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Multi-aperture solar telescope

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Abstract. A proposal for a new ground based solar telescope of very high angular resolution is presented. The science goals that drive the need for this facility are enumerated. The proposed strategy, of combining several smaller aperture telescopes to provide the desired angular resolution, is out-lined.

Key words : Solar Telescope

1. Introduction

Ground based facilities for solar optical observations in India have not kept pace with the developments taking elsewhere in the world. The new renaissance taking place in solar physics as a result of recent results obtained from space-borne telescopes and the technological revolution taking place in India, together offer compelling reasons for installing a new large solar facility. In what follows, we elaborate on our goals and the means to achieve these in a cost-effective way.

2. Science goals

2.1. High Angular Resolution Studies

Recent results obtained from the SOHO/MDI instrument (Schrijver et al. 1998) have shown the importance of obtaining statistical information on small scale magnetic fields for estimating the parameters of the diffusion and destruction of magnetic flux. Likewise, the study of small scale fields in the polar region of the sun will provide extremely important observational constraints on contemporary models of the solar cycle (Choudhuri, 2000). G-band bright points are another example were recent results (Lofdahl, et al. 1998) show possibilities of looking for chromospheric (Krishnakumar and Venkatakrishnan, 1999) and coronal (van Ballegooijen et al. 1998) heating agents. The proposed telescope will be able to operate in the multi-aperture mode providing resolution down to 0.05 arcsec, which translates to 35 km on the sun. At this resolution, one can hope to look for the proposed MISMA, i.e. very fine scale magnetic fields that have been invoked to explain recent polarized spectral line measurements (Almeida, 1998). We can also hope to look for signatures of inverse cascade, which has been proposed to explain supergranulation (Krishan, 1991).

2.2. Solar polarimetry

The largest number of applications of solar polarimetry is in the measurement of solar magnetic field using the Zeeman effect. However, there have been several results in recent times that use the Hanle effect as well to study the polarisation induced by scattering within resonance lines. Measurements of the chromospheric magnetic fields are hard to come by because most of the strong chromospheric lines are resonance lines whose polarisation is hard to interpret. Recent developments in polarised radiative transfer theory have enabled better application of resonance line polarimetry. For example, the pattern of polarisation within resonance lines has been used to propose a novel technique for detecting waves in the chromosphere (Rangarajan, 1998).

2.3. Mechanisms of solar variability

Solar flare prediction is an important component of space weather forecasting. The current progress on this kind of activity leaves ample room for improvement. The lack of success using photospheric magnetic fields (Ambastha, Hagyard, and West 1993) could well be due to the constraints imposed on the photospheric field by sub-photopheric dynamics (Hagyard, Stark, and Venkatakrishnan, 1999). The velocity fields associated with the active regions might also provide another handle to this problem (Debiprasad, 2000). Monitoring of the chromospheric magnetic fields promises to improve our predictive capability because the chromospheric magnetic fields are more force-free in nature. This expectation is reinforced by recent success in relating changes in H-alpha filaments to flares (Sivaraman et al., 1993). Along with flare prediction, one needs to forecast coronal mass ejections too. This would require the close monitoring of filament activity and prominence activity. The surest way to look at the interaction of various scales of solar variability is to collect a consistent data set of full disk measurements. These need to have modest spatial resolution (1 arc-sec) and need to be measured at a reasonably high cadence (1 per hour). It is proposed to dedicate one of the 60 cm aperture telescope to this activity. The upgraded GONG magnetograms will also be useful for this purpose. The scattering of sound waves from magnetic structures can provide diagnostics about the internal fine-structure of these elements (Venkatakrishnan, 1979). It has also become imperative to look for short period waves that seem to be the agent for heating the "basal chromosphere" (Ulmschneider, 2000). Thus, it would be very important to study the time variability on very short time scales.

3. Conceptual design

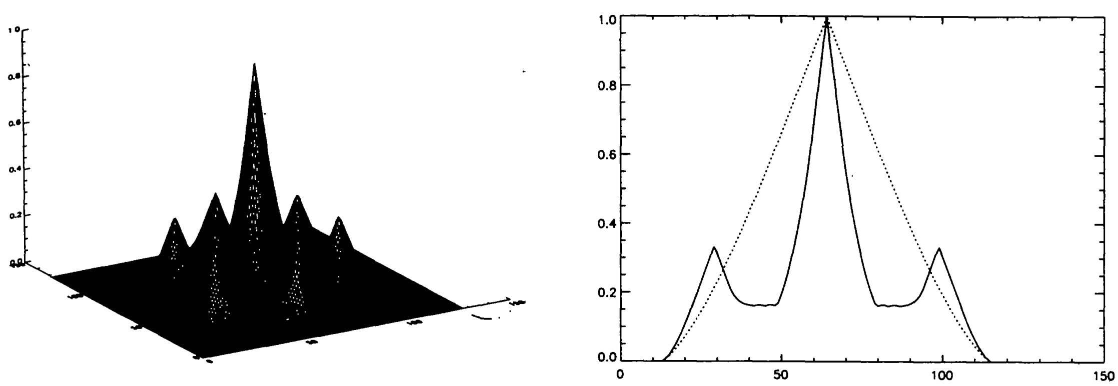
The proposed telescope aims at the following requirements. (a) High angular resolution, (b) A broad wavelength coverage, (c) A large photon flux, (d) Low instrumental polarization, and (e) Simultaneous and synoptic observation capability.

3.1 Optics

The primary difficulty in observing the Sun is to get around the solar heating. At the same time, modern solar research requires relatively large collecting area of the telescope for special applications, which adds to this problem. Therefore special care must be taken to design both the instrument and its location for solar observations. The main problem in such telescopes is the rejection of heat. A 60 cm collector will generate about 0.5 KW of power. This much heat must be thrown out of the telescope to minimize the internal seeing. The heat problem of a Ritchey-Critien system can be overcome by using the active cooling system of the secondary mirrors and streamlined air circulation.

3.2 Multi-aperture telescope

Large single telescopes will not be very useful to obtain the high-resolution images of the sun due to bad daytime seeing. Therefore, we propose for a multi aperture telescope. This telescope will have six telescopes of 60 cm each of the "open" type, mounted on a single steearable structure with the capability of beam combination. This combined beam can be used at times of superlative seeing to achieve angular resolution of .05 arc seconds by off-line speckle reconstruction techniques.



(a) (b)

Figure 1. a) The MTF of the combined beam. b) The 1-D plot of the MTF along the v=0 axis. The ordinates in both figures represent spatial frequencies with zero frequency at 64 and the least count in spalial frequency being equal to 4 cm on the wavefront.

Figures 1a and b show the two dimensional MTF and a one dimentional scan of the MTF. During other times, each telescope will operate with dedicated instruments for polarimetry, spectroscopy and synoptic imaging. The off-line reconstruction is eminently doable because we avoid the rather difficult problem of co-phasing the individual telescopes. For the off-line techniques, the atmospheric turbulence will produce a decrease in fourier amplitude of only .01 percent for an optical bandwidth of 100 pm. The fourier phase can be readily obtained by the method of closure phase, which we have already implemented for single telescopes. In this way, we will have the double advantage of having modest aperture telescopes for conventional programmes, as well as the possibility to operate as the largest solar telescope in the world to study problems requiring ultra-high spatial resolution. The atmospheric path delay fluctuation at 2.1 m separation is only 2 microns compared to the 30000 microns coherence length for bandwidth of 100 pm. The structural vibration would impose critical design considerations. By designing the structures to be transparent to mechanical frequencies larger than few hertz, it is possible to separate the domain of sampling frequency from the structure vibration frequency. Active tilt correction at individual telescopes can take care of the slower mechanical vibrations at subhertz frequencies.

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