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National Large Solar Telescope of India

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Abstract. The National Large Solar Telescope NLST will be a state-of-the-art 2-m class telescope for carrying out high-resolution studies of the solar atmosphere. Sites in the Himalayan region at altitudes greater than 4000-m that have extremely low water vapor content and are unaffected by monsoons are under evaluation. This project is led by the Indian Institute of Astrophysics and has national and international partners. Its geographical location will fill the longitudinal gap between Japan and Europe and is expected to be the largest solar telescope with an aperture larger than 1.5 m till ATST and EST come into operation.

NLST is an on-axis alt-azimuth Gregorian multi-purpose open telescope with the provision of carrying out night time stellar observations using a spectrograph at the final focus. The telescope utilizes an innovative design with low number of reflections to achieve a high throughput and low polarization. High order adaptive optics is integrated into the design that works with a modest Fried parameter of 7-cm to give diffraction limited performance. The telescope will be equipped with a suite of post-focus instruments including a high-resolution spectrograph and a polarimeter.

Keywords : Sun: general – telescopes

1. Introduction

Ground based optical solar astronomy is presently at an exciting phase of development. Till recently, only one meter class solar telescopes were in existence throughout the world. From 2009 onwards 1.5-m class, telescopes have come into existence. The next step would be a 2-m class facility. The Adaptive Optics technology crucial to taking forward the large telescopes to the diffraction limited performance has come of age for observations of the Sun. Efficient heat rejection and cooling systems are being

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designed recently. Such major initiatives are necessitated by the quest for advancing our knowledge of the Sun and understanding its impact on the terrestrial environment.

The Indian Institute of Astrophysics (IIA) has proposed a 2-m class, state-of-the-art National Large Solar Telescope (NLST) that will permit scientists to carry out cutting edge research aimed at understanding the fundamental processes taking place on the Sun. Its innovative design and backend instruments will enable observations with an unprecedented high spatial resolution that will provide crucial information on the nature of magnetic fields in the solar atmosphere. These fields are organized in flux tubes with horizontal sizes ranging from thousands of kilometers down to a few kilometers. Recent numerical simulations suggest that crucial physical processes like vortex flows, dissipation of magnetic fields and the generation of MHD waves can occur efficiently on length scales even as small as 10 km. Such waves are likely candidates for transporting energy to the upper atmosphere of the Sun. Resolving these structures observationally is of utmost importance to study and improve our understanding of the different physical processes involved. Unfortunately, even the largest current solar telescopes are limited by their apertures to resolve solar features to this level at visible wavelengths. On the global scale, the energy stored in magnetic fields is eventually dissipated in the higher layers of the solar atmosphere, for instance in the form of flares and coronal mass ejections (CMEs) that release energetic solar plasma into the interplanetary medium.

Presently, the best spatial resolution that the existing generation of solar telescopes can attain during moments of good seeing and using adaptive optics is limited to about 0.13 arcsec. In addition to the requirement of good angular resolution, a high photon throughput is also necessary for spectropolarimetric observations to accurately measure vector magnetic fields in the solar atmosphere with a good signal to noise ratio. Consequently, in order to resolve structures with sub-arcsec resolution in the solar atmosphere as well as to carry out spectropolarimetry, a sufficiently large aperture telescope is required.

Taking a cue from recent simulations, one needs at least a 2-m class telescope, operating at its diffraction limit, to observe processes occurring on spatial scales of tens of kilometers (Schüssler, private communication). Such a telescope would require about 2.5 s (at 630 nm) to carry out a single polarimetric observation (Keller 2003), which corresponds to an optimal exposure time of about 10 s to determine the 4 Stokes parameters needed for measuring the vector magnetic field.

Based on such considerations as well as practical reasons related to design and costs, we have proposed a 2-m class National Large Solar Telescope (NLST) for India. NLST will be larger than the current solar telescopes such as the 1.5-m German telescope GREGOR (on Tenerife) and the 1.6-m New Solar Telescope at Big Bear. On the other hand NLST is small enough not to run into the design problems which are related to the 4-m class projects such as the ATST (Advanced Technology Solar Telescope) and EST (European Solar Telescope) and can be completed on a much shorter time scale of about 3 years. A novel feature of NLST is that it will also be possible to carry out night time observations of stars.

2. Science objectives

NLST is envisaged as a multi-purpose instrument that will serve the needs of the national and international solar astronomers. Some of the main science goals are:

2.1 Magnetic field generation and the solar cycle

It is now well recognised that the magnetic fields on the Sun are the basic cause of this variability. Solar dynamo models that can predict the solar cycle are now possible (e.g. Choudhuri et al. 2007). Understanding how the magnetic fields are generated and maintained on the Sun, i.e. understanding the solar dynamo, hence, is basic to understanding the origin and nature of solar cycle and variability, and to predict in advance its behaviour both on short and long time scales. A high spatial, spectral and temporal resolution observation over a sustained period of time is a key requirement for such studies. NLST will fulfill such requirements to facilitate answering the following questions pertaining to the above aspects of solar dynamo: (1) how do the convective flows and associated turbulence stretch, twist and fold the local small-scale magnetic fields, and, how do such processes change the magnetic flux budget, locally and globally? (2) how do strong fields in the large scale, e.g. sunspots, filaments, etc., interact with the small-scale fields? and (3) how do large scale convective (supergranular and other possible larger scale) and meridional flows advect and diffuse the magnetic field ? and how do they change with time?. Answers to these questions will provide key observational inputs to constrain the global interior dynamo models and thus in improving the predictive capabilities of such models.

2.2 Dynamics of magnetic regions

Understanding the nature of magnetic fields is crucial for unravelling the processes that heat the solar chromosphere and corona. Observations have revealed the presence of fine-scale flux tubes in the magnetic network on the Sun. The physical processes that produce the enhanced emission in the network are still not fully understood. It has been suggested that the dissipation of magneto-acoustic, generated at the footpoints of network flux tubes, could play an important role in chromospheric heating (Hasan et al. 2005; Hasan & van Ballegooijen 2008). New observations have led to a rethinking on the nature of internetwork magnetic fields (e.g. Lites 2008; Stenflo 2010). When viewed at high resolution, sunspots reveal a complex and intricate structure, such as umbral dots, light-bridges and the interlocking-comb structure in the penumbra which is still not well understood (e.g. Thomas 2010). In addition, current vector magnetograms show a persistent pattern of electric currents and helicity associated with strong magnetic fields of active regions. Measurements of currents and twists in emerging flux tubes is important both to infer the dynamical evolution of the magnetic flux tubes while they rise through the solar interior to the surface as well as to understand the role of the twist leading to instabilities and eventual dissipation of magnetic energy in the solar atmosphere. Studies of helicity and energy fluxes in active regions (Ravindra et al. 2008) give important insights into the coronal dynamics and activity.

2.3 Helioseismology

Helioseismology is a powerful technique for probing the solar interior using acoustic oscillations. This involves coverage of the full sun and continuous observations over a long period of time. Some key problems that are under active study include detailed behaviour of the differential rotation and constraining solar abundances using helioseismic data (Basu& Antia 2008). Recently, new methods using local helioseismology have been developed (Duvall & Kosovichev 2001) that use solar oscillations to probe physical processes in localized regions and enable us to unravel the complexities of near surface convection and its interaction with magnetic fields. This technique along with 3-D tomography imaging capabilities has led to new results on the sound speed and flow structures beneath sunspots (e.g. Rajaguru et al. 2007). NLST will be able to shed light on these questions by providing accurate velocity and magnetic field information over a region extending a few arcmin.

2.4 Energetic phenomena

The corona displays a myriad of phenomena that include loops, prominences, flares and CMEs, that are believed to be inherently magnetic in nature. Space observations from SoHO, TRACE and Hinode have provided considerable information on their properties. However, a detailed picture of the underlying physical mechanisms that are responsible for their occurrence is still lacking.

Recently it has been conjectured that the onset of flares has a sub-photospheric effect that manifests itself through variations in properties of acoustic p-modes (Maurya, Ambastha & Tripathi 2009) which can be used as a proxy for flare forecasting. An important goal of NLST will be to observe the magnetic field and dynamic changes that occur during solar flares. Uniform sequences of high-resolution and high temporal cadence vector magnetograms of an active region before, during and after a flare are required to address this important issue. These changes will also be studied at different layers of the atmosphere using G band, Ca II K and H_α images. With better resolution, and with vector magentographic capabilities, NLST will be able to study much clearly fast magnetic field evolution and flux cancellations in flaring regions.

Table 1. Technical specifications of NLST.

Aperture (primary mirror M1)	:	2 metre with f/1.75
Focal length	:	4 metre
Optical configuration	:	3 mirror, Gregorian on-axis
Aberration free Field of view (FOV)	:	300 arcsec
Final focal ratio of the system	:	f/40
Image scale	:	2.58 arcsec mm^{-1}
Optical quality	:	80% of energy to be within circle of 0.1 arcsec diameter over entire field of view of 200 arcsec at 500 nm
Wavelength of operation	:	380 nm to 2.5 microns
Polarization accuracy	:	better than 1 part in 10,000
Active and Adaptive optics	:	to realize near diffraction limited performance
Strehl ratio within the isoplanatic patch	:	> 0.5
Spatial resolution	:	< 0.1 arcsec at 500 nm

This will provide important insights into the nature of magnetic energy annihilation and release during flares.

NLST will also contribute towards a better understanding of CMEs by combining optical data with radio to determine the connection between the changes that occur at chromospheric layers through H_α observations and type III radio bursts during the flares.

2.5 Night time astronomy

We propose to use NLST for carrying out stellar observations during the night using a FEROS type high resolution spectrograph. The broad areas that will be investigated are: (a) Activity monitoring in Ca, He and Balmer lines; (b) Cycles on solar-like stars; (c) Doppler imaging; (d) Radial velocity monitoring; (e) Extrasolar planets; and (f) Elemental abundances.

3. Technical specifications

Keeping in mind the aforementioned science goals, the broad technical specifications of NLST are presented in Table 1.

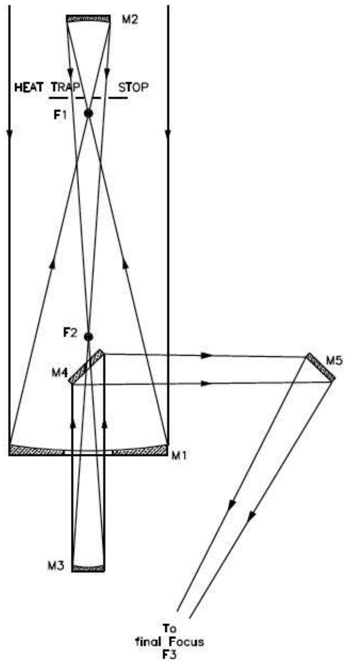

Figure 1. Optical layout of NLST.

3.1 Design

The guiding philosophy in the optical design of NLST is high optical efficiency which has been implemented by limiting the number of mirrors to only 6. NLST has a high throughput, 8 times more than GREGOR, which is highly desirable for polarimetry and speckle interferometry. The telescope has a high-order adaptive optics (AO) system to ensure diffraction limited performance. The optical design is shown in Fig. 1.

A 2-m parabolic primary mirror M1 (f/2) forms an image of the solar disk with a diameter of 33 mm at the prime focus F1. Here a cooled heat stop rejects and dissipates all the energy which does not pass through the stop. The primary mirror is cooled from below to keep it close to the ambient temperature. A beam, providing a field of view (FOV) of 300 arc sec, passes through the center hole with 3.4 mm diameter. An elliptical mirror M2 creates a f/7.7 beam and forms a secondary focus F2 at a distance of 600 mm in front of M1 and about 200 mm above the elevation axis. Here a FOV of 300 arc sec corresponds to a scale of 15 mm. A weak negative field lens is also situated here (see below). The F2 image is picked up by another elliptical mirror M3 which changes the f-ratio to f/40 in the beam that produces a final image at F3. Here we have the desired image scale of 2.58 arc sec mm^{-1}.

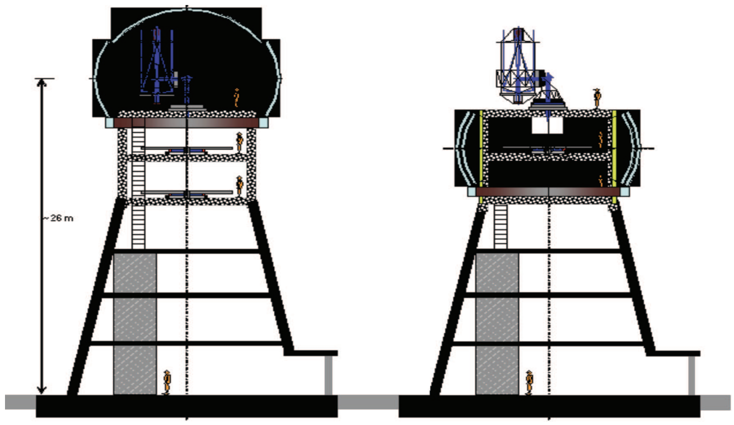

Figure 2. NLST with the dome deployed (left panel) and dome retracted (right panel)

M4 is a flat mirror with a central hole that reflects the beam into the elevation axis. The mirror group M5/M6 reflects the beam into the azimuth axis which in our design is besides the telescope. By means of the field lens in F2 the pupil is imaged on M6 which can serve as the tip tilt mirror of the AO. M5 is a deformable mirror. F3 is about 6200 mm below the elevation axis which allows for convenient access of the focus stations in the building.

A mechanical turntable behind the telescope moves the whole post focus assembly and so compensates for the rotation of the image due to the alt-azimuth telescope system. Several ports for post focus instruments are provided. These instruments include a high resolution spectrograph and polarimeter, a tunable Fabry-Perot filter for narrow band imaging at multiple wavelengths, narrow pass band filters for H_α, Ca II K, CN band, G band and 1083.0 nm observations and a fibre-fed echelle spectrograph for night time astronomy.

The telescope has an open design with a simple retractable dome that will cover the telescope during the period when there are no observations. Fig. 2 shows a vertical cross-section through the telescope, instrument platform and tower top with (a) the dome deployed (left panel) and (b) the dome retracted (right panel).

3.2 Polarimetric package

Polarimetric investigations form a major objective of NLST. We need to minimize instrumental polarization which will adversely affect the performance of the telescope. The F2 focus is unaffected by instrumental polarization because the layout is rotationally symmetric up to that point, which we find is the natural place for either calibration or modulation units. In both cases such a device contains at least one polarizer and

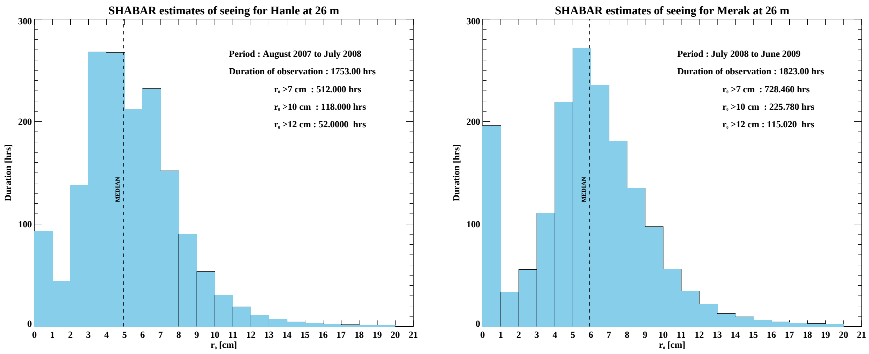

Figure 3. Histogram of r_0 for the periods (a) August 2007- July 2008 at Hanle (left panel), and (b) July 2008 - June 2009 at Merak (right panel)

one retarder with variable retardance. The polarimetry package will be placed in a space which extends 400 mm in the vertical direction and has a width three times the beam diameter.

4. Site characterization

Site characterization for NLST is being carried out at the following three sites in north India: Hanle and Merak in Ladakh (Jammu & Kashmir) and Devesthal (Uttarakhand) using a Solar Differential Image Motion Monitor (SDIMM), Shadow Band Ranger (SHABAR), automatic weather station (AWS), all sky camera, an automatic sky radiometer and a micro-thermal data acquisition system, designed and built in-house.

Two years of results obtained so far suggest that the site at Merak has excellent seeing conditions, with an average of 2270 annual sunshine hours, a median wind speed of 4.9 m s^{-1} and about 540 hours annually of seeing with a Fried's parameter $r_0 > 7$ cm (at a height of 8-m). Fig. 3 shows a histogram of the Fried's parameter using data during 2008-09. It is worth pointing out that there are a significant number of hours (over 100 in a year) with $r_0 > 10$ cm. Consequently, Merak is comparable to the best sites in the world for solar observations such as Haleakala and Big Bear.

5. Current status

The detailed concept design of NLST has been carried out by MT-Mechatronics, Germany with technical support from the Kiepenheuer Institute, Freiburg. A Detailed Project Report was brought out recently which provides details on: (a) The need for a large solar telescope; (b) the scientific objectives; (c) Site characterization programme; (d) Strategy for implementation of the project; (e) Human resource development; (f)

Budget; and (g) Technical aspects that includes a detailed concept design. The project is awaiting formal sanction from our funding agency. The fabrication of NLST is expected to begin by late 2012 and be completed by early 2016. The backend instruments for day time observations will be made in house and work on a prototype spectropolarimeter has already commenced. The spectrograph for night time astronomy will be developed by the Hamburg Observatory, Germany.

6. Summary

NLST will be a state-of-the-art 2-m class telescope for carrying out high resolution studies of the solar atmosphere. An innovative design with minimal number of mirrors, high throughput and high order adaptive optics will provide close to diffraction limited performance. Its geographical location will fill the longitudinal gap between Japan and Europe. NLST will be the largest solar telescope with an aperture greater than 1.5 m, till ATST and EST come into operation.

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