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Review Article

Solar Astronomy at High Altitude

S S HASAN*, S P BAGARE and K E RANGARAJAN
Indian Institute of Astrophysics, Bangalore 560 034, India

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A major project called the National Large Solar Telescope (NLST) has been proposed for pursuing Solar Astronomy at High Altitude. The project envisages the development of a state-of-the-art 2-m class telescope to carry out high-resolution studies of the solar atmosphere. 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 nighttime stellar observations using a spectrograph at the Nasmyth 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 Frieds parameter of 7-cm to give diffraction limited performance. The telescope will be equipped with a suite of post-focus instruments including broad and narrow band imagers, a high-resolution spectrograph and a polarimeter. A comprehensive site characterization programme has demonstrated the presence of at least two excellent sites for setting up observational facilities for solar astronomy at high altitude in India.

Key Words: Astronomy; The Sun; Telescope

Introduction

Temperature fluctuations and wind in the terrestrial atmosphere give rise to turbulence which causes blurring and twinkling of astronomical objects observed from ground. The turbulence degrades the quality of the image of celestial bodies observed through a telescope, causing it to constantly shift inposition and vary in intensity contrast or sharpness of the image over the field of observation. The perturbation caused by the Earths atmosphere is referred to as astronomical seeing. The seeing at any given place varies with time depending upon the prevailing meteorological conditions. The typical seeing conditions at various locations vary widely depending upon the geographical, topographical, and meteorological conditions of the sites.

During the day, the Sun itself contributes significantly to seeing by heating the ground, which in turn induces thermal stratification in the atmosphere. The prevailing wind and convection mix different regions in the atmosphere producing moving cells that cause perturbations in its refractive index. The energy input into the atmosphere at large length scales of hundreds of metres or more is finally dissipated by cascading down to smaller cells reaching the molecular level (Coulman andVernin, 1991; Bagare, 1995). The best possible angular resolution, meaning the smallest feature on the Sun that a telescope can resolve is limited by various physical conditions of the site. If the perturbations are strong and remain for long, the seeing will be poor while a constant flushing of the thermal variations by cool winds of moderate speed can

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*Author for Correspondence: E-mail: hasan@iiap.res.in

provide good conditions of seeing. During the past few decades, it has become possible to quantify these perturbations by measuring various parameters related to seeing.

It is, therefore, necessary to study the various conditions cited above at a wide variety of locations in order to find a suitable site for installation of a large modern solar telescope. If the location selected provides good conditions of nearly one arc second of angular resolution or better for significant continuous periods, the technology of active and adaptive optics can measure and correct for the atmospheric perturbations online, to achieve near diffraction limit of the large telescope. This means that large ground based solar telescopes can achieve better resolution than their smaller counter parts in space, where the size restrictions apply due to limitations of payload. Added to this is the advantage of the feasibility, on ground, for providing heavy back end instruments which are essential to understand the physics of the solar atmosphere.

Interestingly, it has been realized that the telescope dome and the back end instrumentation contribute significantly to the image degradation by producing thermal effects within the structure. These challenges are confronted by constant improvements in the design of the dome and the building, aimed at optimal utilization of the physical conditions prevailing such as the wind direction and speed at the site to flush away the thermals. Techniques have also been developed for efficient rejection of heat generated within the telescope. A modern solar telescope built today will benefit from these technological innovations.

Historically, it was thought that mountain sites provide the best of seeing conditions for solar observations. Various solar observatories in the early 20th century to the 1960s, such as those at Mt. Wilson, Kodaikanal, Pic-du-midi, and Sacramento Peak, belonged to this era. While these observatories provided major breakthrough in our understanding of the Sun, the need was increasingly felt to carefully examine and quantify the parameters at a wide variety of locations.

Recently, several international projects have come up such as the 4-m ATST (Advanced Technology Solar Telescope) and EST (European Solar Telescope) that will use the most modern technology to provide a new window for solar studies. In the national context, the Indian Institute of Astrophysics (IIA) has plans for setting up a 2-m class National Large Solar Telescope (NLST). Its innovative design, large collecting area, diffraction limit and post- focus instruments are aimed at understanding the fundamental nature of magnetic fields in the atmosphere of the Sun. It will replace the existing aging national facilities built several decades ago that have lost their competitive edge. NLST will be the largest solar telescope in the world for several years till the next generation of American and European facilities become operational. It will enable us to observe solar features with unprecedented detail.

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 kilometres. The diffraction limit of a 2-m solar telescope at 500 nm is 0.06 arc second which corresponds to about 40 km on the solar surface. 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 (about 90 km). 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.

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 recently commissioned telescopes such as GREGOR (the 1.5-m German telescope on Tenerife) and the 1.6-m NST (New Solar Telescope) at Big Bear. On

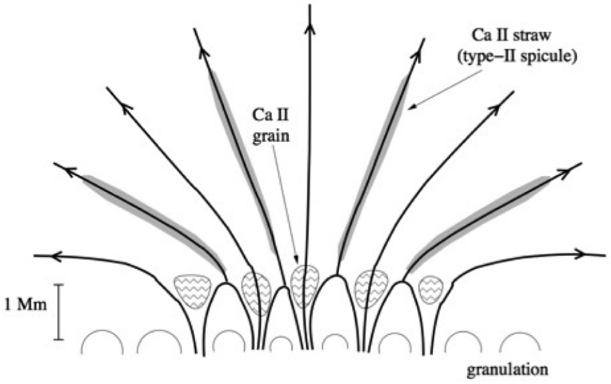

Fig. 1: **Schematic diagram showing the structure of a magnetic network element on the quiet Sun. The thin half-circles at the bottom of the figure represent the granulation flow field, and the thick curves represent magnetic field lines of flux tubes that are rooted in the intergranular lanes. The Ca II bright grains are thought to be located inside the flux tubes at heights of about 1 Mm above the base of the photosphere. We suggest that the Ca II straws may be located at the boundaries between the flux tubes (from Hasan and van Ballegooijen, 2008)**

the other hand NLST is small enough not to run into the design problems which are related to the telescopes with 4-m and larger apertures.

NLST will be a state-of-the-art 2-m class telescope giving diffraction limited images at visible wavelengths. It will be a fully reflecting on-axis alt-azimuth Gregorian multi-purpose open telescope with the provision of carrying out night time stellar observations. Its field-of-view of 300 arc sec will enable access to the 0.38 to 2.5 micron wavelength range. 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.

Science Goals

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 andUitenbroek, 1991). A possible interpretation of the Ca II observations is summarized in Figure 1 where we show a vertical cross section of a magnetic network element consisting of several discrete flux tubes. Hasan and Ballegoiijen (2008) suggest that the Ca II network grains are located inside the magnetic flux tubes, and give rise to the bulk of the Ca II emission from the network element. The grains are thought to be located at heights between 500 km and 1500 km above the photosphere where the flux tubes are no longer "thin" compared to the pressure scale height (about 200 km), but are still well separated from each other. The Ca II straws (type-II spicules) have widths of order 100 km, and are located at larger heights (several Mm) where the widths of the flux tubes are much larger than 100 km. 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.

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 *et al.*, 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.

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, 2010). 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.

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 kilometres 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.

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.

High Altitude Advantages for Infrared and UV Observations

High altitude sites with low water vapor provide the advantage of carrying out observations in infrared (IR) wavelengths. It is well known that the negative Hydrogen H- ion (bound-free transitions) in the visible and H- (free-free transitions) in the infrared (IR) wavelengths respectively are the principal sources of continuous opacity in the Sun. Furthermore, this opacity is lowest at 1.58μ, and hence offers a window to observe the deep layers below the photospheric level at this wavelength. The Fe I lines at wavelengths close to 1.56μ have high Landé g-factor and so are useful for the measurements of weak, small-scale magnetic fields (Solanki *et al*., 1992; Lin and Rimmele, 1999; Socas-Navarro and Lites, 2004 and references therein). A large fraction of the solar magnetic flux is likely contained in these weak fields and their importance for the solar dynamo is not yet understood (Schüssler, 2005).

He I 108.30 nm can be used to measure chromospheric magnetic fields, for example, in filaments, prominences and spicules (Lin *et al*., 1998). Simultaneous photospheric and chromospheric magnetic field measurements (Socas-Navarro, 2005) performed with instruments such as the SPINOR (Spectropolarimeter for Infrared and Optical Regions) (Elmore *et al*., 2005;Socas-Navarro *et al*., 2006) that provide crucial information about the 3-D structure of the magnetic field. NLST backend instruments will also be designed in a similar fashion for multiline polarimetry at visible and infrared wavelengths. In combination with a large photon collecting area, it will provide a unique tool for polarimetric investigations of the upper solar atmosphere.

Scattering polarization is more pronounced at shorter wavelengths, due to a number of physical arguments. The near ultraviolet part of the solar spectrum therefore ideally complements the visible and near infrared portionsof solar radiation, which are traditionally used in Zeeman imaging. A spectral line that has proven to be particularly suited for this purpose is the Ca I line around 422.7 nm. Observations in these wavelengths reveal complicated polarisation effects of both the Hanle and the Zeeman effects and are therefore of particular interest for the understanding of chromospheric magnetic fields.

Night Time Astronomy

We propose to use NLST to carry 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.

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

Design

The guiding philosophy in the optical design of NLST is high optical efficiency that has been implemented by limiting the number of mirrors toonly 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 scheme is shown in the top panel of Fig. 2. There are three mirrors (M1, M2 and M3) with power, and four flat mirrors including the deformable mirror (DM) M5 and tip/ tilt (TT) mirror M6. The imaging is shown in orange and the pupil imaging in blue. The M2 mirror magnifies the image by a factor of 5 and produces an image at the secondary focus F2. Close to this focus is a weak negative field lens which is used to provide a pupil on the tip tilt mirror (M6).

The bottom panel in Fig. 2 schematically depicts the optical layout of the telescope: a 2-m parabolic primary mirror M1 (f/1.75) forms an image of the

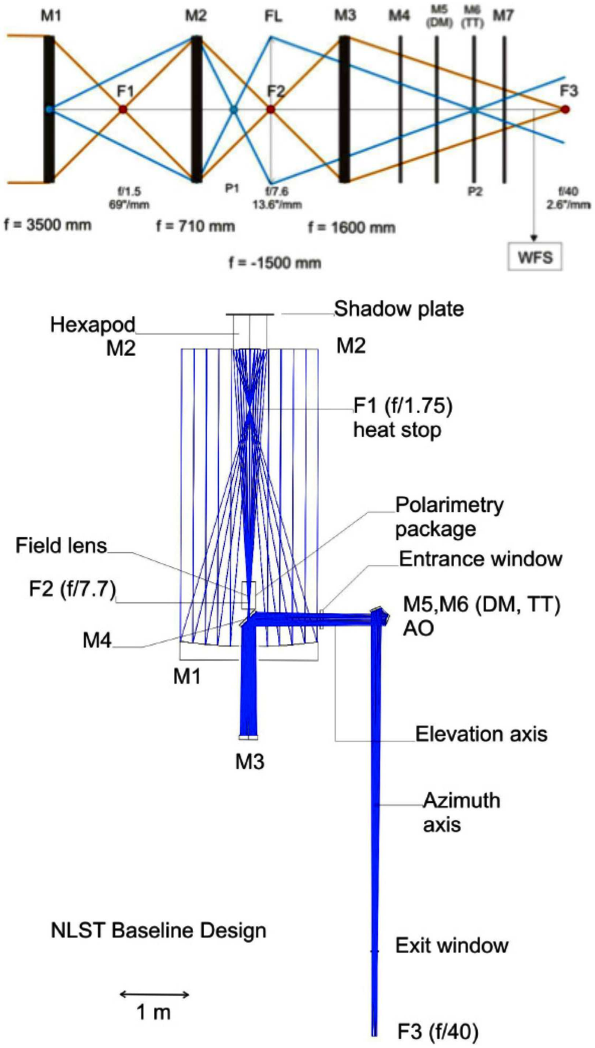

Fig. 2: **NLST Optical scheme (top panel) and schematic optical layout (bottom panel)**

Table 1: Technical specifications of NLST

Aperture (primary mirror M1)	2 metre
Focal length	3.5 metre
Optical configuration	3 mirror, Gregorian
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

solar disk with a diameter of 34 mm at the prime focus F1. Here we have the largest heat concentration of about 2.8 $\mathrm{MW/m}^2$. A reflecting and cooled heat stop rejects and dissipates all the energy that does not pass through the stop. The primary mirror that receives a heat load of 3 kW is cooled from below using cold air to keep it close to the ambient temperature. This cooling is further facilitated by the natural airflow owing to the open design of the telescope. A beam, providing a field of view (FOV) of 200 arc sec, passes through the field stop. 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 M1and about 200 mm above the elevation axis. 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 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 to prevent heat accumulation in the structure. The left panel in Fig. 3 schematically shows an overview of the telescope structure and the right panel shows the telescope with a simple retractable dome that will cover the telescope during the period when there are no observations.

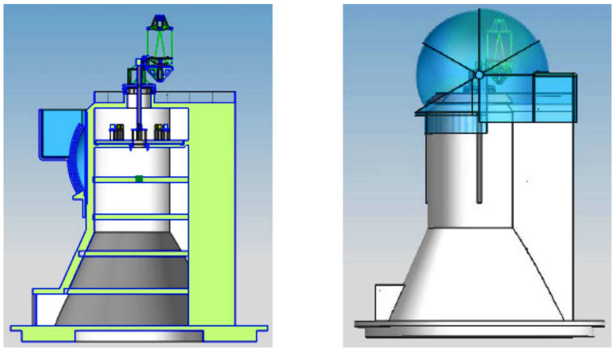

Fig. 3: Overview of the telescope structure (left panel) and the telescope and tower with the dome retracted (right panel)

Spectropolarimeter

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.

A 2-m aperture 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 with a high time cadence and good spatial and spectral resolution. The instrument will have flexibility to observe any given line or a combination of lines either on the disk or off limb so that a broad range of scientific problems can be investigated.

Narrow Band Imaging

Narrow band imaging will provide observations that will enable a study of a large class of problems such as (a) the determination of shear in active region magnetic fields, (b) evolution of magnetic fields during filament eruption, (c) emergence of magnetic flux, and (d) flare induced changes in spectral line properties. The proposed narrow band imager for the NLST is based upon the dual Fabry-Perot (FP) etalons placed in tandem. Table 2 gives the design specification of the narrow band imager.

Table 2: Specifications of the Narrow Band Imager

Spectral resolution	$\geq$ 200000 at 600 nm
Spectral range	500-900 nm
Field of view (FOV)	$\leq$ 1.5 arc min
Maximum ghost transmission	10^{-4}
Signal to noise ratio	$\geq$ 500
Peak transmission	$\geq$ 50%
Wavelength stability	$\leq$ 10 m Å hr^{-1}
Tuning rate	$\geq$ 10pm ms^{-1}
Blocking filter	2-3 Å range
Maximum stray light	10^{-3}
Image cadence	$\geq$ 1frame per sec

Broad Band Imaging

The prime objective of the instrument is to obtain high spatial and temporal resolution images of the region of interest on the Sun in the wavelength range from 390 nm to 1083 nm. This instrument will provide high resolution, fast cadence movies of penumbral fibre formation, umbral flows, and interactions. It will use several wavelength bands to discriminate between various layers in sunspot umbral and penumbral structure. Simultaneous broad-band imaging and the polarimetric observations of sunspots would help assessing the three dimensional structure of sunspots and their magnetic fields. By observing faculae embedded in the granulation at the very high spatial and temporal resolutions one can investigate the detailed contribution to the irradiation that faculae provide. High spatial resolution observations at different wavelengths that reflect atmospheric variations at different heights with a cadence of 10 s or less are required to probe the chromospheric heating mechanisms.

Site Characterization

Critical to the successful implementation of NLST is the selection of a site with optimum atmospheric properties. Absence of clouds is one of the primary criteria. Another is the frequent presence of good seeing over long periods of time. Also of importance are good clear skies. ‘Good seeing’ includes not only good image quality but also atmospheric optics parameters which influence the design and performance of solar adaptive optics (isoplanatic patch diameter and time constant of wavefront changes).

Several surveys were taken up and carried out successfully during the latter part of the 20th century, leading to the discovery of some of the best sites in the world for solar observations. Some of the major surveys include the Caltech survey in southern California during 1970s (Zirin and Mosher, 1988), the Large European Solar Telescope (LEST) survey of 1970s and 80s (Brandt and Righini, 1985), the ATST survey of 1990s to 2000s (Socas-Navarro *et al.*, 2005). The Caltech survey covered, for the first time, a wide variety of topographies and showed the advantages of lake sites and also found that coastal and sea level inland sites do not provide the desirable conditions of seeing. It must be noted here that John Evershed, who spent a couple of years observing the Sun from lake sites in Kashmir, had realized the advantage of a water body for providing a good site for solar observations (Evershed, 1915).

Surveys in China (eg. Li Shuang-xi *et al*., 2004) showed that the Tibetan plateau has the best of astronomical sites at the high altitudes of over 3000 m. Some of the measurements at solar observatories in India, at the Kodaikanal Observatory at altitude of 2343 m (Bagare, 1995) and at the Udaipur Solar Observatory at altitude of about 700 m (Kumar *et al*., 2007) show that the seeing is moderate at these inland sites, at averages of 2 arc sec and 3 to 4 arc sec respectively. The daytime seeing is comparable to these at the Nainital solar facility, at an altitude of about 2100 m.

Benefiting from the experiences of above cited earlier surveys, a preliminary study of the Indian geographical bounds was carried out during early 2006. It was noted that the Indian sub-continent faces the two major monsoons. Also, the coastal and inland sites, as shown by the Caltech survey, do not provide the best of locations. It was realized that the mountain desert conditions of Ladakh provide good number of sunshine hours with minimal precipitation and have the other advantages of high altitude.

Fig. 4: Collage of instruments, clock wise from top right, (1) SDIMM and SHABAR, (2) sky radiometer and all sky camera, (3) data acquisition facility at Merak site of Pangong lake, and (4) AWS at Merak. The picture in the middle is of the micro thermal tower at Merak

Hanle, at an altitude of 4500 m in the Great Himalayan range in Ladakh, with known good conditions for astronomical seeing for night sky, and the advantage of existing infrastructure, was chosen as one of the sites for evaluation. Similarly, Devasthal which is in the Shivalik Hills of the Central Himalayan range and has been shown to have good night sky conditions, for the ARIES 1.3-m and 3.6-m stellar telescopes, was also chosen for detailed evaluation since it provides another topographical environment at an altitude of 2500 m.

Reconnaissance was carried out for lake sites in the Ladakh region of Great Himalayan range and in the Shivalik Hill range. The available access to the southern skies for observing the Sun during most parts of the year at this northern latitude and the obstructions by surrounding hills to solar observations, as well as the prevailing wind conditions which are expected to favour the daytime seeing, were examined. This led to the identification of Pangong lake site for detailed characterization. Pangong lake appeared promising specially due to the following advantages; (a) about 40 km stretch of the lake within India, (b) the several land incursions mostly surrounded by water body of the lake, (c) the almost east west elongation, (d) the wind ducting from east to west which is expected to be favourable for daytime conditions, (e) the large flat land at the southern shore allowing good access to the southern declination, (f) the atmosphere has low water vapor content, and (g) the region is unaffected by the monsoon.

One set of Solar Differential Image Motion Monitor (SDIMM) and a Shadow Band Ranger (SHABAR) developed for the ATST site survey was procured on loan from the National Solar Observatory (NSO), Tucson. Simultaneously, the indigenous development of SDIMM was taken up at the laboratories in Bangalore. Work on building micro thermal devices and towers were also carried out with the aimstudying the thermal fluctuations in the near ground to about 15 metre height at the sites. All sky cameras, a sky radiometer and high cadence automatic weather stations were also procured. Figure 4 shows the various instruments on location at Merak. Table 3 specifies the various parameters and the corresponding instruments used for site characterization.

Table 3: Parameters and corresponding instruments chosen for site evaluation

Parameter	Instrument
Annual sunshine hours	All sky camera, automatic weather station (AWS) - irradiance measure
Fried's parameter (r_o) above ground	Solar Differential Motion Monitor (SDIMM)
Fried's parameter (r_o) up to 100-m above ground	Shadow Band Ranger (SHABAR)
Sky brightness, aerosol, dust & contaminants	Sky radiometer
Precipitation, wind and humidity	AWS
Temperature variation with height	Microthermal tower

Starting early 2007, and until recently, regular observations of seeing and other related parameters outlined above were carried out at Hanle and at Merak. At Devasthal the AWS and micro thermal observations started in October 2009, whereas SDIMM observations began in December 2009. Data collection, archival, reduction, analysis and studies were carried out on a regular basis at the NLST laboratory in Bangalore. A comprehensive site characterization report was prepared based on these studies. We quantify the "seeing" conditions in terms of the Fried parameter r_0. Table 4 summarizes the seeing conditions at various sites in terms of continuous blocks with r_0 greater than various values for several durations (in minutes). The last two columns depict the corrected annual hours taking in to account the instrument down time.

The highlights of the findings are as follows:

- Merak on the shores of the Pangong lake is a world class site comparable to the best such as

Table 4: Summary of daytime seeing condition at three sites

Site	Blocks of $r_0 > 7$				Blocks of $r_0 > 12$				Corrected Annual Hours	
	30	60	120	240	30	60	120	240	$r_0 > 7$	$r_0 > 12$
Devesthal	59	31	7	1	7	2	-	-	62	8
Hanle	241	48	9	5	12	3	1	-	214	11
Merak	707	271	100	10	28	5	2	-	495	28

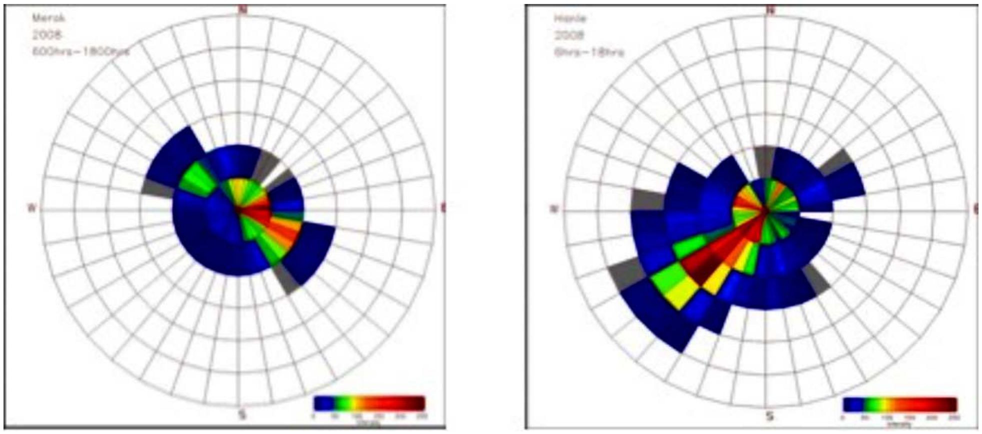

Fig. 5: **Polar plots of wind speed and directions at Merak and Hanle. The concentric circles show wind speed in steps of 5 mps. The number density of points is colour coded. The favourable wind conditions at Merak is cognizable. The heavy wind conditions at Hanle, reaching 25 mps can be seen in the left panel. These conditions prevail in the post noon hours**

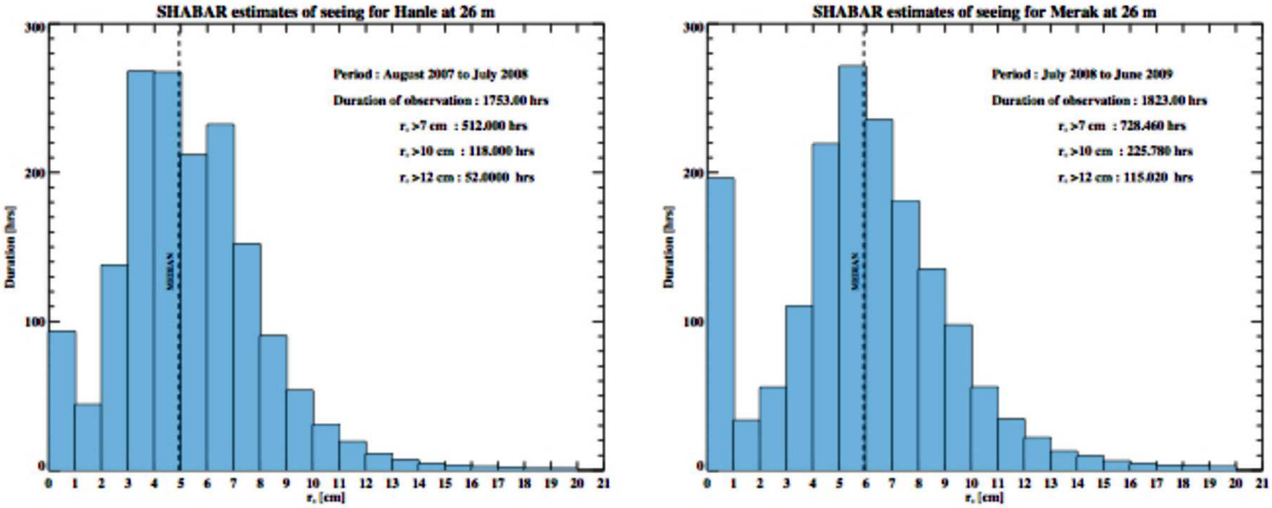

Fig. 6: Histogram of r_0 for the periods (a) August 2007-July 2008 at Hanle (left panel) and (b) July 2008-June 2009 at Merak (right panel)

Haleakala and Big Bear, and well suited for the installation of a large solar telescope for optical and near IR observations (advantage of high altitude desert). It also provides significant periods of coronagraphic skies (high transparency). The laminar winds with mild gusts throughout the day provide periods of outstanding seeing (see left panel in Fig. 5). The prevailing wind is very advantageous since it passes over several kilometres of water body. The wind direction is also remarkably steady, guided and ducted by the mountain ranges on both sides. The total annual sunshine hours is in the range of 1700 hours. As seen from Table 4 and Figure 6 (right panel) the site has excellent sky conditions which shows about 730 hours annually with a Fried's parameter $r_0 > 7$ cm and several blocks (2 hours and above) with $r_0 > 12$ cm at heights 26-30 m above the ground;

- Hanle is next best with good to excellent seeing conditions, providing significant durations of good periods of $r_0 > 7$ and 12 cm, at heights of 30 to 36 m (see left panel in Figure 6). The best observation conditions are in the morning hours while the afternoon periods sometimes experience windy conditions (see the left panel in Figure 5). The total annual sunshine hours are in the range of 1600 to 1750 hours. Good spells of sub arc second periods do occur for significant durations. The aerosol and dust content studies have been studied and the results show that the aerosol content is extremely low, typical of the mountain site. The dust is generally low except during windy conditions when winds from Saharan region from southwest seem to be moving into the region (Verma *et al*., 2009). It is better suited than Merak for near IR studies and is practically comparable for coronagraphic quality of skies;

- Devasthal has good periods of seeing in very short spells but not in blocks of 30 min to 2 hours, which are essential for a large solar facility. The winds are extremely low in speed and not sufficient to flush the thermals. The thick vegetation does not seem to favour day sky observations, as was illustrated for the Sacramento Peak Observatory in New Mexico, U.S.A.. The site is suitable for near IR studies for a limited period of about two months in a year. The annual sunshine hours is low in the range of 1280 ± 150, which is caused by severe monsoon period between June and September each year.

Current Status

The detailed concept design of NLST was been carried out by MT Mechatronics, Germany with technical support from the Kiepenheuer Institute, Freiburg. A Detailed Project Report was brought out which provided details on the scientific and technical aspects (including a detailed concept design) of the project as well as a site characterization report. Environmental impact assessment and feasibility studies were also carried out which concluded that the project has no adverse environmental impact and that the proposed sites in the Jammu and Kashmir region are feasible from geotechnical considerations forthe construction of NLST. A technical committee identified a vendor for fabricating the telescope.

The project is awaiting formal sanction from our funding agency. We expect that the fabrication of NLST will commence in 2016 and be completed by 2019. The backend instruments for daytime observations will be made in house – work on the development of prototype instruments that include narrow and broad band imagers and spectropolarimeter has already commenced. Collaborations with various international agencies are being explored.

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