Two thousand metres closer to the Sun – the National Large Solar Telescope project

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The highest and oldest functioning solar observatory in India – the Kodaikanal Solar Observatory rests on the southern tip of Palni Hills in Tamil Nadu at an altitude of 2343 m. One of the major current projects in the field of astronomy and astrophysics in India promises a new advanced 2 m solar telescope which will be located 2000 m closer to the Sun.

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THE solar eclipse in 1868 marked the birth of solar physics in India, when helium was discovered in the solar spectrum. Soon after, in 1901, the Kodaikanal Solar Observatory commenced its first solar observations. It was here that two years after his arrival, John Evershed discovered the radial outflow of gas in sunspots known as the Evershed effect[1]. The Tower Tunnel Telescope at the Kodaikanal Solar Observatory has been a major source of quality data for solar physics research in India for the last 35 years[2]. Moderate solar telescope facilities exist in Nainital and a new 50 cm Multi-Application Solar Telescope (MAST) at Udaipur has recently been installed. The proposed National Large Solar Telescope (NLST) is a 2 m class on-axis Gregorian telescope, designed to observe the Sun with unprecedented spatial resolution and sensitivity. The Indo-German collaborative initiative, led by the Indian Institute of Astrophysics (IIA), Bangalore will be a giant step forward for the modern solar observations in India, and a platform for promoting scientific research among young people. Furthermore, the new facility will generate important opportunities for new and exciting collaborations with the astrophysics community outside India.

The NLST project, funded by the Department of Science and Technology will bring together the diverse expertise and research potential of Indian and German institutions. IIA is the leading institution in the NLST project with the Indian Space Research Organization, the Aryabhatta Research Institute of Observational Sciences, and Physical Research Laboratory being its Indian collaborators. Keiepenheuer Institute for Solar Physics, Freiburg, and the Hamburg Observatory are the German partners in this project. At present, a detailed concept design has been completed and the prototype development of a spectropolarimeter as one of the back-end instruments has started at IIA[2]. The project planning and timeline indicate 2014 as the likely year when NLST should be fully operational.

NLST belongs to a new class of large, open-structure solar telescopes along with GREGOR (a 1.5 m solar telescope expected to be commissioned in 2011 on the island of Tenerife, Spain) and the New Solar Telescope (a 1.6 m solar telescope recently installed at Big Bear Solar Observatory, CA, USA). The National Science Foundation, USA, has funded the design and construction of a 4 m Advanced Technology Solar Telescope in the Haleakala National Park, Maui, Hawaii. The European analogue for it would be the 4 m European Solar Telescope. Both these projects pose scientific and technological challenges that dictate long-time frames on the scale of a decade. The 2 m NLST avoids the uncertainties ensued by such long-term scientific projects, while still improving the spatial, spectral and polarimetric resolution of the currently existing solar telescopes.

Two major factors ignite the motivation for current solar physics research. On one hand, the solar elecromagnetic and particle radiation defines life processes here on Earth and influences all terrestrial climate and weather phenomena. Having realized this a long time ago, humanity has pushed forward large intellectual potential and effort towards better understanding of the fundamental laws that govern the physical processes in the Sun. On the other hand, solar physics as a branch of stellar physics takes advantage of our proximity to the Sun to study its structure and dynamics in detail and apply this knowledge to similar stars located much further away in the universe.

Years of extensive research have significantly improved our understanding of solar physics today. It is now largely accepted that the magnetic fields of the Sun are the primary defining forces of almost all observed processes like prominences, flares, sunspots, coronal mass ejections, solar cycle activity, etc. Given this, contemporary solar physics research is largely focused on discovering the underlying laws and principles that govern solar magnetism and their

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connection to the observed phenomena in the photosphere, chromosphere and corona of the Sun. This task can be achieved with the development of observational technology and instrumentation with higher sensitivity, polarimetric accuracy, and spatial, temporal and spectral resolution. The NLST project is the joint effort of a number of researchers and engineers to construct the required next level instrumentation for such advance solar observations.

NLST will primarily observe: (i) small-scale solar magnetic structure, active regions, sunspots and their dynamical evolution, (ii) magnetoconvection and the processes that are responsible for generating magnetic fields at the solar surface and (iii) dynamics of the chromosphere and the corona, etc. The capability of NLST for night-time stellar observations will also deliver useful data in the areas of Doppler imaging, radial velocity monitoring and understanding the properties of extrasolar planets[2].

The project will address a diverse set of scientific goals. Despite the significant progress in the development of 3D models of magnetic fields of the Sun, many questions are still unanswered with no generally accepted theory among the solar physics community. NLST will make observations on the magnetic field topology and small-scale flux tubes in the magnetic network of the Sun with very high spatial and spectral resolution[3]. Such observations are crucial for advancing our understanding of the complex structure of sunspots. The existing knowledge of the dynamic evolution of the magnetic flux tubes in the active regions is still limited and only a few systematic observations have been made of the magnetic helicity, which is crucial for understanding the energy release mechanism in flares and other processes in these regions[3].

To examine the above questions, observations require a high throughput (photons per pixel per second) of the telescope that can guarantee spectropolarimetric measurements of the vector magnetic fields with good signal-to-noise ratio, spatial resolution of the order of few tens of kilometres as well as temporal resolution of a few seconds. NLST and its post-focus instrumentation meet all of these requirements, while at the same time, an entire active region is captured through its large field of view (FOV). Fine-scale vector magnetic field measurements carried out with NLST will also study the magnetic topology of a number of coronal processes like flares, prominences and CMEs. While advancing our understanding of the mechanisms behind such phenomena, NLST vector magnetic field measurements may also provide new insight into the processes leading to coronal heating – an elusive question popularly called the 'coronal heating problem'. NLST performance characteristics combined with sophisticated backend instrumentation are sufficient to deliver reliable, simultaneous photospheric and chromospheric magnetic field measurements from which the 3D magnetic field structure of the Sun can be deduced. Furthermore, multiline polarimetry at visible and infrared wavelengths will be used to probe the polarimetric properties of the upper solar atmosphere[3].

Several major considerations drive the design concept of NLST – (i) the size of the primary mirror should provide spatial resolution that is high enough (the final resolution is also dependent on the telescope optics); (ii) the number of mirrors should be minimized to achieve high throughput and minimize the instrument polarization; (iii) the adaptive optics (AO) system should be integrated into the optical design, and (iv) the mechanical structure should take advantage of the local environmental conditions and serve as an integral part of the telescope cooling system[3]. A 2 m diameter primary mirror provides a diffraction limit of 0.06 arcsec at a wavelength of 500 nm, which translates to about 40 km of spatial resolution on the surface of the Sun. This resolution is better than the best currently reported resolution of 90 km for the existing class of solar telescopes[3]. The innovative optical design of NLST utilizes only six mirrors and one lens before the output reaches the science focus where the back-end instrumentation will be installed. This is a crucial requirement for achieving the desired high throughput and minimizing the instrument polarization, thus improving the telescope polarimetric sensitivity. The optical scheme of NLST is depicted in Figure 1. The parabolic primary mirror M1 forms a focus at the stopfield F1, which will reject 99% of the incoming radiation of about 3 kW. A central hole at the stopfield sets the FOV of the telescope at 200 arcsec (~ 133,000 km on the surface of the Sun). An elliptical mirror M2 forms a secondary image at F2 and the science focus is formed at F3 by the elliptical mirror M3. M4 directs the output along the elevation axis to the M5/M6 section, which constitutes the integrated adaptive optics of NLST. M5 and M6 are the tip-tilt and the deformable mirror, respectively. The AO is also used to tilt the output beam 90° to the azimuth axis, where the mirror M7 delivers it to the post-focus instrumentation. The final f-ratio of NLST is $f/40$. In order to have the AO integrated into the system, a small lens close to F2 is used to create the pupil at the desired M6 deformable mirror. NLST is also designed in a way that provides an opportunity for a polarization optics to be placed near F2, where the polarization errors from the instrument are negligible. The configuration described above will deliver diffraction limited images in the 0.38–2.5 μm wavelength range.

In order to keep the number of mirrors in the telescope to a minimum, the mechanical design of NLST is asymmetric with the elevation and azimuth axes intersecting beside, rather than within, the telescope tube. The advantage of such an asymmetrical structure is that for each elevation there are two azimuth positions (separated by 180°), such that the lee side position of the telescope tube can be chosen in strong wind conditions. The disadvantage in this case is an increased dome size. Another important feature of NLST is its open structure designed to exploit the naturally available laminar wind flows to further cool down the primary mirror and the stopfield, and keep the system at ambient temperature, therefore significantly improving the seeing. In order to avoid any negative effect of the dome edges to air flow in the lower part of the telescope, the NLST dome is designed as a fully retractable dome that can be completely pulled back below the telescope platform[4]. Detailed dynamic analysis and simulations were performed to determine the shape and robustness of the structure as well as the overall pointing error budget. The final shape and design of the building and platforms were chosen such that the simulated wind patterns reduce wind-induced vibrations. The control and instrumentation rooms will be located on the upper section of the tower. The total height from the ground to the telescope axis is 26 m and the dome platform has a diameter of 12 m. Figure 2 shows the mechanical structure of NLST along with the dome and tower.

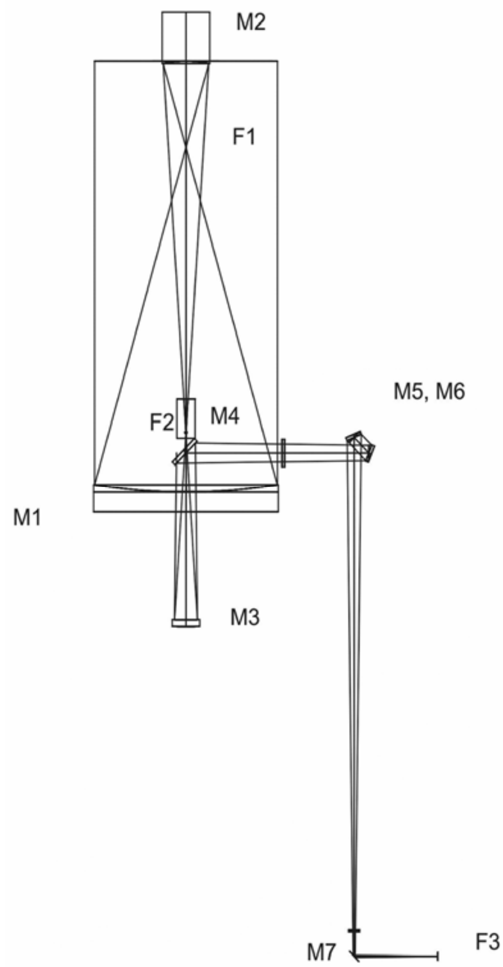

Figure 1. Optical design concept for the National Large Solar Telescope. Image credit: Hasan *et al.*[4].

The proposed measurements with NLST require complex and custom-built back-end instrumentation. To study magnetohydrodynamic waves and oscillations, researchers will look at intensity variations and velocities of the magnetic field. Such measurements need spatial information from a spectropolarimeter with spectral resolution of a few tenths of a picometre, polarization accuracy of 0.1%, and high cadence imaging. Active region evolution will also be studied using velocity and vector magnetic field measurements carried out with a spectropolarimeter. To capture the entire active region, the telescope should operate with its maximum FOV of 300 arcsec. On the other hand, photospheric small-scale structure measurements require spectropolarimetric measurements with a FOV of around 30 arcsec. Offlimb observations will be carried out using a spectropolarimeter with a high-resolution spectrograph. This large spectrum of scientific observations imposes diverse requirements on the instrumentation that cannot be achieved with a single spectropolarimetric device. Therefore, three separate instruments will be developed in-house here in India. These are the multi-slit imaging capable spectropolarimeter using an integral field unit; a single-slit high spectral resolution spectropolarimeter, and a Fabry–Perot-based imaging spectropolarimeter[2]. A research group at IIA has already started the development of the Fabry–Perot-based imaging spectropolarimeter. Apart from the spectropolarimeters, a fibre-fed high-resolution spectrograph will be developed by the Hamburg Observatory, Germany and used for night-time stellar observations on NLST.

Finally, the NLST team of researchers is involved in a comprehensive evaluation of a few suitable deployment

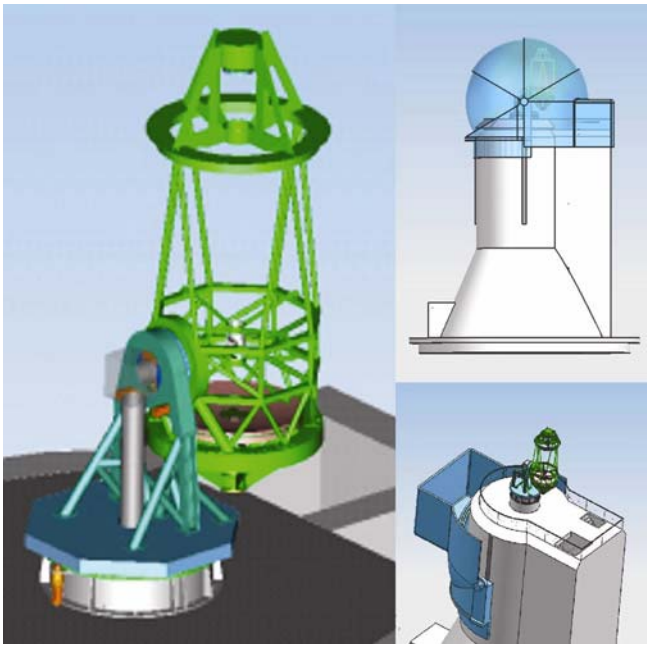

Figure 2. Mechanical design concept for NLST. Image credit: Hasan *et al.*[4].

sites for the NLST telescope. Some of the major factors defining a good astronomical seeing include clear skies, stable atmospheric conditions, reduced atmospheric turbulence and a low water-vapour content (required for infrared observations). Several international surveys (Caltech survey, Large European Solar Telescope survey, ATST survey, etc.) conducted in the last few decades provide an extensive reference of the most favourable conditions for solar telescope observations[3,5]. Based on these, the NLST team of researchers and engineers narrowed its choice to three sites: Hanle in Ladakh, at an altitude of 4500 m; Merak village by the Pangong Lake, Ladakh at an altitude of 4350 m, and Devesthal in the central Himalayan region at an altitude of 2500 m (ref. 5). Extensive site characterization for the last two years has revealed that the seeing conditions in Ladakh region are better than those in Devesthal, as Ladakh is unaffected by monsoon and provides almost uninterrupted clear skies. The conditions at Hanle and Merak were found to be similar in terms of seeing, but strong unfavourable afternoon winds were observed at Hanle. Thus, Merak with around 1700 h of annual sunshine hours, stable east-west winds of a few metres per second, and low water-vapour content needed for infrared observations was identified as the most suitable deployment location for NLST. The flat land in the south allows for access to southern declinations and the land incursions surrounded by water provide stable atmospheric conditions (the advantages of lake sites come from the fact that over water, evaporation occurs simultaneously with cooling, which provides a natural temperature inversion that reduces local refractive index fluctuations).

Pangong Lake is one of the largest brackish lakes in Asia that has been recognized as an important high-altitude wetland habitat (http://www.ramsar.org). It lies on the migratory route of many birds, including the elusive black-necked crane – the state bird of Jammu and Kashmir. Embracing the responsibility of holistic assessment of the goals and impact of the project, IIA is conducting research to estimate the possible imprint of NLST on the local environment and bird species. The results of this research will be used to propose strategies which will ensure that the construction, as well as operational phases of the project can be undertaken with minimal disturbance to the local flora and fauna.

Born as a concept that emerged from the collective intellectual potential of researchers who all share the quality of unquenchable urge to probe further into the unknown, today NLST is a full-running project expected to deliver the largest solar telescope in 2014. Indian institutions, collaborating with German partners have combined their effort and expertise in the development of the telescope, its mechanical structure and back-end instrumentation. The NLST data with their unprecedented spatial resolution will allow scientists to refine models, test existing theories and set the groundwork for the development of new ones. Many questions will be answered and many more will be formulated – that is the inherent nature of research. At Pangong Lake, the gleaming rays of the Sun will soon meet the craving eyes of the black-necked crane, and NLST.

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