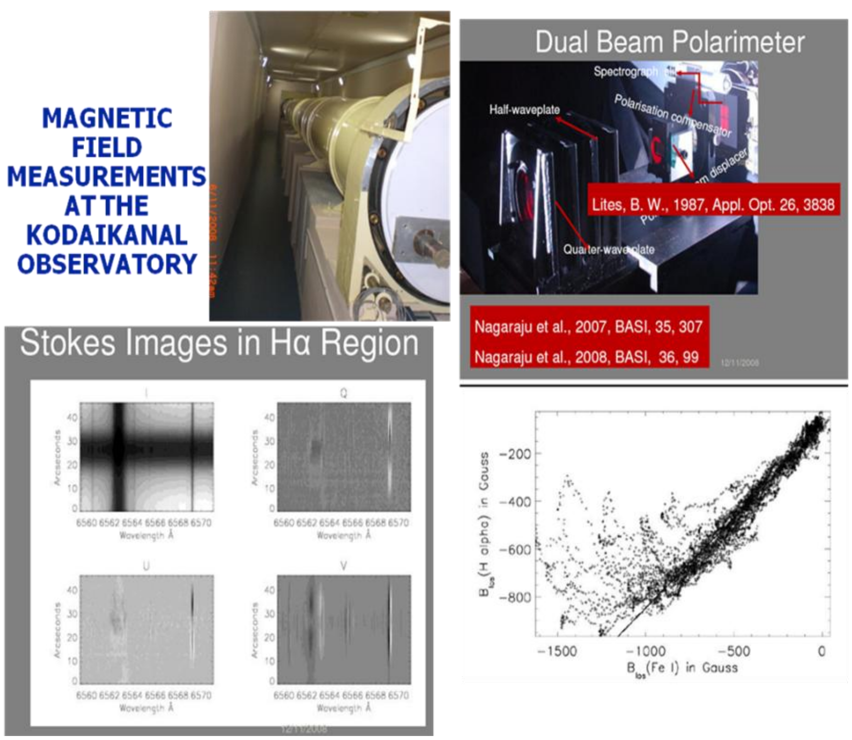
Spectropolarimetry with the NLST

Spectropolarimeter tradition:

A good tradition exists within IIA for developing polarimeters based on a high resolution spectrograph at Kodiakanal Tower Telescope. Starting with J.C. Bhattacharya, four PhD theses were completed based on development of different generations of polarimeters with increasing sensitivities and accuracies.

The first magnetometer was built during 1970 (Bhattacharyya, 1970). The initial instrument made simple measurement of magnetic field by measuring the polarization at the two wings of a chosen spectral line. The Kodaikanal Tower Tunnel (KTT) telescope was used for this purpose. The instrument was then upgraded to a spectropolarimetric instrument (Bhattacharyya and Balasubramaniam (1986), Balasubramaniam (1988)). The polarimetric measurements were done manually along with photographic films to record the two-dimensional Stokes profiles. The polarimetric part was then automated (Ananth et al., 1994). The consistent vector field measurements were started when the single-beam polarimeter was coupled with the area-scan CCD (Sankarasubramanian, 2001). The instrumental polarization produced by the oblique reflections of the KTT telescope was modeled (Balasubramaniam 1985, Sankarasubramanian 2001). The importance of the oxide layers on the KTT telescope mirrors were studied and verified experimentally (Sankarasubramanian et al., 1999).



Magnetic field measurements at the Kodaikanal observatory.

The upgraded instrument was then used to obtain the first consistent vector field map of a sunspot (Sankarasubramanian et al., 2002). However, the achieved polarimetric accuracy was limited to 1%. The current spectropolarimeter at the KTT telescope is an improved version that uses a dual beam system (Nagaraju, 2009). The dual beam provides higher spectropolarimetic accuracies (~0.1%) compared to the single beam system used in the earlier versions. The new system can also provide spectropolarimetic observations in the solar chromospheres. The new instrument has already produced interesting results (Nagaraju et al., 2008). The development of spectropolarimeter for the NLST will benefit from these long standing developmental efforts of IIA.

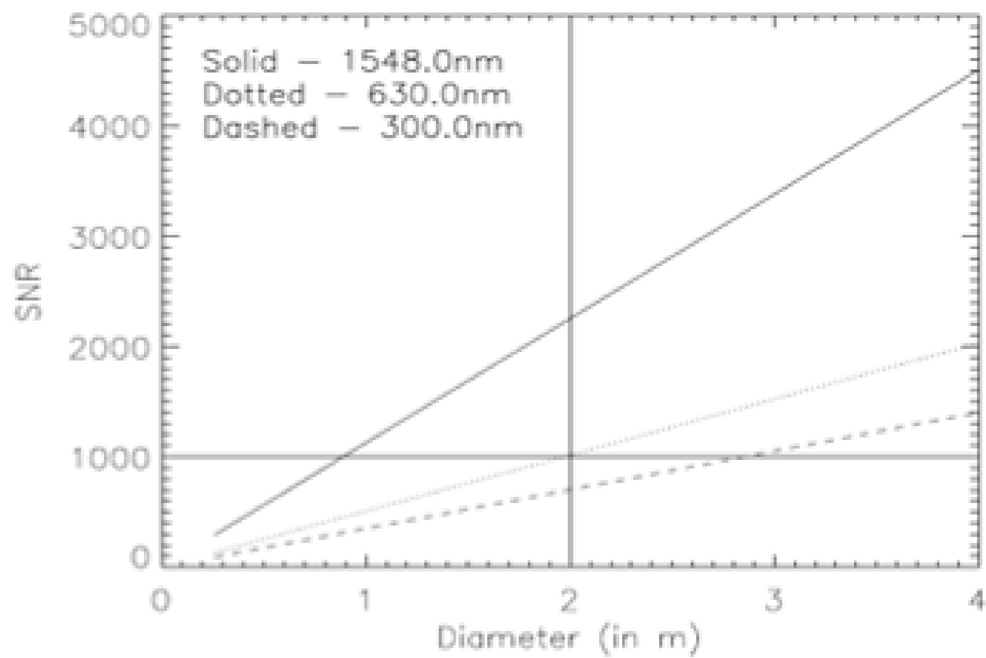
The spectropolarimetry for the NLST will be an advanced version of the previous developments: (a) it would cover a large wavelength region in order to cover several interesting spectral lines which form at the photosphere as well as at the chromosphere, (b) it would have an polarization accuracy an order higher than that previously achieved. Due to this versatility, this instrument can act as a research instrument to tackle any new research problem, whereas some of the current breed of instruments are either fixed for synoptic observations (Keller, 1998) or for high spatial resolution stand-alone mode (Lites et al., 2001; Sankarasubramanian et al., 2003; Schmidt et al., 2003; Solanki et al., 2003). This proposed instrument will be similar to that of SPINOR operated as a backend instrument for the National Solar Observatory (Soccas-Navarro, 2006). However, coupled with NLST the proposed spectropolarimetry can provide data with a spatial resolution 2.5 times better than that achieved with the SPINOR during favorable seeing conditions.

The spectropolarimeter design for the NLST will be based on the Spectropolarimetry for the Infra-red and Optical Region (SPINOR) design. It would consist of two units,

(i) Polarimetric Modulation unit and
(ii) Flexible Spectrograph unit.

(i) Polarimetric Modulation Unit: The polarimetric modulation unit will be placed close to the secondary focus (F2) of the NLST (see the optical layout of the NLST for the location of F2). The modulator will consist of an achromatic 0.375 waves rotating waveplate. The achromatic retarder can either be made using the Pancharatnam technique or using the bi-crystalline achromatic retarder (Guimond and Elmore, 2004). Both the achromatic retarders have been in operation for several years in Astronomical observations. The bi-crystalline modulator used in the SPINOR covers a wide wavelength range from 430nm to 1600nm. The details of the SPINOR instrument can be seen in Socas-Navarro et al. (2006). The modulator optics will be Anti-reflection (AR) coated in order to reduce any reflection loss. Also, this modulator should have zero or negligible wedge in order not to introduce any wobble on the tip-tilt or deformable mirror. The modulator is kept close to the F2 in order to minimize any instrumental polarization from the telescope as the optical components in the light path before the modulator are all symmetric. The wavelength range covered by this modulator can accommodate most of the spectral lines of interest to the scientific community.

Just before the modulator optics, a calibration unit will be placed. The calibration unit is a must in order to calibrate any residual polarization from the telescope. Due to this calibration mechanism, the achieved accuracies can be as high as 10^{-4}. The calibration unit will consist of an achromatic quarter-wave plate followed by an achromatic linear polarizer. When the quarter wave plate and the polarizer are in the optical beam, then it produces circularly polarized beam to the modulator. For the generation of linear polarization, the quarter wave plate is taken out of the beam. During the regular observations of the solar features, both the quarter wave plate and the polarizer will be out of the beam. The rotation modulator uses the principle similar to that of the Advanced Stokes Polarimeter (Elmore et al., 1992).



Aperture size vs signal to noise ratio (SNR) for polarization observations.

At different phases of the rotation, it modulates the input Stokes vector in to the output intensity. By synchronizing the output intensity measurements, the input Stokes vector can be retrieved back with high accuracies. For more details of such rotating type polarization modulation techniques, the readers are referred to Lites (1988).

(ii) Flexible Spectrograph Unit: A spectrograph at the focal plane of the telescope is used to capture the spectral line profiles. A 40-60 micron slit at the focal plane will be the slit of the spectrograph.

Instrument specifications:

Specification	Requirement	Goal	Prio-rity	Subsystem controlling the specs.
Wavelength Range	380nm – 1.6micron	380nm – 2.5micron	1	Telescope, Spectrograph, Polarimetry, & Camera
No. of simultaneous wavelengths	<= 3-lines	5-lines	1	Spectrograph
Spatial Resolution	0.1arc sec	Diffraction Limit	1	Telescope, AO, Spectrograph
Image stability	AO for disk observations	AO for disk as well as near limb	1	AO, Telescope
Spatial FOV	> 1.5 arcmin	3.3 arcmin	1	Telescope, Spectrograph
Spectral Resolution	< 3.0pm @630nm	1.0pm @630nm	1	Spectrograph
Spectral Sample	<1.5pm @630nm	0.5pm @630nm	1	Spectrograph, Camera
Spatial scan range	> 1.5 arcmin	3.3 arcmin	1	Spectrograph scanning mechanism
Scan accuracy	< 40micron	10 micron	1	Spectrograph scanning mechanism
Scan repeatability	< 10micron	2.5 micron	1	Spectrograph scanning mechanism
Polarimetric accuracy	$< 10^{-3}$ Ic	10^{-4} Ic	1	Telescope, Camera,Polarimetry, Spectrograph,
Temporal Resolution	0.1% in polarization within 10-seconds	< 0.1% in polarization for longer integration or reduced resolution	1	Telescope, Spectrograph, Polarimetry, Scanning mechanism, & Camera and instrument control software
Operation with other instrument	Atleast with the broad band imager	With broadband imager as well as FP-based system	2	Telescope, Polarimetry, Beam-splitters , & Instrument control software
Wavelength Division for other instrument	Using Dichroic filters (wavelength division)	Using both Dichroic as well as 50:50 beam splitters	2	Telescope, Polarimetry, Beam-splitters, & Instrument control software
Data acquisition & archival	Raw intensity data as a standard	Apart from the raw data, demodulated and standard ME inverted data as standard	2	Instrument control software, Data pipeline, & analysis software

A 1200mm lens collimates the light beam passing through the slit. A high blaze angle grating (63degree and 79 lines per mm) will be used as the dispersing element. The lower number of lines per mm minimizes any partial polarization effect from the grating which is unavoidable in high dense grating (like the 1200 lines per mm). The high blaze angle compensates for the lower density and hence retains the higher spectral resolution. A large format grating (width about 200mm) will be necessary to achieve a spectral resolution of > 200,000. Such high spectral resolution is important in resolving the line profiles and hence higher accuracies in the estimated vector field measurements. The dispersed light can then be captured by a set of camera lenses with each lens for a particular wavelength of interest. This type of spectrograph is very similar to that of the ASP and allows the user to select more than one line for simultaneous studies. However, only a limited combination will be possible with a given grating depending on the overlap of orders and the wavelength requirement. However, change of grating which changes the grating parameters can be used to achieve many combinations of spectral lines of interest.