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India's Participation in the Thirty-Meter Telescope Project

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Abstract. In 2010, the Department of Science and Technology (DST), Govt. of India, approved astronomers' proposal of India joining the international consortium of the USA, Japan, Canada and China to build and operate the next generation mega ground based optical and infrared telescope known as the Thirty-Meter Telescope (TMT) after its aperture size of 30-meter diameter. Since then, India is engaged in many aspects of the TMT project, both at technical and policy levels. In this article, I confine to the description of India's efforts leading up to the decision to join the consortium, and the progress made since then with respect to India's technical contributions to the project.

Key words. Telescope: thirty-meter telescope—India TMT: India TMT Co-ordination Center.

1. Background

The quest for understanding fundamental issues such as the possible existence of life beyond the solar system, the so-called dark energy believed to be causing the Universe to accelerate, and many other astrophysical phenomenon such as formation of planetary systems, and formation and evolution of stars and galaxies led astronomers the world over to propose to build the next generation mega ground-based optical and infrared telescopes. Thus formed the three independent international consortia consisting of countries and institutes cutting across the continents: The Giant Magellan Telescope (25-m; GMT, site: Las Campanas, Chile), the Thirty-Meter Telescope (30-m; TMT, site: Mauna Kea, Hawaii, USA) and the European-Extremely Large Telescope (39-m; E-ELT, site: Cerro Armazons, Chile). The GMT consortium is led by universities in the USA, Australia and South Korea; the EELT is primarily led by the European Southern Observatory (ESO), the 14 European member countries and Brazil, and the TMT project is led by the University of California, Caltech (USA), Canada, Japan, China and India. The three projects are in the design and early construction phase and expected to be operational in early 2020s. The cost and the technologies involved in the projects are such that no single country/institute can afford to build and sustain these facilities on its own. This required to forge collaborations with all the interested communities in the world. The three projects approached

Institutes in India for their participation in the design, construction and operations of the telescopes. It is an excellent opportunity for India to invest for future generations to pursue their varied astrophysical interests ranging from solar systems studies to the studies of farthest stars and galaxies, and also to augment technical capability in this field.

For India, the motivation to consider to join in this scientific endeavour stems from three principal factors: (1) opportunity to carry out frontline research in astronomy, (2) technology transfers, (3) sharing the cost, which would be prohibitive for any single country. Here, I provide a brief description of a few compelling reasons that motivated astronomers in the country to join the 'Thirty-Meter Telescope' project.

1.1 *A rational for India's participation*

In India, astronomers have very limited access to state-of-the-art observing facilities. This is in spite of the fact that India built indigenous optical telescope of 2.3-m diameter known as Vainu Bappu Telescope (VBT) which was commissioned in early 1980s. At that time, the VBT was one of the largest optical telescopes in the world, just a notch below the 5-m class telescopes, that were being used elsewhere. Presently, India operates three 2-m class optical telescopes (VBT, Kavalur, Himalayan Chandra Telescope, Hanle since 2000, and IUCAA Telescope at Girawali since 2006) and plans to establish a 3.6-m telescope optical telescope at Devasthal by 2014. However, during the period between 1980–2000, astronomers the world over got access to next generation astronomical facilities by building 8–10-m class optical and infrared telescopes. There are a dozen of them in the world which have been operational. In Table 1, a snapshot of a comparison of optical facilities in the country versus elsewhere is provided.

Apart from huge capital and high-end technologies, exceptional sites are essential to provide a maximum number of clear (cloudless) and dry (less humid) nights with sub-arc second seeing (stable atmosphere). Thus, most of the current 10-m large telescopes were built through international collaborations, and most of them are located either in Andes mountains (Chile), Mauna Kea, Hawaii (USA), or Tenerife (Spain) which are the best-known astronomical sites in the world. Though the Hanle region in western Himalayas, a site of 2-m telescope at the Indian Astronomical Observatory, is one of the best in the country, the fraction of sub-arc second seeing nights are significantly less compared to Mauna Kea (see Table 2), the site for the TMT observatory. Mauna Kea boasts of having seeing values below 0.75 for about 75% of observing time. Seeing and Precipitable Water Vapour (PWV) are very important parameters for very large telescopes with Adaptive Optics (AO) and infrared astronomy.

One may ask why India has to participate in the international collaboration. The alternate possibility could be India building a world class facility on its own. Based on the costs, level of technologies and the size of the community, a 10-m class telescope is definitely feasible for India to build. However, given that this will take about ten years to complete, the world would have moved on to next-generation telescopes of 25+ metre class era by then. A 10-m class facility can never be a substitute in place of access to telescope with an aperture greater than 25 metres. On the other hand, by joining one of the GSMTs and by actively participating in its construction through key in-kind contributions, institutes and industry in the country can enhance

Table 1. Comparison of optical facilities in India and the rest of the world.

Period	India (Optical and IR facilities)	Rest of the world (Optical and IR facilities)
Before 1950	...	1–5 m class telescopes (USA and Europe): 1 m Yerkes, 2.5 m Mount-Wilson, 5.1 m Hale Telescope (Palomer)
1950–1980	1 m class telescopes: UPSO (1 m IR:1972), VBO (1 m:1972), Rangapur Obs. (1.2 m: 1968)	4–6 m facilities: CFHT (3.6 m), UKIRT (3.8 m IR), 6 m Russian telescope, AAT (3.9 m) (USA, Europe, Australia, Canada)
1980–1990	1–2 m class facilities: VBT (2.4 m: 1984)	4–6 m class telescopes (UK, USA, Australia, Russia, Europe), HST (2.4 m)
1990–2000	1–2 m class facilities	8–10 m class facilities: 2 Keck (USA, Canada), 4 VLTs (EU), Gemini South, North (USA, Canada, Chile, Brazil, UK, Argentina, Australia)
2000–2010	2m–4m class facilities: HCT (2 m: 2003), IGO (2 m:2005), DOT(3.6 m: 2012/13)	More 8–10 m telescopes: Subaru (Japan), HET (USA, Germany), SALT (South Africa, USA, Europe, India), GTC (USA, Spain, Mexico, ESO)
2010–2020	...	24–42 m telescope facilities: GMT (25 m), TMT (30 m) and EELT (42 m). USA, Canada, China, Japan, Australia, South Korea, 14 European countries, few South American nations.

their expertise and credibility. In the future, the country can then aspire to lead a consortium for building a 10-metre class or larger facility. The complementary nature of these two approaches (international participation vs. indigenous development) finds resonance in a relevant extract from the *'Decadal Vision Document 2004'* sponsored *by the Indian Academy of Sciences and the Astronomical Society of India* (Srinivasan 2004).

"...While indigenous efforts are absolutely essential for science to take root, as well as to build a sizeable scientific community, one must be aware of the ever widening gap between the state-of-the-art facilities abroad and what we can realistically hope to have in India. Indeed, the next generation facilities that are being planned are so expensive that even the United States of America cannot raise the required resources. Multinational collaboration is the new paradigm in big science. This is going to be true in all branches of astronomy."

Table 2. A few parameters of astronomical sites: Mauna Kea, Hawaii, USA and Hanle, Ladak, India.

Site	Altitude (m)	Median (arc-sec)	Seeing clear sky fraction (%)/ clear nights	PWV (mm)
Mauna Kea 13N	4050	0.75	76/277	1.9
Hanle, Ladakh	4500	$\sim$1.2	71/259	<2.0

1.2 *Science with TMT*

TMT with its 30-meter primary and futuristic integrated Adaptive Optics (AO) technology will be many-fold more powerful in angular resolution (7 mas at 1 μm) and in reaching the farthest regions (epochs when the first stars were being formed) in the Universe than any of the current astronomy facilities. The AO technology enables TMT to correct image distortions caused by the Earth's atmosphere. The AO capability will make TMT a factor of 3 better than the current 10-meter telescopes and 12 times the Hubble Space Telescopes (HST) in resolving objects (for more details, see Sanders 2013). With the TMT it would be possible to resolve objects of size as small as 25 km at the Jupiter's distance (5 AU) and monitor its satellites. In sensitivity, TMT will be a factor of 14 (seeing limited where $S \propto D^2$) to 200 (AO where $S \propto D^4$) times better than the current largest telescopes. TMT with the proposed suite of instruments and operating wavelength 0.31 μm–28 μ will explore nearly every area of astronomy and astrophysics catering to astronomers in all branches of astronomy in the optical and IR wavelength domain. Also, one needs to note that most often discoveries are unexpected and our participation would provide plenty of such opportunities to astronomers for decades to come. I desist to describe detailed science cases as these are covered by Silva *et al.* (2007) and other authors in this volume (e.g. Simard 2013; Sengupta 2013; Pandey 2013).

2. India TMT

Since 2007, astronomers in the country led by Aryabhatta Research Institute for Observational Sciences (ARIES, Nainital), Indian Institute of Astrophysics (IIA, Bangalore), and Inter-University Center for Astronomy and Astrophysics (IUCAA, Pune), with the initiation by the Department of Science and Technology, collected and consolidated inputs from all the concerned parties. These include the three proposed international projects, the astronomy community at Institutes and Universities, as well as industry in the country. After thorough deliberations on the pros and cons, astronomers found the TMT project as the most suitable of the three to participate. TMT project offered a greater participation in building the telescope by accepting most of our contributions through in-kind, in terms of providing various sub systems to the project rather than just cash. This is one of the main reasons for the choice. Based on the detailed report (Reddy *et al.* 2010; Reddy & Ramaprakash 2012), DST approved India's participation in the project in June, 2010. Since then, India is participating in all the policy decisions (science and instrument priorities, organization etc.) and development activities of the project. The DST also has provided a seed fund for technology capability development and demonstration of a number of high technology components related to GSMTs which could be used ultimately in the TMT project.

To provide a greater impetus to our efforts, Department of Atomic Energy (DAE) and DST, in March 2012, decided to set-up a Coordination Center that would address all aspects towards India's participation in the TMT project as an extra mural national project. The two departments will jointly fund the project. The coordination center, with the Indian Institute of Astrophysics, Bangalore as its nodal agency, is known as 'India TMT Coordination Center (ITCC)' (hereafter India TMT).

3. Role of India TMT

The 30-m diameter aperture consists of 492 hexagonal segments of diameter of 1.44-m each. The challenge is maintaining the final wavefront at the focal plane as if it is reflected by a single monolithic 30-m diameter mirror. This involves developing a host of new technologies in mechanics, electronics, optics and software. India consciously chose, with the aim of acquiring key technologies in this field, to provide a portion of the 492 segments (M1) and the complete primary mirror support system consisting of 492 segment supports (SSA) and M1 control systems (M1CS): actuators, and edge sensors (see Fig. 1). A major part of the observatory control software is also a part of our contribution.

It is mandatory that all the key subsystems of the TMT be prototyped and demonstrated to the design specifications. Scientific institutes and the industries in the country are presently engaged in developing and demonstrating the technologies required for the components that India TMT chose to provide to the project. In this process, state-of-art technologies in the field are being transferred to the country. Funds spent on prototyping will be treated as India's in-kind contribution to the project, irrespective of the outcome. The successful completion would help scientists and engineers

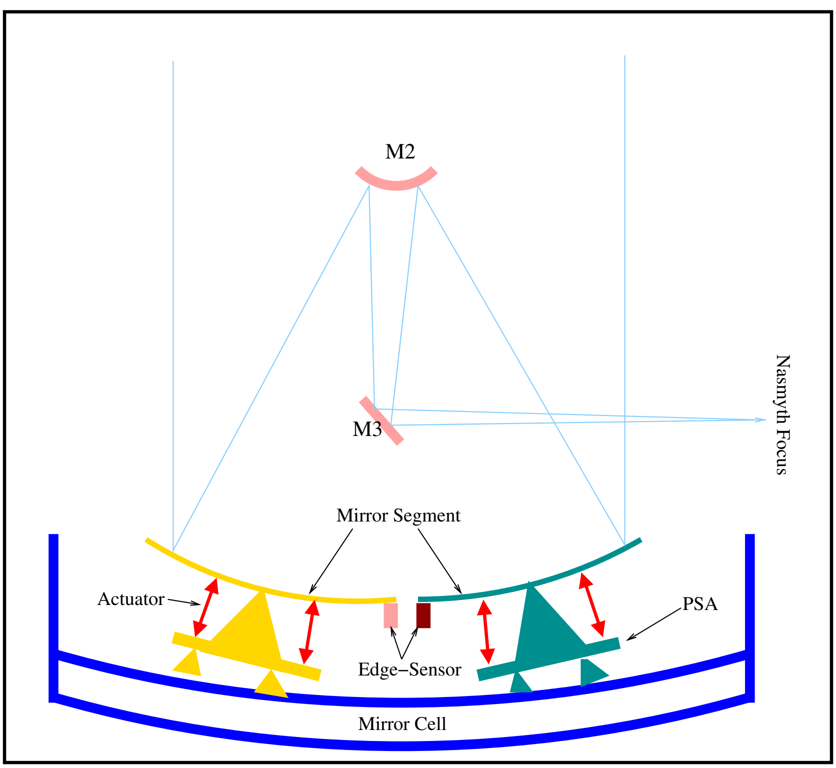

Figure 1. Schematic optical layout of TMT. India TMT work packages include about 100 segments of primary mirror and the entire Primary Segment Assembly (PSA): edge sensors, actuators and segments support systems which are shown in the diagram.

in the country to master technologies and develop future facilities in the country. Apart from major hardware systems, India is also collaborating on instrument development.

4. India's work packages and technology demonstrations

In today's cost, it is about US $1.5 billion to build the TMT observatory with three first light instruments: Infrared Imager and Spectrometer (IRIS), Wide-Field Optical Spectrometer and Imager (WFOS), and InfraRed Multi-slit Spectrometer (IRMS). Details of the telescope and instruments can be found at www.tmt.org. India is a 10% partner in the project which translates to about INR 800 crores. Most of India's participation is through in-kind contributions by providing some of the key systems: Entire M1 control system (edge sensors, actuators, segment supports), about 100 M1 segments, mirror coating system and software. All partners have to demonstrate the technology required for their respective systems by the end of 2013. Here, I provide a brief account of recent progress on some of these work packages.

4.1 *Edge sensors*

During the course of science operations segments may get displaced relative to each other due to varying gravity and thermal loads which degrade image quality. Thus, all the 492 segments must be actively co-phased to maintain the correct surface shape to produce sharpest possible images and, in the case of AO mode, diffraction limited images. Edge sensors would measure relative displacement, tip, and tilt of the segments which would be relayed to actuators. The current TMT design requires six edge sensors per segment, which is a total of about 3444 edge sensors. Sensors are critical to the operation of segmented mirror technology telescope by allowing the individual segments to form part of a single optical surface. India TMT with the help of General Optics Asia Ltd (GOAL), Puduchery produced 12 capacitive edge sensor prototypes (Fig. 2) which are under technical trial in Jet Propulsion Lab (JPL), USA.

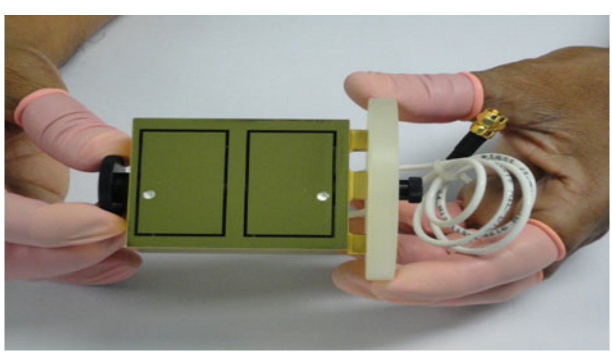

Figure 2. Prototype Edge Sensor at GOAL, Puduchery.

4.2 *Actuators*

The actuators are an extremely important component of the primary mirror segment cell. These are very high precision components, whose use is very specific to segmented mirror technology and as such a technology that is not freely available. The 492 mirror segments of the primary are required to function as a single mirror with the required specifications at any given time. This requires constant control of the phase, position and orientation of each individual segment, which is performed by actuators that are part of the segment cell. Three actuators are required per segment, and about 1500 in total. We have taken up technology demonstration of 10 prototype actuators which are being developed by Avasarala Technologies, Bangalore. The first three actuators (Fig. 3) are assembled and tested successfully for all basic functionalities.

4.3 *M1 segments*

Segments are the most critical components for the TMT project. There are 574 (including 82 spare segments) segments of 1.44 m diameter each with thickness of 45 mm. All the segments need to be hexcut and polished to the roughness of about 22 Å RMS or to about 20 nm peak-to-valley (PV), and without any subsurface damage. All the segments are off-axis and aspheric. Asphericity is of the order of a few microns for the innermost segments to 220 microns for the outermost segments. Challenge is to produce at least two fully polished segments per week over the duration of TMT construction starting from 2014 to 2020/21. As of now, India does not possess the technology required to meet the stringent design parameters of segment polishing. Also, we do not have infrastructure to mass produce the segments. However, these issues could be mitigated with clear planning and target oriented goals of technology development within the country. Providing primary mirror segments

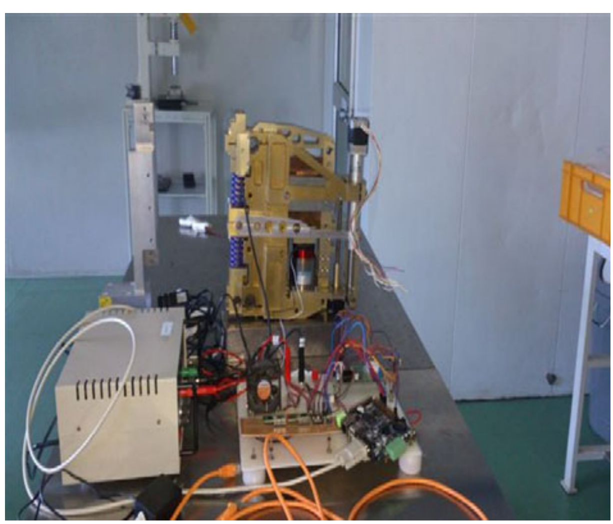

Figure 3. One of the first fully assembled TMT actuator at Avasarala Technologies, Bangalore.

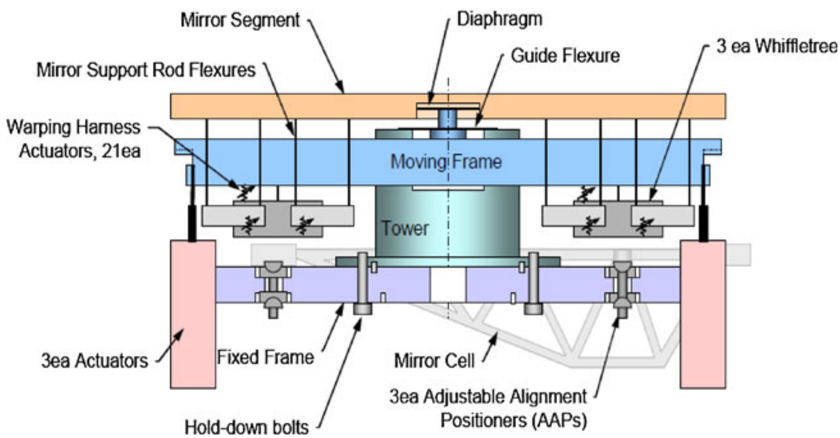

Figure 4. Schematic diagram of SSA for TMT.

to the TMT is one of the major aims of TMT-India. We are optimistic that some of the Indian industries in collaboration with public sectors units such as ISRO and IIA could rise to the challenge.

4.4 *Segment Support Assembly (SSA)*

The primary mirror control system (M1CS) is responsible for maintaining the overall shape of the segmented M1 mirror despite deformations of the telescope structure caused by temperature, gravity and disturbances from wind and vibrations (observatory generated and seismic). Properly supported mirror segments can be treated as rigid bodies and their positions can be described by six parameters; three in-plane motions are controlled passively via SSAs and three out-of-plane motions (piston, tip and tilt) are actively controlled by the M1CS via three actuators per segment and a pair of edge sensors per inter-segment gap. Each mirror segment requires an SSA (Fig. 4) that has several subcomponents that are to be manufactured separately and integrated. Godrej Industries, Mumbai and Avasarala Technologies, Bangalore have been identified to manufacture prototype SSA's. The work is under progress.

5. Summary

Cutting edge science and technology development is required to build and operate this next generation observatory. TMT is an unique opportunity for advancing science and technology, in particular to the field of astronomy and astrophysics. As a result of participation in the TMT project, several key technologies related to astronomy are being transferred to the country such as stress mirror polishing (SMP) of thin light weight segments, manufacturing of very high precision M1 controls etc. A prolonged association with the project would help scientists and engineers in the country to master these technologies and eventually develop our own or lead a consortium to build 8–10 m class telescope facilities in the country/elsewhere. 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.

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References

Pandey, S. B. 2013, *JAA*, **34**, 157.

Reddy, B. E., Ramaprakash, A. N. 2012, "India's Participation in the Thirty-Meter Telescope Project: Technology capability development and demonstration report" submitted to the Department of Science and Technology, Govt. of India, New Delhi.

Reddy, B. E., Ramaprakash, A. N., Anupama, G. C. 2010, "India's Participation in an International Giant Segmented Mirror Telescopes: A detailed Project Report" submitted to the Department of Science and Technology, Govt. of India, New Delhi.

Sanders, G. H. 2013, *JAA*, **34**, 81.

Sengupta, S. K. 2013, *JAA*, **34**, 151.

Silva, D., Hickson, P., Steidael, C., Bolte, M. 2007, Thirty-Meter Telescope: Detailed Science Case., Pasadena.

Simard, L. 2013, *JAA*, **34**, 97.

Srinivasan, G. 2004, in "Astronomy and Astrophysics: A decadal Vision Document", INSA, New Delhi.