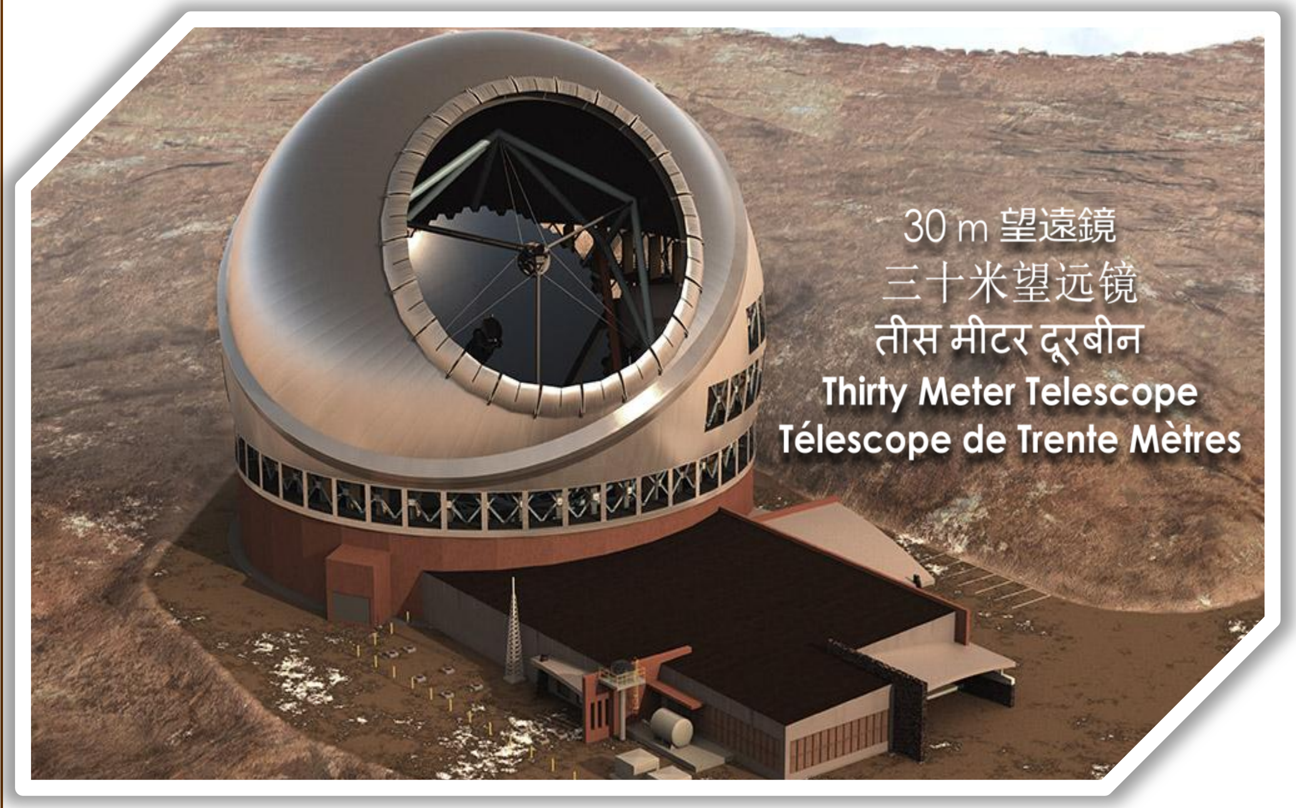
TMT THIRTY METER TELESCOPE

A New Window to the Universe



India TMT Digest

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सत्यमेव जयते
Department of Science and Technology
Ministry of Science and Technology
Government of India

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IUCAA

ITCC

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TMT Project Web Pages

Main Site
http://tmt.org/

TMT India
http://tmt.iiap.res.in/

TMT Canada
http://lot.astro.utoronto.ca/

TMT China
http://tmt.bao.ac.cn/

TMT Japan
http://tmt.mtk.nao.ac.jp/

The Background

Prior to Galileo Galilei, our view of the universe was largely constrained to the unaided vision of the eyes. A mere 3-inch telescope used by him in 1608 brought a revolution in astronomy. This simple but novel instrument revealed the vastness and grandeur of the night sky which hitherto was unknown to humanity. Large telescopes (up to 10 m diameter) built in the last 20 years have led to many fascinating and intriguing discoveries in astronomy. With the advancement in technology, a tremendous progress has been made in understanding several aspects of the observable Universe. Some of the notable findings in the last few decades include the discovery of planets around other stars, irrefutable evidence for accelerating universe, indirect clues of supermassive black holes in the center of many galaxies, powerful gamma ray bursts originating from the distant corners of the Universe, existence of dark matter and dark energy, detailed identification and monitoring of asteroids and comets that could pose a serious threat to the inhabitants of the Earth and many more.

Further advancement in astronomy would require giant telescopes to probe the Universe at a deeper scale, to unravel its formation and evolutionary history and discover the existence and possibility of life elsewhere in the Universe. The cutting edge optical and IR astronomy is expected to move from the present 8-10 m class telescopes (e.g., Keck: 10 m, Subaru and VLT: 8 m) to the ground-based Giant Segmented Mirror Telescopes (GSMTs) of diameters over 20 m, signifying the next major leap in this area of scientific pursuit. Building such mega facilities requires innovative ideas, new technologies and immense funds. These formidable requirements have forged collaborations between institutes and countries across the world, to pool financial and technical resources to build and operate the most ambitious observatories in the near future. Most notably, three international consortia, namely, the Giant Magellan Telescope (GMT) with an aperture of 24.5 m diameter, the Thirty Meter Telescope (TMT) with an aperture of 30 m diameter, and the European Extremely Large Telescope (E-ELT) with an aperture of 39 m diameter, have been formed to build and operate the next generation mega optical and near-infrared telescopes. All three projects are scheduled for commissioning by the end of this decade.

India has already developed a world class observing facility at radio wavelengths –the Giant Metre-wave Radio Telescope (GMRT) and will soon launch a dedicated astronomy satellite –the ASTROSAT, with multi-wavelength capabilities in the X-ray and UV domain. However, we lack a similar powerful facility in the optical and infrared domain. Presently, we have three 2 m class optical-IR telescopes and a 3.6 m telescope to be commissioned sometime in 2013. Though Indian astronomers have been using many of the existing 8-10m class international facilities, such usage has so far been limited to either individual efforts or - less frequently - to institute-level collaborations.

India TMT

India's participation in international projects was envisaged in the Astronomy and Astrophysics '*Decadal Vision Document 2004*' sponsored by the Indian Academy of Sciences and the Astronomical Society of India. In this backdrop, when the three international consortia for mega telescope projects (GMT, TMT and E-ELT) approached astronomy institutes in the country for India's participation, the astronomy community after due diligence and thorough deliberations, arrived at the conclusion that TMT presents the best options for India and participation in the project at a 10% level would be optimal.

FIGURE 1: THE ARTISTIC RENDITION OF THE TMT OBSERVATORY PLANNED FOR CONSTRUCTION AT MAUNA KEA IN HAWAII

The Department of Science and Technology (DST) reviewed the proposal and approved observer status for India in the TMT project in June 2010. Since then, India has been participating in all the policy decisions and development activities of the project.

The Aryabhatta Research Institute for Observational Sciences (ARIES), Nainital; the Indian Institute of Astrophysics (IIA), Bangalore; and the Inter-University Center for Astronomy and Astrophysics (IUCAA), Pune; are the three main institutes spearheading the efforts. The activities of TMT-India will be coordinated by the India TMT Coordination Center (ITCC) set up by the Department of Science and Technology. The IIA is the nodal agency of ITCC. India TMT will be jointly funded by the Department of Science and Technology and Department of Atomic Energy, Government of India.

Overview of TMT Observatory

The Thirty Meter Telescope (TMT) will be the world's most advanced ground-based observatory that will operate in optical and mid-infrared wavelengths. It will be equipped with the latest innovations in precision control, phased array of mirror segments and laser guide star assisted adaptive optics system. At the heart of the telescope is the segmented mirror, made up of 492 individual hexagonal segments, each 1.44 m in size. Precisely aligned, these segments will work as a single reflective surface of 30 m diameter.

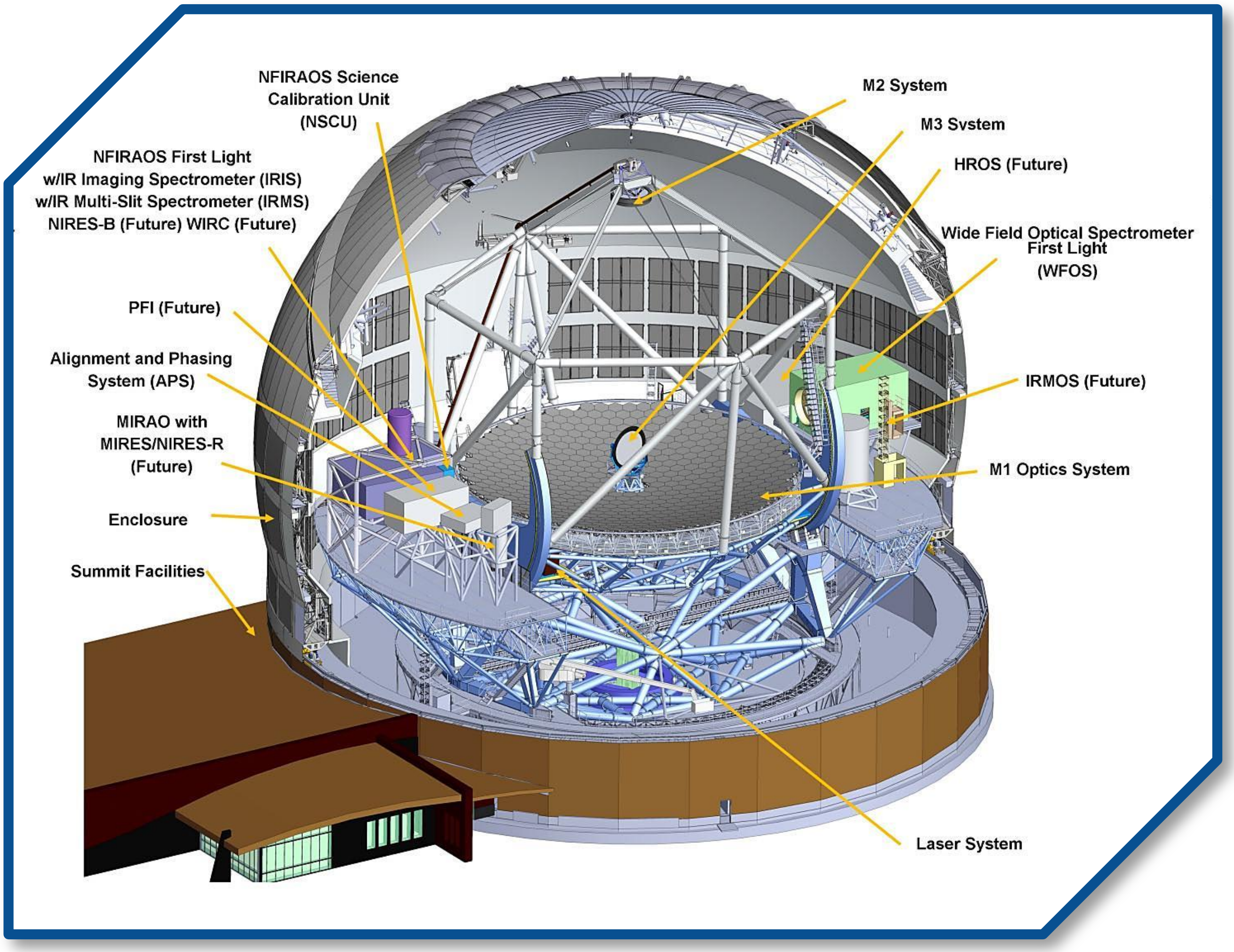


FIGURE 2: TMT OBSERVATORY DESIGN SHOWING THE TELESCOPE STRUCTURE, OPTICS AND HOST OF SCIENCE INSTRUMENTS

TMT will be located just below the summit of Mauna Kea on the Big Island of Hawaii, at an elevation of 4,050 m.

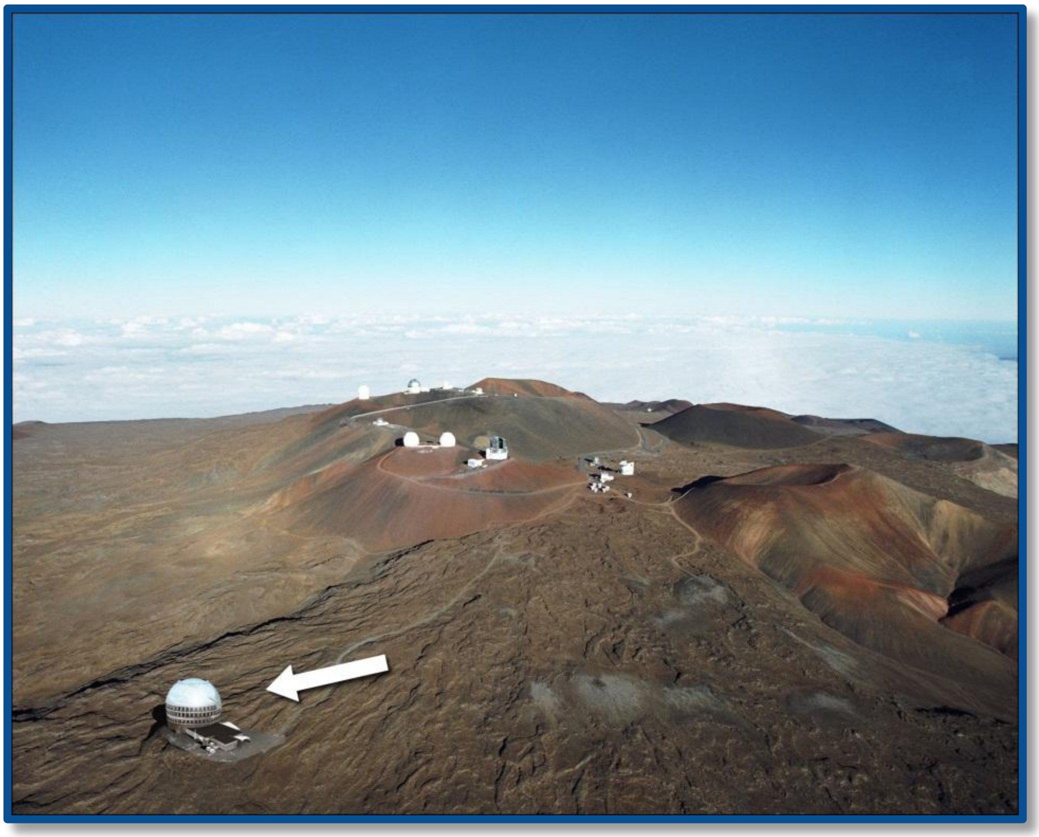


FIGURE 3: AN ARTIST'S CONCEPT OF PROPOSED TMT OBSERVATORY SITE AT MAUNA KEA

AO is a technology driven solution to compensate the degrading effect of the atmosphere. The fundamental goal of any AO system is to improve the telescope performance from seeing limited, meaning the image quality is limited by the atmosphere above the telescope, toward the diffraction limited, meaning images as sharp as those that could be obtained with the same diameter telescope located in space. Even in the seeing limited mode, the large light gathering capacity of the TMT will yield an order of magnitude improvement over existing observatories. The Narrow Field Infrared Adaptive Optics System (NFIRAOS) is the TMT's adaptive optics system for infrared instruments.

The unprecedented light gathering capability and angular resolution of TMT will shed new light on many unsolved and challenging problems in astronomy and astrophysics. Most importantly, several unanticipated and fundamental discoveries made by TMT will help shape the course of future research in astronomy. In short, TMT will be a leading new generation telescope posited to serve the world-wide astronomy community as a flagship research facility.

Science Impact

TMT has a collecting area of 650 m^2 and will observe through the atmospheric windows from Ultraviolet to mid-infrared wavelengths. The large collecting area makes TMT 81 times more sensitive (sensitivity is a measure of the minimum signal that a telescope can distinguish above the random background noise) than the current largest ground based (10 m class) telescopes. The AO capability enables TMT to resolve objects by a factor of 3 better than the 10 m class telescopes and 12 times better than the Hubble Space Telescope.

Telescope	Aperture (meters)	Angular resolution in arcsec at 1 micron (Diffraction limited)	Relative Sensitivity
HST	2.4	0.086	4.1×10^{-5}
JWST	6.5	0.032	2.2×10^{-3}
Keck	10	0.021	12.3×10^{-3}
TMT	30	0.007	1.0

TABLE 1: PERFORMANCE COMPARISON OF TMT WITH EXISTING TELESCOPES

The 20 arcmin diameter field of view facilitates the deployment of wide-field imagers and multi-object spectrographs. These capabilities will enable ground breaking advances in a wide range of scientific areas starting from our own Solar system to the most distant parts of the Universe. Some of the high impact science cases are discussed in the following.

Birth of the First Stars and the Formation of the Earliest Galaxies

Based on our current understanding, the Universe began 13.7 billion years ago in a rapidly expanding burst of matter and energy. We see the imprints of that event today as cosmic microwave background. As the Universe continued to expand and cool, matter began to collapse under gravity, eventually forming its first stars. The TMT will be able to look farther back in time than is currently possible, to search for first star clusters and primordial galaxies.

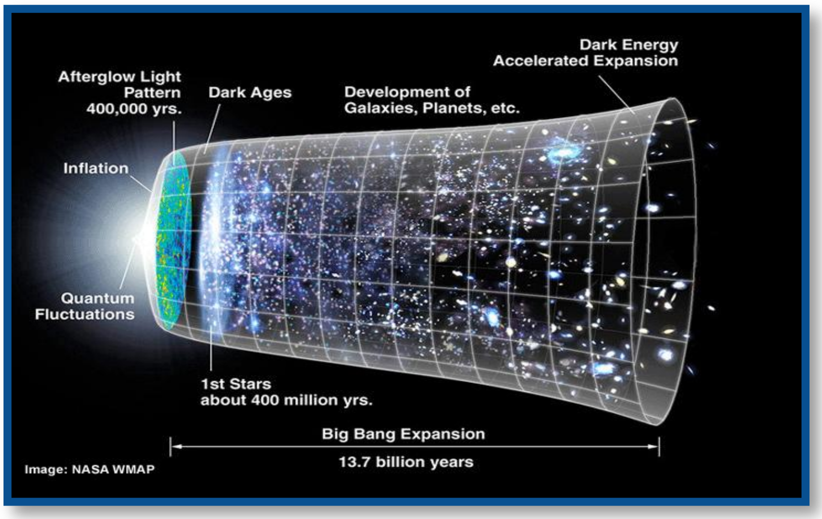


FIGURE 4: EXPANSION OF THE UNIVERSE AFTER THE BIG-BANG

Nature and Composition of the Universe

Normal matter – baryons that constitute stars, planets and life- makes up only a small fraction of the Universe. Much more plentiful is dark matter, matter that neither emits nor reflects light, but interacts gravitationally. The vast majority of space however is made up of dark energy, a mysterious repulsive force that is responsible for the accelerated expansion of the Universe. Study of distribution of distant stars and galaxies using TMT is expected to unravel the nature of dark matter and dark energy.

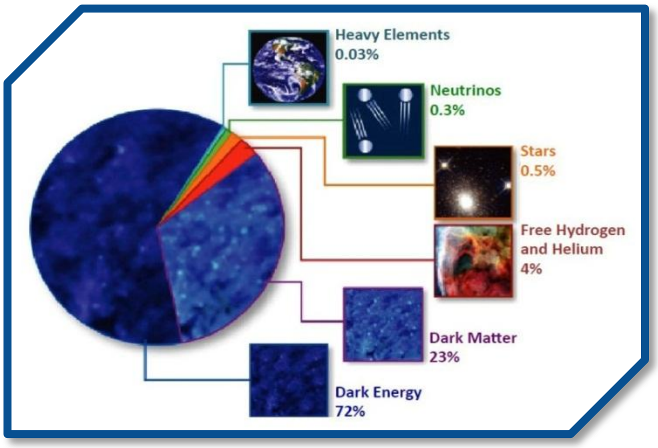


FIGURE 5: COMPOSITION OF THE UNIVERSE

Relationship between Black Holes and Galaxies

At the center of our Milky Way Galaxy, and perhaps inside every large galaxy, lurks a super-massive black hole- an infinitely dense point that can wrap space, trap light and stretch time. The TMT will have the resolution and instrument capabilities to map the motion of gas and stars at the centers of nearby galaxies which will help to detect and understand the effect of black hole in the evolution of galaxies.

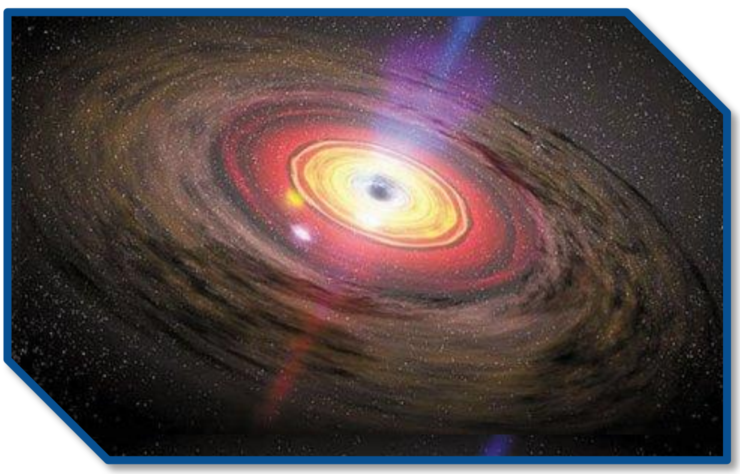


FIGURE 6: ARTIST'S IMPRESSION OF A SUPERMASSIVE BLACK HOLE AT A GALAXY CENTRE

Study of the Milky Way

Understanding the different structures of our Milky Way galaxy - their origins and dynamics, is one of the fundamental questions in astronomy. With its capabilities, TMT will provide a wealth of information about of our own Galaxy.

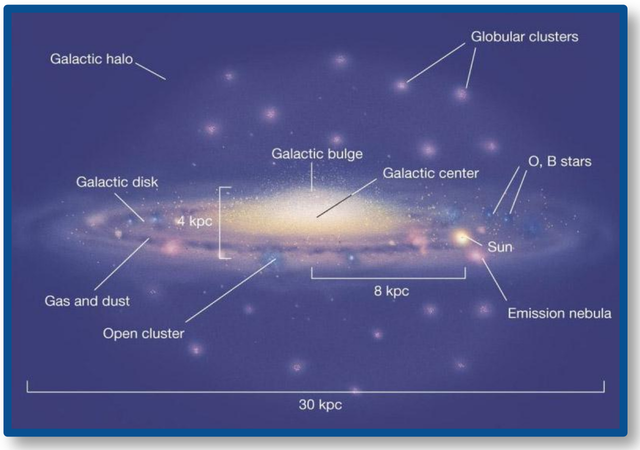


FIGURE 7: A 3-D MAP OF THE STRUCTURE OF THE MILKY WAY

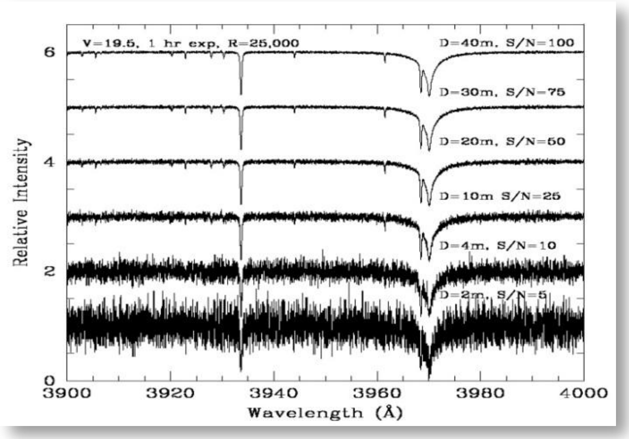


FIGURE 8: SIMULATED SPECTRA SHOWING THE S/N THAT IS ACHIEVED FOR A STAR OF V=19.5 MAG, WITH TELESCOPES OF DIFFERENT SIZES AT A RESOLUTION OF R=25,000 AND EXPOSURE TIME OF 60 MIN, FOR A METAL POOR STAR IN THE GALACTIC HALO (Figure: Gajendra Pandey)

Formation of Stars and Planets

Deep within towering clouds of dust and gas, pockets of higher density collapse to form swirling disks, which are destined to become new stars. Leftover debris around these stars collides and combines to build up rocky objects. The largest of these become planets, gathering up the remaining gas and dust as they orbit. TMT's infrared mission will peer into these dusty areas, revealing new solar systems in the making, helping us better understand how our own world was formed 4.6 billion years ago.

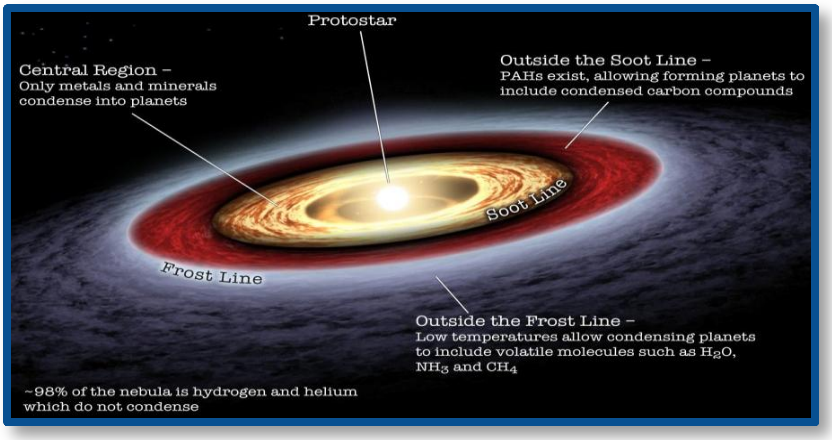


FIGURE 9: PICTORIAL DEPICTION OF STAR FORMATION PROCESS IN THE INTERSTELLAR MEDIUM

Extra Solar Planets and Search for Life in the Universe

The first planet around another star was discovered in 1995. Since then, the number of exoplanets discovered by space and ground telescopes has crossed 1,000. With its excellent sensitivity and angular resolution, TMT will be capable of directly imaging the reflected stellar light from planets that are at a distance of 1 AU from the parent star within a distance of 140 pc. Analysis of the reflected stellar light through exoplanet atmospheres will reveal the chemical composition of exoplanetary atmospheres, including bio-markers such as oxygen and water molecules.

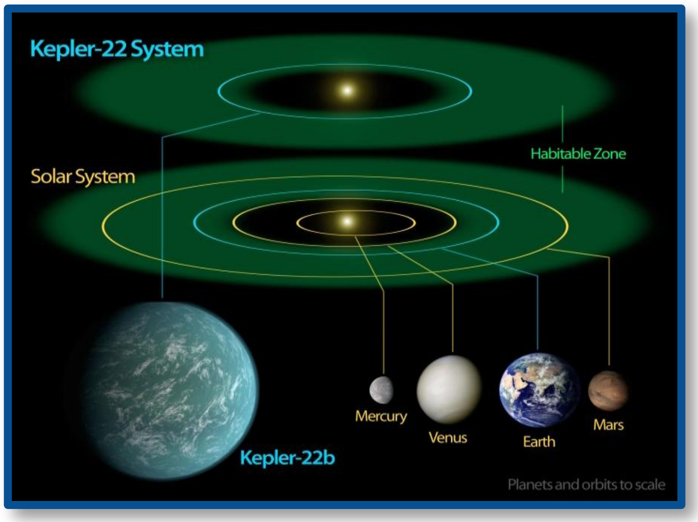


FIGURE 10: A RECENT DISCOVERY OF AN EXO-PLANET FOUND WITHIN THE HABITABLE ZONE OF KEPLER-22 SYSTEM

Our Solar System

Our own Solar System is the planetary system that we can study in more detail with the capabilities of TMT, and provide a reference for studies of exoplanets. TMT's resolution will facilitate the direct observations of objects as small as 25 km at the distance of Jupiter (5 AU). With that TMT will contribute greatly to our knowledge, particularly of the planets, satellites and small bodies of our solar system.

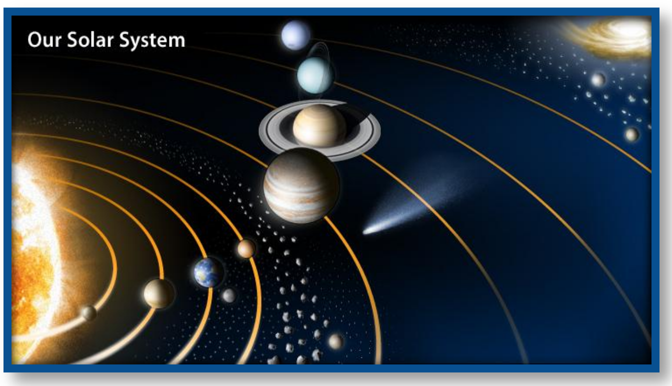


FIGURE 11: A VIEW OF OUR SOLAR SYSTEM (NOT TO SCALE)

Science Synergies

Synergy with the current and upcoming ground/space based observing facilities of India is an important aspect of the TMT.

The TIFR GMRT Sky Survey (TGSS) is an ongoing sky survey with the GMRT. The newly identified sources in TGSS require follow up in shorter wavelengths and a good fraction of them will be beyond the reach of current 8-10 m class telescopes. TMT's sky coverage is similar to that of GMRT, providing imaging and spectroscopic data at shorter wavelength and higher spatial resolution than currently possible.

FIGURE 12: THE GIANT METERWAVE RADIO TELESCOPE NEAR PUNE

India is also participating in the upcoming world's largest and most sensitive radio telescope project, called the Square Kilometer Array (SKA). More than 50% of the SKA identified sources may require follow up with TMT. India will be soon launching its astronomy dedicated satellite, ASTROSAT. TMT will be able to do the sensitive spectroscopy required to classify and characterize the newly discovered transients by ASTROSAT.

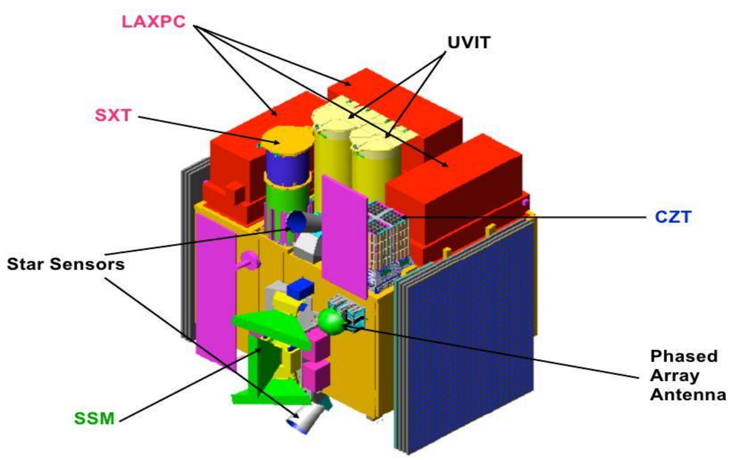


FIGURE 13: DIFFERENT ASTRONOMY MODULES ON THE UPCOMING ASTROSAT PAYLOAD

Project Status and Partners

The TMT project is in the process of obtaining the relevant licenses, permits, and sublease from the State of Hawaii and from the University of Hawaii. With the completion of the Design Development Phase (DDP) of the TMT Project on March, 2009, the TMT Project entered its Pre-construction Phase in April 2009 and plans to initiate the Construction Phase in April, 2014. The construction phase is expected to be completed in 2022 and this will be followed by an operations phase of at least twenty years as per the proposed agreement.

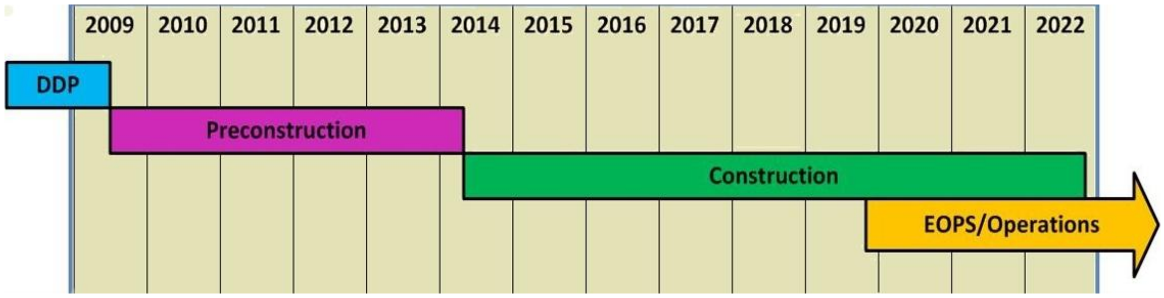


FIGURE 14: PROJECT TIMELINE SHOWING DDP, PRE-CONSTRUCTION, CONSTRUCTION AND EARLY PHASE OPERATIONS

The most critical path in the schedule starts with the on-site work (civil construction activities, the erection of the enclosure and the telescope structure at the summit) and concludes with the assembly, integration and verification (AIV) of all remaining systems at the observatory. The TMT project is an international partnership involving India, the USA, Canada, Japan and China.

India's Role

Participation in the TMT will provide Indian astronomers an opportunity to carry out frontline research in astronomy. Another major reason to participate in this scientific endeavour is to bring home some of the much needed high-end technology in this field through international collaboration.

The primary mirror of the TMT has an aperture diameter of 30 m, consisting of 492 individual 1.44 m hexagonal segments. The main challenge is to maintain the final wavefront at the focal plane as though formed by a single monolithic 30 m diameter mirror. This involves developing a host of new technologies in mechanics, electronics,optics and control software. India chose, with the aim of acquiring key technologies, to provide a portion of the 492 segments and the complete segment support system consisting of ~ 1,500 actuators and ~ 3,000 edge sensors. A major part of the observatory control software would also be a part of India's contribution.

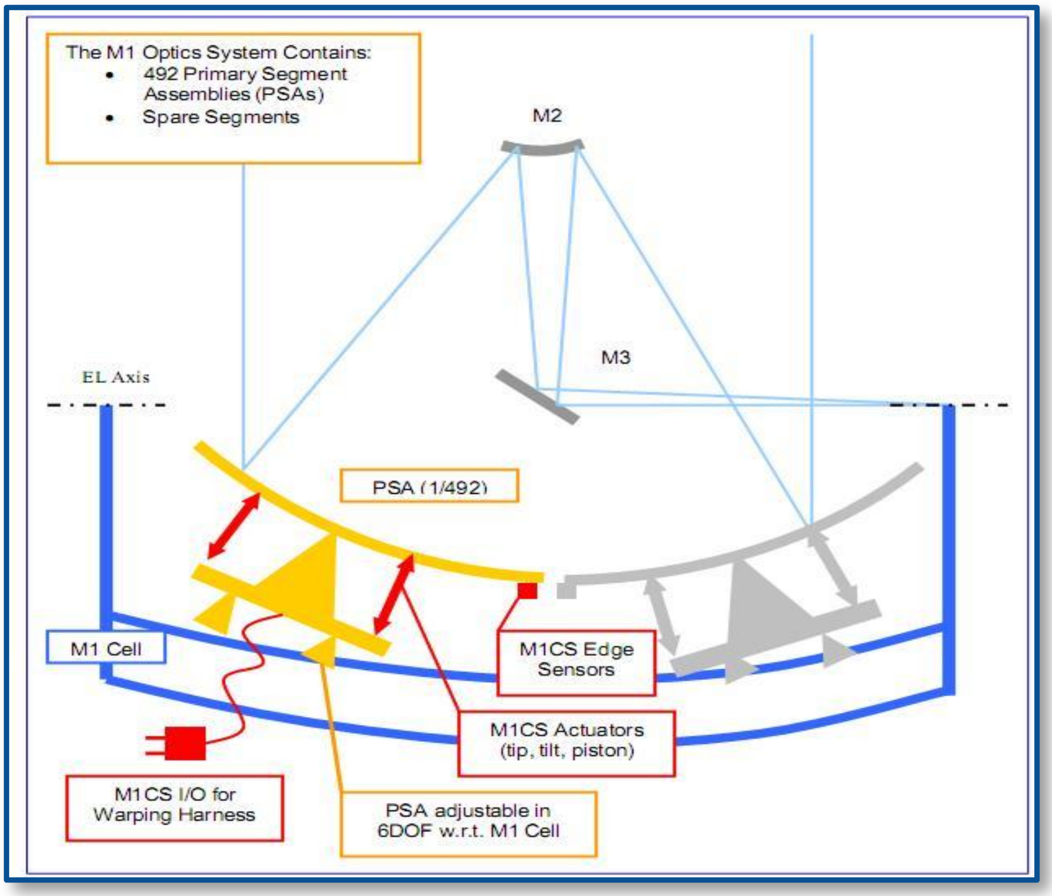


FIGURE 15: OPTICAL LAYOUT OF THE TELESCOPE SHOWING DETAILS OF INDIA'S CONTRIBUTION - THE PRIMARY MIRROR CONTROL SYSTEM

Edge Sensors: **Edge sensors are an important component of the TMT. They measure the relative displacement, tip and tilt of the segments. Each segmented mirror will have 12 edge sensors and in total 3,234 sensors for entire M1. The work to produce 25 prototype sensors has already been initiated by TMT-India at General Optics Asia Limited (GOAL) Puducherry.**

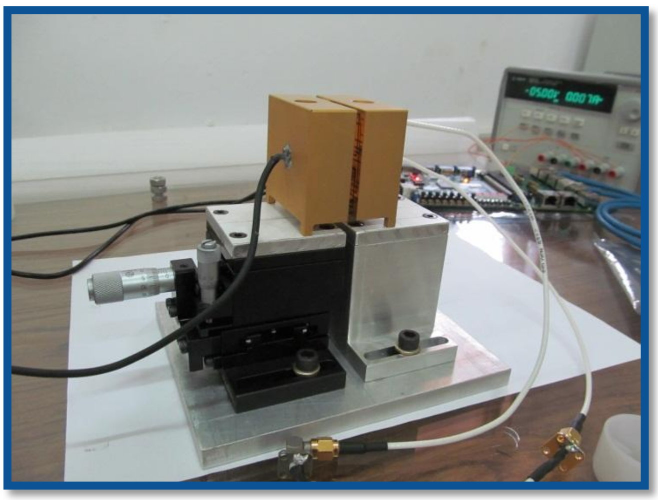


FIGURE 16: CALIBRATION AND TESTING OF THE EDGE SENSORS AT ITCC LABORATORY

Actuators: In order to achieve very high spatial resolution as well as sensitivity, all the 492 hexagonal mirror segments of the TMT must be precisely positioned with respect to each other to form a 30-meter hyperboloid primary mirror. The M1 control system (M1CS) performs this task, with the help of actuators that correct for the segments' tip-tilt and piston errors measured by edge sensors. Each mirror segment will be driven by three actuators and altogether 1,476 actuators are required to keep all the segments aligned. 10 such prototype actuators are under manufacture at Avasarala Technologies Limited (ATL), Bangalore.

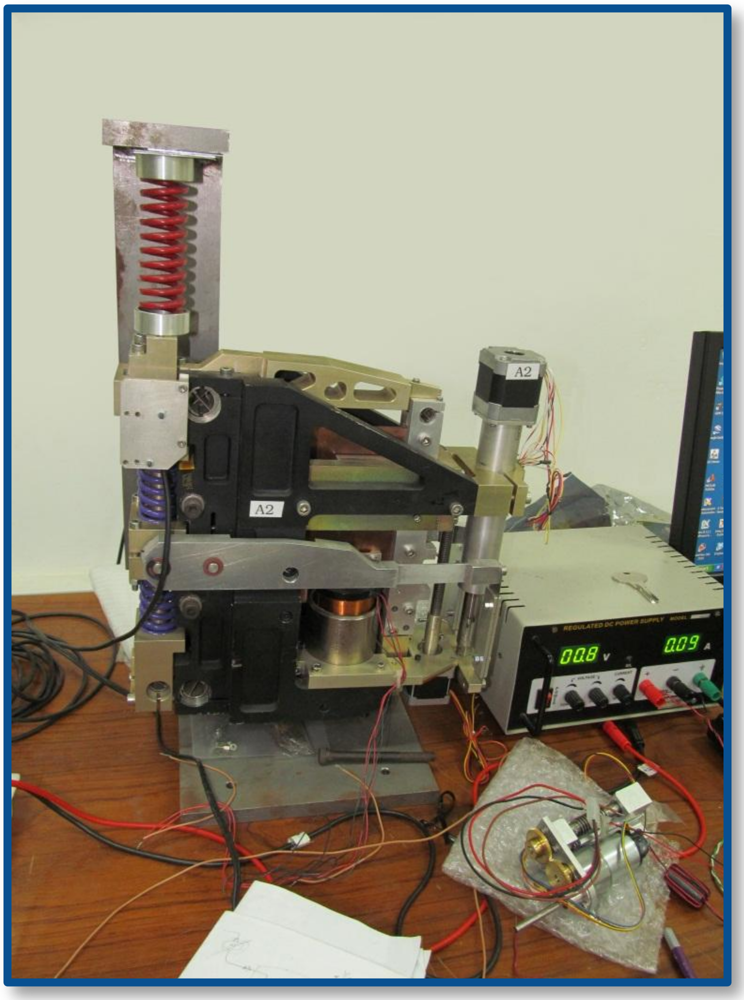


FIGURE 17: A TMT ACTUATOR BEING TESTED AT ITCC LABORATORY

Segment Polishing: Providing primary mirror segments to the TMT is one of the major goals of India-TMT. As a first step towards this, India has to demonstrate segment polishing capability either using Stress Mirror Polishing (SMP) technique or CNC approach.

Segment Support Assemblies (SSAs): **Each mirror segment will be mounted on a Segment Support Assembly (SSA). Each SSA is tuned for a specific type of segment, so there will be 82 types of SSAs. Each mirror segment requires an SSA that has several sub-components that are to be manufactured separately and integrated.**

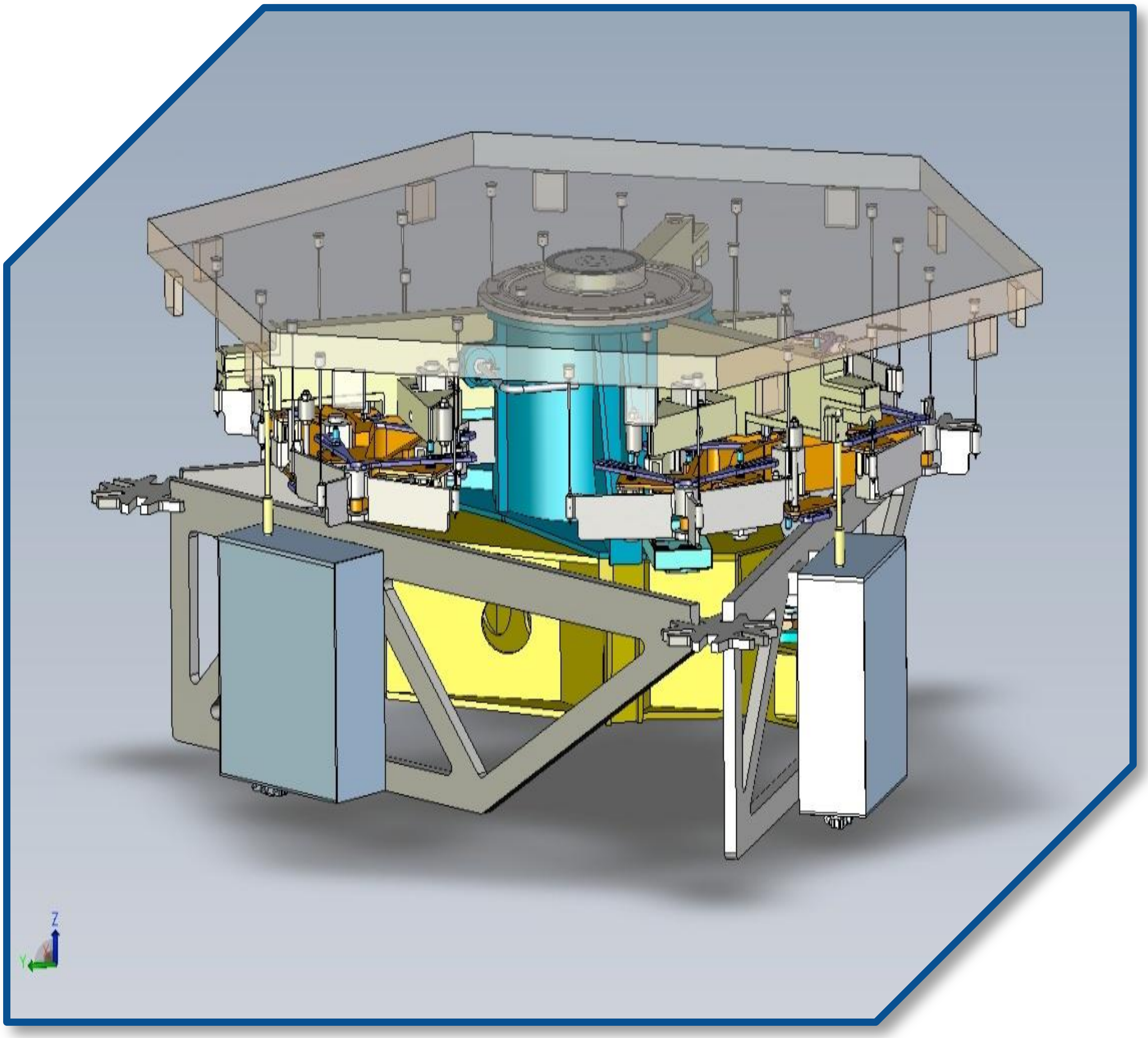


FIGURE 18: MECHANICAL DESIGN OF SEGMENT SUPPORT ASSEMBLY (SSA)

Initiatives in ITCC Laboratory,: A laboratory to facilitate TMT related research and development activities has been set up by the India TMT Coordination Center (ITCC) within the campus of IIA, Bangalore. Assembly, testing and calibration of various sub-systems being developed in India will be carried out in this laboratory. The TMT observatory control software consists of a set of software components that control the operations of the telescope, the mirrors, the telescope dome or enclosure, and the various instruments. India is responsible for the Observatory Software (OSW), Data Management System (DMS) Image and Object Catalogs (CAT).

Observatory Control Software: The TMT observatory control software consists of a set of software components that control the operations of the telescope, the mirrors, the telescope dome or enclosure, and the various instruments. India is responsible for the Observatory Software (OSW).

- **Event Services**: Event Service is a software-only product that provides a high-performance publish and subscribe messaging infrastructure between the different software components. Efforts to identify the software and an implementation scheme are underway.

- **Generation of Infrared Guide Star Catalog:** TMT instruments operating in the infrared wavelength regime will be supported with AO system. In addition to the laser guide stars, the observations with AO system also require natural guide stars. A catalog of guide stars with their parameters to the required accuracy should be available before the operation of TMT begins. Currently such a catalog in infrared does not exist. Institutes in India are involved in the generation of this catalog. The initial phase of this process is completed and the next phase has started.

TMT International Observatory Organization

TMT International Observatory Organisation (TIO) will be governed by a Board of Governors represented by up to three members from each of the partner institution or the country representing partner's financial, institutional and scientific interests. The Board of Governors shall have authority over the affairs of TIO such as determination and prioritization of scientific objectives and technical capabilities of the Observatory, approval of project agreements and work packages, appointment of the Executive Director, the Project Manager and the Observatory Director.

The Executive Director will have oversight responsibility during the construction phase with respect to the TMT Project Office. He will directly report to the Governing Body. The Project Mangers is the overall in-charge of the Project Office and oversees the design, development and construction of the TMT project. He will have oversight responsibility with respect to the performance of the partners’ obligations during the construction. Once the project construction is completed the Observatory Director will be in-charge of the day-to-day operations of the Observatory.

TMT Partnership Governance Structure

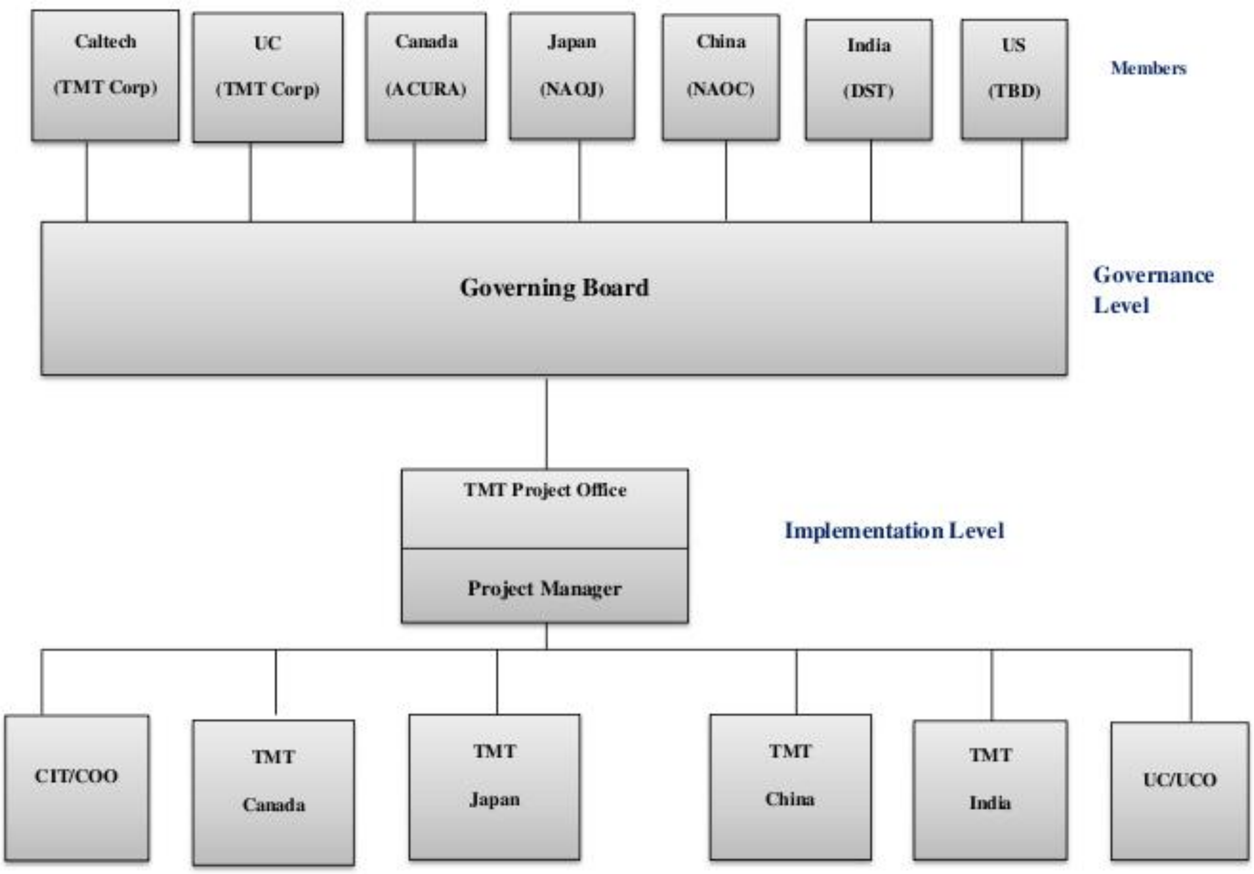


FIGURE 19: GOVERNANCE STRUCTURE

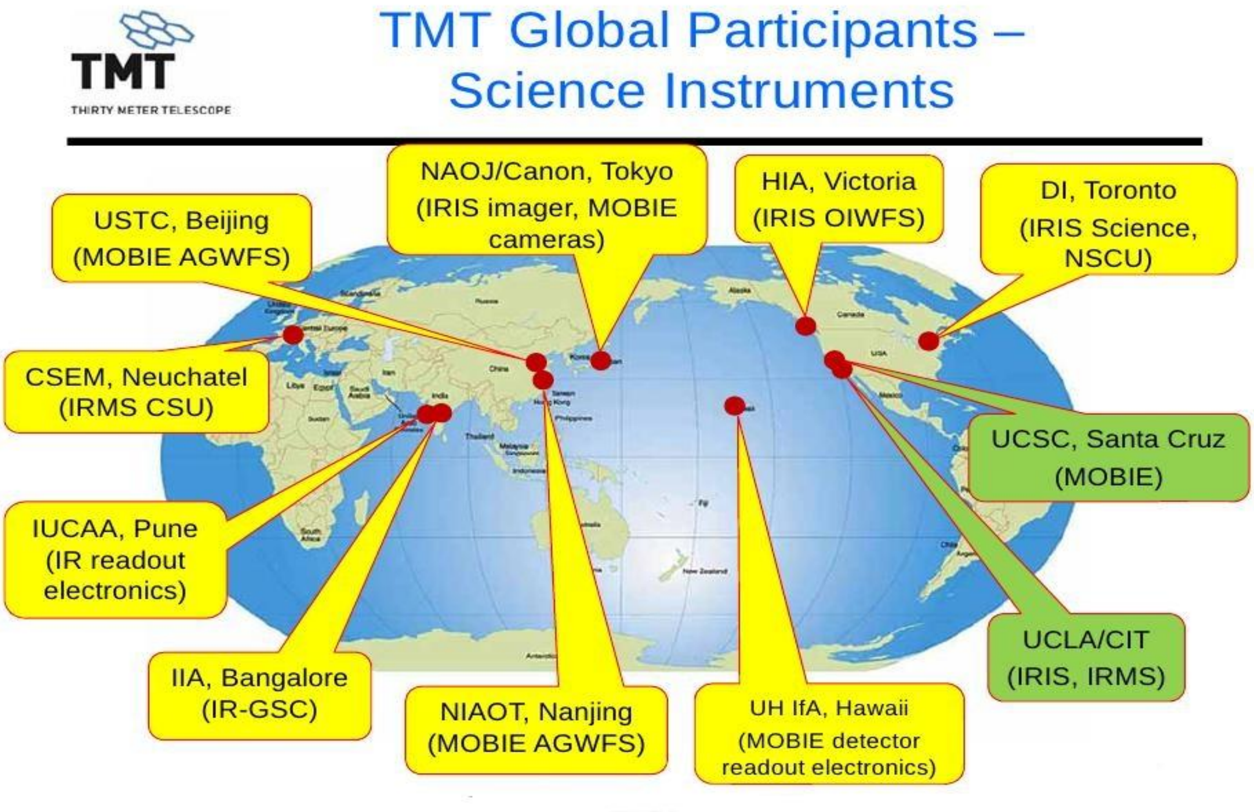


FIGURE 20: GEOGRAPHICAL LOCATIONS OF PARTNER COUNTRIES AND HOST INSTITUTES

Broader Impacts

TMT is a unique opportunity for advancing science and technology. Cutting edge science and technology development is required to build and operate this next generation observatory. As a result of participation in the TMT project, several key technologies related to astronomy are being transferred to the country. A prolonged association with the project would help scientists and engineers in the country to master these technologies and eventually develop our own 8-10 m class telescope facilities on Indian soil. This is imperative to expand research in astronomy to a wider pool of talent existing at university level. Besides astronomy, TMT will contribute to engineering and technology, international relations and workforce development. This international partnership will enable opportunities for scientific, technical and community collaborations.

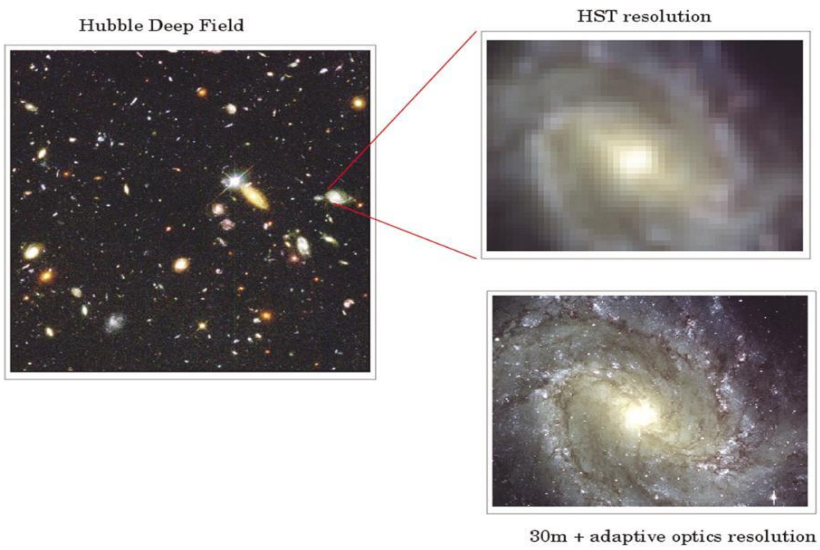
Quick Look

- Thirty Meter Telescope (TMT) is an international project involving India, the USA, Canada, Japan and China.

- TMT will be built on the summit of Mauna Kea in Hawaii, at an elevation of 4,050 m. Construction phase will begin in 2014 with completion in early next decade.

- The primary mirror is designed to be 30 m across consisting of 492 hexagonal segments, each 1.44 m in size. The TMT design offers 10 times more light gathering power than the largest existing ground based facilities.

- The AO capability enables TMT to resolve objects by a factor of 3 better than the current 10 m class telescopes and 12 times better than the Hubble Space Telescope.

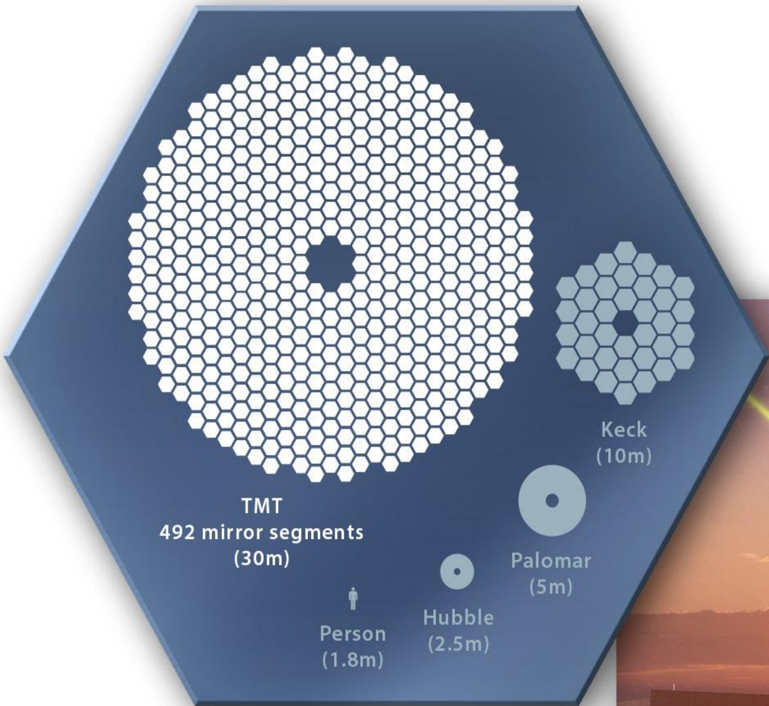


- These capabilities will enable ground breaking advances in a wide range of scientific areas starting from our own solar system to the most distant parts of the Universe.

- The project cost is approximately $ 1.4 billion. India's contribution is about 10% of the total cost and is jointly funded by Department of Science & Technology and Department of Atomic Energy.

- Much of India's contributions will be through providing vital components such as actuators, edge sensors and segment support assemblies. A major part of the observatory control software will also be part of India's contribution.

- This international partnership will enable opportunities for scientific, technical and community collaborations.



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