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The Indian National Large Solar Telescope (NLST)

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Abstract. The Indian 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.

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. The telescope utilizes an innovative design with low number of reflections to achieve a high throughput and low instrumental polarization. High order adaptive optics is integrated into the design that works with a modest Fried's 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. A detailed concept design of the telescope is presently being finalized and fabrication is expected to begin in 2010 with first light in 2014.

Keywords. instrumentation: high angular resolution, instrumentation: adaptive optics, site testing, Sun: magnetic fields

1. Introduction

Understanding the interaction of magnetic fields with plasma is central to interpreting various processes in the atmosphere of the Sun. 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 arc sec. 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-arc sec 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 (e.g. Schüssler 2009). 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 telescopes which are now close to completion such as GREGOR (the 1.5-m German telescope on Tenerife). 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).

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. *Dynamics of the magnetic network*

Observations have revealed the presence of fine-scale flux tubes in the magnetic network on the Sun. In Ca H or K line images, the network shows up as a collection of "coarse mottles" or "network grains" that stand out against the darker background. These features are continuously bright with intensities that vary slowly in time, in contrast to the "fine mottles" or "cell grains" which are located in the cell interiors and are much more dynamic (e.g. Rutten & Uitenbroek 1991). The physical processes that produce the enhanced emission in the network are still not fully understood. Is the network heated by wave dissipation, and if so, what are the properties of these waves? Unambiguous observations of waves would be required to settle this and related questions.

2.2. *Internetwork magnetic fields*

A major finding has taken place recently regarding the nature of magnetic fields in the internetwork (IN). New observations from the Hinode Stokes Polarimeter (SP) (with a spatial resolution of 0.3) reveal the ubiquitous presence of horizontal fields with an average value of about 55 G (Lites 2008). These observations show that, whereas the vertical magnetic field mainly occurs in the intergranular lanes at the network boundaries, the field in the internetwork regions is dominantly horizontal and well separated from the vertical fields. However, the situation may be more complex as pointed out by Stenflo (2010) on the basis of an independent analysis of the same data. More observations with good spatial and high spectropolarimetric sensitivity are needed to settle this question.

2.3. *Nature of sunspots*

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. Despite noteworthy progress on the theoretical front particularly through sophisticated numerical simulations in 3-D, there is still no general agreement on many features including the overall picture of whether sunspots are monolithic flux tubes or consist of a cluster of several flux tubes as originally proposed by Parker (1977) (for a recent review see Thomas 2009). Sunspots exhibit a range of oscillatory motions, including umbral flashes, oscillations and running penumbral waves. Sunspot seismology can serve as a probe to study the internal structure of these features. Furthermore, even after a century of its discovery, there is no universally accepted model for the Evershed effect. The above topics will form a part of the NLST observational programmes that will attempt to accurately determine the magnetic field topology with high spatial and spectral resolution.

2.4. *Action region dynamics*

A study of active regions can provide useful clues to the solar dynamo believed to be located at the base of the convection zone. Preliminary observations show that newly emerging flux has nearly constant twist. The measurement of the twist 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. Current vector magnetograms show a persistent pattern of electric currents and helicity associated with strong magnetic fields of active regions. The knowledge we have gained so far of active regions is limited. Systematic observations of magnetic helicity in these regions are lacking. Such observations require vector magnetic field measurements on spatial scales of a few tens of kilometers combined with a temporal resolution of few seconds. A large field of view of the order of 5 arc min is also essential in order to capture a full view of the entire active region.

2.5. *Coronal structures and transient 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. A quantitative understanding of these processes requires an accurate determination of the magnetic topology through vector magnetograms at high spatial resolution. This would enable us to model the complex magnetic structure in the corona through a measurement of the field in the photosphere and corona, which provides the lower boundary for the field. Such investigations would also shed new information on mechanisms responsible for coronal heating.

2.6. *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:
- Activity monitoring in Ca, He and Balmer lines;
- Cycles on solar-like stars;
- Doppler imaging;
- Radial velocity monitoring;
- Extrasolar planets;
- Elemental abundances.

3. Technical Specifications

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

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

Table 1. Technical specifications of NLST.

Aperture (primary mirror M1)	:	2 metre
Focal length	:	3.5 metre
Optical configuration	:	3 mirror, Gregorian on-axis
Field of view(FOV)	:	300 arc sec
Final focal ratio of the system	:	f/40
Image scale	:	2.5 arc sec mm^{-1}
Optical quality	:	0.06 arc sec over limited FOV of 200 arc sec and $<$ 0.3 arc sec within 300 arc sec
Wavelength of operation	:	380 nm to 2.5 microns
Polarization accuracy	:	10^{-4}
Active and Adaptive optics	:	to realize near diffraction limited performance
Strehl ratio within the isoplanatic patch	:	$>$ 0.5
Spatial resolution	:	$<$ 0.1 arc sec at 500 nm

speckle interferometry. The telescope has a high-order adaptive optics (AO) system to ensure diffraction limited performance. The optical design is shown in Figure 1.

A 2-m parabolic primary mirror M1 (f/1.75) 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 200 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 200 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 2.5 arc sec mm^{-1}.

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

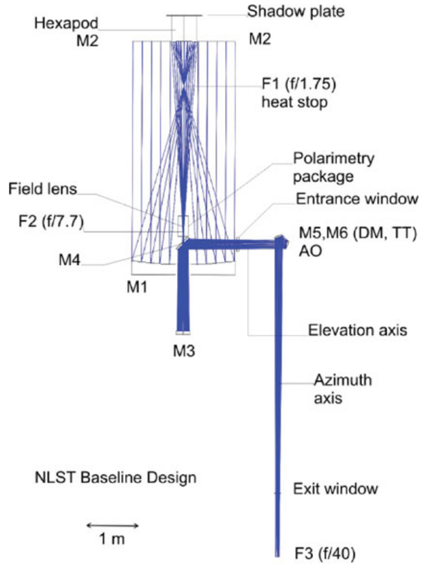

Figure 1. Optical layout of NLST

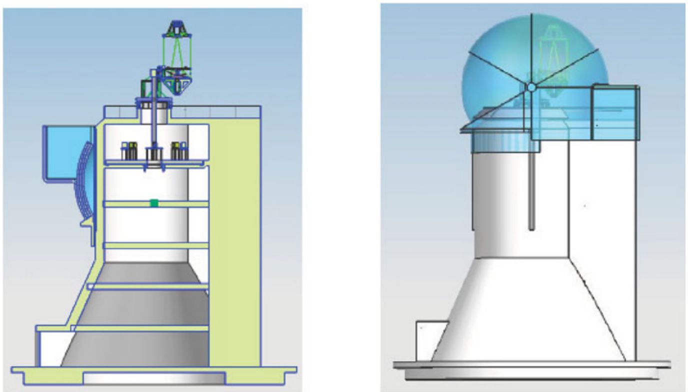

Figure 2. NLST with the dome retracted (left panel) and dome deployed (right panel)

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-alpha, 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. Figure 2 shows a vertical cross-section through the telescope, instrument platform and tower top with (a) the telescope open (left panel) and (b) the dome deployed (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 a calibration unit or a modulation unit. In both cases such a device contains at least one polarizer and 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). Figure 3 shows a histogram of the Fried's parameter using data during

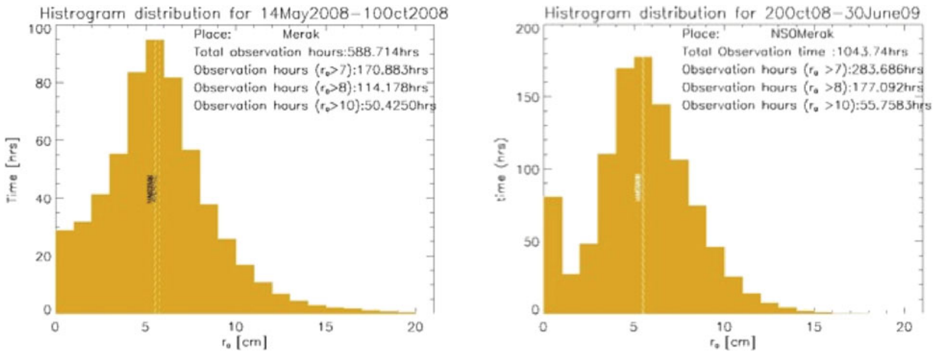

Figure 3. Histogram of r_0 for the periods (a) May 2008- Oct. 2008 (left panel), and (b) Oct. 2008 - June 2009 (right panel)

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 concept design report is now ready and a detailed proposal is under preparation for submission to our funding agency. The fabrication of NLST is expected to begin by late 2010 and be completed by early 2014. 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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