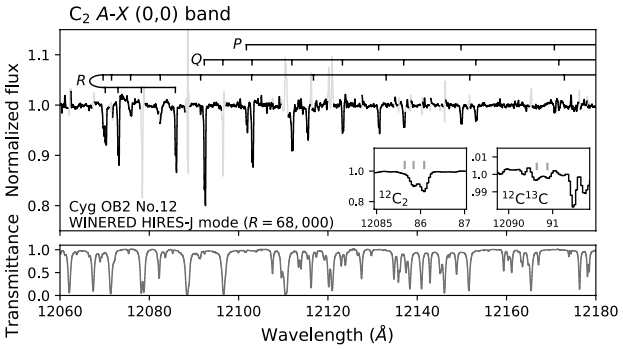

Figure 1: Near-infrared high-resolution spectrum of C_2 *A–X* (0,0) band of Cyg OB2 No. 12 (upper panel). The three velocity components could be clearly resolved (left inset of upper panel). Very weak absorption lines caused by $^{12}C^{13}C$ were probably detected (right inset of upper panel) [1].

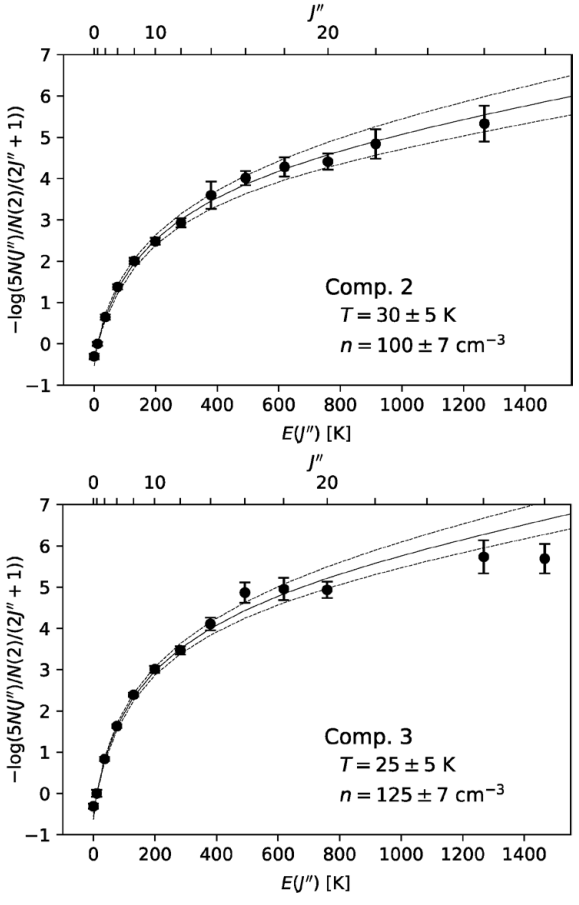

Figure 2: The C_2 Boltzmann diagrams of two velocity components in the line of sight of Cyg OB2 No. 12 [1].

Reference

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Annual Parallax and Galactic Orbit of Y Librae (IRAS 15090–0549) Mira Variable Star

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Astrometric observations with VLBI and Gaia have measured the parallax and proper motion of the source and revealed the structure of the Milky Way. We performed the astrometric observations of an H_2O maser source in a variable star of Mira Cet type, Y Librae (Y Lib) using the VLBI Exploration of Radio Astrometry (VERA) [1]. The trigonometric parallax (π), proper motion ($\mu_\alpha \cos\delta$, μ_δ), and radial velocity ($v_{\rm LSR}$) of Y Lib were measured to be π = 0.855±0.050 mas, ($\mu_\alpha \cos\delta$, μ_δ) = (−10.15 ± 2.39, −15.02 ± 4.26) mas yr^{-1}, and $v_{\rm LSR}$ = 14.40 ± 1.05 km s^{-1}, respectively. The parallax is corresponding to a distance of 1.17 ± 0.07 kpc.

We also performed infrared observations of Y Lib using the Kagoshima University 1 m telescope and measured the mean J, H, and K'-band magnitudes to be 4.34 ± 0.22 mag, 3.62 ± 0.18 mag, and 3.25 ± 0.16 mag, respectively. The pulsation period was obtained to be 277.2 ± 13.9 d. Combining the photometric and astrometric results, we derived the effective temperature and radius to be 3100±125 K and 211±11 $R_\odot$, respectively.

The velocities and positions of sources within the Milky Way are fully described by astrometric motion measurements. From the measured distance, proper motion, and radial velocity, the peculiar motion of Y Lib was derived to be (U_s, V_s, W_s) = (5, −99, −14) km s^{-1}, where U_s is the motion towards the Galactic center, V_s is the motion in the direction of Galactic rotation, and W_s is the motion towards the Galactic North Pole. We traced the past 1 Gyr orbit of Y Lib in the Milky Way using GALORB (GALactic ORBit) Python tool [2]. Figure 2 shows the obtained orbit. It is suggested that the orbit of Y Lib produced high eccentricity in the direction perpendicular to the Galactic center.

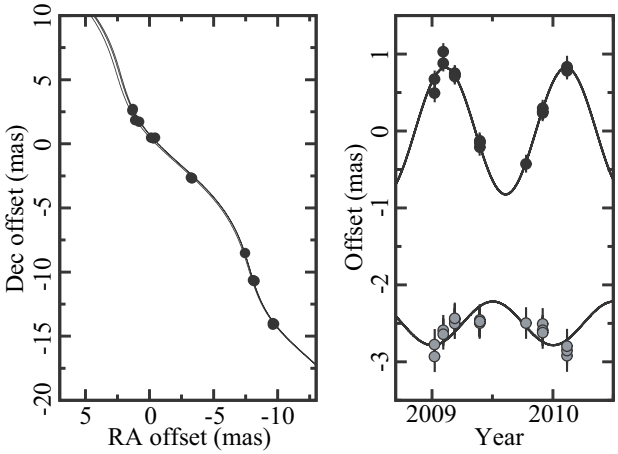

Figure 1: Proper motion (left) and parallax (right) of Y Lib. The proper motion towards the south-west direction and the parallax with a period of 1 yr can be seen.

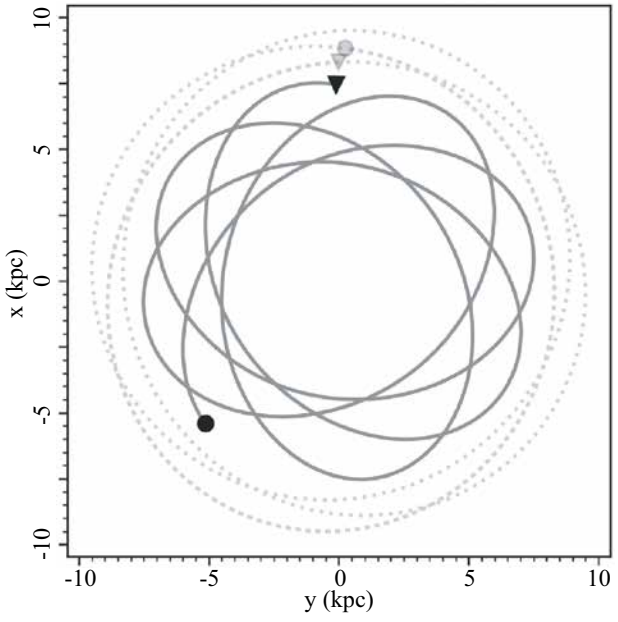

Figure 2: The past 1 Gyr orbits of Y Lib (solid line) and the Sun (dashed line) in the Milky Way.

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[2] https://bitbucket.org/r et d/galorb/wiki

SILVERRUSH. VII. Subaru/HSC Identifications of Protocluster Candidates at $z \sim 6$–7: Implications for Cosmic Reionization

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The scenario of cosmic reionization is important topic to study. Theoretical models predict that star-forming galaxies make ionized regions in the intergalactic medium (IGM) around galaxies (ionized bubbles). It is expected that the large ionized bubbles form in galaxy high-density regions and the cosmic reionization proceeds from high- to low-density regions (inside-out scenario) [1,2]. To test the inside-out scenario, it is necessary to observe galaxy high-density regions around the epoch of cosmic reionization (EoR) and find evidence of ionized bubbles. The study of galaxy high-density regions at high redshift is also important for that of the early galaxy-cluster formation because they are expected to evolve into massive galaxy clusters today. We call these galaxy high-density regions protoclusters, which are usually defined as regions that are predicted to evolve into galaxy clusters with a halo mass $10^{14}\,M_\odot$ by $z = 0$ [2]. Despite their importance, the number of reported protoclusters around EoR is still small [2]. To make samples of protoclusters larger, it is an efficient way to conduct a large field survey of galaxy high-density regions. In this study, we conduct a protocluster survey at $z = 5.7$ and 6.6 based on the large samples of Lyα emitters (LAEs) selected with narrowbands of Subaru/Hyper Suprime-Cam (HSC) [3,4].

We use 1,077 (1,153) LAEs at $z = 5.7$ (6.6) from HSC SSP data to calculate LAE overdensity δ and to detect galaxy high-density regions [5]. By selecting regions where δ are significantly high, we find 14 and 26 LAE high-density regions at $z = 5.7$ (6.6) over 14 (16) deg^2 area. We estimate the halo masses of these protocluster candidates by comparing with them the cosmological Lyα radiative transfer (RT) model around EoR [6]. We find that more than half of these LAE high-density regions are going to evolve into the clusters with a mass of $10^{14}\,M_\odot$ by $z = 0$. Thus we regard the LAE high-density regions as protocluster candidates. From the 40 protocluster candidates, we find 6 of them include spectroscopically confirmed LAEs.

Due to its dependence on the neutral fraction of IGM, Lyα rest-frame equivalent width of an LAE (EW) is useful to study the IGM ionization state [7]. From the cosmological Lyα RT model [6] it is also suggested that the correlation between δ and EW would evolve significantly during EoR because the ionized bubbles around protoclusters are expected to ease the escape of Lyα photons through the neutral IGM. Thus we study the redshift evolution of the correlation between δ and EW during EoR. To test the evolution of the correlation, we calculate EW and δ of the LAE sample and fit a linear function to the EW-δ data. We find that there is not a significant evolution of the correlation from $z = 5.7$ to 6.6 beyond the errors derived from our LAE sample. It is suggested that there is a possibility of detecting the significant evolution of the EW - δ correlation from $z = 5.7$ to 7.3 using the scheduled HSC narrowband observations which enable us to use a larger sample of LAEs at $z = 5.7$–6.6 and a new sample of LAEs at $z = 7.3$.

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The First Detection of $^{13}C^{17}O$ in a Protoplanetary Disk with ALMA : A Robust Tracer of Disk Gas Mass

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Thanks to high spatial resolution and high sensitivity of ALMA, a variety of rare isotopologues have been newly discovered in protoplanetary disks, natal place of planet formation. In addition to deuterated species, nitrogen isotope containing species have been newly detected by ALMA [1]. Meanwhile, CO isotopologues of $^{12}C^{16}O$, $^{13}C^{16}O$, $^{12}C^{18}O$, and $^{12}C^{17}O$ were observed towards disks before ALMA, and $^{13}C^{18}O$ was newly discovered by ALMA [2]. In this observation, we have detected an even rarer isotopologue, $^{13}C^{17}O$, for the first time [3].

In this study, we observed the protoplanetary disk around the young intermediate mass star, HD163296, with ALMA Band 7 and detected the $^{13}C^{17}O$ J = 3–2 emission line (Fig. 1). The Keplerian mask and the matched filter analysis method, developed for detecting the weak emission from the disks, were used. The emission line is detected with the signal-to-noise ratio of 7 (rms noise level: 0.08 Jy/beam). The beam size is 0.87″×0.51″.

In the HD163296 disk, multiple emission lines of $^{12}C^{16}O$, $^{13}C^{16}O$, $^{12}C^{18}O$, and $^{12}C^{17}O$ have been observed so far [4,5]. By adding the detected $^{13}C^{17}O$ emission line, we have constructed a model that reproduces all the observed line fluxes (Fig. 2) and estimated the mass of the disk. We found that the mass of the disk was 2–6 times larger than the previously adopted model. The total disk mass is 0.21 solar mass. It becomes difficult to estimate the mass when the line emission becomes optically thick. In this work, we have detected the rarest isotopologue of $^{13}C^{17}O$, that is, the optically thinnest line emission among the CO isotopologues, and then successfully measured the disk mass most accurately.

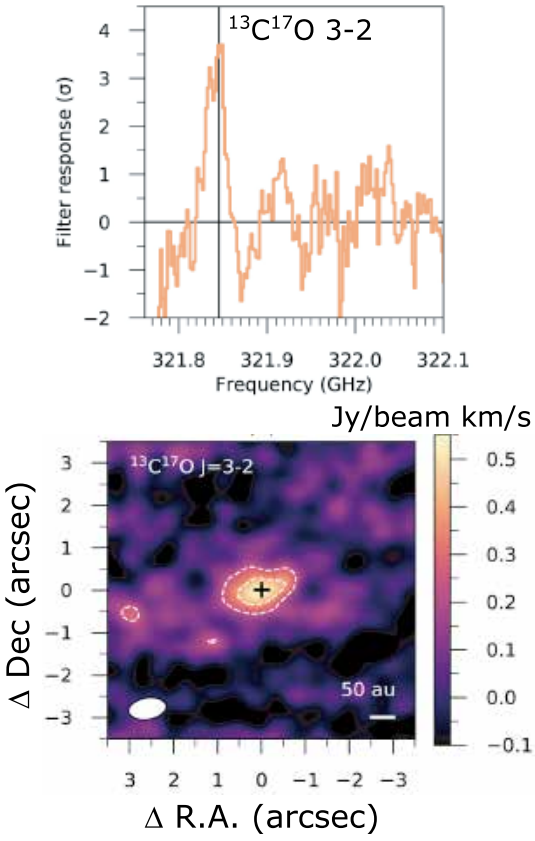

Figure 1: Detection of the $^{13}C^{17}O$ J = 3–2 line emission from the HD163296 disk [3].

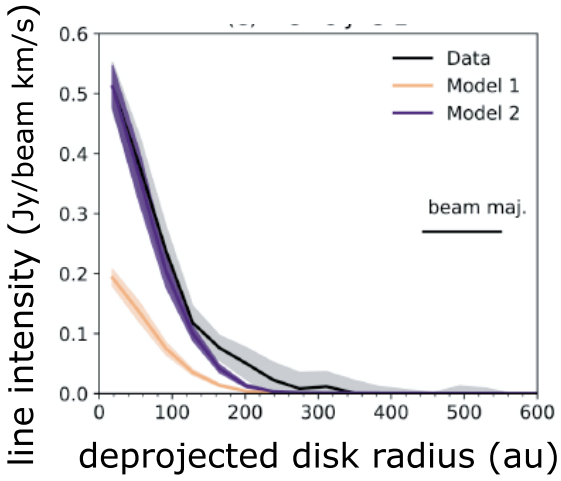

Figure 2: Comparison of observations and model calculations of the radial distributions of the $^{13}C^{17}O$ emission line fluxes from the disk. The previous model (Model 1) cannot reproduce the observations [3].

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Probing the Neutrino Oscillation by Supernova Nucleosynthesis

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The neutrino (ν)-process is the nucleosynthesis mechanism induced by the neutrinos produced in core-collapse supernova (CCSN) explosions. It is a unique nucleosynthesis process that only affects the abundances of some rare nuclei. A comparison of calculated ν-process abundances with observational abundances or meteoritic analyses can provide valuable information on the associated ν physics and CCSN physics. However, there still remain some ambiguities in treating the ν physics in CCSNe. One example is the ν mass hierarchy (MH). The neutrino MH strongly affects the ν-flux and the subsequently produced ν-process abundances. Another is the matter-enhanced ν oscillation, *i.e.* the MSW effect that gives rise to additional ν mixing from that of free space around the bottom of the C/O-rich layer. The third important aspect is the ν self-interaction (ν-SI) arising from non-linear ν-ν scattering. This is usually negligible, but near to the neutrinosphere the ν-density approaches $\sim 10^{32}$ cm^{-3}. This density is large enough that the ν-SI should be taken into account for the ν-flux. In this work [1], we calculate the abundances of ^{7}Li, ^{11}B, ^{92}Nb, ^{98}Tc, ^{138}La, and ^{180}Ta produced by ν induced reactions in a CCSN. We consider the modification by ν-SI near the ν-sphere and the MSW effect in the outer layers based on time-dependent ν-energy spectra.

Figure 1 shows the mass-fractions of ^{92}Nb, ^{98}Tc, ^{138}La and ^{180}Ta with and w/o the ν-SI in each MH scheme. Abundances of ^{92}Nb, ^{98}Tc, and ^{138}La decrease with increasing M_r except for those in the valleys. This trend stems from the ν-induced reaction rate which is proportional to the ν-flux which scales as r^{-2}. Note that the insensitivity of the ^{180}Ta production to the ν-SI comes from the fact that most of the ^{180}Ta is not produced via the ν-process in the present model. Because most of the heavy nuclei are produced inside the MSW region, their abundances depend strongly on the ν-SI. We stress that the ν-SI effect decreases the ^{92}Nb, ^{98}Tc and ^{138}La abundances by a factor of 1.5–2.0 and each final abundance in the NH scheme is larger than that in the IH scheme by about 20–30 %. Bottom panel shows the light nuclei, ^{7}Li and ^{11}B. The total abundance of ^{7}Li is much decreased by the ν-SI in the IH scheme, whereas in the NH scheme the ^{7}Li abundance is slightly increased, because related cross sections of the two CC reactions are larger than those of the NC reactions by a factor of 2–3. Although ^{11}B is also generated by CC reactions with ν_e and $\bar{\nu}_e$ on ^{12}C in addition to NC reactions, these three reactions have contributions of the same order of magnitude. Thus, ^{11}B production is relatively insensitive to ν-SI and its abundance decreases by only 5–10 %.

In conclusion, abundances of ^{7}Li and the heavy isotopes ^{92}Nb, ^{98}Tc and ^{138}La are reduced by a factor of 1.5–2.0 by the ν-SI. In contrast, ^{11}B is relatively insensitive to the ν-SI. We find that the abundance ratio of heavy to light nuclei, ^{138}La/^{11}B, is sensitive to the ν-MH, and the normal MH is more likely to be consistent with the solar meteoritic abundances.

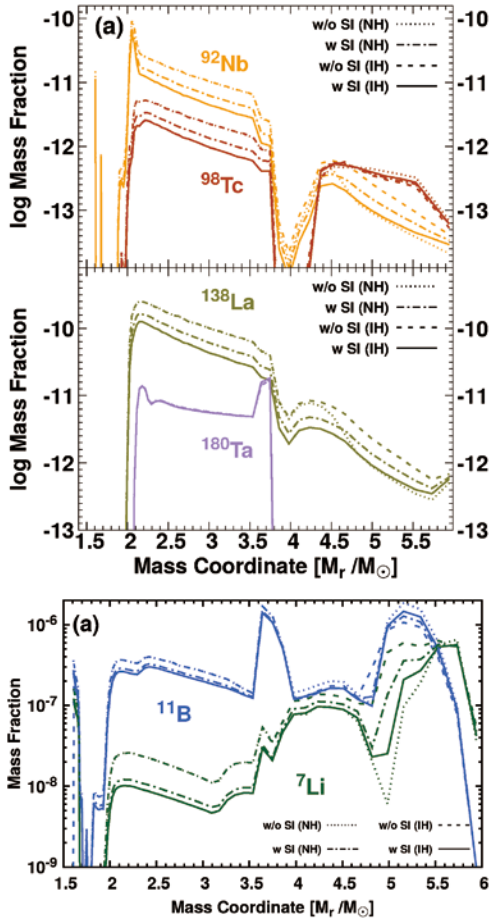

Figure 1: Mass fractions in log scale of ^{92}Nb, ^{98}Tc, ^{138}La and ^{180}Ta (top), and ^{7}Li and ^{11}B (bottom) in the NH and IH schemes. We show four different cases of w/o SI (NH) (dotted), w SI (NH) (dash-dotted), w/o SI (IH) (dashed) and w SI (IH) (solid).

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Effects of Shock Propagation on Neutrino Oscillation and *ν*-induced Nucleosynthesis in Supernova [1]

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Since the discovery of all neutrino (ν) mixing angles and their partial mass differences which properly elucidated the ν-oscillation in free space, understanding of the ν-oscillation in matter has been extensively discussed in neutrino physics as well as astrophysics. In particular, supernova (SN) neutrinos are supposed to propagate in a dense matter shocked by the core collapsing SN explosion and change their flavors. But most of the calculations assumed that variations of matter density by the shock (SH) propagation do not affect so much the ν properties during the propagation. However, some hydrodynamic (HD) models employed in the SN explosion calculation may have some non-adiabatic as well as adiabatic properties in the SH propagation.

In this paper [1], we discuss effects of SH propagation on neutrino ν-oscillation in SN environment, which affects directly ν-induced nucleosynthesis. For non-adiabatic change of density, the Landau-Zener (LZ) crossing formula, $P = \exp(-\pi\gamma/2)$, is very useful for the ν-flavor transition in matter, which implies a kind of transition (or flavor-flip) probability by the non-adiabatic change of matter. The γ is an adiabatic parameter depending on the adiabaticity, *i.e.* whether they are adiabatic or non-adiabatic process. The ν-mixing stemming from the adiabatic parameter is calculated by the diagonalization of the total neutrino Hamiltonian including the varying matter density.

Our results of the ν-oscillation at $t = 0$ and $t = 3$ s are shown in Fig. 1. Panel (b) shows the multiple resonances for electron neutrino at $t = 3$ s after SH propagation. The first resonance occurs in the inner region near to 1.65 $M_\odot$ because the n_e in the present model decreased just after the SH and reached to a resonance density. In the region near the resonance, the adiabatic parameters are $\gamma \approx$ 1.63–4.8 and the flip probability $P_f = \exp(-\frac{\pi}{2}\gamma)$ can be applicable and its value is $8\times10^{-2} \sim 5\times10^{-4}$. In the region around 3.3 $M_\odot$, the 2nd ν-flavor oscillation occurs and the electron neutrino returns to its initial flux before the third resonance near to 4.7 $M_\odot$.

Finally, we apply the reaction rate changed by the SH wave to the explosive nucleosynthesis calculation. Fig. 2 (b) shows abundances of the synthesized elements with and w/o SH wave effect on ν-oscillation. Inside of M_r = 3.3 $M_\odot$, the reaction rates are increased compared to those w/o SH wave propagation, so that the abundances increase. But in the region of 3.6 $M_\odot < M_r <$ 4.7 $M_\odot$, where the 2nd resonance occurs, the ν-spectra return to the original ν-spectra and the abundances decrease.

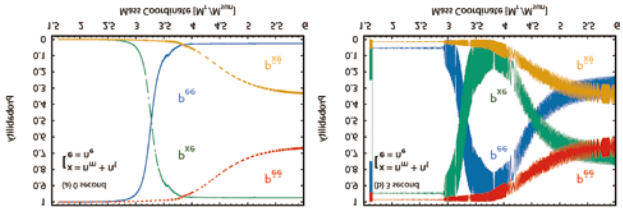

Figure 1: Flavor transition probabilities at $t = 0$ s (a) and $t = 3$ s after the shock (b), respectively, for $E_\nu = 15$ MeV in the NM hierarchy.

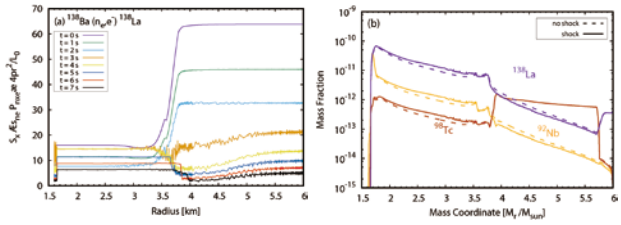

Figure 2: Reaction rates of ^{138}Ba(ν_e, e^-)^{138}La multiplied by $4\pi r^2$ and divided by initial ν-luminosity at $t = 0$, 1, ..., 7 s (a) and abundances of ^{92}Nb, ^{98}Tc and ^{138}La in case of with and w/o shock propagation effect on ν-oscillation (b).

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Current Status of r-process Nucleosynthesis [1]

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Origin of heavy nuclei like uranium is still an unanswered biggest question in modern science B2FH [2]. The rapid neutron capture process (r-process) is believed to be responsible for about half of the production of the elements heavier than iron up to uranium and contributes to abundances of some lighter nuclides as well.

GW170817/GRB170807A/SSS17a [3] was an event of the century that has opened a new window to the frontier of multi-messenger astronomy and nuclear astrophysics. Gravitational wave from most likely the merging neutron star (NSM) was detected by LIGO-Virgo collaboration, and short-duration gamma-ray bursts were observed in Fermi- GBM and INTEGRAL. Although none the emission line from specific heavy r-process elements was detected, total energy in observed optical and near-infrared emissions is consistent with radiative decays of r-process nuclei which are predicted theoretically. However, NSMs could not contribute to the early Galaxy for cosmologically long coalescence time-scale for very slow GW radiation [4,5]. Nevertheless, NSM like GW170817/GRB170807A/SSS17a is still a possible nucleosynthetic site for the solar-system heavy elemental abundances.

Therefore, there remain questions as to the contribution over the history of the Galaxy to the current solar-system r-process abundances from other sites such as neutrino-driven wind (neutrino-WIND) or magnetohydrodynamical ejection (MHD Jet) of material from core-collapse supernovae. A universal pattern of r-process elemental abundances is observed in some metal-poor stars of the Galactic halo. This suggests that a well regulated combination of astrophysical conditions and nuclear physics conspires to produce such a universal abundance pattern. These SN r-process nucleosynthesis can very naturally explain the observed universality [6,7].

In this review [1] we highlight some current issues surrounding the nuclear physics input, astronomical observations, galactic chemical evolution, and theoretical simulations of r-process astrophysical environments with the goal of outlining a path toward resolving the remaining mysteries of the r process.

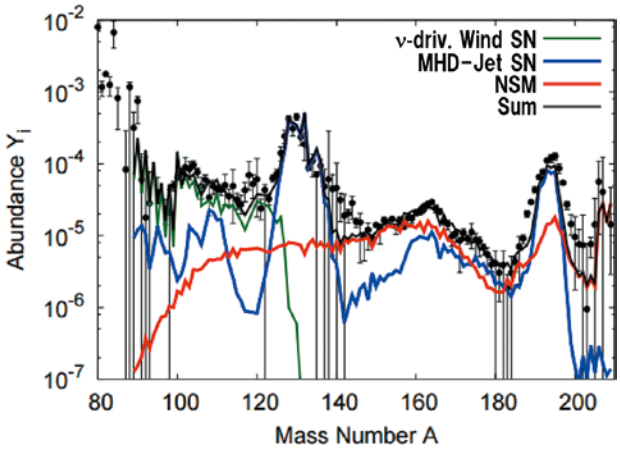

Figure 1: Comparison between calculated and observed r-process abundance patterns in te solar system.

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II Status Reports of Research Activities

1. Subaru Telescope

1. Subaru Telescope Staff

As of the end of FY 2019, the Subaru Telescope staff consisted of 22 dedicated faculty members including seven stationed at Mitaka and two stationed at Okayama; four engineers including one stationed at Mitaka; five senior specialist; and three administrative staff members. Additional staff members include four project research staff, seven senior specialist, one research expert, and five administration associates, all of whom are stationed at Mitaka. There are also one engineer, one administrative maintenance staff member and two administration associates stationed at Okayama. Moreover, 16 research/teaching staff members, 13 of whom are stationed at Mitaka and three of whom are stationed at Pasadena; and three engineers, one each stationed at Mitaka, Nobeyama, and Mizusawa, are posted concurrently. The project also has 73 local staff members dispatched from the Research Corporation of the University of Hawai'i (RCUH), including scientific assistants; engineers in charge of software and observational instruments; technicians for facilities, machinery, vehicles, and laboratories; telescope/instrument operators; secretaries; administrative staff; researchers employed for Grants-in-Aid for Scientific Research; 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 2019, Subaru Telescope produced many outstanding scientific outcomes which were published in major international journals. Below are some examples:

(1) Using the very wide field optical camera, Hyper Suprime-Cam (HSC), a search for gravitational microlensing events in the Andromeda Galaxy was conducted. The results have ruled out the possibility that primordial black holes smaller than a tenth of a millimeter make up most of the dark matter.

(2) Using the High Dispersion Spectrograph (HDS), a star with a chemical composition unlike any other Galactic star was discovered in the Milky Way halo. Since this chemical composition has been seen in a small number of stars in dwarf satellite galaxies orbiting the Milky Way, this result suggests that the star was a member of a dwarf galaxy that merged into the Milky Way in the past.

(3) A new cutting-edge planet-imaging system, the SCExAO (Subaru Coronagraphic Extreme Adaptive Optics) adaptive optics system coupled to the CHARIS integral field spectrograph provided the first-ever direct, sharp look at a young star that had been thought to have three planets orbiting it. It revealed that most of the light thought to have come from the planets originates from a disk of gas and dust; thus, planets orbiting this star, if they exist, must be fainter and likely lower in mass.

(4) Using HSC, a proto-cluster containing 12 galaxies in the constellation Cetus was discovered about 13.0 billion light-years away, which is the earliest protocluster ever found. This discovery suggests that large structures such as protoclusters already existed when the Universe was only about 800 million years old, 6 % of its present age.

3. Open-use

In S19A, 46 programs (74 nights including 12 nights for ToO programs) were accepted out of 133 submitted proposals, requesting 354.9 nights in total. In S19B, 34 proposals (49.6 nights including 10.5 nights for ToO programs) were accepted out of 142 submitted proposals, requesting 323.9 nights in total. In S19A and S19B, 5.5 nights for 2 programs and 12 nights for 5 programs respectively were allocated to the continuous intensive programs. Service observations were made for 8.5 nights. In S19A and S19B, 5 and 4 respectively of the programs accepted were open-use proposals by foreign principal investigators, excluding the University of Hawai'i. The number of applicants in submitted proposals was 2338 for Japanese researchers (Japanese astronomers at any institute and non-Japanese astronomers belonging to Japanese institutes) and 883 for foreign researchers. The number of researchers in accepted proposals was 812 for Japanese astronomers and 209 for foreign astronomers. In S19A and S19B, the number of open-use visiting observers was 229, of which 30 were foreign astronomers. A total of 137 astronomers observed remotely from Mitaka. In S19A and S19B, 92.04 % 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 4.55 %, 0.29 %, 3.06 %, and 0.06 % of observing time was lost due to instrument trouble, communication trouble, telescope trouble, and operation trouble, respectively. In S19A and S19B, remote observations from Hilo were conducted for 27 programs with 32.2 nights. On the other hand, remote observations from Mitaka were conducted for 96.8 nights with 32 programs, including HSC SSP. The numbers of telescope time exchange nights between Subaru Telescope and Keck were 7.5 nights in S19A and 8.0 nights in S19B. Regarding those between Subaru Telescope and Gemini, Subaru Telescope users used Gemini time 4.5 nights in S19A and 5.0 nights in S19B (not including Fast Track programs) while Gemini users used Subaru Telescope time 8.9 nights in S19A and 4.9 nights in S19B.

4. Telescope Maintenance and Performance Improvement

The following major repairs, maintenance, and changes were implemented in FY 2019.

(1) Cassegrain rotator (AG/SH layer) overhaul:
The failure of the Cassegrain rotator (AG/SH layer) occurred in mid-May. After removing it from the telescope, it was found that the AG/SH layer cable wrapper had been damaged. We installed dummy weights instead of the removed AG/SH layer to continue the observations. As a result of repair work in cooperation with the relevant divisions of the observatory, we were able to resume the operation within 14 working days. In this repair, the telescope maintenance operation support contract with MELCO that started this year worked well, and we were able to restore the damaged unit without affecting the observations using the Cassegrain Unit.

(2) Recoating of the infrared secondary mirror (IRM2):
The silver coating of the infrared secondary mirror was completed safely. The mirror's surface discoloration and deterioration, which were thought to be due to the effects of volcanic gas, were very severe. Some portions of the mirror surface were very vulnerable; they could be peeled off even by cleaning with pure water. A relatively large earthquake occurred during the recoating work, but it did not affect the work. The reassembly and operation test of the secondary mirror drive unit were performed with no problems. This work was completed successfully within about a month.

(3) Main shutter mechanical structure repair:
The repair work on the dome main shutter was led by the Technical Planning and Development Division, which was set up inside Subaru Telescope. We had to suspend the work for about a month due to road blockages related to the TMT construction issue. After part of the roadblock was lifted, we resumed work and completed the planned renovation on the main shutter.

(4) Improvement of observation environment:
In order to realize "Unmanned Summit observation" in the near future, we have constructed a monitoring system that allows remote operation of the local control units of the telescope. This will enable quick analysis in the troubleshooting and help to realize the efficient arrangement of staff. Currently, the system is under test operation to check the stability. Also, we are strengthening and updating the surveillance camera function, and are promoting the introduction of high-sensitivity cameras that can clearly watch the status inside the dome even at night. Furthermore, we are proceeding with preparations to update the control units (PLC) of the dome so that their status can be monitored remotely.

(5) Other Activities
We have been working on the renewal of the primary UPS 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/dome, and repairing sudden failures. In order to carry out these tasks more effectively, we changed the organization structure of the observatory.

5. Instrumentation

In FY 2019, 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-element 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 previously reported, there have been discussions on how we maintain or stop the operations of the facility instruments except for HSC. COMICS will be decommissioned after the semester S20A based on the previous decision. MOIRCS is going to be hibernated from S21A to S22B because of the planned science operation of the carry-in instrument SWIMS which is an infrared camera and spectrograph developed by the University of Tokyo and has similar functions to MOIRCS. On the other hand, HDS and IRCS, which will be kept at least for several years, had some issues in their control systems due to aging and need renewals.

HSC had a few problems in this fiscal year; a stain on the wide field corrector lens and a connection problem with the Filter Exchanger Unit. The latter trouble caused cancellations of several observing nights. They have already been resolved, and HSC is now being operated without major issues.

There are ongoing upgrade projects for the other facility instruments. For AO188, the upgrades of the laser guide star system and installation of Transponder-Based Aircraft Detector system are ongoing, and they will start operations from around the end of FY 2020. The upgraded grisms of MOIRCS have been successfully installed into the instrument and will achieve first light in the summer of 2020. The final design study of the NsIR beam switcher, which will enable switching between NsIR instruments without physically moving the instruments, was started in FY 2019.

As carry-in (PI-type) instruments, SCExAO (Subaru Coronagraphic Extreme Adaptive Optics), CHARIS (high-contrast integral-field spectrograph), and VAMPIRES (visible aperture masking interferometer with differential polarimetry), which are used in combination with AO188, have been offered for the Subaru Telescope open-use program. IRD (InfraRed Doppler instrument) with NGS (Natural Guide Star) mode has been offered for the Subaru Telescope open-use program since S18B. In addition to the open-use program, the IRD SSP (Subaru Strategic Program) has been started from S19A, with a condition of 70 nights. One of the other two PI-type instruments proposed by the University of Tokyo teams, MIMIZUKU (mid-infrared

multi-field imager and spectrograph) finished all of its carry-in activities in FY 2019. SWIMS (Simultaneous-color Wide-field Infrared Multi-object Spectrograph) was reviewed for its science/open-use operation at the Subaru Telescope, and is being prepared for observations after S21A.

6. Computer and Network

The Subaru Telescope computing system supported by Fujitsu Engineers included a major adjustment in this 2nd year of the contract agreement. Fujistu support engineers where reduced from 2.5 persons per day, to 0.5 person (remote support from Japan). This is the first time in Subaru Telescope's existence that support engineers are not based in Hilo. Computer and Data Management division (CDM) has assumed all responsibilities, with limited support from Fujitsu Japan.

The computing and network systems remain very stable, with continued plans to increase utilization. Virtualization is always a goal to help reduce the operating footprint of physical systems at both Hilo and the Summit Facilities, while providing a stable and easily recoverable environment. Currently Observation Control Processors (OBCP) for the instruments IRCS, MOIRCS, HDS, and COMICS have virtual environments. Also, Subaru Telescope Telemetry, Data Analysis, and instrument offline storage are supported in this virtual environment.

Subaru Telescope Archive System (STARS) remains a stable archive environment, providing query/retrieval of data from the following types of observations; traditional, queue, and SSP. Recently STARS has worked with instrument support teams to add new instrument's data. STARS also supports a near real-time delivery for HSC Data through Japan and UH (University of Hawai'i) based observations.

CDM continues to work with UH and Mitaka network engineers to improve the network capacity from Hawai'i to further support large observation data sets. IfA (University of Hawai'i Institute for Astronomy) has been working on building new network paths, between Asia-Hawai'i-Mainland USA, with new DTN (Science DMZ/Data Transfer Nodes) to support high speed transfer to specified areas. This will allow potential Subaru Telescope observers to retrieve data without the network latency issues.

Subaru Telescope has officially offered remote observations from Mitaka using the Remote Observation Monitor System since 2015. Remote observation is now available for more instruments than before. An increasing number of observers use the Remote Observation Monitor System in Mitaka (See Open-use section). But as of March 25, with the COVID-19 pandemic, CDM and Observation Control Software division (OCS) started to build a server environment to support remote observation from locations other than Hilo and Mitaka.

Subaru Telescope continues to support the commissioning the PFS instruments, through the backend user server and network support. CDM has agreed to support the PFS On-site Cluster; new systems and storage are being installed and configured. Mitaka support personnel, primarily, will configure the new system, while CDM will support on-site maintenance. HSC data analysis (HSC On-site Data Analysis System) continues to evolve with new hardware, and support of existing hardware continues. HSC Admins continue prototyping high speed filesystems (LUSTRE) to improve computation to support observation. In Mitaka, an HSC off-site data analysis system and HSC data archive system are in operation. The HSC data archive provides the reduced data from HSC to researchers worldwide.

Subaru Telescope has been developing and operating web applications that support open-use observations. The Proposal Management System (ProMS) supporting calls for proposals changed. Subaru Telescope has developed and implemented PRORES, a web-based system supporting Time Allocation Committee (TAC) - open-use users - referees communication for proposal refereeing. Online visitor forms support visiting on-site or remote observers, engineers, and support contractors for Hilo and Mitaka campuses. Subaru Telescope continues support of other web base applications: 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 (the Graduate University for Advanced Studies) was ten. The number of SOKENDAI students who had primary supervisors affiliated with Subaru Telescope (including those concurrently belonging to Subaru Telescope) was ten, 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 2019, Subaru Telescope hosted three graduate students for long stays in Hilo, of which two 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 18 and 8, 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 six new SOKENDAI students held in September 2019. In the Hilo office, we had regular Subaru Telescope seminars in English one or two times per month, where open-use observers, visitors, and Subaru Telescope staff members presented their own new research. Also in the Subaru Telescope Mitaka office, we had many official and informal seminars, many of which were jointly organized with other divisions in NAOJ and/or neighboring universities.

8. Public Information and Outreach (PIO)

The goal of the Public Information and Outreach Office (PIO) is to document, share, and promote the activities and scientific achievements of Subaru Telescope throughout the general population. Raising positive awareness of Subaru Telescope —

within the local community, in particular — is critical for the success of the Subaru Telewcope as well as the next generation telescope project on Maunakea. PIO has three major tasks to achieve its goal.

Task 1: Provide information about activities and scientific results from Subaru Telescope by effectively using website and social media platforms. Subaru Telescope provides press releases to the Japanese, local, and international media and holds press conferences. During FY 2019, there were 37 web-postings (19 in Japanese and 18 in English) about discoveries from Subaru Telescope. Articles about instrument development; the work and activities at the Subaru Telescope; and other announcement totaled 44 (24 in Japanese, 20 in English). For major scientific discoveries, PIO actively distributes press release articles to local and Japanese media as well as an international network via the American Astronomical Society's mailing exploder. As a result, scientific results from Subaru Telescope often appear in Japanese and local newspapers and web news. In addition, Subaru Telescope's website for the public was renewed in March 2020.

Social media tools such as Twitter, Facebook, and YouTube are highly effective nowadays in rapidly disseminating information. Subaru Telescope's PIO has effectively used these new platforms by producing and sharing photographs and videos. Media inquiries and filming requests totaled 7 from Japanese media and 10 from English media. In addition to media interaction, PIO also responds to the numerous inquiries and questions from educational institutions and museums.

Task 2: Provide escorted tours of the summit and base facilities for the public and special groups. Subaru Telescope started the public tour program in 2004, providing opportunities for guests from Hawai'i, Japan, and around the world to see the telescope up-close. Those requesting tours receive prompt responses from a dedicated full-time tour staff. People can sign up for summit tours via an online form on the Subaru Telescope website. During FY 2019, 325 people visited the summit facility through the public tour program. This number does not include tours that were suspended due to reasons including closure of the summit access road and the wintertime tour-suspension period. An additional 42 groups visited the summit facility via special tour programs. In total, 539 people visited the summit facility in FY 2019. In addition to that, 6 special tours dedicated for the residents of Hawai'i were conducted and 96 local people participated. All tours are escorted by assigned staff and conducted in either Japanese or English.

Tours of the Hilo base facility are often accompanied by a special lecture by staff or a hands-on astronomy workshop. A total of 12 groups (249 people) visited the base facility this year.

Task 3: Provide on-site and remote lectures for the local community as well as Japanese schools and museums. During FY 2019, PIO provided/coordinated a total of 53 lectures at the Subaru Hilo Base Facility or at nearby locations, such as 'Imiloa Astronomy Center and local schools. In collaboration with the 'Imiloa Astronomy Center, the Japanese Chamber of Commerce & Industry of Hawaii, and the Hawaii Japanese Center, the Tanabata Star Festival, celebrating the Subaru Telescope's 20th anniversary, was held to deepen interaction with the local Nikkei-jin (Japanese Americans) and about 2,500 citizens who were interested in astronomy and Japanese culture participated. Other than that, PIO also conducted 6 outreach activities including exhibitions and interacted with about 13,000 people.

In addition to providing lectures, Subaru Telescope actively participates in various outreach events on Hawai'i Island. One of the major outreach events is AstroDay, a family-friendly event held at the local shopping mall. Each year, more than 3,000 people come to this event. AstroDay is coordinated by Maunakea observatories, and many astronomy and scientific institutions such as 'Imiloa Astronomy Center, Maunakea Visitor Information Station, and the University of Hawai'i at Hilo participate. AstroDay was also held in Kona, on the west side of the island.

Another major outreach event on Hawai'i Island is the annual Onizuka Science Day at the University of Hawai'i at Hilo. Students between grades 4 and 12 (upper elementary school to high school) with families and teachers from all over the island come to this event. Subaru Telescope PIO provided hands-on astronomy workshops and held an exhibit booth. Events like these where Subaru Telescope staff meet and directly interact with students and members of the local community are effective for improving the recognition of the Subaru Telescope. The Subaru Telescope PIO has been sharing information about outreach activities via the website and social media.

FY 2019 was the 20th anniversary of the Subaru Telescope's first light. The 20th anniversary ceremony of the Subaru Telescope was held at Hitotsubashi Hall in Tokyo in June 2019. The special website "Subaru Telescope: 20 Years of Observing the Heavens" was also released in July 2019 as a collaboration with the Public Relations Center. In cooperation with the Office of International Relations and the Maunakea Observatories, a public relations booth was exhibited at the annual meeting of the American Astronomical Society held in Honolulu, Hawai'i, in January 2020. In this booth, the results of the Subaru Telescope, including observations using HSC, and the efforts of the Maunakea Observatories were reported to visitors mainly coming from the astronomical community.

2. Nobeyama Radio Observatory

1. Nobeyama 45-m Radio Telescope

(1) Open Use Observations

The 38th open use observations term started on December 2, 2019. The statistics of the successful proposals are as follows, "General Programs": 10 programs were accepted out of 21 submitted proposals including 2 programs from abroad (out of 9 submitted), "GTO (Guaranteed Time Observation) Programs": one program was accepted out of one submitted. "Large Program": no proposals were submitted. VLBI open use observations including the 45-m telescope: three proposals were accepted out of six submitted.

Remote observations were conducted from Mitaka, Iriki, Kagoshima University, Kyoto University, Nagoya University, Keio University, Hokkaido University, and ASIAA (Taiwan).

(2) Improvements and Developments

Taking into account the reduction of the human and budgetary resources of Nobeyama Radio Observatory, we stopped the call for Nobeyama Development Proposals. A total of five proposals are in progress. (3-band simultaneous observing system HINOTORI, frequency-modulation local oscillation FMLO, Band 1 receiver by Taiwan, "Millimetric Adaptive Optics: Development of a Wave-front Sensor," and "100-GHz, 109-element camera")

Maintenance of the 45-m telescope, the receiver systems, the cryogenics, etc. was performed as follows.

- Regularly scheduled and preventative maintenance were performed.
- The replacement of a beam switching system was completed.
- Development of the data reduction procedure with the CASA pipeline has continued. This will lead to an automated observing system in the future.
- Stand-alone use of the 86 GHz band receiver (that modified the TZ) was commissioned using a frequency selective filter developed by the HINOTORI program.

(3) Scientific Results

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

1) 45-m Telescope Legacy Projects

(a) Star Formation Legacy Project

In the Star Formation Legacy Project, we conducted large-scale mapping observations toward three nearby star-forming regions, Orion A, Aquila Rift, and M17 in ^{12}CO (1–0), ^{13}CO (1–0), C^{18}O (1–0), and N_2H^+ (1–0). A total of 44 ^{12}CO outflows were identified in the Orion A giant molecular cloud, of which 17 were new detections. Based on observations of cloud cores in M 17 SWex as well as measurements of near-infrared polarization, it is suggested that the magnetic field may prevent the cores from collapsing, causing the low level of massive star formation in this cloud. (Nakamura et al., Tanabe et al., Shimoikura et al.)

(b) Galactic Plane Survey Project (FUGIN: FOREST Unbiased Galactic plane Imaging survey with the Nobeyama 45-m telescope)

A simultaneous survey of the ^{12}CO (1–0), ^{13}CO (1–0), and C^{18}O (1–0) emission lines in the Galactic Plane at the highest spatial resolution to date was conducted using FOREST on the 45-m telescope. In the Galactic arms, the dense-gas mass fraction was estimated to be ~4 %–5 %, while in the bar and inter-arm regions it was as small as ~0.1 %–0.4 %, probably resulting in differences in star formation efficiencies. Based on observations of a molecular bow shock (MBS) at G24.4+00+112, a scenario of galactic sequential star formation along the spiral arms was proposed. (Torii et al., Sofue)

(c) Nearby Galaxy Project (COMING: CO Multiline Imaging of Nearby Galaxies)

The COMING (CO Multiline Imaging of Nearby Galaxies) project mapped 147 nearby galaxies in ^{12}CO (1–0), ^{13}CO (1–0), and C^{18}O (1–0) emission lines using FOREST. It was found that the fraction of the total molecular gas mass to the total stellar mass in galaxies does not depend on their Hubble types nor the existence of a galactic bar, although when galaxies in individual morphological types are investigated separately, the fraction seems to decrease with the total stellar mass in early-type galaxies and vice versa in late-type galaxies (Sorai et al.). Fourier decomposition of velocity fields of 20 galaxies revealed that the ratios of noncircular to circular velocities of molecular gas in barred spiral galaxies exhibit 1.5–2 times higher value than those of non-barred spiral galaxies. (Salak et al.) Four papers including these two works were published in refereed journals.

2) Results from Open Use Programs with the 45-m Telescope

- The first clear detection of the Zeeman splitting of a CCS emission line at 45 GHz toward the nearby pre-stellar dense filament TMC-1 was reported (Nakamura et al.)
- Based on the position–velocity diagrams of CCS, the existence of velocity-coherent substructures in the TMC-1 filament was clearly shown (Dobashi et al.)
- An energetic high-velocity compact cloud, CO−0.31+0.11, was discovered in the central molecular zone of our Galaxy (Takekawa et al.)
- Based on observations of CCH and its two ^{13}C isotopologues, ^{13}CCH and C^{13}CH toward two starless cores, L1521B and L134N (L183), it was found that high ^{12}C/^{13}C ratios of CCH seem to be caused by reactions between hydrocarbons and C^+ (Taniguchi et al.).

2. Research Support

(1) SPART (Osaka Prefecture University)

In order to investigate the effects of stellar activity on the chemistry and dynamics of Earth-like planets, SPART (Solar Planetary Atmosphere Research Telescope) is promoting monitoring observations of carbon monoxide (CO) fluctuations in the Venusian middle atmosphere using a NMA 10 m single dish telescope. In FY 2019 the solar activity is in the transition phase from cycle 24 to cycle 25. As if in response to this, the upward trend of the CO mixing ratio has reached a plateau at an altitude of about 80 km on Venus. This result suggests an anti-correlation between solar activity and CO fluctuations. Such behavior of the Venusian atmosphere was not previously known. This anti-correlation is thought to be driven by the photochemistry of a oxidizer such as chloride induced by a combination of solar UV and the material circulations between the lower and the upper layers, rather than by solar high-energy events which are weak at this altitude. This interpretation is also supported by the negative rate of the chemical reaction, d [CO]/dt = Jco [CO2] -k [Cl] [CO] [CO2] at this altitude. For a comprehensive investigation about the link between material circulations and photochemistry in the Venusian atmosphere, we have started to develop the Venusian global climate model (GCM) by implementing the atmospheric radiative transfer process, physical and chemical environments peculiar to Venus, and solar activity, in cooperation with research groups at Nagoya University and Tohoku University. This model is constructed with the model for interdisciplinary research on climate (MIROC), the chemical AGCM for study of atmospheric environment and radiative forcing (CHASER), and the spectral radiation-transport model for aerosol species (SPRINTRAS). This approach with the Venusian GCM model is supported by a Grant-in-Aid for Scientific Research on Innovative Areas of JSPS. The results of this research were presented in the invited lecture of the Japan Geoscience Union Meeting 2019 in May. The introduction of this research and the demonstration of operation with SPART were also carried out in the special open day of NRO in August.

(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 have 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, 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. As of the end of FY 2019, remote observation tests are being conducted with operation in Atacama in mind. In FY 2019, a peer-reviewed paper (Fernandes et al. 2019) and a proceeding (Masui et al. 2019 ISSTT 2019) on the development of the instrument were published.

(3) Nobeyama Radioheliograph (Nagoya University)

In FY 2015, an international consortium (ICCON) assumed operation of the Nobeyama Radioheliograph (NoRH, see https://hinode.isee.nagoya-u.ac.jp/ICCON/). The remote operating system via the internet has functioned very well. About 30 researchers from nine countries (Belgium, China, Germany, Japan, the Republic of Korea, Russia, Switzerland, the UK, and the USA) participated in operation, including the system health check and data verification. Observational data are automatically transferred to NAOJ and Nagoya University and are stored/maintained there. Using data of NoRH, 5 refereed papers were published in Fiscal Year 2019. Finally, NoRH was shut down at the end of March, 2020.

3. Public Outreach

(1) PR activities at Nobeyama Campus

The Nobeyama Campus received a cumulative total of 41,617 visitors throughout the year, including participants in the Special Open House event. While, the campus was closed for public from March 6 to 31 as a precaution against the spread of COVID-19. Staff members conducted 27 guided tours, including ones for Super Science High School (SSH) students and the Campus Tour Week, while 33 requests for on-site filming and interviews were granted. The Campus Tour Week for educational institutions was scheduled during the summer. Three groups took advantage of this opportunity. For the workplace visits, 6 students from 4 schools, mainly local junior-high schools, visited the observatory. For the SSH initiative, 2 schools and groups visited NRO and participated in lectures. The filming and interview requests were mainly about cooperation with the local government, promotion of the "Nagano Prefecture is Astro-Prefecture," introducing NRO, and financial difficulties. Especially, TV Shinshu Broadcasting, one of the local broadcast stations, had interviewed NRO members starting from last fiscal year and broadcast the resultant program for not only Nagano Prefecture but also nationwide. We received many responses about the program from the public.

In the area for permanent public access, the exhibition room of the control building for the 45-m radio telescope was closed due to moving the NRO main office. In contrast, we opened the Nobeyama Exhibition Room of NINS every day and show the 4D2U theater more than the last year. A controllable radio-telescope antenna miniature was repaired to stabilize its operation.

Moreover, we received and answered about 230 phone calls this year from the public regarding the regular opening of the observatory, observatory events, and general astronomy (including 13 interviews).

(2) Cooperation with Local Communities

The annual Nobeyama Special Open House was held with

contributions by Nagano Prefecture as well as Minamimaki Village, the Minamimaki Chamber of Commerce, and its youth division. Moreover, with a contribution from NRO, "Jimoto Kansha Day (Thanks Day for the Locals)" was held as the Special Open House for locals (Minamimaki and Kawakami Village) at Vegetaball With, Minamimaki Village Rural Exchange Center by Nobeyama Station, Faculty of Agriculture, Shinshu as the main host. Special sponsorship was made to the sora-girl event "Tebura de Hoshizora Kansho-kai (Drop-by Star Gazing Event)," hosted by the Minamimaki Tourism Association.

Moreover, the "Nagano Prefecture is Astro-Prefecture" stamp-rally 2019 was carried out the same as last year by the "Nagano Prefecture is Astro-Prefecture" liaison council, which was founded in 2016 through cooperation with Kiso Observatory and other organizations. The fourth meeting was held at Omachi Community hall, Branch Office on February 22 with about 60 participants. Some activity reports and discussion on the future activities were presented. Meanwhile, associated open lectures were also held with about 90 participants.

(3) NINS Nobeyama Exhibition Room

The NINS Nobeyama Exhibition Room, the former building of the Nobeyama Millimeter Array, was officially opened thorough the year in cooperation with NINS and the other institutes. It was open to the public at the same time as the open time of Nobeyama Campus. The 4D2U theater was operated during the winter season from December to February as well as the summer season from April to September. The exhibition room played a role in improving awareness of NAOJ and the other institutes of NINS. However, the exhibition room was closed to the public from February 28 to March 31 as a precaution against the spread of COVID-19.

4. Education

SOKENDAI held the workshop on Radio Astronomical Observation using the Nobeyama 45-m Radio Telescope from June 3 to 7, with 12 undergraduate students in attendance. While guiding the students, from observations to presentation of the results, requires significant efforts, the event offers an invaluable opportunity for undergraduates to experience observations using a radio telescope and think of their future careers.

5. Misc. Activities

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

In the last fiscal year, NAOJ and Minamimaki Village made 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 started by Minamimaki Village and the promotion corporation. They had about 25 groups as paid tours in the first year.

(2) Hiring, Transfer (incoming)

Uchiyama, Yoshifumi: Senior Staff, from Shinshu University

(3) Retirement, Transfer (outgoing)

Minamidani, Tetsuhiro: Assistant Professor, moved to ALMA Project
Takahashi, Masaru: Senior Staff, moved to Shinshu University
Nishitani, Hiroyuki: Engineer, moved to ALMA Project
Torii, Kazufumi: Project Assistant Professor, retired
Kaneko, Hiroyuki: Project Research Staff, retired
Takekawa, Shunya: Project Research Staff, retired
Kikuchi, Kikue: Administrative Supporter, retired
Yokomori, Yasuyuki: Administrative Maintenance Staff, retired

(4) NRO Conference Workshops and Users Meeting

- December 18–19, 2019, NAOJ Mitaka, Large Seminar Room
  ALMA/45-m/ASTE Users Meeting 2019 (Organizing Committee: Hiroshi Nagai, Alvaro Gonzalez, Misato Fukagawa, Daisuke Iono, Ken Tatematsu, Shinichiro Asayama (NAOJ))

- September 4–6, 2019, Nobeyama Radio Observatory, Conference room
  Nobeyama Science Workshop Reiwa Era Year 1 (Organizing Committee: Shunya Takekawa, Hiroyuki Kaneko, Kazufumi Torii (NAOJ), Mitsuyoshi Yamagishi (ISAS/JAXA), Tatsuya Takekoshi (IoA/UT), Tomoharu Oka (Keio Univ.), Kazuo Sorai (Hokkaido Univ.)

3. Mizusawa VLBI Observatory

NAOJ Mizusawa VLBI Observatory operates facilities such as VERA (VLBI Exploration of Radio Astrometry) and KaVA (KVN and VERA Array), and provides their machine time to the international user community to support research activities at universities and research institutes. Astronomical research using these VLBI arrays is also conducted at our observatory, focusing on the Galactic structure, celestial masers, AGNs and so on. Using a rare dual-beam system which is capable of phase referencing by observing two sources simultaneously, VERA conducts high-accuracy astrometry of maser sources and determines the detailed structure of the Milky Way. In addition to the operation of VERA, maintenance and operation support were provided to the Yamaguchi 32-m Radio Telescope and two Ibaraki 32-m radio telescopes in collaboration with the local universities. International collaboration has been promoted particularly in the East Asia region through the joint operation of KaVA and the East Asian VLBI Network, the latter of which is a joint VLBI array between the People's Republic of China, Japan, and the Republic of Korea. We also promote mm-VLBI observations as a partner institute of the Event Horizon Telescope project. In 2019, the first-ever image of the shadow of M87's black hole was released and became a big news story, crowning the 120th anniversary of the establishment of the observatory, which was originally founded as one of the International Latitude Observatories.

In addition to VLBI related activities, "The Central Standard Time" is kept at the observatory as an obligation of NAOJ, Esashi Earth Tides Station is operated for geophysical research, and Ishigakijima Astronomical Observatory is jointly operated with the local city for public outreach and astronomical research.

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 2019, a total of 278 (2,492 hours) VLBI observations were conducted with VERA; such as common-use observations; VERA project observations; fringe detection observations for maser and reference sources; geodesy 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 with the 43, 22, and 6.7 GHz bands for semesters 2019B and 2020A were released in April and October, respectively. In FY 2019A, no proposals were submitted to VERA. 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 2019, Mizusawa VLBI Observatory published a total of 44 refereed journal papers for scientific achievements. Among them, five papers were published by the Observatory staff as a PI. It should be noted that 5 papers were published by graduate students in Kagoshima University and Yamaguchi University as a PI. Among the most important results, 4 papers were related to astrometry observations with VERA, 2 were results from the Korea-Japan international collaboration project KaVA (KVN and VERA Array), and 1 was from the Japanese VLBI Network (JVN) telescopes. For the observational results from VERA, statistical studies on the 3-dimensional structure of the Galactic Local Arm were published by comparing to the GAIA DR2 database. The vertical structure of the outer spiral arm was also investigated by using the VERA astrometry data. Both results provide a detailed picture of the local structure in the Milky Way Galaxy. In addition, accurate distance measurements were carried out for Mira variable stars to establish the period-luminosity relationship of Mira variables. Variability studies on maser sources in star-forming regions were intensively carried out. In particular, international collaboration studies for maser variability by the Maser Monitoring Organization (M2O) have been actively conducted in this FY 2019 using VLBI, interferometers, and single-dish telescopes around the world. As a result, a total of 8 refereed journal papers were published, reporting the discovery of episodic mass accretion events in high-mass star-forming regions. As for AGN studies, 17 refereed journal papers were published based on VERA, KaVA, and further follow-up studies with other instruments and theoretical works. The most notable achievement is the six refereed journal publications reporting the first direct imaging of the black hole shadow in M87 by the Event Horizon Telescope (EHT), which became pressreleases in April 2019. Moreover, a paper on M87 jet kinematics based on the KaVA Large Program was published. Other than VLBI, there were high resolution studies with the Atacama Large Millimeter/Submillimeter Array reported by combining new data with earlier results from VLBI.

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 about 300 hours in total in FY 2019. The

main research subjects are thermal emissions of extremely compact HII regions, active galactic nuclei, and CH_3OH masers. In addition, single-dish observations of up to 4000 hours were carried out as research related to JVN by Ibaraki University.

In 2019, JVN was re-defined as 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) An extremely compact HII region 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 follow-up observations of bursting methanol maser activity in G358-MM1 were examples of the JVN observations in 2019.

In this year, four papers (Uchiyama et al. 2020, Burns et al. 2020, Macleod et al. 2019, Nagoshi et al. 2019) that used the JVN telescopes were published. Researchers of JVN also published six papers as PIs. One international and three domestic workshops were held by JVN groups as follows: 12th East-Asian VLBI Workshop, High mass star-formation Workshop 2020, AGN circum-nuclear region and related research, and Ibaraki-Yamaguchi Joint seminar.

For development study, Prof. Imai (Kagoshima University), Prof. Niinuma (Yamaguchi University), and Prof. Ogawa (Osaka-pref. University) are up-grading the VLBI observation system at the Nobeyama 45-m Radio Telescope by obtaining a Grant-in-Aid for Scientific Research (A). Some students of Ibaraki and Yamaguchi Universities were supervised by Professor Ogawa in Osaka Prefecture University. There were more than 30 students who graduated from the JVN group, as well as 12 masters and 2 doctors.

3. Japan-Korea VLBI

(1) Observations and Common Use Observations

In FY 2019, a total of 36 (304 hours) VLBI observations, common use observations, large program observations, and test observations were conducted by KaVA (KVN and VERA Array) with the 43 and 22 GHz bands. The data of the seven VLBI stations were correlated at the Korea-Japan Correlation Center at KASI Daejeon Campus in Korea. KaVA common-use calls-for-proposals for semester 2019B and 2020A were made in April and October of 2019, respectively. In total, 14 proposals requesting a total time of 681.5 hours were submitted for the KaVA common-use. 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 10 proposals were accepted in 2019B and 2020A for 237 hours of KaVA observations.

(2) Results of Research

Since the start of open-use observations in FY 2014, science outcomes using KaVA data are constantly increasing. In FY 2019, a total of 4 papers based on KaVA common-use data were published in peer-reviewed journals, and 2 of them include substantial contributions from members of Mizusawa VLBI Observatory.

Both of the two papers are detailed studies of AGN: one for M87 where the acceleration profile of the inner jet was accurately determined based on the KaVA Large Program data (Park et al. 2019); and the other for a gamma-ray bright blazar 4C21.35 where KaVA discovered a strong jet ejection associated with a high-energy gamma-ray flaring event from the core (Lee et al. 2019).

The KaVA Large Programs that started in FY 2015 were completed in mid-FY2019, and each science working group is currently compiling their massive dataset. In the AGN working group, besides M87, papers on the Galactic Center SgrA* are being prepared, while a paper on a massive star forming region G25.82-0.17 was submitted from the Star Formation working group. These papers are all led by young PhD students at Mizusawa VLBI Observatory or universities in East Asia.

4. East Asian VLBI and Global VLBI

(1) Observations and Common Use Observations of EAVN

Observations and Common Use Observations of EAVN (East Asian VLBI Network) utilize KaVA, the Tianma 65-m, Nanshan 26-m, and Nobeyama 45-m radio telescopes. In FY 2018, a total of 107 (783 hours) VLBI observations, common use observations, and test observations, were conducted by EAVN with the 43 and 22 GHz bands. The recorded data were correlated at the Korea-Japan Correlation Center at KASI Daejeon Campus in Korea. EAVN common-use calls-for-proposals for semester 2019B and 2020A were made in April and October of 2018, respectively. In total, 29 proposals requesting a total time of 897 hours were submitted (excluding proposals only requesting KaVA observations). 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 22 proposals (431 hours) were accepted in 2019B and 2020A. From 2020A, the Takahagi 32-m antenna operated by Ibaraki University also joined the EAVN common-use.

Regarding global mm-VLBI, the millimeter-wave VLBI observation of EHT was not performed during the April 2019 season due to various circumstances.

(2) Results of Research

EAVN started open-use observations from late FY 2018, and the observed data have been delivered to users. In FY 2019 two refereed papers were published based on EAVN data from FY 2018 common-use and earlier commissioning data, in both of which members of Mizusawa VLBI Observatory made substantial contributions. For the first TeV gamma-ray burst event GRB190114C which occurred in January 2019, EAVN performed the world's fastest VLBI follow-up observations only 6 days after the event. The EAVN data set an upper limit of the radio flux and constrained the theoretical modeling of TeV GRB (An et al. 2019). In the M87 EHT black-hole shadow paper

(EHT Collaboration et al. 2019 Paper IV), contemporaneous EAVN 43 GHz data determined the flux of the emission from the jet base, which helped constraining the EHT emission model surrounding the shadow. The EAVN monitoring of the M87 jet is continuing in FY 2019 and especially joint sessions with Italy (EATING VLBI) became more frequent, expanding to a regular-basis global VLBI. Moreover, EAVN performed the first dual-polarization observations including all VERA 4 stations. In September 2019, the 12th EAVN Workshop was hosted at Ibaraki University, and a variety of discussions were held, including discussion of collaboration with Southeast Asian countries (Thai, Malaysia, Indonesia etc.) and East-Asia mm-VLBI (EAVN-high) and low-frequency EAVN with FAST (EAVN-low).

Regarding the activities of the international millimeter-wave VLBI, we completed the analysis of EHT's 2017 observation data in collaboration with researchers around the world, and successfully captured the shadow of a supermassive black hole at the center of M87. This provided the first-ever visible evidence of the existence of a super-massive black hole, and the black hole mass and brightness temperature of the surrounding gas were also measured. The results were published in a series of 6 papers in the Astrophysical Journal Letters as the initial results of EHT, and press releases were made in six places around the world on April 10, 2019. The achievement was widely featured by media on a global scale and became the biggest news in the scientific community in 2019. In this result, the image analysis software SMILI (Sparse Modeling Imaging Library for Interferometry), to which people at Mizusawa VLBI Observatory have greatly contributed, has been used as one of the three image analysis tools, for the cross-check of the results as well as the creation of the released image.

5. Future Plans for SKA

From FY 2019, the SKAI Study Group (SKASG) was organized under Mizusawa VLBI Observatory. The charges of SKASG until FY 2021 were given by the headquarters of NAOJ and SKASG conducted its activities based on them. SKASG has submitted a proposal as a big science project for Master Plan 2020, which is led by the Science Council of Japan. Our proposal was evaluated as a prioritized project to submit to Roadmap 2020, which is organized by MEXT. Finally, it was submitted by Nagoya University to MEXT. SKASG has started to make a concrete contribution plan mainly based on Assembling, Integration, and Verification (AIV); Science Verification (SV); and Science Regional Center (SRC) development through negotiations with SKA HQ. SKASG distributed a questionnaire survey to the Japanese astronomy community about the possibility of committing to SKA1 as science and engineering contributors, to establish a basic understanding about Japan's future contributions to SKA. SKA consortium in Japan and SKASG organized the Japan SKA symposium in September at Mitaka, and the Japan SKA Science Book 2020 was published. Many Japanese researches attended several SKA meetings including SKA General Science Meeting and Key Science Workshop 2019 in April at Manchester, SKA-VLBI Key Science Projects and Operations Workshop in October at SKA HQ, and 2019 SKA Shanghai meeting in November which was to discuss the whole system of SKA1 before the system CDR. These activities encouraged the SKA community of science and engineering, and stimulated international collaborations. For the planning of SRC commitment, SKASG has joined the international working group of SRC and is collaborating with Shanghai Astronomical Observatory. The East Asian SKA meeting was held in May at Shanghai and had attendees from Japan, China, Australia, and Korea. Japan showed their high level of science activity and started real collaboration for the SRC development. Japan and China had a meeting about SRC in September. SKASG has conducted a risk assessment for SKA-LOW EoR science, at the request of NAOJ HQ. For this purpose, SKASG has evaluated MWA data. SKASG has attended the LOW AIV planning activities such as test procedure investigations at CSIRO in October. SKASG members visited SARAO to discuss our collaboration related to SKA MID AIV. Related to the Japanese commitment to VLBI system development, SKASG visited and discussed about the system development collaboration with JIVE and the organization of the VLBI development working group. Japan proposed five science use-cases as a PI for Band 6/7, which is higher than 15 GHz, and has joined the activity of Band 6/7 design with Onsala Space Observatory of Sweden and other institutes as an international working group. As precursor research to LOW VLBI, SKASG has started a collaboration with Tohoku University to make 300-MHz VLBI experiments with international stations, and also conducted research of space-debris tracking using MWA using funds from the SCOPE program of MIC.

6. 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, wideband observations using OCTAD-OCTADISK2 have become regular programs.

In FY 2019, VERA internal geodetic observation was conducted 18 times, including joint observation with KVN, and we participated in IVS sessions 8 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 63 mm to the southeast direction and 14 mm to the upward direction were confirmed during FY 2019 as the post-seismic creeping of Mizusawa after "The 2011 off the Pacific coast of Tohoku Earthquake" (Mw 9.0). In addition, temporal fluctuations of the displacement velocity vector were confirmed

in Iriki, Ogasawara, and Ishigaki Island.

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 VERA accurate astrometry through GPS observations. The result of GPS positioning at Mizusawa shows a post-seismic motion to the East-Southeast direction even though 9 years have passed since the occurrence of the 2011 off the Pacific coast of Tohoku Earthquake. The gravity change observations at Ishigaki Island 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 tilt 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.

7. System Development

In FY 2019, as development for EAVN, we developed a down-converter for dual polarization receiving of the K,Q-band for EAVN. We installed it at Ogasawara Station and performed VLBI experiments with KaVA. As a result, we obtained good fringes and started scientific test observations with KaVA. We also developed and installed new RF direct A/Ds "OCTAD" and a RF-IF switch system at the upper cabin of Ogasawara Station. These instruments enabled us to conduct observations (broad-band, dual-polarization and 2 beam) using the RF direct A/D technique. We have upgraded the GP-GPU correlators at Mizusawa Correlation Center. As a result of this improvement, we achieved 8 times faster processing. This upgrade contributed to maintenance efficiency and cost reduction. We are continuing discussion on the future projects (including SKA) of Mizusawa VLBI Observatory. As a technology related to SKA and promotion, we developed the L-band patch antenna arrays and receivers with a superconductor filter and OCTADs systems. These systems were installed at Mizusawa and Ishigakijima Stations last year. We have verified their performance and operated them. As a result, we successfully obtained the first fringes on the baseline between Mizusawa and Ishigaki at 1.4, 1.6 and 2.2 GHz simultaneously. We developed and installed the same system at the NARIT 4.5-m telescope and firstly detected signals. We participated in an SKA1-study group and considered AIV and VLBI back-end system development as potential items to be contributed from Japan. We visited CSIRO, SARAO, Astron, and JIVE to discuss international collaboration. We have established a path for future VLBI international test observations and establishment of the SKA-VLBI consortium.

8. Timekeeping Office Operations

The Timekeeping Office operates four cesium atomic clocks together with a hydrogen maser atomic clock at Mizusawa VERA Station. The facilities contribute to the determination of UTC (Coordinated Universal Time) through international time comparison by BIPM (Bureau International des Poids et Mesures). The NTP (Network Time Protocol) server at the Timekeeping Office provides "Japan Central Standard Time" on a network. This service has been in great demand; 5 or 6 million daily visits have been recorded.

9. Ishigakijima Astronomical Observatory

FY 2019 was the 14th year of the Ishigakijima Astronomical Observatory (IAO). One refereed paper with observational contributions from IAO was published, and the total number has reached 27. The number of visitors was 13,139 and has exceeded 10,000 for the past 7 years in a row. The establishment purpose of observational study, public outreach, and regional promotion has been adequately fulfilled. The total number of visitors since 2006 reached 140,000 in July. The number of foreign tourists was 862, and has exceeded 800 for the past 2 years consecutively.

In terms of the research, we observed 60 objects for 61 nights including joint observations with Japanese universities and two international projects of JOVIAL for detection of Jupiter oscillations with Japan, France, and the United States; and GROWTH with Titech, Caltech, and others. (Operation, however, was suspended due to trouble with the telescope for about 5 months).

In regards to the education, more than 1,000 people visited IAO as group visits of elementary and junior high schools and inspections by government offices. The Chura-boshi Research Team Workshop for high school students (19 participants) and the observational experiment for undergraduate students of the University of the Ryukyus (18 participants) were held in July and August. We contributed to the regional education through the support of the two graduate studies, the lectures for "Certification of Astronomy Guides" (110 participants) held in the university, and a distance classroom of astronomy for elementary school students in a remote island.

As for the public outreach, two special events were held. A total of 961 people attended the Golden Week event. Also, 513 people visited IAO during the "Southern Island Star Festival" event. A total of 10,439 people took part in the 18th year of the "Southern Island Star Festival" which is co-hosted with Ishigaki City. And 250 people attended the star festival held in Yonaguni Island co-sponsored with the Yeayama Greater Metropolitan Area Affairs Association. Also 160 people joined in the weather class for families co-hosted with Ishigakijima Local Meteorological Observatory.

On the other hand, the "Stamp Rally" was held in July through collaboration between IAO and Nayoro Observatory KITASUBARU with which IAO concluded an exchange agreement. By the deadline at the end of March, 29 people who collected the stamps of both observatories applied. Anniversary gifts were presented to 6 people among them by lottery. In addition, Dr. HANAYAMA Hidekazu (Project Research Staff)

was awarded the Excellence Award in the "2019 'Local' Star View Photo Contest (GOTO INC)".

10. Public Relations (PR) and Awareness Promotion Activities

(1) Open House Events

At each telescope site operated by Mizusawa VLBI Observatory, we held the following open house events.

On April 21, 2018: the Tenth Open Observatory Event held at the Ibaraki University Center for Astronomy, and NAOJ Mizusawa VLBI Observatory, Ibaraki Station, with a cumulative total of 535 visitors in attendance.

From August 3 to August 12: "The Southern Island Star Festival 2019" held together with a special open house event at the VERA Ishigakijima Station and Ishigakijima Astronomical Observatory with approximately 10,439 visitors to the whole "Star Festival." Events included the astronomical observation party at Ishigakijima Astronomical Observatory, attended by 513 visitors; and the special public opening of the VERA Station attended by 269 visitors.

On August 10: Special open house of VERA Iriki Station held jointly with "The Yaeyama Highland Star Festival 2019," was canceled due to a typhoon.

On August 24: "Iwate Galaxy Festival 2019," open house of NAOJ Mizusawa Campus, held with 1,398 visitors in attendance.

On February 15, 2020: "Star Island 19," open house event of VERA Ogasawara Station held, with 260 visitors in attendance.

(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 every day, 9 a.m. to 5 p.m., except during the New Year's season. Ishigakijima Astronomical Observatory is open 10 a.m. to 5 p.m., Wednesday to Sunday, except during the New Year's season and other closures.

The numbers of visitors to each facility is as follows,

a) VERA Mizusawa Observatory 25,837
   The campus is regularly open to the general public with the cooperation of the Oshu Uchu Yugakukan (OSAM: Oshu Space & Astronomy Museum) located in the campus.
b) VERA Iriki Station 1,462
c) VERA Ogasawara Station 7,280
d) VERA Ishigakijima Station 3,449
e) Ishigakijima Astronomical Observatory 13,139
   [including Stargazing sessions (4,895): Evenings on Saturdays, Sundays, and Holidays. and "The Starry Sky Study Room" (featuring the 4D2U "Four-Dimensional Digital Universe," 4,023) in Ishigakijima Astronomical Observatory.]

(3) Other

The results of black hole shadow observations by the EHT project were released on April 10, 2019, and one of the international press conferences, being held at six locations around the world, was held at Kioi Conference center in Tokyo. There was much news coverage on TV and newspapers regarding this achievement. In addition, EHT members of Mizusawa VLBI Observatory gave many public lectures held throughout Japan.

11. Education

(1) University and Post-Graduate Education

Regarding postgraduate education, Mizusawa VLBI Observatory assisted 1 doctor and 2 master course graduate students from the University of Tokyo, and 2 doctor and 1 master course graduate students from SOKENDAI with their research. Three of them were from foreign countries. One undergraduate student each from Hiroshima University and Keio University were accepted as summer students of SOKENDAI in Mizusawa and Mitaka, respectivley. The University of the Ryukyus and NAOJ have offered a joint course on astronomy from FY 2009. Classroom lectures at the university took place August 19–22 at the Nishihara main campus and were opened to the public at the satellite campuses. Observational workshops were held in Ishigaki Island from August 26–29, with about 18 participants. In addition, staff members of Mizusawa VLBI Observatory give lectures at the University of Tokyo and Tohoku University as visiting professors.

(2) Research Experience for High School Students

From July 31 to August 2, the VERA Ishigakijima Station and Ishigakijima Astronomical Observatory held "The Churaboshi Research Team Workshop" for 19 high school students including 8 from the Okinawa Main Island and 3 from outside of Okinawa prefecture, including Tokyo, Okayama, and Kumamoto prefectures. It was organized under support from JSPS. The students discovered one new maser source with VERA, and a results press release was featured in the local newspapers. "The 13th Z Star Research Team Event" was held August 6–8 to use the VERA Mizusawa antenna for observation. A total of 10 high school students from the Tohoku region were accepted for research experience. The students could not discover a new source with VERA, but they had good experiences with observations, and the event pressrelease was covered in the local newspapers.

4. Solar Science Observatory (SSO)

This project started at the beginning of FY 2017 by combining two projects, the 'Hinode Science Center' and 'Solar Observatory,' to pursue cutting-edge solar science through observations with the Hinode satellite and ground-based observatories.

1. Hinode Space Observatory

The scientific satellite Hinode is an artificial satellite that was launched on September 23, 2006, by the ISAS division of 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 for analysis are ready.

The Hinode Science Working Group (SWG), composed of representatives from the international team, offers support in scientific operation and data analysis. It has a total of 17 members, including three from SSO: Y. Katsukawa for secretary, Y. Suematsu for SOT, and H. Hara for EIS. The Science Schedule Coordinators (SSC) have been organized to leverage the open-use observation system. Two Japanese members from NAOJ (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 satellite or ground-based observatories.

FY 2019 corresponds to the third 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 in the polar regions during the declining activity phase; and joint observations with ALMA and other ground-based observatories. The Hinode science payload has been steadily observing the Sun from space, except for the SOT filtergraphic instrument which was terminated in February 2016. New science results have been obtained via joint observations with SDO, IRIS, ALMA as well as long-term standalone observation by Hinode. The number of Hinode related refereed papers published in FY 2019 is 40, and further achievements are expected in the coming years. One of them is a review paper, which is the culmination of 11 years of achievements since the launch of Hinode. There are also two PhD recipients in 2019 (one in France and one in Japan), bringing the total number of degree recipients so far to 98 (including 18 in Japan).

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. SSO is jointly operating SDAS with ADC and the open-use data analysis system of Hinode data is maintained under MDAS.

2. Ground-based Observations in Mitaka Campus

Full-disk observations of the Sun have been carried out in the western area of the Mitaka Campus for recording solar activity. The primary instrument is a telescope measuring the solar magnetic fields. The others include an Hα imaging instrument for detection of solar flares and an optical imaging instrument observing sunspots and active regions as a proxy of long-term solar magnetic activity.

The magnetic field observation that has been conducted with the Solar Flare Telescope (SFT) since 1992 has provided vector magnetic fields in the photosphere with a field of view covering sunspot 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 measurement of magnetic fields in the chromosphere at 1.083 microns and those in the photosphere at 1.565 microns. Factors that determine the efficiency and precision of magnetic field measurements are the imaging pixel format of the imaging camera and the read noise. Toward introduction of a large-format detector and low-read-noise performance, an imaging camera with an H2RG sensor is being developed in the Program of the Solar-Terrestrial Environment Prediction (PSTEP), Grant-in-Aid for Scientific Research on Innovative Areas. A polarization modulator was installed in the infrared camera in FY 2018, and actual polarization photometry experiments were conducted at Hida Observatory, Kyoto University, in FY 2018–2019 to confirm that the performance meets specifications.

The sunspot observation that started in 1929 continues, although it was upgraded to imaging observation using a digital camera in 1998. Full-disk imaging observations in the visible continuum, the G-band (430 nm), Ca II K line (393 nm), and Hα

line (653 nm) are regularly conducted with the SFT to monitor the photosphere and chromosphere which change according to the solar magnetic activity. The Hα observation is currently carried out at multiple wavelength points within the absorption line with narrow-band filters to enable the measurement of the Doppler velocity of eruptive prominences associated with solar flares. These regular observation data including a set of real-time images are available on the SSO website.

NAOJ has long-term solar observation data, the initial 70 years of which were acquired by the Tokyo Astronomical Observatory, the predecessor of NAOJ. FY 2019 corresponds to the 102nd year since the record-keeping began. Full-disk images, observed in the continuum, Ca II K line, and Hα line, were recorded on film, photographic plates, and hand-drawn sketches. SSO proceeds with the digitization of these data for research on the long-term variation of the solar activity. While these digitized data are opened to the public when ready, high precision digitization has been applied to the Ca II K line data for improving the quality as a part of the PSTEP research activity and papers using those data are beginning to be published.

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 in 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 SSO leads the scientific verification and calibration of the data with the solar researchers in universities and the National Institute of Information and Communications Technology. Since FY 2019, SSO started to take responsibility for the operation and maintenance for the radio polarimeter in place of NRO. In FY 2019, scientific observations at 2 GHz, which had been impossible due to mobile phone signals, were resumed by modifying the receiver to change the receiving frequency to reduce interference. Besides, development was carried out for an origin sensor for pointing, which had been frequently malfunctioning in winter.

4. Cooperation with SOLAR-C Project

SSO jointly worked for the proposal of the EUV high-throughput Spectroscopic Telescope (Solar-C_EUVST) mission to JAXA in January 2018 by using the opportunity provided by the JAXA Competitively-chosen Middle-class Satellite Mission and in FY 2019 worked for the update of the proposal documents to proceed to the next mission definition phase; Pre-Phase-A2. SSO also supported technical studies for CLASP-2; successfully launched in April 2019, and the Sunrise-3 balloon-borne experiment scheduled in the summer of 2022.

5. Educational Activity

SSO staff accepted and is supervising three Ph.D. course students of SOKENDAI and two Master course students from the University of Tokyo, and three postdocs (two Specially Appointed Research Staff and one Gakushin PD). Dr. Y. Katsukawa contributed to the undergraduate course lectures in astronomy at the University of Tokyo.

6. Public Outreach (PO) Activity

SSO has been conducting various public outreach activities for education and returning 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. Since solar VR contents developed for the exhibition at the FY 2017 NAOJ open house were well-received by visitors, SSO started the distribution of the software for smartphones from July 2018. The observing campaign with Hinode entitled “Let’s observe the Sun with Hinode,” in which Japanese junior-high/high (JH/H) school students participated, was carried out once from August 19 to 24.

7. Science and Community Meetings

The Hinode Science Meeting has been regularly held to advance the solar physics research with the Hinode satellite. We jointly organized the 13th meeting with IPELS (Interrelationship between Plasma Experiments in the Laboratory and in Space) from September 2 to 6, 2019 in Hongo Campus of the University of Tokyo. The number of participants and papers was 208 and 201, respectively. SSO organized a solar physics community meeting: ‘JSPC (Japan Solar Physics Community) Symposium’ (February 17–18, 2020 at NAOJ).

8. Others

The 10-cm coronagraph of the former Norikura Solar Observatory now relocated to Yunnan, China is used for corona observation in China, and the observational situation is disclosed on a web page. In FY 2019, the staff of SSO visited China to advance the improvement of the coronagraph.

In Peru, astronomical instruments from SSO have been installed, and SSO is promoting the use of a coelostat and spectrograph at Ica University in collaboration with Kyoto University for astronomical education and research in Peru. In addition, it is also under discussion to transfer to Peru the so-called “new coronagraph” (diameter 10 cm) of the former Norikura Solar Observatory.

Y. Katsukawa of SSO has been a member of the Science Working Group of the Daniel K. Inouye Solar Telescope (DKIST,

a first-light observation in January 2020), a 4-m telescope at Haleakala, Hawai'i. Aiming to participate in DKIST, SSO staff cooperated for the development of the critical science plan of DKIST. Besides, a task force team for DKIST participation was established with members including university staff, and applied for a research fund to promote research personnel exchange with DKIST. Furthermore, intending to provide DKIST focal plane equipment, we are working for the development of new instruments, applying for external research grants.

In Europe, another 4-m solar telescope (EST) is now in the planning stage. SSO is participating in the board meetings as an observer to watch the progress, and joining 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. In FY 2019, the slicer unit of the IFU was designed and fabricated with a Grant-in-Aid for Scientific Research.

For three months starting from July 1, 2019, Dr. D. Orozco-Suarez from Spain stayed as a resident researcher and conducted joint research on solar magnetic field measurement and analysis for the balloon-borne experiment Sunrise-3. Regarding personnel affairs, Dr. M. Hagino (Research Expert) and Mr. S. Ishii (Research Supporter), retired due to the expiration of their terms of office. Mr. K. Itami (Research Supporter) arrived in March 2020, to replace Mr. Ishii. Due to modification of the solar projects, Dr. N. Narukage (Assistant Professor) and Ms. H. Uekiyo (Administrative Supporter) of the SOLAR-C project will be transferred to SSO, and Ms. J. Sugimoto (Administrative Supporter) will be transferred to the SOLAR-C project in April, 2020.

5. ALMA Project and NAOJ Chile

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 large parabolic antennas in the 5000-m altitude Atacama highlands in northern Chile. ALMA aims to achieve a spatial resolution of 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 project, which includes results of the open-use scientific observations and public outreach activities. The ASTE telescope is a single-dish 10-m submillimeter telescope located in the Atacama highlands and has been operated to make headway into submillimeter observations toward the ALMA Era. This report also describes the progress of the ASTE telescope.

The mission of the NAOJ ALMA Project includes: executing the functions of the East Asian ALMA Regional Center to provide support to East Asian users; coordinating the worldwide Project activities together with international partners; preparing future project plans; and making budget requests. On the other hand, the main mission of NAOJ Chile is to manage and oversee the NAOJ researchers working at the Joint ALMA Observatory (JAO) and to support the on-site operations of ALMA in Chile.

1. Progress of ALMA Project

ALMA scientific observations and commissioning observations are currently underway. Scientific observations have been proceeding steadily, and the latest results were presented at the ALMA international conference titled "ALMA2019: Science Results and Cross-Facility Synergies" held in Cagliari, Italy, from October 14 to 18, 2019. The joint international conferences have been held every three years, and the conference this year was attended by many Japanese astronomers as in previous years. In commissioning observations, we have carried out solar observation tests, polarization tests, and high-frequency long-baseline observation tests. Hiroshi Nagai and Koichiro Nakanishi at NAOJ contributed to the implementation of new functions for polarization observations. In the high-frequency long-baseline observation test, led by Yoshiharu Asaki and with contributions by Hiroshi Nagai, an unprecedented spatial resolution of nearly 6 milli-arcsec was achieved. Moreover, Shin'ichiro Asayama and Hiroshi Nagai have participated in an international working group established to define technical specification on receivers and digitizers for the implementation of "The ALMA Development Roadmap" to improve the scientific performance of ALMA in the coming decade. In fact, S. Asayama has been leading this working group. In addition, an international workshop was held in the U.S. to discuss the specifications of the next generation ALMA correlators and their priorities. The sub-components developed by Japan such as the ACA antennas, and the ACA correlator and receivers (Bands 4, 8, and 10) are working properly.

2. ALMA Open-Use and Scientific Observations

The eighth round of ALMA open-use observations commenced in October 2019 as Cycle 7. The main capabilities of Cycle 7 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 observations with at least three 12-m antennas); eight frequency bands (Bands 3, 4, 5, 6, 7, 8, 9 and 10); with maximum baselines of 16.2 km for Bands 3, 4, 5, 6, and 7, and of 3.6 km for Bands 8, 9, and 10. In addition to these, Cycle 7 continuously provides: open-use opportunities for Target of Opportunity (ToO) Observations; Large Programs that exceeds 50 hours on the 12-m array or 150 hours on ACA in stand-alone mode; millimeter-wavelength VLBI; ACA stand-alone mode, solar observations, and polarization observations. Especially notable new capabilities of Cycle 7 are: Band 7 observations with the maximum baseline of 16.2 km which will provide the highest spatial resolution ever of about 10 milli-arcsec; solar observations in Band 7 which provide similar angular resolutions in Band 3, 6, and 7; and improved observing efficiency for spectral scans. In response to the Cycle 7 Call for Proposals, there were submissions of 1,773 proposals from all over the world.

In September 2019, the Cycle 7 Supplemental Call was issued as scheduled. This was an ACA stand-alone Supplemental Call for Proposals aimed to maximize the scientific output of ACA. For the proposal review, the Distributed Peer Review process was newly adopted, and the verification of its validity was also conducted. In response to the Supplemental Call for Proposals, there were submissions of 249 proposals from all over the world, and observations started from December 2019.

However, Cycle 7 observations have been suspended since March 2020, affected by the spread of the novel coronavirus infection (COVID-19). In order to protect the staff of the observatory from the infection and prevent the spread of the disease in Chile, the ALMA Array Operation Site (AOS) and the Operations Support Facility (OSF) have both been closed from March 22, 2020 and remained closed at the time of this writing (end of May 2020). Nevertheless, even after the shutdown of the facilities, a small number of staff members, including Norikazu Mizuno, an International Staff Member from NAOJ at the Joint ALMA Observatory and Head of the ALMA Department of Engineering, has been working in shifts for minimum facility maintenance and for safety control. Taking the current state of the world into consideration, the ALMA Board decided in late April 2020 to extend the period of Cycle 7 observations until the end of September 2021.

The Call for Proposals for the ninth round of open-use observations was issued as Cycle 8 in March 2020. However,

due to the outbreak of COVID-19 just after the issuance of the call, the deadline for submitting proposals was extended as an emergency measure. Subsequently, as the situation worsened and the observatory shutdown started to affect Cycle 8 planning, it was decided to suspend the call. Cycle 8 will start from October 2021 in the current plan approved by the ALMA Board in April 2020.

The open-use of ALMA has already produced a number of scientific results. The following paragraphs provide some highlights of the scientific achievements made by East Asian researchers.

Takuya Hashimoto at Waseda University and his team used ALMA to observe B14-65666, a distant galaxy located 13.1 billion light-years away, and successfully detected radio emissions from oxygen, carbon, and dust in the object. Although it had been already known that B14-65666 consists of two clusters of stars, the teams discovered that the galaxy has two blobs, each of which contains oxygen, carbon, and dust. From the spatial distribution and velocity distribution of these emissions, Hashimoto concluded that the blobs are two similar-sized galaxies in the process of merging. This is an important scientific result for understanding the dynamic activities of the earliest merging galaxies at less than one billion years after the birth of the Universe.

A research team led by Takashi Tsukagoshi at NAOJ conducted high-resolution observations with ALMA of the protoplanetary disk around the young star TW Hydrae in the solar neighborhood and detected a small radio source which had never been noticed before in the disk. Tsukagoshi and his team suppose that it could be a 'circumplanetary' disk feeding a Neptune-sized infant planet, or it might be swirling gas raking up the dust particles in the protoplanetary disk which has the potential to grow into a planet. In either case, it is an ongoing process of planetary formation in the disk, which brings us further understanding of planetary formation processes.

Aya Higuchi at NAOJ and her team used ALMA to observe the debris disk around the young star 49 Ceti and detected the distribution of an astonishing amount of neutral carbon gas. The star is 40 million years old and conventional theories of planet formation predict that the gas should have disappeared by that age. However, the result defied the prediction. This is an important achievement that calls for a reconsideration of the gas dispersion process and the final phase of planetary formation.

A research team led by Tao Wang at the University of Tokyo and NAOJ observed 63 candidate distant objects, which were detected by the Spitzer Space Telescope but not captured by the Hubble Space Telescope, and successfully detected submillimeter-wave emission from 39 out of the 63 objects. The observation results indicate that all of them are massive active star-forming galaxies and are representative of the majority of massive galaxies in the Universe 11 billion years ago. Since no major theories for the evolution of the Universe have predicted such an abundance of star-forming galaxies, this result will be important evidence that challenges our current understanding of the evolution of galaxies.

Seiji Fujimoto at the University of Tokyo, NAOJ, and Waseda University examined the ALMA data archive and collected all the data that contain radio signals from carbon ions in distant galaxies, and discovered gigantic clouds of gaseous carbon spanning more than a radius of 30,000 light-years around young galaxies. Since the present theoretical models are unable to explain such large carbon clouds around young galaxies, some new physical process must be incorporated into cosmological simulations. This result posed a question about the conventional understanding of the evolution of the Universe.

The Event Horizon Telescope (EHT) collaboration announced that it had successfully captured the first picture of the black hole's shadow in the center of M87 as a result of the millimeter VLBI observation including ALMA in 2017. The accuracy of the overall observation was significantly improved with the participation of ALMA which achieves overwhelmingly high sensitivity in comparison to other telescopes in the EHT observation. For ALMA's contribution to this achievement, the Senate of Chile awarded medals to two researchers at universities in Chile and five scientists at the Joint ALMA Observatory (JAO), including Akihiko Hirota from NAOJ. Furthermore, the 2020 Breakthrough Prize in Fundamental Physics was awarded to 347 members who co-authored any of the papers published by the EHT. The winners of the award include Hirota and Nagai.

3. Educational Activities and Internship

During summer holidays of universities, NAOJ Chile and the ALMA Project accepted six undergraduate students, four of whom were engaged in research activities in Mitaka and another two in Chile. Moreover, NAOJ ALMA Project accepted two post-doctoral fellows; one from the Vietnam National Space Center (VNSC) for about six weeks and another from the National Astronomical Observatories of China, Chinese Academy of Science (NAOC) for about two weeks.

A website called "ALMA Kids" has been prepared in Japanese in cooperation with the Joint ALMA Observatory (JAO) to provide fun, educational content for kids about the ALMA telescope and its scientific outcomes. ALMA Kids also provides various scientific observation results.

4. Public Outreach Activities

Achievements of ALMA scientific observations were covered by over 140 newspaper/journal articles and 12 television/radio programs in FY 2019, featuring observation results with ALMA achieved in various fields of astronomy. In particular, the detection of gigantic clouds of gaseous carbon around distant galaxies was reported in news programs called "News 7" and "News Watch 9" on NHK G channel. Also, the ALMA telescope appeared in several variety shows, such as "Uchu Kagaku Tokusotai presented by Koji Higashino" on ABC TV in September 2019, "Naruhodo the World" on Fuji TV in January 2020, and "Sekai Marumie! TV Tokusobu" on Nippon TV in February 2020. These programs helped make the ALMA telescope widely known to ordinary people who do not have a

specific interest in science.

The NAOJ ALMA website posted 36 news articles and 15 press releases. A mailing-list-based newsletter has 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 48,400 followers as of the end of FY 2019.

In May 2019, NAOJ ALMA Project hosted a week-long ALMA booth at the Japanese Geoscience Union Meeting held in Makuhari Messe. Public lectures and Science Cafe events were organized on 8 occasions in FY 2019 to share the current status of ALMA through dialogue with visitors with an aim to familiarize people with the ALMA telescope and its recent achievements. Also, in February 2020, the NAOJ Public Talk/24th ALMA Public Talk titled "Formation and Evolution of Galaxies Explored by ALMA" was held at the Tokyo International Exchange Center (TIEC) in Koto, Tokyo. The event was attended by 258 people at the venue, and viewed in real time by about 1000 people via internet.

From mid-March 2015, ALMA started to accept public visitors to the ALMA Operations Support Facility (OSF) at an altitude of 2,900 meters. Every Saturday and Sunday, ALMA is open to the public up to 40 people/day (advance registration is required). Visitors to the OSF can have a guided OSF tour including the control room tour and watching videos on ALMA. The registration often reaches the full capacity soon after the start of registration every weekend. Public visits to ALMA are good opportunities to provide many people with live experience at the workplace of ALMA researchers. The number of public visitors in FY 2019 was 3,506 people.

On August 7, 2019, a traditional TANABATA event was held by NAOJ Chile in collaboration with JAO, in San Pedro de Atacama, a town at the foot of the ALMA site. Inviting local residents and tourists to write wishes on tanzaku (small pieces of colored paper), TANABATA star festival was celebrated with tanzaku decorations on bamboo stalks and a star party. The event was a great opportunity to make more people in the local community familiar with the ALMA project and NAOJ while promoting international friendship.

5. International Collaboration (committees, etc.)

In the international ALMA project, meetings are held frequently by various committees. In FY 2019, the ALMA Board met face-to-face twice, and the ALMA Scientific Advisory Committee (ASAC) twice. In addition to these, teleconferences have been held on a near-monthly basis among the members of the ALMA Board and ASAC. The ALMA East Asian Science Advisory Committee (EASAC) had meetings face-to-face or via teleconferences on a quarterly basis. Each working group holds meetings and teleconferences more frequently to maintain close communication in implementing their respective tasks in the international project.

6. Workshops and Town Meetings

- April 2, 2019 ALMA Cycle 7 Proposal Preparation Workshop at Mitaka
- September 17 to 20, 2019 ngVLA Workshop Mitaka
- December 10 to 11, 2019 East Asian ALMA Development Workshop 2019 at Mitaka
- December 17, 2019 ALMA Grant Fellow Symposium at Mitaka
- December 18 to 19, 2019 ALMA/45m/ASTE Users Meeting at Mitaka
- March 31, 2020 ngVLA "Kick-off" Meeting

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

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

8. Specially Appointed Research Staff Changes

(1) Hired
- Shigeki Inoue: Project Research Staff (secondment to Tsukuba University)
- Yang Yi: Project Research Staff (secondment to the University of Tokyo)
- Gianni Cataldi: Project Research Staff (secondment to the University of Tokyo)

(2) Departed or transferred
- Patricio Sanhueza: Project Research Staff
- Seiji Fujimoto: Project Research Staff
- Sanemichi Takahashi: Project Research Staff
- Yoshito Shimajiri: Project Research Staff

9. Main Visitors

- August 23, 2019
  Chile Ambassador to Japan Julio Fiol and Chilean Olympic and Paralympics team members visited NAOJ Mitaka Campus
- December 3, 2019
  President of the National Institute of Information and Communications Technology Tokuda, Hideyuki visited NAOJ Mitaka Campus
- February 17, 2020
  Japanese Ambassador to Chile Yoshinobu Hiraishi visited NAOJ Mitaka Campus

10. Progress of ASTE Telescope

The ASTE telescope has been utilized mainly for verification of observations to strengthen ALMA observation proposals and also for promotion of development focused on the enhancement of ALMA capabilities.

Although it took two months to repair the aging failure of the subreflector control computer that occurred in mid-March 2019, owing to the subsequent preparation works being promptly implemented, the open-use program for the 2019a term started from June 17, with a delay of about two weeks from the initial starting date of June 1. The observing instruments provided in the 2019a open-use program include the existing two heterodyne receivers, DASH345 (345 GHz) and ASTE Band 8 (490 GHz), and the Wideband and High Dispersion Spectrometer system with FFX correlator (WHSF). The high-dispersion mode (F-FX mode) of WHSF was provided for the first time starting from this fiscal year.

Starting with the 2019a open-use program, remote observations became possible, upon application in advance, from locations other than the ASTE operation rooms, such as a university to which the observer belongs. As a result, about a half of the total 26 observations, which include carryovers from FY 2017 and FY 2018 and the observation time allocated to Chile, were carried out remotely. Despite the delayed start of the open-use observation program due to the aging failure of a component, the total of 26 observations was completed by September 30 as scheduled by making schedule adjustments with the observers. From this fiscal year, the obtained data have been delivered to observers through the Nobeyama 45m/ASTE Science Data Archive, after primary processing.

The Call for Proposals for the 2020a open-use program, targeting East Asian researchers, started from February 7 and closed on March 7. In parallel, the Call for Proposals targeting researchers in Chile was also implemented during the same period.

A new observing instrument, the Band 10 (787–950 GHz) receiver was upgraded to a wideband, higher sensitivity receiver, supported by Grants-in-Aid for Scientific Research. After performing an evaluation in the laboratory, the receiver was transported to Chile, and integrated into the three-cartridge-type cryostat of ASTE from October, after the completion of the 2019a open-use observations. Following the commissioning and science verification, a demonstration science observation was carried out on the "Extra Success" level. This observation delivered good outcomes such as observation data of line emissions of CO J=7–6 and [CI] $^3P_2$-$^3P_1$ in the Orion A molecular cloud OMC-1, as well as observation data of [CI] $^3P_2$-$^3P_1$ in the massive star forming region RCW38 where demonstration science data of [CI] $^3P_1$-$^3P_0$ had already been obtained. The data of these observations were distributed to some members of the user community upon request, and calibration processing was conducted for data release.

In 2019, a total of 12 peer-reviewed papers were published, including five papers written by external researchers in Japan (outside NAOJ) and seven by overseas researchers. Five out of the 12 papers are related to the instrumental development. A decrease in the number of published papers was unavoidable due to the impact of no scientific operations being conducted in FY 2018. On the other hand, the results of the science verification of the world's first superconducting on-chip filterbank spectrometer DESHIMA, which was installed in ASTE, was published in Nature Astronomy. It was an outstanding achievement that may lead to novel cosmic radio observing technology in the future.

In response to the request from the management of NAOJ, an application was submitted to designate ASTE as a separate A project, not being part of ALMA, in accordance with the internal policy to make small-scale projects more visible, with regard to the scientific goals, required staffing, costs, etc. Along with this application, it was proposed that the key science of ASTE will be centered on the research using the ASTE Band 10 receiver and DESHIMA2 to be installed in ASTE in the near future. The application was approved by the management.

6. 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, and a general-purpose PC cluster for small-scale calculations; carrying out research and development of computational astrophysics; and performing astronomical research with simulations. The 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 general-purpose PC cluster. Furthermore, CfCA started operating a general-purpose GPU cluster. Efforts in visualizing astronomical data also continue.

2. Open Use of Computers

(1) General Status

This year marked the second 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 below. 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 137 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: 8486.9
  Annual core operation ratio by users' PBS jobs: 93.52 %
- Number of users
  Category S: 1 adopted in the first term, 1 in the second term; total 2
  Category A: 12 adopted at the beginning of the year, 0 in the second term; total 12
  Category B+: 20 adopted at the beginning of the year, 1 in the second term; total 21
  Category B: 131 adopted at the beginning of the year, 6 in the second term; total 137
  Category MD: 22 adopted at the beginning of the year, 3 in the second term; total 25
  Category Trial: 44 (year total)
  Total number excluding category overlap 230 (at the end of the fiscal year)

GRAPE/GPU system

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

General-Purpose PC cluster

- Operating hours
  Annual operating hours: 8688 (a ballpark figure)
  Total number of submitted PBS jobs: 586,709
  Annual core operation ratio by users' PBS jobs: 74 % (a ballpark figure)
- Number of users
  50 (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.

- Cray XC50 workshop for beginning users
  October 8, 2019, 5 attendees
- Cray XC50 workshop for intermediate users
  Scheduled on March 10, 2020, but cancelled due to concerns over the spread of COVID-19
- iSALE tutorial sessions
  July 30 - August 1, 2019, 12 attendees

● Hydrodynamics simulation school
December 23-24, 2019, 16 attendees
● Users meeting
January 20-21, 2020, 56 attendees (51 on site + 5 through Zoom)
● N-body simulation Spring School
January 22-24, 2020, 13 attendees for hands-on training, ~16 participants in classroom lectures

3. PR Activity

In FY 2019, the following press releases were issued from the center:

● "Simulations Find Mechanism of Brightest Flashes in Universe"
April 3, 2019, Hirotaka Ito (RIKEN)
● "Planet-scale Telescope and Supercomputers Uncover a Black Hole"
April 4, 2019, Tomohisa Kawashima (CfCA), et al.
● "Planets Around a Black Hole? — Calculations Show Possibility of Bizarre Worlds"
November 25, 2019, Keiichi Wada, Yusuke Tsukamoto (Kagoshima University), and Eiichiro Kokubo (CfCA)
● "Artificial Intelligence Tool Developed to Predict the Structure of the Universe"
February 5, 2020, Takahiro Nishimichi (Kyoto University), Masahiro Takada (Kavli IPMU)
● "Safety Zone Saves Giant Moons from Fatal Plunge"
March 9, 2020, Yuri Fujii (Nagoya University) and Masahiro Ogihara (Division of Science, NAOJ)

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

● "Gravitational Wave Object Follow-up Observation Team Researchers Receive the MEXT Commendation for Science and Technology"
April 18, Michitoshi Yoshida (Subaru Telescope), Masaomi Tanaka (Tohoku University), and Yosuke Utsumi (Stanford University)
● "Constraining the Formation of the Four Terrestrial Planets in the Solar System"
October 11, 2019, Patryk Sofia Lykawka (Kindai University) and Takashi Itoh (CfCA)
● "Black Hole Photograph Team Including CfCA Researcher Wins Breakthrough Prize"
November 5, 2019, Tomohisa Kawashima (CfCA) et al.
● "Researchers Discover Asteroidal Ice Fossils in Primitive Meteorite"
December 23, 2019, Megumi Matsumoto (Tohoku University), Akimasa Kataoka (CfCA) et al.
● "Here and Gone: Outbound Comets are Likely of Alien Origin"
January 17, 2020, Arika Higuchi (RISE) and Eiichiro Kokubo (CfCA)
● "Simulation of dwarf galaxy reveals different routes for strontium enrichment"
February 18, 2020, Yutaka Hirai (RIKEN)

The center took part in the special open house of Mizusawa Campus, Iwate Galaxy Festival 2019, held on August 24, 2019. About 90 visitors attended the ATERUI II guided tours and experienced a close-up observation of the facility. At the Mitaka open house held on October 26, 2019, CfCA made the computer room accessible to the public and introduced simulation astronomy with GRAPE and the PC cluster.

In addition, with the cooperation of Oshu City, a panel explaining ATERUI II was set up for visitors in front of the supercomputer room at Mizusawa Campus. On December 14, 2020, the panel unveiling ceremony was held in the presence of Ozawa Masanori, the mayor of Oshu City, and it was reported in the local newspapers and TV news.

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.

A simulation movie titled "Thermal Convection and Magnetic Fields in the Solar Interior" (simulation: Hideyuki Hotta/Chiba University, visualization: Takaaki Takeda) was released on the 4D2U website in March 2020 and Domemaster files for planetariums have been distributed. This movie was also published on the 4D2U YouTube channel with a format for VR on smartphones. In addition, we visualized particle simulation data for the shape evolution of asteroids and as an attempt to visualize a fluid simulation also visualized a simulation of black hole accretion disks.

The updated versions 1.6.0 and 1.6.0a of the four-dimensional digital universe viewer, "Mitaka," were released in January and March 2020. In these versions, command execution functions were implemented. By reading command sequences created by the user, it became possible to automatically operate Mitaka and output sequentially numbered image files for video production.

In FY 2019, at the Mitaka open campus day, about 140 people participated in the project to experience Mitaka VR. In addition to the experiences with Oculus Rift, experiences using HTC Vive were also conducted. Furthermore, on July 18, 2019, we exhibited the 4D2U theater at an Independence Day reception held at the residence of the U.S. Ambassador to Japan, and many other people from Japan and abroad including His Excellency William F. Hagerty, the U.S. Ambassador to Japan, enjoyed 4D2U with stereoscopic vision.

4D2U content was provided both domestically and internationally for TV programs, planetarium programs, lecture presentations, books, and so on.

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 (it has now expanded to include eight institutes). 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, and astrophysics. The scientific goal of the institute is to promote fundamental research based on computational science by encouraging interdisciplinary research between elementary particle physics and astrophysics. 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 "Research and Development, Application Development of scientific/social issues that require particular attention by the use of the Post K-computer" in FY 2014.

In order to implement research plans, Tomohisa Kawashima was engaged as a project assistant professor. A Boltzmann based general relativistic radiation-MHD code was developed, and some test problems were successfully solved using the code. It was found that our new code can give more accurate radiation fields in the regions above the accretion disks than the conventional code base on the moment method. In addition, the spectra of the super-Eddington flows around black holes as well as neutron stars were calculated by a general relativistic radiation transfer code (RAIKOU). We found that the hard X-rays are diluted via the electron scattering which occurs above the disks. The reduction of the hard X-rays is more effective for the neutron star case than for the black hole case. RAIKOU succeeded in calculating the black hole shadow of M87.

Representing CfCA, Professor Kohji Tomisaka and Project Visiting Professor Ken Ohsuga 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 post-K (aka "Fugaku") project has already started, and its R&D is ongoing. The primary institutes and groups responsible for its development have been established. Now the detailed discussions as to how we can fully exploit the resources of Fugaku have begun in relevant communities and organizations. The detailed hardware specifications of Fugaku have been opened to the public, and broad discussions involving academic society are now underway about the kinds of software applications that should/could be run on it.

6. Staff Transfers

Staff members hired in this FY
(Research Supporter) Kano, Kaori
(Administrative Supporter) Mashiko, Kyoko

Staff members who departed in this FY
(Project Assistant Professor) Kawashima, Tomohisa
(Research Supporter) Oshigami, Shoko

7. Gravitational Wave Science Project

Since the first direct detection of gravitational waves from a binary black hole merger in 2015, the field of gravitational wave astronomy has been expanding at an ever-increasing speed. The gravitational waves from the merger of binary neutron stars were detected in August 2017, and the intense follow-up observations including the Subaru Telescope also observed a Kilonova, the corresponding electromagnetic astronomical object. Thus, astronomy entered a new era of multi-messenger astronomy lead by gravitational wave observations.

In FY 2019, the third observation run (O3) was carried out by advanced LIGO in the United States and advanced Virgo in Europe. Japan's large-scale cryogenic gravitational wave telescope, KAGRA, had also completed its construction and had started its efforts to improve sensitivity continuously to participate in O3. But due to the world pandemic of COVID-19, the O3 observation was interrupted and joint observation has been postponed.

At TAMA300 in Mitaka Campus, we, the Gravitational Wave Science Project (GWSP) have been conducting research and development on frequency-dependent squeezing technology and obtained the world's first successful demonstration in a practical 100 Hz band, which was published in Physical Review Letters (Published in April 2020).

In addition to these, research has also progressed on the evaluation of the optical absorption and birefringence of sapphire mirror substrates adapted in KAGRA.

1. Development of KAGRA

KAGRA is a laser-interferometric gravitational-wave detector in an underground site at Ikenoyama, Kamioka, Hida-city, Gifu-prefecture in Japan. Cryogenic sapphire mirrors for the reduction of thermal noise as well as the use of a quiet and stable underground environment are two unique features of KAGRA compared with other gravitational wave detectors in the world. KAGRA's construction had been divided into several phases which gradually upgrade the interferometer to its final configuration. In April 2018, KAGRA demonstrated the first operation of a 3 km-long cryogenic interferometer with a simple Michelson configuration. This test operation provided us with critical experience regarding the cryogenic operation of a large underground interferometer. Throughout this time, NAOJ GWSP worked hard to install all the remaining components necessary to operate the full-configuration KAGRA interferometer and the final configuration was completed in May 2019. The construction period was about 10 years. From June, the sensitivity improvement was carried out by the interferometer commissioning, and a sensitivity of 1 Mpc was achieved in the binary neutron star merging range, which was the immediate target. This led to the implementation of observation in February 2020. However, the COVID-19 desease spread worldwide while the coodination for O3 observations with LIGO and Virgo was being made, and the O3 observation was stopped. The joint observation has been suspended since then.

NAOJ GWSP has been contributing significantly to the completion of KAGRA as one of the sub-promotion institutes of the KAGRA project. Our largest responsibility is for the development and operation of ultra-high-performance vibration isolation systems for the interferometer, the auxiliary optics systems, mirror characterization, and the main interferometer. NAOJ GWSP has also been contributing to KAGRA's project management through activities of the Executive Office, the Systems Engineering Office, the Committee for Publication Control, the Publication Relation Committee, and the Safety Committee. And the previous memorandum of understanding (MoU) with the Institutes for Cosmic Ray Research (ICRR) at the University of Tokyo and the High Energy Accelerator Research Organization (KEK) was updated to a new MoU, which reflected the coming observation period since the construction period of KAGRA was completed.

(1) Vibration Isolation Systems

In KAGRA, vibration isolation systems are necessary to isolate all the interferometer mirrors and some optical components from the ground vibrations. We have developed four different types of vibration isolation systems (Type-A, Type-B, Type-Bp, Type-C) to meet various isolation requirements of different components. Within the last fiscal year, we completed installation of all the isolation systems necessary for the operation of KAGRA. This year we replaced the OSTM in suspension system (Type-C) due to a change of the mirror thickness. Also, the commissioning of the installed vibration isolation systems for the start of observation was completed. Specifically, we have optimized damping control and drift control ; improved vibration isolation performance at low frequencies using inertial sensors ; and automated operation.

(2) Auxiliary Optics

The auxiliary optics subsystem (AOS) is responsible for providing optical components for stray light control, optical angular sensors, beam reducing telescopes (BRTs), beam-monitoring cameras, and optical windows.

In FY 2019, in early June, one of the BRTs' vibration isolation system, which was the last device of the plan, was installed on schedule at the end of the Y-arm of KAGRA. This was work to remove the BRT that was already installed once, and to replace the fixed stage and the vibration isolation stage in a short period of time. It was done in a tight and complex schedule with commissioning work of the interferometer already using the BRT. In addition, we were able to catch up with the observation by taking measures against stray light on the side of the signal detection port, which was an urgent task, at a rapid pace. Support from the Advanced Technology Center (ATC) was essential for these activities. In particular, ATC made a great contribution for us over a wide range of fields such as mechanical design, thermal design, optical design, assembly and

repair work, and advice for maintenance.

(3) Mirror Characterization

At the beginning of FY 2019, KAGRA discovered a strange effect related to the birefringence in the sapphire input test masses. In order to evaluate the impact of this effect on the detector sensitivity, we modified the PCI (photothermal common-path interferometer) system, originally designed to measure absorption in coatings and substrates, to be able to also measure birefringence properties of bulk materials. We then conducted a measurement campaign to characterize KAGRA sapphire in order to understand the origin of the effect and how to reduce its impact on the interferometer. We established further collaboration with crystal maker companies, as well as with the Virgo group in iLM (Institut Lumière Matière / Institute of Light and Matter, France). Two papers on the results obtained from this measurement campaign are being produced.

2. R&D

KAGRA Up-grade

(1) Filter Cavity

Since 2015, GWSP is carrying on an R&D activity to realize a frequency dependent squeezing source able to reduce quantum noise in gravitational wave detectors at all frequencies. The source includes a 300 m optical cavity hosted in one arm of the former TAMA interferometer and a frequency independent squeezing source that has been realized for this purposed by the group. In this FY, we worked to optimize the operation of both systems and to couple them together. Finally, in January we were able to obtain the first measurement of frequency dependent squeezing, with a rotation angle below 100 Hz. This is a crucial result for the gravitational wave community as it validates a technology that will bring a major improvement in the detector sensitivity in the next years. The paper reporting this result was accepted by Physical Review Letters on March 23, 2020.

(2) Other R&D

The absorption measurement bench developed to characterize the KAGRA mirror is also used to study the performance of crystalline coatings, a possible solution to reduce coating thermal noise. The calibration of the crystalline coating absorption measurement is not trivial since the thermal properties of the system are not only defined by the bulk (which is the usual case with IBS coating) but also by the coating transfer method. We theoretically analyzed a new calibration technique which is very promising, and we started its implementation.

We are also developing a facility to directly measure the coating thermal noise at cryogenic temperatures using a folded cavity with multiple higher-order modes. This year, we constructed the input optical system for this experiment.

3. Education

During FY 2019, GWSP included among its members one graduate student from the University of Tokyo and three graduate students from Sokendai. GWSP also hosted in total five graduate students from the University of Tokyo, the Rome University (Italy), Wuhan University (China), the Chinese University of Hong Kong (Hong Kong), and Nikhef (National Institute for Subatomic Physics in the Netherlands) over a period of several months to one year. One undergraduate student with the Sokendai Summer Student Program was also hosted in the Kamioka Branch Office. The members of GWSP gave lectures at the University of Tokyo and Sokendai on gravitational waves and at Hosei University on fluid mechanics.

4. Outreach

In FY 2019, GWSP joined two KAGRA press releases in collaboration with the Institute for Cosmic Ray Research (ICRR) at the University of Tokyo and the High Energy Accelerator Research Organization (KEK). One was about the KAGRA completion ceremony held on October 4, and the other was about the start of KAGRA observation on February 25, 2020. Also, a member of GWSP showed up on a TV program, Galileo X (BS Fuji), which was broadcast on September 22, 2019, and explained KAGRA.

Also, there were interviews with the Kumamoto Nichinichi Shimbun and Symmetry Magazine. Regarding outreach, staff members gave lectures at Asahi Culture Center in Shinjuku, Science Cafe in Kamioka, and Sundai Gakuen Junior-High / High School. We also accepted many visitors to TAMA300 and KAGRA.

5. International collaboration and visitors

GWSP is a member of the KAGRA collaboration, a scientific collaboration which also includes members from abroad. During FY 2019, the Ph.D. student from The Chinese University of Hong Kong who had visited the Kamioka branch of GWSP in the preceding fiscal year continued to work on the topic of optimizing the control systems/schemes for the KAGRA VIS for an additional 6.5 months. Apart from KAGRA, GWSP continued its collaborations with CNRS/APC (France), Beijing Normal University (China), and National Tsing Hua University (NTHU, Taiwan) on the development of a frequency dependent squeezed vacuum source at TAMA. In this context we received visits from Ph.D. students, engineers, and researchers affiliated with CNRS/APC, NTHU, and other institutions. The GWSP also received several visits by researchers from INFN PISA and EGO (Virgo, Italy) under the framework of the EU funded NEWS project.

6. Publications, presentations, and workshops organization

The GWSP members were authors of 30 refereed

publications in international journals, 3 English conference proceedings, 3 Japanese conference proceedings, and one English publication. GWSP had 21 international conference presentations and 35 domestic conference presentations.

7. Acquisition of external funds

In FY 2019, no external funds other than scientific research funds have been obtained.

8. Staff

(1) Hired
- Raffaele Flaminio: Professor (Cross Appointment)
- Simon Zeidler: Senior Specialist (transfer from Project Research Staff)
- Chihiro Kozakai: JSPS Postdoctoral Fellow
- Tatsuki Washimi: JSPS Postdoctoral Fellow

(2) Transfer / Retirement
- Mark Barton: Project Research staff (transferred to Glasgow University, UK)
- Simon Zeidler: Senior Specialist (transferred to Rikkyo University)
- Megumi Oyama: Administrative Expert (transferred to Tokyo University of Agriculture and Technology)
- Mikiko Harada: Research Supporter (transferred to NAOJ Office of International Relations)
- Eri Sakamoto: Administrative Supporter (transferred to the University of Tokyo)

8. 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 five partner countries: Japan, the United States, Canada, China and India. 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 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 NAOJ is the TMT Project, with its name change from TMT-J Project Office.

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 September 2017, on-site construction was planned in FY 2019. However, demonstrations and road blockades by those opposed to TMT on Maunakea prevented the start of construction. Currently, together with the State, the project holds discussions and dialogues with the community of Hawai'i. Adjusting their schedules with consideration given to this situation, the partners are committed to the design and fabrication of their workshares. In FY 2019, Japan made continued efforts for creation of fabrication drawings and preparation for a production readiness review for the telescope structure; production of the primary mirror segments; and design and development of the science instruments. While making steady progress in its development, the NAOJ TMT Project evaluated in detail the feasibility of the alternative site and its conditions for astronomical observations for its own independent analysis, in case construction in Hawai'i becomes infeasible. In addition, it further investigated potential scientific programs, which are expected to be achievable through cooperation between TMT and the Subaru Telescope, with scientists nationwide, and published a science book.

1. TMT Project Progress and Status of the Hawai'i Construction-site

The construction of TMT is led by the participating countries and organizations under the TMT International Observatory 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 by the US National Science Foundation (NSF).

The TMT International Observatory, 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 seven times in FY 2019 to cope with the on-site construction issue described below and other matters as the situation surrounding the project unfolded rapidly. The Members' meetings were also held four times to discuss pivotal issues of the project.

In the United States, the science community made submissions to the Decadal Survey which decennially evaluates and identifies the most compelling challenges in the field of astronomy. The TMT Project proposed to the Decadal Survey a joint program called the US Extremely Large Telescope (US-ELT) Program, which will allow all-sky observation by working in concert with TMT and the Giant Magellan Telescope (GMT, a telescope with an aperture of 24 m currently under construction in Chile). TMT International Observatory gave a presentation about the program for an Astro2020 report to be published in 2021. Additionally, in line with this program, a design-stage proposal for TMT was prepared with a view to NSF's participation.

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. All necessary procedures were completed for on-site construction on Maunakea, including a sublease to use the TMT site issued by the University of Hawai'i, which is responsible for management of the summit area of the mountain.

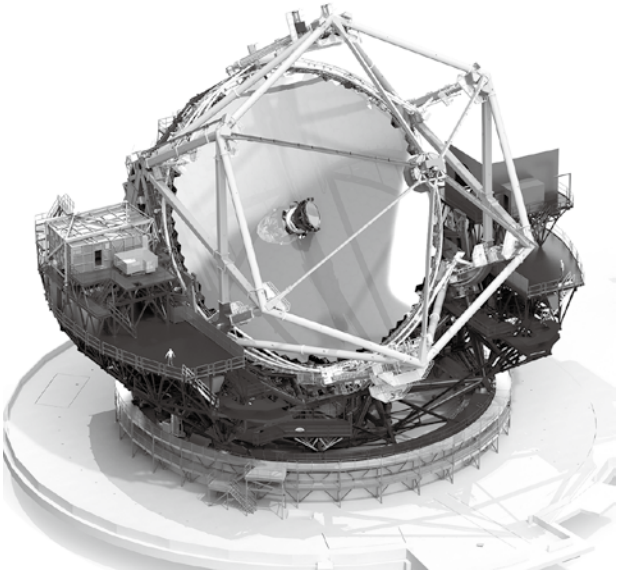


Figure 1: Conceptual image of TMT.

The TMT International Observatory and the Governor of Hawai'i announced that construction of TMT would begin in July 2019.

In response to this announcement, those opposed to TMT on Maunakea staged demonstrations, including some sit-ins on the access road to the summit region, preventing construction vehicles from ascending to the site. Both the State and the County have been committed to a resolution of this situation, but on-site construction has not been initiated as of the end of FY 2019.

A forum for discussion was created later in FY 2019, where the NAOJ Director General and others from the TMT International Observatory participated in a dialogue with leaders of the movement and other relevant parties. The State Legislature called for establishment of a reconciliation commission to address Native Hawaiian issues in a broader historical context, followed by a working group's discussion.

When the necessity arose for the State to redo the permit application process for the TMT construction on Maunakea in 2015, TMT International Observatory selected a site on the island of La Palma of the Canary Islands in Spain as the alternate site for TMT in 2016. The process for construction permits subsequently took place there, including the formulation of an Environment Impact Study. In November 2019, all the necessary permits for construction at the alternative site were obtained.

2. Japan's Progress on Its Work Share – Fabrication of the Telescope Structure and the Primary Mirror and Promotion of Development of 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. In FY 2019, the progress below was made.

(1) Fabrication of the primary mirror segments

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

Of these processes, the plan calls for Japan to fabricate all the mirror blanks and to perform spherical grinding on all 574 segment mirrors. With the share of work for the processes beginning from aspherical grinding and polishing and ending with mounting of the mirror segment on a support assembly distributed among four countries, Japan is leading this work for 175 of the mirror segments. In FY 2019, 28 blanks were fabricated, and 64 segments were spherically ground, of which 27 were delivered overseas. The first batch of blanks destined for India were delivered in January 2020. The running total rose to 341 for the mirror blanks that have been spherically ground by the end of FY 2019. Also, 29 segments were aspherically ground, with completion of aspherical surface polishing work on 11 of them.

(2) Design and fabrication of the main telescope structure and its control system

Japan is responsible for the design and production of the telescope structure, as well as its control system, which functions as a mount for the optics systems such as the primary mirror and the science instruments, and points them in the direction of a target astronomical object. Following the baseline and detailed designs developed by FY 2016 and preparation for fabrication in FY 2017, FY 2018 saw the launch of the fabrication process for the telescope structure. In FY 2019, work on the structure mainly consisted of production of fabrication drawings of key components in the elevation and azimuth structures and the Nasmyth structure. Those efforts culminated in successfully passing a production readiness review for essential components of the elevation and azimuth axes in March 2020.

(3) Science instruments

International collaboration plays a central role in the design and fabrication of three first-light science instruments to 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. Entering the detailed design phase during FY 2017, IRIS further progressed in its development and design in FY 2019, mainly consisting of: analysis of tolerances and stray light for the optics in the imager; measurement and analysis of deformation of a large-size mirror caused by cryogenic cooling; lifetime testing of motor and cable prototypes; and preparation for a simulator to establish an interface with an adaptive optics system. A Wide-Field Optical Spectrograph or WFOS, currently at the conceptual design stage, is under development for a conceptual design review which is scheduled at the end of FY 2020. Japan's WFOS group plays the main role in the design of a mask exchange system and the spectrograph camera optics. It also proposed an image slicer for WFOS based on experience with FOCAS's image slicer for the Subaru Telescope, and is working on its design now. Furthermore, a Multi-Object Diffraction-limited High-Resolution Infrared Spectrograph (MODHIS) was adopted for development as a first-light instrument with its primary research focus on exoplanets. Japan is planning to contribute to its development in cooperation with the Astrobiology Center of NINS.

3. Planning of TMT Science, Instrumentation, and Operation

The TMT International Observatory's Science Advisory Committee, consisting of researchers from the Members' countries and institutions, discusses science programs and science instrumentation envisioned with TMT. The committee's focus in FY 2019 was on investigation of observing conditions at the alternative site in light of the situation of the on-site construction, as well as examination of science instruments. The TMT Science Forum, which is annually convened for international stakeholders together with the TMT members for discussion of science programs and science instrumentation for TMT, was held at Xiamen University, China, in November 2019, where ten members from Japan attended.

The TMT-J Science Advisory Committee, which is a domestic committee established for Japanese stakeholders, reviewed domestic and international efforts with the aim of enabling Japanese researchers to make scientific achievements by using TMT. With an eye to maximizing TMT's capability for high resolution and high sensitivity for conducting research during the operation phase, TMT is expecting to collaborate with the Subaru Telescope which has an extraordinary wide-field capability. It is essential to develop a scheme of science instrumentation and operations for both of the telescopes during the construction phase so that Japanese researchers can take full advantage of observational opportunities. In response to a review by the TMT-J Science Advisory Committee and the Subaru Telescope's Science Advisory Committee, the NAOJ TMT Project organized a series of meetings with scientists throughout Japan to discuss science programs achievable through collaboration between TMT and the Subaru Telescope. As part of its effort to leverage the potential of this collaboration, it also convened a special session at the Astronomical Society of Japan's Autumn Annual Meeting, held at Kumamoto University in September 2019, and compiled articles by 80 authors to publish a science book.

With the continuation of the fundamental research fund for the purpose of element technology research for the development and design of second-generation science instruments, support

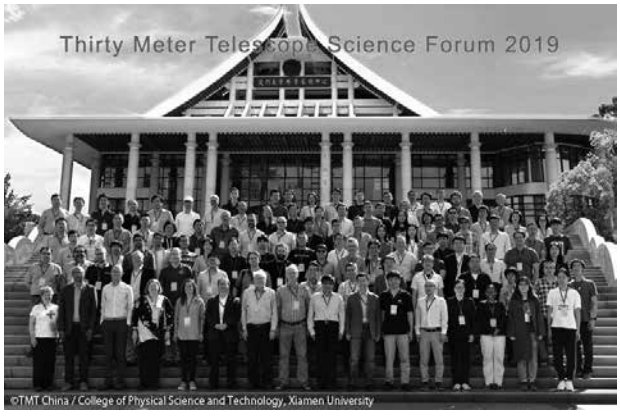


Figure 2: TMT Science Forum, held at Xiamen University, China (November 2019).

Figure 3: Science Book, produced in collaboration with scientists nationwide.

Figure 4: Session of the Astronomical Society of Japan's Autumn Annual Meeting to explain about TMT's situation, held at Kumamoto University in September 2019.

funding for development was made available and provided to five universities and institutions that applied to the public call for the funding support. In March 2020, the NAOJ TMT Project held a session to debrief the funding recipient groups, and discussed a new structure for development and the way the funding should be conducted.

It also strengthened efforts to have more opportunities, such as the Astronomical Society of Japan's Autumn Annual Meeting in September 2019, to explain about the situation of the project to astronomy and other science communities after the halt of on-site construction of TMT in July 2019. Additionally,

the NAOJ TMT Project extensively investigated observation conditions at the alternative site on the island of La Palma for its own independent analysis, so that they can be examined by the TMT-J Science Advisory Committee and other stakeholders, and be fully shared with the community.

4. Public Relations, Outreach, and Education

Information on the TMT Project is provided on the NAOJ TMT Project website, including updates particularly regarding the situation at the Maunakea construction site and the work share progress made by Japan. Additionally, TMT Newsletters No. 62 through 65 were delivered. Efforts for public outreach were made through lectures and exhibitions in various regions of Japan. A total of 50 lectures and classes on demand were held for the public.

The NAOJ TMT Project sent its members to participate as on-demand lecturers in the science/technology education and PR event "Journey Through the Universe" (March 2020) held in Hawai'i where TMT is to be constructed. The fourth international workshop designed for early-career researchers and engineers was scheduled to take place in Hawai'i in January 2020, but is now being rescheduled in light of the current situation surrounding the project and due to the global spread of COVID-19.

With donations toward the TMT Project raised continually, these were utilized for a program named FUREAI (Friendly) Astronomy, which offers children opportunities to learn about astronomy directly from astronomers who visit schools throughout Japan on demand.

5. Organization

By the end of the fiscal year, three Professors, six Associate Professors, three Assistant Professors, two Research Engineers, a Project Associate Professor, a Project Assistant Professor, five Senior Specialists, a Special Senior Specialist, three Project Researchers, and two Administrative Supporters held full-time positions in the NAOJ TMT Project. In addition, two Professors, two Associate Professors, an Assistant Professor, and an Engineer in the TMT Project have concurrent positions in the Advanced Technology Center, Subaru Telescope, or the NAOJ Chile Observatory; 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 TMT International Observatory, another five members were transferred to the NAOJ California Office in Pasadena, which brings the total number of members assigned there to six.

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. The NAOJ TMT Project is continuously examining them, and implements feasible parts of the plan for the purpose of effective and efficient operation of the two telescopes through involving in TMT construction those with a wealth of experience in maintenance, repair, and operation of the Subaru Telescope; and flexible personnel allocation between TMT and the Subaru Telescope.

9. 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 Office, NAOJ, is as follows. We participate in and contributes 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 Office.

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. The target launch date is mid-2020s. 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). 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; formations 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 that of Gaia. Launch opportunities for the Nano-JASMINE satellite are under consideration.

(2) Major Progress in FY 2019

1) Organization of the office

The JASMINE Project Office is composed of six full-time staff members, one project research staff member, one research supporter, one technical supporter, and three 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

Small-JASMINE was selected by ISAS/JAXA in May 2019 for the unique candidate for the JAXA Competitive Middle-Class Science Missions No.3. Previously, Small-JASMNE had passed some reviews, including reviews by a science committee at ISAS and an international review. NAOJ has established a Small-JASMINE working group (hereafter referred as the WG) under the NAOJ Scientific Advisory Committee. The purpose of the WG is to "work as a management advice body on a wide range of items related to the Small-JASMINE Project." The WG is composed of seven members inside and outside of NAOJ. The WG has been discussing the scientific goals of Small-JASMINE, including their merits and technical feasibility. The JASMINE Project has established a JASMINE consortium. The purposes of the consortium are to conduct the science study, and is to prepare a data analysis team, data validation team, and outreach team. At present, about 45 domestic members are participating. In August 2019, a consortium kick-off meeting was held in Mitaka Campus, which also served as an open science workshop for Small-JASMINE. In international cooperation, a United States team was formed and we asked the United States team to manufacture, test, and deliver the detector box unit (detector, ASIC, detector box for thermal control of the detector, control system for electronics, etc.). Furthermore, the official negotiation has begun between ISAS/JAXA and ESA for the use of the high-latitude ground station owned by ESA for Small-JASMINE to downlink scientific data. Regarding astrometry data analysis, a researcher from Heidelberg University stayed at NAOJ for several days to prepare for development of the data analysis system of Small JASMINE. Regarding the satellite system development, we conducted discussions with multiple satellite manufacturers. As for the mission system, we developed and tested in-house the thermal control system, filter, structural system, optical system, etc.

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 2019, the RISE Project Office led the operation of the Laser Altimeter (LIDAR) of Hayabusa2 and produced science outcomes. The operation for conjunction finished on December 29, 2018, and a new mission phase started. The RISE Project Office (1) coordinated science operations and prepared operation procedure documents every week, (2) organized operators' meetings, (3) prepared data for publication, and (4) determined routinely the Hayabusa2 spacecraft's position using LIDAR range data. Meanwhile the project members attended the special operations for two sampling touchdowns and an impact experiment at the Operation Center at Sagamihara Campus of ISAS to monitor telemetry downlinked from the spacecraft. For science achievements of LIDAR, we conducted scanning operations from low altitudes, and obtained a topographic data set covering the whole sphere of Ryugu. At the same time, obtained data were processed routinely in a pipeline to estimate the position of the spacecraft precisely and the alignment of LIDAR with respect to the camera. Level 2 products of LIDAR rage data were regularly processed from Level 1 data. Members of the LIDAR science team analyzed and interpreted LIDAR data to accomplish scientific goals. One member of the RISE Project published a paper regarding an estimate of spacecraft positions as the first author, and two RISE members submitted papers about precise positions of the spacecraft and the alignment of LIDAR, also as first authors. In addition, three papers for initial outcomes of Hayabusa2 were published and RISE members were included as co-authors.

Second, in order to forward a future plan for lunar and planetary sciences in NAOJ, four guests representing the astronomy and planetary science communities were invited to Mizusawa Campus. (One guest attended remotely.) On February 13, 2020, they discussed (1) science goals that the Project should aim for Martian Moons eXploration (MMX), (2) the responsibility of the Project as a part of an inter-university joint research institution, (3) the role of NAOJ in International Space Exploration, and (4) a new definition of the Project.

Third, the RISE Project Office supported future exploration projects of Japan, namely, the development of the Ganymede Laser Altimeter (GALA) of the Jupiter Icy Moon Explorer (JUICE) mission and the sub science team (SST) of MMX. A RISE member examined the twist elasticity of the thermal strap of GALA Pre-Flight Model as a follow-up for the same measurement for the Engineering Model detector to help the German Aerospace Center (DLR) revise the Interface Control Document. For MMX, we organized the initial members of the Geodesy SST. Furthermore, we investigated the content of the data produced by the Geodesy SST and LIDAR teams, image acquisition conditions in Quasi-Satellite Orbit (QSO) at different altitudes and their influences on estimates of Phobos's shape model and rotation state. Also, we investigated improvements to Hayabusa2 LIDAR required for the MMX altimeter.

Fourth, we obtained three external grants for development of a gravity gradiometer (GGM), and tested the functions of its sensor component. We designed GGM and GGM-L (Laser interferometric GGM), and started manufacturing of bread board models.

2. Educational Activities/Internships

Seven RISE members delivered lectures in turn at the graduate school of the University of Aizu for half a year. Also, one RISE member served as a part-time lecturer at the University of Tokyo for half a semester for an undergraduate class and half a semester for a graduate class. Another member served as a part-time lecturer for the "Experimental Radio Astronomy Class" of SOKENDAI.

3. Outreach/PR

In FY 2019, the Office members volunteered for Kirari Oshu City Astronomy School as well as five times for FUREAI (Friendly) Astronomy classes. In addition, RISE members provided five special lectures for the public.

4. Joint Research/International Collaborations

Form July 17 to 20, the RISE members co-organized a summer school for lunar and planetary science and exploration in east Asia in Wuhan City, China. One RISE member brought three Japanese students to participate in the summer school and promoted international exchange.

11. SOLAR-C Project

The SOLAR-C Project, renamed from SOLAR-C Project Office in 2019, has engaged in planning the next solar observation satellite mission SOLAR-C; promoting the sounding rocket experiments FOXSI-3 (Focusing Optics X-ray Imaging Spectrometer) and CLASP (the Chromospheric LAyer Spectro Polarimeter); and also preparing for participation in the large balloon-borne experiment Sunrise-3. Through these activities, we are researching and inheriting technologies required for satellite mission development and management methods for international joint projects.

1. Solar-C_EUVST

SOLAR-C is a planned project and may become Japan's fourth solar observation satellite, after Hinotori, Yohkoh, and Hinode. The plan is to realize the launch in the mid-2020's. The project is intended to investigate the solar magnetic plasma activities that influence space weather and space climate around the Earth, by attaining an order of magnitude higher spatial resolution and throughput than Hinode/EIS with a wide temperature sensitivity from the chromosphere to the 10 million degree corona. The themes include major problems in solar research: the heating mechanism of the chromosphere/corona and the origin of solar explosive events. Since its establishment, the SOLAR-C project WG has involved many non-Japanese specialists in addition to Japanese researchers. Provisionally, Japan will be responsible for the launch vehicle, satellite bus, and telescope assembly; and the science instruments will be developed through international collaborations with the U.S. and European space agencies and institutions.

We proposed the EUV high-throughput Spectroscopic Telescope (Solar-C_EUVST) mission to JAXA in January 2018, using the opportunity provided by the JAXA Competitively-chosen Middle-class Satellite Mission. The EUVST proposal received high assessment from the Mission Selection Committee, and was recommended as a pre-candidate for the Competitively-chosen Middle-class Satellite Mission No. 3 or 4 by the ISAS Science and Engineering Committee in July, 2018, and then proceeded to the next mission definition phase; Pre-Phase-A2 in FY 2019. In FY 2019, we examined the following issues that need to be resolved as soon as possible. (1) A simplified FEM model of the telescope structure was provided on the bus side and examined to confirm that it satisfies the vehicle's launch conditions. (2) The thermal design of the primary mirror assembly was investigated to confirm its validity. (3) The development plan of the primary mirror tilting mechanism, the focus adjustment mechanism, and the electric box for control was studied. (4) Draft specifications for structural and electrical interfaces with components provided from overseas institutes were developed. (5) Development proceeded for the telescope and spectrograph performance verification test plan to achieve the required spatial resolution. (6) As a satellite bus, both a small-satellite standard bus and a newly-developed small bus were investigated. (7) The development of the high-precision solar sensor UFSS was promoted. As a result of these studies, we successfully underwent the candidate selection review for the competitively-chosen Middle-class Satellite Mission No. 4 in February-March 2020, with the prospect of passing the review.

2. Short-term Flight Experiments

(1) CLASP Project

The CLASP project is an observational sounding rocket experiment aiming to detect solar magnetic fields in the chromosphere and transition region through polarization observation in the ultraviolet wavelengths. In the second flight experiment CLASP-2 (Japanese PI: Assistant Professor Ishikawa, launched in April 2019) following the successful polarization spectroscopic observation using the hydrogen Lyman alpha line (121.6 nm) in 2015, we have successfully observed the Mg II h & k line (~280 nm) of ionized magnesium with high precision polarization spectroscopy. In addition to the linearly polarized light of these emission lines derived from the scattering polarization, we have been able to obtain clear circularly polarized light due to the Zeeman effect in the active region. We are analyzing the data to publish scientific results, and also preparing to publish the data from the CLASP-1 and CLASP-2 observations.

(2) Sunrise-3 Project

The Sunrise-3 project is the third balloon-borne experiment in the German-led Sunrise program. The preparation of the plan started in FY 2015 and following NASA's approval of the gondola budget in 2018 the flight experiment scheduled in the summer of 2022. In order to realize the SCIP, the Sunrise Chromospheric Infrared spectroPolarimeter, we are developing and testing a flight model with ISAS/JAXA small-scale project and Grant-in-Aid for Scientific Research (S) funding. Environmental tests were carried out to verify the soundness and performance in the flying environment for the waveplate rotation drive mechanism and the scan mirror mechanism, which are the key components for high-precision polarization observation. The fabrication of the optical and structural components of the SCIP has been almost completed, and assembly has started in the end of FY 2019. At the same time, we have been developing a method to analyze the high-precision polarization data of the chromosphere in cooperation with the Instituto Astrofísica Andalucía (IAA, Spain), which will be applied not only to the Sunrise-3 but also to the chromospheric observation with the large solar telescope DKIST.

(3) FOXSI-3 Project

The Focusing Optics X-ray Solar Imager (FOXSI) is a joint Japan-U.S. sounding rocket experiment to observe X-rays emitted from the solar corona by 2D focused imaging and spectroscopy, and 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). For FOXSI-3, the scientific analysis and calibration of the instruments were carried out in parallel to produce the initial results in FY 2019, and research activities were carried out to produce scientific results.

3. Others

Although the SOLAR-C Project is reimbursed by NAOJ for its general operation and contingencies, a large part of the expenses for supporting the project preparation is funded by other external sources including Grants-in-Aid for Scientific Research (Kiban-S for Sunrise-3, Kiban-A for FOXSI-3, Kiban-B for CLASP-2, JAXA's study-acceleration and basic development fund for Solar-C_EUVST, and the JAXA'S small-sized mission program grant for CLASP-2 and Sunrise-3). The SOLAR-C project has been redefined from FY 2020 as a project dedicated to the development and execution of Solar-C_EUVST and its subsequent science operations, and the short-term flight experiments will be transferred to the Solar Science Observatory, which will be positioned as a demonstration test for the supportive observation by Hinode and for the future satellite program. As a result of this project modification, Dr. N. Narukage (assistant professor) and Ms. H. Uekiyo (administrative supporter) will be transferred to the Solar Observation Science Project from April 2020.

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 2019

(1) Subsystem assembly

PFS consists of the Prime Focus Instrument (PFI), Optical Fiber Cables, Spectrograph System (SpS), and Metrology Camera System (MCS). Assembly of all the actuator modules for PFI was completed at Caltech, and their installation into the PFI structure has started at ASIAA. Making bundles of optical fibers has finished in the UK and they were shipped to Brazil to have connectors attached. Prototype optical cables have been attached to the Subaru Telescope and we are monitoring the variation of throughput and focal-ratio degradation caused by telescope motion and environment changes in order to optimize the fiber routing.

SpS consists of four identical spectrograph modules. In FY 2019, the fist spectrograph module was delivered to the Subaru Telescope summit facility and assembled smoothly (Fig. 1). We confirmed optical alignment as good as that achieved at France before shipping.

MCS was delivered and tested in FY 2018, but we found image degradation in the camera. In FY 2019, the mirror supports were replaced with improved components and we confirmed the improvement of the image quality of the MCS camera. We also investigated the dome seeing, which affects the positioning error of the optical fibers at the prime focus when using MCS.

(2) Operation model, data pipeline, and science database

PFS is going to adopt the queue observing system for efficient observations. In order to fully exploit PFS's high multiplexity, we will let separate observing programs to share fibers in the same field of view. We formed a working group to discuss the framework of the fiber-sharing and how we will execute the queue observation. We made good progress and we now have a good sense for what an observing block should look like, how we use the operation database at the summit, etc. There is also progress in the fits header definition of raw PFS data.

We plan to perform an on-site quick reduction of PFS data to perform quality assurance tests. We have purchased a set of computing nodes and file servers for this quick reduction. We have also started to prepare a large computing system for the science database, which we describe below, with large file servers and computing nodes. We will continue to make the system more powerful over the next few years.

The PFS data processing pipeline is being developed by NAOJ, Princeton, and IPMU. NAOJ is responsible for flux calibrations and making a framework for automated processing. There is major progress in the flux calibration part and we have fitted a large grid of theoretical stellar spectra with the radial basis function in order to instantaneously generate a spectrum for a given parameter set (temperature, surface gravity, etc.). This is an important tool for stellar typing that is required to perform accurate flux calibrations. As for the processing scheme, we now have a good overall framework that is flexible enough to allow a variety of processing runs.

The pipeline processed data will be combined with imaging data from HSC for scientific explorations. As the data from PSF and HSC are going to be extremely large, we need a sophisticated and fast database. We have been working on the science database together with Johns Hopkins University and we released the proto-type system version 2 in 2019 and collected useful user feedback. The version2 was well received by the science community and we continue to work on it to make it better. In particular, fast database operations are important as the database is getting larger and larger.

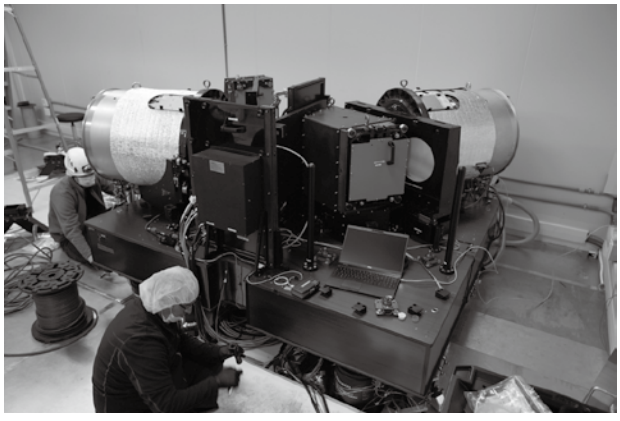


Figure 1: The first spectrograph module assembled at the Subaru Telescope.

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 improves the seeing by a factor of 2 over a wide field of view up to ~20 arcmin in diameter.

The GLAO project successfully completed the conceptual design phase in FY 2018. In FY 2019, the GLAO project was accepted for the NAOJ's call for A project proposals and has started the preliminary design phase. In the A-project period, the GLAO project aims to complete the preliminary design of the GLAO system and the prototyping of the key subsystems within 3 years, followed by final design, production, assembly, integration, and test phases. The GLAO project is planning to implement the GLAO system at the Subaru Telescope and start its commissioning run by the end of FY 2025.

2. Staff

The GLAO project team mainly consists of members of Subaru Telescope. At the end of FY 2019 there were one dedicated associate professor, 4 assistant professors, and 8 RCUH employees (5 research staff and 3 engineering staff) appointed concurrently. In addition, 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 2019 was 7.04. Etsuko Mieda (RCUH employee) resigned at the end of November, 2019.

3. Major Progress in FY 2019

The GLAO project has identified the top-level science requirements based on its primary science goal of understanding galaxy formation and evolution, and then defined system level requirements for the GLAO system and its backend science instruments.

We have also formed a GLAO science team with the mission to expand our science cases beyond the primary science goal and to summarize the extended top-level science requirements for defining the requirements for the backend science instruments toward the completion of their conceptual design. The GLAO science team plays a crucial role in establishing the strategy of our optical/infrared astronomy community toward the 2030s (TMT era). In July 2019, we organized a science workshop to discuss wide-field (near)-infrared survey science in the 2020s. More than 70 scientists participated in the workshop, with financial support from NAOJ. We also organized a special session during the Subaru 20th Anniversary conference in November 2019. This was a very big conference with more than 240 participants from all over the world - and it was a great opportunity to promote our Subaru GLAO project as the next important instrumentation program for the Subaru Telescope.

The GLAO preliminary design has been conducted for its main subsystems: the adaptive secondary mirror (ASM), the laser guide star facility (LGSF), the wavefront sensor system (WFS), and the real-time controller (RTC). In FY 2019, we identified the interface requirements between the Subaru Telescope and the ASM, and defined performance requirements of the ASM required for the adaptive optics system. We have completed a feasibility study of the ASM for the Subaru Telescope in collaboration with the AdOptica consortium in Italy. Based on the conceptual ASM design, we have roughly estimated the schedule and the cost of its fabrication and testing.

To identify the interfaces between the GLAO subsystems and the backend science instruments, we have started a conceptual design for the science instruments. Our plans 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. MOIRCS is currently being used at the Cassegrain focus. It will be relocated to the Nasmyth IR platform and fed by the GLAO corrected beam. We have conducted a feasibility study for relocating MOIRCS and found that cooled focus relay optics are required to use MOIRCS at the Nasmyth IR without compromising its image quality and sensitivity. We are currently conducting conceptual design studies of the relay optics and an instrument rotator to compensate for the field rotation. We conducted optical and mechanical conceptual design studies for WFI and successfully obtained an optical prescription to realize almost diffraction limited image quality over a 14x14 sq. arcmin field in 0.9–2.5 micron. Finally, conceptual design studies of a cryostat for WFI and its support structure to attach to the Cassegrain interface together with the GLAO WFS have also been conducted.

A new LGSF with a high-power (~20 W) TOPTICA fiber laser and four Shack-Hartmann WFSs for tomographic wavefront reconstruction are being developed at Subaru Telescope and Tohoku University to demonstrate their performance and technical feasibility for the future GLAO system. In FY 2019, we completed a final design of the LGSF and Shack-Hartmann WFSs and entered the production phase. The LGSF will be installed at the Subaru Telescope in FY 2020 and tested with the existing AO system (AO188). The Shack-Hartmann WFSs will be tested in Tohoku University in FY 2020 and implemented at the Subaru Telescope in FY 2021.

4. Outreach

To inform the astronomical community and general public about the Subaru GLAO project and its scientific motivation and goals, we have launched a public web site and made an official logo for the project (https://ultimate.naoj.org). To make

our project more visible in broad astronomical communities, we distributed brochures summarizing the overview of the GLAO project during the Subaru 20th International Symposium, held at Waikoloa, Hawaii in November 2019 and during the American Astronomical Society Meeting held at Honolulu in January 2020.

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 2019, we submitted funding proposals to the Australia Research Council (ARC) and Japanese Society of the Promotion of Science (JSPS) to collaborate with ANU on the development of the WFS system and the LGSF for the GLAO system and on the performance demonstration of a tomographic wavefront reconstruction algorithm including simulation and on-sky experiments. We also conducted conceptual design studies for the Nasmyth IR relay optics and instrument rotator in collaboration with ASIAA.

14. Astronomy Data Center

1. Introduction

The Astronomy Data Center (ADC), a central core of computing and archiving for astronomical data, supports scientists worldwide by providing a variety of data center services. In addition, ADC is driving forward research and development programs for future generations of service. Our activities consist of the DB/DA Project, JVO Project, HSC Data Analysis/Archiving Software Development Project, and open-use computer system and service.

2. DB/DA Project

The DB/DA Project conducts research and development on astronomical Databases and Data Analysis. It also opens various astronomical data and catalogs to researchers and educators (http://dbc.nao.ac.jp/).

SMOKA (http://smoka.nao.ac.jp/) is the core of the DB/DA Project and opens archival data of the Subaru Telescope, Okayama Branch Office 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), and NAYUTA 2-m telescope (University of Hyogo). SMOKA provides astronomical research infrastructure to enable verification of research results from others, and hence improves the reliability of astronomical results produced from observational data stored in the archive.

The total amount of opened raw observational data is about 27 million frames (233 TB) as of May 2020. SMOKA contributes to many astronomical publications. The total number of refereed papers using SMOKA data is 250 as of May 2020.

Data taken with the observing instruments IRD and SWIMS attached to the Subaru Telescope, NIC on the NAYUTA telescope, and digitized data from photo plates taken with the Kiso Schmidt telescope were newly opened in 2019. Development of new functionalities requested from users and improvements for efficient operation were also conducted.

3. JVO Project

The data from the Nobeyama COMING project was updated. In addition, new COMING data was released from the project and was integrated into the JVO Nobeyama FITS Archive.

Several new functionalities were made available in JVO. The VO crawler data search system was developed. It gathers various meta-data for observing data from VO services worldwide and provides a quick search. It was implemented in the VO search function in the ALMA and Nobeyama FITS Archive, which enables users to search the relevant multi-wavelength data easily and quickly. The functionality of Subaru WebQL (Quick look visualization of Subaru Telescope imaging data) was migrated and merged into the FITS WebQL v4. The FITS WebQL v4 was also modified so that it can display external FITS image data retrieved from a given URL. A Gaia DR2 data viewer was also developed.

These new features of the JVO system were presented at the Astronomical Data Analysis Software & Systems (ADASS) conference and spring annual meeting of the Astronomical Society of Japan.

The total access count for the JVO services was 3.8 million and the download size was 11 TB in the 2019 fiscal year.

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 8th data release (S19A) to the SSP team collaborators in September 2019, which covers roughly 421 degree^2 of quality areas, with 475 TB of files. The catalog database includes about 450 million objects. We have continued developing various user interface software for providing images and catalog products. The second public data release (PDR2; May 2019) is accessed by over 1200 registered users from more than 45 countries. We are preparing the next internal data release for SSP collaborators, and the 3rd PDR is being planned in 2021 based on this data set. We have also been supporting the on-site data evaluation for HSC observations. We have started new development for a fast catalog query system with a next-generation database, and aim to apply forefront technology to the query services for huge HSC catalogs.

Commissioning of some instrumental components for the next-generation multi-object spectrograph PFS is underway. We have been involved in discussions of data formats, and development of science data archives which are to be combined with the HSC products, in cooperation with Subaru Telescope.

5. Open-use Computer System and Service

"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 Cluster (LSC)" for analyzing the big astronomical observation data such as HSC. The LSC system has been in operation for general HSC observers since September 2019. In addition, a major upgrade of the LSC system is on-going (the addition of 1,500 CPU cores, etc.). We have procured a large number of parts in JFY 2019, and we are planning to have it in operation by the middle of 2020 (upgrade work was completed but the system is still in the test operation phase as of May 2020).

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 system. The dates and numbers of participants in JFY 2019 were as follows.

1. ALMA data analysis school for beginners (Co-host), May 14–15, 2019, 12 users
2. IDL school for beginners, July 18–19, 2019, 6 users
3. SOKENDAI summer student program (Support), Aug. 5 – Sep. 3, 2019, 9 users
4. Python + Jupyter notebook data analysis school, Aug. 29–30, 2019, 12 users
5. HSC data analysis school (Co-host), Nov. 7–8, 2019, 15 users
6. Database school for beginners, Dec. 5–6, 2019, 6 users
7. SOKENDAI Asia Winter School (Support), Jan. 6 – Mar. 9, 2020, 4 users
8. ALMA data analysis school for imaging, intermediate (Co-host), Jan. 15–16, 2020, 12 users
9. N-body simulation school (Co-host), Jan. 22–24, 2020, 13 users
10. IDL school for FITS data analysis, Feb. 6–7, 2020, 5 users
11. Solar data analysis workshop (Support), Feb. 17–21, 2020, 10 users
12. Astronomy research experience 2020 (Support), Feb. 25–28, 2020, 9 users

The total number of participants of the schools in JFY 2019 was 113 users.
* "SOKENDAI spring school" was cancelled and "PyRAF mini school" was postponed due to the expansion of the COVID-19 infection.

6. Others

As part of outreach and promotion activities, 119 issues of "ADC News" were published from No. 844 to No. 962 in JFY 2019. These articles were distributed to users by E-mail and posted on the ADC public web pages.

15. Advanced Technology Center

1. Summary of Activities in ATC

The Advanced Technology Center (ATC) is the core research organization of the technological development at the National Astronomical Observatory of Japan (NAOJ), and is the research and development (R&D) center for advanced astronomical observation instruments, from radio waves to visible and ultraviolet light, both on the ground and in space. In this fiscal year, we have begun restructuring the current organization to develop the instruments more systematically, which will further enhance our international competitiveness for the R&D of the instruments. This new organization structure will be implemented in the next fiscal year. As in the last fiscal year, the following three developments were promoted as "prioritized area development" which is for ongoing astronomical projects driven by NAOJ: (a) the observation instruments of the Infrared Imaging Spectrograph (IRIS) and Wide-Field Optical Spectrometer (WFOS) for the Thirty Meter Telescope (TMT), (b) the maintenance and future development of superconducting receivers for the Atacama Large Millimeter/submillimeter-wave Array (ALMA), and (c) the instruments for the gravitational wave telescope KAGRA. As "advanced technology development" which is positioned as the development research contributing to the future astronomical projects, we supported the development of the instruments related to the Solar-C Project. Most of these developments were supported by "Workshops and Development Support Facilities." ATC was also involved in the development/manufacturing of other instruments and related technology developments for projects inside and outside of NAOJ. There were many visitors for ATC facility tours including members of the Diet, administrative agencies, academic institutions, companies, and researchers and students from Japan or foreign countries. We had about 40 tours in total. These were good opportunities to publicize our cutting-edge technology development activities which are playing an important role to develop advanced observation instruments. It should be highlighted that a 3-dimensional metal printer and a 5-axis machining center have been installed. In terms of R&D, an image sensor has been newly developed to enable us to develop a wide field mosaic camera. It also should be mentioned that the CLASP2 sounding rocket experiment with an observation instrument developed with our support has been launched and all the data stored in the instrument were recovered successfully in this fiscal year. 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. In this period, we have newly established the Additive Manufacturing team (AM team) in addition to the three preexisting teams (Design team, Machining team, and Measurement team). All four teams cooperate with each other to meet the various needs from NAOJ projects and other institutions by leveraging their expertise.

1) Design team

The Design team has worked on mechanical design and related measurement, assembly, and installation for TMT/IRIS, KAGRA, TMT/WFOS, and SUNRISE-3.

TMT/IRIS: as the first year of the two years of the final design phase, the design team worked on detailed mechanical designs of each subsystem that constitutes the Imager. Some of the subsystems had significant design changes from the preliminary design phase, based on the results of the prototype tests. For those changes, additional FE analysis and prototype tests were performed to ensure the functionality and reliability of the updated design. The following detailed designs were made: a) Cold stop mechanism, b) Filter exchanger mechanism, c) Atmospheric dispersion corrector mechanism, d) Detector mount, e) Slicer pick off mechanism, f) Imager to Science cryostat fixture, and g) TMA mirror mount. We also made the following prototype tests under 77 K: a) Durability test of the gear box, b) Durability test of the 4 inch bearing, c) Durability test of the worm gear, and d) Deformation measurement of the TMA mirror.

KAGRA: We mainly worked for a new design, a design update, and continuing jobs from last year, which are a) Design update of the GAS filter structure, b) Design of TMS-VIS moving mass balancer, c) Assembly of the TMS (Transmission Monitor System) vibration isolation stage for Y-end, and static / dynamic performance verification, and on-site installation.

TMT/WFOS: We progressed on the conceptual design of three subsystems and contributed to the top-level requirement analyses, which are a) Conceptual design of camera lens barrel (Trade-off study of lens mounting method, design of barrel structure, and CAD data creation), b) Conceptual design of slit mask changer (Requirement analysis, functional analysis and architecture design, interface discussion, and CAD data creation), c) Conceptual design of optomechanics of the integral field spectroscopy unit (Examination of optical elements mounting system and entire structure, and CAD data creation), d) Generating top level documents (DRD, DDD), and e) Mass budgeting.

SUNRISE-3: For SCIP, which is in the AIT phase, we mainly progressed on assembly of optomechanical flight components, specifically a) Bonding of the optical elements and mounting structures for the spetcropolarimeter (8 types, 9 elements, design of bonding jigs, and fabrication arrangement including outsourced design validation), b) Installation on optical bench and preparation for 3D coordinate measurement after integration, c) Design and fabrication arrangement for

various mounting structures such as scan mirror mechanism and PMU, and d) Creation of structural numerical model.

2) Additive Manufacturing (AM) team

The AM team was organized as a team of the ME shop starting from April 2019 in charge of installation preparation, machine installation, and initial startup for the metal 3D printer for which the budget was approved in July 2018. The following three members were assigned for the initial development.

a) Tomio Kanzawa: April 2019 Transfer from Nobeyama Observatory Effort 75 % (concurrently appointed at Nobeyama)
b) Kenji Mitsui: Effort 50 % (concurrently holds position in ultra-precision machining and Optical shop)
c) Keiko Kaneko: Effort 30 % (concurrently holds position in ALMA receiver development)

Major activities in FY 2019 are as follows: a) Construction of installation environment, b) Layout of the room, c) Installation (August 2019), d) Operation training for main unit and peripheral devices, e) Initial study and practice for fabrication and machine operation, f) Evaluation of basic physical properties, g) First trial for ALMA Band 1 horn fabrication.

3) Machining team

The machining team has responded to fabrication requests ranging from major NAOJ projects to open-use users. In FY 2019, the main contribution was to work for installation of the 5-axis machining center for which preparation had begun last period. In particular, the factory operation was temporarily stopped, and large-scale work was done during the renovation of the building and the relocation of existing facilities. After the installation, the startup work and verification work for steadily operation were started and will be carried over to the next fiscal year. As a new activity, we have started test machining of shaped products using the metal 3D printer.

The main requests are as follows:

a) For TMT/IRIS, fabrication of parts for element tests being conducted by design team.
b) For airborne instrumentation, fabrication of flight parts for SUNRISE-3.
c) Fabrication of experimental equipment parts for infrared detector development and terahertz detector development.
d) For open use, we responded to requests of TAO (University of Tokyo Institute of Astronomy) and radio camera (University of Tsukuba).

As for Fabrication by the Ultra-precision Section, we made trial production of a profiled horn for ALMA Band 10. This is a project that has been ongoing since last fiscal year. In order to complete it as an element, we investigated improving the tools and changing the material, and as a result, we applied a special DLC coating to the existing tools. In the future, we will try processing using the tools. Furthermore, we fabricated a metal spring for removing heat from an optical element. Since the performance of trial part fabricated in last period was judged to be good enough to use, we worked on processing it as a flight part for SUNRIS-3. We have delivered one of the required two. The remaining one will carry over to the next fiscal year.

4) Measurement team

The measurement team has responded to general requests and supported other teams in order to assure the required quality. In collaboration with the machining team, we measured the products that required detailed measurement, and in the design team, we provided consultation measurement and evaluation. In addition, we are also collaborating with the AM team that was newly established this period. For SUNRISE3, we conducted detailed measurement of various parts and measurement of position adjustment for the optical system. As for the additive manufacturing by the metal 3D printer, we measured reference samples for laser parameter correction. Finally, measurement for accuracy verification was made for the 5-axis machining center.

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. We are developing a cryogenic applicable non-optical contactless linear encoder to use for positioning mechanisms in radio and infrared instruments. In FY 2019, with the cooperation of Magnescale Co., Ltd., we picked a sensor from their products, and performed a functionality check and thermal cycle test at R.T. to 77 K. The sensor survived both tests successfully and we are planning to measure the temperature dependency of the sensor output in FY 2020.

(2) Optical Design and Development

An engineer dedicated to optics is involved in multiple projects, providing cross-project optical development functions, such as optical design, optical performance analysis, measurement, specification development, and procurement. In FY 2019, as projects for NAOJ, optical design and the development for SUNRISE-3, Solar-C_EUVST, TMT/WFOS, and KAGRA were made. As open-use and joint research projects, the optics of the focal plane instruments of the two submillimeter-wave telescopes that are being developed by the University of Tsukuba and the University of Tokyo were

Table 1: The requests in FY 2019.

From FY 2018	2
ATC	24
TMT/IRIS	16
ALMA	1
KAGRA, Gravitational Wave Project	5
SOLAR-C, CLASP2, SUNRISE-3, FOXSI-3	11
Subaru Telescope	2
External Organizations	
Univ. of Tokyo	5
Univ. of Tsukuba	3
Total	69
To FY 2020	4

designed. In addition to this, based on a request from Ibaraki University, the figure error of the primary mirror polished by Kunitomo Ikkansai during the Edo period was measured. This measurement and the results were broadcast on NHK's "Ohayo Nippon." In addition, in order to introduce optical equipment that can be used for current and future development within a limited budget, proposals based on requests obtained from the development of several projects have been made. In FY 2019, three instruments were proposed for the NAOJ Leadership program and approved for introduction. These instruments consisted of 1. A clean booth unit for an ultra-high precision 3D profiler; 2. A high-speed autocollimator; and 3. A Fizeau interferometer. The first two pieces of equipment were delivered during FY 2019, and the remaining piece is scheduled for delivery in July 2020.

(3) Thin Film Processing Unit

Fundamental experiments were continued to design and to develop the concrete processes of coating for use with inhomogeneous multilayers. The interface program between inhomogeneous multilayer design software and the coater was improved for accuracy and reproducibility. Various data about the relation between the status of the coater and the film characteristics are obtained to consider the possibility of controlling the film inhomogeneity.

(4) Space Chamber Shop and Space Optics

As project support, we have participated in the development activities of the balloon experiment SUNRISE-3 and the next solar observation satellite Solar-C_EUVST. In SUNRISE-3, we contributed to the development of the main structure of the Sunrise Chromospheric Infrared Polarimeter (SCIP) through property tests such as thermal expansion, swelling deformation measurements, and outgassing measurements of CFRP structural materials. We have also assisted vacuum tests of the Polarization Modulator Unit (PMU) and the Scan Mirror Mechanism (SMM), and outgassing measurements of equipment components and materials. A 3D CAD model of the vacuum chamber was constructed in preparation for a thermal-optical vacuum test of the SCIP in the next fiscal year. For the Solar-C_EUVST, we have started the preparation of a contamination transport model and the study of a high-efficiency bakeout method for achieving a low outgassing condition.

In terms of equipment development and management, we have started to develop a telemetry system. We aim to remotely monitor the measurement of experiments, operate equipment, and watch the environment in the clean rooms. The installation of communication hardware and the development of Web applications are in progress, and some of the systems were put into operation. In addition, as a measure to prevent falling accidents in the operation of the large vacuum chamber, the introduction of a crane lifting jig has led to work safety.

From this fiscal year, fluid analysis has been started as support for the project development activities. Thermal-fluid coupled analysis of the room where the Subaru Prime Focus Spectrograph (PFS) is installed has been conducted. A simulation model was completed using the software (PHOENICS), and the temperatures of the spectrographs and optical benches were calculated from the heat exchanger capacity and temperature conditions.

(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. The followings are our activities:

a) Repairing and upgrading measurement systems

- Inspection of optical system for UV-3100PC (SHIMADZU)
- Rearrangement in measurement room of optical shop
- Relocation and installation of simple type clean room for work by users

b) Open use

- The number of annual users: 282
  NAOJ: 243 (including 122 from ATC)
  External organizations: 39
- Use of LEGEX910 (large-scale 3-D measurement machine): 14
  Number of operating days: 18
- Technical consulting for users: 47

(6) Optical and Infrared Detector Group

Near infrared image sensors for low-noise astronomical observation have been supplied only by a company in the United States. It is extraordinary expensive, and difficult to export from the United States due to the export restrictions.

The optical and infrared detector group has been developing a near infrared image sensor in cooperation with a domestic company, which has performance competitive with the existing sensors. We have successfully resolved three problems in this year, which are readout noise, persistent image, and a 3-side buttable package. The newly developed image sensor enables us to develop a wide field mosaic camera. We also started development for longer-wavelength near-infrared image sensors. A medium format CMOS readout circuit has been designed and manufactured to study feasibility in this year.

(7) Terahertz Experimental Group

We support developments in superconducting detectors, cryogenic electronics, and cryogenic systems. Especially, a submillimeter-wave Fourier transform spectrometer is operated for optical evaluation of instruments in terahertz frequencies. For the development of a MKID camera in collaboration with Tsukuba University, we have advanced in evaluation of FTS spectra and beam shape measurements using a cryogenic blackbody. In the development of terahertz photon detectors in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST), an evaluation of SIS photon detectors with low leakage junctions of 1 pA showed

high optical performance in the submillimeter-wave band. For cryogenics, a 0.8 K sorption cooler has been developed in collaboration with industry, which successfully demonstrated operation of a very compact sorption cooler with Helium-4 down to 0.75 K for 3 hours.

(8) Facility Management Unit

The Facility Management Unit conducts daily inspections and operations of buildings, external equipment, and CE (cold evaporator) equipment based on the law; And performs overall Management work such as laboratory maintenance including clean rooms, construction, hazardous materials, laboratory operation plan, etc. In the clean rooms (SIS clean room, (101) large clean room) of Instrument Development Building (2), renewal and repair of the entire air conditioner system was performed. This construction will maintain stable environmental conditions inside both cleanrooms for the next 15 years.

The water pipelines of the circulating cooling water system were inspected and cleaned to prevent deterioration of the water quality because of the high level of contamination due to aging. In the newly built Building (3) (TMT building), construction of circulating cooling water facilities was completed so that refrigerators could be used in each laboratory, and construction of one large clean room was almost completed. In addition, piping from the existing CE facility has been completed so that nitrogen gas can be used in each laboratory. Some laboratories, staff rooms, and conference rooms in Building (3) have begun to be used.

3. Prioritized Area Developments

(1) TMT

1) IRIS

The detail design phase of the near-infrared imaging spectrograph, IRIS, has been started from the middle of FY 2017. In the detailed design phase, NAOJ is responsible for leading the system engineering of IRIS, contributing to the IRIS software team, and the overall development of the IRIS imager. The opto-mechanical design, analysis, and prototype testing have been mainly conducted at ATC at NAOJ. The major progresses in FY 2019 is as follows: optical tolerance analysis and stray light analysis; deformation measurement and analysis of the surface of the large spherical mirror at cryogenic temperature; prototype test of durability of moving mechanisms; mechanical design and analysis; software design; and concept study of the calibration light source, which simulates the adaptive optics system of TMT, NFIRAOS, for confirming the interfaces with IRIS.

In particular, the surface deformation of the large spherical mirror at cryogenic temperatures was measured by the Fizeau interferometer, Zygo GPI, which is a facility instrument of ATC, in collaboration with the optical researchers and engineers of the IRIS imager team and engineers and technicians in the mechanical engineer shop of ATC. Based on the measurement results, a mirror deformation model has been created by various design and analysis software owned by ATC's mechanical engineering shop. In addition, prototype tests and mechanical design were carried out mainly by the design team of ATC's mechanical engineering shop.

2) WFOS

During this fiscal year 2019, the international WFOS development team has been working on the tasks defined for the Conceptual design (Phase 2) whose review is scheduled at the end of 2020. WFOS-J team has been carrying out the following assigned task items.

a) Conceptual studies of camera lens barrel; WFOS camera optics require large (~ 40 cm diameter) CaF_2 which is quite brittle and requires special care to hold in the lens barrel. We examined the past designs and made trade-off studies for some of the promising cases. We identified at least one satisfying solution based on the FEM studies on the stress tensor and deformation. We are exploring better solutions as well as the studies about the impact of environmental change.

b) Conceptual Design of the Mask Exchanger: The analysis of the necessary functions and components has been done, and we started to define the mechanical interface to the main structure of WFOS. We also clarified the specifications on the forming and alignment error of masks to the exchanger system. Masks need to be warped at the focal plane and we are working on how to realize that efficiently.

c) Development of IFU concept: As an original contribution to WFOS, we are proposing an IFU as a promising option in the era of ground-layer adoptive optics. Based on the heritage from the IFU on the Subaru Telescope, which has been used already by general observers, we have been carrying out the conceptual studies of the optics and mechanical structure. We are also leading discussions about the mechanical structures which are closely related with the later installation of the IFU.

d) Contribution to the WFOS system engineering: Working as a member of the WFOS system engineering team, we have been revising various Level 1 Documents. Among them, the essential OAD and ORD have been completed and we are now working on a level 2 DRD document.

(2) ALMA

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

The band 4, 8, and 10 receiver cartridges of ALMA developed and mass-produced by Japan completed shipment of 73 units in each band for a total of 219 units during FY 2013. 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 cartridge failures that occurred during operation since FY 2014. In FY 2019, two Band 10 receivers were repaired

and delivered to the ALMA Operations Support Facility in Chile. These failures were caused by degradation of the mixer performance and a partial disconnection of the circuit between the mixer, the isolator, and the resistor board. One receiver was repaired by replacing the mixer block, the other by replacing the mixer block and parts connecting from the mixer to the isolator and the resistor board. In addition to these repairs, we provided operational support for the Joint ALMA Observatory by providing information and discussion for investigating the cause of problems with Bands 8 and 10 receivers in Chile. In order to continue stable observation operation of ALMA, we will maintain a maintenance system within ATC that can quickly respond to ALMA receiver malfunctions.

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.

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 to cryogenic maintenance of cryocoolers at ASIAA, and support to procurement and shipping of several important components, such as cryogenic low-noise amplifiers and photomixers in cooperation with the NAOJ ALMA project. We will deliver several dozens of corrugated horns to ASIAA for ALMA band 1 production, including corrugated horns fabricated by traditional techniques at the University of Chile, under a collaboration agreement, and units to be produced at ATC. NAOJ plans to fabricate horns with the metal 3D printer which was installed in ATC in August 2019.

The band 2 project (RF: 67–116 GHz) led by ESO (European Organization for Astronomical Research in the Southern Hemisphere) is in the preproduction phase (the first 6 receivers have been produced). We have contributed to the Band 2 receiver development with the design, fabrication, and testing of waveguide components and receiver optics based on a dielectric lens. The Critical Components Down-selection meeting was held in June 2019 and optical components including a corrugated horn, circular-square waveguide transition, and waveguide orthogonal mode transducer designed by NAOJ were selected as the baseline design for the receiver cartridge towards the Critical Design Review. To improve the receiver noise temperature, we also updated the optical design in collaboration with ESO and the University of Chile.

2-2) Development for the next generation projects

The ultra-wideband receiver is being developed for the future ALMA receiver upgrade. A double sideband (DSB) mixer developed at ATC in the last fiscal year showed quantum-limited performance in the 275–500 GHz RF range across 3–22 GHz Intermediate Frequency (IF). Based on this DSB mixer, we established a wideband receiver system in combination with a 4–21 GHz IF backend, including a 32 Gsps high-speed analog-digital converter. The test results demonstrate 17 GHz instantaneous bandwidth and meet the requirements for future ALMA upgrades. We have also performed theoretical and experimental studies to improve the performance of our wideband sideband separating (2SB) receiver. In addition, we have applied digital-based amplitude and phase correction techniques for a wideband 2SB receiver and demonstrated significant improvement of image rejection ratio in collaboration with the University of Chile. These activities demonstrate the feasibility of these technologies and future prospects for implementation in ALMA.

The terahertz (Band 10) receiver technologies have been developed to upgrade the receiver in two directions: 1) wide IF bandwidth mixer, and 2) 2SB mixer. We have developed an SIS-mixer-preamplifier module which integrates an SIS mixer based on high current density junctions and a wideband cryogenic low-noise amplifier. The results showed low-noise performance over the whole 4–18 GHz IF range. In addition, a compact 2SB mixer block which integrates RF waveguide components, mixer chip slots, and 4–12 GHz IF planar circuits was designed and fabricated. The performance will be evaluated soon.

The multibeam receiver is being developed based on the hybrid planar integration (HPI) scheme. An original concept that was proposed by us for the construction of compact focal plane SIS heterodyne receiver arrays, a 2 x 2 dual polarization balanced SIS array receiver, has been designed and developed at 2 mm wavelengths. This compact array demonstrated uniform LO distribution and low crosstalk between pixels. The demonstration of this fully-functioning compact array declares the birth of this new type of receiver for radio astronomical observation, which achieves unprecedented high-density integration.

The SIS junction development has been suspended for about 6 months due to a complete renovation of the air-conditioning/positive pressure system of our cleanroom. Nevertheless, we successfully proceeded with the study of the fabrication of SIS mixers on silicon membranes, which is the key technology for SIS heterodyne array receivers implemented with the HPI scheme. Plasma enhanced chemical vapor deposition (PE-CVD) is replaced by RF magnetron sputtering in the insulator layer deposition because of superior step-coverage. Stack-layered SiO_2 films, consisting of a tensile film sandwiched by two compressive films, are deposited to achieve a low film stress, which is favorable for the junction quality. The SiO_2 films deposited with PE-CVD brought about a clear improvement in the fabrication uniformity and yield. We also carried out preliminary studies on silicon micromachining by fabricating an anti-reflection surface on silicon by deep reactive etching.

This is a supporting technology for the implementation of the HPI scheme at THz frequencies.

(3) KAGRA

For KAGRA, the laser interferometric gravitational-wave telescope in Japan, we have developed the auxiliary optics subsystem (AOS) and vibration-isolation subsystem (VIS) in cooperation with the Gravitational-wave Science Project (GWSP). Concretely, the AOS instruments are optical subsystems including optical baffles or beam dumps for mitigating stray light, a number of optical angular sensors for monitoring mirrors, light-beam reduction telescopes (BRT), high-speed cameras for monitoring light beams at several ports of the laser interferometer, and viewport windows for extracting the light beams from vacuum enclosures. Most of the AOS instruments have been shipped in the last fiscal year. In FY 2019, a vibration-isolation stage for the BRT, which is the last instrument on the schedule in the initial plan, was assembled and tested at Mitaka, and shipped to the KAGRA site. We also took care of the packing of the instrument, as the KAGRA site is in a tunnel, a special environment. Besides, we visited the site to install it and performed commissioning work in cooperation with site workers there. The work was completed on schedule at the beginning of June even in the face of the tight but fluffy scheduling of the KAGRA construction. Regarding VIS, most of the required work for ATC was completed in the last fiscal year.

KAGRA will start actual observation runs in this fiscal year; at the same time, it will join the ongoing 3rd international gravitational-wave network observing run, O3. A number of instruments shipped from ATC are essential for KAGRA to start the actual operation. From this viewpoint, the ATC's contribution can be quantified and qualified as around the highest level within the KAGRA collaboration.

We have started to improve the design of our instruments to be required for upgrading KAGRA after the O3 run. For AOS, we have designed a balancing attachment for the BRT's vibration-isolation stage to facilitate finding its balance. This will also improve the work efficiency for the further upgrading of the BRT itself. In the next fiscal year, we will fabricate a prototype of the balancing attachment and test it. By the way, the upgrade plan of KAGRA includes an option of increasing the mass of the sapphire mirrors, which are supported by the VIS instruments. To deal with this option, KAGRA wanted us to furbish the design of the outermost shroud of the vibration-isolation filters, which had been designed in another company. The purpose of the re-design is to make the filters more organized for better work efficiency. We have performed the first trial of the re-design. We will continue this work to derive requirements, including unconscious ones, through discussions with KAGRA and to optimize the design.

4. Advanced Technology Developments

(1) CLASP2/SUNRISE/SOLAR-C

We have been cooperating with the Solar-C Project to develop space-/balloon-borne instruments as technical items of the advanced technology development. CLASP2, whose development was completed last fiscal year, was launched on April 11, 2019 by a NASA sounding rocket. High precision spectropolarimetric observation in the ultraviolet wavelengths was performed successfully for the first time in the world. The evaluation of the magnetic field in the upper chromosphere of the Sun has started with the data obtained. In parallel, the development of the spectropolarimeter SCIP for the balloon-borne experiment SUNRISE-3 has progressed. In addition to testing the mechanisms that were fabricated last fiscal year, the development of the optical and structural components was completed, and the assembly of the flight instrument has been in progress while performing optical adjustments. For the small satellite program SOLAR-C, preparatory activities for the management of outgassing from composite and organic materials have started, which is one of the key technical items for the project's success.

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 and commitment of ATC members. In FY 2019, we made calls for open use programs twice, accepting applications for 9 collaboration programs and 18 facility use programs.

Development Building 3 started operation, and some of common use programs started using the building. Around the end of the fiscal year, the effect of COVID-19 limited operation of common use programs. 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. In FY 2019, the Center has been comprised of 7 offices and 1 unit: the Public Relations Office, the Outreach and Education Office, the Ephemeris Computation Office, the Library Unit, the Publications Office, the IAU Office for Astronomy Outreach (OAO), the General Affairs Office, and the newly established Spectrum Management Office.

2. Personnel

In FY 2019, the Public Relations Center was composed of Director Toshio Fukushima and the following staff members: 2 professors, 1 project professor, 2 associate professors, 4 assistant professors (each holds concurrent posts), 1 research engineer, 1 engineer, 1 section leader, 1 project research staff member, 6 senior specialists, 2 research experts, 1 research supporter, 21 public outreach staff members, 1 administrative expert, and 1 re-contracted employee.

On April 1, project professor Masatoshi Ohishi and research supporter Junko Tsuneyama arrived in the Spectrum Management Office, Leader of the Library Unit Mizuho Tamefusa, Senior Specialist staff member Izumi Ka Hoku Hula O Kekai Hansen arrived in OAO, project research staff member Ikko Shimizu arrived in the Ephemeris Computation Office, and public outreach staff member Ryo Sato arrived in the Public Relation Office.

On May 31, public outreach staff member Satomi Hatano resigned. On June 5, public outreach staff member Ayako Fujimura resigned. On June 30, public outreach staff member Yukiko Shibata resigned. On February 29, public outreach staff member Natsuki Yonetani resigned.

On March 31, professor Toshio Fukushima, project research staff member Ikko Shimizu, and public outreach staff members Taiga Hamura and Noriko Takabatake resigned.

Project assistant professor Wanda Liz Diaz-Merced arrived in OAO on July 19 and resigned on December 27.

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 conducted observation campaigns to promote astronomical phenomena of interest to the public, like the meteor showers. We conduct not only public outreach activities using SNS (social networking services) and movies, 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. To improve the skills of outreach personnel, we invited Mr. Takashi Kobayashi, Head of the Public Relations Office of the National Institute for Materials Science (NIMS), as a guest lecturer and held a workshop.

(1) Online-Based Information Sharing

The Public Relations Office runs the NAOJ website (https://

Month	Access counts	Month	Access counts	Month	Access counts
April 2019	675,962	August 2019	775,116	December 2019	1,195,449
May 2019	526,289	September 2019	644,551	January 2020	739,451
June 2019	473,617	October 2019	544,460	February 2020	512,886
July 2019	577,069	November 2019	578,854	March 2020	537,346
Total: 7,781,050					

Table 1: Monthly website access statistics for the Public Relations Office website, NAOJ Public Relations Center (April 2019–March 2020).

NAOJ Promotion Video	English Version
Astronomy Information Movies (June 2019 to March 2020, uploaded monthly, 10 videos in total)	Japanese Version
Mizusawa VLBI Observatory Short PV (2019)	Japanese/English Versions
Sign-Language Videos Introducing Open Facilities of Mitaka Campus No. 01–06	Japanese Version
Mitaka: The Space Simulator	English Version
Your Galactic Journey as a Citizen Scientist	Japanese/English Versions
A partial solar eclipse captured by the Solar Flare Telescope on January 6, 2019	Japanese Version

Table 2: Summary of Produced Videos.

April 3, 2019	Simulations Find Mechanism of Brightest Flashes in Universe
April 26, 2019	ALMA Discovers Aluminum around Young Star
April 30, 2019	Star with Strange Chemistry is from Out of Town
May 30, 2019	Subaru Telescope Captures 1800 Exploding Stars
June 18, 2019	ALMA Finds Earliest Example of Merging Galaxies
June 26, 2019	ALMA Pinpoints the Formation Site of Planet around Nearest Young Star
July 8, 2019	Massive Stars Grow Same Way as Light Stars, Just Bigger
July 24, 2019	Production Sites of Stars are Rare
August 8, 2019	ALMA Identified Dark Ancestors of Massive Elliptical Galaxies—Unexpected Hidden Galaxies Question Theories of Universe Evolution
October 4, 2019	Massive Filaments Fuel the Growth of Galaxies and Supermassive Black Holes
October 31, 2019	Worldwide Observations Confirm Nearby "Lensing" Exoplanet
November 19, 2019	Subaru Telescope Detects the Mid-infrared Emission Band from Complex Organic Molecules in Comet 21P/Giacobini-Zinner
November 25, 2019	Planets Around a Black Hole?—Calculations Show Possibility of Bizarre Worlds
December 19, 2019	The 'cores' of massive galaxies had already formed 1.5 billion years after the Big Bang
December 23, 2019	Massive Gas Disk Raises Questions about Planet Formation Theory
January 8, 2020	Stellar Heavy Metals can Trace History of Galaxies
January 15, 2020	Active Asteroid Unveils Fireball Identity
January 17, 2020	Here and Gone: Outbound Comets are Likely of Alien Origin
February 5, 2020	Artificial Intelligence tool developed to predict the structure of the Universe
February 14, 2020	Galactic Cosmic Rays Affect Titan's Atmosphere
March 5, 2020	ALMA Spots Metamorphosing Aged Star
March 9, 2020	Safety Zone Saves Giant Moons from Fatal Plunge
March 23, 2020	Star Formation Project Maps Nearby Interstellar Clouds
March 27, 2020	ALMA Resolves Gas Impacted by Young Jets from Supermassive Black Hole

Table 3: Web Releases.

April 10, 2019	Astronomers Capture First Image of a Black Hole ? Japanese researchers contribute to paradigm-shifting observations of the gargantuan black hole at the heart of distant galaxy Messier 87
September 27, 2019	Oldest Galaxy Protocluster forms "Queen's Court"
October 4, 2019	Three gravitational-wave detectors sign agreement to begin joint observation
November 14, 2019	Two Cosmic Peacocks show Violent History of the Magellanic Clouds
December 16, 2019	Carbon Cocoons Surround Growing Galaxies—ALMA Spots Earliest Environment Pollution in the Universe—

Table 4: Press Conferences.

www.nao.ac.jp/en/), disseminating information via the internet. Table 1 shows the access counts for the website.

The Office opened Twitter accounts and Facebook accounts in Japanese and English sequentially from 2010. We have been 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 2020, the number of Japanese version twitter followers exceeds 190,000. Information dissemination via the English version of Twitter, the interactive NAOJ quizzes on Twitter, as well as the release of visual images on Instagram have been conducted continuously this year.

NAOJ e-mail newsletters No. 203–214 were issued, introducing research results and NAOJ hosted events.

We continued to produce videos explaining research results, videos explaining astronomical phenomena, and videos introducing outreach activities. Including English versions, 23 original videos were produced. The videos are uploaded mainly on YouTube. As of the end of March 2019, these videos have accumulated a total of 473,123 minutes of play time and 1,117,297 views. The total number of views almost doubled compared to that of the last fiscal year. Continued from the last fiscal year, our office performed live stream broadcasting of heavenly bodies with the 50-cm Telescope for Public Outreach. Particularly this year, we provided a live stream featuring the black hole that dominated news coverage. This year's live programs ran seven times, accumulating a total of 234,388 views. Like last fiscal year, we have been approved as an official program by DWANGO Co., Ltd., which manages a live broadcast for niconico, and our viewers are increasing. Upon the nationwide school closure due to the spread of COVID-19, we delivered special lectures for primary, junior high, and high school students through live streaming and archive videos. These lectures accumulated a total of 63,874 views. In addition,

we conducted live internet broadcasts of lectures on the Special Open House Day for Nobeyama Radio Observatory and Mitaka Open House Day.

(2) Research Result PR

There were 33 research result announcements (compared to 26 in FY 2018 and 27 in FY 2017). We released 29 of them in both English and Japanese. For domestic audiences, we have continued to organize press conferences, as well as e-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, AlphaGalileo, and EurekAlert! from AAAS. We also continued to experiment with ResearchSEA. As in the previous fiscal year, we e-mailed press releases for overseas audiences to an original media list.

(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 February 2, 2020, the NAOJ lecture meeting/24th ALMA public lecture "The Birth and Evolution of Galaxies Investigated by ALMA" was held at the International Conference Hall, Plaza Heisei, Tokyo International Exchange Center, with 258 guests in attendance.

We also created a website for the SOLAR-C Project.

To publicize NAOJ abroad, we co-hosted a booth with the Institute of Physical and Chemical Research (RIKEN) at an overseas meeting where the press, researchers, and educational officials gather (The 11th World Conference of Science Journalists in Lausanne, Switzerland, July 2019).

(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 was a total of 24 reports including confirmation requests for new celestial object candidates and other reports. The contents were: 14 novae/supernovae, 5 comets/cometary objects, 1 star, 1 planet, 1 fireball, 2 luminous objects. Among the many examples of reporting a known asteroid or ghosts as a new object, the report of an object in August 2019 was communicated via NAOJ to the IAU Central Bureau for Astronomical Telegrams (CBAT) and was recognized as the discovery of the nova V2860 Ori. The two reports of an object in September 2019 were communicated via NAOJ to CBAT as well and were recognized as independent discoveries of the nova V1707 Sco. The report in January 2020 was communicated via NAOJ to the IAU Minor Planet Center (MPC) and was recognized as the discovery of COMET C/2020 A2 (Iwamoto). Furthermore, the report in February 2020 was communicated via NAOJ to CBAT and was recognized as the discovery of the nova V6556 Sgr.

(5) Citizen Astronomy

"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.

We jointly developed the GALAXY CRUISE website with Subaru Telescope, through which citizens participate in galaxy classification. The Japanese version was released on November 1, 2019, and the English version was released on February 19, 2020. GALAXY CRUISE used the data from the second public release of the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) released in May 2019. Citizens inspect the galaxies captured in the data and decide whether or not they are gravitationally interacting and what kinds of interaction features are present. As of the end of 2019, GALAXY CRUISE garnered a total of 19 pieces of newspaper/online coverage (including reprints) and one piece of radio coverage, accumulating a total of 1388 registered users or "citizen astronomers." This project was introduced in the NHK News in January 2020 and, following the emergency school closures in March 2020, promoted on the website managed by JACST and Miraikan that provides digital scientific content. As a result, the number of registered users increased, especially with children under 10 years old, to 2640 by March 15, 2020. Overseas, GALAXY CRUISE garnered a total of 12 pieces of online coverage in the UK, the USA, Canada, Germany, Russia, and Ukraine, and was introduced in one American blog and one Russian YouTube channel, radio report, and SNS account. Registered users increased especially in Russia and the USA, totaling 3207 people from 52 countries including Japan as of March 15, 2020.

4. Outreach and Education Office

In FY 2019, the budget allocated to the Outreach and Education Office was less than half of the previous year's level due to NAOJ's severe financial condition. The office therefore had to scale down public visit events and discontinue most of the outreach and education activities.

(1) Public Visits

A total of 20,131 people participated in Mitaka Campus Public Visits (former name was Visitors' Area) in FY 2019. In addition, the group tours in 2019 consisted of 103 general tours (3,615 guests), and 20 workplace visits by schools (235 guests), and 10 others such as inspections (255 guests), for a total of 133 tours accommodating 4,105 guests. Therefore, 24,236 guests visited Mitaka Campus in total. Note that for the integrated studies, lectures by researchers, question-and-answer sessions, and visits to research facilities also took place. In addition to audio guides, we installed video sign-language guides at some of the facilities. Stargazing parties after February 22 and all the public access programs scheduled after February 29 to the end of the fiscal year were canceled as a preventative measure against the spread of COVID-19.

Regular stargazing parties were held twice a month (the

	Solar Ephemeris	Lunar Ephemeris	Ephemeris	Time	Solar System	Universe	Astronomy	Other	Total
April–June	133	68	28	10	124	102	81	581	1,127
July–September	105	112	40	12	349	115	97	832	1,662
October–December	120	98	37	12	221	95	89	671	1,343
January–March	138	103	30	5	174	84	89	454	1,077
Total	496	381	135	39	868	396	356	2,538	5,209

Table 5: Telephone inquiries made to the Outreach and Education Office of the NAOJ Public Relations Center (April 2018–March 2019).

day before the 2nd Saturday and the 4th Saturday) with the 50-cm Telescope for Public Outreach. These were held regardless of cloudy or rainy weather, but some were canceled due to health concerns (see above). Advance booking (300 people for each session; a lottery system from April to September and advanced reservations until filled system from October to March) was introduced in FY 2012 for these events. However, from this May, the maximum capacity was reduced to 200. A total of 19 sessions were held with 2,459 participants this year. In addition to this, the telescope was used by 10 groups (610 people) for group tours, inspections, etc.; so a total of 3,069 people observed with the 50-cm Telescope for Public Outreach.

The Outreach and Education Office held the regular public screenings at the 4D2U Dome Theater four times per month (1st, 2nd, 3rd Saturday, the day before the 2nd Saturday). Advanced reservations were required for these. A total of 42 sessions were held with 5,012 participants this year. For one of the regular public screenings, the office held "Astronomers' Talks" where researchers talked about the latest research and this was popular. Group screenings were performed on Wednesdays and Fridays for 69 groups (2,020 people). In addition, 64 group tours (837 people) were organized and a total of 7,869 guests watched the 4D2U stereoscopic movies.

The cultural property event (the NAOJ Solar Tower Telescope Special Open Days) scheduled for the spring was canceled as a preventative measure against the spread of COVID-19.

(2) Telephone Inquiries

The office received inquiries from the media, government offices, and the general public, and responded to a total of 4,784 inquiries (Table 5), including 590 media inquiries, 101 letters, and 31 official documents.

(3) Media Reception

We received 157 interview and filming requests from various media. Among these, we dealt with 132 requests. The contents were: 31 news-paper articles; 46 TV programs (18 news programs, 14 science programs, 2 dramas, 12 others); 29 publications (25 magazines, 4 books); 13 websites (6 news sites); 5 radio programs; 1 animation movie; 7 others. In this fiscal year, we started to charge a fee for commercial filming and photography in the campus. The office received a total of 4 filming/photography requests including 1 commercial, 1 drama, 1 documentary program, and 1 gravure photoshoot.

(4) Educational and Outreach Activities

The "FUREAI (Friendly) Astronomy" project, now in its 10th year, was planned to provide lectures to 125 schools. However, lectures scheduled at two schools for the end of the fiscal year were canceled due to COVID-19, so the actual number was only 123. In this fiscal year, a minimum of 5 and a maximum of 280 students participated in each lecture and a total of 60 lecturers provided events for 11,951 students. In 10 years, a total of 66,431 students have attended the lectures in 684 schools from Hokkaido in the north to Okinawa, Hachijō-jima, and Ogasawara in the south, as well as Myanmar and Argentina.

"Astronomy Classes for Kids in Summer" and "Astronomy Workshop for Communicators," which were held until last fiscal year, were canceled due to the budget reduction.

The Public Relations Center served as the secretariat for the "Mitaka Open House Day," a special public event held at Mitaka Campus and organized by the steering committee, and contributed to some of the programs. This event was held with the theme "20 Years of the Subaru Telescope," which also served as the theme for this year's lecture. It was co-hosted by the Astrobiology Center, National Institutes of Natural Sciences; the Institute of Astronomy, the School of Science, the University of Tokyo; and the Department of Astronomical Science at the School of Physical Sciences of the Graduate University of Advanced Studies. The event was originally planned for two days, on October 25 (Fri.) and 26 (Sat.). However, the pre-open day scheduled for the 25th was canceled due to a heavy rain warning and only the open day scheduled for the 26th took place. The event flourished: a total of 4,113 guests attended on the open day. In FY 2019, we discontinued a stamp rally because of the budget reduction, but instead, introduced several recommended routes for visitors to accommodate a wide range of generations. The attractions included tours of research facilities usually inaccessible to the public; hands-on exhibits and mini lectures; games and quizzes for children; immersive VR experiences; and other events presented by various NAOJ projects.

(5) Community Activities

The "Mitaka Picture Book House in the Astronomical Observatory Forest" welcomed 33,559 visitors in FY 2019. The Outreach and Education Office supervised the exhibition "Connecting with the Universe" (July 2019 to June 2020). We also cooperated with an opening ceremony, modern and traditional Tanabata events, moon viewing event, and other

events. In addition, through the "Mitaka Picture Book House in the Astronomical Observatory Forest, Picture Book Original Drawings Hallway Exhibit Contest" which started from FY 2013, the Outreach and Education Office cooperated in the selection of 5 winning books.

The Outreach and Education Office conducted the 11th "Mitaka Solar System Walk" from September 20 (Fri) to Sunday, October 27 (Sun) in cooperation with Mitaka City and the non-profit organization (NPO) Mitaka Network University. Stamps were placed at 225 shops and facilities around Mitaka City. Adding 25 limited event stamps, 250 stamps were placed. Approximately 19,000 guide-maps/stamp sheets were distributed, of which 2,843 people turned theirs in for a prize. In 2019, the "Mitaka Solar System Walk" (co-hosted by NAOJ) executive committee received the 2019 (36th) Special Award of the Community Renovation Recognition Association for its 10 years of dedicated service.

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 and also assisted by providing teachers and workshops.

The "Information Space of Astronomy and Science" for which Mitaka City, Mitaka NETWORK University, and Mitaka City Planning Board co-operate celebrated the fifth year since its opening and eight exhibitions were held in FY 2019. The Public Relations Center had proposed four of these exhibitions and helped with three lectures and workshops.

The office contributed to publicizing NAOJ's activities and to playing monthly astronomical information videos, and contributed to the "Cosmic Reading Bookstore" and the "M-Marche Project" held on every fourth Saturday. We had 15,304 visitors in FY 2019, with the cumulative number since the foundation reaching 79,127 as of March 2020. It has been acknowledged as a location in town where science can be easily accessed.

(6) Merchandizing Business

The "You are Galileo!" project was launched in 2008 aiming to provide more chances for the world's children to observe the sky through astronomical telescopes. In FY 2019, the project advanced the development, production, and sale of a telescope kit. The kit was originally named the "NAOJ Telescope Kit," but the IAU nicknamed it the "Kaifu-NAOJ Telescope Kit." These 5-cm aperture telescope kits, with eyepieces of 16x and 66x magnification, started to be sold and distributed in July 2019. The total number of kits produced so far is 2,400, and 350 of them were distributed for teachers' training around the world as a part of the IAU100 projects.

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 dedicated site for Mars' closest approach, an astronomical event that is expected to attract much attention in 2020.

5. Spectrum Management Office

The Spectrum Management Office (hereafter the "office") was established in the Public Relations Center on April 1, 2019. This new office aims to preserve the environment for radio astronomy observations. The former Radio Astronomy Frequency Committee was responsible for this task until FY 2018. The office consists of four staff members, including two dedicated (Head and a research supporter) and two members with concurrent posts. Its activities include both domestic and international affairs. The scope of its activities is limited, for the time being, to the radio astronomy environment. But in the medium and long term, the office is expected to extend its task to include light pollution, a pressing issue for optical astronomy.

This fiscal year, the office participated in six international meetings and 36 domestic meetings. In addition to these, the office has also participated in e-mail discussions and video conferences as needed.

(1) Establishment of New Framework for Spectrum Management

The duties of the Radio Astronomy Frequency Committee have been changed significantly upon the establishment of the office; accordingly the committee rules have also been revised. This revision redefined the relationship between the office and the committee as:

The office shall be an implementation body of spectrum management for radio astronomy, and work as the unified communication gateway for MIC and ITU.

The committee shall supervise the activities of the office and advise it so that its duties are adequately carried out.

Figure 1 shows a conceptual diagram of this new framework. These changes were communicated to the related domestic radio astronomy observatories.

Meanwhile, the office uses practically the same communication lines with all parties involved as those used

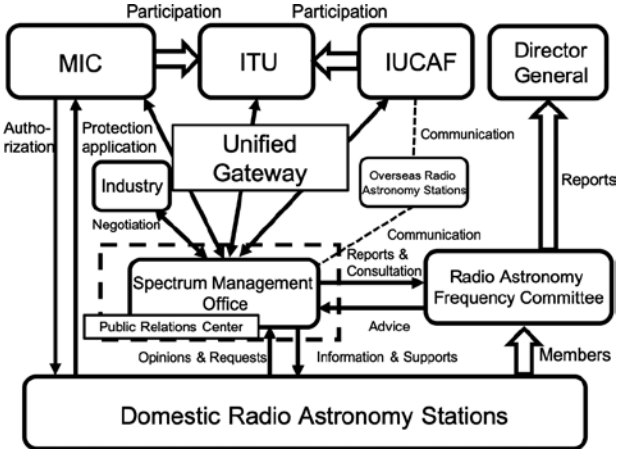


Figure 1: Conceptual diagram of Japanese Implementation System for Spectrum Management.

by the former Radio Astronomy Frequency Committee, but rearranged in the following manner:

Wiki site only accessible to those involved with Japanese spectrum management (password required)
http://freqras-int.mtk.nao.ac.jp/secure/wiki/index.php?FrontPage

Mailing list for those involved with Japanese spectrum management
freqmgr-smo@ml.nao.ac.jp
(Currently, 24 NAOJ e-mail addresses and 10 non-NAOJ email addresses are registered.)

Website to publicize spectrum management activities (no password required)
https://prc.nao.ac.jp/freqras/

(2) Results on International Issues

As for international issues, the office participated in the discussions on the agenda items of the World Radiocommunication Conference 2019 (WRC-19). This conference was held in November 2019 on the initiative of the International Telecommunication Union (ITU), the international organization that regulates the use of radio resources, and was hosted by the ITU Radiocommunication Sector, ITU-R. The agenda items were discussed in the meetings of ITU-R Working Party 7D (WP7D) and the Asia-Pacific Telecommunity (APT). The Head of the office participated in WRC-19, WP1A, WP7D, and APG-19 (APT Conference Preparatory Group for WRC-19), and contributed to the discussions. The results of the discussions are summarized below.

1) The Results of WRC-19

The World Radiocommunication Conference 2019 (WRC-19) was held between October 28 and November 22, 2019, in Sharm El Sheikh on the southern tip of the Sinai Peninsula. WRC-19 addressed over 30 agenda items in preparation for a future revision of the Radio Regulations (RR), the international rules for the use of radio resources. The draft revisions to RR proposed at WRC-19 are available at the ITU-R website as the Final Acts, which will be later examined by the Radiocommunication Bureau of the ITU-R and be published as a new edition of RR (RR2020).

https://www.itu.int/pub/R-ACT-WRC.14-2019

Brief summaries of the WRC-19 results are given as follows:

(a) Spectrum allocation for IMT2020 (5G) (Agenda Item 1.13): The frequency bands 24.25–27.5 GHz, 37–43.5 GHz, 47.2–48.2 GHz, and 66–71 GHz were recognized as new spectrum allocations available in Japan. It has been confirmed that at least 35–45 km of separation distance is required to protect the 42.5–43.5 GHz radio astronomy band from their interference. There are no ongoing projects that plan to operate in the 66–71 GHz band.

(b) Widening the use of Iridium (Agenda Item 1.8): This item was to consider a possible deployment of additional maritime radiocommunication systems including modernization of the Global Maritime Distress and Safety System (GMDSS). WRC-19 discussed the modernization of GMDSS that allows effective rescue operations when a maritime emergency occurs, and the introduction of a satellite system into the VHF Data Exchange System (VDES), which is expected to provide a worldwide communication service for vessels. The discussion concluded with an agreement that the 1621.35–1626.5 MHz band is allocated to utilize the Iridium satellite system for GMDSS. To avoid interference to the OH band by the band used by Iridium, a mandatory provision was included in the RR footnote 5.372.

Since the iridium satellite system operates in the 1.6 GHz band, it has caused illegal interference in the OH band for the past 21 years. It was impressive that, during the meeting, European and other countries repeatedly denounced the illegal activities of Iridium.

(c) Band Identification for land-mobile and fixed service applications (Agenda Item 1.15): The 275–450 GHz band was identified for use by land-mobile and fixed service applications. This frequency band was previously used only by passive services such as radio astronomy or Earth observations, which only involve receiving radio waves. This band is expected to be used primarily in low-altitude locations, so the adverse effects on radio astronomy observations, which are conducted only in high altitudes, are thought to be minimal.

(d) Agenda Items for 2023 World Radiocommunication Conference (WRC-23)
Several agenda items related to IMT were adopted. WP7D (radio astronomy) is expected to contribute particularly to the agenda items 1.2, 1.4, 1.6, 1.11, and 1.14. There is no room in this report for full details of the items, but the number of agenda items is small compared to the number addressed in a normal study cycle.

2) The Results of the WP1A and WP7D Meetings

One WP1A meeting was held from May 27 to June 7, 2019, at the ITU Headquarters in Geneva. The 2019 WP7D meeting was held at the same place from May 27 to May 31.

At the WP1A meeting, the office participated in discussions on the Wireless Power Transfer (WPT) system. While Japan is promoting the WPT system as a national priority, many of the overseas countries did not seem to have positive attitudes toward it. At the WP7D meeting, the office contributed in finalizing a new ITU-R Report that assesses the impacts on radio astronomy by automotive radars that operate in the 76–81 GHz band. The results have already been published in the Report ITU-R RA.2457 “Coexistence between the radio astronomy service and radiolocation service applications in the

frequency band 76–81 GHz."

(3) Results and current status of MIC's investigation subjects

Currently, the following working groups related with radio astronomy are organized under the MIC Information and Communications Council.

1) Working Group of the Satellite Communications System Committee: This working group aims to provide regulatory measures in Japan applied to global internet access through massive satellite constellations including Starlink and OneWeb. It has been proposed to use a frequency band adjacent to the 10.6–10.7 GHz radio astronomy band. As for OneWeb, which became a subject of investigation first, it was agreed that the satellites must be equipped with filters and deactivate the 10.7–10.95 GHz channel near observatories in order to protect radio astronomy observations. Following OneWeb, Starlink officially announced intentions to enter into the Japanese market, so the working group started to investigate its potential impacts.

2) UWB Radio System Outdoor Use Working Group of the Land Wireless Communication Committee: This working group aims to make ultra-wideband (UWB) radio systems, which operate in the 7–10 GHz band, available outdoors. It was organized in response to requests from Apple and other overseas companies. It has been agreed to reduce the unwanted emission levels from UWB systems to protect the 6.7 GHz CH_3OH maser observations from harmful interference. The report is being prepared.

3) New Generation Mobile Communication System Committee: This committee considers issues related to 5G mobile communication systems in Japan. This investigation subject is closely linked to WRC-19 agenda item 1.13 (see subsection 2.1) and includes the use of the 41–43.5 GHz band. It was concluded that at least 35–45 km of separation distance is required to coexist with radio astronomy observations in the 42.5–43.5 GHz band.

4) 60 GHz Band Radio Facilities Working Group of the Land Wireless Communication Committee: This working group was organized in response to Google's request to use the 57–64 GHz band to achieve high range resolution sensing. Since the second harmonic frequency range overlaps the CO J=1–0 line, it has been agreed to reduce the unwanted emission levels of 60 GHz systems. This agreement has been communicated to Nobeyama Radio Observatory.

5) Discussions Toward Aerial Use of Mobile Phones: Current mobile phones are, in principle, supposed to be used 1.5 m above the ground. There have been discussions on requests to use a mobile phone mounted on an unmanned aerial vehicle (or drone) for radio communication. As a result, aerial use of mobile phones up to 150 m above the ground is to be approved except for ones that operate in the 1.5 GHz band, which will impair radio astronomy observations.

6) WPT System Working Group of the Land Wireless Communication Committee: This working group seeks the possibility of using the 920 MHz, 2.4 GHz, and 5.7 GHz bands for wireless power transfer (WPT). The results, which include the possible ways to avoid adverse effects on radio astronomy observations, have been summarized in the report titled "Technological requirements for WPT systems" published by the committee.

(4) Application for Designation of Receiving Equipment: Present and Near Future

Applications for designation of receiving equipment are based on the Radio Law, Article 56. When 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 other radio stations or equipment designated by the Ministry of Internal Affairs and Communications. The designation approved this fiscal year was for a short-wave-band radio astronomy station operated by Tohoku University and was published in a public notice (MIC Public Notice No. 3 of January 16, 2020). Also, the deletion of the 1.4 and 1.6 GHz bands used by Nobeyama Radio Observatory was published in an official gazette (MIC Public Notice No. 4 of January 16, 2020). As for four VERA stations, whose designation period expires in December 2020, we need to wait for the decision of Mizusawa VLBI Observatory.

(5) Mega-constellations (Starlink and others)

The IAU, NAOJ, and other astronomy-related organizations have issued position statements expressing their concerns about mega-constellation projects such as Starlink and OneWeb, which aim to provide global Internet access through massive satellite networks. Mega-constellations operate in the 10.7–12.7 GHz band. However, we can avoid their interference in the radio astronomy band (10.6–10.7 GHz) immediately below the satellite band if mega-constellations deactivate the 10.7–10.95 GHz band near observatories and are equipped with filters. On the other hand, sunlight reflected from the satellites can impair optical-infrared observations. If the mega-constellation projects launch their satellites as planned, around 600 satellites are expected to be visible at any given time at magnitudes ranging from 2–7. Given that the mega-constellation side is working hard to reduce reflected light, the astronomy side should measure the brightness of the satellites. Both sides must work together to maintain the best possible observation environment. For this reason, we started preparing to measure the brightness of the satellites from Ishigakijima Astronomical Observatory. The observations will start in FY 2020.

This matter attracted great interest from Japanese media and was reported many times in various media outlets including the NHK News, the Asahi Shimbun, and the Mainichi Shimbun. We are still receiving calls from media agencies.

(6) Maintenance of the Agreements on L-band Operations

Through negotiations with satellite service providers, we have set coordination zones around three observatories—the Nobeyama Radio Observatory (NRO), the Usuda Deep Space Center (UDSC), and the Kashima Space Technology Center (KSTC), and based on these negotiations, we have signed multiple operational agreements. This is because Inmarsat and Thuraya handsets, which operate in the 1.6 GHz band (L-band), can cause interference with the three observatories. In response to the decommissioning of 1.6 GHz band observations at NRO, we are amending the existing agreements to remove terms related to NRO.

Among these agreements, the one with SoftBank Corp. was signed again on September 20. However, because Typhoon Faxai has destroyed the Kashima 34-m Antenna, the only radio observatory covered by the agreements is now UDSC of ISAS. The existing agreements, therefore, need to be amended to cover UDSC alone, and JAXA or ISAS should lead the procedures.

(7) Negotiation with Iridium

For almost two years, we have been negotiating with Iridium on how radio astronomy observations at 1.6 GHz can coexist with Iridium's next-generation satellite system. Iridium is refusing to take standard interference mitigation measures (separation distance) and insisting that monitoring the use of mobile devices alone is sufficient. From the radio astronomy perspective, on the other hand, we doubt that monitoring alone can prevent interference. Because KSTC of NICT has become unable to operate due to Typhoon Faxai and UDSC is now the only relevant observatory, we conducted a more detailed interference assessment for UDSC that considered the effects of terrain and other factors. The minimum clearance was measured clockwise from the north at 45° intervals and found to be 6.5 km at most. Future negotiations are to be entrusted to JAXA/ISAS.

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 2020 edition of the "Calendar and Ephemeris" and compiled the 2020 version of the Ephemeris section of the "Rika Nenpyo" (Chronological Scientific Tables). ECO also posted the 2021 edition of the "Reki Yoko" in the official gazette on February 3, 2020. In addition to those paper-oriented products, ECO maintains web versions of "Calendar and Ephemeris" and "Reki Yoko" and updated data simultaneously with the release of "Reki Yoko." In FY 2019, ECO adopted the WGCCRE Report 2015 and to catch up with the change of era name, ECO revised the web version of "Reki Yoko 2020."

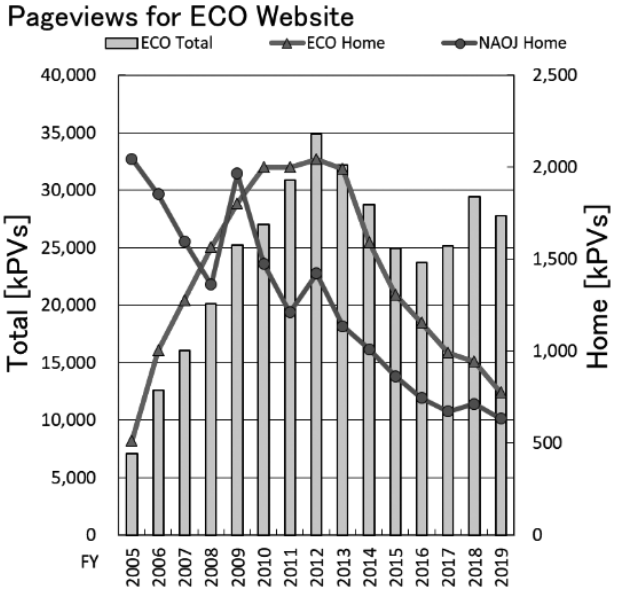


Figure 1: Pageviews for ECO Website.

(2) As for the website (https://eco.mtk.nao.ac.jp/koyomi/index.html.en), ECO continuously updated the contents of the Ephemeris Wiki and released long term databases for eclipses and Japanese historical dates. Despite the end of the astronomical phenomena awareness campaigns, ECO provided the radiant points of the Perseid and Geminid meteor showers in Sky Viewer. In FY 2019, there were about 27.8 million page views for the ECO website.

(3) The Japan Association for Calendars and Culture Promotion hosted Mini Forum, its 9th General Meeting, and the annual Calendar Presentation Ceremony.

(4) ECO hosted a regular exhibition in collaboration with the Library, selecting from NAOJ's invaluable collection of historical archives for Japanese and Chinese books. The theme of the 58th regular exhibition was "Subaru and the Great Comet of 1882." Past exhibitions are also 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.

For non-NAOJ personnel who wish to use the Mitaka Library materials, the Library is open to the public on weekdays. In FY 2019, the Library temporarily stopped the public service in March as a preventative measure against the spread of COVID-19, but a total of 601 non-NAOJ personnel had used the Library by the end of February. Also, for researchers and students belonging to other organizations, we

lend books or provide photocopies via the institute's library. In FY 2019, photocopies or loans were provided in a total of 104 cases.

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. We also lent our documents to history and art museums for exhibitions. These items have appeared in various external publications.

During the Mitaka Open House Day festivities in October, we opened part of the Mitaka Library to the public as in the past. Most of the reading room on the first floor was opened to the public. In addition to materials for general and young readers, we actually allowed visitors to take a look at many specialized books related to astronomy.

The number of books and journals owned by Mitaka Library and each observatory and the condition of continuing NAOJ publications are published in Section XII 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 31 Fiscal 2018 (Japanese)
- Annual Report of the National Astronomical Observatory of JAPAN Volume 21 Fiscal 2018 (English)
- NAOJ Pamphlet (Japanese)
- NAOJ Pamphlet (English)
- NAOJ News, No. 309 – No. 320 (April 2019 – March 2020)
- NAOJ Calendar (The 15th in the series)
- Radio Astronomy Public Relations Comic "ALMAr's Adventure" (#9)

In FY 2019, the office thoroughly revamped the NAOJ pamphlets (Japanese/English versions) to reflect NAOJ's long-term research direction, introducing new information on collaborative research involving major telescopes. Aside from these pamphlets, the office produced and distributed the Annual Report of the NAOJ (Japanese/English versions) in normal business. In the systematic production of special editions with the goal of developing project outreach support in NAOJ News, extra copies of each of the special editions ("ALMA Special Edition" September; "Nobeyama Observatory 50 Anniversary Special Edition" November; "Mizusawa VLBI Observatory 120th Anniversary Special Edition" part one December and part two January; and "Welcome to GALAXY CRUISE" February) were printed and these aided the outreach efforts of each project. From now on, to develop and share NAOJ News articles as a resource to be used as outreach content for each project, we plan to promote the production of overall, basic articles through close cooperation with researchers and promote international magazine compiling. Other than periodicals, the 2020 calendar "NAOJ Nobeyama Radio Observatory 2019" (the 15th since 2005) was created. In addition, like in other years editing support was also given to the publication of the "Rika Nenpyo 2020 (Chronological Scientific Tables, Astronomy section)."

9. International Astronomical Union Office for Astronomy Outreach (IAU/OAO)

In FY 2019, the OAO focused on supporting the activities of the National Outreach Coordinators (NOCs) in the IAU100 projects. The year 2019 marked the 100th anniversary of the IAU. The OAO implemented the IAU100 projects internationally in cooperation with the IAU100 Secretariat based at Leiden University in the Netherlands. Using the NOC network as the core of the implementation, the organization established committee-led IAU100 projects in 123 countries to secure cooperation among major national/regional communities. In FY 2019, nearly 5000 IAU100 activities were implemented in 143 countries/regions, involving 5–10 million participants and reaching an estimated 100 million people through media coverage.

The OAO published the Communicating Astronomy with the Public Journal (CAPjournal) Vol. 26 and Vol. 27. The special edition about "Outreach for Development" welcomed as guest editors colleagues from the OAO's sister office in Cape Town, the Office of Astronomy for Development (OAD). The online editions can be freely browsed at the CAPjournal and the IAU websites.

OAO posted a total of 500 posts on the OAO social media (Facebook, Twitter). The total followers of OAO social media pages increased significantly with the large IAU100 visibility and high profile of the celebrations. The followers of our Facebook page, in particular, reached 5357. In FY 2019, the IAU Astronomy Outreach Newsletter (e-mail news) was delivered twice a month or 24 times with six issues related to the IAU100. A total of 273 items were provided to 5258 subscribers all over the world. The newsletter has been translated into seven different languages and redistributed by collaborators in the respective countries. The OAO is also responsible for making the IAU website content (Themes) for the public, publishing in 2019 a new Theme on satellite constellations.

For the first time, in FY 2019, the OAO implemented a grant program for NOCs. The applications for this IAU support program were limited to multi-national NOC partnerships. A total of 19 proposals involving 39 countries were submitted and after a two-step selection process, four proposals involving 15 NOC groups were awarded with the IAU grants. This support program is expected to continue in the coming fiscal years through the support of the IAU.

The OAO received the 2019 NAOJ Director General's Prize for its leading role in the Scientific Organizing Committee (SOC) and the Local Organizing Committee (LOC) of the IAU Symposium 358 held at NAOJ Mitaka Campus in November 2019.

The IAU Astronomy Translation Network (ATN) has 382

registered volunteers, divided into 10 different language groups and translate each language. Based on a partnership agreement with the National Astronomical Research Institute of Thailand (NARIT), the OAO welcomed a trainee from NARIT for six months starting in December 2019.

10. IAU Symposium 358

From November 12 to 15, 2019, the IAU Symposium 358 on "Astronomy for Equity, Diversity and Inclusion - a roadmap to action within the framework of the IAU centennial anniversary" was held at NAOJ Mitaka Campus. This symposium, celebrating the 100th anniversary of IAU, was the first of the series dedicated to discussing the advancement of equity, diversity, and inclusion in astronomy. The PRC staff members from OAO, PRO and other offices played major roles, from planning to organizing, in the symposium. The symposium welcomed 124 participants from 31 different countries, including the IAU President and IAU officials, and applications for participation totaled nearly 240, which is almost double the capacity (120 people) of the conference room. The total number of attendees was kept small in order to generate more meaningful connections between individuals working to improve equity, diversity, and inclusion in astronomy.

The conference hosted four keynote sessions; 57 talks and 37 posters; four Shared Spaces; one Safe Space; and two special sessions dedicated to the Mitaka Resolutions.

Along with the symposium, we held the tactile exhibition "Inspiring Stars," one of the IAU 100 projects, at the lobby of the Main Building. The exhibition features tactile models educational for everyone, whether or not they have a visual impairment, and a demonstration of a data-to-sound converter. These exhibition pieces were developed by eight countries including Japan. Participants as well as NAOJ staff stopped by to enjoy the exhibition throughout the symposium.

17. Division of Science

1. Overview

The previous Division of Theoretical Astronomy was reorganized and a new Division of Science has been established so that the division now consists of observational astronomers as well as theoretical astronomers and astrophysicists. The Division of Science aims at achieving internationally outstanding research results both in quality and quantity toward the accomplishment of the following four goals that were set by the NAOJ Board, and is engaged in research activities for FY 2019 accordingly:

- Advance the world class cutting-edge astronomy research.
- Pursue astronomy research, particularly in areas that utilize the NAOJ supercomputer or large-scale observational instruments to give further insight for the development of new instruments.
- Encourage collaborations among researchers in Japan and strengthen the domestic astronomy research.
- Invigorate postgraduate education.

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, planetary formation, activities of compact objects, and plasma phenomena in astronomy and astrophysics; joint research between theoretical and observational astronomy using observational facilities of various frequency bands such as the Subaru Telescope, ALMA, and the Nobeyama 45-m Radio Telescope; and interdisciplinary research on the physics of elementary particles and atomic nuclei.

The Division of Science aims to facilitate Japan's high competitiveness on the international plane through continuous production of world leading research results and offers a superb research environment as a base for astronomy research accessible to researchers in Japan and overseas. It has accepted a wide range of both Japanese and international researchers as visiting professors, research affiliates, and visiting joint research fellows who actively engage in various research projects in the division. In particular, the division has fostered research developments to create an influential research center for young researchers and is actively engaged in personnel exchanges with many universities and research institutes. In addition, the division actively organizes numerous cross-disciplinary international conferences, domestic meetings, and seminars for the fields of theoretical astronomy and astrophysics, observational astronomy, and physics; and it leads research activities in various related fields of astronomical science. The division's full-time professors, associates, assistants, and project assistant professors, together with NAOJ postdoctoral fellows and JSPS fellows, conduct a variety of unique research projects involving postgraduate students from the Graduate University of Advanced Studies and the University of Tokyo.

2. Current Members and Transfers

In FY 2019, the dedicated faculties of the Division of Science included five professors, one project professor, one associate professor, and six assistant professors in addition to one adjunct professor and one adjunct assistant professor who concurrently held primary positions at the Center for Computation Astrophysics. In addition to these research and educational members, the division was aided by eight project assistant professors, four project research staff, one EACOA fellow, one special researcher of the Japan Society for the Promotion of Science, one research supporter, and in addition two administrative supporters who gave full support to all activities of the division.

3. Research Results

The refereed research papers and refereed proceedings papers for the presentations in the international conferences carried out by the division members as authors or presenters are, respectively, more than 200 and 60 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:

- Discovery of High-Redshift Superluminous Supernovae by the Subaru Hyper Suprime-Cam (MORIYA, Takashi)
- Origin of Titan (OGIHARA, Masahiro, et al.)
- The First Detection of $^{13}C^{17}O$ in a Protoplanetary Disk with ALMA: A Robust Tracer of Disk Gas Mass (NOMURA, Hideko, et al.)
- Probing the Neutrino Oscillation by Supernova Nucleosynthesis (SASAKI, Hirokazu, KAJINO, Toshitaka, et al.)
- Neutrino-^{13}C Cross Sections at Supernova Neutrino Energies (KAJINO, Toshitaka, BALANTEKIN, Baha A., et al.)
- Identification of Hermit-Gaussian Photon with Compton Scattering (KAJINO, Toshitaka, et al.)
- Effects of Shock Propagation on Neutrino Oscillation and ν-induced Nucleosynthesis in Supernova (KAJINO, Toshitaka, et al.)
- Current status of r-process nucleosynthesis (KAJINO, Toshitaka, BALANTEKIN, Baha A., et al.)
- Many others.

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.)
- Researchers Discover Asteroidal Ice Fossils in Primitive Meteorite (KATAOKA, Akimasa, et al.)
- De-noising cosmic mass density maps with deep learning

(SHIRASAKI, Masato, et al.)
- Central engine model for bright supernovae (SUZUKI, Akihiro, et al.)
- A Successful Simulation of 3D Turbulence in O-shell Burning in Core-Collapse Phase of a Massive Star (TAKIWAKI, Tomoya, et al.)
- Asteroseismology of proto neutron star suggests linkage of gravitational wave and f-mode oscillation (SOTANI, Hajime, TAKIWAKI, Tomoya, et al.)
- A strange supernova discovery by Subaru/Hyper Suprime-Cam (MORIYA, Takashi, et al.)
- Pinpointing the Formation Site of Planet around Nearest Young Star with ALMA (TSUKAGOSHI, Takashi, et al.)
- Unveiling Mechanism of X-ray flares in Protostars (TAKASAO, Shinsuke, IWASAKI, Takasao, et al.)

4. International and Domestic Collaborations and Cooperation

The Division of Science played a leading role in research activities in the fields of astronomy and astrophysics. This division organized numerous cross-disciplinary international conferences, domestic meetings, and seminars in various related fields of astronomical science. The division members played several important roles in these science activities and domestic and international committees:

- The 10th European Summer School on "Nuclear Astrophysics," Catania in Italy, June 16–23 in 2019.
- The 15th International Symposium on the "Origin of Matter and Evolution of Galaxies (OMEG)," Yukawa Hall in Kyoto University, July 2–5, 2019.
- Workshop on "Cosmology and Galaxy Redshift-Survey," NAOJ, August 21–22, 2019.
- NAOJ Science Workshop on "Planet Formation," NAOJ, November 15–19, 2019.
- International Workshop on the "Origin of Elements and Cosmic Evolution: From Big-Bang to Supernovae and Mergers," Beihang University in China, November 27–29, 2019.
- 1st International JINA-CEE IReNA/NAOJ Workshop, NAOJ, December 3–4, 2019.
- RIRONKON Symposium, NAOJ, December 15–27, 2019.

Takashi Moriya chaired the HSC SSP Transient Working Group and ULTIMATE-Subaru Time-Domain Science Working Group and co-authored the Subaru+TMT Science Book 2020. Akihiro Suzuki served as a reviewer for the Subaru Telescope proposal. Eiichiro Kokubo was a member of the Subaru IRD and the Inter-Division A-F Commission of the International Astronomical Union (IAU). Masahiro Ogiwara served as a reviewer for the Subaru Telescope proposal and a member of the Subaru IRD SSP. Akimasa Kataoka served as a reviewer for the Subaru Telescope proposal and was a member of the East-Asia ALMA Science Workshop 2019. Hideko Nomura served as a member of the TMT Scientific Advisory Committee, ALMA JSAC/EASAC, the SPACA Research Promotion Committee, and the SPICA Science Study Team, and co-authored the Subaru+TMT Science Book 2020. Toshiki Kajino signed the JINA-CEE IReNA/NAOJ International Research Exchange Agreement as a representative of Japan Forum of Nuclear Astrophysics, and served as a member of the International Evaluation Committee of the Canadian Science and Technology Council, the European Institute for the Advancement of Advanced Computer Science, the Swiss National Science Foundation, and the International Associate of the European Center for Nuclear Physics. He also served as editor-in-chief of the Open Nuclear and Particle Journal, International Friendship Committee member of the American Physical Society, council member of the Yamada Science Foundation, and member of the Sigma Committee of the Atomic Energy Society of Japan. He also served as the chair, organizing committee member, or international advisory committee member of five international conferences on astrophysics and nuclear physics.

5. Educational and Outreach Activities

The members of the Division of Science actively engaged in both graduate and undergraduate lectures at the University of Tokyo and many other institutes and universities including classes at Super Science High Schools. They also engaged in public promotions and outreach activities by offering lectures to the general public.

6. Awards

Masami Ouchi was recognized as a Highly Cited Researcher of 2019 by Clarivate Analytics, Inc. Mitsuru Sôma received the 2019 Homer F. DaBoll Award from the International Occultation Timing Association. Toshitaka Kajino was awarded the 2019 Best Science Award and the International Contribution Award by Beijing University of Aeronautics and Astronautics. Luo, Yudong received the Young Asian Physical Society Award at the 15th International Conference on The Origin of Matter and The Evolution of Galaxies, Hideaki Takemura and Yuta Yamazaki received the 49th Summer School Oral Awards for Young Astronomy and Astrophysics, and Misako Tatsuma received the Student Presentation Award at the 2019 Annual Meeting of the Japan Geoplanetary Science Union.

7. Main Visitors from Overseas

The Division of Science strives to fulfill its roles as a center of excellence in Japan for the studies in astronomy and astrophysics and also as an international research institution by providing an excellent research environment. It engages in various joint research projects with visiting researchers from overseas, with the help of Grants-in-Aid for Scientific Research, government subsidies for operating expenses, the NAOJ budget for guest visitors, and others. The main international visitors of FY 2019 to the division are listed below:

BALANTEKIN, Akif B. (University of Wisconsin–Madison,

USA)
CAO, Li-Gang (North China University of Electronics, People's Republic of China)
CHEOUN, Myung-Ki (Soongsil University, South Korea)
FAMIANO, Michael A. (Western Michigan University, USA)
HE, Meng (Beihang University, People's Republic of China)
HE, Zhenyu (Beihang University, People's Republic of China)
LAI, Shih-Ping (National Tsinghua University, Taiwan)
MATHEWS, Grant J. (University of Notre Dame, USA)
MAZZALI, Paolo (Liberpool John Moores University, UK)
NAGY, Andrea (University of Szeged, Hungary)
NGUYEN, Thi Phuong (Vietnam National Space Center, Vietnam)
NORMAN, Colin Arthur (Johns Hopkins University, USA)
PEREIRA, Jpnas Pedro (Federal University of ABC, Brasil)
PIAN, Elena (Italian National Institute of Astrophysics/Institute of Space Astrophysics and Cosmic Physics, Italy)
VAN DER MAREL, Nienke (University of Victoria, Canada)
WANG, Wei (Wuhan University, People's Republic of China)
YAO, Xingqun (Beihang University, People's Republic of China)
ZHANG, Shisheng (Beihang University, People's Republic of China)

18. Office of International Relations

The Office of International Relations strives to promote and facilitate further internationalization at NAOJ by maintaining 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; managing Security Export Control; offering support for hosting international conferences, workshops, and seminars; hosting booths at international events; and providing support for visiting international staff and students.

1. Support for International Collaborative Projects

The Office of International Relations handled administrative coordination in approval processes to sign agreements and memoranda for international collaborations, conducting preliminary reviews for legal documentation, and managing export security control for export of goods or transfer of technology. In FY 2019, the Office was responsible for drafting and/or reviewing a total of fourteen new or renewed international agreements. In the area of security export control, activities included review and processing of 210 cases (310 items). An explanatory session hosted by NINS was held at NAOJ on February 5, 2020 (66 participants from NAOJ).

2. Liaison Work for Overseas Astronomical Research Organizations

The Office also assisted the Executive Advisor to the Director General in charge of international research coordination upon coordinating with the other 3 institutions forming the East Asian Core Observatories Association (EACOA) including NAOC (China), KASI (Republic of Korea), and ASIAA (Taiwan) for selection and interview of the 2020 EACOA/EAO postdoctoral fellowship program recipients.

For the annual meeting of the American Astronomical Society (AAS) held in Honolulu from January 5–9, 2020, to make the best use of the limited budget, the Office participated in a joint booth with the Maunakea Observatories, which include the Subaru Telescope. With an aim to promote NAOJ to young researchers from around the world, the Office mainly contributed financially by providing promotional items, covering the cost for the exhibition booth, and supporting the travel expenses of staff belonging to the Subaru Telescope.

Same as last year, the Public Relations Office was responsible for organizing overseas activities in relation to the general public, while 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. Some examples of such services include on-site assistance with administrative procedures at municipal and governmental offices, providing help in searching for housing, gathering information relating to a child's education, and offering consultation relating to health problems or worries in everyday life. In particular, during FY 2019, the SD collaborated closely with the host researcher at NAOJ in the day-to-day support of a long-term (6 months) stay of an international visiting staff member having a disability and severe medical conditions. The SD successfully completed this unprecedented attempt through careful preparations such as securing hospitals that offer treatment to international patients and finding medical specialists who have abundant knowledge of the visitor's medical condition.

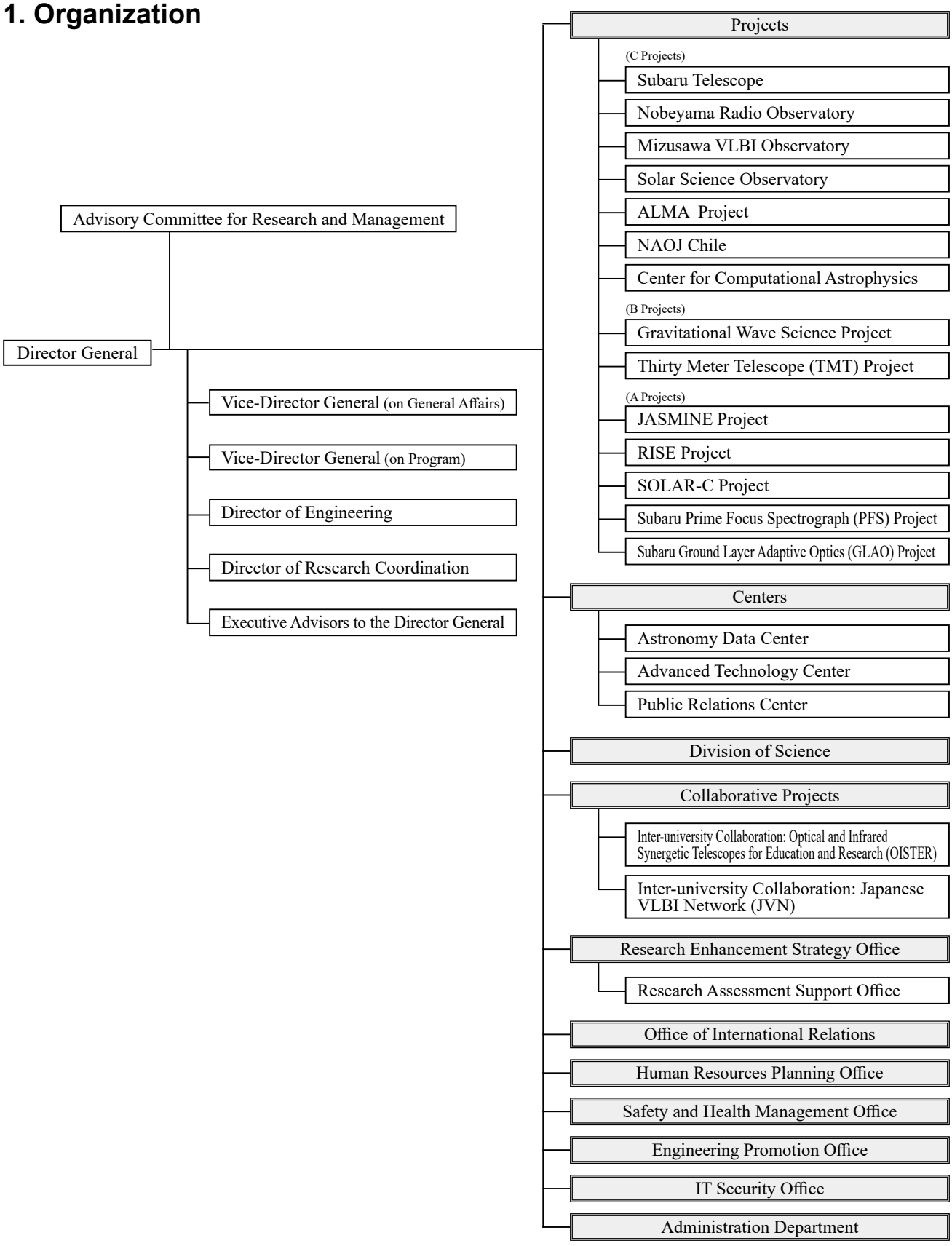
To provide better services, the SD has been changed to operate under a 2 staff × 3 days shift since October 2017. Thus, on Thursdays, when both of the SD staff are at the office, meetings are held between the SD staff and the other office members to ensure the smooth transfer of on-going issues, as well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

The Office continued the Japanese language lessons, helping the international members of NAOJ acquire beginner level capability, and for FY 2019, a combination of E-learning features and classroom lessons were provided, as was in the previous year.

The Office continued its activities to support non-Japanese speaking staff, by translating various forms for applications and notices, including e-mail text and explanations of procedures (35 documents).

III Organization

1. Organization



2. Number of Staff Members

(2020/3/31)

Director General	1
Research and Academic Staff	145
Professor	26
Executive Engineer	0
Associate Professor	39
Senior Research Engineer	11
Assistant Professor	55
Research Associate	0
Research Engineer	14
Engineering Staff	39
Administrative Staff	57
Research Administrator Staff	6
Employees on Annual Salary System	153
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	32
Full-time Contract Employees Transferring to the Mandatory Retirement System	2
Part-time Contract Employees	88
Part-time Contract Employees Transferring to the Mandatory Retirement System	16

3. Executives

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

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	Takeda, Yoichi
Associate Professor	Tanaka, Masayuki
Project Associate Professor	Kambe, Eiji
Project Associate Professor*	Narita, Norio
Senior Research Engineer	Iwashita, Hiroyuki
Senior Research Engineer	Kumura, Yoshinori
Assistant Professor	Imanishi, Masatoshi
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	Ono, Yoshito
Assistant Professor	Onodera, Masato
Assistant Professor	Pyo, Tae-Soo
Assistant Professor*	Suto, Hiroshi
Assistant Professor	Yagi, Masafumi
Assistant Professor	Yanagisawa, Kenshi
Project Assistant Professor*	Hashimoto, Jun
Project Assistant Professor	Hayashi, Masao
Project Assistant Professor*	Hori, Yasunori
Project Assistant Professor	Izumi, Takuma
Project Assistant Professor*	Kuzuhara, Masayuki
Research Engineer	Bando, Takamasa
Research Engineer	Oomiya, Jun
Engineer (Gishi)	Namikawa, Kazuhito
Engineer (Shunin Gijyutsuin)	Sato, Tatsuhiro
Engineer (Gijyutsuin)	Konno, Yusuke
Engineer (Gijyutsuin)	Miura, Takuya
Project Research Staff*	Komatsu, Yu
Project Research Staff*	Kosugi, Makiko
Project Research Staff	Kubo, Mariko
Project Research Staff*	Omiya, Masashi
Project Research Staff	Rusu, Cristian Eduard
Project Research Staff*	Suzuki, Taiki
Project Research Staff*	Takahashi, Aoi
Project Research Staff	Uchiyama, Hisakazu
Project Research Staff	Yamashita, Takuji
Senior Specialist (Tokuninsenmonin)	Ikeda, Hiroyuki
Senior Specialist (Tokuninsenmonin)	Koike, Michitaro
Senior Specialist (Tokuninsenmonin)*	Kusakabe, Nobuhiko
Senior Specialist (Tokuninsenmonin)	Mineo, Sogo
Senior Specialist (Tokuninsenmonin)	Nakajima, Masayo
Senior Specialist (Tokuninsenmonin)	Okura, Yuki
Senior Specialist (Tokuninsenmonin)	Takita, Satoshi
Senior Specialist (Tokuninsenmonin)	Tanaka, Mitsuhiro
Senior Specialist (Tokuninsenmonin)	Yamada, Yoshihiko
Senior Specialist (Tokuninsenmonin)	Yamamiya, Osamu
Senior Specialist (Tokuninsenmonin)	Yamanoi, Hitomi
Research Expert	Kawanomoto, Satoshi
Administrative Expert	Yoshida, Chie
Administrative Supporter	Kimura, Hiroko
Administrative Supporter	Kuwata, Hitomi
Administrative Supporter	Shibata, Junko
Administrative Supporter	Suehiro, Yoko
Administrative Supporter	Suzuki, Mayumi
Research Assistant	Kikuta, Satoshi

*concurrently appointed in NINS

Administration Department

Manager	Seto, Yoji
Accounting Unit	
Leader	Sugawara, Satoshi

RCUH

RCUH	Akiona, Jordan
RCUH	Ali, Sadman
RCUH	Alpiche, Dex
RCUH	Aoki, Kentaro
RCUH	Balbarino, Michael
RCUH	Boggess, Christopher
RCUH	Case, Dolen
RCUH	Chung, Hiromi
RCUH	Clergeon, Christophe
RCUH	Conol, Jonah

RCUH	Deo, Vincent
RCUH	Doi, Yoshiyuki
RCUH	Elms, Brian
RCUH	Endo, Mari
RCUH	Ferreira, James
RCUH	Formanek, Keiko
RCUH	Fujiwara, Hideaki
RCUH	Fujiyoshi, Takuya
RCUH	Guyon, Olivier
RCUH	Hand, Derek
RCUH	Harakawa, Hiroki
RCUH	Hattori, Takashi
RCUH	Hora, Brendan
RCUH	Inagaki, Takeshi
RCUH	Jeschke, Eric
RCUH	Kackley, Russell
RCUH	Kerns, Michael
RCUH	Koshida, Shintaro
RCUH	Krishnamoorthy, Preethi
RCUH	Kudo, Tomoyuki
RCUH	Lee, Riki
RCUH	Lemmen, Michael
RCUH	Letawsky, Michael
RCUH	Lozi, Julien
RCUH	Medeiros, Carolyn
RCUH	Morris Marita
RCUH	Murai, Rieko
RCUH	Nabeshima, Yoshitake
RCUH	Nakata, Fumiaki
RCUH	Namiki, Shigeru
RCUH	Neugarten, Andrew
RCUH	Niimi, Yuka
RCUH	Nishimura, Tetsuo
RCUH	Otsuki, Noriko
RCUH	Ramos, Lucio
RCUH	Roth, Noriko
RCUH	Rousselle, Julien
RCUH	Sahoo, Ananya
RCUH	Schubert, Kiaina
RCUH	Schumacher, Larissa
RCUH	Shimakawa, Rizumu
RCUH	Simunovic, Mirko
RCUH	Spencer, Robin
RCUH	Suh, Hyewon
RCUH	Sur, Ryoko
RCUH	Tait, Philip
RCUH	Tajitsu, Akito
RCUH	Takagi, Yuhei
RCUH	Tamae, Richard
RCUH	Tanaka, Makoto
RCUH	Tanaka, Yoko
RCUH	Terai, Tsuyoshi
RCUH	Tomono, Daigo
RCUH	Toyofuku, Ralph
RCUH	Vievard, Sebastien
RCUH	Villegas-Villeza Jr., Loreto
RCUH	Wahl, Matthew
RCUH	Weber Mark
RCUH	Winegar, Tom
RCUH	Wung, Matthew
RCUH	Yoshida, Hiroshige
RCUH	Yoshiyama, Naomi

Okayama Branch Office

Director	Izumiura, Hideyuki
Associate Professor	Izumiura, Hideyuki
Assistant Professor	Maehara, Hiroyuki
Engineer (Gijyutsuin)	Tsutsui, Hironori
Administrative Supporter	Shibukawa, Hiroko
Administrative Supporter	Yamashita, Ayako
Administrative Maintenance Staff	Watanabe, Noriaki

Nobeyama Radio Observatory

Director	Tatematsu, Ken'ichi
Professor	Tatematsu, Ken'ichi
Assistant Professor	Ishizuki, 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
Project Research Staff	Kim, Gwanjeong
Project Research Staff	Takekawa, Shunya
Senior Specialist (Tokuninsenmonin)	Hamada, Kaname
Senior Specialist (Tokuninsenmonin)	Kinugasa, Kenzo
Senior Specialist (Tokuninsenmonin)	Takahashi, Shigeru
Technical Expert	Hayashi, Mitsuru
Technical Expert	Ide, Hidemi
Technical Expert	Inoe, Norio
Research Supporter	Maekawa, Jun

Administration Office

Deputy Manager	Otsuka, Tomoyoshi
General Affairs Unit	
Administrative Supporter	Kikuchi, Kikue
Administrative Supporter	Shingai, Hisako
Administrative Supporter	Yoda, Chizuko
Administrative Maintenance Staff	Fuji, Shigeru
Administrative Maintenance Staff	Hinata, Shigeto
Administrative Maintenance Staff	Kikuchi, Tsuyoshi
Administrative Maintenance Staff	Yokomori, Yasuyuki
Accounting Unit	
Leader	Takeda, Kiyotaka

Senior Staff	Uchiyama, Yoshifumi
Administrative Supporter	Kodaira, Toshiko
Administrative Supporter	Takasawa, Mitsue
Administrative Supporter	Takemura, Miwako

Mizusawa VLBI Observatory

Director	Honma, Mareki
Professor	Honma, Mareki
Project Professor	Kobayashi, Hideyuki
Associate Professor	Shibata, Katsunori
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
Research Engineer	Ishikawa, Toshiaki
Research Engineer	Suzuki, Syunsaku
Engineer (Shunin Gijyutsuin)	Ueno, Yuji
Engineer (Gijyutsuin)	Hirano, Ken
Project Research Staff	Akahori, Takuya
Project Research Staff	Hanayama, Hidekazu
Project Research Staff	Horiuchi, Takashi
Project Research Staff	Sakai, Daisuke
Project Research Staff	Tazaki, Fumie
Senior Specialist (Tokuninsenmonin)	Adachi, Yuki
Senior Specialist (Tokuninsenmonin)	Kim, Mi Kyoung
Senior Specialist (Tokuninsenmonin)	Nagayama, Takumi
Senior Specialist (Tokuninsenmonin)	Oyama, Tomoaki
Senior Specialist (Tokuninsenmonin)	Ozawa, Tomohiko
Senior Specialist (Tokuninsenmonin)	Terasawa, Toshio
Technical Expert	Asakura, Yu
Technical Expert	Hachisuka, Kazuya
Technical Expert	Matsukawa, Yuki
Technical Expert	Sato, Gen
Technical Expert	Sato, Kaori
Technical Expert	Shimada, Kanae
Technical Expert	Takahashi, Ken
Technical Expert	Yamashita, Kazuyoshi
Technical Expert	Yoshida, Toshihiro
Administrative Expert	Endo, Kana
Research Supporter	Kudo, Yohei
Research Supporter	Yamauchi, Aya
Technical Supporter	Konishi, Satoru
Administrative Supporter	Katsukawa, Marie
Administrative Supporter	Komori, Akiyo

Administration Office

Deputy Manager	Onuma, Toru
General Affairs Unit	
Leader	Onuma, Toru
Re-employment Staff	Hommyo, Susumu
Administrative Supporter	Murakami, Mie
Administrative Supporter	Oizumi, Yuka
Administrative Supporter	Sasaki, Mie
Accounting Unit	
Leader	Yamaguchi, Shinichi
Administrative Supporter	Kikuchi, Sachiko
Administrative Supporter	Ogihara, Yoko

Ishigakijima Astronomical Observatory

Director	Honma, Mareki

Time Keeping Office

Director	Tamura, Yoshiaki

Solar Science Observatory

Director	Suematsu, Yoshinori
Associate Professor	Hanaoka, Yoichiro
Associate Professor	Katsukawa, Yukio
Associate Professor	Sekii, Takashi
Associate Professor	Suematsu, Yoshinori
Project Assistant Professor	Benomar, Othman Michel
Engineer (Gishi)	Shinoda, Kazuya
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	Ishii, Shuichi
Research Supporter	Itami, Kiyoshi
Administrative Supporter	Sugimoto, Junko
Research Assistant	Ishikawa, Ryohtaroh

ALMA Project

Director	Gonzalez Garcia, Alvaro
Professor	Fukagawa, Misato
Professor	Iguchi, Satoru
Project Professor	Hasegawa, Tetsuo
Associate Professor	Gonzalez Garcia, Alvaro
Associate Professor	Iono, Daisuke
Associate Professor	Kiuchi, Hitoshi
Associate Professor	Kosugi, George
Associate Professor	Minamidani, Tetsuhiro
Associate Professor	Shimojo, Masumi
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	Indriolo, Nicholas
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	Ueda, Junko
Research Engineer	Ashitagawa, Kyoko
Research Engineer	Nakazato, Takeshi
Research Engineer	Yamada, Masumi
Engineer (Gishi)	Kato, Yoshihiro
Engineer (Gishi)	Nakamura, Kyoko
Engineer (Shunin Gijyutsuin)	Nishitani, Hiroyuki
Engineer (Gijyutsuin)	Shizugami, Makoto
Project Research Staff	Bakx, Tom Johannes Lucinde Cyrillus
Project Research Staff	Cataldi, Gianni
Project Research Staff	Guzman Fernandez, Andres Ernesto
Project Research Staff	Higuchi, Yuichi
Project Research Staff	Inoe, Shigeki
Project Research Staff	Lee, Seokho
Project Research Staff	Lu, Xing
Project Research Staff	Nguyen, Duc Dieu
Project Research Staff	Nishimura, Yuri
Project Research Staff	Shimoda, Takanobu
Project Research Staff	Suzuki, Tomoko
Project Research Staff	Tanaka, Kei
Project Research Staff	Tokuda, Kazuki
Project Research Staff	Wang, Tao
Project Research Staff	Wu, Benjamin
Project Research Staff	Wu, Yu-Ting
Project Research Staff	Yang Yi
Project Research Staff	Zahorecz, Sarolta
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)	Kishimoto, Mayumi
Senior Specialist (Tokuninsenmonin)	Matsui, Takayuki
Senior Specialist (Tokuninsenmonin)	Miel, Renaud Jean Christophe
Senior Specialist (Tokuninsenmonin)	Miyachi, Akihira
Senior Specialist (Tokuninsenmonin)	Miyata, Keiko
Senior Specialist (Tokuninsenmonin)	Morita, Eisuke
Senior Specialist (Tokuninsenmonin)	Nakanishi, Takashi
Senior Specialist (Tokuninsenmonin)	Niizeki, Yasuaki
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	Kamada, Masako
Technical Expert	Tanaka, Rie
Research Supporter	Ban, Makiko
Administrative Supporter	Obana, Yasuyo
Administrative Supporter	Otawara, Hikaru
Administrative Supporter	Saito, Naoko

NAOJ Chile

Director	Asayama, Shinichiro
Professor	Kameno, Seiji
Professor	Mizuno, Norikazu
Professor	Sakamoto, Seiichi
Associate Professor	Asaki, Yoshiharu
Associate Professor	Asayama, Shinichiro
Associate Professor	Okuda, Takeshi
Associate Professor	Sawada, Tsuyoshi
Associate Professor	Takahashi, Satoko
Assistant Professor	Hirota, Akihiko
Assistant Professor	Ishii, Shun
Project Assistant Professor	Hull, Charles Lindsay Hopkins
Engineer (Gishi)	Kobiki, Toshihiko
Engineer (Shunin Gijyutsuin)	Ito, Tetsuya
Project Research Staff	Silva Bustamante, Andrea Ludovina
Project Research Staff	Walker, Daniel Lewis
Chile Employee	

Chile Employee	Aguilera, Javier
Chile Employee	Ichiyama, Kotoyo
Chile Employee	Jara, Ricardo
Chile Employee	Krapivka, Gabriela
Chile Employee	Toro, Lorena
Chile Employee	Zenteno, Javier

Administration Department

Acting Deputy Manager	Asayama, Shinichiro
General Affairs Unit	
Staff	Isozaki, Yuka
Accounting Unit	
Staff	Yamafuji, Yasuto

Center for Computational Astrophysics

Director	Kokubo, Eiichiro
Professor	Kokubo, Eiichiro
Assistant Professor	Iwasaki, Kazunari
Project Assistant Professor	Kawashima, Tomohisa
Project Research Staff	Ishikawa, Shogo
Project Research Staff	Ohtani, Yukari
Project Research Staff	Taki, Tetsuo
Senior Specialist (Tokuninsenmonin)	Fukushi, Hinako
Senior Specialist (Tokuninsenmonin)	Hohokabe, Hirotaka
Senior Specialist (Tokuninsenmonin)	Kato, Tsunehiko
Research Expert	Nakayama, Hirotaka
Research Supporter	Hasegawa, Satoki
Research Supporter	Kano, Kaori
Administrative Supporter	Mashiko, Kyoko

B Projects

Gravitational Wave Science Project

Director	Tomaru, Takayuki
Professor	Tomaru, Takayuki
Project Professor	Flaminio, Raffaele
Assistant Professor	Akutsu, Tomotada
Assistant Professor	Leonardi, Matteo
Assistant Professor	Takahashi, Ryutaro
Project Assistant Professor	Shoda, Ayaka
Research Engineer	Ishizaki, Hideharu
Engineer (Shunin Gijyutsuin)	Tanaka, Nobuyuki
Senior Specialist (Tokuninsenmonin)	Hirata, Naoatsu
Senior Specialist (Tokuninsenmonin)	Zeidler, Simon
Research Supporter	Harada, Mikiko
Administrative Supporter	Yoshizumi, Mizuho
Research Assistant	Li, Pengbo

Kamioka Branch

Professor	Tomaru, Takayuki
Associate Professor	Aso, Yoichi
Administrative Supporter	Sakamoto, Eri

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
Project Associate Professor	Oya, Shin
Assistant Professor	Nishikawa, Jun
Project Assistant Professor	Hattori, Masayuki
Research Engineer	Tazawa, Seiichi
Project Research Staff	Hamano, Satoshi
Project Research Staff	Ozaki, Shinobu
Project Research Staff	Schramm, Malte
Project Research Staff	Sorahana, Satoko
Senior Specialist (Tokuninsenmonin)	Endo, Tatsuki
Senior Specialist (Tokuninsenmonin)	Ishii, Miki
Senior Specialist (Tokuninsenmonin)	Kakazu, Yuko
Senior Specialist (Tokuninsenmonin)	Kusumoto, Hiroshi
Senior Specialist (Tokuninsenmonin)	Shindo, Miwa
Senior Specialist (Tokumeisennmonin)	Iye, Masanori
Administrative Supporter	Tatsugi, Tomoko
Research Assistant	Matsuno, Tadafumi

NAOJ California 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	Goda, Naoteru
Professor	Goda, Naoteru
Assistant Professor	Miyoshi, Makoto
Assistant Professor	Tatsumi, Daisuke
Assistant Professor	Tsujimoto, Takuji
Assistant Professor	Ueda, Akitoshi
Assistant Professor	Yano, Taihei
Project Research Staff	Baba, Junichi
Research Supporter	Mase, Ichiro

Technical Supporter	Kashima, Shingo

RISE Project

Director	Namiki, Noriyuki
Professor	Namiki, Noriyuki
Associate Professor	Matsumoto, Koji
Senior Research Engineer	Tsuruta, Seiitsu
Assistant Professor	Araki, Hiroshi
Assistant Professor	Noda, Hirotomo
Research Engineer	Asari, Kazuyoshi
Project Research Staff	Higuchi, Arika
Project Research Staff	Nomura, Reiko
Project Research Staff	Yamamoto, Keiko
Administrative Supporter	Uemura, Yuiko

SOLAR-C Project

Director	Suematsu, Yoshinori
Associate Professor*	Goto, Motoshi
Associate Professor	Hara, Hirohisa
Associate Professor	Kano, Ryohei
Assistant Professor	Ishikawa, Ryoko
Assistant Professor	Kubo, Masahito
Assistant Professor	Narukage, Noriyuki
Project Research Staff	Kawabata, Yusuke
Senior Specialist (Tokuninsenmonin)	Nodomi, Yoshifumi
Research Supporter	Tsuchiya, Chie
Administrative Supporter	Uekiyo, Hatsue

*concurrently appointed in NINS

Subaru Prime Focus Spectrograph (PFS) Project

Director	Takato, Naruhisa

Subaru Ground Layer Adaptive Optics (GLAO) Project

Director	Minowa, Yosuke

Centers

Astronomy Data Center

Director	Takata, Tadafumi
Associate Professor	Ichikawa, Shinichi
Associate Professor	Takata, Tadafumi
Assistant Professor	Furusawa, Hisanori
Assistant Professor	Ito, Takashi
Assistant Professor	Shirasaki, Yuji
Project Research Staff	Aoyama, Shohei
Project Research Staff	Furusawa, Junko
Project Research Staff	Higuchi, Aya
Project Research Staff	Kakuwa, Jun
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
Administrative Supporter	Ishii, Yuko

Advanced Technology Center

Director	Uzawa, Yoshinori
Vice-Director	Hayano, Yutaka
Professor	Miyazaki, Satoshi
Professor	Motohara, Kentaro
Professor	Uzawa, Yoshinori
Project Professor	Mitsuda, Kazuhisa
Associate Professor	Hayano, Yutaka
Associate Professor	Kojima, Takafumi
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
Assistant Professor	Nakaya, Hidehiko
Assistant Professor	Oshima, Tai
Research Engineer	Obuchi, Yoshiyuki
Research Engineer	Sato, Naohisa
Engineer (Gishi)	Kamata, Yukiko
Engineer (Gishi)	Kubo, Koichi
Engineer (Gishi)	Omata, Koji
Engineer (Gishi)	Tamura, Tomonori
Engineer (Gishi)	Uraguchi, Fumihiro

Engineer (Shunin Gijyutsuin)	Fukuda, Takeo
Engineer (Shunin Gijyutsuin)	Ikenoe, Bungo
Engineer (Shunin Gijyutsuin)	Inata, Motoko
Engineer (Shunin Gijyutsuin)	Iwashita, Hikaru
Engineer (Shunin Gijyutsuin)	Kaneko, Keiko
Engineer (Shunin Gijyutsuin)	Mitsui, Kenji
Engineer (Shunin Gijyutsuin)	Waseda, Koichi
Engineer (Gijyutsuin)	Ezaki, Shohei
Engineer (Gijyutsuin)	Sakai, Ryo
Engineer (Gijyutsuin)	Shimizu, Risa
Engineer (Gijyutsuin)	Tsuzuki, Toshihiro
Project Research Staff	Nagai, Makoto
Project Research Staff	Uchiyama, Mizuho
Senior Specialist (Tokuninsenmonin)	Saito, Sakae
Technical Expert	Aiba, Kazukiyo
Technical Expert	Katsumoto, tatsuo
Research Supporter	Nakajima, Shizuka
Administrative Supporter	Kuroda, Kyoko
Administrative Supporter	Murakami, Hiromi
Administrative Supporter	Sato, Takashi
Research Assistant	Giraud, Alexandra Sacha Nadia Marie

Public Relations Center

Director	Fukushima, Toshio
Professor	Fukushima, Toshio
Professor	Watanabe, Junichi
Project Professor	Oishi, Masatoshi
Associate Professor	Agata, Hidehiko
Associate Professor	Yamaoka, Hitoshi
Research Engineer	Katayama, Masato
Engineer (Shunin Gijyutsuin)	Nagayama, Shyogo
Project Research Staff	Shimizu, Ikkou
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)	Tsuzuki, Hiroko
Senior Specialist (Tokuninsenmonin)	Usuda-Sato, Kumiko
Research Expert	Ono, Tomoko
Research Expert	Takata, Hiroyuki
Re-employment Staff	Matsuda, Ko
Administrative Expert	Noguchi, Sayumi
Research Supporter	Tsuneyama, Junko
Public Outreach Official	Endo, Isao
Public Outreach Official	Fujita, Tokiko
Public Outreach Official	Hamura, Taiga
Public Outreach Official	Hibino, Yumi
Public Outreach Official	Ishizaki, Masaharu
Public Outreach Official	Ito, Hironori
Public Outreach Official	Koike, Akio
Public Outreach Official	Kubo, Maki
Public Outreach Official	Kume, Kaori
Public Outreach Official	Mikami, Naotsugu
Public Outreach Official	Naito, Seiichiro
Public Outreach Official	Natsugari, Satomi
Public Outreach Official	Oguri, Junko
Public Outreach Official	Sato, Ryo
Public Outreach Official	Shioya, Yasuhisa
Public Outreach Official	Takabatake, Noriko
Public Outreach Official	Takeda, Takaaki

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	Fukushima, Toshio

The Office for Astronomy Outreach of the IAU

Director	Agata, Hidehiko

Administration Office

Director	Matsuda, Ko

Division of Science

Division Head	Tomisaka, Kohji
Professor	Kawabe, Ryohei
Professor	Nomura, Hideko
Professor	Ouchi, Masami
Professor	Tomisaka, Kohji
Professor	Yoshida, Haruo
Project Professor	Kajino, Toshitaka
Associate Professor	Nakamura, Fumitaka
Assistant Professor	Hamana, Takashi
Assistant Professor	Kataoka, Akimasa
Assistant Professor	Morino, Junichi
Assistant Professor	Moriya, Takashi
Assistant Professor	Soma, Mitsuru
Assistant Professor	Takiwaki, Tomoya
Project Assistant Professor	Nakajima, Kimihiko
Project Assistant Professor	Ogihara, Masahiro
Project Assistant Professor	Shirasaki, Masato
Project Assistant Professor	Sugiyama, Naonori
Project Assistant Professor	Suzuki, Akihiro
Project Assistant Professor	Tsukagoshi, Takashi
Project Research Staff	Kusune, Takayoshi
Project Research Staff	Nozawa, Takaya
Project Research Staff	Takahashi, Sanemichi
Administrative Supporter	Izumi, Shioko
Administrative Supporter	Matsunaga, Choko

5. Research Support Departments

Research Enhancement Strategy Office

Director	Iguchi, Satoru
Professor	Sekiguchi, Kazuhiro
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	Watanabe, Junichi
Senior Specialist (Tokuninsenmonin)	Hori, Kuniko

Office of International Relations

Acting Director	Watanabe, Junichi
Senior Specialist (Tokuninsenmonin)	Chapman, Junko
Senior Specialist (Tokuninsenmonin)	Haruki, Mutsumi
Senior Specialist (Tokuninsenmonin)	Matsumoto, Mizuho

Support Desk

Research Supporter	Shirato, Reiko
Research Supporter	Uno, Junko

Human Resources Planning Office

Director	Noda, Noboru
Senior Specialist (Tokuninsenmonin)	Noda, Noboru

Safety and Health Management Office

Director	Okamoto, Koichi
Senior Specialist (Tokuninsenmonin)	Okamoto, Koichi
Technical Expert	Takayama, Nobuhiro

Engineering Promotion Office

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

IT Security Office

Director	Watanabe, Junichi
Vice Director	Oe, Masafumi
Chief Research Engineer	Nakamura, Koji
Engineer (Gijyutsuin)	Matsushita, Sayaka
Administrative Expert	Aoki, Makiko

Administration Department

General Manager	Sasagawa, Hikaru
Senior Specialist	Tsukano, Satomi
Leader	Chiba, Satoko

General Affairs Group

Manager	Harada, Eiichiro
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)	Takahashi, Hidehiro
Senior Specialist (Tokuninsenmonin)	Yamamoto, Chieko

General Affairs Unit

Leader	Kawashima, Ryota
Staff	Matsukura, Koji
Staff	Mochimaru, Shiori
Staff	Saito, Masahiro
Re-employment Staff	Amemiya, Hidemi
Administrative Supporter	Kobayashi, Kayo
Administrative Supporter	Seki, Kumi

Personnel Unit

Leader	Yamanouchi, Mika
Senior Staff	Iida, Naoto
Staff	Iwasaki, Yumi
Staff	Kayamori, Shinji
Staff	Sakamoto, Misato

Payroll Unit

Senior Staff	Furukawa, Shinichiro
Staff	Inoue, Miyuki
Staff	Takahashi, Sachiko
Administrative Supporter	Kawabata, Ritan
Administrative Supporter	Takase, Kazuhiko

Employee Affairs Unit

Leader	Yamaura, Mari
Staff	Ouchi, Kaori
Staff	Tanaka, Masashi
Administrative Expert	Noguchi, Megumi

Research Promotion Group

Manager	Hosoya, Akio
Senior Specialist	Onishi, Tomoyuki
Administrative Supporter	Matsuda, Yukie

Research Support Unit

Leader	Goto, Michiru

Staff	Nakagawa, Yukie
Administrative Expert	Yoshizawa, Mariko
Administrative Supporter	Komoda, Chizuru
Administrative Supporter	Okada, Naomi
Administrative Supporter	Shimizu, Ayane
Administrative Supporter	Suzuki, Yoshiko

Graduate Student Affairs Unit

Leader	Fujimori, Mihiro
Administrative Expert	Inoue, Mizuho
Administrative Supporter	Omura, Yumiko

International Academic Affairs Unit

Staff	Hiramatsu, Naoya

Financial Affairs Group

Manager	Honda, Daisuke
Deputy Manager	Iwashita, Kanefumi
Specialist (Audit)	Chiba, Yoko

General Affairs Unit

Leader	Chiba, Yoko
Staff	Saito, Keisuke
Administrative Supporter	Sasaki, Sayuri

Budget Unit

Leader	Yamamoto, Shinichi
Staff	Masuda, Akio
Administrative Supporter	Yano, Kumiko

Asset Management Unit

Leader	Kikkawa, Hiroko
Staff	Naraoka, Aone

Receiving Unit

Leader	Kikkawa, Hiroko
Administrative Supporter	Nakagomi, Kimitoshi
Administrative Supporter	Shibui, Junko
Administrative Supporter	Tsukamoto, Satoko

Accounting Group

Manager	Tanaka, Masaru

Accounting Unit

Leader	Akeno, Aya
Staff	Okubo, Kazuhiko
Administrative Supporter	Ando, Sayaka
Administrative Supporter	Nakayama, Keiko
Administrative Supporter	Suzuki, Yukiko

Procurement Unit

Leader	Sato, Kanako
Staff	Morita, Akitsugu
Staff	Sugimoto, Naomi
Staff	Takada, Miyuki
Re-employment Staff	Hyuga, Tadayuki
Administrative Expert	Miyata, Kana
Administrative Supporter	Ochiai, Nana

Facilities Group

Manager	Takahashi, Kazuhisa

General Affairs Unit

Leader	Ishikawa, Junya
Staff	Tamura, Makoto
Administrative Supporter	Hagino, Hiromichi

Facilities Direction Unit

Leader	Murakami, Kazuhiro
Administrative Supporter	Nagata, Yomogi
Administrative Supporter	Takizawa, Minoru

Maintenance Unit

Leader	Narisawa, Hiroyuki
Staff	Hayashi, Yuki
Staff	Kurose, Takahiro

6. Personnel Change

Research and Academic Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/4/1	Tomaru, Takayuki	Hired	Gravitational Wave Project Office, Professor	(High Energy Accelerator Research Organization Applied Research Laboratory Cryogenics Science Center, Associate Professor)
2019/4/1	Nomura, Hideko	Hired	Division of Science, Professor	(Tokyo Institute of Technology School of Science, Associate Professor)
2019/4/1	Omiya, Jun	Hired	Subaru Telescope, Research Engineer	
2019/8/16	Ouchi, Masami	Hired	Division of Science, Professor	(The University of Tokyo Institute for Cosmic Ray Research, Associate Professor)
2019/10/1	Nakamoto, Takashi	Hired	Thirty Meter Telescope Project, Research Engineer	(ALMA Project, Senior Specialist)
2020/1/1	Sugimoto, Kanako	Hired	ALMA Project, Senior Research Engineer	(National Radio Astronomy Observatory, Software Engineer IV)
2020/2/18	Kumura, Yoshinori	Hired	Subaru Telescope, Senior Research Engineer	
2019/4/30	Kajino, Toshitaka	Resigned	(Division of Science, Project Professor)	Division of Science, Associate Professor
2019/9/30	Ohashi, Nagayoshi	Resigned		Subaru Telescope, Professor
2020/3/31	Shibata, Katsunori	Resigned		Mizusawa VLBI Observatory, Associate Professor
2020/3/31	Ishii, Shun	Resigned	(ALMA Project, Project Associate Professor)	NAOJ Chile, Assistant Professor
2020/3/31	Fukushima, Toshio	Retired		Public Relations Center, Professor
2020/3/31	Yoshida, Haruo	Retired		Division of Science, Professor
2020/3/31	Takeda, Yoichi	Retired		Subaru Telescope, Associate Professor
2020/3/31	Tsuruta, Seiitsu	Retired		RISE Project, Senior Research Engineer
2020/3/31	Soma, Mitsuru	Retired		Division of Science, Assistant Professor
2020/3/31	Suzuki, Shunsaku	Retired		Mizusawa VLBI Observatory, Research Engineer
2020/3/31	Ishikawa, Toshiaki	Retired		Mizusawa VLBI Observatory, Research Engineer
2019/5/1	Minamidani, Tetsuhiro	Promoted	ALMA Project, Associate Professor	Nobeyama Radio Observatory, Assistant Professor
2019/8/1	Takato, Naruhisa	Promoted	Advanced Technology Center, Professor	Subaru Telescope, Associate Professor
2019/8/1	Miyazaki, Satoshi	Promoted	Advanced Technology Center, Professor	Advanced Technology Center, Associate Professor
2019/9/1	Sawada, Tsuyoshi	Promoted	NAOJ Chile, Associate Professor	NAOJ Chile, Assistant Professor
2019/12/1	Minowa, Yosuke	Promoted	Subaru Telescope, Associate Professor	Subaru Telescope, Assistant Professor
2019/12/1	Shimojo, Masumi	Promoted	ALMA Project, Associate Professor	ALMA Project, Assistant Professor
2019/12/1	Kojima, Takafumi	Promoted	Advanced Technology Center, Associate Professor	Advanced Technology Center, Assistant Professor
2020/3/1	Takahashi, Satoko	Promoted	NAOJ Chile, Associate Professor	NAOJ Chile, Assistant Professor

Engineering Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2020/1/1	Miura, Takuya	Hired	Subaru Telescope, Engineer	
2020/3/1	Kon'no, Yusuke	Hired	Subaru Telescope, Engineer	
2019/8/19	Sato, Tatsuhiro	Promoted	Subaru Telescope, Engineer	Subaru Telescope, Engineer
2019/8/19	Nishitani, Hiroyuki	Promoted	ALMA Project, Engineer	Nobeyama Radio Observatory, Engineer
2019/10/1	Tamura, Tomonori	Promoted	Advanced Technology Center, Engineer	Advanced Technology Center, Engineer

Administrative Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/4/1	Iwashita, Kanefumi	Hired	Administration Department Financial Affairs Group, Deputy Manager	(The University of Tokyo)
2019/4/1	Tamefusa, Mizuho	Hired	Public Relations Center Administration Office Library, Leader	(The University of Tokyo)
2019/4/1	Akeno, Aya	Hired	Administration Department Accounting Group Accounting Unit, Leader	(Tokyo Medical and Dental University)
2019/4/1	Sato, Kanako	Hired	Administration Department Accounting Group Procurement Unit, Leader	(Tokyo Gakugei University)
2019/4/1	Tanaka, Masashi	Hired	Administration Department General Affairs Group Employee Affairs Unit, Staff	(Niigata University)
2019/4/1	Naraoka, Aone	Hired	Administration Department Financial Affairs Group Asset Management Unit, Staff	
2019/4/1	Hayashi, Yuki	Hired	Administration Department Facilities Group Maintenance Unit, Staff	
2019/7/1	Yamaguchi, Shin'ichi	Hired	Mizusawa VLBI Observatory Administration Office Accounting Unit, Leader	(Iwate University)
2019/8/1	Uchiyama, Yoshifumi	Hired	Nobeyama Radio Observatory Administration Office Accounting Unit, Senior Staff	(Shinshu University)
2019/10/1	Hosoya, Akio	Hired	Administration Department, Research Promotion Group, Manager	(Tokyo University of Foreign Studies)
2019/6/30	Ito, Hiromasa	Resigned	(Iwate University)	Mizusawa VLBI Observatory Administration Office Accounting Unit, Leader
2019/6/30	Tanigaichi, Takuya	Resigned	(The University of Tokyo)	Administration Department Financial Affairs Group Budget Unit, Leader
2019/7/31	Takahashi, Masaru	Resigned	(Shinshu University)	Nobeyama Radio Observatory Administration Office Accounting Unit, Senior Staff
2020/3/31	Chiba, Satoko	Resigned	(Tokyo Medical and Dental University)	Administration Department, Leader
2020/3/31	Fujimori, Mihiro	Resigned	(The University of Tokyo)	Administration Department Research Promotion Group Graduate Student Affairs Unit, Leader
2020/3/31	Mochimaru, Shiori	Resigned		Administration Department General Affairs Group General Affairs Unit, Staff

2020/3/31	Inoue, Miyuki	Resigned		Administration Department General Affairs Group Payroll Unit, Staff
2020/3/31	Masuda, Akio	Resigned	(The University of Tokyo)	Administration Department Financial Affairs Group Budget Unit, Staff

2020/3/31	Harada, Eiichiro	Retired	(Administration Department, Senior Specialist)	Administration Department General Affairs Group, Manager

2019/4/1	Furukawa, Shin'ichiro	Promoted	Administration Department General Affairs Group Payroll Unit, Senior Staff	Administration Department General Affairs Group Payroll Unit, Staff
2019/7/1	Tsukano, Satomi	Promoted	NAOJ Chile Administration Department, Head of Administration Office	Administration Department Research Promotion Group International Academic Affairs Unit, Leader

2019/4/1	Miura, Susumu	Reassigned	National Institutes of Natural Sciences Administrative Bureau Liaison and Planning Division, Specialist	Administration Department Accounting Group, Specialist (Contracts)
2019/4/1	Saito, Keisuke	Reassigned	Administration Department Financial Affairs Group General Affairs Unit, Staff	National Institutes of Natural Sciences Administrative Bureau Financial Affairs Division Accounting Section, Staff
2019/4/1	Saito, Masahiro	Reassigned	National Institutes of Natural Sciences Administrative Bureau Financial Affairs Division Accounting Section, Staff	Administration Department General Affairs Group Employee Affairs Unit, Staff
2019/4/1	Takai, Tetsuya	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 Accounting Group, Staff (Ministry of Education, Culture, Sports, Science and Technology-Japan, Administrative Intern Trainee)
2020/2/1	Saito, Masahiro	Reassigned	Administration Department General Affairs Group General Affairs Unit, Staff	National Institutes of Natural Sciences Administrative Bureau Financial Affairs Division Accounting Section, Staff

Employee on Annual Salary System

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/4/1	Kobayashi, Hideyuki	Hired	Mizusawa VLBI Observatory, Project Professor (Distinguished Professor)	(Division of Radio Astronomy (Mizusawa VLBI Observatory), Professor)
2019/4/1	Oishi, Masatoshi	Hired	Public Relations Center , Project Professor	(Astronomy Data Center, Associate Professor)
2019/4/1	Sugiyama, Naonori	Hired	Division of Science, Project Assistant Professor	
2019/4/1	Takasao, Shinsuke	Hired	Division of Science, Project Assistant Professor	
2019/4/1	Matsumoto, Takuma	Hired	Solar Science Observatory, Project Research Staff	
2019/4/1	Uchiyama, Hisakazu	Hired	Subaru Telescope, Project Research Staff	
2019/4/1	Kubo, Mariko	Hired	Subaru Telescope, Project Research Staff	(TMT-J Project Office, Project Research Staff)
2019/4/1	Yang, Yi	Hired	ALMA Project, Project Research Staff	
2019/4/1	Shimajiri, Yoshito	Hired	ALMA Project, Project Research Staff	
2019/4/1	Inoue, Shigeki	Hired	ALMA Project, Project Research Staff	
2019/4/1	Sorahana, Satoko	Hired	TMT-J Project Office, Project Research Staff	(Astronomy Data Center, Project Research Staff)

2019/4/1	Shimizu, Ikko	Hired	Public Relations Center, Project Research Staff	
2019/4/1	Nozawa, Takaya	Hired	Division of Science, Project Research Staff	(Division of Theoretical Astronomy, Project Assistant Professor)
2019/4/1	Kato, Tsunehiko	Hired	Center for Computational Astrophysics, Senior Specialist	
2019/4/1	Miyata, Keiko	Hired	ALMA Project, Senior Specialist	
2019/4/1	Morita, Eisuke	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2019/4/1	Matsui, Takayuki	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2019/4/1	Kawasaki, Wataru	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2019/4/1	Kishimoto, Mayumi	Hired	TMT-J Project Office, Senior Specialist	
2019/4/1	Furusawa, Junko	Hired	Astronomy Data Center, Senior Specialist	
2019/4/1	Lundock, Ramsey Guy	Hired	Public Relations Center, Senior Specialist	(Research Enhancement Strategy Office (Public Relations Center), Research Administrator Staff Senior Specialist)
2019/4/1	Pires Canas, Lina Isabel	Hired	Public Relations Center, Senior Specialist	(Public Relations Center, Senior Specialist)
2019/5/1	Kajino, Toshitaka	Hired	Division of Science, Project Professor	(Division of Science, Associate Professor)
2019/5/1	Rusu, Cristian Eduard	Hired	Subaru Telescope, Project Research Staff	
2019/6/1	Takahashi, Sanemichi	Hired	Division of Science, Project Research Staff	(ALMA Project, Project Research Staff)
2019/6/1	Zeidler, Simon	Hired	Gravitational Wave Project Office, Senior Specialist	(Gravitational Wave Project Office, Project Research Staff)
2019/7/1	Benomar, Othman Michel	Hired	Solar Science Observatory, Project Assistant Professor	
2019/7/1	Fujimoto, Seiji	Hired	ALMA Project, Project Research Staff	
2019/7/1	Sotani, Hajime	Hired	Division of Science, Project Research Staff	(Division of Science, Project Assistant Professor)
2019/7/15	Cataldi, Gianni	Hired	ALMA Project, Project Research Staff	
2019/8/1	Song, Donguk	Hired	Solar Science Observatory, Project Research Staff	(SOLAR-C Project, Project Research Staff)
2019/8/1	Higuchi, Aya	Hired	Astronomy Data Center, Project Research Staff	
2019/9/1	Kurasaki, Takaaki	Hired	Project Professor	
2019/9/1	Yamamiya, Osamu	Hired	Subaru Telescope, Senior Specialist	
2019/9/1	Hansen, Izumi Ka Hoku Hula O Kekai	Hired	Public Relations Center, Senior Specialist	
2019/9/24	Kawabata, Yusuke	Hired	SOLAR-C Project, Project Research Staff	
2019/10/1	Zang, Liangjian	Hired	ALMA Project, Senior Specialist	(ALMA Project, Senior Specialist)
2019/10/1	Yamane, Satoru	Hired	Astronomy Data Center, Senior Specialist	
2019/10/21	Aoyama, Shohei	Hired	Astronomy Data Center, Project Research Staff	
2019/11/1	Nagai, Hiroshi	Hired	ALMA Project, Project Associate Professor	(ALMA Project, Project Associate Professor)
2019/11/1	Shimajiri, Yoshito	Hired	ALMA Project, Project Associate Professor	(ALMA Project, Project Research Staff)
2019/11/1	Furusawa, Junko	Hired	Astronomy Data Center, Project Research Staff	(Astronomy Data Center, Senior Specialist)
2019/11/1	Tanaka, Mitsuhiro	Hired	Subaru Telescope, Senior Specialist	
2019/11/29	Sanhueza Nunez, Patricio Andres	Hired	ALMA Project, Project Assistant Professor	(ALMA Project, Project Research Staff)
2020/1/1	Kakuwa, Jun	Hired	Astronomy Data Center, Project Research Staff	

2020/2/1	Nakajima, Yasushi	Hired	Astronomy Data Center, Senior Specialist	
2020/3/1	Nakajima, Kimihiko	Hired	Division of Science, Project Assistant Professor	

2019/5/31	Takahashi, Sanemichi	Resigned	(Division of Science, Project Research Staff)	ALMA Project, Project Research Staff
2019/6/30	Barton, Mark Andrew	Resigned		Gravitational Wave Project Office, Project Research Staff
2019/7/31	Song, Donguk	Resigned	(Solar Science Observatory, Project Research Staff)	SOLAR-C Project, Project Research Staff
2019/9/10	Kroug, Matthias Nils	Resigned		ALMA Project, Project Research Staff
2019/9/30	Nakamoto, Takashi	Resigned	(Thirty Meter Telescope Project, Research Engineer)	ALMA Project, Senior Specialist
2019/10/31	Shimajiri, Yoshito	Resigned	(ALMA Project, Project Associate Professor)	ALMA Project, Project Research Staff
2019/10/31	Sotani, Hajime	Resigned		Division of Science, Project Research Staff
2019/10/31	Furusawa, Junko	Resigned	(Astronomy Data Center, Project Research Staff)	Astronomy Data Center, Senior Specialist
2019/11/30	Fujimoto, Seiji	Resigned		ALMA Project, Project Research Staff
2020/1/5	Espada Fernandez, Daniel	Resigned		ALMA Project, Project Associate Professor
2020/1/14	Sugiyama, Koichiro	Resigned		Mizusawa VLBI Observatory, Project Research Staff
2020/1/31	Torii, Kazufumi	Resigned		Nobeyama Radio Observatory, Project Assistant Professor
2020/1/31	Miura, Rie	Resigned		ALMA Project, Project Assistant Professor
2020/3/15	Takasao, Shinsuke	Resigned		Division of Science, Project Assistant Professor
2020/3/15	Kaneko, Hiroyuki	Resigned		Nobeyama Radio Observatory, Project Research Staff
2020/3/31	Takekawa, Shun'ya	Resigned		Nobeyama Radio Observatory, Project Research Staff
2020/3/31	Kubo, Mariko	Resigned		Subaru Telescope, Project Research Staff
2020/3/31	Aoyama, Shohei	Resigned		Astronomy Data Center, Project Research Staff
2020/3/31	Shimizu, Ikko	Resigned		Public Relations Center, Project Research Staff
2020/3/31	Kim, Mi Kyoung	Resigned		Mizusawa VLBI Observatory, Senior Specialist
2020/3/31	Ikeda, Hiroyuki	Resigned		Subaru Telescope, Senior Specialist

2019/4/30	Sugiyama, Motokuni	Contract Expired		TMT-J Project Office, Senior Specialist
2019/5/31	Zeidler, Simon	Contract Expired	(Gravitational Wave Project Office, Senior Specialist)	Gravitational Wave Project Office, Project Research Staff
2019/6/30	Sotani, Hajime	Contract Expired	(Division of Science, Project Research Staff)	Division of Science, Project Assistant Professor
2019/9/30	Zang, Liangjian	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2019/10/31	Nagai, Hiroshi	Contract Expired	(ALMA Project, Project Associate Professor)	ALMA Project, Project Associate Professor
2019/11/28	Sanhueza Nunez, Patricio Andres	Contract Expired	(ALMA Project, Project Assistant Professor)	ALMA Project, Project Research Staff

2020/3/31	Kawashima, Tomohisa	Contract Expired		Center for Computational Astrophysics, Project Assistant Professor
2020/3/31	Tazaki, Fumie	Contract Expired		Mizusawa VLBI Observatory, Project Research Staff
2020/3/31	Schramm, Malte	Contract Expired		Thirty Meter Telescope Project, Project Research Staff
2020/3/31	Baba, Jun'ichi	Contract Expired	(JASMINE Project, Project Assistant Professor)	JASMINE Project, Project Research Staff
2020/3/31	Uchiyama, Mizuho	Contract Expired		Advanced Technology Center, Project Research Staff
2020/3/31	Nagai, Makoto	Contract Expired	(Advanced Technology Center, Project Research Staff)	Advanced Technology Center, Project Research Staff
2020/3/31	Kusune, Takayoshi	Contract Expired		Division of Science, Project Research Staff
2020/3/31	Yamada, Yoshihiko	Contract Expired		Subaru Telescope, Senior Specialist
2020/3/31	Matsui, Takayuki	Contract Expired		ALMA Project, Senior Specialist
2020/3/31	Niizeki, Yasuaki	Contract Expired		ALMA Project, Senior Specialist
2020/3/31	Miyachi, Akihira	Contract Expired	(Advanced Technology Center, Engineer)	ALMA Project, Senior Specialist
2020/3/31	Uemizu, Kazunori	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2020/3/31	Otawara, Kazushige	Contract Expired	(ALMA Project, Senior Specialist)	ALMA Project, Senior Specialist
2020/3/31	Zeidler, Simon	Contract Expired		Gravitational Wave Science Project, Senior Specialist

Employees on Annual Salary System Transferring to the Mandatory Retirement System

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/4/1	Yamamoto, Chieko	Hired	Administration Department General Affairs Group, Senior Specialist	(Administration Department General Affairs Group, Employee on Annual Salary System Senior Specialist)

Research Administrator Staff

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/7/31	Miura, Mitsuo	Resigned		Research Enhancement Strategy Office (Mizusawa VLBI Observatory), Senior Specialist
2019/6/30	Hasuo, Ryuichi	Contract Expired		Research Enhancement Strategy Office (Office of International Relations), Senior Specialist

Research Administrator Staff Transferring to the Mandatory Retirement System

Date	Name	Change	New Affiliated Institute, Position	Previous Affiliated Institute, Position
2019/4/1	Chapman, Junko	Hired	Research Enhancement Strategy Office (Office of International Relations), Senior Specialist	(Research Enhancement Strategy Office (TMT-J Project Office), Research Administrator Staff Senior Specialist)

Foreign Visiting Researcher

Name	Period	Affiliated Institute
Balantekin, Akif Baha	2020/1/14 ~ 2020/3/6	University of Wisconsin, Madison (U.S.A)
Diaz Merced, Wanda Liz	2019/7/19 ~ 2019/12/27	Office of Astronomy for Development, IAU (South Africa)

Secondment Staff

Name	Term of Secondment	Main Institute, Position	Secondment Institute, Position
Flaminio, Raffaele	2019/4/1 ~ 2020/3/31	The French National Centre for Scientific Research, First Class Researcher	Gravitational Wave Science Project, Project Professor
Motohara, Kentaro	2019/12/1 ~ 2020/3/31	The University of Tokyo Graduate School of Science Institute of Astronomy, Associate Professor	Advanced Technology Center, Professor
Mitsuda, Kazuhisa	2019/12/1 ~ 2020/3/31	Japan Aerospace Exploration Agency Institute of Space and Astronautical Science, Professor	Advanced Technology Center, Project Professor

7. Advisory Committee for Research and Management

Members

From universities and related institutes

	Chiba, Seiji	Graduate School of Science and Faculty of Science, Tohoku University
○	Doi, Mamoru	School of Science, The University of Tokyo
	Fujisawa, Kenta	The Research Institute for Time Studies at Yamaguchi University
	Ichimoto, Kiyoshi	Kwasan and Hida Observatories, Graduate School of Science, Kyoto University
	Kusano, Kanya	Institute for Space-Earth Environmental Research, The University of Nagoya
	Matsushita, Kyoko	Faculty of Science Division1, Tokyo University of Science
	Mitsuda, Kazuhisa	Institute of Space and Astronautical Science
	Murakami, Izumi	National Institute for Fusion Science
	Ohashi, Masatake	Institute for Cosmic Ray Research, The University of Tokyo
	Kawakita, Hideyo	Faculty of Science, Kyoto Sangyo University

From NAOJ

	Fukagawa, Misato	ALMA Project
	Gouda, Naoteru	JASMINE Project
	Honma, Mareki	Mizusawa VLBI Observatory
	Iguchi, Satoru	Vice-Director General (on Program)
	Kokubo, Eiichiro	Center for Computational Astrophysics
	Saito, Masao	Director of Research Coordination
	Takami, Hideki	Subaru Telescope
	Tomisaka, Kohji	Division of Science
	Usuda, Tomonori	TMT Project
●	Watanabe, Junichi	Vice-Director General (on General Affairs)
	Yoshida, Michitoshi	Subaru Telescope

● Chairperson ○ Vise-Chairperson

Period: April 1, 2018 - March 31, 2020

8. Professors Emeriti and Staffs Emeriti

Professors Emeriti (NAOJ)

Arimoto, Nobuo
Ando, Hiroyasu
Chikada, Yoshihiro
Fujimoto, Masakatsu
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
Yokoyama, Koichi

IV Finance

Revenue and Expenses (FY 2019)

(Unit: ¥1,000)

Revenue	Budget	Final Account	Budget − Final Account
Management Expenses Grants	10,403,461	10,315,219	88,242
Facilities Maintenance Grants	3,527,659	2,259,891	1,267,768
Subsidy Income	1,450,080	1,450,180	−100
Miscellaneous Income	50,287	78,788	−28,501
Industry-Academia Research Income and Donation Income	232,882	656,888	−424,006
Reversals of Reserves for Specific Purposes	0	0	0
Total	15,664,369	14,760,966	903,403
Expenses	**Budget**	**Final Account**	**Budget − Final Account**
Management Expenses	10,453,748	9,538,166	915,582
Employee Personnel Expenses	3,608,606	3,582,924	25,682
Operating Expenses	6,845,142	5,955,242	889,900
Facilities Maintenance Expenses	3,527,659	2,259,891	1,267,768
Subsidy Expenses	1,450,080	1,450,174	−94
Industry-Academia Research Expenses and Donation Expenses	232,882	493,675	−260,793
Total	15,664,369	13,741,906	1,922,463
Revenue-Expenses	Budget	Final Account	Budget − Final Account
	0	1,019,060	−1,019,060

V KAKENHI (Grants-in-Aid for Scientific Research)

1. Series of Single-year Grants for FY 2019

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	88,000	26,400	114,400
Scientific Research (S)	1	28,170	7,740	35,910
Scientific Research (A)	11	87,170	26,100	113,270
Scientific Research (B)	11	53,440	15,570	69,010
Young Scientists (A)	2	3,400	1,020	4,420
Grant-in-Aid for Challenging Research (Pioneering)	2	13,000	3,900	16,900
JSPS Research Fellows	10	11,500	3,450	14,950
JSPS International Research Fellows	1	1,000	0	1,000
Publication of Scientific Research Results	2	1,190	0	1,190
Total	49	286,870	84,180	371,050

2. Series of Multi-year Fund for FY 2019

Research Categories	Number of Selected Projects	Budget (Unit: ¥1,000)		
		Direct Funding	Indirect Funding	Total
Scientific Research (C)	27	27,500	8,250	35,750
Young Scientists (B)	4	3,000	900	3,900
Early-Career Scientists	19	17,900	5,370	23,270
Research Activity Start-up	2	2,200	660	2,860
Promotion of Joint International Research	3	5,100	1,530	6,630
Total	55	55,700	16,710	72,410

VI Research Collaboration

1. Open Use

Type	Project/Center	Category	Number of Accepted Proposals	Total Number of Researchers	Notes
Open Use at Project/Center	Subaru Telescope		80	229 (30)	38 Institutes, 8 Countries
	Subaru Telescope Okayama Branch	SEIMEI Telescope	28	89 (4)	8 Institutes, 2 Countries
	Solar Science Observatory	Ground-based Solar Observatory	*	*	*
		Sun-observing satellite “Hinode”	**	**	**
	Nobeyama Radio Observatory	45-m telescope (Regular Program)	9	65 (25)	32 Institutes, 12 Countries
		45-m telescope (Large Program)	1	11 (0)	3 Institutes
		45-m telescope (Guaranteed Time Observations)	1	7 (2)	6 Institutes, 1 Country
	Mizusawa VLBI Observatory	VERA	31	288 (213)	52 Institutes, 19 Countries
	Astronomy Data Center		366	366 (40 at foreign institutes)	83 Institutes, 13 Countries
	Center for Computational Astrophysics		298	298	65 Institutes, 9 Countries
	Advanced Technology Center	Facility Use	18	58	22 Institutes
		Joint Research and Development	9	36 (1)	12 Institutes, 1 Country
	ALMA Project	ALMA (Cycle 6)	369	4194 (3580)	352 Institutes, 42 Countries
		ASTE	6	38 (1)	8 Institutes, 1 Country
Joint Development Research			7		4 Institutes
Research Assembly			18		10 Institutes
NAOJ Symposium			1		1 Institute

The number of foreign researchers shown in brackets ( ) is included in the total.

Notes show the number of institutes and foreign countries represented by the proposal PIs. The country count does not include Japan.

The period of ALMA (Cycle 6) is from October 2018 to September 2019.

* The observation data are 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 Astronomical data center, there is no procedure for application and adoption of projects for “Hinode.”

2. Commissioned Research Fellows

Visiting Scholars (Domestic)

Name	Position at NAOJ	Affiliated Institute	Period	Host Project/Center/ Division
Nagao, Toru	Visiting Professor	Ehime University, Research Center for Space and Cosmic Evolution	2019/4/1–2020/3/31	Subaru Telescope
Shoji, Isao	Visiting Professor	Tokyo University of Science, School of Management, Department of Business Economics	2019/4/1–2020/3/31	Astronomy Data Center
Kotake, Kei	Visiting Professor	Fukuoka University, Department of Applied Physics	2019/4/1–2020/3/31	Division of Science
Yamaguchi, Hidetoshi	Visiting Associate Professor	The University of Tokyo, Graduate School of Science, Center for Nuclear Study	2019/4/1–2020/3/31	Division of Science
Nakagawa, Akiharu	Visiting Research Fellow	Kagoshima University, Graduate School of Science and Engineering	2019/4/1–2020/3/31	Mizusawa VLBI Observatory

Visiting Scholars (Foreign)

Name	Position at NAOJ	Affiliated Institute	Period	Host Project/Center/ Division
Mazzali, Paolo	Visiting Professor	Astrophysics Research Institute, Liverpool John Moores University	2019/4/18–2019/5/21	Division of Science
Pian, Elena	Visiting Professor	Italian National Institute of Astrophysics, Institute of Space Astrophysics and Cosmic Physics	2019/4/18–2019/5/21	Division of Science
Parthasarathy, Mudumba	Visiting Professor	Indian Institute of Astrophysics (IIA)	2019/9/1–2019/10/31	Thirty Meter Telescope (TMT) Project

JSPS (Japan Society for the Promotion of Science) Postdoctoral Research Fellows

Name	Research Subject	Acceptance Period	Host Researcher
Tadaki, Kenichi	Revealing evolutionary pathways from disk- to elliptical galaxies with ALMA	2017/4/1–2020/3/31	Iono, Daisuke
Kawamuro, Taiki	Constraints on Supermassive Black Hole Growth Rates with Observations at Submm/mm Wavelengths, and Investigation of the Growth History	2017/4/1–2020/3/31	Imanishi, Masatoshi
Oshima, Kenta	Elucidations and Applications of Chaotic Transport Mechanisms in the Solar System: Development of Medium-Energy Orbital Mechanics	2018/4/1–2020/3/31	Fukushima, Toshio
Michiyama, Tomonari	ALMA observations of star formation activities inside molecular outflows associated with merging galaxies	2019/4/1–201911/5	Iono, Daisuke
Kozakai, Chihiro	Development and installation of low frequency calibration method in KAGRA	2019/4/1–2021/3/31	Tomaru, Takayuki
Washimi, Tatsuki	Evaluation of the glitch noise for burst gravitational wave detection	2019/4/1–2022/3/31	Tomaru, Takayuki
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, Takashiro	Probing rocky and icy planetesimal formation through two-dimensional simulations of gas and dust co-evolution	2019/4/1–2022/3/31	Kataoka, Akimasa

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

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. (School of Mathematical and Physical Sciences was reorganized into School of Physical Sciences in April 2004.)

(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 state-of-the-art optical-IR and radio telescopes, and theoretical research, the research and 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 students with a wide variety of backgrounds can perform original and creative research in the ever-developing field of astronomy, they are guided to focus on learning basic astronomy in the first year. In order to focus on astronomical research, including the basis of observational astronomy, instrument development, and theoretical astronomy, from the second year onwards students learn subjects ranging from principles to applications of advanced technologies that will be the basis of astronomical observations; how to design, fabricate, and test new instruments; and the forefronts of data acquisition and data analysis.

(5) Financial Supports

In order to provide students with an economical basis upon which they can develop into young researchers skilled in conducting research effectively, the department has set up the Associate Researcher program in addition to the Research Assistant system. In addition, the department plans to introduce the 'NAOJ Junior Fellow' system from FY 2020 to create an environment in which outstanding students can devote themselves more to their studies and research, and to further improve the standards of researchers produced by the department.

In FY 2019 there were 18 Associate Researchers and 3 Research Assistants.

To further improve the research environment for the students, the department provides the Overseas Travel Fund, to encourage the students to participate in international conferences to give English talks, conduct observations at various overseas

observational facilities, and so on; and the Research Fund to help them pursue their own original ideas to plan and carry out research, experiments, etc. In FY 2019 the Overseas Travel Fund sent 12 students abroad for various research activities.

(6) Undergraduate Students

For undergraduate students, and for students abroad, we run the Sokendai Summer Students Program, Spring School, and Asian Winter School to offer chances to experience research at the Department of Astronomical Science. Admission Guidance also targets undergraduate students. In FY 2019, 22 students participated in the Sokendai Summer Students program, and 13 students from 6 countries participated in Asian Winter School.

(7) Number of Affiliated Staff (2020/3/31)

Chair of the Department of Astronomical Science	1
Optical and Near Infrared Astronomy Course	
Professors	9
Associate Professors	12
Assistant Professors	12
Radio Astronomy Course	
Professors	10
Associate Professors	12
Assistant Professors	19
General Astronomy and Astrophysics Course	
Professors	11
Associate Professors	15
Assistant Professors	16
Total	116

(8) Graduate Students (26students)

1st year (5 student)

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 Research on the Formation Process of Celestial Bodies
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

2nd year (2 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Takemura, Hideaki	Nakamura, Fumitaka	Hirota, Tomoya	Dense core-survey in Orion A molecular cloud for the studies of high-mass star-forming regions by ALMA
Liang, Yongming	Tanaka, Masayuki	Matsuda, Yuichi	Correlation between galaxy and IGM at z=2.2 based on MAMMOTH overdensities mapped by HSC

3rd year (6 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Ito, Kei	Tanaka, Masayuki	Matsuda, Yuichi	The systematical study of protocluster 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	Study on galaxy evolution by the measurement of galactic dark matter profile.
Tsuda, Shuichiro	Honma, Mareki	Shibata, Katsunori	The observational study of Sgr A* with KaVA data
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

4th year (7 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	Direct measurement of coating thermal noise using a folded cryogenic optical cavity
Hatta, Yoshiki	Sekii, Takashi	Hara, Hirohisa	Asteroseismic measurements of internal rotation of stars via solving inverse problems
Watanabe, Noriharu	Usuda, Tomonori	Takami, Hideki Aoki, Wako	Research for giant planets around hot stars
Cui, Yuzhu	Honma, Mareki	Nagai, Hiroshi	Observational study of jets in active galactic nuclei with the East Asian VLBI Network
Sahoo, Ananya	Minowa, Yosuke	Takato, Naruhisa	Advanced wavefront control in adaptive optics for exoplanet imaging and spectroscopy
Zhao, Yuhang	Leonardi, Matteo	Flaminio, Raffaele	Frequency dependent squeezing for gravitational wave detector

5th year (6 students)

Name	Principal Supervisor	Supervisor	Title of Research Project
Kambara, Nagaaki	Tomisaka, Kohji	Hara, Hirohisa	Spectroscopic diagnostics of highly ionised astrophysical plasma
Kikuta, Satoshi	Imanishi, Masatoshi	Matsuda, Yuichi	Systematic study of the interplay between supermassive black holes and their environments
Matsuno, Tadafumi	Aoki, Wako	Komiyama, Yutaka	Pioneering stellar research to clarify the formation history of the Galactic halo
Yoshida, Masaki	Suematsu, Yoshinori	Hara, Hirohisa	Study of Solar Chromospheric Dynamic Phenomena by Spectro-polarimetric Observationsns
Fukagawa, Nao	Aoki, Wako	Iono, Daisuke	Mass and environmental dependence of gas inflow and outflow of galaxies around the cosmic noon
Kim, Jungha	Honma, Mareki	Shibata, Katsunori	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
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	Star Formation in M17
Huang, Shuo	The University of Tokyo	Okuda, Takeshi	Study of Bulge Formation in High-z Submillimeter galaxies
Gotoh, Kohki	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
Nakatsuno, Naoki	The University of Tokyo	Goda, Naoteru	Analysis of the Milky Way Galaxy by the use of astrometric data
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
Okino, Hiroki	The University of Tokyo	Honma, Mareki	Observational study of AGN jets with VLBI
Kataoka, Satoru	The University of Tokyo	Goda, Naoteru	Analysis of the Galaxy using astrometric data
Kawakami, Tomohiro	The University of Tokyo	Fukagawa, Misato	Observational Study of Star Formation
Hoshino, Haruka	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study on Formation of Planetary Systems
Yamazaki, Yuta	The University of Tokyo	Nakamura, Fumitaka	Cosmic time Evolution of r-process isotopic abundances
Ishizuka, Noriyoshi	The University of Tokyo	Hara, Hirohisa	Study on Magnetic Reconnection Site in Solar Flares
Kashiwada, Yuki	The University of Tokyo	Goda, Naoteru	Quantitative assessment of the effects of stellar velocity dispersion in the analysis of solar motion
Guo, Kangrou	The University of Tokyo	Kokubo, Eiichiro	Theoretical Study on Formation of Planetary Systems
Lee, Sujin	The University of Tokyo	Honma, Mareki	Radio observations of pulsars/magnetars
Tatsuuma, Misako	The University of Tokyo	Kokubo, Eiichiro	Formation Process of Planetesimals Investigated with Numerical Calculation of Material Strength of Small Solar System Bodies
Mori, Kanji	The University of Tokyo	Nakamura, Fumitaka	Exploring x-ray bursts with numerical simulations, nuclear experiments, and astronomical observations
Luo, Yudong	The University of Tokyo	Nakamura, Fumitaka	Big-Bang Nucleosynthesis with Primordial Magnetic Field
Sasaki, Hirokazu	The University of Tokyo	Nakamura, Fumitaka	Neutrino oscillations in core-collupse supernovae
Fujii, Yoshinori	The University of Tokyo	Flaminio, Rafaele	Development of the vibration isolation system for the KAGRA detector
Yamada, Ayato	The University of Tokyo	Goda, Naoteru	Effects of the orbital resonances on the Milky Way rotation and solar motion

3. Commissioned Graduate Students

Doctoral Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Mukae, Shiro	The University of Tokyo	2018/11/1–2019/10/31	Hayano, Yutaka	Verification of the correction accuracy of optical distortion for TMT/IRIS imager. Measurement and analysis on optical surface form under the cryogenic environment.
Chin, Kahwuy	The University of Tokyo	2019/4/1–2020/3/31	Kawabe, Ryohei	Development of Multichronic for mm/submm wave Multichroic Camera
Aritomi, Naoki	The University of Tokyo	2019/4/1–2020/3/31	Flaminio, Raffaele	Frequency dependent squeezing for future upgrade of the KAGRA gravitational wave detector
Murayama, Yosuke	University of Tsukuba	2019/4/1–2020/3/31	Shan, Wenlei	Development of large-format focal plane array using microwave kinetic induction
Yamaguchi, Masayuki	The University of Tokyo	2019/4/1–2020/3/31	Kawabe, Ryohei	Diversity of Planet Formation Explored by ALMA Using Super-resolution Imaging
Kim, Seongjoong	Tokyo Institute of Technology	2019/5/1–2020/3/31	Nomura, Hideko	Research on dust and gas structure in protoplanetary disks through ALMA observations
Wei, Chen-En	Tokyo Institute of Technology	2019/5/1–2020/3/31	Nomura, Hideko	Model calculations of formation of complex organic molecules in protoplanetary disks
Kozuki, Yuto	The University of Electro-Communications	2019/10/1–2020/9/30	Uzawa, Yoshinori	Study on SIS frequency up-converters
Kang, Haoran	The University of Tokyo	2019/10/1–2020/9/30	Gonzalez, Alvaro	Study of array receivers in millimeter/submillimeter waves

Master's Course	Affiliated Institute	Period	Supervisor	Title of Research Project
Eto, Yuki	Kagoshima University	2018/10/1–2019/9/30	Kameno, Seiji	Observational Study on Protostar-Jet Driving Mechanism with ALMA Polarimetry
Mizoguci, Genma	Nagoya University	2019/4/1–2020/3/31	Uzawa, Yoshinori	Development of high dynamic range series-connected SIS junction mixer
Nishiumi, Taku	Kyoto Sangyo University	2019/4/1–2020/3/31	Aoki, Wako	Analysis of transit light carve at multiple-wavelengths
Matsuda, Kazuma	The University of Tokyo	2019/7/1–2020/3/23	Yamashita, Takuya	Observational studies of exoplanets
Ishimura, Shuhei	Ibaraki University	2019/10/1–2020/9/30	Watanabe, Junichi	Ham-band Radio meteor Observation
Tanaka, Kenta	The University of Tokyo	2019/10/1–2020/3/31	Aso, Yoichi	Gravitational wave astronomy

4. Degrees Achieved with NAOJ Facilities

Name	Degree	Title of Research Project
Kikuta, Satoshi	Doctor of Philosophy, SOKENDAI	Galaxy Formation at Cosmic Noon Probed with Lyman-Alpha Emission
Matsuno, Tadafumi	Doctor of Philosophy, SOKENDAI	High-Precision Abundance Study for the Milky Way Halo Stars with Kinematics and Asteroseismology
Yoshida, Masaki	Doctor of Philosophy, SOKENDAI	Magnetic Energy Transport through Chromospheric Spicule Revealed with Lyman-Alpha Spectro-Polarimetric Observation

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 (37 days in total): November 30 (due to equipment inspection); October 12–14 and 25 (due to weather warnings or bad weather); February 29–March 31 (due to the novel coronavirus)

Visitors: 24,236 (Including 4,105 in group tours.)

Open Facilities: Observatory History Museum (65-cm Telescope Dome, closed January 20–March 27 due to roof-leak repair work), 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

[Regular Star Gazing Party]

Dates: Friday before second Saturday; fourth Saturday

Visitors: 2,459 (22 events planned and 19 events held)
The maximum number of participants has been decreased from 300 to 200 since May 2019. The parties scheduled for February 22, March 13, and March 28 (3 events in total) were canceled as a preventive measure against the novel coronavirus.

Open Facility: 50-cm Telescope for Public Outreach

[4D2U Theater Showings]

Dates: Friday before second Saturday; first, second, and third Saturdays

Visitors: 5,012 (47 events planned and 42 events held)
The showing scheduled for October 12 was canceled due to a Typhoon Warning. The showings scheduled for March 7, 13, 14, and 21 (4 events in total) were canceled as a protective measure against the novel coronavirus.

Open Facility: 4D2U Dome Theater

[Special Open-House Event] Mitaka Open House Day

Dates: October 25 (Fri), 2019, 14:00–19:00 (Canceled)
October 26 (Sat), 2019, 10:00–19:00

Topic: Subaru Telescope 20th Anniversary

Visitors: 4,113
The pre-open day scheduled for October 25 was canceled due to a Typhoon Warning.

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. It has been held for 2 days each year, starting from 2010. The perennially popular lectures related to this year's topic were hosted by the Institute of Astronomy, University of Tokyo ("My 20 Years at Universities and the Subaru Telescope" Kentaro Motohara, Associate Professor at the University of Tokyo) and NAOJ ("20 Years of the Subaru Telescope — The Universe Revealed by the Subaru Telescope" Michitoshi Yoshida, Professor at NAOJ / SOKENDAI; and "The Forefront of Planetary System Formation Research Explored with the Subaru Telescope and ALMA" Misato Fukagawa, Professor at NAOJ / SOKENDAI).

*Guided tours corresponding to group tours (Dantai Kengaku) and cultural property tours were also held, but the NAOJ Solar Tower Telescope Special Open Days scheduled in March were postponed as a preventive measure against the novel coronavirus. In addition, the "Information Space of Astronomy and Science" was opened in 2015 near the south entrance of Mitaka Station to distribute information.

2. Mizusawa Campus

[Open year-round]
Dates: April to March (except for the New Year season), 9:00–17:00 daily
Visitors: 25,837
Open Facilities: Kimura Hisashi Memorial Museum, VERA 20-m antenna, 10-m VLBI antenna

The open house event is held at the campus with the cooperation of the Oshu Space and Astronomy Museum (OSAM: Yugakukan) located in the campus.

[Special Open Day] Held as part of Iwate Galaxy Festival 2019
Date: August 24 (Sat.), 2019, 10:00–20:30
Visitors: 1,398 (Number of people accepted)

Same as last year, the Open Day was co-hosted with Ihatov Space Action Center / the Oshu Space and Astronomy Museum (OSAM: Yugakukan) and the city of Oshu. The event was opened with a performance by a marching band from a local elementary school. NAOJ offered such attractions as exhibits about the research results of VERA, RISE, and CfCA; tours of the 20-m parabolic antenna; plastic bottle rocket launch; a quiz game; tours of the supercomputer "AteruiII"; and a special guided tour for the Array Operations Center (AOC) and the VLBI correlator.

This year, the Japanese representative for the black hole imaging project is Prof. Mareki Honma, Director of Mizusawa VLBI, and since many of the members are in Mizusawa, we held special sessions and exhibitions focusing on black holes which were enormously well received.

OSAM (Yugakukan) offered various experiments in the science stalls, workshops, etc., which were run by the student interns. The Open Day was a great success, strengthening ties with the local people.

Iriki: VERA Iriki Station

[Open year-round]
Dates: April to March (except for the New Year season)
Visitors: 1,462

[Special Open Day]
Date: August 10 (Sat.), 2019, 12:00–21:00
Visitors: Approximately 300

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, the event was cancelled due to strong winds caused by a typhoon that made it difficult to set up tents and other facilities. It was held in a reduced scale as “NAOJ VERA Iriki Station Special Open Day.”

At the NAOJ VERA 20-m radio telescope and the Kagoshima University 1-m optical/infrared telescope facilities, guided tours of telescopes and observation buildings were held. NAOJ offered such attractions as parent-child science experiments, the making of toys out of bamboo, and a live relay of daytime Venus observations by the 1-m optical/infrared telescope. This time offered a chance to try-on a JAXA space suit, which was well received.

A special lecture of the year was given by Director Takeshi Fujita from JAXA Kagoshima Space Center. All visitors had fun and were satisfied with the scientific programs offered in this festival.

Ogasawara: VERA Ogasawara Station

[Open year-round]
Dates: April to March (except for the New Year season)
Visitors: 7,280

[Special Open Day]
Date: February 15 (Sat.), 2020, 10:00–16:00
Visitors: 260

A special open house event was held this year again under the name “Star Island 19.” Same as last year, the free shuttle buses were appreciated by the visitors. The number of visitors was 260. Because the population of the island is about 2,000, approximately 10 % of the residents visited this event.

NAOJ offered such attractions as exhibits about the research results of VERA and RISE, driving experience of 20-m parabolic antenna, quiz games, a commemorative photo booth, strange science experiments, and short lectures.

On the night before the special open house, a Space Lecture was given by Fumie Tazaki Project Research Staff Mizusawa VLBI Observatory at the Ogasawara Visitor Center with 44 guests in attendance.

Ishigaki-jima: VERA Ishigaki-jima Station

[Open year-round]
Dates: April to March (except for the New Year 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: 3,449

[Special Open day] The Special Open Day was held as a part of the Star Festival of the Southern Island.
Date: August 4 (Sun.), 2019, 10:00–17:00
Visitors: 269

Same as previous years, attractions like antenna tours, a commemorative photo booth, Mini lectures, and exhibits were offered.

Ishigaki Island: Ishigakijima Astronomical Observatory

[Open year-round]

Dates: April to March

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, Holidays, (20:00–22:00), two 30-minute sessions per evening

4D2U Screenings: from 15:00 to 15:30 every day when the Observatory is open

Visitors: 13,139 (513 during the Star Festival of the Southern Island)

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 (including exhibits of astronomical images)

The "Hoshizora Manabi no Heya" (Starry Sky Study Room), constructed adjacent to the observatory in 2013 by the city of Ishigaki, was very popular, welcoming 4,023 guests.

[Special Open day] [Southern Island Star Festival 2019]

Dates: August 3 (Sat.) to August 12 (Mon.), 2019

Visitors: 9,000

This year is the 18th anniversary of both the completion of VERA Ishigakijima Station and the Star Festival of the Southern Island. This year's event was held at Minami-Nuhama-cho Green Park under fine weather, and many people attended. The evening visit to Ishigakijima Local Meteorological Observatory was cancelled due to a typhoon. The annual planetarium screening was attended by 552.

The activities at Ishigakijima Astronomical Observatory boost regional promotion like school education, lifelong learning, and sightseeing. The cooperation agreement between NAOJ and the Tourism Association of the city of Ishigaki has been finalized. And it is widely recognized that the starry sky can be used as a tourism resource. Considering this situation, we will continue to strengthen our ties with other associations.

3. Nobeyama Campus

[Regular Open]

Open Time: 8:30–17:00 (every day except around New Year's Day (Dec. 29 to Jan. 3), especially, open until 18:00 during the summer (Jul. 20 to Aug. 31))

Visitors: 39,656

Open Facilities: 45-m Radio Telescope, Nobeyama Millimeter Array, Nobeyama Radioheliograph, etc. (just viewing) and NINS Nobeyama Exhibition Room

[Open House Day]

Date: August 24 (Sat), 2019, 9:30–16:00

Visitors: 1,961

The theme of the 2019 Open House Day was "45-m Radio Telescope and new friends." We had two lectures on the theme, which attract large audiences every year. One was "Antarctic Terahertz Telescope Project -the enigmas of galaxies explored from the best sky on Earth" by Prof. Kuno, Nario (University of Tsukuba/Kwansei Gakuin University). The other was "Coming Soon! A new parabolic Antenna being constructed by JAXA" by Associate Prof. Murata, Yasuhiro (ISAS/JAXA, Usuda Deep Space Center).

Although the large number of rainy days in that summer season was cause for concern, it was fine from the early morning on Open House Day and a comfortable climate typical of Nobeyama. We had 1,961 visitors, which was a little less than the last year. We had some established hands-on events such as touch the main reflector panel of the 45-m Radio Telescope, the antenna handicrafts, and the antenna origami. At the NINS exhibition room, the presentation of the 4D2U theater, exhibitions of other institutes such as NIFS, and operation demonstrations of the 10-m antenna by Osaka Prefecture University were carried out. In addition, the NAOJ Chile team performed the ALMA panel sessions and some short lectures. Moreover, the many visitors were pleased with the NRO character, Dr. Nobeyama, and the Nagano Prefecture PR character, Arukuma. Many participants had a good smile at the Open House day because we were supported by many people from the local community and Shinshu University, Faculty of Agriculture, as well as NAOJ and other institutes of NINS.

[Jimoto Kansha Day (Thanks Day for the locals)]

Date: December 7 (Sat), 2019, 13:00–16:30

Visitors: 30

The local people have difficulty joining the Open House Day during the farming season. They have said that they do not know much about what we, not only NRO but also Tsukuba and Shinshu Universities, study in Nobeyama. In response to these comments, we established this event in cooperation with Shinshu University, Faculty of Agriculture, Education and Research Center of Alpine Field Science and University of Tsukuba, Mountain Science Center, Yatsugatake Forest. This year, the event was hosted by Shinshu University at Vegetaball

With, Minamimaki Village Rural Exchange Center. We had three lectures, “The neighborliness of galaxies to be resolved by the Nobeyama telescope” from NRO and “Forest and coniferous trees around Yatsugatake area” from the University of Tsukuba, and “Introduction of the agriculture in the habitable boundary area ~ on Sahel, in west Africa,” and their question and answer sessions. Moreover, we had some booths introducing and selling fruits and vegetables from Shinshu University and introducing the agriculture and culture of west Africa. The event was held in a delightful atmosphere, though not so many participants due to cold weather.

4. Subaru Telescope

[Summit Facility Tour]

Dates Open for Public Tours: 31 (These dates are listed in the public tour program page at the Subaru Telescope's web site. Due to the summit access road closure the public tours were suspended between July 13 and November 30 in 2019. No tours were scheduled during the winter time between December and March.)

Public Tour Visitors: 325

Special Tour Visitors: 42 groups, 214 visitors

[Base Facility Tour]

Special Tour Visitors: 12 groups, 249 visitors

[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 18 English articles

• Special activities reports, announcements on Call for Proposals, and recruitment – 24 Japanese and 20 English articles.

○ Web postings are supplemented by social media via official accounts

• Twitter accounts – SubaruTelescope (for Japanese), SubaruTel_Eng (for English)

• Facebook pages – 国立天文台 (for Japanese), National Astronomical Observatory of Japan, and Subaru Telescope Hawaii Outreach (for English)

• YouTube channels – SubaruTelescopeNAOJ (for Japanese), SubaruTelescopeNAOJe (for English)

[Outreach]

1. Lectures, workshops, etc. at nearby facilities, 53 cases, 2000 people in total

2. Others: 6 exhibitions and community involvement activities, able to interact directly with about 11,500 people.

Breakdown as follows:

Approximately 3000 people at the Merrie Monarch Parade

About 3000 at Astro Day

About 1500 at Astro Day West

Approximately 2500 people at the Tanabata Hoshimatsuri Festival

Approximately 500 people at Hawaii Explorations Expo

Approximately 1,000 at Onizuka Science Day

3. Media Interview/Filming

Japanese media 7

English media 10

IX Overseas Travel

Research and Academic Staff Overseas Travel

(Including employees on annual salary system)

category / country/area	Business Trip	Training	Total
South Korea	15	0	15
China	37	0	37
Thailand	15	0	15
Taiwan	28	0	28
Hong Kong	0	0	0
Singapore	5	0	5
Indonesia	2	0	2
Philippines	0	0	0
Other areas in Asia	18	0	18
Hawai`i	60	0	60
U.S.A.	93	0	93
Australia	11	0	11
Italy	28	0	28
U.K.	12	0	12
France	18	0	18
Canada	5	0	5
Guam, Saipan	0	0	0
Germany	24	0	24
Other areas in Europe and Oceania	57	0	57
Mexico	3	0	3
Brazil	1	0	1
Africa	3	0	3
Other areas in South and Central America *	23	0	23
Total	458	0	458

* Most travelers to South and Central America went to Chile.

X Award Winners

Award Recipients	Affiliated Division	Job Title	Award	Date
Yoshida, Michitoshi et al.	Subaru Telescope	Professor	FY2019 The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Prizes for Science and Technology (Research Category)	2019/4/17
Hirota, Akihiko	NAOJ Chile	Assistant Professor	Silver medal awarded by the Chilean Senate	2019/4/17
Zhao, Yuhang	SOKENDAI	Student	Best poster award in the 22nd KAGRA Face-to-Face Meeting	2019/4/21
The Event Horizon Telescope Collaboration*			NSF Diamond Achievement Award	2019/5/9
Tsuneta, Saku	NAOJ	Director General	Japan Academy Prize	2019/6/17
Gonzalez Garcia, Alvaro	ALMA project	Associate Professor	The 8th NINS Young Researcher's Prize	2019/7/7
Imanishi, Masatoshi	Subaru Telescope	Assistant Professor	Jury Award from the JSPS	2019/7/11
Sawada, Tsuyoshi; Takahashi, Satoko; Hirota, Akihiko; Okuda, Takeshi; Mizuno, Norikazu	NAOJ Chile	Associate Professor/ Associate Professor/ Assistant Professor/ Associate Professor/ Professor	2018 NAOJ Director General Prize	2019/7/30
Aritomi, Naoki	The University of Tokyo	Student	The 23rd KAGRA face-to-face meeting Best Poster Award	2019/8/24
Hull, Charles Lindsay Hopkins	NAOJ Chile	Project Assistant Professor	Tinsley Scholar Lectureship	2019/9/10
Soma, Mitsuru	Division of Science	Assistant Professor	IOTA's 2019 Homer F. Daboll Award	2019/9/21
Aritomi, Naoki	The University of Tokyo	Student	Student Presentation Award of the Physical Society of Japan on 2019 Autumn Meeting	2019/10/19
Sugiyama, Naonori	Division of Science	Project Assistant Professor	The 11th Senshi-kai Award	2019/10/26
The Event Horizon Telescope Collaboration*			2020 Breakthrough Prize in Fundamental Physics	2019/11/3
Mizusawa VLBI Observatory			the 72nd Iwate Nippo Culture Award	2019/11/3
Honma, Mareki	Mizusawa VLBI Observatory	Professor	SUITS OF THE YEAR 2019 innovation Section	2019/11/7
Agata, Hidehiko; Mitaka taiyokei-walk executive committee	Public Relations Center et al.	Associate Professor, etc.	FY2019 (the 36th) Chiki-zukuri Award by Ministry of Land, Infrastructure, Transport and Tourism	2019/11/28
Hanayama, Hidekazu	Mizusawa VLBI Observatory	Project Research Staff	2019 Local starry sky photo contest Award	2019/11/X
Kajino, Toshitaka	Division of Science	Project Professor	Best International Academic Award	2019/12/1
Sawada, Tsuyoshi	NAOJ Chile	Associate Professor	JAO Values Award	2019/12/6
The Event Horizon Telescope Collaboration*			Albert-Einstein-Society, Einstein Medal	2019/12/27
Mizusawa VLBI Observatory			Special Merit Award by Oshu City	2020/1/6
Ouchi, Masami	Division of Science	Professor	Highly Cited Researchers 2019 by Clarivate Analytics	2020/1/9
Mizusawa VLBI Observatory			the Kahoku Culture Award	2020/1/17

The Event Horizon Telescope Collaboration*			AAS Bruno Rossi Prize2020	2020/1/28
Shimojo, Masumi	ALMA project	Associate Professor	Young Career Award, Runners-up, 5th Asia-Pacific Solar Physics Meeting	2020/2/7
Akiyama, Kazunori	Mizusawa VLBI Observatory	Research Affiliate	FY2019 The Astronomical Society of Japan Research Award	2020/3/17
Matsuno, Tadafumi	SOKENDAI	Student	The 4th SOKENDAI Award	2020/3/25

* The Event Horizon Telescope Collaboration
Cui, Yuzhu; Hada, Kazuhiro; Hirota, Akihiko; Homma, Mareki; Kawashima, Tomohisa; Kono, Yusuke; Nagai, Hiroshi; Okino, Hiroki; Oyama, Tomoaki; Tazaki, Fumie; Tsuda; Shuichiro

XI Library, Publications

1. Library

Number of books in each library (2020/3/31)

	Japanese Books	Foreign Books	Total
Mitaka	18,085	47,802	65,887
Nobeyama	1,128	5,891	7,019
Mizusawa	4,986	18,113	23,099
Hawai`i	1,699	4,683	6,382
Total	25,898	76,489	102,387

Number of journal titles in each library (2020/3/31)

	Japanese Journals	Foreign Journals	Total
Mitaka	370	1,675	2,045
Nobeyama	16	82	98
Mizusawa	659	828	1,487
Hawai`i	15	12	27
Total	1,060	2,597	3,657

2. Publication

Here we list continuing publications produced by NAOJ in FY 2019.

(Mitaka)
01) Report of the National Astronomical Observatory of Japan, Vol. 20: 1 issue
02) Annual Report of the National Astronomical Observatory of Japan (Japanese), No. 31, Fiscal Year 2018: 1 issue
03) Annual Report of the National Astronomical Observatory of Japan (English), Vol. 21, Fiscal Year 2018: 1 issue
04) Calendar and Ephemeris, 2020: 1 issue
05) NAOJ News, No. 309–320: 12 issues
06) NAOJ Pamphlet (Japanese): 1 issue
07) NAOJ Pamphlet (English): 1 issue
08) Rika Nenpyo (Chronological Scientific Tables), 2020: 1 issue
09) Publication of the National Astronomical Observatory of Japan, Vol. 14: 1 issue

3. Publication Support

In FY 2019, the NAOJ Reprints were replaced by publication support.

National Astronomical Observatory publication support, No. 3182–3333*: 150 issues
*Excluding No. 3188 and No. 3205

XII Important Dates

April 1, 2019 – March 31, 2020

2019	
April 2	ALMA Proposal Preparation for Cycle 7 and Proposal Helpdesk was held at NAOJ Mitaka Campus
April 10	A press conference "Astronomers Capture First Image of a Black Hole — Japanese researchers contribute to paradigm-shifting observations of the gargantuan black hole at the heart of distant galaxy Messier 87" was held at Kioi Conference. The organizations that co-hosted the domestic conference were: Joint Institute for Computational Fundamental Science, Kogakuin University, the Institute of Statistical Mathematics, the Graduate University for Advanced Studies, the School of Science at the University of Tokyo, Tohoku University, and Hiroshima University. The conference was attended by 61 participants from 27 media companies. Coordinated press conferences were also held by overseas institutions at the same time across the globe (Washington, D.C.; Brussels; Santiago; Shanghai; and Taipei).
April 17	Chilean Senate distinguished researchers in the Joint ALMA Observatory, including assistant professor Akihiko Hirota, in recognition of its role in obtaining the first image of a black hole published by the Event Horizon Telescope.
April 17	Dr. Michitoshi Yoshida, the Subaru Telescope Director, received the Science and Technology Award from the Minister of Education, Culture, Sports, Science and Technology.
April 21	10th Open Observatory event held at the Ibaraki University Center for Astronomy and the NAOJ Mizusawa VLBI Observatory Ibaraki Station, with 535 visitors in attendance.
April 24~26	An exhibition and lecture were held at the Optics & Photonics International Exhibition 2019 (OPIE'19) at PACIFICO Yokohama.
April 27	About 30 people from the Subaru Telescope participated in the Merrie Monarch Parade Festival in downtown Hilo, Hawaii and walked with the Subaru Telescope and astronomy banners and placards, showing them to audiences alongside the roads as they walked along. Deepened interaction with 3000 local people.
May 4	22 Subaru Telescope staff participated in the "Astro Day" event held at a shopping mall in Hilo on Hawaii Island, where hands-on activities related to Subaru Telescope and astronomy were conducted. Deepened interaction with about 3,000 local citizens in and around the Hilo area.
May 4~5	Minister of Education, Culture, Sports, Science and Technology, Masahiko Shibayama, visited the Subaru Telescope.
May 25	4th NRO photograph event was held with 34 participants. It was fine weather and many beautiful photos were taken.
June 3~7	Observation training of Radio Astronomy at Nobeyama Radio Observatory for Undergraduate Students was performed; there were 12 participants.
June 12	The 20th anniversary ceremony of the Subaru Telescope was held at Hitotsubashi Hall in Tokyo.
June 21	At the Maunakea Skies Talk event at Hilo's Imiloa Astronomy Center, a researcher from the Subaru Telescope gave a public talk entitled "Galaxy Evolution and Galaxy Ecology."
June 22	Professor Seiichi Sakamoto gave an astronomy lecture for the women's club of the Japan-Chile Chamber of Commerce and Industry at the NAOJ Santiago Office.
July 1~5	The Public Relations Center co-hosted a booth with the Institute of Physical and Chemical Research (RIKEN) at the 11th World Conference of Science Journalists in Lausanne, Switzerland.
July 2	Eclipse viewing event for Santiago Japanese School was held at the NAOJ Santiago Office. Assosiate professor Shin'ichiro Asayama gave a lecture.
July 4~5	The ALMA Operations Support Facility and Array Operation Site accepted public visits in conjunction with the total solar eclipse and 37 Japanese tourists visited the sites.
July 5	The 20th anniversary special website of the Subaru Telescope "The appearance of the universe as seen by Subaru Telescope-Research results of 20 years of the Subaru Telescope-" was released.
July 7	In collaboration with the Imiloa Astronomy Center, the Japanese Chamber of Commerce & Industry of Hawaii, and the Hawaii Japanese Center, the Tanabata Star Festival was held to deepen interaction with the local Nikkei (Japanese Americans) and about 2500 citizens who were interested in astronomy and Japanese culture participated.
July 7	Associate professor Alvaro Gonzalez received the 8th NINS Young Researcher Award and gave a lecture at Miraikan.

July 22~26	Facility Guide Week for Educational Organization was carried out at Nobeyama Radio Observatory.
July 24	Teachers of Santiago Japanese School visited the ALMA Operations Support Facility and Array Operations Site.
July 31 ~August 2	Chura-boshi Research Team workshop for high school studants held at VERA Ishigakijima Station and Ishigakijima Astronomical Observatory, with students from Ishigaki Island, from the main island of Okinawa, and from high schools in Tokyo, Hiroshima, and Kumamoto in attendance. The team was divided into two groups: a radio observation group and a visible-light observation group using the Murikabushi Telescope. The radio observation group discovered a new radio star, the RR star in the constellation of Magi, which had never been detected before. The discovery of the new radio star is the eighth such object in total since fiscal 2015.
August 3~12	The Southern Island Star Festival (corresponding with the open house events for Ishigakijima Astronomical Observatory and VERA Ishigakijima Station) was held. The entire star festival was held at various places in Ishigaki City, and the Ishigakijima Astronomical Observatory was almost full during each day, with 269 visitors to the special opening of the VERA Ishigakijima Station. In the commemorative lecture by Mareki Homma, Director of Mizusawa VLBI, he introduced the process from the construction of VERA Ishigakijima Station to the black hole photography in an easy to understand manner, and all the participants listened with great interest.
August 7	A traditional Tanabata event was held in San Pedro de Atacama.
August 10	This year's "Yaeyama Highland Star Festival 2019" was cancelled due to two typhoons that lined the southern ocean of Kyushu from the day before the event, but a scaled-down event was held including an antenna tour and a tour of the observation building, a lecture by Takeshi Fujita, Director of the JAXA Kagoshima Space Center, and an event prepared by students from the Kagoshima University Science Department, "NAOJ VERA Iriki Station."
August 10 ~September 7	As a part of the summer student program held by NAOJ and the Department of Astronomical Science of SOKENDAI, two undergraduate students stayed at NAOJ Chile and conducted research with ALMA data.
August 24	Open House day of Nobeyama Radio Observatory. There were 1,961 visitors for this event.
August 24	Iwate Galaxy Festival 2019, a special open house day of Mizusawa Campus, held with 1,398 people in attendance.
August 30	Professor Norikazu Mizuno gave a lecture in the Buenos Aires Japanese School.
August 1~31	Sokendai students were accepted by Subaru Telescope as part of the Summer Student Program.
September 4~6	"Nobeyama Science Workshop Reiwa Era Year 1" was held on the latest results and the future plan of the 45-m radio telescope. There were 72 participants, mainly young researchers.
September 5	The 2020 Fundamental Physics Breakthrough Award was given to the team from the international project Event Horizon Telescope (EHT), which announced that it had achieved a direct image of a black hole. Among the 347 awardees, 11 researchers belong to the National Astronomical Observatory of Japan (NAOJ), including the Japanese representative of the EHT, Mareki Homma, Director of Mizusawa VLBI.
September 5	ALMA Cycle 7 Supplimental Call Proposal Preparation Meeting was held at NAOJ Mitaka Campus.
September 10	Press conference on the achievements based on the observations of the Subaru Telescope and ALMA "Discovering the traces of star formation 13.5 billion years ago! -The farthest exploration of the old galaxies-" was held at the Kumamoto Prefectural Office sponsored by the Astronomical Society of Japan.
September 16	A memorial ceremony of Former Director General Norio Kaifu who passed away on April 13 was held.
September 27	A press conference "Oldest Galaxy Protocluster forms "Queen's Court"" was held at the Administrative Bureau of the National Institutes of Natural Sciences. The conference was hosted jointly by 14 organizations including the University of Tokyo and Waseda University, with 9 media companies in attendance.
September 30	A press tour of the KAGRA experiment facility (Kamioka-cho, Gifu Prefecture) was held ahead of the completion ceremony of the Large-scale Cryogenic Gravitational Wave Telescope KAGRA. A total of 27 media companies attended the tour.
October 1	Press conference on the achievements based on the observations of the Subaru Telescope and ALMA, "The space network found in the early universe-a clear stream of the universe that brings benefits to galaxies and black holes", was held at the Ministry of Education, Culture, Sports, Science and Technology sponsored by the Institute of Physical and Chemical Research (RIKEN).
October 4	The ceremony and conference celebrating the completion of the Large-scale Cryogenic Gravitational Wave Telescope KAGRA were held at the KAGRA experiment facility (Kamioka-cho, Gifu Prefecture) and in Toyama City. These events were held jointly with the Institute for Cosmic Ray Research of the University of Tokyo, the High Energy Accelerator Research Organization, and the University of Toyama. The research agreement among KAGRA, LIGO (U.S.A), and Virgo (Italy) was signed on the same day. The ceremony and conference were both attended by 21 media companies.
October 25~26	The pre-open day of "Mitaka Open House Day" on October 25 was canceled due to a Typhoon Warning. For details, see the section "Public Access to Facilities."

October 27	In collaboration with the Hawaii Science and Technology Museum, a science event for the general public was held at Hilo, Hawaii. The Subaru Telescope staff conducted hands-on activities related to science and astronomy to deepen interaction with citizens.
November 1	A Citizen Astronomy program called "GALAXY CRUISE" using observation data of the Subaru Telescope was launched. (Joint program between Subaru Telescope and the Public Relations Center)
November 2	Special sponsorship was made to the sora-girl event "Tebura de Hoshizora Kansho-kai (Drop-by Star Gazing Event)," hosted by the Minamimaki Tourism Association at Vegetaball With, Minamimaki Village Rural Exchange Center.
November 3	NAOJ Mizusawa VLBI Observatory received the 72nd Iwate Nippo Culture and Sports Award, which honors the achievements of people who have contributed to the development of Iwate.
November 3	The Subaru Telescope staff participated in the "Astro Day West" event sponsored by Maunakea Observatories to deepen interaction with approximately 1500 local citizens in the Kona area.
November 12~13	Manufactruing Readiness Review of the ALMA Band 1 receiver was held in Taiwan.
November 12~15	The IAU Symposium 358 "Astronomy for Equity, Diversity and Inclusion" was held at Mitaka Campus, welcoming 124 participants from 31 different countries.
November 13	Night operator staff of Subaru Telescope attended a Girl Scouts event held at a local elementary school in Hilo to explain the observatory's work and achievements and deepen interaction with local female students.
November 14	A press conference "Two Cosmic Peacocks show Violent History of the Magellanic Clouds" was held at Hitotsubashi Hall in cooperation with Nagoya University and Osaka Prefecture University. The conference was attended by 7 media companies.
November 17~22	"SUBARU TELESCOPE 20TH ANNIVERSARY—Optical & Infrared Astronomy for the Next Decade—" International Research Meeting to celebrate the 20th anniversary of the Subaru Telescope was held at Waikoloa, Hawaii.
November 30 ~December 22	To commemorate the 120th anniversary of the start of latitude observations in Mizusawa, exhibitions were held at three venues in Mizusawa Campus: the Oshu Space Museum (former Main Building of the Latitude Observatory), the Kimura Memorial Hall (former Temporary Latitude Observatory), and the former Ocular Observatory. More than 500 people visited during the period, reminiscing about 120 years.
December 2~6	The Event Horizon Telescope Collaboration Meeting 2019 was held in Hilo, Hawaii, USA, with 114 participants from 16 countries and regions around the world, and included short- and long-term action plans for the project as a whole, reports on each working group's activities, future plans, and issues to be discussed.
December 3	A comprehensive coordinated promotion agreement with the National Institute of Information and Communications Technology was signed.
December 4~5	Critical Design and Manufacturing Review of the new ACA spectrometer was held in Korea.
December 7	"Jimoto Kansha Day (Thanks Day for the Locals) & Open Symposium" was held as the Special Open House for locals (Minamimaki and Kawakami Villages) at Vegetaball With, Minamimaki Village Rural Exchange Center by Nobeyama Station, Facultuy of Agriculture, Shinshu University as the main host. It was carried out by 3 Nobeyama Institutes (Tsukuba and Shinshu Universities and Nobeyama Radio Observatory). There were about 30 participants.
December 10~11	East Asian ALMA Development Workshop 2019 was held at NAOJ Mitaka Campus.
December 13~14	"The 17th Mizusawa VLBI Observatory Users Meeting" was held with approximately 50 participants. There was spirited discussion of Japanese, East Asian, and world VLBI programs.
December 14	To celebrate the 120th anniversary of the start of latitude observations at Mizusawa, we held a ceremony and a celebration, looking back on the 120 years of history and wishing for further development and challenges for astronomical research in the future.
December 15	On the occasion of the 120th anniversary of the start of latitude observations in Mizusawa, a lecture was held for the general public, mainly from Oshu City and Iwate Prefecture, based on a basic policy of Mareki Honma, Director of Mizusawa VLBI, "an observatory in harmony with the community." The three speakers were Mareki Honma, Director of Mizusawa VLBI, Noriyuki Namiki, Director of the RISE Project, and Eiichiro Kokubo, Director of the Center for Computational Astrophysics, as well as Yukie Baba, Assistant Professor of the Center for Historical Social Science Literature, Hitotsubashi University who is researching the history of NAOJ Mizusawa.
December 16	A press conference "Carbon Cocoons Surround Growing Galaxies—ALMA Spots Earliest Environment Pollution in the Universe—" was held jointly in Tokyo with the Institute for Cosmic Ray Research and Osaka University. The conference was attended by 10 media companies.
December 17	ALMA Grant Fellow Symposium 2019 was held at NAOJ Mitaka Campus.
December 18~19	ALMA/45m/ASTE users meeting 2019 was held at NAOJ Mitaka Campus.

December 20	A special facility tour was held at the Hilo Base Facility of Subaru Telescope. A work class and a science class were held with 43 children and 15 guardians from the Hale-Aloha-Nazarene school in Hilo in attendance.

2020

January 4~8	In cooperation with the Office of International Relations and the Maunakea Observatories, an information booth was hosted at the annual meeting of the American Astronomical Society, where the results of the Subaru Telescope, including observations using HSC, and the efforts of the Maunakea Observatories were reported to visitors mainly coming from the astronomical community.
January 6	NAOJ Mizusawa VLBI Observatory was awarded a special merit award for contributions to the promotion of public welfare in Oshu City, having made an outstanding contribution to the city and having become a model for the citizens.
January 15~16	ALMA Data Analysis Workshop (Imaging for Pre-Intermediate Level) was held at NAOJ Mitaka Campus.
January 17	NAOJ Mizusawa VLBI Observatory was awarded the Kahoku Culture Award, which is given to individuals and organizations that have made outstanding achievements in the academic, artistic, athletic, industrial, and social fields of Tohoku.
January 25	At the event of "Onizuka Science Day" held at the University of Hawaii at Hilo, staff members of the Subaru Telescope held an exhibition and workshop on the Subaru Telescope and astronomy, and interacted with about 500 citizens who visited.
February 2	NAOJ Public Talk/24th ALMA Public Talk was held at the Tokyo International Exchange Center.
February 3	The 2021 edition of Reki Yoko was released.
February 11	Female staff of the Subaru Telescope (five staff members including night operators, engineers, and scientists) participated in a science outreach event of "the International Women & Girls Day" at the local Kamehameha High School and Waiakea High School. They gave a talk about their work and its rewards from the point of view of women working at the observatory.
February 13~15	Star Island 19 open house event of VERA Ogasawara Station held, with 260 visitors in attendance.
February 17	His Excellency Yoshinobu Hiraishi, Japanese Ambassador to Chile, visited NAOJ Mitaka Campus.
February 19~21	East Asian ALMA Science Workshop 2019 was held at the Academia Sinica Institute of Astronomy and Astrophysics.
February 22	The Fourth "Nagano is Astro-Prefecture" meeting and Open Lectures were held at Omachi Community hall, Branch office 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 90 in the open lectures.
February 25	The Large-scale Cryogenic Gravitational Wave Telescope KAGRA started continuous operation to observe gravitational waves.
February 28	A special facility tour was held at the Hilo Base Facility of the Subaru Telescope. A guided facility tour, telescope experience corner, work class, and science class were held by 25 staff members of Subaru Telescope, and deepened interaction with 68 local De Silva Elementary school children and 7 teachers.
February 28 ~March 31	NINS Nobeyama Exhibition Room and 4D2U theater was closed as a precaution against the spread of the new coronavirus (COVID-19).
March 4~8	A total of 17 Subaru Telescope staff and TMT Project staff participated in the 2019 Journey Through the Universe on-site lesson program held at public schools in the Hilo area and interacted with approximately 1,000 local students.
March 5	Exhibition booth hosted at the Reception for the Emperor's Birthday held in the ambassador's residence in Chile.
March 5&13	Approximately 10 Subaru Telescope staff members participated in two Career Fairs on March 5 and 13 on Hawaii Island to introduce the work of the Subaru Telescope to high school students as future job opportunities and deepened the exchange.
March 6	Students and staff from Yamagata University visited the NAOJ Santiago Office.
March 7~31	Regular Open area of Nobeyama Campus was closed as a precaution against the spread of the new coronavirus (COVID-19).
March 13	Subaru Telescope website was renewed.
March	The "Subaru + TMT Science Book 2020," which examined and compiled a unique science strategy that links the Subaru Telescope and TMT was published. (Jointly between Subaru Telescope and the TMT Project)

Throughout the year	Special opening of the summit facility to local residents, “Kamaaina Observatory Experience.” Every year, the Subaru Telescope holds this special summit facility tour for local residents every three months, in February, May, August, and November. However because of the summit access road closure from July 13, 2019 only two times were held this fiscal year. Breakdown: May 18: Five Subaru Telescope staff members supported the “Kamaaina Observatory Experience” Summit Facility Tour: 48 participants in 4 groups. February 15: Three Subaru Telescope staff members supported the “Kamaaina Observatory Experience” Summit Facility Tour: 24 participants in 2 groups.

XIII Publications, Presentations

1. Refereed Publications

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