

Large Indian Solar Observatory

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1. Introduction

More than three decades back, Dr. M. K. V. Bappu, the father of modern Indian Astronomy, wrote the following paragraph in "Current Science", about a solar physicist's dream. "On the solar side, the ground-based telescope still offers the maximum for the high-resolution study. The vacuum telescope located at a good site should be able to obtain spectra of features less than half a second of arc. Choice of site in a wide expansion of water holds much promise. Very small islands, less than a 100 meters across in an ocean, are a good possibility. Much careful study should be made in this regard before locating a large vacuum telescope of the order of 150 cm in aperture. A bright solar image of large scale under almost perfect conditions of seeing would be answer to the solar physicist's dream"¹. There have been several attempts, in the mean time; to build a large ground based solar telescopes during the last thirty years^{2,3}. At the same time, there have been great advances in the field of solar physics both from ground based and space observations. Specially the last decade have witnessed a great progress in solar research due to a host of space missions like Yohkoh, SOHO, TRACE and RHESSI. At the present time, the 50 cm solar space telescope, capable of 0.5 arc second spatial resolution, is being built for deployment in early 2006. There are two major ground based facilities, one 4 meter aperture solar telescope in USA "Advanced Technology Solar Telescope" and the other 1.4 meter aperture telescope in Germany "GREGOR" are being built to be operative in 2010 and 2005 respectively. Clearly, these two instruments will make great contributions in our understanding of the fine solar features. Besides these new instruments, there have been a number of telescopes that were equipped with instruments to correct the atmosphere induced effects for image distortion (adaptive optics) leading to very high spatial resolution observations of the sun. In the recent past, the Indian solar researchers have been seriously contemplating to make a large telescope for observational study of the solar features. Here, I describe various aspects of such an instrument and outline a possible scenario to realize it.

2. Science Goals

The physics of the sun is interesting at least from two points of view. The first one is related to the utility point of view, as the life on earth is governed by it. The terrestrial and near earth space weather in the near earth environment is basically governed by the electromagnetic and particle radiation emerging from the sun. However, the study of solar role in terrestrial and space weather requires accurate measurements of global properties of the sun such as "solar irradiance" in various wave bands and properties of Coronal Mass Ejection and its propagation. Last decade have witnessed a great progresses of coronal physics especially from space observations as described by Dwivedi in past issues of this Journal^{4,5}. As such, the high spatial resolution, which is the goal of large solar telescopes, is of limited relevance in such studies. The other aim of solar physics is related to the sun itself and it as the "Rosetta stone" in astrophysics. The sun is a typical star, being nearest to earth, gives a unique opportunity to study various physical processes in detail. It is now well known that magnetic activity of the Sun plays a dominant role in virtually all processes in the solar atmosphere. It is responsible for the energy balance of the outer atmosphere; it causes the activity cycle and the concomitant variability of the solar luminosity. The solar magnetic field is responsible for most of the spectacular visible phenomena, like sunspots, prominences, flares and coronal mass ejections.

From theoretical and numerical computations it is known that much of the interaction between the solar plasma and the magnetic field occurs on very small spatial scales of about 70 km on the Sun, corresponding to an angular size of 0.1 arcsec. One of the outstanding problems of the solar physics is to understand the stability and decay of the sunspots⁶. These objects are cool regions of the sun with intense magnetic field. They appear on the sun within days and survive for several weeks to months. They have a cold dark central region known as umbra, surrounded by filamentary channels of penumbra. The high spatial resolution image of the umbra also shows filamentary structure⁷. The filaments join the umbra with the photosphere. These fibril structures has a dark core of about 100 km size as revealed by recent observations of high resolution images shown in Figure: 1.⁸ The magnetic

field at the penumbra-photosphere boundary are highly inclined⁹ and interact with the surface convection which result the granular structure¹⁰. The quantitative nature of these interactions, which involve complex physical processes, are not known. Also, the sunspots appear in variety of sizes and shapes. Their lifetime also vary from days to months. To understand these objects, which are the key ingredients of the solar activity cycle, holds the key to such understanding.

Besides understanding the sunspots, the transportation of energy to high atmosphere is unclear. Most probably the energy is transported through the magnetic flux tubes, whose nature can be studied with very high spatial resolution observations¹¹. Multi height observations of magnetic and velocity field using different spectral lines simultaneously would be very useful to understand the energy transport from photosphere to higher layers. The high spatial and spectral observations need more light gathering power leading to the requirement of large telescopes.

The other major problem is to understand the solar convection on various scales and their interrelation, starting from granules of about few hundred kilometers to meso- and super granulation with scales of few megameters¹².

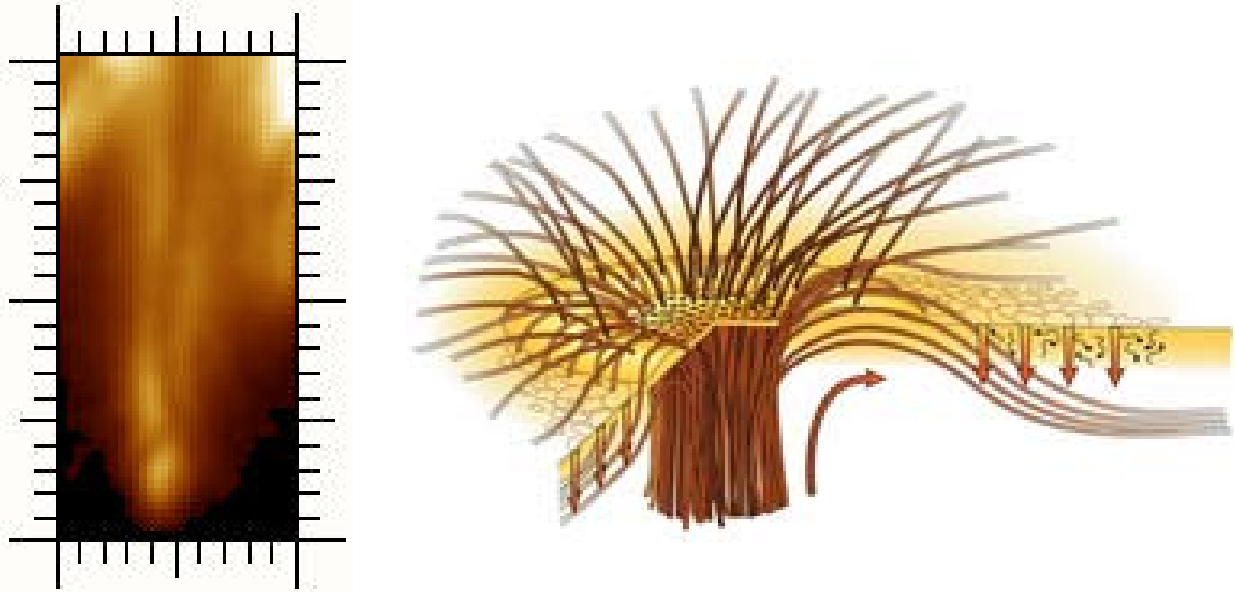


Figure 1: (left) Example of a penumbral fibril with a dark core. The fibril is extracted from the largest spot of the active region 9957 on 22 May 2002. The spatial tick marks have 100 km spacing (Göran B. Scharmer, Boris V. Gudiksen, Dan Kiselman, Mats G. Löfdahl & Luc H. M. Rouppe van der Voort, *Nature* 420, 151-153, 2002) (right) Sketch showing the interlocking-comb structure of the magnetic field in the filamentary penumbra of a sunspot. The bright radial filaments, are the magnetic fields inclined (at about 40° to the horizontal in the outer penumbra), alternate with dark filaments in which the field is nearly horizontal. Within the dark filaments, some magnetic flux tubes (that is, bundles of magnetic field lines) extend radially outward beyond the penumbra along an elevated magnetic canopy while other, 'returning' flux tubes dive back below the surface. The sunspot is surrounded by a layer of small-scale granular convection (thin squiggly black arrows) embedded in the radial outflow (thick curved brown arrow) associated with a long-lived annular super granule (the moat cell). The submerged parts of the returning flux tubes are held down by turbulent pumping (indicated by thick vertical brown arrows) due to granular convection in the moat. There is also a persistent horizontal outflow in the penumbra (the Evershed flow), which is mostly confined to thin, nearly horizontal, radial channels within the dark filaments. Because of the relatively high electrical conductivity of the gas, this flow is constrained to be along magnetic field lines. A small fraction of the flow runs along field lines that extend radially outward beyond the penumbral boundary along the magnetic canopy, elevated slightly above the surrounding quiet photosphere. Most of the Evershed flow, however, runs along arched magnetic flux tubes that dive back down below the visible surface at points either just within or just outside the outer boundary of the penumbra. (Thomas, J. H. N. O. Weiss, S. M. Tobias, and N. H. Brummell) *Nature*, Vol. 420, p. 390, 2002).

3. Location of the observatory

For high spatial resolution observations of the sun, it is very important to locate the solar telescope at a good site. The modern image techniques such as adaptive optics (AO) can improve the "good" images to "best" images but not

“bad” images to “good” images. To express it quantitatively, the current adaptive optics set up can improve images when the site seeing is better than an arcsec and becomes inoperative when the seeing exceeds about one arc seconds or so. Therefore, even in case of employing the AO, it is very important to locate the telescope in good seeing conditions.



Figure 2: Udaipur solar observatory on an island. (Up) with water body around the lake (down) during the dry conditions.

located at Naintal (latitude: 29 24' N, longitude: 79 28' E) and Udaipur (latitude: 24 59' N, longitude: 73 71' E). Naintal is also a mountaintop observatory similar to Kodaikenal. In contrast to these two solar observatories, Udaipur observatory is situated on an island, similar to the Big Bear solar observatory (BBSO), which provided vast amount of



The oldest solar observing facility in India is situated at Kodaikenal (latitude: 10 13' 50"; longitude: 77 28' 07). As John Evershed¹³ pointed out this site is only good for obtaining the daily images of the sun and not suitable for extended solar research. The other two observatories are the high-resolution images of the solar features. However, unlike BBSO, at the Fathesagar lake the observing site is surrounded by the mountains, which makes it hard to maintain the uniformity of atmospheric temperature for a long time. However, it produced some good quality chromospheric images with fast exposure of about 0.25 seconds. As a result of excessive use of the lake by city community, the lake gets dried frequently, about 40% of the time, in last 20 years, as seen in Figure 2. Therefore, for a future ground based solar observing facility, it is important to look for a good observing site.

It was recognized by John Evershed in 1917, that the mountain sites are not suitable for the solar observations.

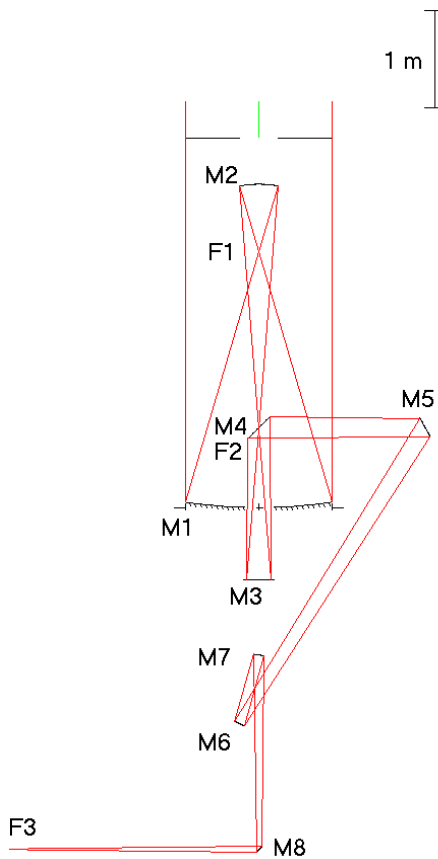
He had carried out extensive search in New Zealand and India to look for a suitable solar observatory. He had concluded that Kashmir valley as an excellent site for solar observation. Although, he does not explicitly advocate for an island site, later it was shown that the water body around the observing site does contribute in stabilizing the atmosphere and add to the improved seeing. Echoing these considerations, Dr. Bappu in 1973 had suggested a small island on sea as a probable site for large solar observatory. Since, Evershed in early 20th century, there was never a serious attempt made for site selection for daytime “seeing” in India. This may a suitable time for such an exercise.

The good solar observing site must meet two criteria. One: it should have maximum number of clear sky or less cloudy days. Two: The site should be located near a large lake preferably on a flat terrain. The high altitude site will be additional advantage. The first criteria narrows down the sites to the northwestern states such as from Uttaranchal to Gujarat. As, in these states there is less rain, number of clear days are more. Table: 1 gives a list of lakes that can be initially investigated in addition to the Gujarat costal area.

Table:1

Region	Lake	Altitude(m)	Size (km)
Ladakh	Tso-Morasi	4900	22 × 5,7
	Pangong Tso	4500	135 × 8
	Kyaghr	4900	3 × 1.5
Kashmir	Wular	2896	200 sq km
Himachal	Govind Sagar	1200	170 sq km
	Chandra Tal	4300	19 sq km
	Maharana Pratap (Pong Dam Reservoir)	450	45,000 Hectares
Uttaranchal	Bhimtal	1371.6	1.701 × .265
Gujarat	Costal area	0	-

4. Telescope, Enclosure and Back-end Instrument



4.1 Telescope: Unlike the stellar telescopes, the solar telescopes get heated due to intense sunlight. In order to minimize the heating, the large solar telescopes have large effective focal length¹⁴. The light path of such telescopes are folded, there by the symmetry of light collection with respect to image plane is lost which introduces the polarization into the observed sun light. As one of the main aims of the solar physics is to measure the magnetic field, which requires the detection of polarized sunlight, the telescopes, in which the light beam is folded before polarization analysis is performed, are not suitable. The other ways to remove the mirror heating is to enclose the telescope on a helium tank. Although, they are viable for telescopes of about 80 cm size, for larger aperture it is practically not possible to manufacture. One of the solutions to overcome mirror heating is to use the metal mirrors made out of silicon carbide.

Figure 3: Sketch of the GREGOR optics. M1, M2 and M3 are concave mirrors, which produce an image of the sky at the focus F3. The other mirrors are flat, and serve only for bringing the light to the instrument area. M6 and M7 will be used for adaptive optics and fast guiding (adopted from the GREGOR web site <http://www.kis.uni-freiburg.de/GREGOR>).

The other problem occurs at the secondary plane, where the light from large primary mirror is concentrated. This is solved by using the Gregorian telescope design, where a real focus is encountered before the secondary mirror. At this place an aperture stop is placed which allows the light only from the region of interest to reach the secondary

mirror and block from other parts of the sun. This minimizes the heating of the secondary mirror. Most of the modern solar telescopes are designed around these two important points. Figure: 3 give the design of a modern optical solar telescope of 1.5 m aperture. The telescope uses a 3-mirror Gregorian configuration with an $f/1.75$ light-weighted primary mirror (M1). A cooled field stop at the prime focus F1 provides a field of view of 300 arcsec. A polarimetry package is located near the secondary focal plane F2, at the center of the tube. A pupil image is formed between M6 and M7. These two mirrors are used as fast steering mirror and for adaptive optics. The effective focal length is 68 m and the final $f/46$ focal plane can be placed in two laboratories. The first three mirrors can be made of light-weighted silicon carbide (SiC), which has a very high thermal conductivity, about 100 times compared to a low thermal expansion glass ceramics that is commonly used for astronomical mirror blanks. This results in a very homogeneous blank temperature, which facilitates the cooling of the reflective surface of the mirror. When the telescope is pointed to the Sun, the mirror absorbs about 170 W, which without cooling, would heat up the reflective layer and the nearby air. The use of lightweight mirrors reduces the overall weight of the telescope. This increases the lowest resonance frequency of the telescope, thus reducing its sensitivity to wind-included vibrations.

Figure 4: two examples of the telescope domes. (left) Dutch open telescope. This telescope is kept with open enclosure. (Right) Retractable dome at Huairou Solar Station in China. The dome can be moved away from the telescope during good weather conditions.



4.2 Enclosure: There exist many versions of telescope enclosure from “no-enclosure” to removable domes. The design of the telescope enclosure mostly depends on the local conditions where the telescope is located. Care must be taken to avoid the creation of thermal inhomogeneity due to the enclosure structure. For avoiding the turbulence of

air in the light path, the air of the enclosure must be maintained at same temperature as the surrounding. Figure: 4 shows two example of solar telescopes.

4.3: Instruments: Whereas the type of instruments of an observatory mostly depends on the user community, for a modern solar observatory, following two instruments seems to be mandatory. One: Adaptive Optics. Two: Spectropolarimeter.

Adaptive optics refers to optical systems, which **adapt** to compensate for optical effects introduced by the medium between the object and its image. Under ideal circumstances, the resolution of an optical system is limited by the diffraction of light waves. This so-called "diffraction limit" is generally described by the following angle (in radians) calculated using the light's wavelength and optical system's pupil diameter:

$$\alpha = 1.22 \frac{\lambda}{D}$$

where the angle is given in radians. Thus, the fully-dilated human eye should be able to separate objects as close as 0.3 arcmin in visible light, and a 2-m telescope should be able to resolve objects as close as 0.065 arcsec. In practice, these limits are never achieved. Due to imperfections in the cornea and lens of the eye, the practical limit to resolution only about 1 arcmin. In astronomy, the turbulent atmosphere blurs images to a size of 0.5 to 1 arcsec even at the best sites. **Adaptive optics (AO)** provides a means of compensating for these effects, leading to appreciably sharper images sometimes approaching the theoretical diffraction limit. At the present time, it is possible to resolve about 100 km on the sun as given in Figure 1.

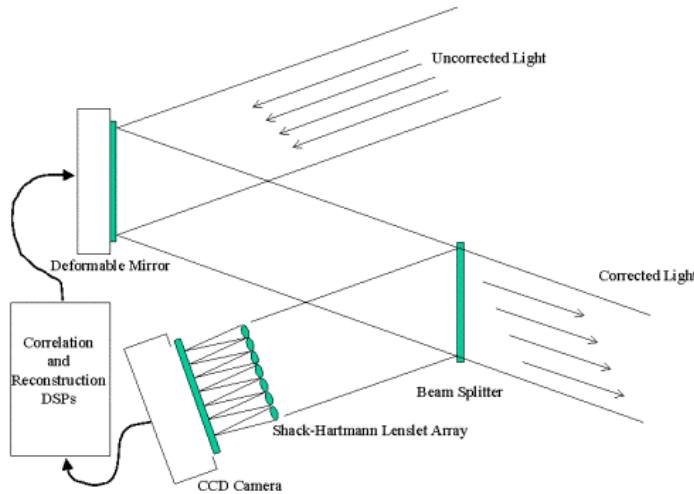


Figure 5: Illustration of Adaptive optics principle (Adopted from NSO/SP).

As shown in Figure: 5, the AO consists of a wavefront-sensing device that detects the distortions in the wavefront and a deformable mirror for correcting these errors introduced by the medium. The wavefront error can be expressed in terms of a series of Zernik polynomials. First few terms represent focus and tilt of the wavefront. Depending on the required degree of sharpness of the final image, one can build the detector and corrector system.

A Spectropolarimeter consists of a polarimeter followed by a spectrograph or a tunable narrow band filter. The polarimeter measures both circular and linear polarization of a Fraunhofer line with finite g-factor. As it has to work in wide wavelength range, tunable opto-electric modulators such as liquid crystal or KD*P poel cells are suitable as polarization analyzers. Similarly, for the polarization response in the wide wavelength range, Glan-Thompson prisms can be employed instead of polymer polarizers. The analyzed light can be dispersed in wavelength by a conventional spectrograph (SP)¹⁵ using a grating or a narrow band spectral isolator such as Fabry-Perot (FP) etalon¹⁶. Both these devices have relative advantages. Whereas SP records the polarized light of all wavelengths simultaneously from a given point of the region of interest (ROI), FP records the light at a given wavelength from entire ROI. The later may be advantages to study the time variation of polarized light over the active regions leading to energetic events.

5. Concluding Remarks

In the concluding section, we may ask the question of whether it is relevant to build a Large Indian Solar Observatory (LISO) at this stage? If yes, what is the practical approach for such a task? The answer to the first question is that it is absolutely relevant to build such an observatory in India. Because, India has a vast community of scientists working on plasma physics, nuclear physics and astronomy. Most of these scientists would find the instrument very useful for their pursuit in research. At the present time, India has the capability to develop large optical mirrors including the metal mirrors such as SiC. This is the perfect opportunity to use the capability for the application in basic science. This will give a moral boost to the opto-mechanical industry in India. Further, as Professor Govind Swarup of National Center for Radio Astronomy puts it - if Dr. Vainu Bappu could make a 2.3-meter class telescope about 25 years back, why cannot astronomical instruments of that magnitude be made by today's astronomers in India?

The practical approach for LISO is to make it a national effort rather than individual and institutional effort in order to pool the capability. At the outset, a core group of dedicated scientists and engineers from different institutes can be made who would be prepared to work on such a project for next seven to ten years. It is preferable that they get the approval from their institutional head. They should be initially provided with the required seed fund to carry out the design and site selection work. Each of the components described above should be fully designed and documented by some of the members of this group. At the same time, they must conduct the site survey at the potential sites, which may include the lake sites given in Table: 1.

Given the present technological capabilities and resources, a telescope of about 2 meter size can be built in India in about five to seven years time frame. This implies that a 2-meter class solar telescope can be completed around the next solar maximum in 2009-2010. By this time, the 50 cm space telescope on Solar-B might have already provided the magnetic field data with 0.5 arc second resolution. The ground based 1.5-meter telescope would also have provided similar data on solar magnetism. This is also the time, the ATST, in USA would be ready for operation. These instruments would also address the problems listed in this article. Therefore, the core group must also concentrate to work closely with the international community and train future manpower by using the existing large solar telescopes around the world to identify core problems

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