TMT
Thirty Meter Telescope
30m望遠鏡

NAOJ/NINS

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Thirty Meter Telescope Project

TMT

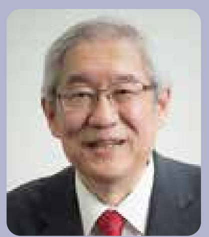
Challenging the frontier of astronomy with a world-class telescope – This is the dream that came to fruit for astronomers of Japan with the commissioning of the Subaru Telescope of NAOJ in 1999. The 8.2m Subaru Telescope constructed atop Maunakea on the Big Island of Hawaiʻi, a site with ideal conditions for performing astronomical observation, went on to make numerous discoveries, including setting one record after another for the discovery of the “farthest galaxy” to be ever observed, and thrusting Japan’s optical infrared astronomy to one of the top standards in the world. And now, Japan’s astronomy community led by NAOJ is set on making yet another significant contribution to world astronomy with its participation in the TMT Project, an international project to construct an extremely large optical infrared telescope at an unprecedented scale.

TMT is an ambitious project with plans to construct on Hawaiʻi an extremely large telescope with an aperture of 30m with the cooperation of five countries including Japan. Currently, telescopes with an aperture of 8 to 10m are heading astronomical observation for optical and infrared light, but with TMT and its aperture of 30m, 10 times as much light can be gathered in comparison to those of other telescopes. Infrared observation with the adaptive optics technology will achieve resolving power 10 times greater than that of the Hubble Space Telescope.

Recent astronomical observations have shed light on the formation of stars and galaxies in an expanding universe and the existence of extrasolar planets, rewriting our understanding of the cosmos and the natural world and opening doors to new mysteries.

The major goals of TMT include revelation of the nature of the first stars and galaxies that formed in this Universe and search for signatures of life on extrasolar planets.

Japan will lead the world in astronomy by applying all of the experience and technology developed in the construction of the Subaru Telescope to the international collaboration to construct the next generation extremely large telescope and also by coordinating scientific observation between the Subaru Telescope and TMT.



The Subaru Telescope and the Atacama Large Millimeter/submillimeter Array (ALMA) have brought major development and stimulus to the world’s astronomy research. Construction and operation of TMT, an observation facility unequaled in the world, under large-scale international cooperation is NAOJ’s another great competitive edge. NAOJ is committed to the TMT Project at full strength.

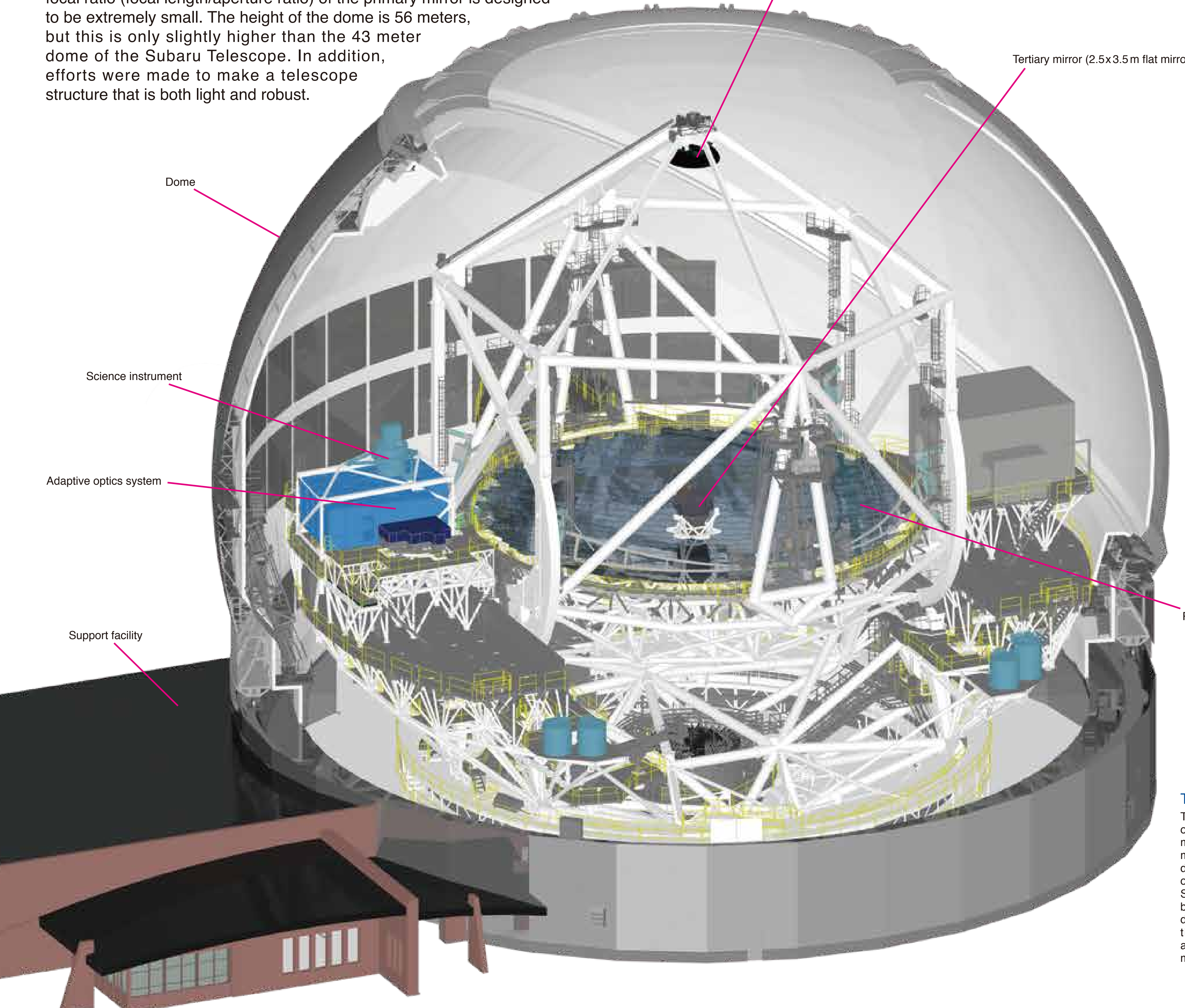
Saku Tsuneta (NAOJ Director General, TMT-J Representative)

Conceptual image of the Thirty Meter Telescope (TMT) scheduled for construction.
In the background is the dome of the Subaru Telescope.

30m telescope with segmented primary mirror

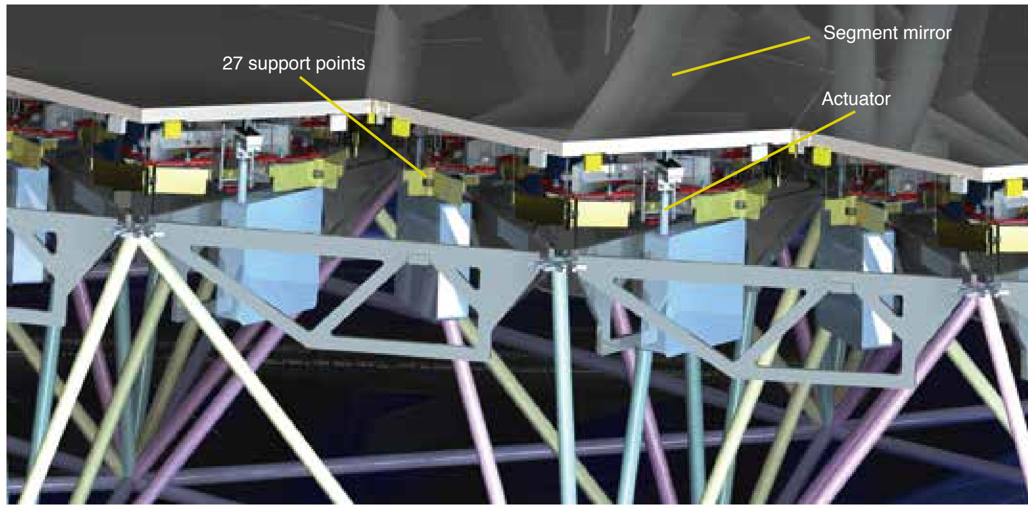
The most unique feature of TMT is its 30 meter diameter primary mirror which significantly eclipses the size of the primary mirror of all other telescopes ever built. While the primary mirror of the Subaru Telescope consists of a single 8.2 meter diameter mirror, the primary mirror of TMT is segmented and composed of multiple segment mirrors.

With increase in the size of the primary mirror, the size of the telescope structure and the dome are also increased. To limit this scale up in size, the focal ratio (focal length/aperture ratio) of the primary mirror is designed to be extremely small. The height of the dome is 56 meters, but this is only slightly higher than the 43 meter dome of the Subaru Telescope. In addition, efforts were made to make a telescope structure that is both light and robust.



The segment mirrors that compose the primary mirror are hexagonal in shape and 1.44 m in length across corners. The primary mirror consists of 492 of these segment mirrors. The overall weight is relatively light with the thickness of each mirror at only 4.5 cm. The surface of each segment mirror is aspherical so that the overall shape of the primary mirror resembles a near-parabolic hyperboloid. It is shaped to within an accuracy of a few one-tenth of the wavelength of optical light, an equivalent of about 10 nm. Seven segment mirrors, which include replacements, will be fabricated for each of the 82 types of segment mirrors with slightly varying surface contour. The surface of the mirrors will be coated in metal with high reflectivity for the range between optical and infrared light. During operation of the telescope, the segment mirrors will be sequentially washed and recoated utilizing replacement mirrors.

30 meter primary mirror comprised of 492 segment mirrors.
Segment mirrors 1.44 m in length across corners are laid out with 2.5 mm of spacing.



Segment mirror support assembly
The shape of each segment mirror is adjusted in the vertical direction at its 27 support points, and the relative positioning of the segment mirrors are actively controlled at 3 points by actuators.

TMT specifications

The focal plane (Nasmyth focus) for performing scientific observation with TMT is formed by the primary mirror, secondary mirror and tertiary mirror on the Altitude-over-Azimuth (Alt-Az) mount of the telescope that moves in the horizontal and elevation directions. The science instruments of the telescope are mounted on the Nasmyth platform located on both sides of the telescope. Since each science instrument is significant in size, switching between instruments for observation is performed by changing the direction of the tertiary mirror while maintaining the instruments in their fixed positions. The field of view for observation (15 arcminute) is approximately half the apparent diameter of a full moon.

Optics system	Richey-Chretien optical design
Focal point	Nasmyth focus
Aperture	30 meters / 492 segment mirrors
Focal length	450 meters
Field of view	15 arcmin
Focal ratio	1
Diffraction limit	8 miliarcsec (at 1 μm)
Wavelength range	0.31 - 28 μm
Telescope hight	51 meters

Superb resolution of the adaptive optics

The resolving power of a telescope is increased in proportion to the size of its aperture. However, observations from ground-based telescopes are affected by fluctuations in the atmosphere, causing disturbance in the imaging of the stars. In order to perform high-resolution observation with an extremely large telescope, adaptive optics technology is a must in order to make corrections against atmospheric disturbances. Adaptive optics is already in use for infrared observation with the Subaru Telescope, but in order to realize this for TMT and its larger aperture, technology at an unprecedented level is required.
Adopting the adaptive optics technology to TMT will enable infrared observation with resolving power 10 times greater than that of the Hubble Space Telescope and 4 times greater than the Subaru Telescope. Higher resolution will also enable interference from the background light (such as infrared light from the Earth atmosphere) to be suppressed, allowing for observation of dim astronomical objects.

TMT First Light Instruments

Infrared Imaging Spectrograph (IRIS)

The instrument, utilizing adaptive optics, will be capable of diffraction-limited imaging and integral-field spectroscopy at near infrared wavelengths (0.8 - 2.4 µm). IRIS will acquire data with an unrivaled level of precision, encompassing a far-reaching array of astronomical phenomena taking place from distant parts of the Universe to the Solar System. Utilizing IRIS, researchers will endeavor to discover small exoplanets near fixed stars, and to measure composition of the atmosphere of those planets through its spectroscopic observation. First celestial objects in the Universe will be closed in on by the instrument's high-sensitivity spectroscopic observation of far-off galaxies.

Wide Field Optical Spectrometer (WFOS)

The instrument is capable of multi-object spectroscopy in a field-of-view of 5 arcminute, which is relatively wide for such a large telescope, for optical light up to a wavelength of 1 µm. The maximum wavelength resolution is 8000. WFOS will help to map out the full picture of galaxy formation during the early Universe, and to reveal distribution of dark matter through spectroscopic observation of many distant, faint galaxies.

Other science instruments under consideration

In order to facilitate various forms of observation, there are plans for new science instruments to be developed after the first light instruments. These instruments include a high dispersion spectrometer that takes advantage of the large light-gathering power of TMT and break up the optical and infrared light based on their frequencies for measurement, an instrument capable of spectroscopy of multiple objects with high spatial resolution, and an instrument for imaging/spectroscopy of mid-infrared light (wavelength of 10µm and greater), which can be observed at high altitudes of Maunakea. An instrument for direct imaging of Earth-like planets is another instrument under consideration.

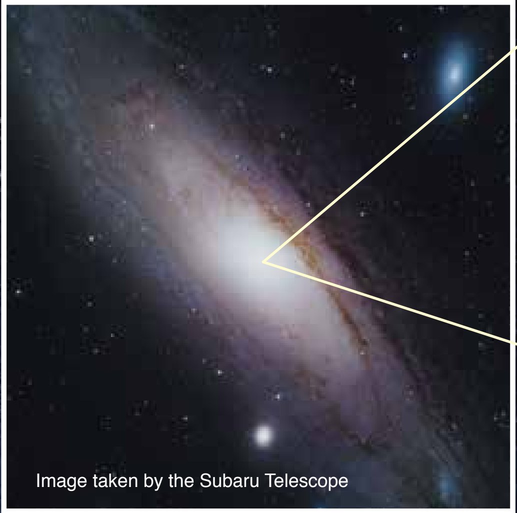


Image taken by the Subaru Telescope

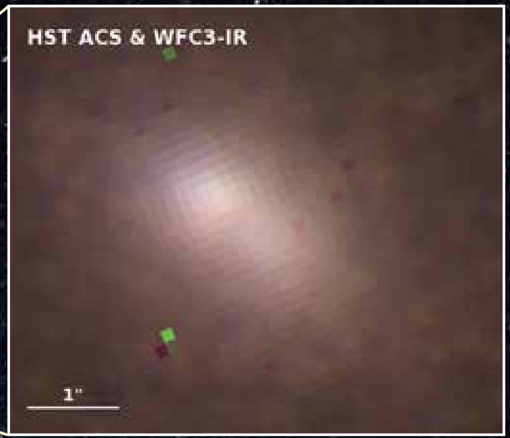
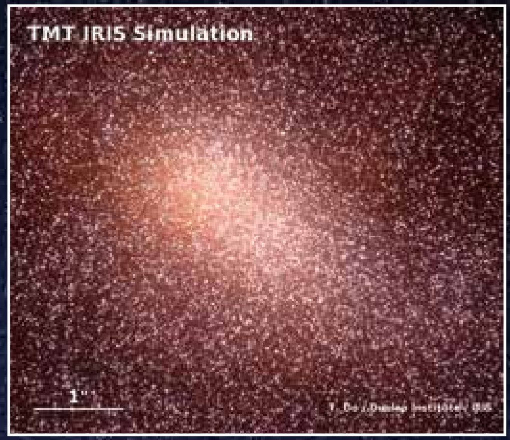


Image of the center of M31 taken by the Hubble Space Telescope



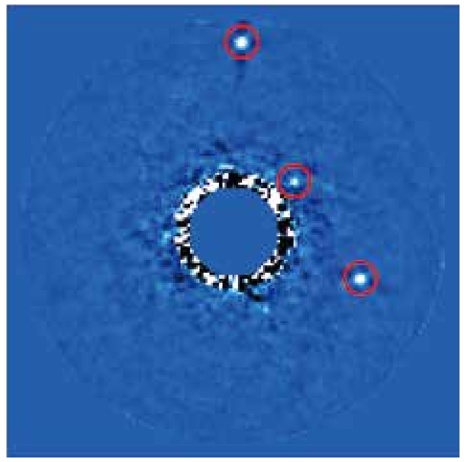
Simulated image based on the resolution of TMT with adaptive optics
© T. Do/Dunlap Institutes/IRIS

Adaptive optics observation utilizing laser guide star (conceptual illustration)
To utilize adaptive optics, a guide star (reference star) is used to measure the atmospheric disturbance on the wavefront of the stellar light, but because a star sufficiently bright for this purpose may not be within the field of view of the telescope, an artificial guide star is created by shooting a laser from the telescope into the atmosphere to light up the sodium layer 90km above.

TMT and the new era of astronomy

In search for life on extrasolar planets

Many planetary systems around stars other than our Sun are being discovered today, and we are learning that there exist planets with various sizes and orbits. Recently, planets similar in size as Earth have been discovered, indicating that there are planetary systems much like our own Solar Sytem. Today, infrared observation has advanced to a point of being able to actually capture images of these planets.
Are there extrasolar planets with existence of life? This is a question common to all humanity. TMT will use two different methods of observation in its attempt to discover signs of life on these planets.



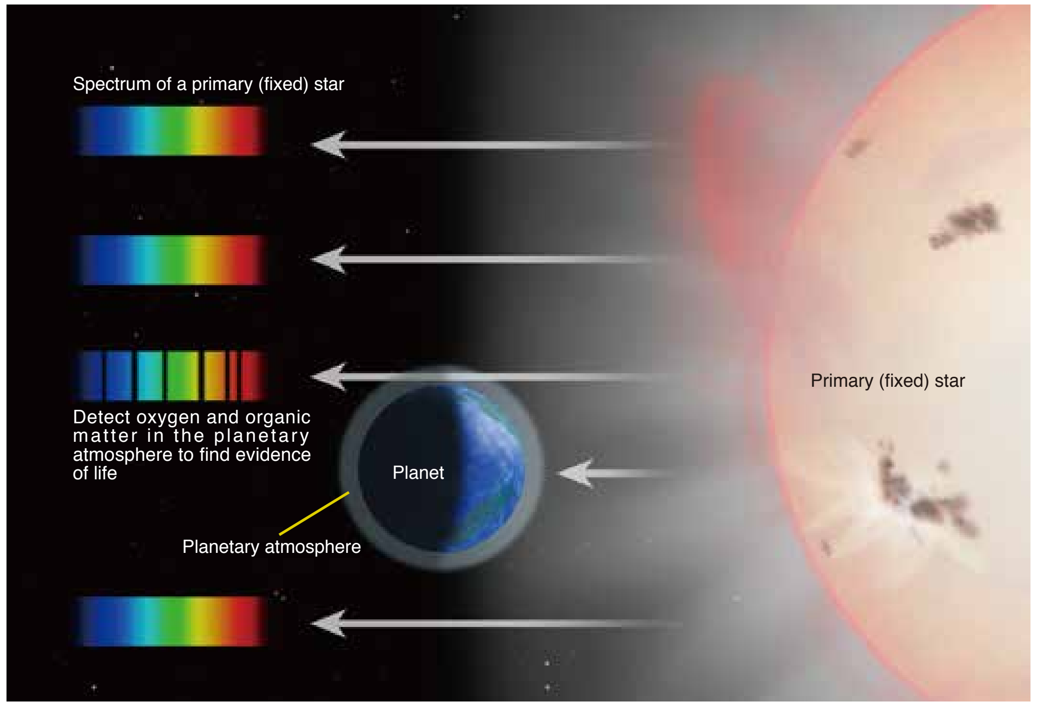
Three Jupiter-like planets around HR8799 discovered by the Subaru Telescope (in red circle). TMT will attempt to directly capture even smaller Earth-like planets. © CHARIS Team of Princeton University, and NAOJ

Studying reflected light of planets

Planets are significantly faint in comparison to bright primary stars (fixed stars), making direct observation of planets extremely challenging. This would be the precise case if we were to capture an image of Earth looking into our Solar Sytem from the outside. In comparison, a less massive star is not as bright as the Sun and would allow for better opportunity to detect a planet.
TMT will attempt to directly observe light (infrared light) from Earth-like planets around stars one-tenth the mass of the Sun. Light from planets will be analyzed to investigate their atmospheric composition to ultimately discover the possibility of existence of life.

Studying transmitted light from planet atmosphere

If a planet has an orbit that crosses directly in front of a primary star from our point-of-view, a portion of the light from the star would transmit through the atmosphere of the planet. This transmitted light can be analyzed to determine the composition of the atmosphere to find evidence of materials related to life such as oxygen and organic substances. Since extracting only light transmitted through the atmosphere is not feasible, light from the star would need to be studied with extremely high level of precision as shown to the right.



Search for life on extrasolar planets
TMT will be able to study the composition of the atmosphere of extrasolar planets through spectroscopic observation. Discovery of oxygen molecules and organic substances could be a signature of existence of extra-terrestrial life.

The 21st Century is the era for discovering life on extrasolar planets. As a pioneer, TMT will endeavor to realize the ambitious goal of capturing actual images of Earth-like planets where there is a possibility of life and investigate them for signs of life.

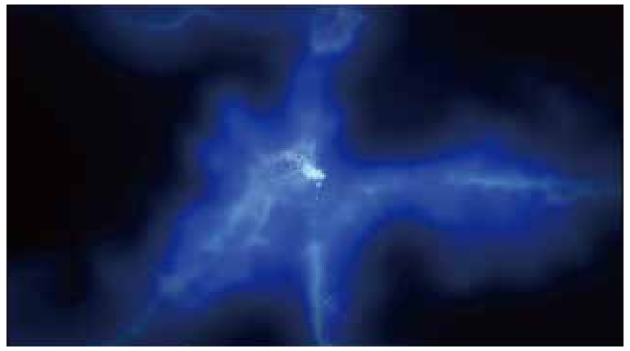
Motohide Tamura (Professor at the University of Tokyo)

Discovering the first stars and galaxies

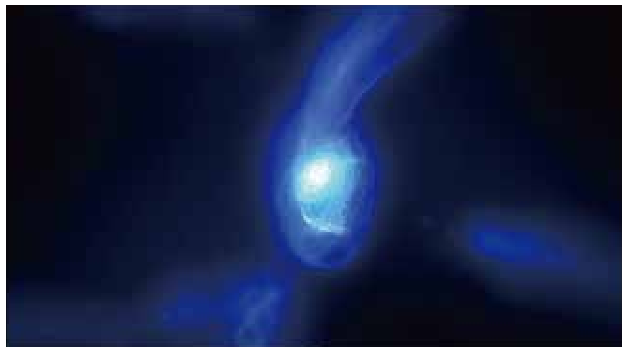
In the current Universe as we know it, galaxies are clustered and distributed throughout space to form what we call the "large-scale structure of the Universe." The popular belief is that the galaxies and the large-scale structure that interweaves the galaxies were formed based on fluctuations of matter density at the time of creation. Astronomers are now mapping out a full history of this period and verifying it through observation.
Revealing how and when the first stars and galaxies in the Universe formed will be the key to uncovering answers to these questions. The Subaru Telescope was successful in discovering galaxies 13 billion light years away, and ALMA pinpointed a galaxy 300 million more light years away. In other words, light from the galaxy approximately 500 million years after the creation of the Universe was captured. TMT will aim to spot ever farther galaxies that include first stars that emerged in the Universe, and to uncover the stars that were formed in those galaxies.

Simulated image of birth of first stars in the Universe © ALMA (ESO/NAOJ/NRAO)

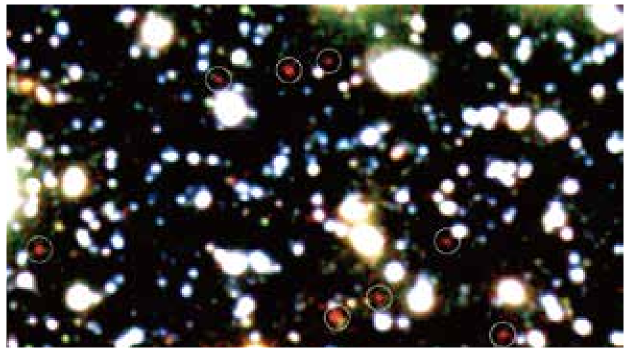
1) about 400,000 years after creation of the Universe
Ionized hydrogen in space became neutral and enabled light to pass, which to that point was obstructed by free electrons from moving forward. This marks the first time that the Universe became transparent to light. Later, hydrogen and helium started to accumulate around areas of high matter density.



2) 200-300 million years (redshift of up to 15)
Gas clouds clustered to eventually form "first stars" made only of hydrogen and helium. TMT will enable us to study star formation at the earliest Universe. Massive stars explode in millions of years, and disperse oxygen, iron and other elements.



3) 500-600 million years (redshift of up to 10)
Galaxies were born as collections of star clusters. ALMA succeeded in detecting a signal of oxygen in a galaxy formed during this period.



© Subaru Telescope

700-800 million years (redshift of up to 7)
Many galaxies emerged over time. The Universe entered the epoch of reionization. The Subaru Telescope discovered a large number of galaxies which were formed around this epoch.

The Subaru Telescope has contributed to the miraculous progress in mapping out the full picture on how structures including galaxies and galaxy clusters formed and evolved during the history of the Universe. The TMT Project will enable the dawn of the Universe seen today by the Subaru Telescope – the first page of the history of galaxies in the cosmos in which structures were formed in the early Universe – to be studied, and capture in detail the evidence of galaxy formation and growth of galaxies such as our own Milky Way galaxy in the 13 billion year history of the Universe.

Toru Yamada (Professor at ISAS/JAXA)

Maunakea and TMT

Maunakea is a 4000-m mountain with gently inclined slopes, isolated in the mid-Pacific Ocean from any other land mass, which makes the mountain one of the exceptionally well-endowed sites for astronomical observations in the world. The minimal cloud cover, atmospheric stability, cold and dry air, and other conditions are all met at the summit area of the mountain to perform the best observation. It is home to international telescopes, which continually conduct forefront astronomy research.

Maunakea is also a sacred place for the people of Hawaiʻi, connecting them to their *kūpuna* (ancestors) and *akua* (gods). It represents a symbol of the Hawaiʻi culture deeply rooted in nature.

A Native Hawaiian legend tells the sky father Wākea and earth mother Papa gave the first birth to the Island of Hawaiʻi, and then created the first *kānaka* or Hawaiian people, who were the ancestors of the Native Hawaiians. Also called Mauna a Wākea or the Mountain of Wākea, Maunakea is "*ka piko o ka moku*," which means the naval of the island that ties the Island of Hawaiʻi to Wākea. Specifically, it is symbolic of Native Hawaiian ties with the gods and ancestors.

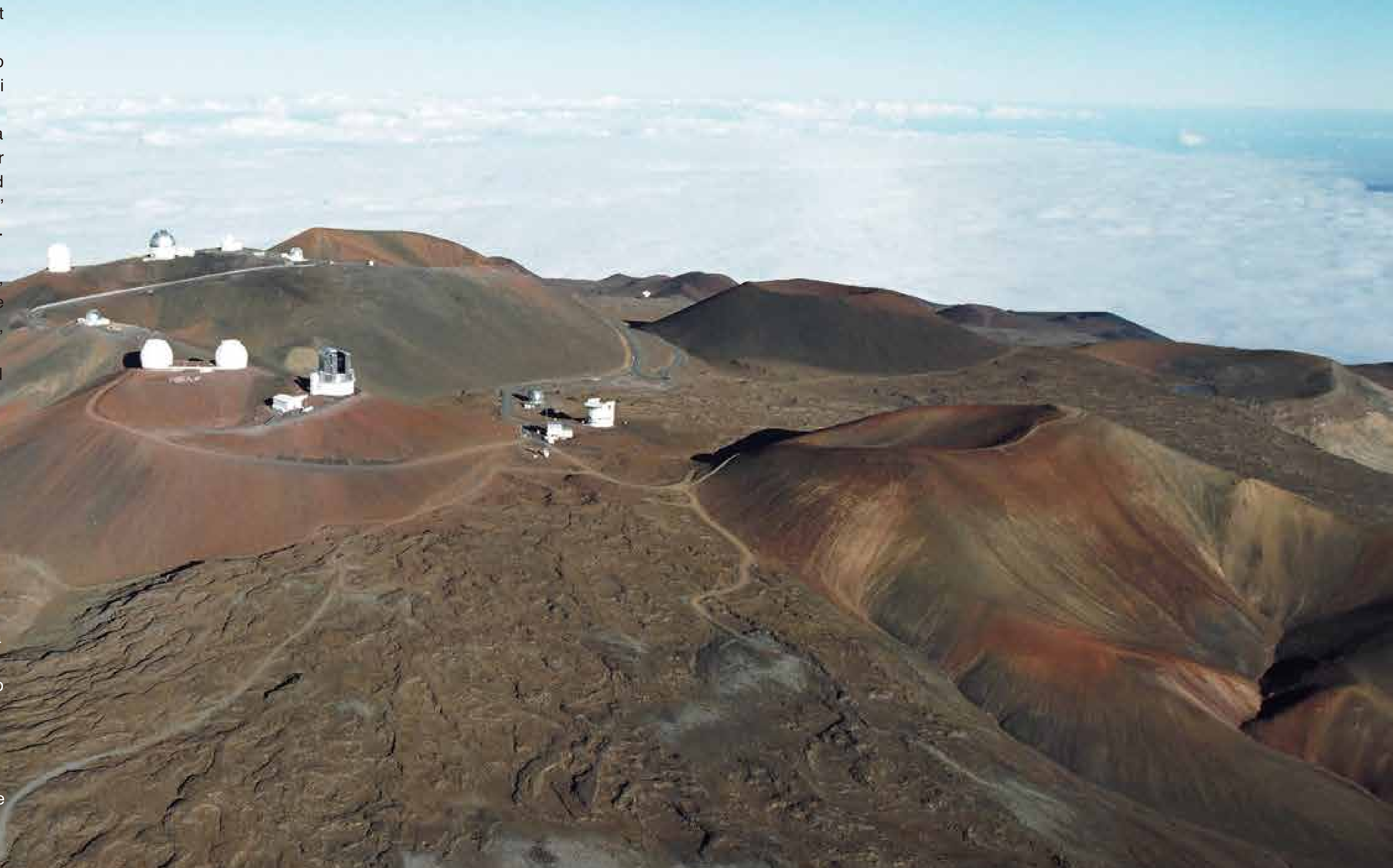
The upland area of Maunakea is traditionally considered to be the *wao akua*, the realm of the gods and spirits. The summit cluster of *puʻu* or cinder cones are named after the gods of the Native Hawaiians, such as Kūkahauʻula, Poliʻahu, Waiau, and Lilinoe.

We are committed to the TMT Project without impeding traditional and customary cultural practices of Hawaiʻi.

Environmental Considerations for Maunakea

The summit region of Maunakea is designated as the Science Reserve. The Comprehensive Management Plan was formulated in 2009 for conservation of the cultural and natural resources on Maunakea to evaluate impacts of telescope construction on many aspects, including existence of the natural and historical resources, the water resources and hydrology, and landscape. Based on this plan, we have taken great care to select a site that has no endangered flora or fauna and no known archaeological shrines or burial sites. Located on a lava plain below the summit, TMT will not be visible from culturally sensitive locations, such as the summit of Kūkahauʻula, Lake Waiau, and Puʻu Lilinoe. No waste from TMT will be left on the mountain. In addition, training programs are provided to all employees and contractors about protection of the cultural and natural resources on Maunakea.

TMT aims to become a model of sustainable astronomy by protecting invaluable resources on the mountain.



TMT is scheduled to be constructed at a location 4012 m in elevation and 1 km away from the Subaru Telescope.

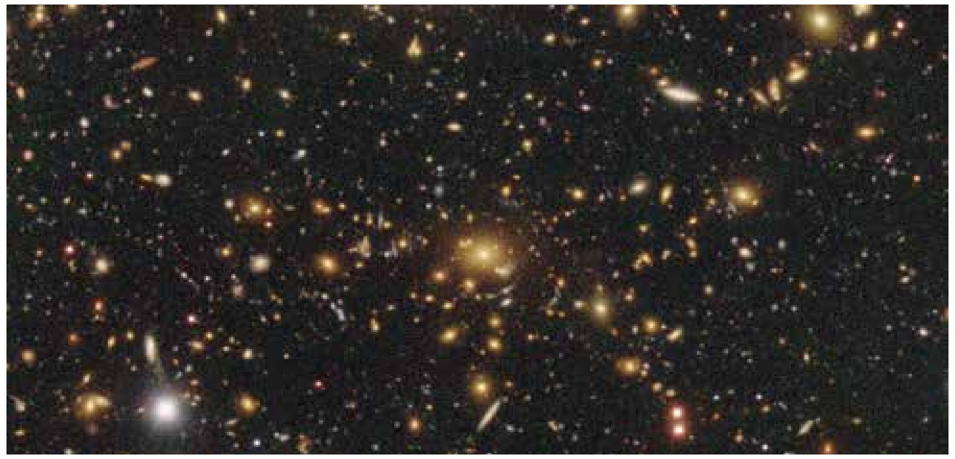
Located in the alpine desert region with the annual precipitation of less than 250 mm, the summit area looks empty of life at first glance, but it is home to mosses, lichens, algae, and more than 40 cold-adapted invertebrates such as the wēkiu bug. (Left: Wēkiu bug © Jesse Eiben, University of Hawaiʻi. Right: Lichen © C.W.Smith, University of Hawaiʻi)

With the recent imaging of the blackhole and its being named Pōwehi, there is a renewed interest in the connection between astronomy and Native Hawaiian culture. We are happy to be a partner with Maunakea telescopes including TMT to offer educational programming for our community that incorporates a cultural lens.

Kaʻiu Kimura (ʻImiloa Astronomy Center CEO)

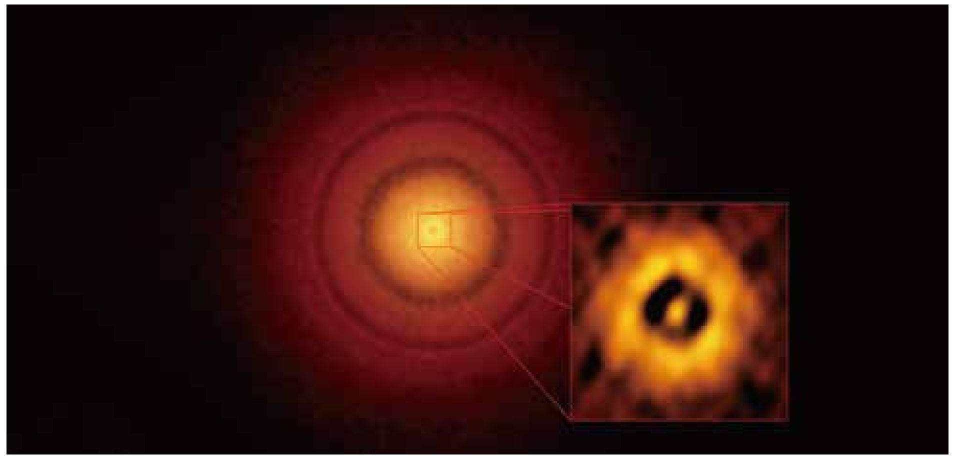
Cooperation with the Subaru Telescope and ALMA

The Subaru Telescope has particularly contributed to astronomical observations by taking advantage of its field-of-view that is exceptionally wide for large telescopes. This has been enabled by the Hyper Suprime-Cam (HSC), a ultra-wide-field camera mounted on the prime focus of the telescope. Prime Focus Spectrograph (PFS), currently under development, is a prime focus spectrometer that will allow for simultaneous spectroscopic observation of 2,400 astronomical objects on a vast patch of the sky. These instruments will keep the Subaru Telescope at the forefront of astronomy.
With the arrival of TMT, studies can be performed in which the Subaru Telescope is assigned to discover objects that are candidates for farthest galaxies, and TMT is assigned to make detailed investigation of their properties. This collaboration between TMT and the Subaru Telescope will support Japan in its effort to lead the world in astronomy.



Part of the image captured by HSC for deep space exploration. The data obtained by HSC is creating an unprecedentedly wide and sharp map of dark matter distribution.

NAOJ also plays an important role in the construction and operation of ALMA, the world's largest radio telescope in the Atacama Desert, Chile. ALMA has produced one epoch-making achievement after another, since the scientific observations started in 2011. Notably in the observations of extrasolar planets, ALMA has finely revealed dust disks around young stars. TMT will directly image planets forming in these dust disks by short-wave infrared observation with a similar resolution to that of ALMA.



Dust disk around TW Hydrae captured by ALMA
It clearly unveiled a series of layers of concentric rings of small dust particles around TW Hydrae, a young star at the age of about 10 million years. The two dark gaps are located 20 AU and 40 AU, respectively, from the central star, similar to the distances from the Sun to Uranus and Pluto. The inset image zooms in on the gap closest to the star that has the radius of 1 AU, which is at the same distance as Earth is from the Sun. It is suggested that planets are being formed in these gaps. TMT will attempt to focus on these planets that are coming into being.

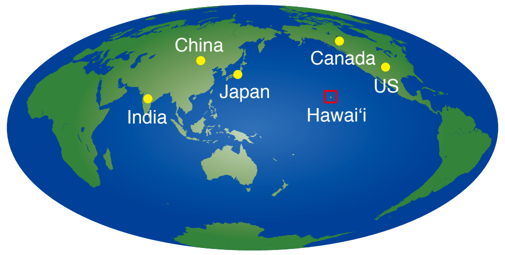
Using instruments like HSC and PFS, the Subaru Telescope will take an overall census of the cosmos to uncover the history of cosmic evolution as well as its fate. TMT is a perfect match for what is needed to study in further detail the objects discovered by the Subaru Telescope. I look forward to the collaborative work between the Subaru Telescope and TMT.

Hitoshi Murayama (University Professor, the University of Tokyo)

Collaborative International Construction Project

Collaboration of five countries

The TMT Project is participated by five countries: Japan, the U.S., Canada, China and India. The TMT International Observatory (TIO) was established in 2014 to manage construction, and commenced full-fledged development and construction. In addition to work of the telescope production shared by the participating countries and institutes, they also work in cooperation for examination of science goals of TMT, education of the next generation, and workforce development.

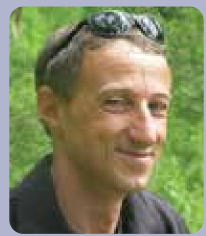


		Japan	US	US	Canda	China	India
Member Institute		National Institutes of Natural Sciences	National Science Foundation	California Institute of Technology	National Research Council (NRC)	National Astronomical Observatories	Dept. of Science and Technology
Decision-making Body	Board of Governors of TIO	National Astronomical Observatory of Japan	AURA	University of California	NRC/ACURA		India TMT Coordination Centre
Performing Institutions	TIO		NOAO		Herzberg Astrophysics		

TMT Project Organizational Chart. Construction is shared by all the members under TIO's oversight. National Institutes of Natural Sciences is a member representing Japan. TIO's Board of Governors, consisting of members' designated representatives, is responsible for determining the project's policy.
* AURA: Association of Universities for Research in Astronomy, NOAO: National Optical Astronomy Observatory, ACURA: Association of Canadian Universities for Research in Astronomy

Participants of the study group for developing the second-generation instrument MICHI (the Mid-Infrared Camera, High-disperser, and Integral field spectrograph). Second-generation instruments are currently being examined with incorporation of science goals pursued by researchers of the TIO members' countries and TMT's International Science Development Teams (ISDTs). Development of MICHI is spearheaded by Japan and the US, in collaboration with researchers in India, Canada, China, and other countries.

International workshop for early-career researchers and engineers who will be pillars of TMT's future. The workshop offers practical learning opportunities for each participant to think about and practice what are needed for a success of the extremely-large telescope project through collaboration of people with diverse cultural backgrounds, as well as to acquire expertise needed for participation in research and development of TMT. © ISEE



ISDTs were created as a kind of organizational structure for involving a broader segment of people in planning future science with TMT. There's lots of great science to be done with the telescopes we have, but there are certain things that you know a giant telescope will enable that are just impossible in any other way. And so I expect that scientifically, TMT will revolutionize many areas of astronomy.

Mark Dickinson (US National Optical Astronomy Observatory)

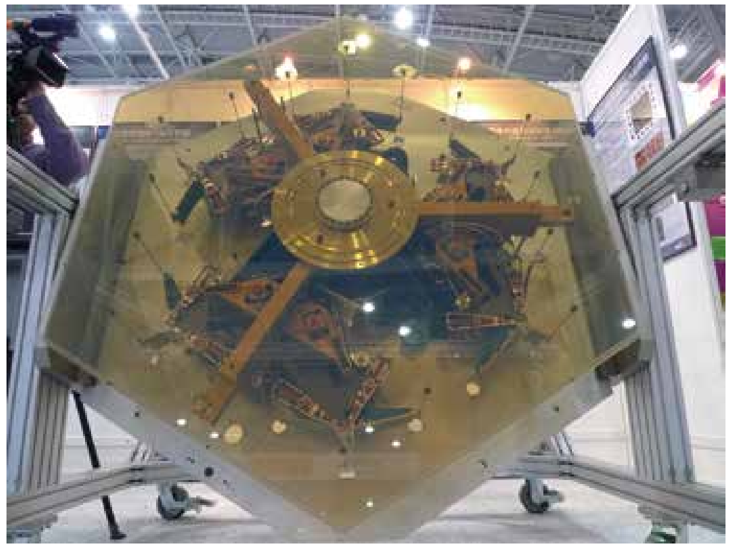
Japan's role in producion

TMT

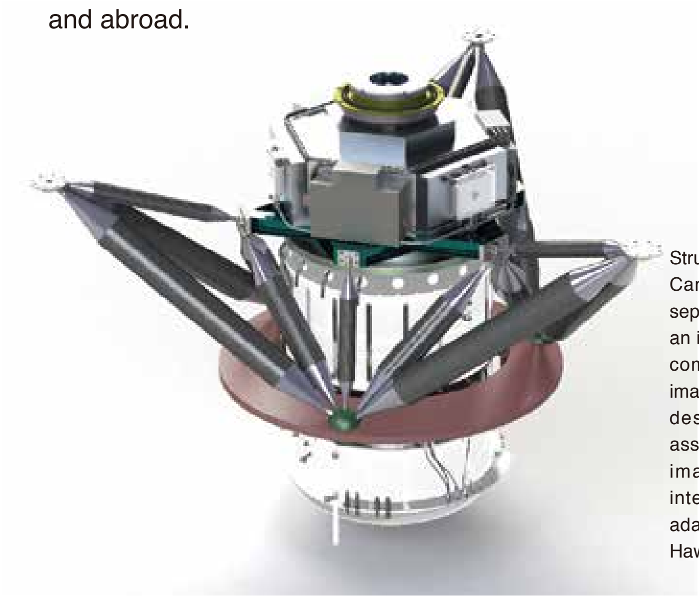
Japan's contributions

With Japan's contribution scheduled to amount to about a fifth of the TMT construction costs, NAOJ is responsible for executing the project. For its share of contribution, NAOJ is manufacturing some of the most important parts of TMT: design and manufacturing of the main telescope structure, and production of all blanks of the primary mirror (a total of 574 segments with replacements included) and polishing of 175 segments. It is also responsible for developing parts of the science instruments. Second-generation instruments are currently being planned in collaboration with universities and research institutes at home and abroad.

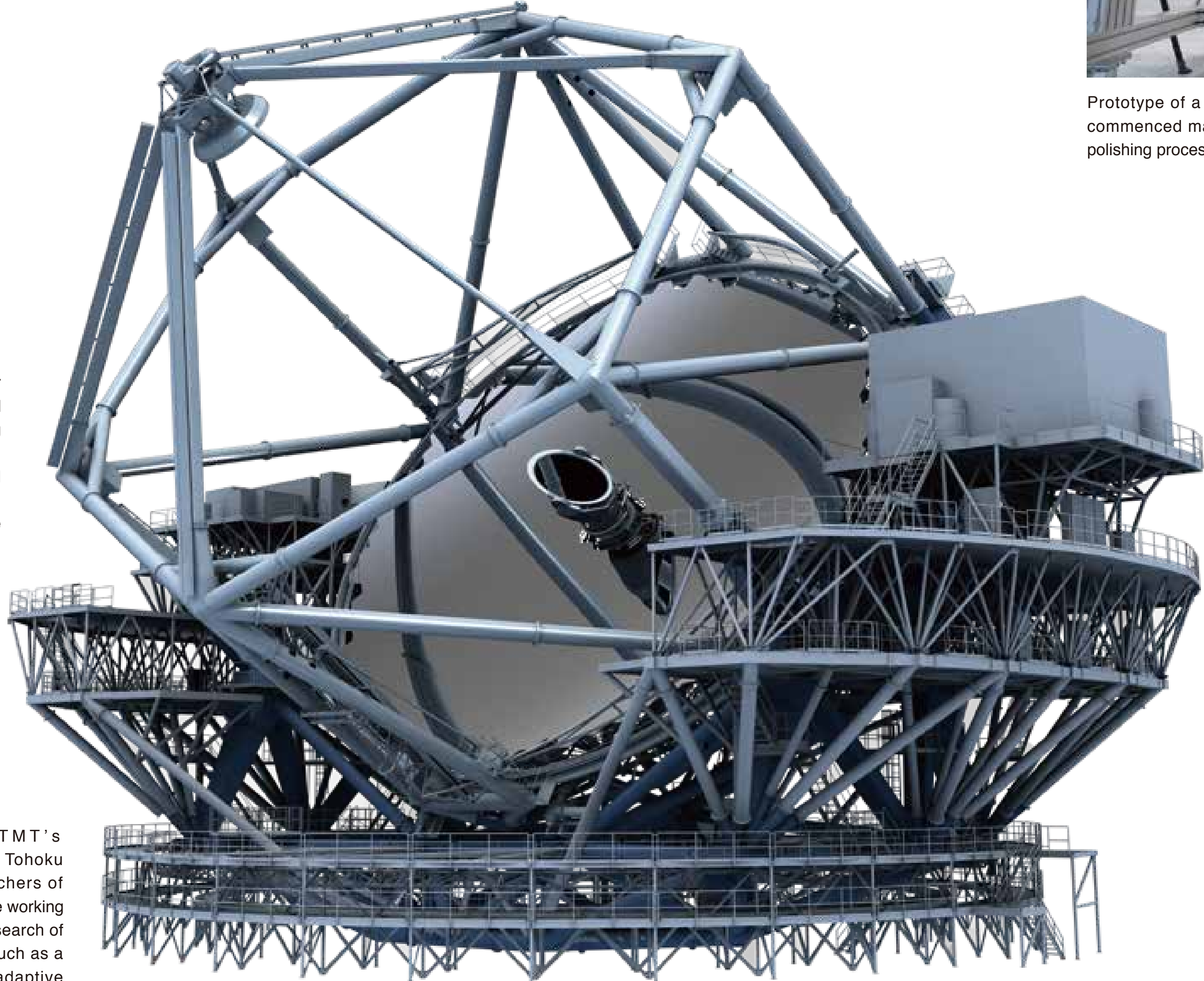
Mass-produced glass blanks for segments of the primary mirror. The segments are being made from Clearceram, a zero expansion glass, so that temperature change overnight will not cause the mirror's expansion or contraction. Segments to be polished overseas are shipped to the US, China, and India when spherically ground.
© NAOJ/OHARA



Prototype of a segment mirror of the primary mirror fabricated in Japan. Japan commenced mass production of mirror blanks in 2013, and started a full-fledged polishing process in 2015 prior to other TIO members.

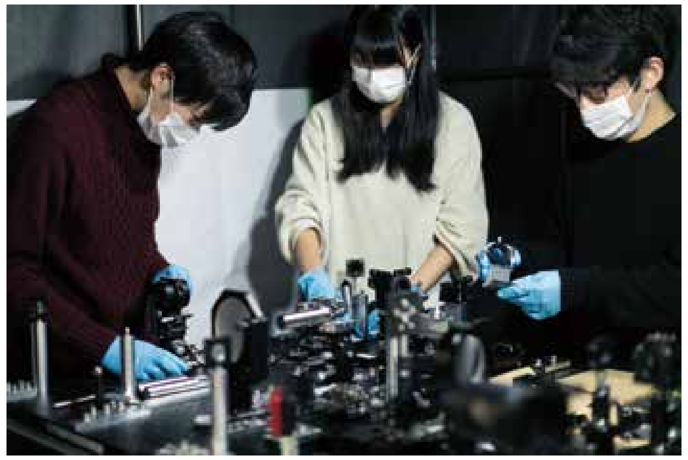


Structure of Infrared Image Spectrograph (IRIS). Canada, Japan and the US are developing IRIS for separate modules: wavefront sensors, an imager, and an integral field spectrograph, respectively. Following completion of the preliminary design phase of the imager in 2017, Japan is now proceeding with the final design. The modules are separately fabricated, assembled and go through performance review. The imager and the integral field spectroscopy are integrated for testing, and are then combined with adaptive optics for a trial to be ready for shipment to Hawai'i.

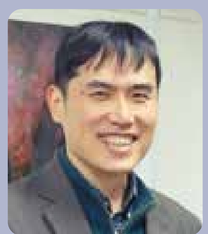


CG image of the telescope structure, whose detailed design was completed. With a proven track record of construction of the Subaru Telescope, Japan is in charge of designing the telescope structure and its accompanied facilities for the TMT Project. TMT has approximately 4 times the size of the Subaru Telescope's aperture, which means TMT's volume and weight would be 50 time larger than those of the Subaru Telescope if equally enlarged, but with efforts to make the telescope lightweight, TMT's structure will weigh about 5 times as much. As the large primary mirror will achieve higher spatial resolution, higher precision is required for TMT's tracking and direction than the Subaru Telescope.

Prototype of a segment-handling robot. In order to keep the highest reflectivity of TMT's primary mirror, 10 segments need to be replaced with recoated ones each day. To ensure swift, accurate, and safe replacement of segment mirrors, the segment-handling robot was devised as an ancillary apparatus.
© Mitsubishi Electric Corporation



Research and development of TMT's second-generation science instrument at Tohoku University's laboratory. In Japan, researchers of NAOJ, universities, and research institutes are working in concert for planning, development and research of potential second-generation instruments, such as a high dispersion spectrometer, wide-field adaptive optics, a mid-infrared instrument, and an exoplanet imaging instrument. NAOJ's Science Advisory Committee takes a lead in identifying science goals and requests of instrument specifications in Japan. (photo provided by Graduate School of Science, Tohoku University, photo: Kohei Shikama)



With an aim to bring about a second-generation instrument, we continue on a series of experiments on adaptive optics that will enable simultaneous detailed study of a great number of celestial objects. Utilizing this instrument, we will focus on figuring out what happened inside galaxies in the early Universe, and on revealing what they have gone through to become the present forms.

Masayuki Akiyama (Professor, Tohoku University)

TMT poses many technical challenges, but we leverage Japan's excellent technology to overcome them. In addition to the technological capabilities, its people's diligence is essential, and serves as a great asset in the project. You will see incredible science results that the forefront telescope TMT will bring, using various technologies.

Tomonori Usuda (Director of TMT-J Project, NAOJ)