Thirty Meter Telescope

Unraveling Mysteries of the Universe

MEGA SCIENCE PROJECTS
75 Years of S&T in India

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Indian astronomers and engineers have joined the International community to build the Thirty Meter Telescope (TMT), which will help Indian industry and science take a giant leap forward. Building TMT will answer some of the nuanced questions that still remain unanswered, like: Are we alone in the Universe? What is the nature of extra-solar planets? How did the first stars and galaxies form? What would be the fate of this accelerating Universe (the Dark-energy conundrum)?

A rendering of the TMT on Mauna Kea, Hawaii. Photo credits: TMT Observatory.

"The great advances in science usually result from new tools rather than from new doctrines"
- Freeman Dyson

WHEN the human minds marvelled at the beauty of the night sky, they started building tools to probe deeper into the Universe. The tools initially simple, over time have become more and more sophisticated and complicated to build. A simple optical telescope which Galileo Galilee used just needed two simple lenses; a simple Newtonian Telescope needed few mirrors and a lens, which could be produced by the efforts of one or two individuals. A modern day optical telescope and its back-end instruments need the collaborative efforts of many engineers and scientists. This process has not only enriched both science and technology but has also benefitted society in ways that were never envisaged.

Currently, telescopes are being built across the entire range of electromagnetic spectra, each region posing its own technological and scientific challenges. Near and Far Infrared instruments need advanced cryogenics, while radio and submillimeter instruments need to be protected from radio interferences produced by humans, large optical telescopes need darker skies with minimal atmospheric turbulence (which owing to other advances in human development have become far and few), and the list goes on. Building of these instruments, testing them, deploying them and using them is now a highly collaborative effort involving teams of scientists and engineers from multiple countries. The Thirty Meter Telescope and its back-end instruments, in which India is a partner is one such prodigious effort.

India's indigenously built largest optical telescope until now has been the 2.3 m Vainu Bappu Telescope at Kavalur, Tamil Nadu, and with international collaboration the 3.6 m Devasthal Optical Telescope at Devasthal, Uttarakhand established recently. However, across the world, efforts are on to build far larger telescopes like the 30 m telescope, 39 m European Extremely Large Telescope (ELT) and 25 m Giant Magellan Telescope (GMT). Realising this, Indian astronomers and engineers have now joined the International community to build the Thirty Meter Telescope (TMT), which will help Indian industry and science take a giant leap forward.

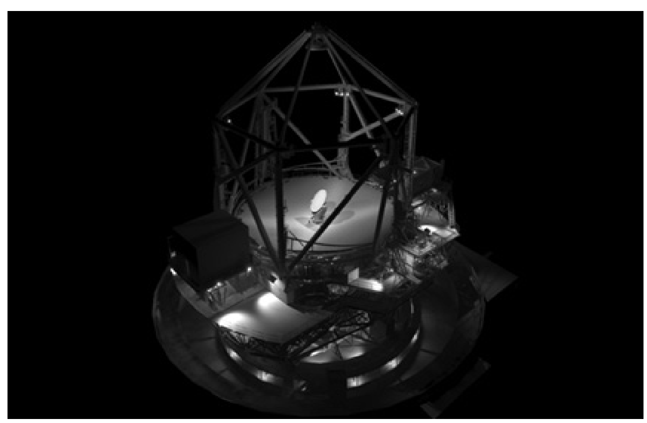
Building TMT will answer some of the nuanced questions that still remain unanswered, like: Are we alone in the Universe? What is the nature of extra-solar planets? How did the first stars and galaxies form? What would be the fate of this accelerating Universe (the Dark-energy conundrum)? These pertinent questions need better and larger telescopes and technology.

In this endeavour, India, Japan, China, Canada, and the University of California and Caltech in the US have come together to build the next generation's most versatile telescope, the TMT. India is a 10% partner in this project.

TMT will be a powerful Optical-Infrared astronomical observatory with a large primary mirror of diameter 30 m, having a light-collecting area of 664.2 sq m. It will collect light that is sensitive to the atmospheric windows in the wavelength range of 0.31-28 μm. The three prime technological capabilities of TMT that will shape the future of astronomy are 492 mirror segments that will act as one mirror of 30 m in diameter, precision control of each of these segments and Adaptive Optics (AO) technology.

The capability of a telescope is measured based on resolving power, light-gathering power and sensitivity which is defined as the minimum signal that a telescope can distinguish above the random background noise. The sensitivity of TMT will be 81 times better than the current largest ground-based telescopes. The Adaptive Optics (AO)-assisted capability enables TMT to resolve objects by a factor of three, better than the existing 10 m class telescopes and 12 times better than the Hubble Space Telescope (HST). TMT, with its AO capabilities, can resolve structures as small as 25 km at a distance of Jupiter. At the distance of the Moon, TMT can resolve structures that are as small as 13 m, while comfortably sitting on the Earth.

Some parts of the pertinent questions mentioned above, like the phenomenon of dark energy, discovering life elsewhere in the Universe, and exploration of exoplanets can be addressed with TMT. TMT along with its back-end instruments would take images and spectra of the farthest and faintest objects in the Universe. It would be able to directly image earth-sized extrasolar planets that are within the habitable zone of their parent star up to a distance of 457 lightyears or $4.3x10^{15}$ km from us. It is capable of detecting the presence of bio-markers like CO_2, H_2O, methane, carbonate-silicates, abiotic-O_2, etc. which are some of the signatures of life in these extra-solar planets. TMT along with its adaptive optics system would aid in discovering streams of things beyond our current imagination.



Picture shows the primary mirror, secondary mirror (on top), tertiary mirror (ellipsoid at the centre). Photo credits: TMT International Observatory.

Adaptive Optics Technology

The turbulence in the Earth's atmosphere is disadvantageous to astronomers as it blurs the image taken from the ground telescope. However, the Adaptive Optics (AO) technology has overcome this drawback using real-time calculations of the distorted wavefront, computer-controlled deformable mirrors that correct these distorted wavefronts and provide a sharp image as good as the one obtained from the sky. AO allows the astronomers to observe finer details of much fainter and farther astronomical objects which are otherwise impossible from the ground.

Powerful lasers are beamed into the Earth's upper atmosphere (90 km) which creates artificial star spots that can be used for distortion corrections. The AO facility of TMT is called NFIRAOS (Near Field InfraRed Adaptive Optics System) and uses both natural stars and laser guide stars for AO corrections. AO technology is applied only to the near-IR region; for the visible wavelength region, it is extremely complex to estimate and apply corrections in real-time.

Mirror Segments and Precision Control

The 30 m primary mirror, M1 as we call it, forms the heart of the telescope. It is a segmented mirror consisting of 492 hexagonal mirror segments each with a size of 1.44 m from edge-to-edge of the hexagon and 45 mm thick. The mirror segments are made from Clearceram glass, which is a zero coefficient of expansion glass. The goal is to produce all the M1 segments accurately, quickly and economically, achieved by a unique technique called Stress Mirror Polishing (SMP) that achieves surface accuracy of the mirror within 20 nm Peak-to-Valley and without any subsurface damage. This technology has been well tested and successfully implemented for the Keck telescope (which has 36 segments) by the University of California and Caltech, US (Lubliner 1980).

However, as the number of segments increases (in this case 492), the complexity in making them work cohesively increases manifold. The workshare of segment production is shared between the partners as shown in the Figure below. India will be producing 86 of the 492 segments at the newly built facility called ITOFF (India-TMT Optics Fabrication Facility), at one of the IIA campuses. The SMP polished mirror segment will then be sent to perform Ion-beam Figuring (IBF) for further etching and polishing reaching an accuracy of 2 nm Peak-to-Valley.

The primary Mirror Control System (M1CS) is responsible for maintaining the overall shape of the assembled mirror segments caused by temperature, gravity, disturbances from wind, seismic vibrations and vibrations that are observatory generated. The M1CS performs this task with the help of three major mechanical structures, namely, Segment Support Assembly (SSA), Actuators and Edge sensors, all working in a closed-loop. India is producing all the required numbers of Edge sensors, Actuators and SSAs for the TMT project.

Edge sensor is the most critical component in controlling the displacement of segments. It is a pair of glass piece, polished and coated with 0.5 μ micron gold over 0.05 μ chromium coating; consisting of a drive half mounted on one segment and the receiver half mounted on the neighbouring segment. Each sensor measures a combined change in the relative height of the two adjacent segments and in the dihedral angle between the two adjacent segments. The relative displacement, tip, and tilt of the segments measured by edge sensors would be relayed to the actuators. India will be producing all 3284 edge sensors for the TMT.

Actuators perform the precision correction for the segments' tip-tilt and piston errors measured by edge sensors. The precision actuator is designed to meet an RMS tracking error as small as 4.5 nm and is designed to meet a travel range of 5 mm. Each mirror segment will be driven by three actuators – altogether 1476 actuators are required to keep all the segments aligned. Prototyping of these soft actuators has

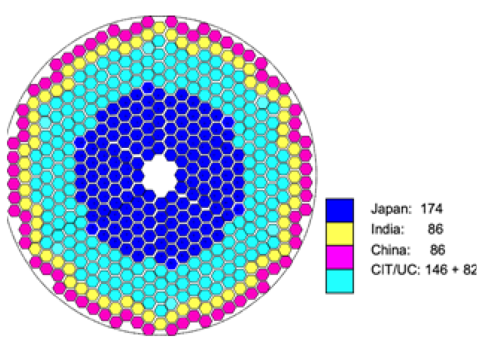
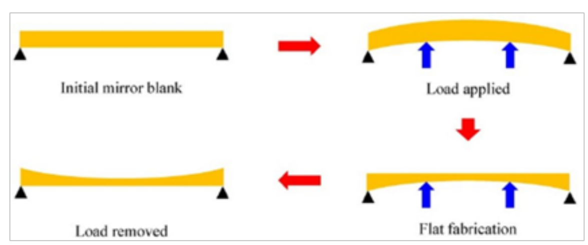
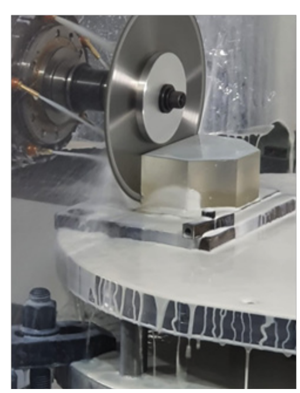


Figure shows the primary mirror segment arrangement. The yellow ring represents the 86 number of segments to be manufactured by ITCC at ITOFF. IIA building (below).





Schematic diagram shows steps involved in Stress Mirror Polishing. Photo shows polishing and Hex-cutting of a practice mirror blank — photocenterica, Bengaluru Credits: S. Sriram, IIA, ITCC been successfully achieved with Indian vendors. All 1476 actuators will be produced in India.

Each mirror segment is mounted on a support system called the Segment Support Assembly (SSA). Each segment requires one SSA and a total of 492 (+82 spares) SSAs completes the primary mirror control system along with edge sensors and actuators. SSA helps in releasing the stress on the mirror segment that occurs not only due to gravity, but also due to the weight of the mirror segment. Whiffletree arrangement spreads the load across the mirror segment in proper proportions to avoid any distortion in the shape of the segment which in turn would result in the degradation of the image quality of the telescope. India will be manufacturing all the 574 SSAs.

Designing Back-end Science Instruments

India is playing a significant role in design and construction of one of the back-end instruments, WFOS (Wide-field Optical Spectrograph). This multi-object spectrograph and imager are designed to operate in the near-UV, visible and near-IR (0.31-1μ) wavelengths. It is capable of performing multi-slit, multi-object spectroscopy of the faintest sources with multiplexing capabilities of 50-100 objects per observation. The spectrograph is split into two colour channels spanning 310-550 nm and 550-1100 nm passbands allowing for several observing modes (imaging, low to medium resolution) to cater to a wide variety of science scenarios. Some of the key subsystems that India is developing for WFOS are the grating exchange system, camera rotation system, filter exchanger, calibration system, electronics integration and the instrument control software. India also contributed to the end-to-en optical design analysis to study the performance of the instrument.

Developing Key Software Systems

India is responsible for developing and delivering some of the principal software systems for the TMT. These include the Observatory Software (OSW), Telescope Control Software (TCS), WFOS instrument controls and Data Management System (DMS). Common Software (CSW) forms the backbone of the software architecture that provides a publish-subscribe communication infrastructure between the principal components of the software system and is completely developed in India.

For AO-assisted science observations, a catalog of natural guide stars across the sky with their parameters to the required accuracy, in infrared, does not exist. Construction of such an Infra-red guide star catalog is also the main contribution from India to the TMT.

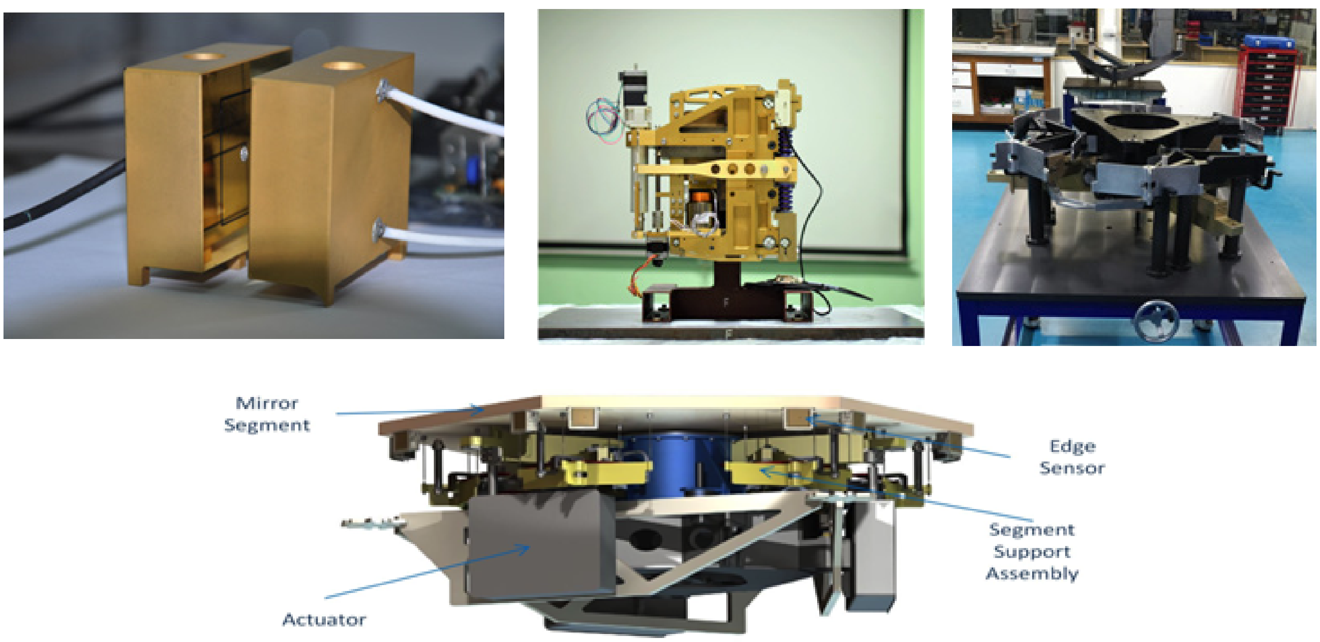


Figure shows a pair of edge sensor, actuator and SSA being assembled at the L&T, Coimbatore. Schematic of single mirror segment along with its support structure is also shown. Photo credits: Kamphues, F., TMT Observatory; Deshmukh, P., Kumar, K., ITCC

TMT is currently in the pre-construction or design phase and will enter into the construction phase in 2024-2025 and the project is expected to be completed by 2035. The most preferred site to build TMT is on the dormant volcano Mauna Kea, on the island of Hawaii, US. TMT observatory has also selected the Observatorio del Roque de Los Muchachos (ORM), in La Palma, on the Canary Islands (Spain) as an alternate site to build TMT. The experience gained in developing precision technologies, building instruments and managing large projects will be useful when India starts to build such projects of its own.