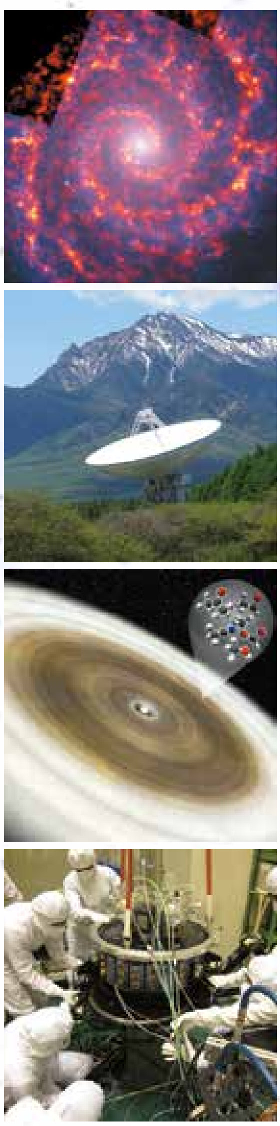
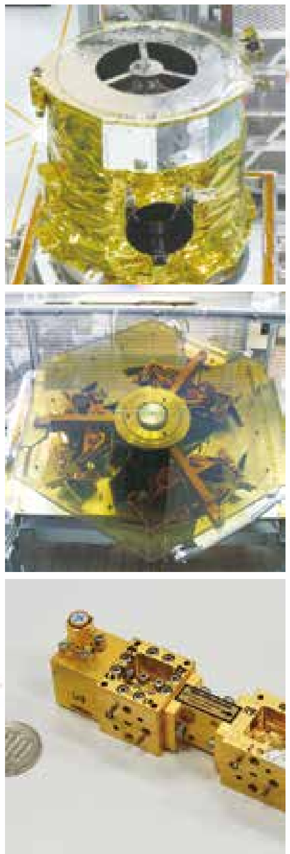
Inter-University Research Institute Corporation
National Institutes of Natural Sciences

National Astronomical Observatory of Japan

NAOJ



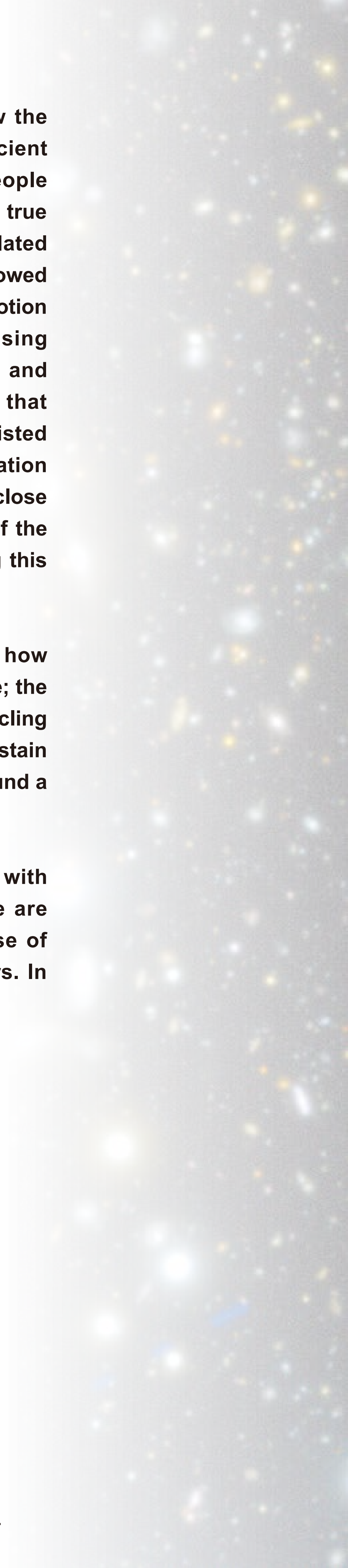


2024
https://www.nao.ac.jp/en/

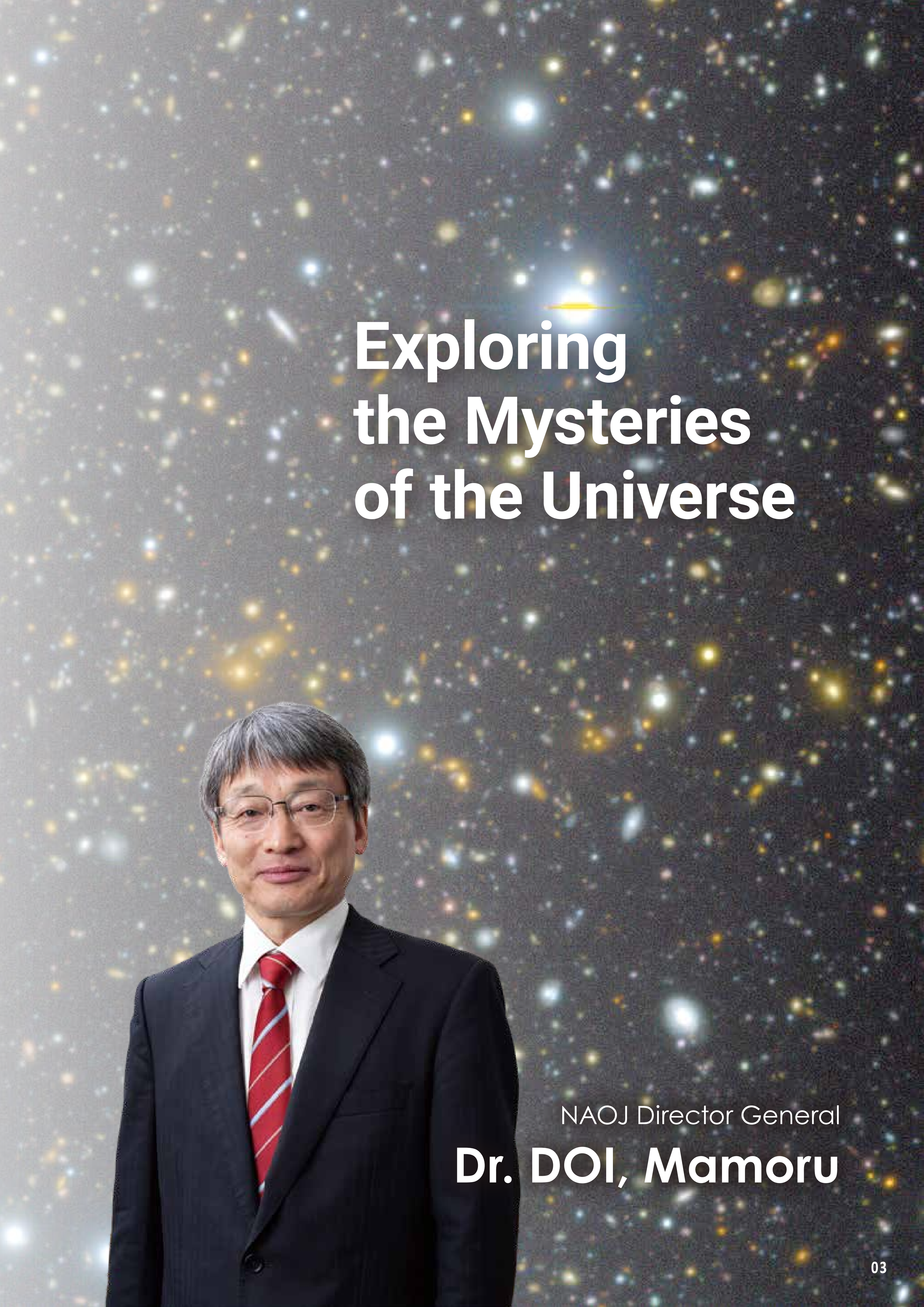
Since ancient times, humans have sought to understand how the Universe works. The visions of the Universe imagined by ancient people are written in the world's mythology. In later ages, people began to little by little use scientific methods to investigate the true nature of the Universe. In Ancient Greece, Eratosthenes calculated the radius of the round Earth. In the 16th century, Copernicus showed that a heliocentric model of the Solar System could explain the motion of the planets. But still, the Universe held surprises surpassing people's imagination. At the start of the 20th century, Hubble and Lemaitre discovered that the Universe is expanding. Tracing that expansion backwards indicates that long ago the Universe existed in an extremely hot, dense state (Big Bang); the vestigial radiation from the Big Bang was actually detected in 1964. Towards the close of the 20th century, we learned that the rate of the expansion of the Universe is currently increasing. The unknown energy powering this acceleration was dubbed "Dark Energy."

The Universe still holds many mysteries: after the Big Bang, how were galaxies born, and how did they evolve to their current state; the birth and evolution of stars and planets within a galaxy; the recycling of material; how many planets have an environment that can sustain life; what phenomena occur in the high-density environment around a black hole; the true nature of dark matter and dark energy ...

At the National Astronomical Observatory of Japan, together with researchers throughout Japan and throughout the world, we are pursuing the many mysteries of the Universe, making full use of leading-edge large observational facilities and supercomputers. In this pamphlet, we summarize our activities.



A menagerie of heavenly bodies photographed by Hyper Suprime-Cam on the Subaru Telescope.



Exploring the Mysteries of the Universe

NAOJ Director General

Dr. DOI, Mamoru

Subaru Telescope

An Eye Scanning the Breadth and Depth of the Universe

Equipped with a unique suite of instruments found nowhere else in the world, the Subaru Telescope continues to produce original research results, one after another. In addition to the stable instruments used in this research, the Subaru Telescope is also open to instruments with experimental components. Please take full advantage of the Subaru Telescope for new research and for instrument development for future telescopes such as TMT.

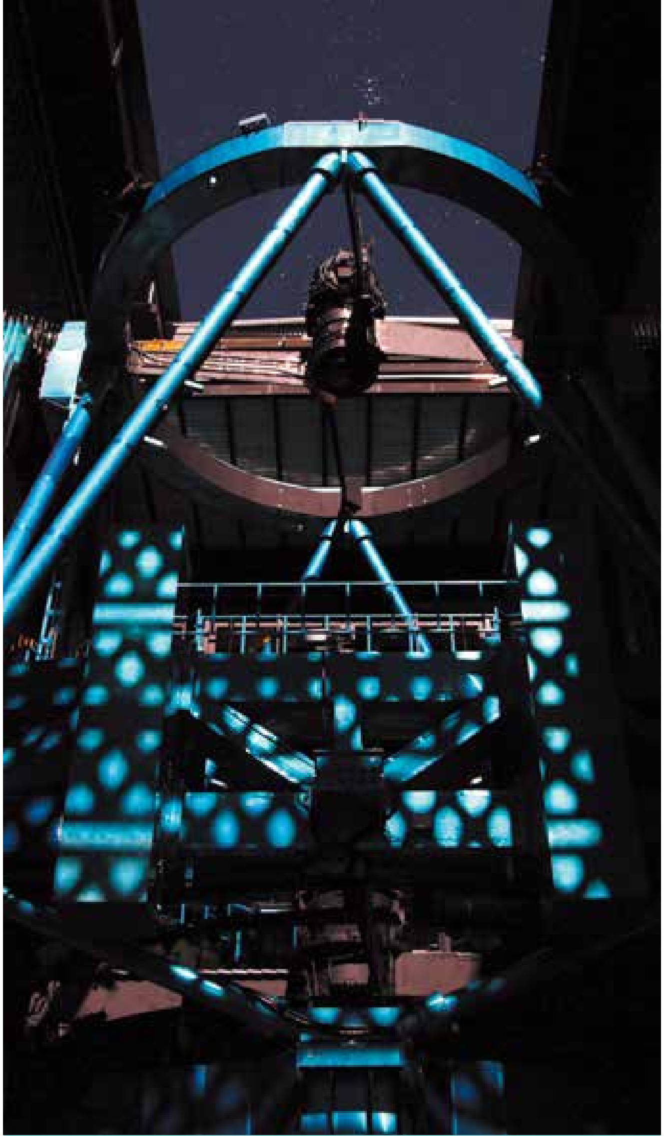
Subaru Telescope Director

MIYAZAKI, Satoshi

NAOJ's optical-infrared Subaru Telescope located near the summit of Maunakea in Hawai‘i boasts a world-class aperture of 8.2 meters. Making maximum use of this potential, the Subaru Telescope scans the breadth and depth of the night sky to investigate the origin of cosmic structure.

The Subaru Telescope is located in the summit region of Maunakea at an altitude of 4139 meters. This is one of the best sites in the world for astronomy with many clear nights and stable air flow. Maunakea hosts one of the world's largest collections of leading-edge astronomy observation facilities. Through more than 20 years of observations since its first light in 1999, the Subaru Telescope has greatly advanced Japanese astronomy. As of the end of 2023, it has contributed to an outstanding total of 2882 papers and 186 doctoral theses. It also appears from time to time in textbooks and various media outlets, making it one of the widely recognized symbols of Japanese science.

The summit region of Maunakea in Hawai‘i: the silhouette of the Subaru Telescope enclosure floating above a sea of clouds on a moonlit night.



The Subaru Telescope illuminated by moonlight. The ultra-wide field-of-view camera Hyper Suprime-Cam (HSC), is mounted at the top of the telescope structure (prime focus). By attaching a camera at the prime focus with a field of view exceeding one square degree, it is possible to capture an area nine times the size of the full moon in each exposure.

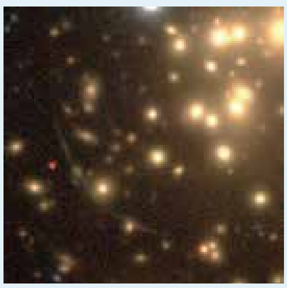
A corner of deep space photographed by HSC on the Subaru Telescope. The light from the galaxies is defected by the gravity from dark matter, so the shapes of the galaxies appear distorted. The contour lines in the image indicate the distribution of dark matter elucidated by measuring the gravitational lensing effect on the galaxy shapes.

Subaru Telescope Science 01

Investigating the Mysteries of Omnipresent Dark Matter and Dark Energy

The Universe is filled with a mysterious substance known as “dark matter”; and a mysterious energy known as “dark energy” is accelerating the expansion of the Universe. It is necessary to unveil the nature of dark matter and dark energy in order to understand the evolution and the physics of the Universe.

One way to do that is by using gravity. By using gravitational lensing, a phenomenon where gravity causes light to curve, we can investigate the distribution of dark matter. With its ultra-wide-field-of-view observation capability, the Subaru Telescope excels at these observations. Boasting 870 million pixels, Hyper Suprime-Cam (HSC) can capture a great number of galaxies in each picture. By precisely measuring the distortion in the galaxy images we can elucidate the 3D distribution of dark matter. In addition, by using the Prime Focus Spectrograph capable of observing approximately 2400 objects simultaneously to accurately measure the distances to many galaxies, we can obtain the 3D distribution of dark matter at high precision. Then, by comparing the 3D dark matter distribution to theoretical models of structure formation and the expansion of the Universe, we can determine the characteristics of dark matter and dark energy.

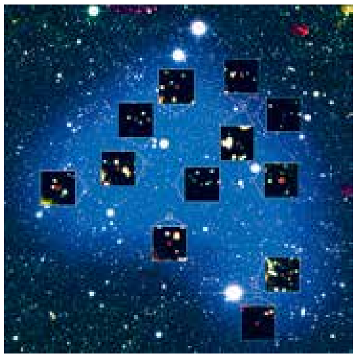


The galaxy cluster Abell 1689 photographed by HSC on the Subaru Telescope. The gravity of the cluster bends the light from background galaxies, causing the images of those galaxies to appear stretched.

Subaru Telescope Science 02

Unlocking the Mysteries of Galaxy Formation and Evolution

The Subaru Telescope, with its ability to survey large expanses of space with its ultra-wide-field-of-view, has vigorously conducted efficient searches for very distant objects. The Strategic Program using Hyper Suprime-Cam (HSC) to photograph 400,000 galaxies has been completed and now researchers are processing and analyzing the huge amount of data. This will provide vital clues for understanding the growth of galaxies. The wavelengths of light from the distant Universe are stretched by the expansion of space. Observing infrared light, with wavelengths longer than visible light, allows us to observe more distant objects. Using a new wide-field, high-resolution infrared camera scheduled for completion in the late 2020s, we expect to discover many newborn galaxies in the early Universe. Follow-up observations of the discovered objects using ALMA or the Thirty Meter Telescope (TMT) will elucidate when the first stars formed and the effects the newborn stars had on their surrounding environment, helping to solve the mysteries of galaxy formation.



The farthest observed galaxy protocluster, z66OD, located 12.97 billion light-years away, as observed by HSC on the Subaru Telescope. The member galaxes of the protocluster are indicated by boxes.

Upgrading to Super Subaru Telescope with “Subaru Telescope 2.0.”

Launched in 2022, Subaru Telescope 2.0 will break new ground in astronomy with next generation facility instruments.

PFS is On Sky

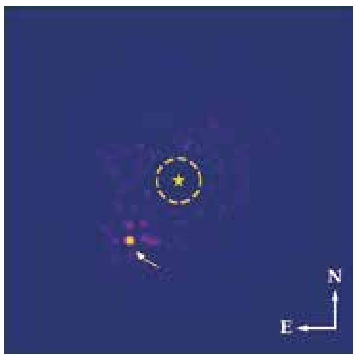
The wide-field multi-object spectrograph, Prime Focus Spectrograph (PFS), is mounted at the prime focus of the Subaru Telescope. It can simultaneously observe up to 2,394 objects across its 1.3 degree diameter field-of-view. (top) One of the spectrograph modules in the telescope dome. (bottom) The Prime Focus Instrument, together with the Wide Field Corrector, mounted at the prime focus of the telescope.

Subaru Telescope Science 03

Discovery of Earth-like Exoplanets

Over 5000 exoplanets have been discovered to date. The Subaru Telescope is also displaying its strength through observations of those exoplanets. In 2013, making the best use of the Subaru Telescope’s high sensitivity, it directly imaged the dimmest planet at that time. Among exoplanets, Earth-like planets are garnering attention. Direct imaging of these comparatively small planets is difficult for 8-meter class telescopes. But by using high-dispersion spectroscopic observations they can discover small planets through the wobble induced in the host star by the orbital motion of the planet. At the Subaru Telescope we have installed a near-infrared Doppler instrument to accurately measure line-of-sight velocities to pursue the search for Earth-like exoplanets. The discovered exoplanets will be observed with the Thirty Meter Telescope (TMT) to analyze their atmospheric composition, and enable us to search for signs of life, advancing the field of astrobiology (Refer to page 16).

Exoplanet HIP 99770 b (lower left) photographed using the Subaru Telescope Extreme Adaptive Optics System.
Credit: T. Currie/Subaru Telescope, UTSA



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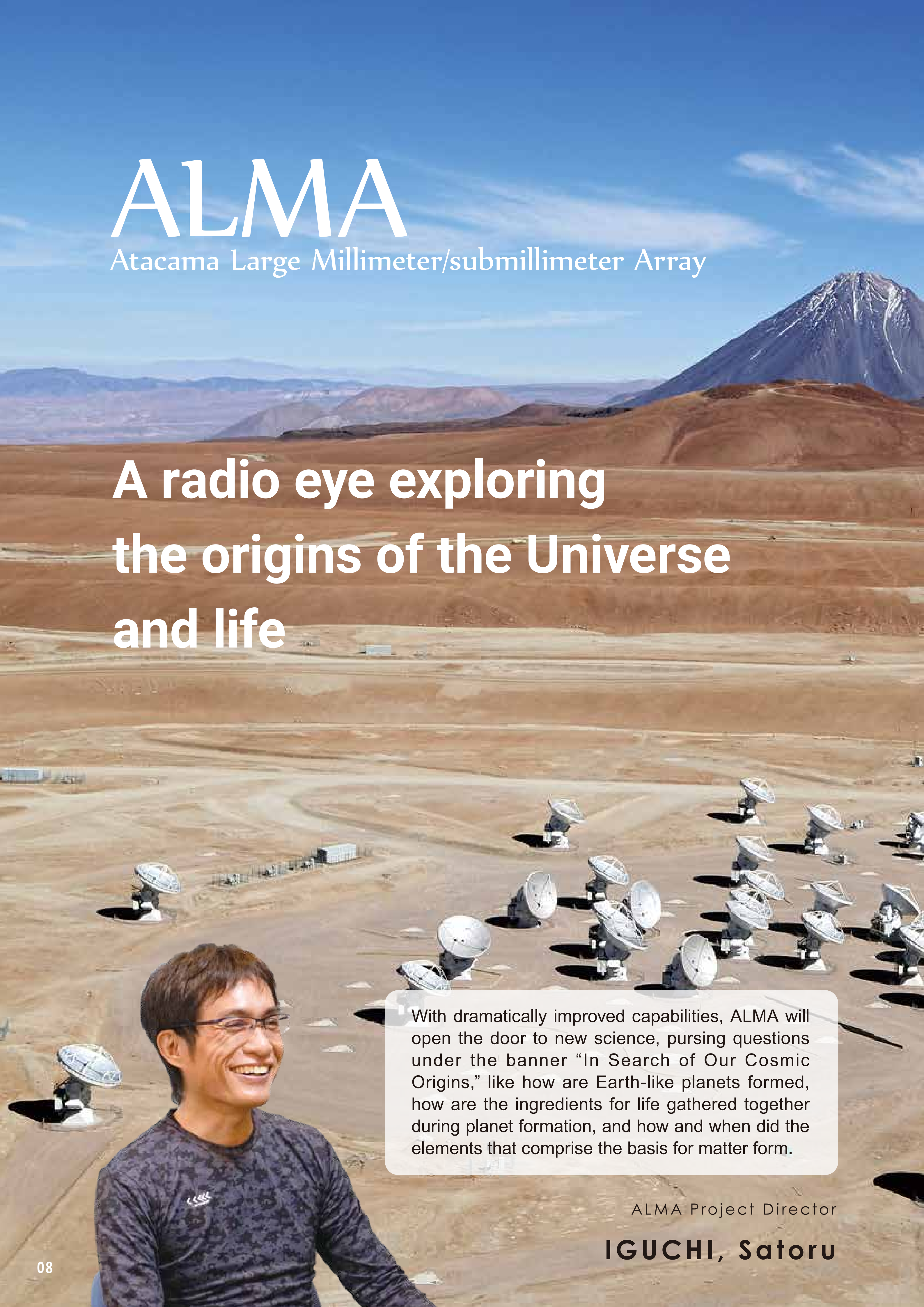


ALMA

Atacama Large Millimeter/submillimeter Array

A radio eye exploring the origins of the Universe and life

With dramatically improved capabilities, ALMA will open the door to new science, pursing questions under the banner "In Search of Our Cosmic Origins," like how are Earth-like planets formed, how are the ingredients for life gathered together during planet formation, and how and when did the elements that comprise the basis for matter form.

ALMA Project Director

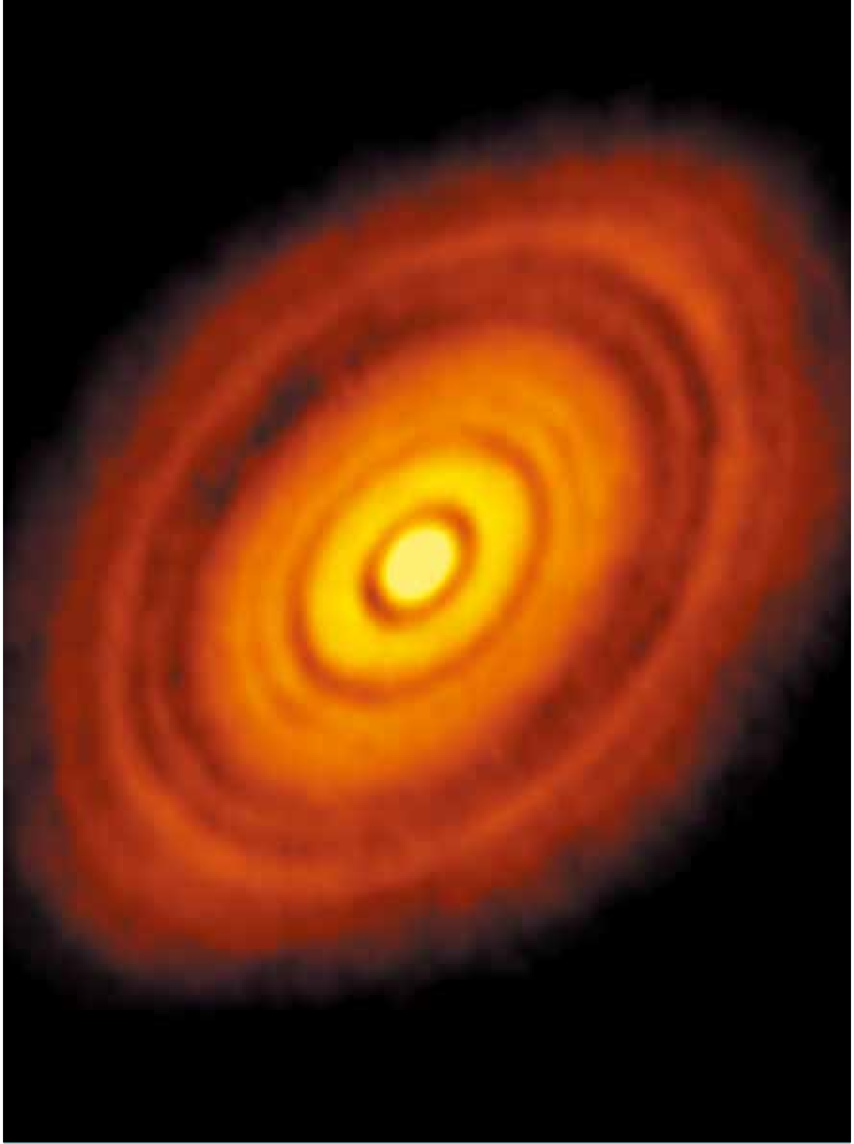
IGUCHI, Satoru

Located in the Atacama Desert, ALMA is one of the world's highest capability radio telescope arrays, achieved through an international collaboration including NAOJ, North America, Europe, and other partners. The 66 individual antennas function together as a single giant radio telescope. Its radio observations show us facets of the Universe impossible to see with visible light.

ALMA is located in the Atacama Desert in northern Chile. The Atacama Desert is said to be one of the driest locations in the world, combined with the 5000 meter altitude, it is a harsh place to construct a telescope array. Because the radio waves ALMA observes (around 1 mm on the border between millimeter waves and submillimeter waves) are absorbed by water vapor, an extremely dry location is needed. In addition an area wide enough to array 66 antennas is needed. Started with the joint site survey by the international team of researchers from the early 1990s, currently 22 countries and regions are participating in the operation of ALMA, including Japan, Taiwan, and the Republic of Korea in East Asia; the United States and Canada in North America; the European Southern Observatory representing its Member States; and the host country of Chile.

ALMA observing from the dry Atacama Desert at an altitude of 5,000 m.
[photo: Clem & Adri Bacri-Normier (wingsforscience.com) / ESO]

The many parabolic antennas of ALMA. Built to withstand the harsh sunlight and temperature fluctuations of the desert, the antennas were developed by combining the technological know-how of the various partners. This photo shows the ALMA antenna array with the Southern Milky Way in the background. (Credit: Y. Beletsky (LCO)/ESO)



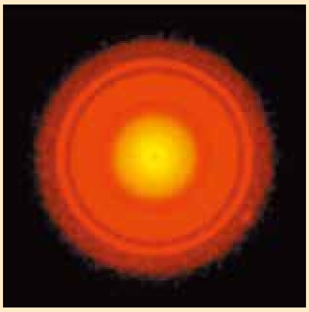
The disk of dust surrounding the young star HL Tauri, which is less than 1 million years old, photographed by ALMA. The dark spaces between the rings are thought to be areas lacking dust to emit radio waves. Some researchers speculate that here, planets are already forming, and that their gravity is creating the gaps by sweeping up the dust.
Credit: ALMA (ESO/NAOJ/NRAO)

ALMA Science 01

Unlocking the Mysteries of Star and Planet Formation

Newborn stars and planets still in the process of forming lurk in the night sky. Diffuse clouds of interstellar gas and dust are the material for stars and planets. These clouds gradually compact, and in their centers stars and planets are born. These newborn stars are hidden inside the parent clouds, where they cannot be observed with visible light. But radio waves can escape from the clouds of gas and dust. ALMA collects these weak radio waves to unlock the mysteries of star and planet formation.

Disks comprised of gas and dust revolve around young stars, with ages between 100 thousand and 10 million years. These protoplanetary disks are the sites of planet formation. ALMA's high angular resolution has revealed concentric ring structures in the disks, as well as disks with spiral or crescent shaped dust distributions. By starting to image the sites of planet formation in detail, we are coming to understand the formation mechanism of the various planetary systems in the Universe, including our own Solar System.

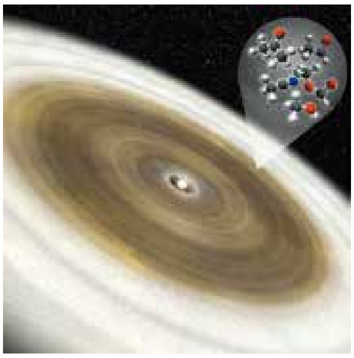


Protoplanetary disk around the young star TW Hydrae photographed by ALMA.
Credit: ALMA (ESO/NAOJ/NRAO), Tsukagoshi et al.

ALMA Science 02

Searching for the Building Blocks of Life in the Universe

ALMA can catch the radio waves emitted by various materials floating in space. Researchers are particularly interested in organic molecules connected to the origin of life. What kinds of molecules are found at the sites of planet formation around young stars? Can the organic molecules that become the seeds of life, for example amino acids, be found here? ALMA has discovered complex organic molecules and simple sugar molecules around newborn stars, as well as mapping the distribution of alcohol molecules in protoplanetary disks. If chemical reactions continue for the tens-of-millions of years it takes planets to form around young stars, what complexity of molecules can appear? To elucidate the evolution of the components for life in the Universe, ALMA is implementing new improvements such as the ability to observe many species of molecules at once.



ALMA observed the protoplanetary disks surrounding young stars and found various organic molecules including methanol and acetaldehyde. Studies of organic molecules at the sites of planet formation will yield important clues about the origin of life.

One Unparalleled Instrument through Global Collaboration, ALMA Completely Changes our View of the Universe!

ALMA receivers developed at NAOJ. From left to right: Band 4 (millimeter wave, 125~163 GHz), Band 8 (submillimeter wave, 385~500 GHz), Band 10 (terahertz, 787~950 GHz).

Credit: ALMA (ESO/NAOJ/NRAO)

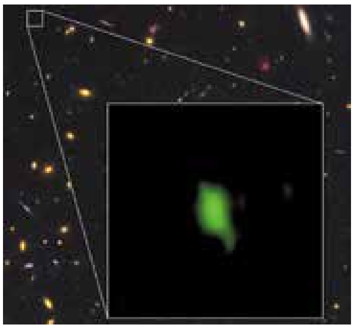
ALMA Science 03

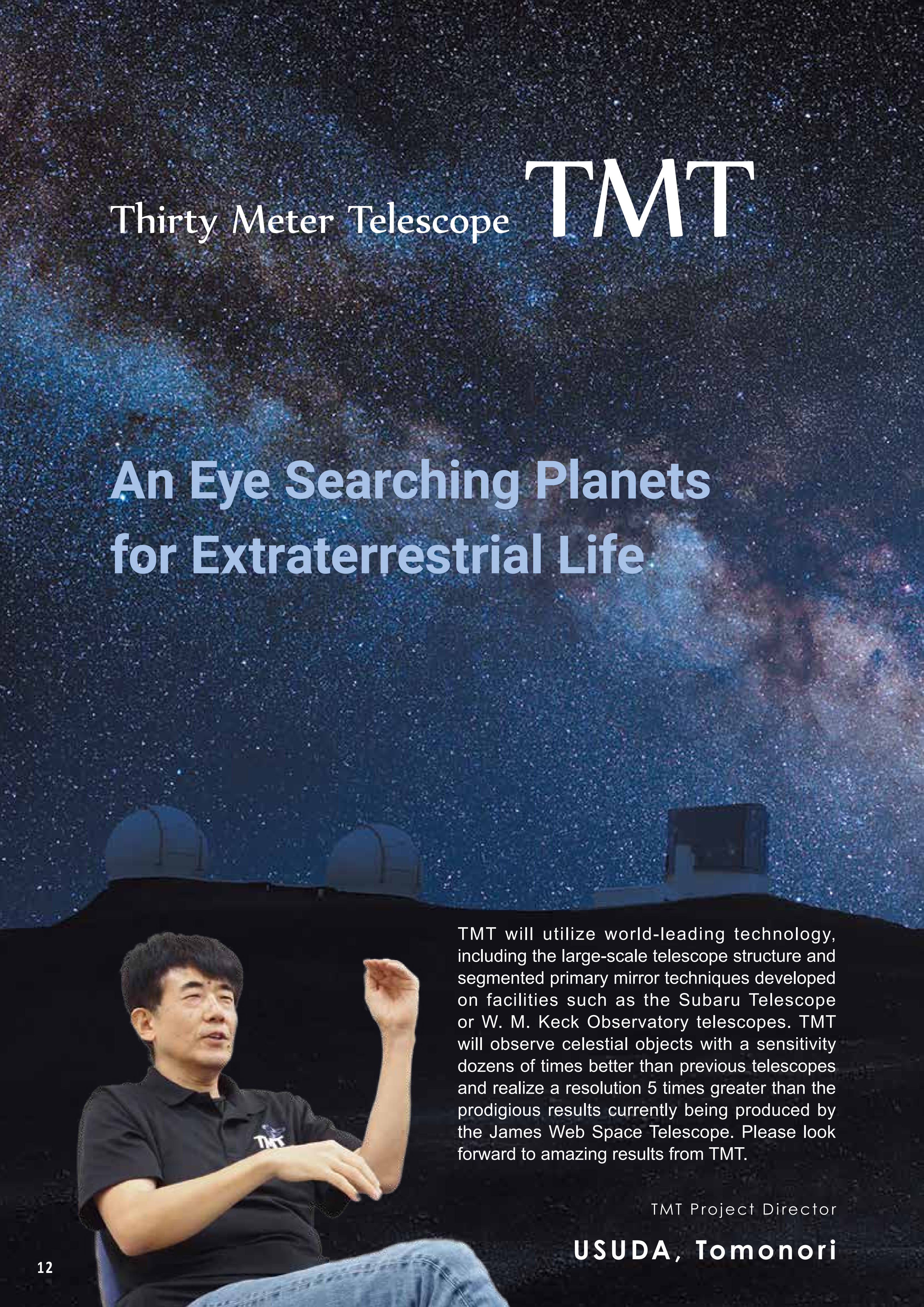
Searching for the Youngest Galaxies formed after the Big Bang

The Universe contains hundreds of billions of galaxies like our home Milky Way, each containing hundreds of billions of stars. When and how were these galaxies formed? How did they evolve? To solve this mystery we need to investigate distant galaxies over 10 billion light-years away; in other words, over 10 billion years back in time. ALMA detected oxygen in the galaxy MACS1149-JD1 located 13.28 billion light-years from Earth. At the time (2018), this was the record for the most distant (and therefore earliest) galaxy where oxygen had been detected. Oxygen didn't exist in the Cosmos right after the Big Bang. It was produced by the nuclear reactions in the cores of stars and then scattered through space when those stars died. So if we can detect oxygen, it means that many stars must have already been born and died before that. From this discovery we learned that active star formation must have started about 250 million years after the Big Bang. ALMA will continue peering back into the era of galaxy formation in the earliest stages of the Universe.

The wavelengths of light reaching us from the distant Universe, in other words the early Universe, have been stretched by the expansion of space. The oxygen in the galaxy MACS1149-JD1 emitted infrared light; but by the time that light reached Earth it had been stretched to radio wavelengths, which can be observed by ALMA. Examining how much the wavelengths have been stretched allows us to accurately determine the distance to celestial objects.

Credit: ALMA (ESO/NAOJ/NRAO), NASA/ESA Hubble Space Telescope, W. Zheng (JHU), M. Postman (STScI), the CLASH Team, Hashimoto et al.





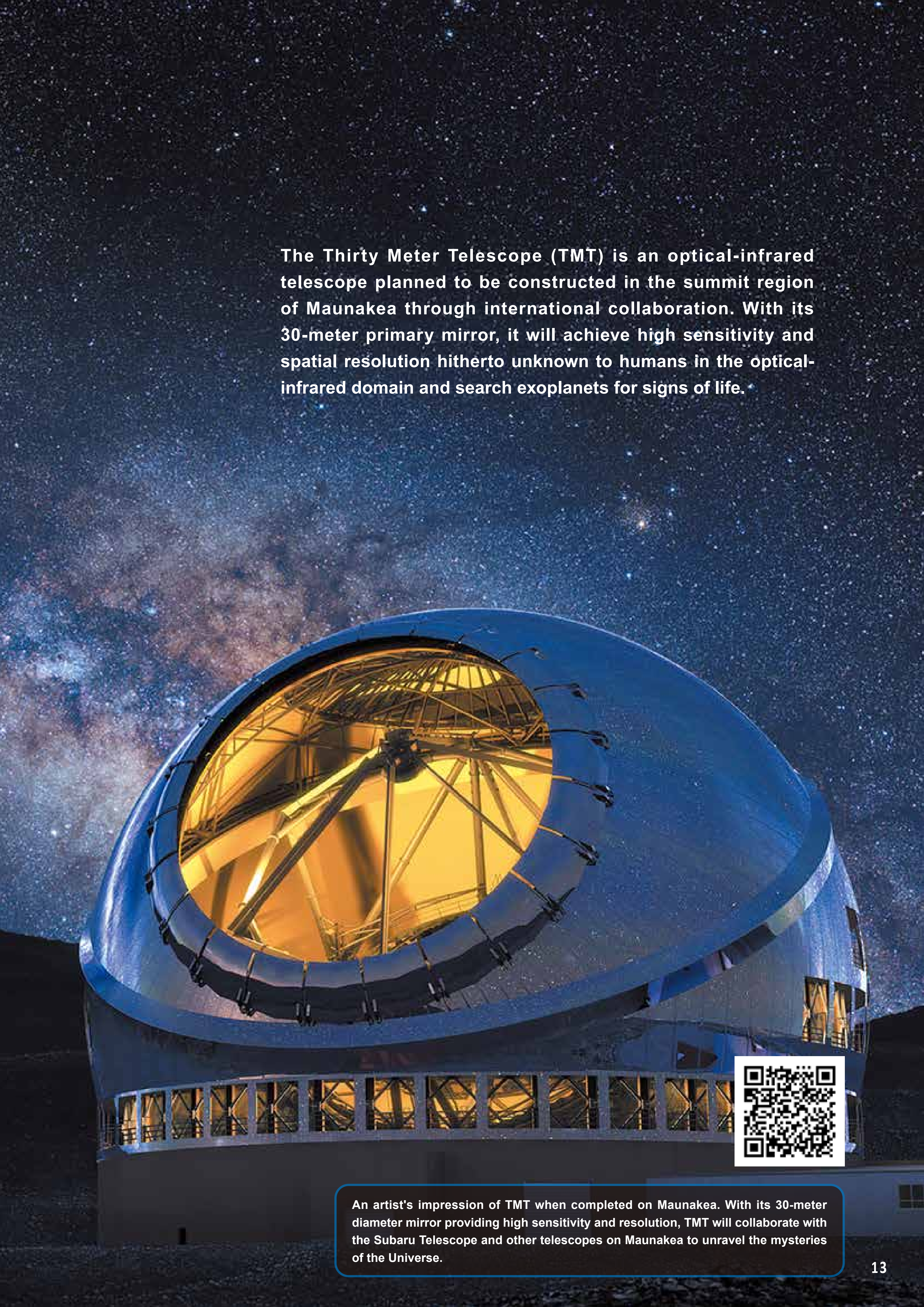
Thirty Meter Telescope **TMT**

An Eye Searching Planets for Extraterrestrial Life

TMT will utilize world-leading technology, including the large-scale telescope structure and segmented primary mirror techniques developed on facilities such as the Subaru Telescope or W. M. Keck Observatory telescopes. TMT will observe celestial objects with a sensitivity dozens of times better than previous telescopes and realize a resolution 5 times greater than the prodigious results currently being produced by the James Web Space Telescope. Please look forward to amazing results from TMT.

TMT Project Director

USUDA, Tomonori



The Thirty Meter Telescope (TMT) is an optical-infrared telescope planned to be constructed in the summit region of Maunakea through international collaboration. With its 30-meter primary mirror, it will achieve high sensitivity and spatial resolution hitherto unknown to humans in the optical-infrared domain and search exoplanets for signs of life.

An artist's impression of TMT when completed on Maunakea. With its 30-meter diameter mirror providing high sensitivity and resolution, TMT will collaborate with the Subaru Telescope and other telescopes on Maunakea to unravel the mysteries of the Universe.

A close-up view of the center of a prototype for the primary-mirror segments developed in Japan. The full segment is hexagonal. When completed, the mirror surface will be coated with silver.

Construction of TMT

Four countries, Japan, the United States, Canada, and India, are participating in the TMT project. In 2014, the TMT International Observatory (TIO) was established to manage the construction. Japan, represented by NAOJ, is obligated to contribute approximately 20 percent of the construction expenditures. NAOJ is responsible for the design and construction of the telescope structure, production of all of the mirror blanks (574 including spares), and polishing for a portion of them (175), as well as development of instruments through international collaboration to achieve the highest sensitivity and spatial resolution. Also, we are working in cooperation with domestic and international universities and research institutions to develop instruments with a wide array of observational capabilities, and to formulate observation plans utilizing these instruments.

The summit region of Maunakea in Hawai'i hosts a collection of large telescopes including the Subaru Telescope and the TMT construction site.
Because the weather in the summit region of Maunakea is stable, allowing sharp images to be taken, large telescopes belonging to countries around the world have clustered here. TMT is scheduled to be constructed about 1 kilometer from the Subaru Telescope, at an altitude of 4012 meters. Because this is approximately 1000 meters higher than proposed sites for other extremely large telescopes, the observing conditions are superior, especially in infrared and ultraviolet wavelengths.

TMT Science 01

Searching for Planets with Earth-like Environments in Pursuit of Signs of Life

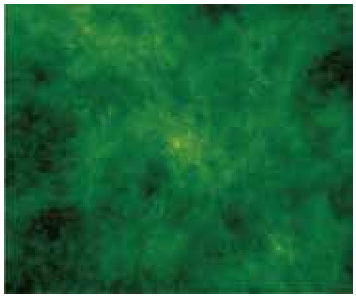
Numerous planetary systems have now been found around stars other than the Sun, including ones resembling the Solar System, and ones harboring terrestrial planets. With much higher resolving power and sensitivity than current telescopes, TMT will undertake hitherto impossible observations of exoplanet systems. The ultimate goal is to find terrestrial planets in the habitable zone where the conditions are right for life, and look for evidence that life actually exists on them. Because terrestrial exoplanets are small and dim, current telescopes can't image them directly. With its high sensitivity, TMT will capture the first image of a terrestrial exoplanet and enable spectroscopic analysis of the light reflected from the planet's surface.
For exoplanets with orbits at special angles to the Earth, TMT will also be capable of spectroscopic analysis of the atmosphere of the planet. TMT has the ability to detect the characteristic colors of plants, as well as oxygen and ozone produced by photosynthesis, and organic molecules of biological origin. TMT will explore the universality of life in the Universe as yet unknown to humankind.

TMT Science 02

Determining the Nature of the “First Objects” Born in the Universe

When and how were the first stars and galaxies in the Universe formed? This is one of the biggest questions in modern astronomy. ALMA and other telescopes have already found signs that the earliest stars formed in the first 200~300 million years after the Big Bang. But they haven't been able to capture the actual light from those stars. TMT with its impressive 30 meter aperture and high sensitivity aims to catch the light radiated by those first stars.

The first stars in the Universe were dazzling bright. When they died in supernova explosions, they ejected elements heavier than hydrogen and helium into their surroundings. In these ways they have had large influences on the following evolution of the Universe. TMT will catch the light from first-generation stars and accurately determine when they formed as well as how their radiation and supernova explosions affected the evolution of galaxies and the Universe.



A scene from a computer simulation depicting the birth of the first stars in the cosmos. Actually observing the light from these stars is one of the important science objectives of TMT.

Credit: Naoki Yoshida

A special glass with an extremely low thermal expansion rate is used for TMT's primary mirror segments, which comprise part of Japan's contribution. As of March 2024, 356 mirror blanks have been produced.

Credit: NAOJ/OHARA

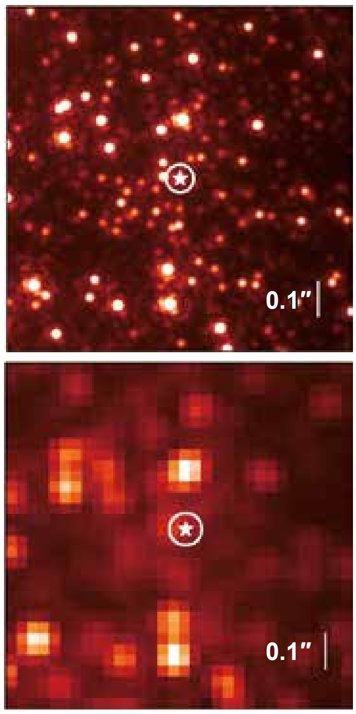
TMT’s Giant Eye will Pierce the Deepest Mysteries of the Universe.

TMT Science 03

Directly Measuring Dark Energy’s Effect on the Expansion of the Universe

Recent observations have revealed that the expansion of the Universe is accelerating. Dark energy is the hypothesized energy acting as the “repulsive force” to explain this accelerating expansion. But its true nature is totally unknown and one of the largest mysteries in modern physics.

To solve the mysteries of dark energy we need to measure how the expansion of the Universe has changed over time and learn the characteristics of dark energy. By measuring the redshifts of many far away galaxies at different distances at some interval, for example 10 years, we can accurately measure how much the expansion of the Universe has accelerated (or decelerated) over that time. TMT’s high light collecting power will enable these kinds of high accuracy observations. We expect TMT to provide clues to understanding the true nature of dark energy.



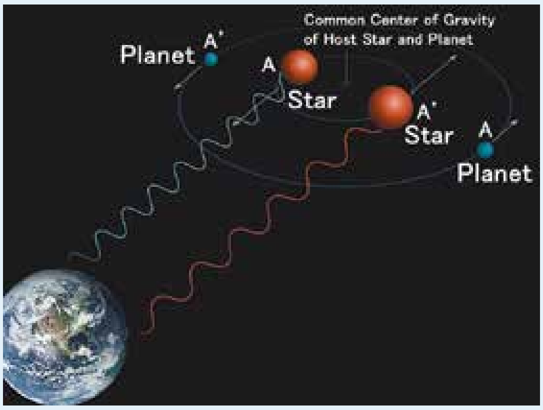
Simulated images comparing the Galactic Center as photographed by TMT (top) and the James Web Space Telescope (bottom). TMT will achieve a resolution 5 times greater than the James Web Space Telescope. The star mark represents the position of the supermassive black hole.

Credit: University of California, San Diego/IRIS

Uniting the Power of Subaru Telescope, ALMA, and TMT

① The Search for Life

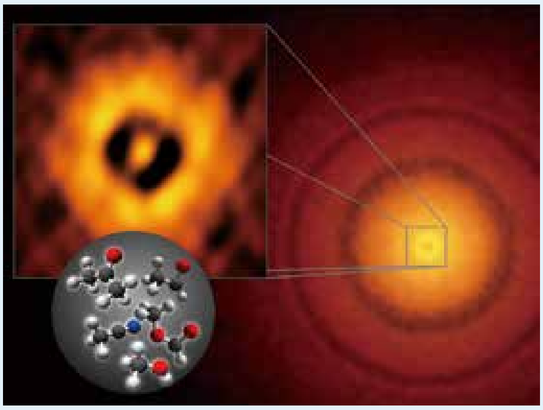
Detailed observations of the increasing number of exoplanets and protoplanetary disks, and searching for life in the Universe are the largest goals for 21st century astronomy. Together the Subaru Telescope, ALMA, and TMT form a winning team in the "search for life."



Finding Habitable ExoPlanets

The Subaru Telescope searches for exoplanets with masses similar to Earth through high precision spectroscopy to detect the wobble in the host star induced by the orbital motion of the planet.

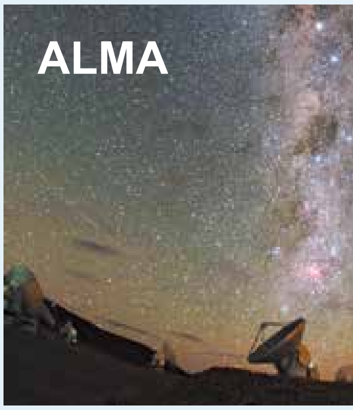
The host star moves in reaction to the planet's orbital motion. Planets can be detected indirectly via spectroscopic observations of the Doppler effect produced in the light from the host star.

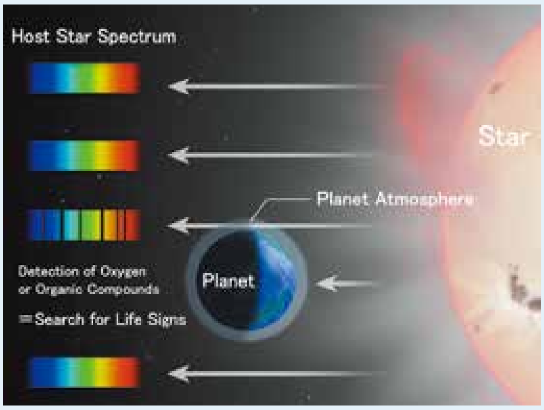


Finding Building Blocks for Life

ALMA devotes its energies to observations of formation sites of planets as the cradles of life, and searches for organic molecules which provide the building blocks for life.

The protoplanetary disk around the young star TW Hydrae photographed by ALMA. The radius of a gap near the central star (inset zoom-in) is comparable to Earth's orbit. ALMA detects the radio waves from various molecules in this kind of planet formation site.★01





Finding Life Signs

TMT will target exoplanets discovered by the Subaru Telescope for detailed investigations of the planets' atmospheres through very high accuracy spectroscopic observations to try to find signs of life. This combined with ALMA's findings about the materials for life found in protoplanetary disks will bring us closer to understanding the origin of life in the Universe.

If oxygen or an organic compound is found through spectroscopic observations of the atmospheres of exoplanets, the odds are high that life exists there.

Credit:★01 S. Andrews (Harvard-Smithsonian CfA) , ALMA (ESO/NAOJ/NRAO) ★02 ALMA (ESO/NAOJ/NRAO), NASA/ESA Hubble Space Telescope, W. Zheng (JHU), M. Postman (STScI), the CLASH Team, Hashimoto et al.

③ Unveiling the mysteries of Dark Matter and Dark Energy

The Subaru Telescope, ALMA, and TMT each boast world leading performance in their respective fields. When their power is combined on common science themes, their capabilities to produce exciting discoveries and revolutionize our understanding of the Universe become even higher. NAOJ will operate these three telescopes organically and efficiently aiming for long term goals. Here let's examine three concrete examples of collaboration themes.

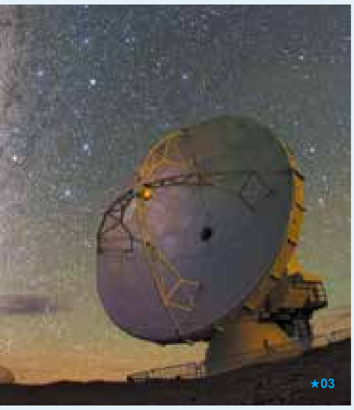
② The Search for the First Stars

One of the biggest problems in modern astronomy is peering into the farthest corners of space to determine the true nature of the first stars formed in the earliest Universe. The combination of the Subaru Telescope, ALMA, and TMT provides positive momentum to achieve this goal.

Search for Very Distant Objects

By searching for very distant objects in survey observations by the Subaru Telescope's ultra-wide-field-of-view Hyper Suprime-Cam, we can find targets for detailed follow-up observations using ALMA or TMT.

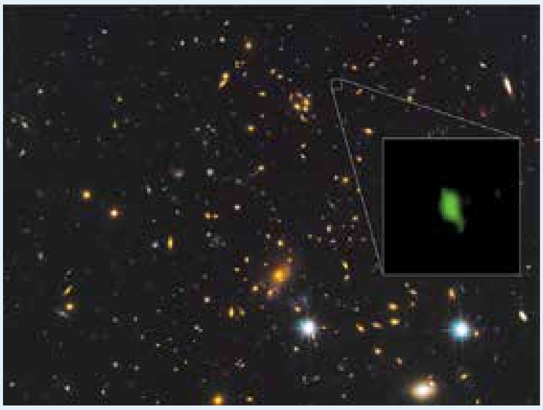
Countless galaxies in the distant Universe photographed by Hyper Suprime-Cam on the Subaru Telescope. The Prime Focus Spectrograph currently under development will accurately determine their distances.



★03

Determining Chemical Composition

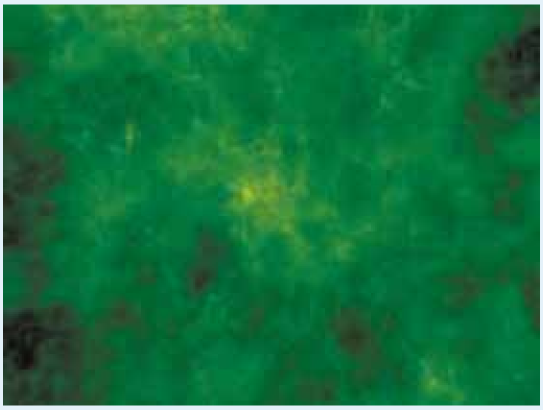
ALMA conducts high sensitivity follow-up observations of very distant object candidates discovered by the Subaru Telescope, catching radio waves emitted by the atoms contained in those objects to determine their chemical composition. This provides clues about the evolution of the earliest galaxies in the Universe.



ALMA false color image (green zoom-in inset) showing the oxygen in the galaxy MACS 1149-JD1 located 13.28 billion light-years from Earth.★02

Finding the First Stars

TMT will conduct high sensitivity follow-up observations of very distant object candidates observed by the Subaru Telescope, detecting the characteristic light emitted by helium atoms to elucidate when the first generation of stars formed and what their characteristics were.



A scene from a computer simulation depicting the birth of the first stars in the Universe. Verifying the results of theoretical studies of the first stars through observations is another important theme.★04

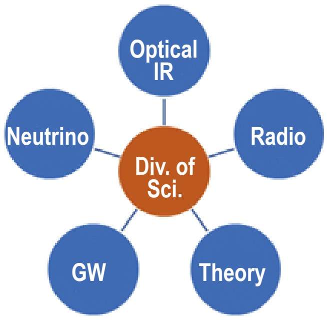
★03 ESO/B. Tafreshi (twanight.org) ★04 Naoki Yoshida

Despite the fact that dark matter and dark energy play critical roles in the formation of celestial objects and the accelerating expansion of the Universe, their true natures remain a mystery. The Subaru Telescope elucidates the 3D distribution of dark matter over wide areas through observations of gravitational lensing based on ultra-wide-field images. In contrast, ALMA uses its high resolution to measure the rotation speeds of individual galaxies and determine the dark matter distribution within a galaxy. By combining these we can determine the characteristics of dark matter spanning a wide scale from tens of thousands of light-years to billions of light-years. As for dark energy, investigating the distribution of dark matter found by the Subaru Telescope will elucidate the role of dark energy in the expansion of the Universe. In contrast, TMT will provide clues to the nature of dark energy by directly measuring the change in the expansion rate of the Universe.

Division of Science

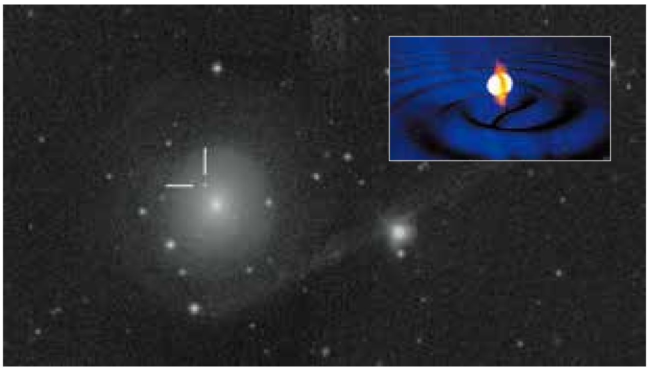
NAOJ advances astronomy research utilizing leading-edge observational facilities like the Subaru Telescope, ALMA, and TMT. The NAOJ Division of Science is the driving force behind that research.

The targets of modern astronomy are scattered across time and space, from the past to the future of the Universe and from cosmology to stars and planets. To tackle these questions, observational astronomy has developed techniques to cover broad expanses of the electromagnetic spectrum as well as non-electromagnetic observations. Additional progress is driven by theoretical astronomy, done with pencil and paper, and simulation astronomy, which studies astronomical phenomena reproduced inside a supercomputer.
Astronomy research is entering a new era of rapid advances, driven by a fusion of theory and observation in which theoretical research analyzes and interprets observational results from new instruments at facilities like the Subaru Telescope or ALMA; multi-messenger astronomy which unveils the true nature of gravitational wave sources through a combination of electromagnetic and non-electromagnetic messengers; and multi-wavelength astronomy combining X-ray, optical infrared, and radio wave observations. The Division of Science is an institute for research into all aspects of modern astronomy, using new techniques including the fusion of theory and observation, multi-messenger and multi-wavelength astronomy, in addition to conventional astronomy techniques.



A diagram of the Division of Science's goal of unified astronomy utilizing various techniques.

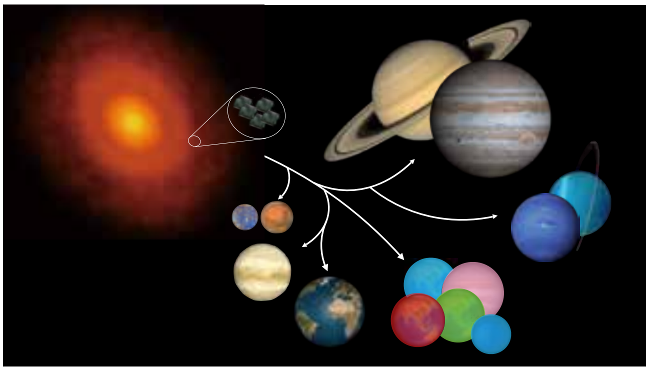
Promoting Multi-messenger Astronomy



Electromagnetic counterpart of gravitational wave source GW 170817 taken by HSC on the Subaru Telescope in 2017, and a visualization of the gravitational waves produced by a neutron star merger (upper right inset).

Until the first half of the 20th century, humanity's observations of celestial objects were limited to visible light. Entering the latter half of the century "multi-wavelength" astronomy utilizing radio waves, X-rays, infrared, and ultraviolet light revolutionized our understanding of the Universe.
Now, additional information has been added by signals other than electromagnetic waves, such as neutrinos and gravitational waves. For example, in 2017, the American LIGO detector captured gravitational waves from the merger of two neutron stars for the first time in history. Comparing the subsequent optical observations conducted by the Subaru Telescope and other telescopes to theoretical predictions by the supercomputer "ATERUI" (Refer to page 21) elucidated the origins of heavy elements such as lanthanide and platinum. This is the new field of "multi-messenger astronomy."
The Division of Science utilizes the supercomputers and observational facilities employed by NAOJ, including Subaru Telescope, ALMA, and Large-scale Cryogenic Gravitational Wave Telescope KAGRA, to contribute to further advances in multi-messenger astronomy.

Studying Exoplanets to Reveal their Diversity



A conceptual image of the evolution from small bodies (upper left, ALMA image, Credit: L. Cieza et al.; ALMA (ESO/NAOJ/NRAO)) to the Solar System or various exoplanet systems.

With the first discovery of an exoplanet at the close of the 20th century, humanity confirmed the existence of planetary systems other than the Solar System. Now over 5000 have now been confirmed. It is thought that the presence of planets is the norm around sun-like stars. The planetary systems discovered so far are diverse and completely unlike the Solar System. We have yet to find what could be called a "Second Solar System." In the Division of Science, we use supercomputers in addition to ground-based and space-based telescopes, with a stress on collaboration between theory and observation, to seek to understand the underlying reasons for the ubiquity and diversity of planetary systems. We also investigate the atmospheric components and climate conditions of planets to investigate the possible existence of habitable planets capable of supporting life outside of the Solar System, or the possibility of new types of habitable planets different from the Earth, conducting fundamental research laying the foundation to for future searches for habitable Earth-line planets and life outside the Solar System.

In the Division of Science, we collaborate with domestic and overseas researchers, and use all techniques to solve the mysteries of the Universe, overcoming the division between theory and observation and other barriers. Please look forward to our future research results.

Division of Science
Director
TOMINAGA, Nozomu

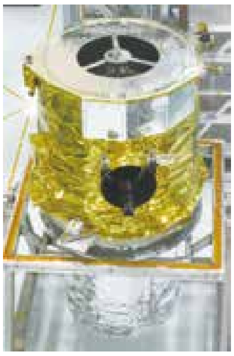
Technology Development

With its capability to develop cutting-edge observational facilities and instruments on its own, NAOJ provides strong support for leading edge research.

1 Large Telescopes for Optical-Infrared and Radio

Starting with the Nobeyama 45-m Radio Telescope, followed by the Subaru Telescope, and ALMA, NAOJ has a history of developing large telescopes with world-leading performance. Based on this experience, NAOJ is now developing the 30 meter optical-infrared telescope TMT. TMT will control its giant 2600 ton telescope structure with a high precision better than one-thousandth of a degree and capture images with a resolution of a few hundred-thousandths of a degree.

2 High Accuracy Optical Space Telescope

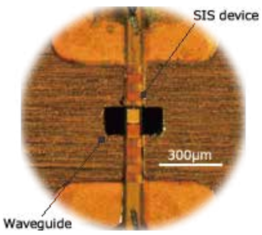


The Solar Optical Telescope mounted on Hinode.

In cooperation with industry, we developed a space telescope with humanity's highest angular resolution for solar observations and had it installed on JAXA ISAS's "Hinode" satellite. In order to achieve diffraction limited performance, we developed advanced technologies including a design which lets out unnecessary sunlight, the primary mirror support structure, low expansion materials, and a tip-tilt mechanism to prevent image deterioration due to minute vibrations in the satellite.

3 Optical and Radio Sensors

We develop high sensitivity detectors to observe the weak light and radio waves from space. In cooperation with industry we developed a CCD with a thicker silicon layer,vastly increasing its sensitivity to red light. We then installed 116 of the CCDs in Hyper Suprime-Cam on the Subaru Telescope and for the first time produced a wide-field 3D map of dark matter.



Superconducting device for ALMA's highest frequency receiver.

NAOJ has specialized cleanroom equipment for developing super-conducting devices and has realized steady production of superconducting components with world-leading performance. Here, we produced ALMA receivers including its highest frequency band (950 GHz). There are only a few facilities in the world that can produce these kinds of superconducting devices and receiver systems.

NAOJ Technology Patents

Because astronomy observations require techniques spanning a wide range of light and radio wavelengths, we can expect new applications improving the standard of living. NAOJ makes efforts to acquire patents for new technologies developed here. Through those patents, we aim to increase Japan's presence in the competitive arena of astronomy and related fields while also generating patent revenue.

Patents held by NAOJ: 18 domestic, 7 overseas

As of September 30, 2024.

4 Adaptive Optics to Correct for Atmospheric Distortion

When we observe heavenly bodies from the ground, fluctuations in Earth's atmosphere cause the image to blur. Adaptive Optics is a technology which greatly improves the angular resolution of a ground-based telescope by correcting for the atmospheric fluctuations. NAOJ developed the adaptive optics system for the Subaru Telescope, successfully improving the angular resolution by a factor of 10 thus far, enabling the discovery of new exoplanets. The same technology can be used for observing the Earth from space, transmitting light signals to space, ophthalmology, or observing living cells under a microscope.

Subaru Ground Layer Adaptive Optics (GLAO) Project

By directing four laser beams into the sky and making the upper atmosphere glow, wide-field adaptive optics create artificial stars (laser guide stars), which enable us to measure and compensate for the blurring by Earth's atmosphere. (Conceptual Image)

5 Photonic Techniques

The photonic technique to produce terahertz frequency radio waves from an optical laser.

We are developing the technology to control laser light to produce signals from low frequencies to terahertz frequencies, with the aim of improving radio telescopes. By using photonic techniques to combine optical and radio we have successfully generated a stable reference signal up to the terahertz band.

In this way, NAOJ is developing a variety of technologies for use in astronomy. We accumulate the knowhow to optimize the overall capabilities of the observational facilities by combining these techniques. There are no other examples of these kinds of activities at Japanese research institutes.

In observational instrument development, we must work hard to produce instruments that not only make full use of novel, cutting edge technology, but are also robust enough to survive under the harsh conditions of a mountain summit or outer space.

Director of Engineering
UZAWA, Yoshinori

International Collaboration

NAOJ actively participates in various international cooperation frameworks and contributes to the advancement of astronomy worldwide. The Office of International Relations (OIR) promotes internationalization to further strengthen these collaborations.

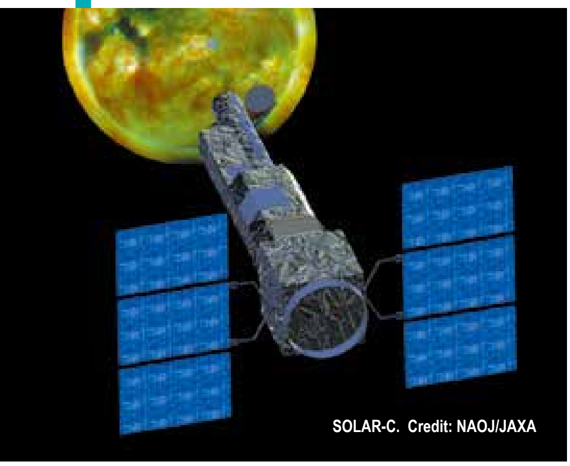
Top: International Researchers and Office of International Relations staff.
Bottom: Consultation about daily life in Japan for foreign research staff.

As the primary liaison for international cooperation among the core observatories in East Asia, the OIR promotes initiatives such as fellowship programs. It also conducts legal checks for various international agreements and plays a supporting role in the advancement of other international cooperation projects. Additionally, the office provides multiple support services to international researchers and students within NAOJ, including Japanese language classes and bilingual support, to help them focus on their research activities in Japan. Furthermore, the office strives to actively disseminate recruitment information to attract outstanding international researchers and students for further internationalization of NAOJ.

Office of International Relations
Director
CHAPMAN, Junko

Collaborative Observations with Spacecraft

In addition to ground-based observational facilities, NAOJ also conducts astronomical observations and celestial body exploration with JAXA/ISAS spacecraft. The SOLAR-C Project is a typical example.



SOLAR-C. Credit: NAOJ/JAXA

The hot chromosphere and corona above the solar surface are filled with fine jets and waves driven by the magnetic field. The solar-observing satellite SOLAR-C aims to elucidate the formation mechanisms of these high-temperature regions and the generation mechanism of explosive flares on the solar surface, which can affect the near-Earth space environment. The Extreme Ultra-Violet High-throughput Spectroscopic Telescope (EUVST) can simultaneously measure the broad temperature range from 20 thousand to 20 million degrees, which appears in the chromosphere and corona. Aiming for a launch in the late 2020s, instrument development is proceeding with contributions from Europe and America.

SOLAR-C Project
Director
HARA, Hirohisa

Future Plans

NAOJ plans to maintain its strong leadership position in world astronomy. Together with the Japanese and worldwide research communities, we will open new doors in astronomy and plan next generation observational instruments.

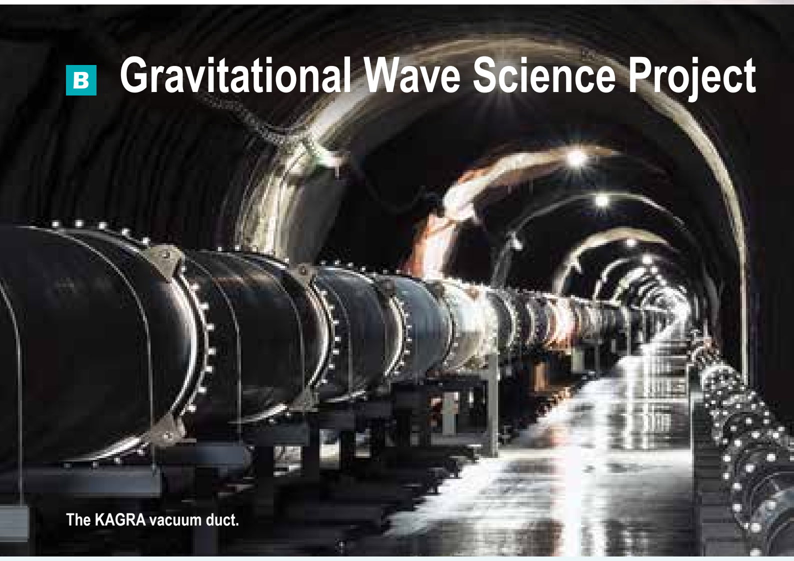
What mysteries of the cosmos is astronomy poised to answer in the 2020s and 2030s? What role should the Japanese astronomy community play internationally? NAOJ is crafting long term plans to greatly advance the level of world astronomy based on a dialog with the astronomy communities inside and outside of Japan.
"Small Project", "Promotion Group", and "Study Group" activities are underway at NAOJ to form the foundation for concrete future plans.
"Small Projects" are projects which have already entered the development phase, including the "JASMINE Project", "RISE Project", "ASTE" (Refer to pages 22, 23), "SOLAR-C Project" (above), the "Subaru Prime Focus Spectrograph Project" (Refer to page 07), and "Subaru Ground Layer Adaptive Optics (GLAO) Project" (Refer to page 19).
"Promotion Groups" and "Study Groups" are groups planning large projects which will carry forward future astronomy or groups considering participation in large international projects. In April 2019, two Study Groups were established: the ngVLA (Next Generation Very Large Array) Group and the SKA1 (Square Kilometer Array 1) Group; the latter became a Promotion Group in April 2023.

Various Projects and Centers Supporting NAOJ's Extensive Astronomy Research

NAOJ has various projects and centers to conduct and support a wide range of astronomy research.

A A Project　B B Project　C C Project　* Center　(Refer to page 25 for information about NAOJ's classification system.)

B Gravitational Wave Science Project

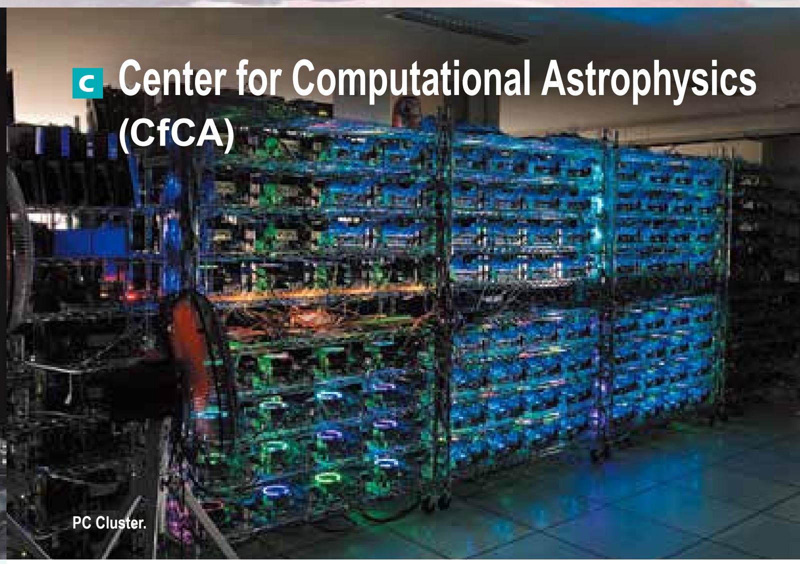

The KAGRA vacuum duct.

"Direct" Observation of Black Holes with Japan's Largest Laser Interferometer

Observations of the Universe through gravitational waves started in 2015 with the first direct detection of gravitational waves from the merger of two black holes. Now many gravitational wave events have been observed, and multi-messenger astronomy is actively underway (see page 18). Together with ICRR, KEK, and other institutes, we are participating in the development and operation of the gravitational wave telescope KAGRA. KAGRA will make important contributions to the International Gravitational-Wave Observatory Network. New technologies are also being developed at the TAMA300 interferometer in NAOJ Mitaka Campus, producing world-leading results in quantum optics.

Gravitational Wave Science Project Director
TOMARU, Takayuki

C Center for Computational Astrophysics (CfCA)


PC Cluster.

Depicting the Invisible Universe with Computer Simulations

In the Center for Computational Astrophysics (CfCA), we promote the open use of computer systems for simulation including a dedicated astronomy supercomputer. We aim to depict the formation and evolution of celestial objects of different scales, ranging from stars and planets to galaxies and the large-scale structure of the Universe through computer simulations based on the laws of physics. The computers we operate and the new technologies we develop enable more realistic simulations which show us facets of the Universe that cannot be observed with telescopes.

CfCA Director
KOKUBO, Eiichiro

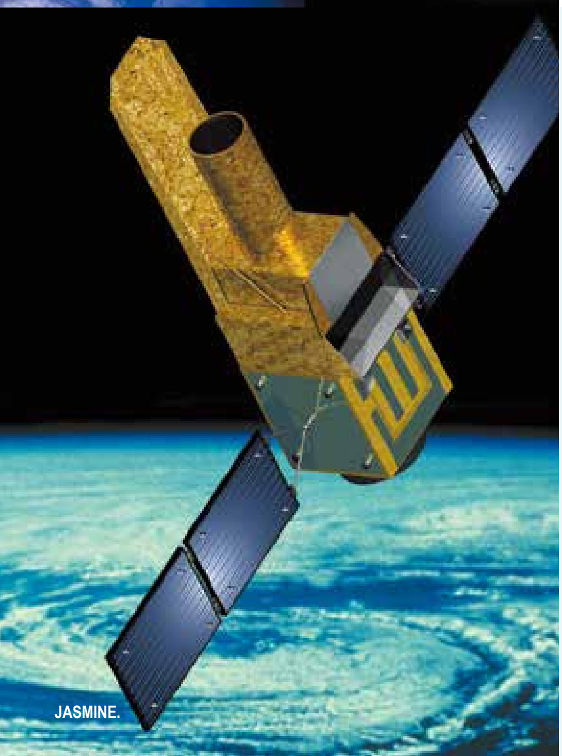
The Solar Flare Telescope (left) and solar observing satellite "HINODE." (Credit: NAOJ / JAXA / MSU)

C Solar Science Observatory

Using Eyes on the Ground and Eyes in Space to Peer into the Sun's Mysteries

Using the solar observing satellite "HINODE," the Solar Flare Telescope, and the Nobeyama Radio Polarimeters, we compile and publish multi-wavelength data ranging from X-ray to radio. This data is valuable worldwide for clarifying the long-term changes in solar activity. By examining the complex magnetic field structure and its temporal evolution from the solar surface to the upper atmosphere, we are working to solve the generation mechanism of sudden explosions "flares" and the "coronal heating problem." We also collaborate with domestic and international research institutions for high-altitude rocket and balloon experiments and the development of cutting-edge technology for the next-generation solar observing satellite "SOLAR-C."

Solar Science Observatory
Director
KATSUKAWA, Yukio



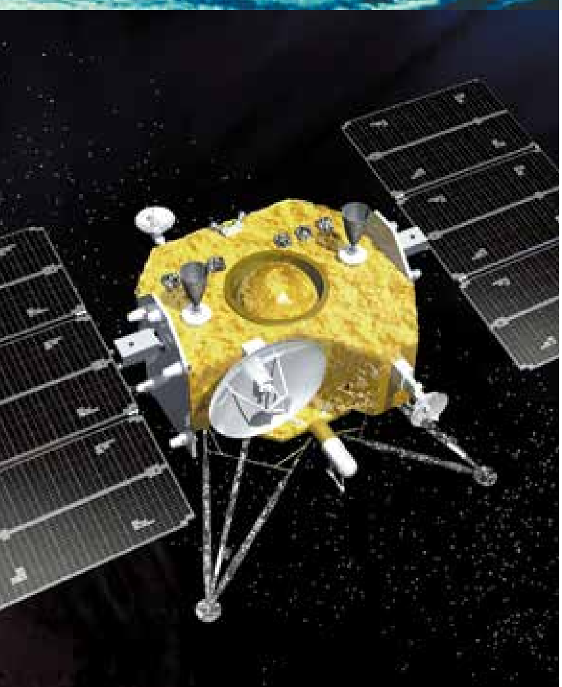
JASMINE.

A JASMINE Project

Research on the Central Core which holds the Key to the Milky Way Galaxy's Formation and the Investigation of Earth-like Exoplanets

The JASMINE Project works to realize the satellite "JASMINE" to reveal the Milky Way's central core structure and formation history by measuring the distances and the motions of stars through high-precision astrometry in the infrared and to explore the evolution history of the Milky Way. The satellite also aims to search for Earth-like habitable exoplanets by detecting the dimming when a planet transits in front of a red dwarf star smaller than the Sun. JASMINE has been selected as the JAXA-ISAS Competitive Middle-Class Science Missions No.3.

JASMINE Project Director
KANO, Ryohei



A RISE Project

Pursuing the Origin and Evolution of the Solar System through In-Situ Observations from Deep Space Probes

We investigate the origin and evolution of the Solar System by measuring the gravity and shape of planets and their moons. This is called planetary geodesy. Our research is founded on in-situ observations of the target body. For this purpose, we collaborate with JAXA and other domestic and international research institutes for instrument development and observational data acquisition. We accomplished science observations of the Japanese lunar orbiter "KAGUYA" and the asteroid sample-return mission "Hayabusa2." Also we are participating in the Jupiter Icy Moons Explorer "JUICE" and leading the international Geodesy Science Strategy Team of the Martian Moons eXploration "MMX" for further understanding of the origin and evolution of the Martian Moons.

RISE Project Director
NAMIKI, Noriyuki

MMX spacecraft CG. (Credit: JAXA)


The 20-m radio telescope at Mizusawa VLBI.

C Mizusawa VLBI Observatory

Exploring the Universe in Higher Resolution by Connecting Radio Telescopes Across East Asia

VERA of Mizusawa VLBI Observatory is a project combining four 20-m radio telescopes located at Mizusawa, Iriki, Ogasawara, and Ishigakijima to create a huge virtual radio telescope with a diameter of 2300 km. VERA maps our Milky Way Galaxy by measuring the distances to celestial objects with high accuracy. Also, by organizing KaVA in cooperation with Korean radio telescopes, and the East Asia VLBI Network including antennas in China, we are researching in detail the jets ejected by super massive black holes and the birthplaces of stars.

Mizusawa VLBI Observatory
Director
HONMA, Mareki


The Nobeyama 45-m Radio Telescope.

C Nobeyama Radio Observatory

Solving Mysteries with the World's Largest Millimeter-wave Antenna and Leading-Edge Receivers

The 45-m telescope at Nobeyama Radio Observatory pioneered millimeter-wave astronomy in Japan. Utilizing its high sensitivity, we observe radio waves emitted from various interstellar molecules. Especially we have investigated where interstellar gas gathers in the Galaxy and how stars are formed in the accumulated gas. One of the fruits of our research is a completed catalog showing the evolution of the Orion molecular cloud complex. We also serve as a testbed for new equipment. Proprietary leading-edge receivers and a radio wave spectrometer have been developed and put into use.

Nobeyama Radio Observatory
Director
NISHIMURA, Atsushi


10-m submillimeter antenna.

A ASTE Project

Pursuing the Mysteries of Distant Galaxies with the World's First On-Chip Superconducting Spectrometer

The ASTE telescope (Atacama Submillimeter Telescope Experiment) is a 10-m diameter submillimeter telescope established in the Atacama Desert (altitude 4860 m) in Chile in 2002. Taking advantage of the wide-area, broad-waveband capabilities provided by a large-aperture, single-dish submillimeter telescope, it provides a platform for advanced research and development and pilot observations leading to future observations with ALMA. It conducts wide-field, submillimeter observations of molecular clouds in the Milky Way and nearby galaxies using the 490 and 810 GHz band receivers, and observational research on distant galaxies using the world's first on-chip superconducting spectrometer.

Large-scale storage and computers for archiving and publishing observational data.

Astronomy Data Center

Advancing Data Science with Astronomy Observation Big Data and High-Performance Computing

We collect, store, organize, and release to the world the astronomy observation data acquired daily by the telescopes and observational instruments of NAOJ and domestic universities. We provide comprehensive services related to astronomy data including application development, open-use of the data analysis computer system for astronomy research, and hosting workshops, so that researchers can effectively use these astronomy big data in their own research. This includes various data archiving services including a virtual observatory, which make it easy to search, view, and retrieve data from facilities such as the Subaru Telescope and ALMA. We also work with the observatory to produce and release calibrated images and object catalog databases for the Subaru Telescope wide-field camera etc.

Astronomy Data Center Director

FURUSAWA, Hisanori

Subaru Telescope's HSC being test-assembled in the laboratory.

Advanced Technology Center

Pursuing Observational Instrument R&D Through a Unified Development Structure

The development of new observation instruments has stimulated advances in astronomy. The Advanced Technology Center is a base for the development of advanced instrumentation for astronomy in wide ranges of wavelengths, both ground-based and space-based. We have developed Hyper Suprime-Cam (HSC) for the Subaru Telescope, receivers for ALMA, a visible-light telescope and an X-ray telescope for Hinode, and optical instruments for KAGRA. While working to develop the technology needed for next generation instruments such as those for the Thirty Meter Telescope TMT, or new receivers for ALMA, we have also established the “Social Implementation Program” to apply the technologies for astronomy instrumentation to industry.

Advanced Technology Center Director

HIRABAYASHI, Masayuki

Regular Stargazing Party using the 50-cm Telescope.

Public Relations Center

Making the Joy and Fascination of Astronomy Accessible to the Public

The Public Relations Center is tasked with delivering astronomy information to the public. Of course this includes the latest astronomy research results, as well as information about celestial phenomena and new astronomical object reports; and information to maintain the Ephemeris and the Central Standard Time of Japan. While distributing this wide variety of information, we are also responsible for answering telephone inquiries; managing public access to Mitaka Campus and Ishigakijima Astronomical Observatory; maintaining relations with our host city of Mitaka; and the activities of IAU Office for Astronomy Outreach. As a center for science communication related to astronomy, we also cooperate with social-education facilities connected to astronomy. We also conduct spectrum management activities to protect the observational environment, as well as providing library services for the general public through our Library Unit with its large collection of rare books and materials related to astronomy.

Public Relations Center Director

WATANABE, Junichi

Organization

The Project System clarifies the activities and plans of NAOJ in terms of projects, centers, and divisions, each with specific goals and timelines. The Project System advances the sharing of resources throughout the entire observatory; defines the responsibilities and capabilities of project leaders and staff; and improves the clarity and independence of research.

- Advisory Committee for Research and Management
  - Project Review Committee
  - Research Coordination Committee
  - Scientific Advisory Committee
  - External Council
- Director General
  - Vice-Director General (on General Affairs)
  - Vice-Director General (on Finance)
  - Director of Engineering
  - Director of Research Coordination
  - Executive Advisors to the Director General

- Projects
  - **C Projects**
    - Mizusawa VLBI (Very Long Baseline Interferometry) Observatory — SKA1 Group
    - Nobeyama Radio Observatory
    - Solar Science Observatory
    - Subaru Telescope — Okayama Branch Office
    - Center for Computational Astrophysics
    - NAOJ Chile
    - ALMA Project — ngLVA Group
  - **B Projects**
    - Gravitational Wave Science Project — Kamioka Branch Office
    - TMT (Thirty Meter Telescope) Project Office — California Office
  - **A Projects**
    - JASMINE (Japan Astrometry Satellite Mission for INfrared Exploration) Project
    - RISE (Research of Interior Structure and Evolution of Solar System Bodies) Project
    - SOLAR-C Project
    - ASTE Project
    - Subaru Prime Focus Spectrograph (PFS) project
    - Subaru Ground Layer Adaptive Optics (GLAO) project
- Centers
  - Astronomy Data Center
  - Advanced Technology Center
  - Public Relations Center
- Division of Science
  - Collaborative Projects
    - Inter-university Collaboration: Optical and Infrared Synergetic Telescopes for Education and Research (OISTER)
    - Inter-university Collaboration: Japanese VLBI Network (JVN)
- Administration Department
  - General Affairs Group
  - Research Promotion Group
  - Financial Affairs Group
  - Accounting Group
  - Facilities Group
- Library
- IT Security Office
- Research Enhancement Strategy Office
  - Research Evaluation Support Office
  - Industry Liaison Office
- Office of International Relations
- Human Resources Planning Office
- Safety and Health Management Office
- Engineering Promotion Office
- Graduate Education Office

3 Groups of Projects and 3 Centers

At NAOJ, projects are divided into 3 groups based on their roles.

C Projects group - the seven projects such as Subaru Telescope, ALMA, the Supercomputer "ATERUI II," Solar Observing Satellite HINODE, etc., which have been completed as NAOJ facilities and are operating. This project group is the main driving force of NAOJ, actively supporting leading edge observations and research.

B Projects group - two project offices that are under construction or being developed. The TMT Project is constructing the 30 meter telescope TMT. The Gravitational Wave Science Project is undertaking gravitational wave observations using KAGRA, the Large-scale Cryogenic Gravitational Wave Telescope.

A Projects group - projects pursuing small-scale development plans. In April 2019, the "Subaru Prime Focus Spectrograph Project" and the "Subaru Ground Layer Adaptive Optics Project" were added to the already existing "JASMINE Project", "RISE Project", and "Solar-C Project."

"Promotion Groups" and "Study Groups" are established to investigate observational instrument development plans closely related to NAOJ's future strategy. Currently the SKA1 Group and ngVLA Group are active.

An additional two, the OISTER Network of optical-infrared telescopes in Japan and Japanese VLBI Network, are being pursued in cooperation with Japanese universities.

The three centers extend across the framework of individual projects and play key roles in equipment development, technological research, data analysis, data archiving, and public outreach activities. The centers provide the basic infrastructure of NAOJ.

NAOJ Facilities

Our research facilities have been set up throughout Japan and around the world in the best observational environments to explore the Universe.

NAOJ Mizusawa

Mizusawa VLBI Observatory (VERA)

NAOJ Mizusawa has a long history since its founding as a part of the International Latitude Observatories. It operates VERA to observe the Milky Way, black holes, etc.

Center for Computational Astrophysics

NAOJ Mizusawa hosts ATERUI II, the world's fastest supercomputer dedicated to astronomy.

RISE Project

The RISE Project has contributed to instrument development, observation operations, and spacecraft orbit estimation for KAGUYA and Hayabusa2, and has been carrying out research and development for exploration of the satellites of Mars and Jupiter.

Japanese Branches

NAOJ Nobeyama

Nobeyama Radio Observatory

Nobeyama Radio Observatory raised Japanese radio astronomy to the top tier internationally. The 45-m Radio Telescope is one of the largest millimeter radio telescopes in the world. It has achieved epoch-making results, such as discovery of new interstellar molecules and detection of the signature of a supermassive black hole in a galaxy. Nobeyama Campus is open daily to the public.

GWSP Kamioka Branch, KAGRA

KAGRA, a gravitational wave telescope constructed in the Kamioka Mine, aims to expand the field of gravitational wave astronomy. The Kamioka Branch of the Gravitational Wave Science Project supports the installation and commissioning of KAGRA.

Subaru Telescope Okayama Branch

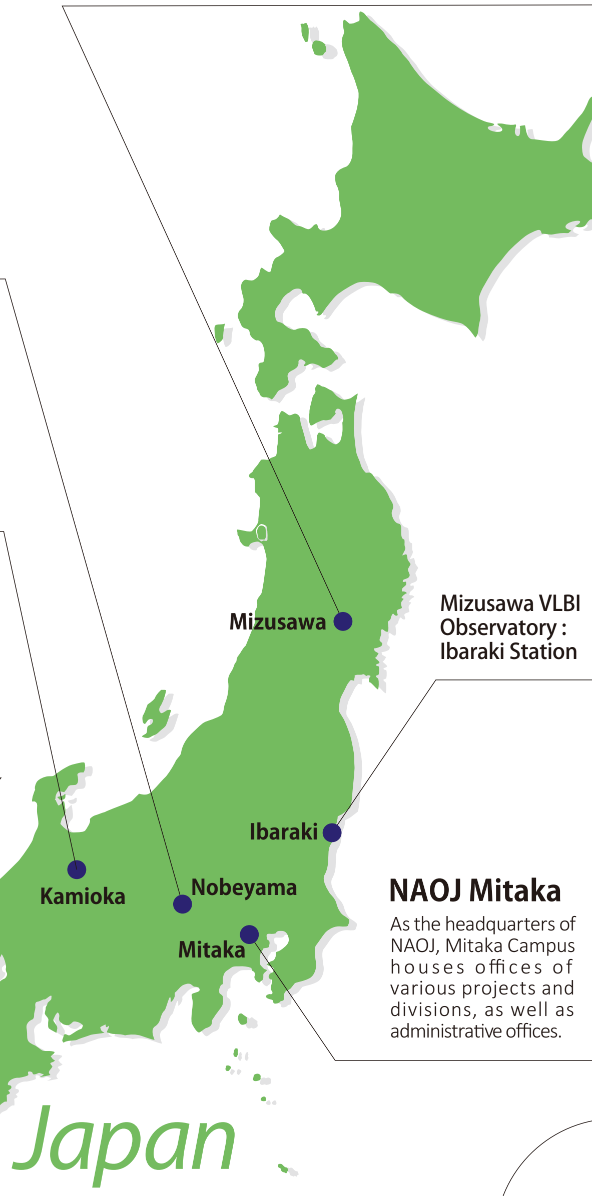
Open-use observations are conducted by NAOJ at the 3.8-m telescope of the Okayama Observatory, the Astronomical Observatory of the Graduate School of Science, Kyoto University. Open-use observing opportunities with the largest optical and near-infrared astronomy facility in Japan are provided.

Mizusawa VLBI Observatory : Ibaraki Station

NAOJ Mitaka

As the headquarters of NAOJ, Mitaka Campus houses offices of various projects and divisions, as well as administrative offices.

Mizusawa VLBI Observatory : Yamaguchi Station

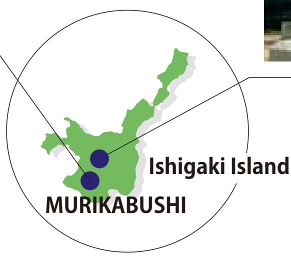


Ishigakijima Astronomical Observatory

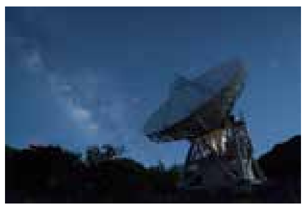
MURIKABUSHI is a 105-cm telescope in Ishigakijima Astronomical Observatory.

Mizusawa VLBI Observatory : Ishigaki-jima Station (VERA)

Mizusawa VLBI Observatory : Iriki Station (VERA)



Mizusawa VLBI Observatory : Ogasawara Station (VERA)



Overseas Branches

NAOJ Hawai'i

Subaru Telescope, NAOJ TMT Project

With many clear nights and stable airflow, the summit region of Maunakea (4200 meter altitude) is well suited for astronomy observations. Here, NAOJ constructed and operates the Subaru Telescope. NAOJ is also advancing the 30 meter optical-infrared telescope TMT through international collaboration.

Hilo Base Facility

The base facility of Subaru Telescope is located in Hilo on the Island of Hawai'i. As the base for the unified operation of the Subaru Telescope and TMT, this facility has laboratories, a machine shop, computer room, a remote observation room, etc.

The Subaru Telescope (left)

This optical-infrared telescope with a world-class 8.2-meter aperture saw first light in 1999 and started full-scale observation in 2000. In FY 2022, a new project called "Subaru Telescope 2.0" started to investigate the evolution of the Universe and the origin of elements with new core instruments.

TMT (right)

An extremely large optical-infrared telescope being constructed through international collaboration between Japan, the United States, Canada, and India. With more than 10 times the light collecting power of the Subaru Telescope, it aims to discover signs of life in the atmospheres of exoplanets and capture the light from the earliest stars in the Universe.

NAOJ Chile

NAOJ Chile, NAOJ ALMA Project

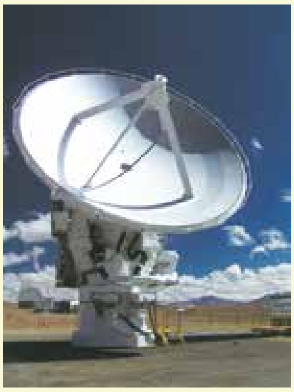
The Atacama Desert in northern Chile, one of the driest places on Earth, is an ideal location for short wavelength radio wave (millimeter and submillimeter wave) observation. ALMA and ASTE have been established here. The NAOJ Chile office and the Joint ALMA Observatory Santiago Central Offices are located in Santiago, the capital of Chile.

ALMA

ALMA, led by NAOJ, the National Radio Astronomy Observatory (US), and the European Southern Observatory, is a giant radio telescope array with 66 antennas operated on a 5000 meter elevation plateau in Chile. NAOJ collaborates in East Asia with the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan and the Korea Astronomy and Space Science Institute. Credit: ESO

ASTE

ASTE observes submillimeter radio waves with wavelengths shorter than 1 millimeter. Established in the Atacama Desert with optimal conditions for submillimeter astronomy, it applies its strength to observations of the southern sky including the Galactic center region, nearby star-forming regions, and distant galaxies.



ALMA Operations Support Facility

The Operations Support Facility is located 30 kilometers away from the ALMA Array Operations Site. It serves as the "base camp" for ALMA with lodgings and a cafeteria for ALMA staff in addition to the control room for remote operation of ALMA and laboratories where instrument maintenance is performed.
Credit: ESO

Public Access to NAOJ facilities

To widely disseminate our research results to the public, the major facilities of NAOJ offer visitors' areas, annual open house days, or regular stargazing parties.

Top Level Research with NAOJ Facilities

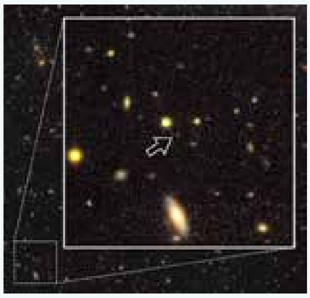
NAOJ develops and operates large-scale research facilities that would be difficult for individual universities to maintain. By sharing these facilities with researchers from universities in Japan, NAOJ provides cutting-edge research environments to them. In addition to sharing facilities, NAOJ provides extensive user support to cultivate young researchers; helps individual researchers improve the quality of their research; promotes interdisciplinary research; and conducts collaborative research with researchers in Japan and abroad. We also give back to the community through activities to support university researchers and raise Japan's international profile including the compilation and publication of various astronomy data and open-use analysis environments by the Astronomy Data Center; collaborative research and facility use in the Advanced Technology Center; and the dissemination of research results in Japan and overseas by the Public Relations Center.

We regularly hold Users' Meetings, in which we share the present state of our telescopes and their future plans to discuss how to yield better results.

Selected Results from the Subaru Telescope

Discovery of many supermassive black holes 13 billion light-years away.

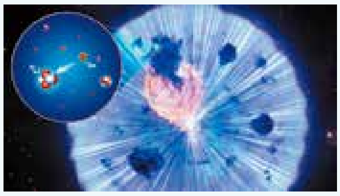
A research team led by Yoshiki Matsuoka of Ehime University used Hyper Suprime-Cam (HSC) mounted on the Subaru Telescope and discovered 83 supermassive black holes 13 billion light-years away. The study showed that a large number of supermassive black holes already existed in the very early phase of the Universe.



A supermassive black hole (red dot indicated by the arrow) located 13.05 billion light-years away.

Little lithium produced in classical nova

A team led by Akira Arai at Kyoto Sangyo University used the Subaru Telescope to investigate beryllium, the precursor of lithium, in classical nova V5669 Sgr to investigate production sites of lithium. The amount of lithium produced in this classical nova is only a few precent of that seen in others, indicating a range of lithium production in classical novae.



Conceptual image of lithium production in nova V5669 Sgr.
Credit: Kyoto Sangyo University

Operation of Okayama 188-cm Telescope and the Seimei telescope

The Subaru Telescope Okayama Branch Office has provided opportunities for observations using the Okayama 188-cm Reflector Telescope and the HIgh Dispersion Echelle Spectrograph (HIDES) for almost 20 years, and contributed to the development of research on exoplanets in Japan, including Japan's first detection of an exoplanet. At present, NAOJ is responsible for the open-use operation of the 3.8-m “Seimei” telescope of Kyoto University.

Integrating NAOJ's Technologies into Society

Aiming to achieve new breakthroughs in astronomy, NAOJ has developed and refined its own technologies to create its world-leading observing facilities. The “technologies for astronomy” that we have developed in the process can be repurposed to benefit our lives and society. We intend to utilize the technologies for astronomy to make our society more secure, convenient, and healthy.

Megapixel CCD with High IR Sensitivity

In collaboration with Hamamatsu Photonics K.K., NAOJ developed a CCD with high infrared sensitivity. As this sensor has a high X-ray sensitivity as well, it was also used in JAXA's X-ray space telescopes. The same type of sensor is used in transmission electron microscopes (TEM). Its high sensitivity in X-ray is also valuable in medicine and can lighten the burden on patients by reducing the dose of X-rays required.

A newly developed megapixel CCD (2048 × 4096 pixels and 30 mm × 60 mm light receiving surface).

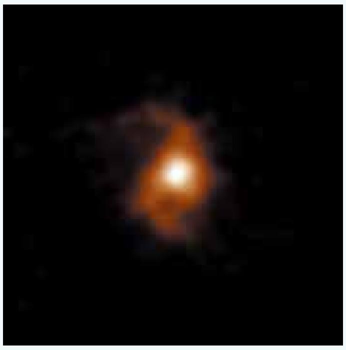
At NAOJ, we use observational instruments incorporating leading-edge technology to explore the mysteries of the Universe. In addition to being a splendid expression of humanity's intellectual curiosity, the developed technologies can also benefit society. Astronomy creates the future.

Industry Liaison Office
Director
HIRAMATSU, Masaaki

Selected Results from ALMA

Most ancient galaxy with observed spirals

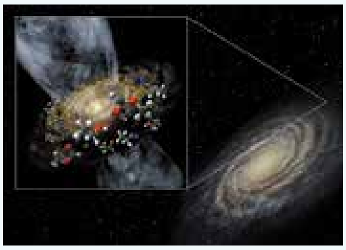
A team led by Takafumi Tsukui, a graduate student at SOKENDAI, found a galaxy with spiral morphology from ALMA data for 12.4 billion years ago. The discovery of a spiral galaxy only 1.4 billion years after the Big Bang could help answer longstanding questions in astronomy about how the shape of a galaxy is determined.



BRI 1335-0417, a galaxy with spirals 12.4 billion years ago observed by ALMA.
Credit: ALMA (ESO/NAOJ/NRAO), T. Tsukui & S. Iguchi

Organic molecules at the edge of the Galaxy

A team led by associate professor Takashi Shimonishi at Niigata University observed the edge of the Milky Way Galaxy with ALMA and found chemically-rich molecular gas including complex organic molecules around a newborn star. The ancient environment is preserved in the extreme outer Galaxy, indicating that organic molecules can be formed efficiently even in the primordial environment.

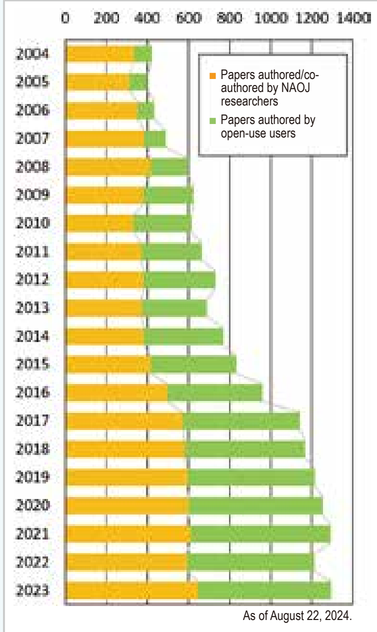


Conceptual image of organic molecules around a protostar in the extreme outer Galaxy.
Credit: Niigata University

Published Papers Statistics

The number of papers published by NAOJ researchers has been increasing in tandem with the progression of the large projects. Through the open-use program, papers published by researchers affiliated with universities are also increasing.

Percentage of the top 10 % most cited papers written by NAOJ researchers: 16.6 % Percentage of the top 1 % most cited papers written by NAOJ researchers: 2.9 % Percentage of international coauthorship: 79.5 %
(2019~2023 Averages, taken from InCites)



Collaboration with Universities

NAOJ operates observation facilities in collaboration with universities and institutions both in Japan and abroad.

The Optical and Infrared Astronomy Research and Education Network (OISTER) aims to conduct immediate follow-up observations of transient astronomical phenomena, such as supernovae, by organically connecting mid-to-small-size telescopes.

The Japanese VLBI Network combines radio telescopes operated by NAOJ and domestic universities to create a giant virtual radio telescope, through which we study the dynamics of gas in star-forming regions and gas jets blasting out from black holes.

At NAOJ, we aim to elucidate the depths of the Universe by making full use of leading-edge technology and theory to open unexplored areas. We contribute to the development of astronomy, with an emphasis on collaboration with universities and international cooperation.

Director of Research Coordination
IKOMA, Masahiro

Repurposing from Superconducting Radio Receivers to Quantum Computers

Techniques to amplify the weak radio signals from space are indispensable in radio astronomy. They are also helpful in the realization of large-scale quantum computers. At NAOJ, we are refining our radio receiver technology and developing small, low-power-consumption microwave amplifiers and isolators.

A novel superconducting microwave amplifier made by connecting frequency mixers.

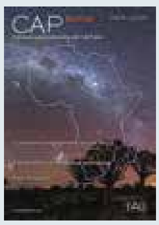
Repurposing from Adaptive Optics Technology to Satellite Optical Communications

The Subaru Telescope uses adaptive optics technology to correct for atmospheric fluctuations and capture sharp images of celestial objects. This same technology can be used to achieve an advanced optical link between a satellite and ground station for high-speed communications.

Conceptual image of satellite optical communications. Credit: NASA/JPL

Leading Astronomy Outreach Initiatives Globally

The International Astronomical Union (IAU) Office for Astronomy Outreach (OAO) is the IAU's international office for outreach located at the NAOJ Mataka Campus. The OAO is a joint venture between the IAU, the largest association of professional astronomers in the world, and NAOJ. It is responsible for engaging the international public with astronomy through its network of National Outreach Coordinators (NOCs) comprised of over 300 volunteers in more than 120 countries. The OAO also aims to professionalize astronomy communication through its portfolio of projects under the umbrella of Communicating Astronomy with the Public. This successful collaboration is one of the many initiatives for internationalization and diversity at NAOJ.



CAPjournal.

Graduate Education

NAOJ makes an effort to educate graduate students who will become leaders in the next generation. Through international education and research in cutting-edge research facilities, we aim to develop not only world-leading researchers and innovative engineers but also individuals who are able to contribute to wider society.

NAOJ accepts graduate students through the following three programs.

❶ The Graduate University for Advanced Studies (SOKENDAI)

Astronomical Science Program, Graduate Institute for Advanced Studies, SOKENDAI is a graduate school based at NAOJ.

❷ Cooperative Graduate School Program

❸ Visiting Graduate Students Program

Number of Graduate Students (as of April 1, 2024)

Students from SOKENDAI (five-year doctoral course) 36
Students from cooperative graduate schools......36
Visiting graduate students......15

NAOJ accepted students from the following graduate schools in the last five years.

Tohoku University, Ibaraki University, University of Tsukuba, The University of Tokyo, Tokyo Institute of Technology, University of Electro-Communications, Niigata University, Nagoya University, Yamaguchi University, Kyushu University, Osaka Metropolitan University, Tokyo City University, Nihon University, Hosei University, Konan University, Shizuoka University, Waseda University, Tokyo University of Agriculture and Technology, Tokyo University of Science, Nara Women's University, Fukushima University, University of Hyogo (in no particular order)

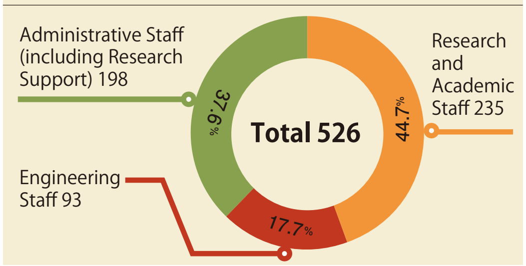
At NAOJ at any given time, there are nearly 100 graduate students, including those from SOKENDAI and the University of Tokyo, engaged in theoretical, observational, and instrument development research. We hope current undergraduate students will consider studying with us in the future.

Graduate Education Office Director

SEKII, Takashi

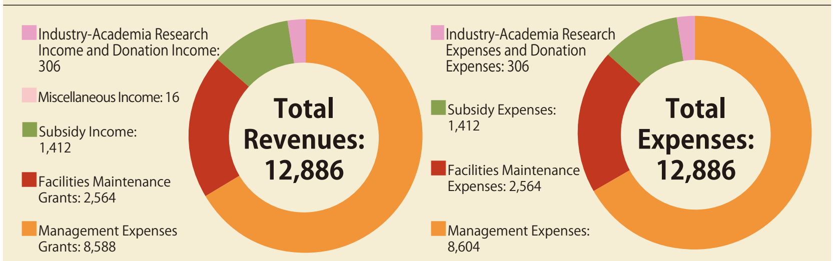
Profile of NAOJ

Number of Employee (as of April 1, 2024)



Budget (FY 2023)

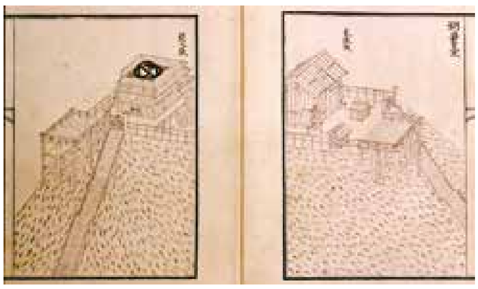
Unit: 1 million yen



History of NAOJ

Tradition and Innovation: playing a part in Japan's natural science research

The origin of NAOJ dates back to the late Edo Era (more than 300 years ago) when the Shogunate Tenmonkata started observations of celestial objects to create ephemerides. NAOJ still carries on the compilation of ephemerides as a part of its duties. The Meiji Era saw the inflow of knowledge about modern astronomy from the West, and as a result, the Tokyo Astronomical Observatory and the Latitude Observatory were established in 1888 and 1899 respectively. Thereafter, Japanese astronomers developed various observing instruments and conducted much research over the next 100 years. Then, in 1988, the Tokyo Astronomical Observatory of the University of Tokyo, the Latitude Observatory, and a part of the Nagoya University Research Institute of Atmospherics were integrated to establish NAOJ. Let's briefly look back on the history of NAOJ which has always been a pioneer at the leading-edge of astronomy research.



The Astronomical Observatory in Asakusa in the Edo Era (From Treatise on the Kansei Calendar).

This year, NAOJ commemorated 100 years since Tokyo Astronomical Observatory moved from Iikura, Azabu to Mitaka. We hope to continue contributing to the development of astronomy as a world-leading research institute for the next 100 years.

General Manager

FUJITA, Hisashi


Latitude Observatory.

1888	The Tokyo Astronomical Observatory was established. (Iikura, Azabu)
1899	The Latitude Observatory was established in Mizusawa.
1924	The establishing of Mitaka Campus started.
1925	Publication of “Chronological Scientific Tables (Rika Nenpyo)“ began.

Rika Nenpyo

Since its first publication in 1925, we have been publishing Rika Nenpyo for almost 100 years in cooperation with many other research organizations. Also available in English.
https://official.rikanenpyo.jp/posts/5905


Mitaka Campus in the early Showa Era.


65-cm Refractor Telescope.


Laser Interferometer Gravitational Wave Antenna (TAMA300).


Mizusawa 20-m Radio Telescope.

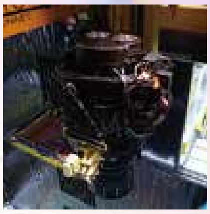

ALMA.

1926	65-cm Telescope Dome completed.
1929	65-cm equatorial telescope was equipped.
1930	Solar Tower Telescope (The Einstein Tower) was built.
1946	Publication of Almanacs and “Calendar and Ephemeris“ began.
1949	Norikura Solar Observatory began observations.
1960	Okayama Astrophysical Observatory began observations.
1962	Dodaira Observatory began observations.
1969	Nobeyama Solar Observatory began observations.
1982	Nobeyama 45-m Radio Telescope began observations.
1988	The National Astronomical Observatory of Japan was established.
1992	Nobeyama Radioheliograph began observations.
1999	Subaru Telescope achieved first light.
1999	Laser Interferometer Gravitational Wave Antenna “TAMA300“ began observations.
2000	Dodaira Observatory was closed.
2000	Visitors’ Area opened at Mitaka Campus.
2001	Agreement for ALMA project among Europe, the United States, and Japan.
2001	VERA Stations began observations.
2004	NAOJ was incorporated as the National Astronomical Observatory of Japan, National Institutes of Natural Sciences, Inter-University Research Institute Corporation.
2006	Ishigakijima Astronomical Observatory began observations.
2006	HINODE began solar observations.
2007	As a part of the Four-Dimensional Digital Universe (4D2U) project, the 3-dimensional dome theater was completed.
2007	The lunar explorer “KAGUYA” was launched and began observations.
2010	Norikura Solar Observatory was closed after 60 years of service.
2011	ALMA Early Science operation started.
2013	Regular ALMA observations started.
2014	TMT International Observatory was established. NAOJ participated as an initial member.
2015	Nobeyama Solar Observatory was closed.
2018	Okayama Astrophysical Observatory was closed.
2018	Super Computer ATERUI II started operation.
2020	KAGRA began observations.


Solar Tower Telescope.

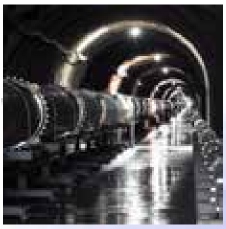
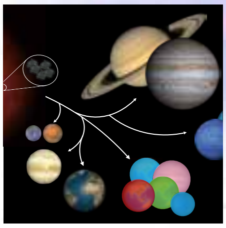
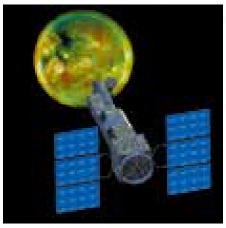

Nobeyama 45-m Radio Telescope.

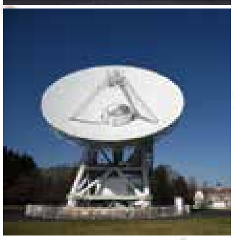

Subaru Telescope.

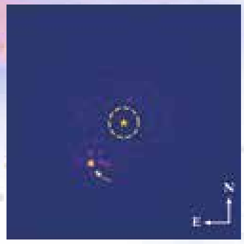




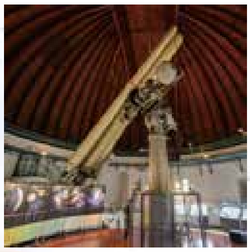








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