PREFACE

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Looking back over the annual report of the National Astronomical Observatory of Japan (NAOJ) for Fiscal Year 2017 (April 2017 – March 2018), we can say that this year saw many important developments in the field of Astronomy. I am pleased to say that NAOJ participated in many of these advancements and discoveries. This year NAOJ was also active developing new instruments to ensure that we will continue to play a major role in world astronomy in the future.

First of course, this year we saw the dawn of a new age of multi-messenger astronomy. The Subaru Telescope detected the electromagnetic counterpart to GW170817, the first recorded gravitational wave produced by the merger of binary neutron stars, which was initially detected by LIGO (Laser Interferometer Gravitational-Wave Observatory) in the United States and Europe's VIRGO in August 2017. Comparing observations of the changes in visible and infrared light over time to numerical simulations helped to finally confirm that rare earth metals such as gold are formed through the process of rapid neutron capture (r-process) in merging neutron stars.

In Japan, NAOJ and the High Energy Accelerator Research Organization are participating in the construction of the Large-scale Cryogenic Gravitational Wave Telescope in Kamioka (Kamioka Gravitational wave detector, KAGRA) led by the Institute for Cosmic Ray Research of the University of Tokyo. KAGRA utilizes the technology and experience gained from NAOJ's TAMA300 300-m laser interferometer gravitational wave detector built in Mitaka Campus in the 1990's. NAOJ was responsible for the basic design of KAGRA, and utilizing the high level engineering skills of the Advanced Technology Center developed a 14-m multilevel ultra-high performance vibration isolator, a transmitted light monitoring system, and also designed and produced baffles to counteract all types of scattered light. NAOJ also established the Kamioka Branch of the Gravitational Wave Project Office and has played a major role in developing KAGRA.

KAGRA hopes to perform joint observation with LIGO and Virgo in the second half of 2019. By joining the world wide gravitational wave detector network, KAGRA will help to improve the localization of gravitational waves sources, as well as greatly improving humanity's gravitational waves observation capabilities. With coordinated follow-up observations by electromagnetic telescopes, expectations for multi-messenger astronomy are very high.

Expectations are also high in radio astronomy. ALMA started the 5th observation cycle (Cycle 5) from October 2017. A total of 1,664 observation proposals were received from all over the world. The total observation time of 4,000 hours using 12-m antennas during Cycle 5 is a substantial increase compared to the 3,000 hours during Cycle 4. This is a credit to the unrelenting efforts of the Joint ALMA Observatory to improve operations. Additionally, for bands 3, 4, and 6 the maximum baseline of 16 km became available, offering unprecedented spatial resolution.

The breakdown of ALMA observation papers by subject is: 23 % "planetary formation", 22 % "interstellar matter/star formation", 22 % "active galaxies", and 33 % miscellaneous areas. Papers utilizing archived data have also been increasing, and now account for 22 % of the total. If we include papers that combine new PI data with archive data, the total rises to 27 %. Japan has been very competitive in publishing research papers using ALMA; it is the nation with the second highest total of papers after the United States.

In 2017, a large number of papers on protoplanetary disks and their varieties were published using ALMA observations. By examining a large number of protoplanetary disks, astronomers hope to better understand the causes of the varieties of exoplanets. Additionally, the discovery of rotating outflows from protostars in Orion has given us a valuable hint to understand protostars and the transport of angular momentum in the disks that surround them.

ALMA has also been contributing to the observation of organic molecules. The organic compound acrylonitrile was discovered in the atmosphere of Saturn's moon Titan. This molecule is thought to be capable of naturally forming membrane-like structures. It is believed that the primeval Earth had an atmosphere similar to Titan's, so this is an important clue to understanding abiogenesis.

Furthermore, observations of a galaxy cluster 9.4 billion light-years away ($z = 1.5$) found that the temperature of the gas in each galaxy decreases for galaxies closer to the periphery of the cluster. This suggests that cold molecular gas belonging to the member galaxies is being stripped off by hot gas from the cluster. This important discovery betters our understanding of the factors contributing to the gradual decline of star formation throughout the Universe since its peak 10 billion years ago.

Last year we reported that ALMA had detected the redshifted 88 μm emission line of ionized oxygen in a distant galaxy discovered by the Subaru Telescope 13.1 billion light-years away ($z = 7.2$). This was the most distant confirmation of oxygen in the Universe. ALMA quickly broke this record with the discovery of oxygen in a galaxy 13.2 billion light-years away ($z = 8.4$), drawing us closer to the epoch of cosmic reionization.

Speaking of the Subaru Telescope, open use at Japan's flagship optical-infrared facility is proceeding well. NAOJ succeeded in creating a wide area three-dimensional map of dark matter using weak gravitational lensing analysis on data from the Hyper Suprime-Cam Subaru Strategic Program (HSC SSP). The scope of this HSC dark matter map is more than 15 times that of previous ones constructed from Hubble Space Telescope data. It provides a detailed picture of the assembly of matter in the Universe over the past 7.5 billion years. Other observations utilizing HSC's ultra-wide field of view discovered a massive cluster of protogalaxies located 12 billion light-years away. Discoveries such as this bring us closer to understanding the composition of the early Universe.

The initial results of the HSC SSP observations were covered in a special edition of the Publications of the Astronomical Society of Japan (PASJ). The data acquired at that time was only about a tenth of the total plan, but its uniqueness enabled the publication of 40 research papers. By 2020, HSC observations are scheduled to cover over 1000 square degrees of the sky with more resolution and depth than ever before. Please watch for future results from HSC.

The Subaru Telescope's next major instrument after HSC, the Prime Focus Spectrograph (PFS), is being developed by a collaboration of seven countries led by Kavli IPMU at the University of Tokyo. PFS is a revolutionary piece of equipment that has approximately 2,400 optical fibers arrayed across a field of view comparable to that of HSC. Light from the sky is directed into four spectrographs, and spectra ranging from 0.38–1.26 μm can be measured simultaneously. Development is being carried out across various institutions, aiming to start scientific observations by 2021. Upon completion, PFS will allow further inquiry into the distance, speed, and chemical composition of the multitude of unidentified celestial bodies captured by HSC. As a result, we expect major progress towards unveiling the mysteries of dark energy, as well as gaining a clearer picture of how galaxies formed throughout the long history of the Universe.

A new exoplanet observation instrument is also under development at the Subaru Telescope. Final adjustments were made at the summit in order for the InfraRed Doppler instrument (IRD) to begin open use in 2018. The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), which allows for direct observation of exoplanets, and the Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) are already available for open use. The development and operation of these instruments are led by the Astrobiology Center, which was established by the National Institutes of Natural Sciences in 2015. In December 2017, the NAOJ Extrasolar Planet Detection Project Office dissolved and relocated to the Astrobiology Center. Progress in not only exoplanet research, but also astrobiology, is expected from coordination between the Astrobiology Center and NAOJ.

At Okayama Astrophysical Observatory, which supported Japan's astronomical research for 57 years, open use observations concluded at the end of 2017. Okayama Astrophysical Observatory served as the cornerstone to elevate Japanese astronomy to the world level during the postwar reconstruction period. It fostered many researchers, and was a driving force behind the very successful Subaru Telescope. In the future, we will shift our focus to the open use for Japanese universities on the Seimei Telescope, Kyoto University's telescope in Okayama Campus. University researchers will assume the operation of the Okayama Astrophysical Observatory telescopes, with support from NAOJ. The Okayama 188-cm Reflector Telescope has produced outstanding achievements, such as discovering over 30 exoplanets. We expect even better results from it in its new role as a dedicated exoplanet telescope.

We also have high hopes for the Thirty Meter Telescope (TMT) Project, a five-nation collaboration between Japan, the United States, Canada, China, and India to construct an extremely large telescope with a 30-meter diameter primary mirror. It is expected to produce groundbreaking results through exploration of terrestrial exoplanets, tracing of the early history of the Universe, identification of dark energy, and other research activities. NAOJ is in charge of some of the key components of TMT, including fabrication of the telescope structure and the primary mirror. The construction site is located on Maunakea on the Island of Hawai‘i; however, on-site construction has been suspended for three years, becoming a cause of concern for all involved. Still, design and fabrication of the respective work responsibilities have progressed steadily in Japan, as well as the other countries, throughout the delay in on-site construction.

The State of Hawai‘i Board of Land and Natural Resources (BLNR) approved the sublease agreement executed between the University of Hawai‘i in charge of the management of the Maunakea lands and the TMT International Observatory (TIO) in July 2014, and in September 2017, granted the Conservation District Use Permit (CDUP) that is required to build in the Maunakea summit area. Lawsuits were filed in response to the BLNR decisions. But the Supreme Court of Hawai‘i ruled that there are no problems in the sublease agreement in August 2018, and in October of the same year the court found the CDUP to be valid. Having continuously engaged in a number of dialogues with the community of Hawai‘i, we have obtained its greater support and understanding, and are currently proceeding carefully in discussions with stakeholders in Hawai‘i to prepare for resuming construction expeditiously.

The scope of astronomy has grown to encompass fields ranging from basic physics to life sciences, making cooperation with physicists, chemists, and biologists vital. University researchers also contribute greatly to the production of research results, as well as to the development of new observational instruments. NAOJ's large-scale observational facilities provide the foundation of an effective dual support system for university researchers. The facilities offer the researchers open use observation time to pursue their own research and also provide a platform for the development of major instrumentation with external funding acquired by the researchers.

There have been concerns about the decline of science in Japan. Eleven of the fourteen fields of natural sciences, which include physics, chemistry, medical science, and materials science, have experienced drops in the number of scientific papers published. And reports have indicated that even the fields that aren't experiencing drops are falling behind the world average. However, astronomy is the only field of study experiencing a growth in scientific articles while also exceeding worldwide averages. Among the fourteen divisions of natural sciences in Japan, Astronomy also has the highest share of papers published worldwide. (Refer to "What price will science pay for austerity?" Nature 543, S10–S15 (23 March 2017), https://dx.doi.org/10.1038/543S10a)

The Subaru Telescope and ALMA have been major milestones in Japanese science. The rapid development of Japanese astronomy, as demonstrated by large-scale observational facilities such as these, acted as a catalyst for new developments and stimulation in Japanese science and research facilities. The remarkable scientific returns enabled by astronomy have increased Japan's international profile, while instilling a sense of national pride, and developing an interest in science among the Japanese people, especially the younger generations. In keeping with its duty as part of the Inter-University Research Institute Corporation, NAOJ will strive to pioneer new technology while proposing and implementing large-scale international collaborative projects dealing with fascinating subjects.

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