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OBSERVATIONAL FACILITIES

A 10-m class national large optical-IR telescope

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Abstract. An observatory class national large optical-IR telescope (NLOT), is proposed to be built and located in the country. The telescope consists of a 10–12 m segmented primary. In order to cater to a diversity of observational programs, the telescope is designed with high throughput in both the optical and IR regions (0.3–5 μm). It should perform reasonably well up to 30 μm. The telescope and instruments should have remote operations capability, allowing for the queue as well as classical scheduling and high reliability and robustness. This article provides a brief description of the science cases that drive the telescope requirements, activities related to optics design and some thoughts on the instruments.

Keywords. General: Optical-infrared astronomy—instrumentation: segmented mirror telescopes, telescope optics design, astronomical instruments.

1. Introduction

The idea of building a large optical telescope in India has been recurring ever since 1984 or so, without any result. With a renewed effort, the Indian Institute of Astrophysics (IIA) proposed a 6.5m telescope in the early 1990s and surveyed a suitable site in the upper and trans-Himalayan regions. They identified Hanle in Ladakh and established the Indian Astronomical Observatory (IAO), which now hosts the 2m Himalayan Chandra Telescope (HCT), the 0.7m GROWTH-India Telescope (GIT) and the gamma-ray telescopes High Altitude Gamma-ray ARray (HAGAR) and Major Atmospheric Cherenkov Experiment (MACE). Following the successful working of the HCT since 2003, the 'dream' of building a large telescope resumed at IIA in the year 2006. As a first step, it was proposed to undertake a detailed characterization of Hanle as well as identify and characterize potential sites in the region around Hanle.

In 2007, two of the 20–30m telescope projects – the 30m Thirty Meter Telescope (TMT) and the 25m Giant Magellan Telescope (GMT) – that were towards the end of their detailed design phase and were seeking new partners approached Indian institutes, inviting India to join the project. After due deliberation by a national group of astronomers, India's participation in

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the 30m TMT project was recommended and subsequently funded by the Government of India. During the course of the deliberations on participation in one of the giant segmented mirror telescope projects, the importance of having a 10m class telescope in India, in addition to the partnership with the TMT was emphasized by the participating astronomers. To effectively utilize India's share of observing nights on the TMT, a 10m class telescope is essential. Indeed, one of the main reasons behind the choice of the TMT project has been the in-kind participation and the cutting-edge technological expertise that this participation brings to the Indian industry and research centers in areas such as segmented mirrors and control systems and, to the astronomical community, in areas such as instrument building and adaptive optics. These are some of the key areas essential to building a modern state-of-the-art telescope, and where there is very little, or no expertise within the country.

A national-level workshop was held in 2019 under the auspices of the Astronomical Society of India (ASI) to discuss several aspects of a 10m class telescope in the country. About 90 participants attended the workshop from various institutes and universities across the country. The country has a suite of 1–4m class telescopes. While being quite heavily utilized, these telescopes are insufficient to be globally competitive. While a small fraction of Indian astronomers have access to the Southern African Large Telescope through the Inter-University Centre for Astronomy and Astrophysics (IUCAA), most do not have access to the present large telescopes. After detailed deliberations, the national workshop participants agreed that there is a strong need for a 10m class telescope in the country and that the telescope can be sited in IAO, Hanle. The presence of an Indian 10m class telescope would encourage and attract young talent within the country and help in further growth of the Indian astronomical community. More importantly, as a collateral benefit, the execution of such a large, technologically advanced project will benefit all of STEM.

We describe in this article the present efforts towards optical design and mechanical conceptualization of the NLOT, instruments and development of the segments alignment and phasing technology.

2. Science goals

The resolution and sensitivity provided by a 10m class telescope with Adaptive Optics (AO) systems, combined with a flexible and powerful suite of instruments, will enable astronomers to address many of the most fundamental questions of the coming decades. Some key areas of interest to the Indian astronomers are mentioned here.

2.1 *Formation of stars and planets*

Stars form inside high-density regions of interstellar medium that are highly obscured and often can be identified only in the near- and mid-infrared and submillimetre wavelengths. These faint sources reveal the early evolution of very low to high mass star formation. Space missions like the Spitzer have identified numerous such sources within our Galaxy. However, the transition from cloud collapse to the initial ignition of nuclear burning is still rarely observed. Disentangling the different emission regions of the forming star and its environment are critical to improve our understanding of this process. The planetary disks and the later stages of the debris disks, for example, hold the signatures of forming planets. The chemistry of such disks is largely unexplored but will become accessible with increased angular resolution and extended wavelength coverage. Therefore, to study these faint sources, a combination of the site located at high altitudes (to access the ultraviolet region of the electromagnetic spectrum) with low water vapor content (to access the near- to mid-infrared part of the electromagnetic spectrum) and a 10m or bigger aperture telescope optimized for covering ground ultraviolet to infrared wavelengths is required.

2.2 *Exo-planets*

We can understand our place in the Universe only if we have a better idea of how the solar system compares to planetary systems around other stars. This has been the most rapidly growing field of astronomy over the past decade and the various surveys have detected thousands of known exoplanets in the last 15 years. The most important goals for the coming years are going to be (a) characterization of the planetary systems, (b) a complete census of the mass distribution of planets and (c) characterization of their chemical composition and temperatures. Significant are the planets residing in the stars' habitable zones where chances of finding life other than in our solar system are higher. We need large aperture telescopes to carry out high spectral resolution and extended time series to measure at least a large fraction of an orbit or several orbits of the planet around a star.

2.3 *Formation and evolution of Galaxies*

Clues to the formation and evolution of our Milky Way Galaxy are embedded in its building blocks — the stars. A systematic study of stellar motions and composition is essential to reveal the origin and evolution of the Galaxy and its present structure. Understanding the different structures of the Milky Way — their origin and dynamics is one of the fundamental issues. Missions like *Gaia* add distance and proper motion information of the stars to kiloparsec scales. Combining chemical abundances of individual stars with astrometry and radial velocity, it would be possible to construct a 3-D view of our Galaxy and identify the distinct components based on a kinematic motion. By looking into space to greater and greater distances, some 13 billion light-years, one can see back into the past, the very first stars and galaxies. We see galaxies interacting dynamically and forming stars at lesser distances, moving forward in time. But it is not yet clear how this produces the diversity of Galaxy types seen today. Other areas of interest include studies on stellar population in the Local Group and nearby Galaxies, understanding baryonic mass assembly in distant Galaxies, kinematics of star-forming Galaxies, correlations between the super-massive black holes and host Galaxy properties.

2.4 *The cosmic chemistry*

The study of the chemical abundances of stellar atmospheres is extremely important as stellar atmospheres contain fossil records of the material from which they formed as well as the products of the nucleosynthesis in the stellar cores that may have been brought up to the surface. Except for a handful, almost all elements in the periodic table are synthesized in the stellar interiors and envelopes during hydrostatic and explosive burning. Hence, chemical evolution in different stellar groups such as red giants, supergiants, AGB and post-AGB stars, RV Tau stars, hydrogen deficient stars, chemically peculiar and metal-poor stars, traces the star formation history and age, and also provides insight into the chemical evolution of Galaxies and the interstellar matter. In addition to elemental abundances, isotopic abundances of several key elements are indicative of nucleosynthesis in the early Galaxy and are useful for testing cosmic homogeneity.

2.5 *Stellar explosions and extreme physics*

The most energetic stellar explosions, the supernovae (SNe) and gamma-ray burst sources (GRBs) are caused by the death of massive stars. The nature and evolution of the explosion and its remnant is determined by parameters such as the progenitor star's mass, metallicity and environment. The high luminosity of these objects enables us to observe them at cosmological distances and make them excellent probes to study the Universe at various redshifts. The nature of the progenitors and explosion mechanisms of core-collapse supernovae, observational signatures of pair-instability supernovae, the Supernovae-GRB connection, understanding the properties of GRB host galaxies are some of the major topics that still lack a deeper understanding. Another area of interest is studying the electromagnetic (EM) counterparts of gravitational wave (GW) sources. GW sources could be merging black holes, merging neutron stars or mergers of a black hole and a neutron star. EM observations will help in a detailed understanding of the physical processes during such mergers.

2.6 *The early Universe*

The epoch of reionization is characterized by the epoch when the first stars began to form, providing the first sources of light and heat in the Universe after the Big Bang. The direct investigation of this epoch, usually accomplished by the observations of high redshift quasars, has, in recent years, been revolutionized by the observations of GRBs. Such observations would provide multiple lines of sight through the intergalactic medium and thus allow us to trace the process of reionization from its early stages. Probing the variation of a fundamental constant is another topic of interest.

3. Site parameters

The candidate site for the NLOT is IAO, Hanle in Ladakh. Stalin *et al.* (2008) present the average site parameters during 2000–2008. We present in Table 1 the site parameters based on estimates made during 2000–2017. While the weather parameters are based on daily measurements, other parameters are based on estimates obtained intermittently.

Table 1. Site parameters of Hanle, Ladakh.

Site parameter	IAO, Hanle
Number of useable nights	72%
Night time median wind speed	2.2 m/s
Median seeing	1 arc-sec
Average sky brightness in V	21.3 mag/arc-sec^2
Average extinction in V	0.11 mag
Average PWV (mm)	1.5–2.2
Median night time RH	33%
Extreme temperature (min/max)	–25/26

The average site parameters of Hanle presented in Table 1 indicate the site is comparable with the best astronomical sites in the world. However, in order to optimize the telescope and dome design, it is desirable to have more continuous and robust estimates of some of the critical parameters, such as seeing, especially at the location of the telescope. Several site characterization instruments have been developed and installed at IAO. These are an automated extinction and sky brightness monitor (Sharma *et al.* 2017a), an IR cloud monitor (Sharma *et al.* 2017b), a lunar scintillometer (Surendran *et al.* 2018) and a DIMM seeing monitor. A MASS-DIMM is under development to obtain seeing at different heights.

4. Baseline requirements and telescope specifications

The telescope specifications are governed by the science requirements and the site parameters. The baseline science requirements are:

- The telescope should cater to diverse observational programs, with high throughput in optical and IR regions (0.3–5 μm). However, the telescope should be able to perform reasonably well up to 30 μm – the criticality of this criterion depends on the site.
- High optical performance – (a) preserve the natural seeing of the site by not degrading it by more than 10% and (b) include adaptive optics right from the design stages.
- Excellent pointing and tracking with active focus correction.
- The telescope and instruments should have remote operations capability, allowing for (a) simultaneous availability of various instruments, (b) queue as well as classical scheduling and (c) high reliability and robustness.

The baseline telescope design requirements are:

- The primary will be segmented, about 10–12 m in diameter, with an *f*-ratio between 1.5 and 1.8. The segments will be of low expansion glass to have high thermal stability.
- The optics configuration will provide for (a) an *f*-ratio of *f*/15 and (b) availability of multiple instrument ports.
- The secondary is to be optimized in such a manner that a single secondary can be used for both optical and IR.
- The minimum un-vignetted field-of-view is 10 arc-min, with a plate scale around 1.1 arc-sec/mm.
- The optics will have a broad-spectrum coating.
- The telescope should have good IR performance and be thermally optimized with an emissivity below 4%.
- The telescope should be able to point to any position with an elevation angle between 15° and 89° for normal observations.
- The telescope drive system must continuously track any object moving at up to 1 arc-sec per second relative to the sidereal rate, when the object has an elevation angle >15°. The zenith blind spot should be at most 1°. A variable tracking rate should also be available for tracking fast-moving objects.
- Open-loop tracking accuracy <2 arc-sec over 1 h.
- A pointing accuracy of 2 arc-sec (rms) is required.
- Possibility of an adaptive secondary for ground layer adaptive optics (GLAO).

The required optical performance that will drive the design of the telescope optics, controls and dome can be finalized only after a detailed, *in-situ* characterization, based on on-site monitoring at the location of the telescope, for at least 1–2 years.

5. Preliminary design studies

5.1 *Telescope optics*

The telescope optics is being designed to achieve the baseline requirements and specifications.

The segmented primary mirror is designed based on the TMT primary segmentation (Baffes *et al.* 2008). The segments are hexagonal, of size 1.44 m (across corners) and thickness of 45 mm with an inter-segment gap of 2.5 mm. The segmentation pattern has a

Table 2. NLOT primary mirror configuration for different *f*-ratios.

	Primary *f*#			
Parameters	1	1.2	1.5	1.75
Conic constant	−1.000928	−1.001497	−1.002734	−1.004206
Nominal ROC (m)	−22.5	−27	−33.75	−39.38
Asphericity (μm)	572	340	176	111
Tel. length (m)	10.2	12.1	14.8	17.04

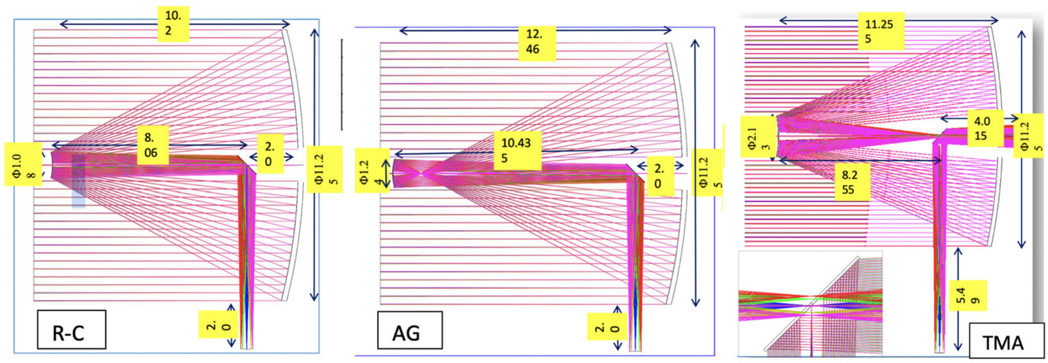

Figure 1. Optical layout of the three telescope configurations considered, shown for an *f*/1 primary as an example. Left: Ritchey–Chretien, middle: aspheric Gregorian and right: three mirror anastigmatic.

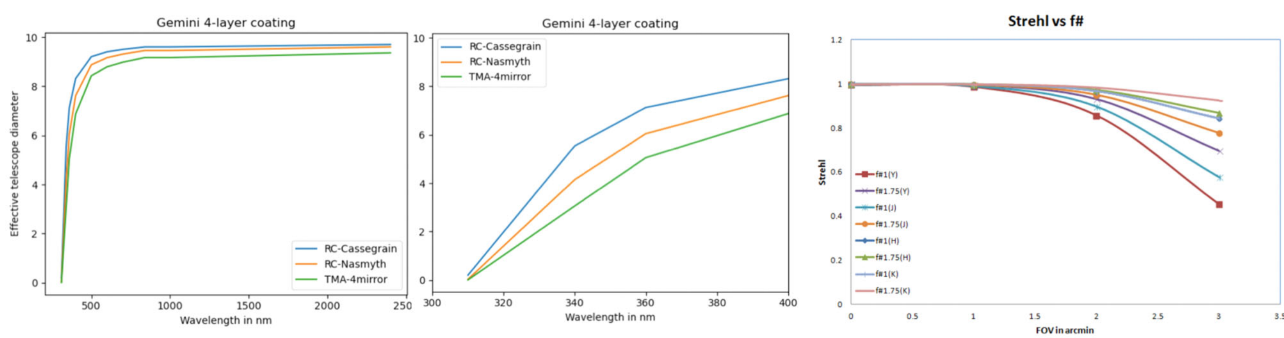

Figure 2. Comparison of the throughput for the three telescope configurations considered (left and middle) and the effect of the primary *f*-ratio on the Strehl (right).

six-fold symmetry. A clear aperture of 10 m requires 60 segments with an outer diameter of 11.3 m. Table 2 provides the details of three *f*-ratio configurations considered for the primary mirror.

Three different optics configurations have been studied for each of the primary *f*-ratios. The configurations are (a) Ritchey–Cretien (RC), (b) Aspheric Gregorian (AG) and (c) Three Mirror Anastigmatic (TMA). Figure 1 shows the optical layout of the three configurations for an *f*/1 primary.

The overall telescope throughput for each configuration is estimated assuming Gemini coating. An estimate of the effect of the primary *f*-number on the Strehl is also made. Figure 2 shows the throughput for the three different configurations considered, and also the effect of the primary *f*-number on the Strehl.

The overall summary of the optical layout summary is as follows:

- R–C, AG and TMA designs are explored for primary *f*-numbers *f*/1 to *f*/1.75.
- Obscuration due to the secondary is $\sim$1% in R–C and AG designs, while it is $\sim$10% in the TMA design.
- RC and AG give diffraction limited performance beyond 1 μm over 6 arc-min, while the

TMA design gives diffraction limited performance over the full field-of-view of 10 arc-min.
- R–C design gives the best throughput.
- A slower primary gives a primary with lower asphericity. This makes the segments safe and easy to fabricate with the existing equipment. Also, slower primary does not affect the Strehl.
- Based on the various design studies, the R–C design with a slower primary (*f*/1.5–*f*/1.74) appears to provide the best performance.

5.2 *Segment support assembly design*

The feasibility of using the TMT segment support assembly (SSA) design for the NLOT segments was studied. The preliminary design study indicates that the TMT SSA can be used for the NLOT segments with minimal modifications. The thermal and gravity effect of the modified SSA on the primary mirror was studied, and the effect is found to be minimal, without any degradation of the mirror surface.

6. Possible instruments

It is suggested that NLOT instruments take advantage of the site's high altitude and cold temperatures and focus on (a) blue sensitivity and (b) mid-IR. Keeping this in mind, possible science instruments suggested are (a) a high throughput imaging spectrograph with polarimetric capability, (b) a medium resolution, single object spectrograph covering the wavelength range of 310–2300 nm, (c) an integral field multi-object spectrograph, (d) a large-field multi-object near-infrared low-resolution spectrograph (AO assisted), (e) a high-resolution infrared spectrograph, (f) exoplanet imager and lenslets spectrographs (AO assisted) and (g) a high resolution, high stability, fiber-fed optical spectrometer and spectropolarimeter.

The possible first light instruments are:

- A seeing limited 0.3–1 μm low-medium multi-object spectrometer camera. At an *f*/15 Nasmyth focus, such an instrument is expected to reach a 3-sigma detection limit of $V = 27$ mag in a 600s exposure in the imaging mode, and $V = 18$ mag with $S/N = 50$ at $R \sim 10,000$. Polarimetric capability is desirable.
- A 0.9–5 μm spectrometer camera. The 3-sigma limiting magnitude for a 600s integration time is expected to be $K = 20.5$ mag for imaging, and $K = 13$ mag with $S/N = 50$ at $R \sim 10,000$.
- A high resolution ($R \sim 50,000$–120000) spectrometer in the 0.3–1 μm range. It would be possible to obtain spectra of a $V = 15$ mag star in a 600s exposure at $R \sim 80000$, with $S/N = 50$. A polarimetric capability will be desirable. (Note: The HESP spectrometer currently in use with the HCT is designed such that it can be used with a 10m class telescope with a re-design of only the fiber input at the telescope focus.)

7. Ongoing capacity building measures

7.1 *Prototype segmented mirror telescope*

Although segmented mirror technology was first used over two decades back, this technology is still being optimised. In particular, further technology development is required in primary controls, alignment and phasing. It is essential to understand this technology before developing a 10m telescope. Towards this, a 7 segment prototype segmented mirror telescope (PSMT) with an effective diameter of 1.6m is under development at IIA (Parihar *et al.* 2018). In the first phase, a seven-segment laboratory testbed will be developed. In the second phase, the full-fledged telescope will be realized. This telescope, after detailed tests at Bengaluru, will be installed at IAO, Hanle to study its on-site performance. As a part of this activity soft actuators have been designed and tested (Deshmukh *et al.* 2018) and design studies for an inductive sensor have been made (Kumar *et al.* 2018). Design studies of segment alignment and phasing system using a pyramid wavefront sensor has been made and a mathematical formulation has been developed for the same (Jacob *et al.* 2018). The segment support has been designed and the prototype has been fabricated. A single segment testbed is to be used to check the basic functions of the segment support and the actuator is ready for tests. The 7-segment laboratory testbed design is ready and all analysis have been completed.

7.2 *International collaborations*

India's participation in the TMT project is bringing in the technology required to build a segmented mirror telescope in areas such as segmented primary mirror controls, telescope control software and instrumentation. As a part of India-TMT's national capacity building, a new state-of-the-art large optics fabrication facility is being built at IIA's CREST campus for polishing and hexing M1 segments of TMT. This facility can be used for NLOT segments. India is participating in the design verification of one of TMT's first light instruments (wide-field optical spectrometer). India is also leading the efforts towards designing and building of a second generation instrument (a high resolution spectrometer).

It is also important to interact with other groups that are either developing or have developed 10–12 m class telescopes in order to understand specific aspects of telescope design and development technology. Most pertinently, it will prevent us from having to 're-invent the wheel'. Examples of such interactions are IUCAA's participation in developing instruments for the SALT, IIA's participation in the primary mirror design studies for the Mauna Kea Spectroscopic Explorer (MSE) and TIFR's collaboration in the build of NIR instruments.

8. Summary

This article provides a brief overview of the activities towards establishing a 10m class optical-IR telescope. This includes detailed measurements of the site parameters, especially at the proposed location of the telescope in IAO, Hanle. A preliminary design study of the telescope optics has been made. A 7-segment testbed laboratory is under development to develop the segment alignment and phasing technology.

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