National Large Solar Telescope

By K.E.Rangarajan
On behalf of NLST team

WHY 2 METRE?

Choice of 2-m aperture was based on:

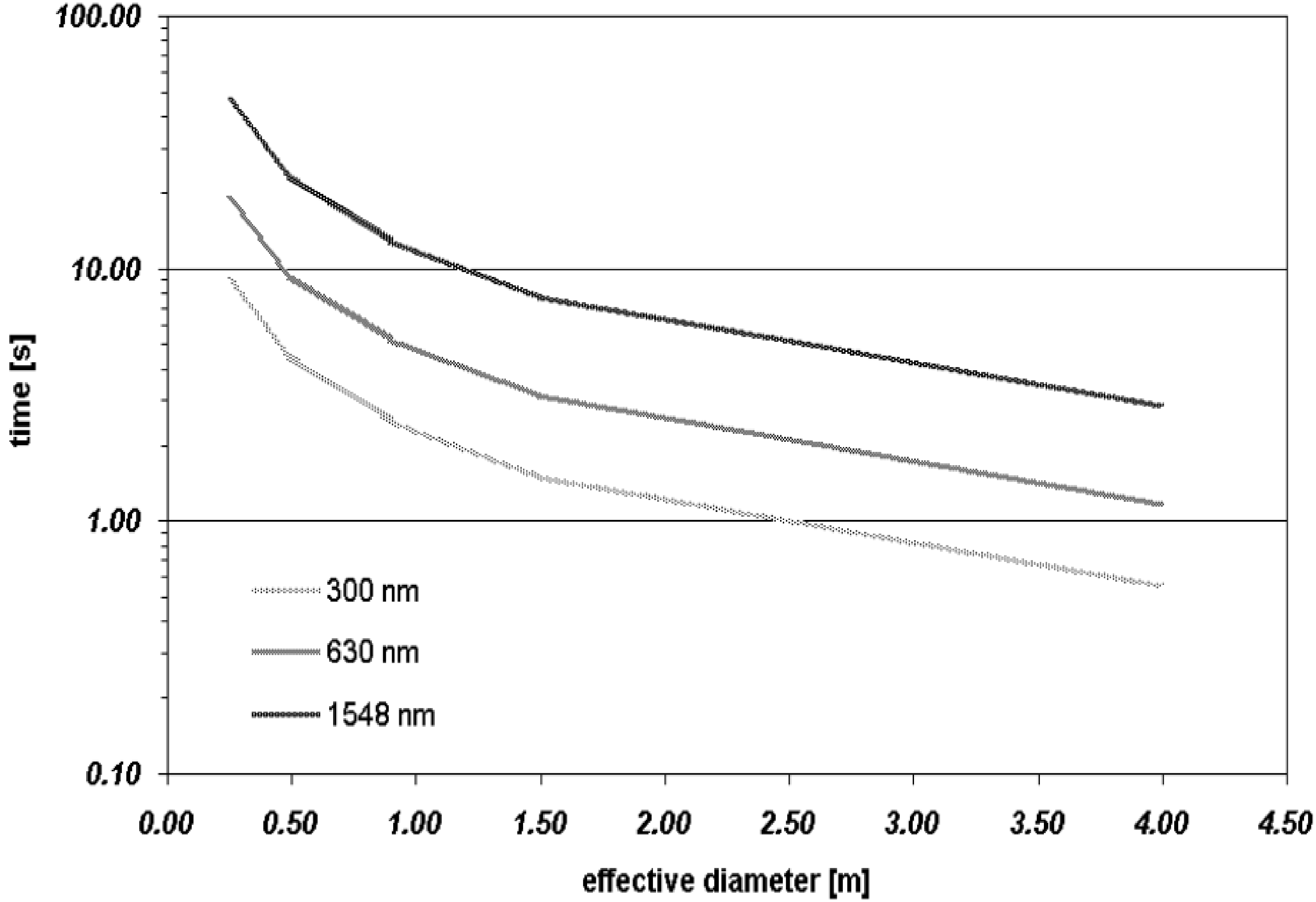
–Scientific objectives: High spatial resolution to resolve features of 40 kilo-metres in size;

–Use a tested design and technology;

–Realize project in a short time scale (3-4 years);

–Keep costs down (The cost of a telescope roughly scales as 2.5 – 2.8 power of the diameter: a 2-m telescope costs twice as much compared to 1.5-m. 4-m class telescope costs about 6 times more than a 2-m telescope).

Exposure time versus aperture size of telescope



Maximum possible exposure time at the diffraction limit as a function of effective aperture for a realistic solar telescope. If the exposure time is longer, smearing due to the evolution of solar features during the exposure will occur. The calculations extend from a 25-cm effective aperture diameter up to 4 m, currently the largest planned solar telescope aperture (Courtesy: C.U. Keller, 2003).

Scientific and Technological Advantages

NLST will be a unique research tool for the country and the world; it will provide a superior platform for performing high quality solar research. This would demand great technological challenges, give several spin-offs both direct and indirect.

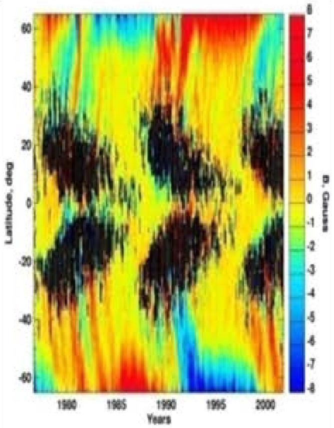
Examples of areas in which NLST will contribute to technology development in the country are adaptive optics (AO) and infrared instrumentation.

The focal plane instruments will be built indigenously through collaborations with other national and international institutions. Work on the prototype instruments has already commenced at IIA.

Scientific and technical manpower will be developed due to the project.

NLST: Major Scientific Aims

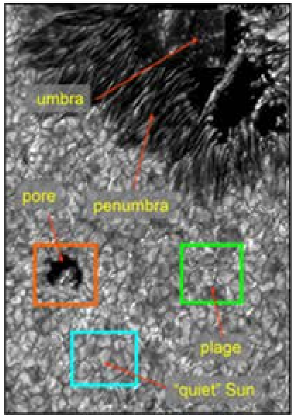
Magnetic field generation & the Solar Cycle



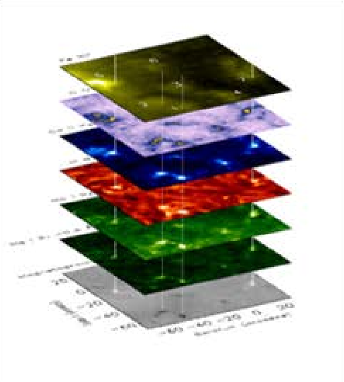
The mechanisms responsible for magnetic field generation and the 11 year sunspot cycle are still not fully understood (Butterfly diagram depicting the sunspot distribution with latitude)

Surface magnetism

Magnetic structures in the solar atmosphere involve characteristic spatial scales that are too small to be fully resolved with current solar facilities



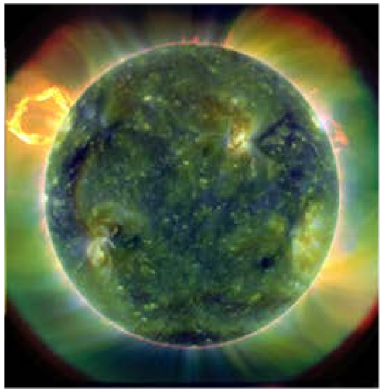
Dynamics of the magnetized chromosphere



The heating of the solar atmosphere is intimately related to the dynamical processes occurring in the magnetic network. (Network Bright Points at various heights).

Activity &Energetic phenomena

Loops, prominences, flares and CMEs are inherently magnetic in nature. (Full disk multi-wavelength extreme ultra-violet image of the sun taken by SDO on March 30, 2010.)

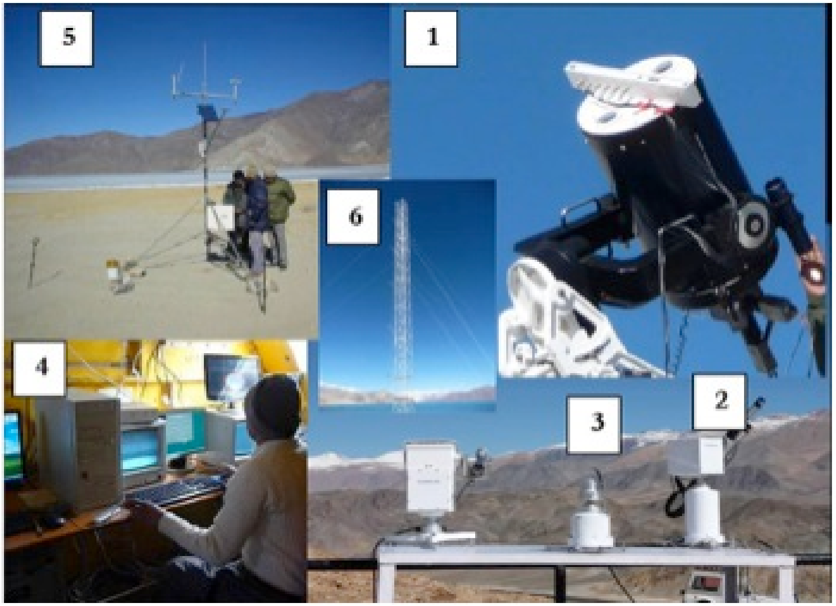


NIGHT TIME ASTRONOMY WITH NLST

- Cycles on solar-like stars;
- Doppler imaging
- Radial velocity monitoring;
- Extrasolar planets;
- Elemental abundances

NLST Site survey

A thorough site survey involving a suite of scientific instruments was carried out at Hanle, Merak and Devasthal in Himalyan mountain range over the past five years (from 2006-2011). The study shows that India has a world class sites at Merak and Hanle in Ladakh region of J&K State suitable for a 2 metre solar telescope.



The above figure shows Collage of instruments used in site survey; clock wise from top right: (1) Solar Differential Image Motion Monitor (SDIMM) and SHAdow BAnd Ranger (SHABAR), (2) sky radiometer, (3) All sky camera, (4) data acquisition facility at Merak , (5) Automatic Weather Station (AWS), and (6) micro thermal tower.

A comprehensive site survey report has been submitted to the Governing Council, IIA and DST.

NLST Fills a Gap

Table ES 3 - Median values of the day time meteorological parameters observed at Hanle

Median	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (mps)	2.5	8.5	2.5	4.7	5.5	4.0	4.7	2.5	3.9	2.5	1.7	1.7
Temperature (°C)	- 9	- 7	- 1	4	7	10	15	15	10	5	- 1	- 7
Pressure (mbar)	587	583	589	591	588	588	589	591	590	591	589	584
Relative Humidity (%)	22	22	14	18	19	19	28	44	27	16	11	14
PWVC (mm)	0.8	0.9	1.1	1.6	1.9	2.7	5.2	8.6	5.2	1.7	0.7	0.5

Table ES 4 - Median values of the day time meteorological parameters observed at Merak

Median	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (mps)	2.5	4.0	2.5	3.2	4.7	4.7	3.9	3.2	3.2	3.2	2.5	3.2
Temperature (°C)	- 8	- 7	- 1	3	6	9	13	15	11	5	0	- 6
Pressure (mbar)	607	603	608	609	608	608	609	610	609	611	609	605
Relative Humidity (%)	40	37	34	35	35	39	45	52	37	26	25	31
PWVC (mm)	1.4	1.4	2.0	3.0	3.6	5.0	8.0	9.8	6.2	2.6	1.5	1.2

Telescope specifications

The telescope should withstand the following parameters:

Wind velocity: Performance up to 15 m / s
Functional up to 20 m / s
Survival 55 m / s

The survival speed refers to enclosure building including Dome. i.e the Dome should be closed so that the telescope can be protected at the above wind speed.

Temperature Range: Performance - 25° C to + 25° C
Functional - 30° C to + 30° C
Survival - 40° C to + 40° C

Relative humidity Performance 5 % to 90 %
Functional 5 % to 95 %
Survival 5 % to 100 %

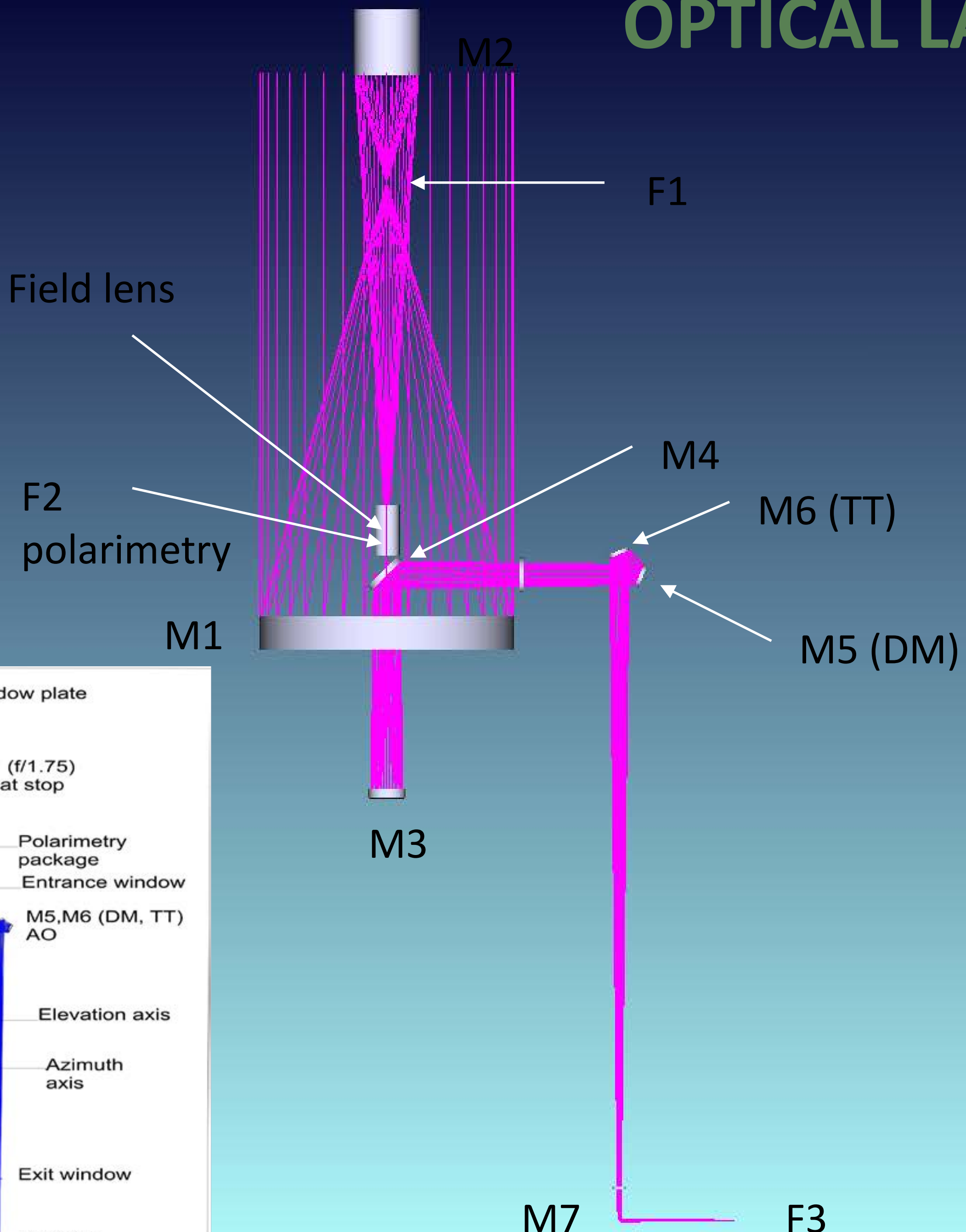
Similarly specifications containing optical layout, thermal, structural, building parameters were made. MTMechatronics made the Detailed Concept Design for the telescope.

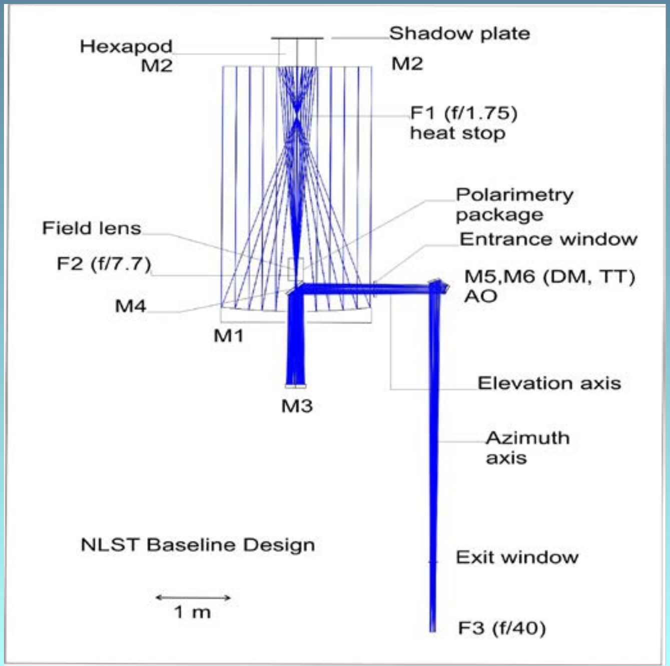
Telescope Features

Aperture (primary mirror M1)	: 2 metre with f/1.75
Focal length (M1)	: 3.5 m
Optical configuration	: 3 mirror , Gregorian on – axis
Field of view	: 200 arc sec
Final focal ratio of the system	: f/40
Image scale	: 2.58 arc sec mm^{-1}
Optical quality	: < 0.1 arc sec over 200 arcsec and < 0.3 arcsec within 300 arcsec
Wavelength of operation	: 3800 A to 2.5 microns
Polarization accuracy	: 1 part in 10,000
Active and Adaptive optics	: to realize near diffraction limited performance
Spatial resolution	: < 0.1 arcsec at 500 nm.

NLST will have a high order adaptive optics system which can provide a Strehl ratio of around 0.65.

OPTICAL LAYOUT





Optical Scheme

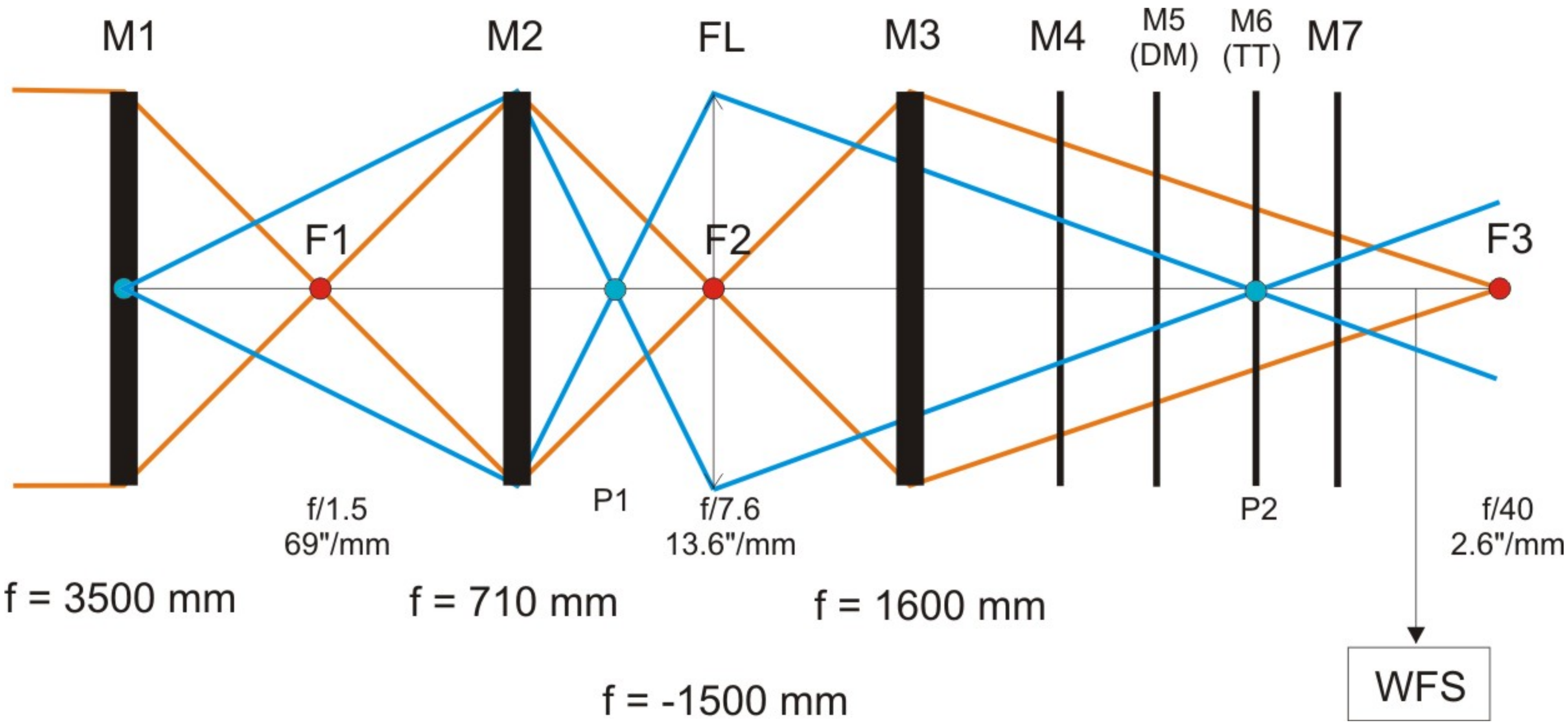


Figure 2: NLST optical scheme. There are three mirrors with power, and four flat mirrors (including the deformable mirror). The imaging is shown in orange, the pupil imaging is shown in blue

Note that the pupil image falls on M6 (due to the field lens).
F-ratios of each of the focal points are marked. Wavefront sensor light will be tapped before the F3 focus. The final f-ratio is f-40.

Optical Design

The special properties of the proposed optical design can be summarized as follows:

The number of mirrors is minimized. The system has only 6 mirrors including AO mirrors to produce the science focus. The small number of mirrors is due to the following facts:

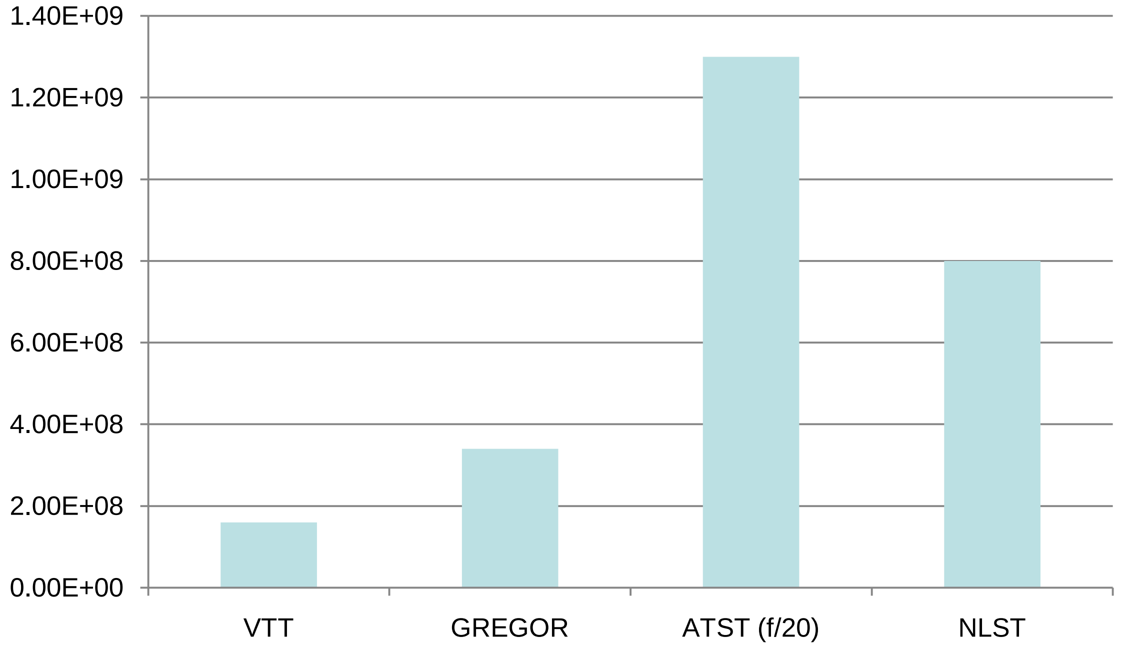
□No relay optics for the AO is needed because a field lens shifts the pupil on M6.

The azimuth axis is beside M1. No reflections are needed to bring the beam into the azimuth axis below the centre of M1.

□Image derotation will be done mechanically by means of rotating stages in the building. So no optical image derotator is needed.

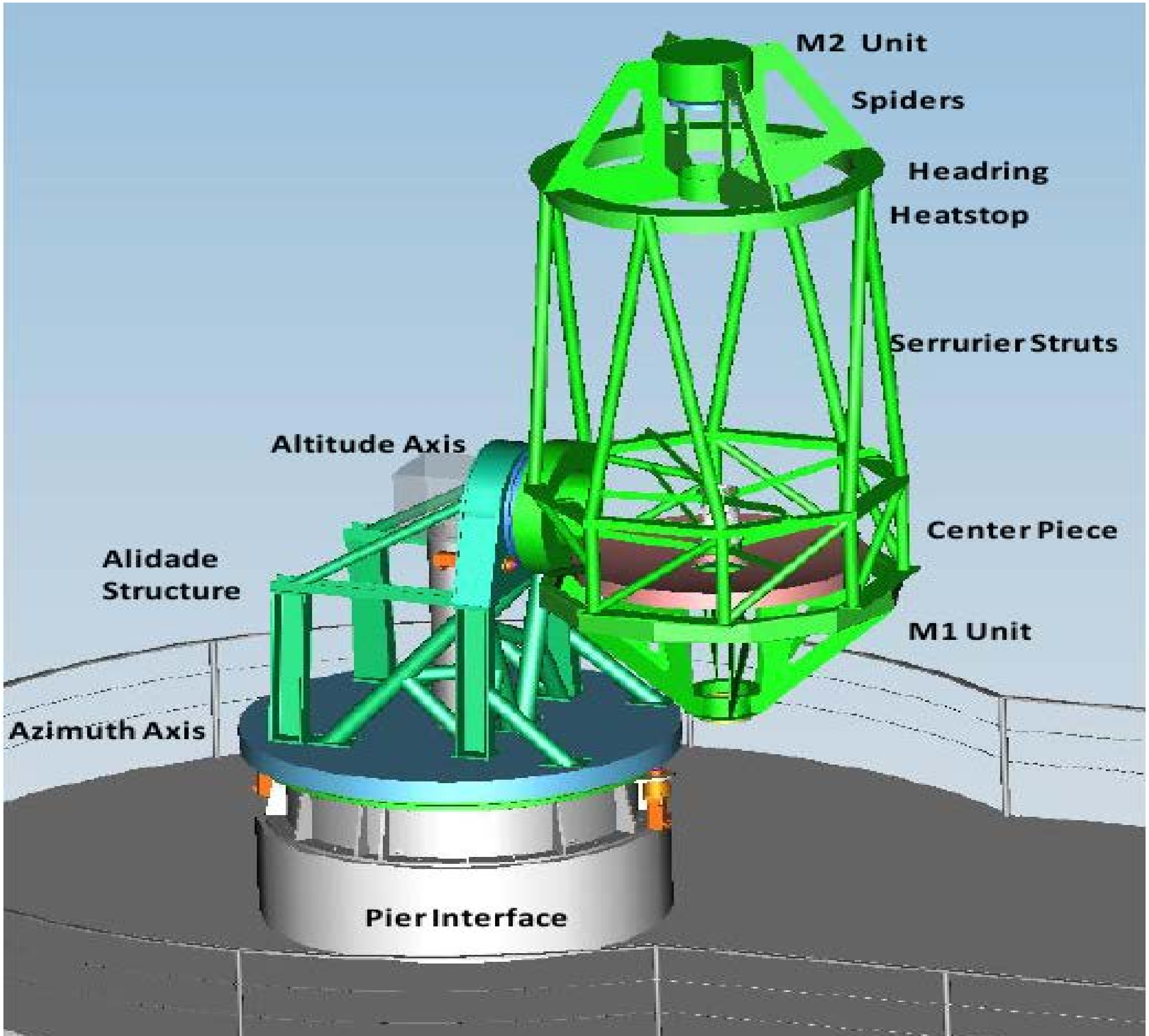
Throughput

Number of photons per second on a 10 µm Pixel at 500 nm calculated for a 1 nm passband filter

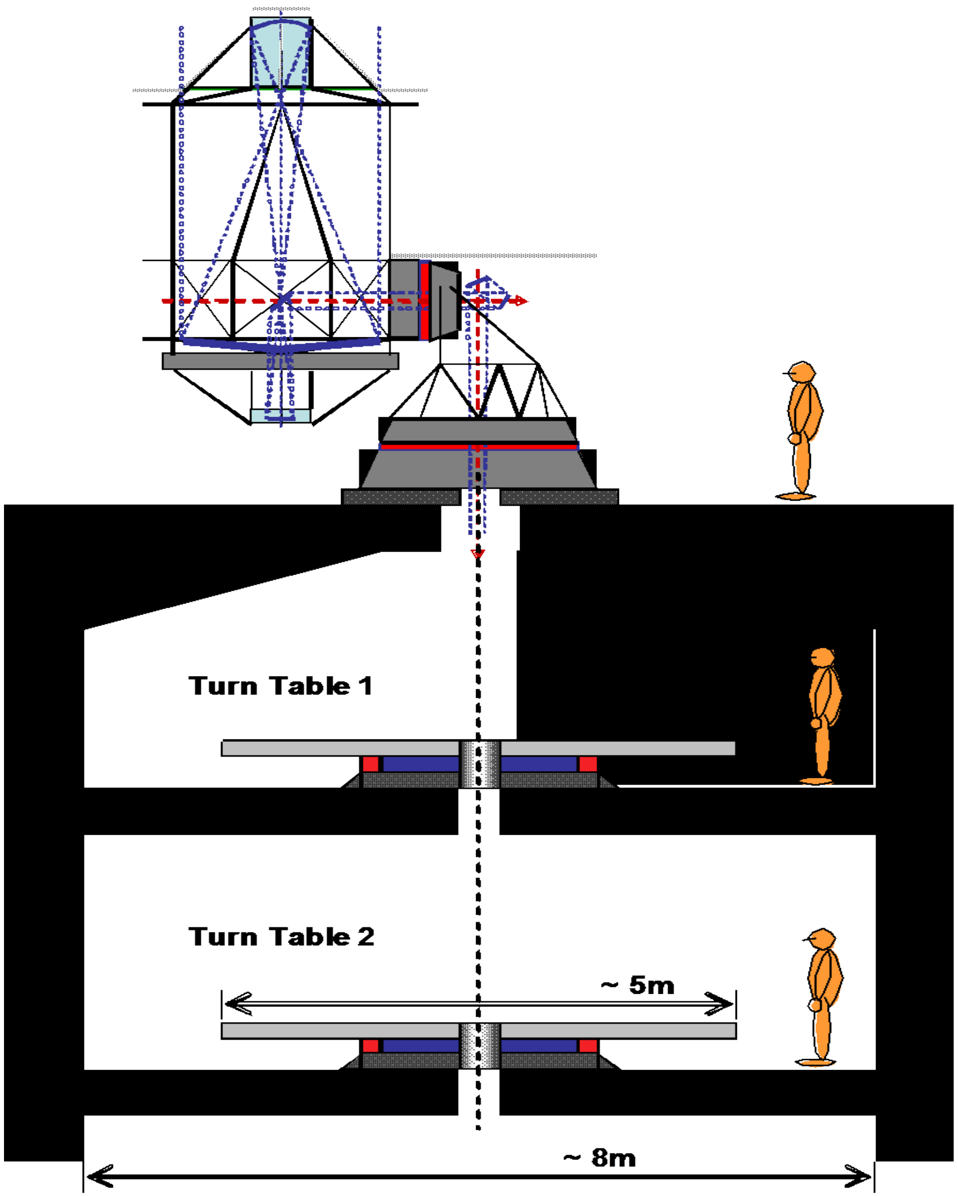


A comparison of number of photons for different telescopes. Note that NLST has considerably large number of photons than GREGOR due to its optimized optical design (less number of mirrors). For NLST millisecond integration time still yields high S/N

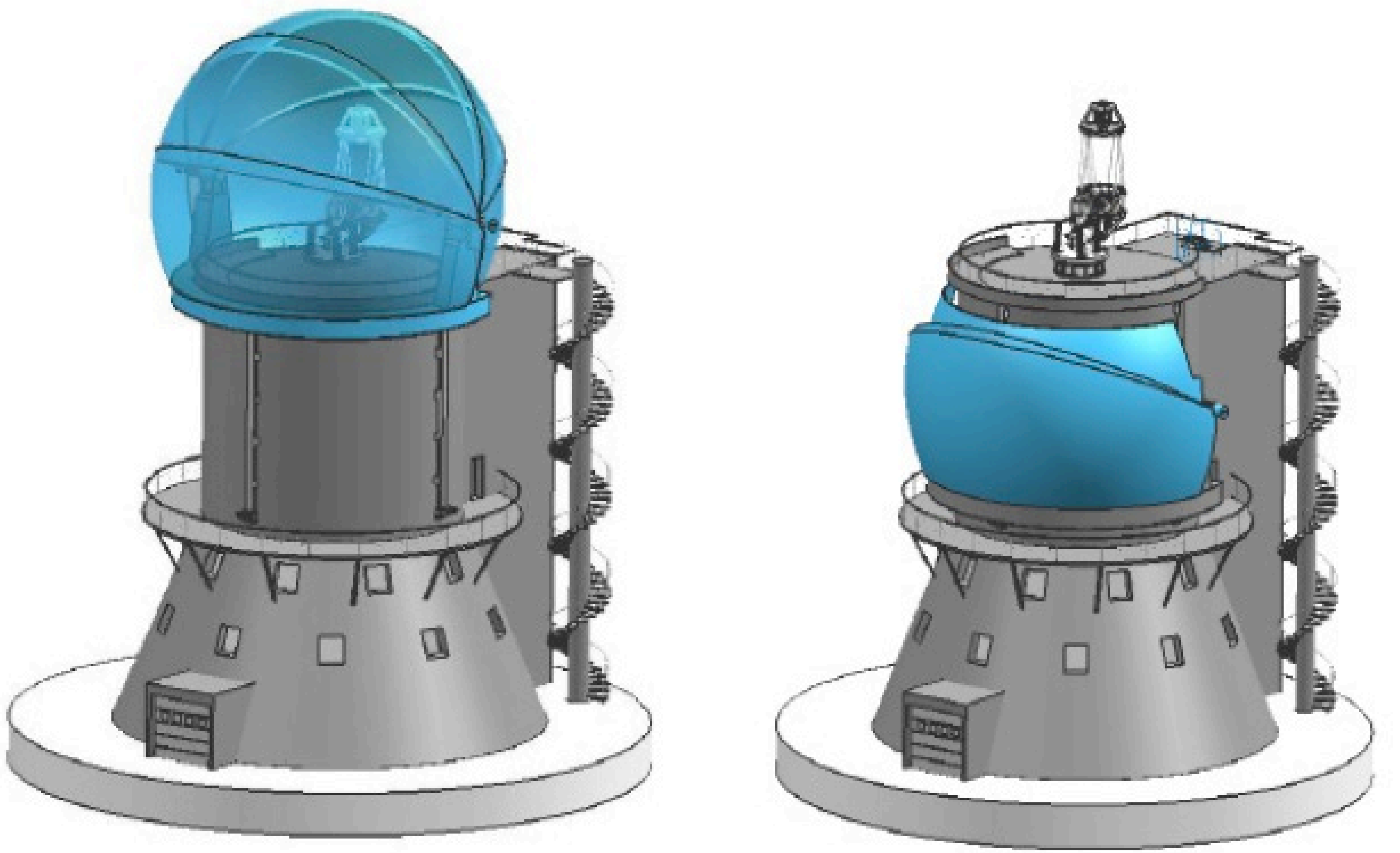
NLST


M2 Unit
Spiders
Headring
Heatstop
Serrurier Struts
Altitude Axis
Center Piece
Alidade
Structure
M1 Unit
Azimuth Axis
Pier Interface

Observation Platform & Laboratories



Telescope Building and fully retractable dome



The fully retractable dome allows the telescope to be completely open without any obstruction.

Consolidated Goal for backend instruments

Project	**λ(Å)**	**Resolution (Spec., Spa., Temp., and pol.)**	**FOV**	**Simultaneous?** **(Spec.)**	**Addnl.**
2D Multi-line Polarimetry	6302; 6563; or 8542	<30mA; <1”; <3min.; 0.1%	70”X70”	Yes	Imaging in G-band and 6563/8542
Penumbral Structures	6302, 8542	~30mA;~ 0.1”; < 1min;0.1%	30” X30”	Yes	G-band and 6563
Small scale fields	6302, 8542, 10830	<30mA;~ 0.1-0.3”; < 3min;0.1%	30” X30”	Yes	G-band and 6563
Local Helioseismology	6302	<30mA; NC; <1min; 0.1%	300” X 300”	NC	NC

Backend instrument development for NLST

This will be done in three phases.

1) Phase 0 - Prototype instruments being made and tested in existing telescopes
2) Phase I
   Conventional type first light instruments : a) Broad Band Imaging System b) Fabry Perot based Narrow Band Imager c) Spectropolarimeter d) spectrograph for night time Astronomy
3) Phase II
   a) Extending Fabry Perot instrument to include imaging polarimetry b) Fiber bundle based multi slit spectropolarimter c) Multi-conjugate Adaptive Optics

Instruments	Wavelenth Range	Field of View (arc sec)	Spatial / Spectral Resolution
New Solar Telescope (1.6 m)			
Nasmyth Focus Filtergraph	430 – 2200 nm	70" X 70"	0.07"
Cryogenic Infrared Spectrograph (CYRA)	1000-5000 nm	70" X 70"	>70 mA
Infrared Imaging Magnetograph (IRIM)	1564.8 nm	70" X 70"	0.25"
Visible Imaging Magnetograph (VIM)	550 - 700 nm	70" X 70"	< 0.1 Å
Fast Imaging Solar Spectrograph (FISS)	400 – 1000 nm	70" X 70"	~35 mA
GREGOR Solar Telescope (1.5 m)			
GREGOR Fabry-Perot Interferometer	530–870 nm	52" X 40"	24 mA
Grating Infrared Spectrograph	1083 nm & 1564.8 nm	69" X 69"	21 mA/pixel
Advanced Technology Solar Telescope (4 m)			
Broad Band Imaging System	380 - 900 nm	120" X 120"	0.03"
Visible Spectro Polarimter	380 – 900 nm	120" X 120"	0.04"
Near-Infrared Spectropolarimetry	400 – 5000 nm	120" X 120"	0.05"/pixel
Visible Tunable Filtergraph	520 - 870 nm	1 arcmin (circular)	0.012"/pixel

NLST – BBIS – Prime objective

- With its large aperture, NLST will provide an angular resolution of < 0.1 arc sec at 5000 Å.
- Broad-band Imaging system is to exploit this high angular resolution and to record images through broad-band filters at a number of fixed wavelengths in the range 380 nm to ~ 1.6 nm.
- Simultaneous measurements at several passbands to sample the atmosphere at different heights.

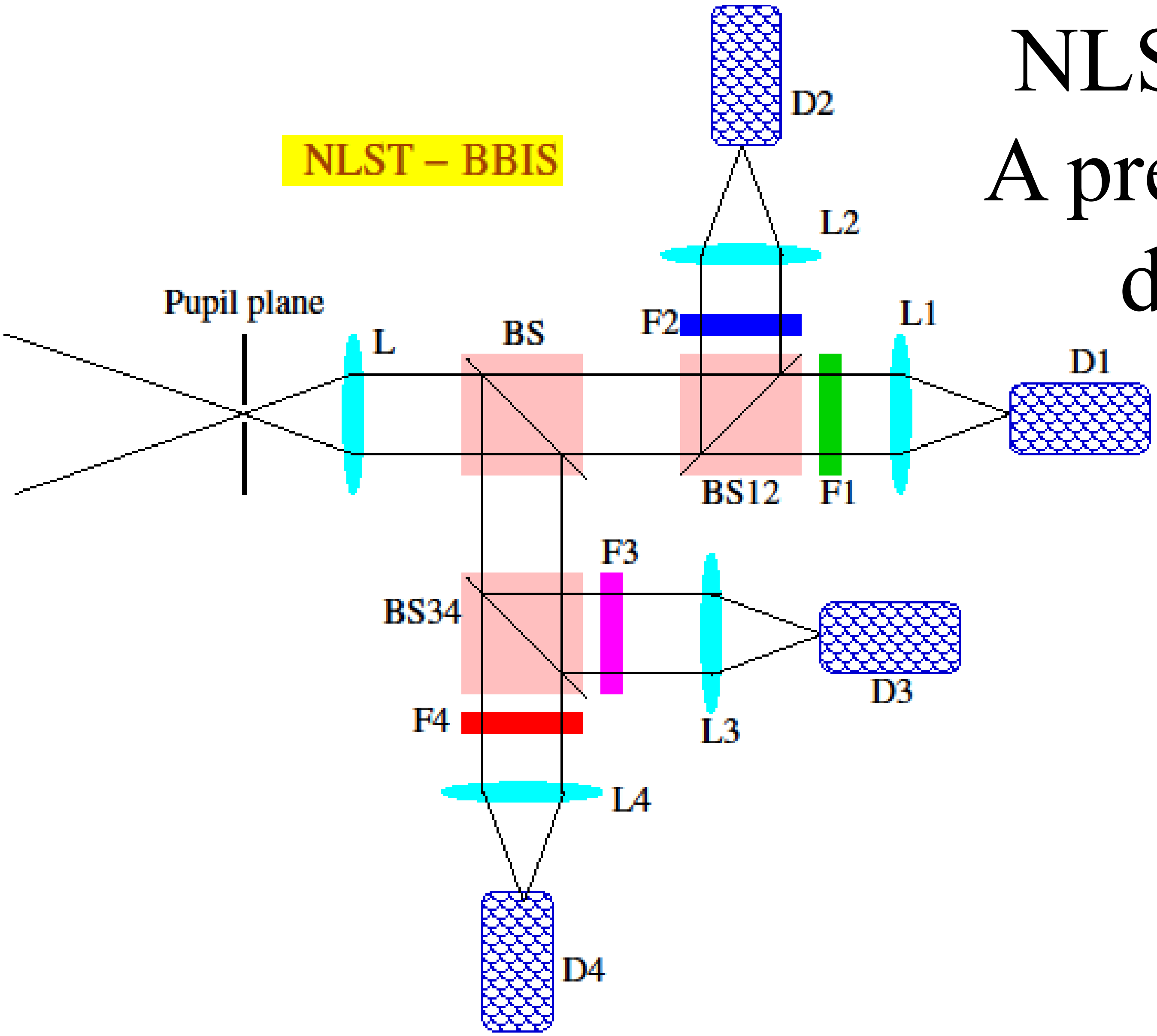
BBIS - Advantage

- With suitable detector quantum efficiency,
- wide bandpass and
- high reflectance/ transmission optics
- And with short exposure times, BBIS
  - will effectively "freeze" atmospheric turbulence,
  - and allow speckle interferrometric image reconstruction

BBIS – Primary Science Goals

- Studies of solar active regions at high spatial resolution.
- Studies of small scale features
  - The filigrees and network bright points.
  - inter-granular lanes
  - Magnetic bright points (MBPs)
  - Emergence and cancellation of small-scale magnetic flux in quiet regions

NLST-BBIS A preliminary design



BBIS – FILTERS - HiRes

Spectral Feature	$\lambda + \Delta\lambda$	Region
G – band	4305 +/- 8 A	Lower Photosphere
Barium continuum	4505 +/- 4 A	Middle photosphere
Ca II H (Line center)	3968 +/- 1.35 A	Lower chromosphere
Ca II	8542 +/- 0.5 A	Middle chromosphere

A Dual Fabry-Perot Based Narrow Band Imager for the National Large Solar Telescope

Specifications

- Spectral resolution ≈ 200000 at 6000 Å
- Spectral range 5000 – 9000 Å
- FOV = 1.5 arc min
- Maximum Ghost Transmission ≈ 10^{-4}
- Signal to Noise Ratio ≈ 500
- Wavelength Stability ≈ 10 mÅ
- Tuning Rate ≈ 10 pm/ms
- Blocking Filter = 2-3 Å
- Maximum Stray Light ≈ 10^{-3}
- Cadence – one image per second (min.)

Exposure Time and SNR

- Solar flux at 6318 Å = 1.638 W m^{-2} nm^{-1}

  Photon flux = 5.201×10^{27} photons/m^2/m/s
- τ = 15 % of the total solar flux
- $\delta\lambda$ = 33mÅ
- δA = 1.5 arc min
- A = 2 m
- SNR = 530
- Exposure Time = 6 frames/second
- Spatial Resolution = 0.06″/pixel
- CCD Camera = 2k X 2k
- Error in Doppler velocity measurement = 24 ms^{-1}

FP Based Narrow Band Imaging System Around the World

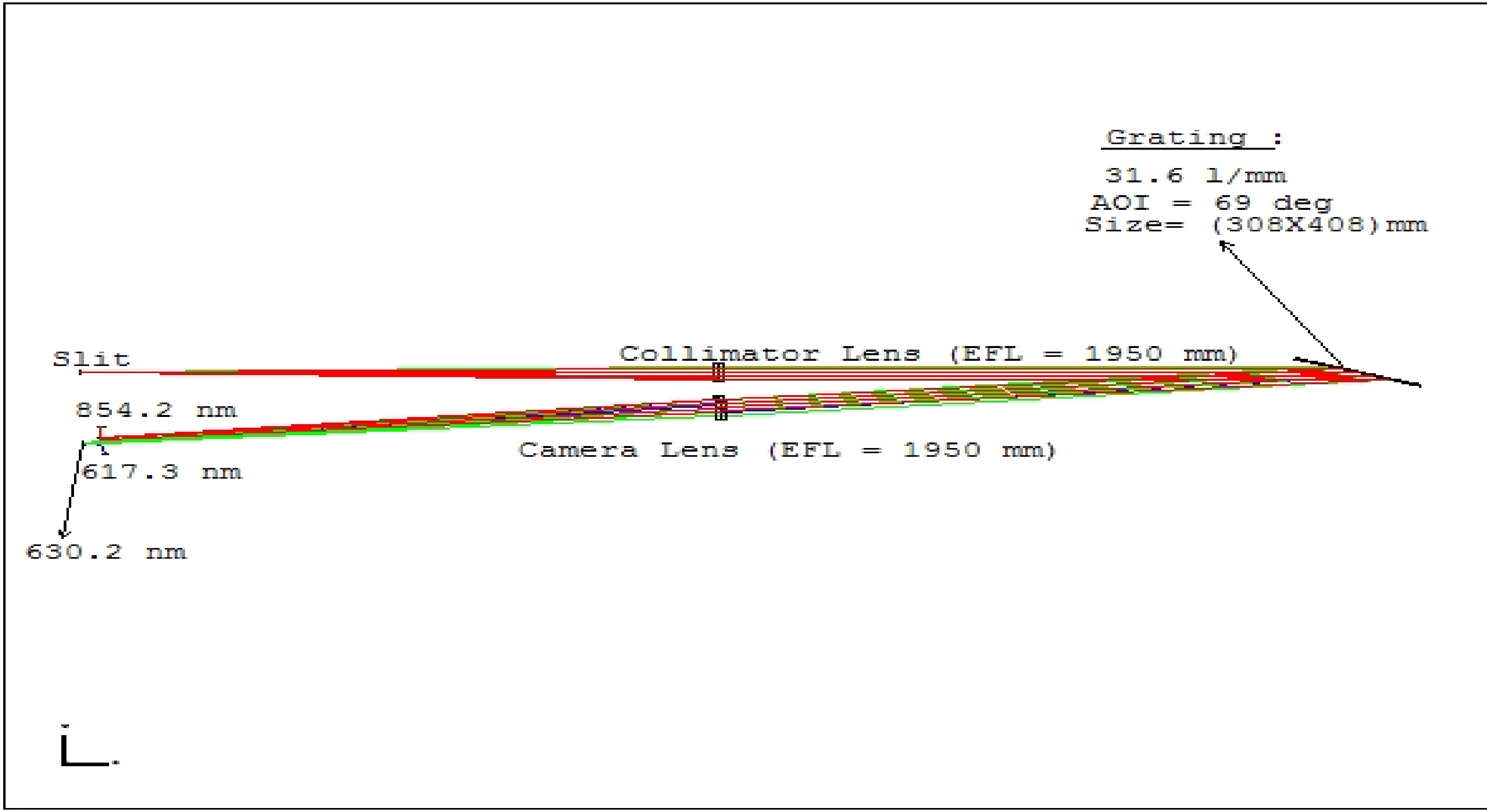
System	$\Delta\lambda$	Res	FOV
TESOS	320000/160000	$0.15''$	$100''$
IBIS	200000	$0.2''$	$80''$
VTT	160000	$0.11''$	$78'' \times 58''$
NLST	200000	$0.06''$ & $0.039''$	$90''$

TESOS: Telecentric Etalon Solar Spectrometer, Tenerife
IBIS: Interferometric Bidimensional Spectrometer, NSO, Sac Peak
VTT: Vacuum Tower Telescope, Institut Fur Astrophysik
NLST: National Large Solar Telescope, IIA, India

Several stages of SP development

Specification	Requirement	Prototype	First Phase
Wavelength range	350 – 1600 nm	350 – 900 nm	350 – 1600 nm
Simultaneous measurements	5 wavelengths	3	5
Spatial resolution	Diffraction limited	Twice telescope	Diffraction limited
FOV	2 arcminute	90 arcseconds	2 arcminute
Spectral resolution	10 milli angstrom	20 milli angstrom	10 milli angstrom
Polarimetric sensitivity	10^-4	10^-3	10^-4
Slit scan accuracy	0.06 arcsec	0.3arcsec	0.06arcsec

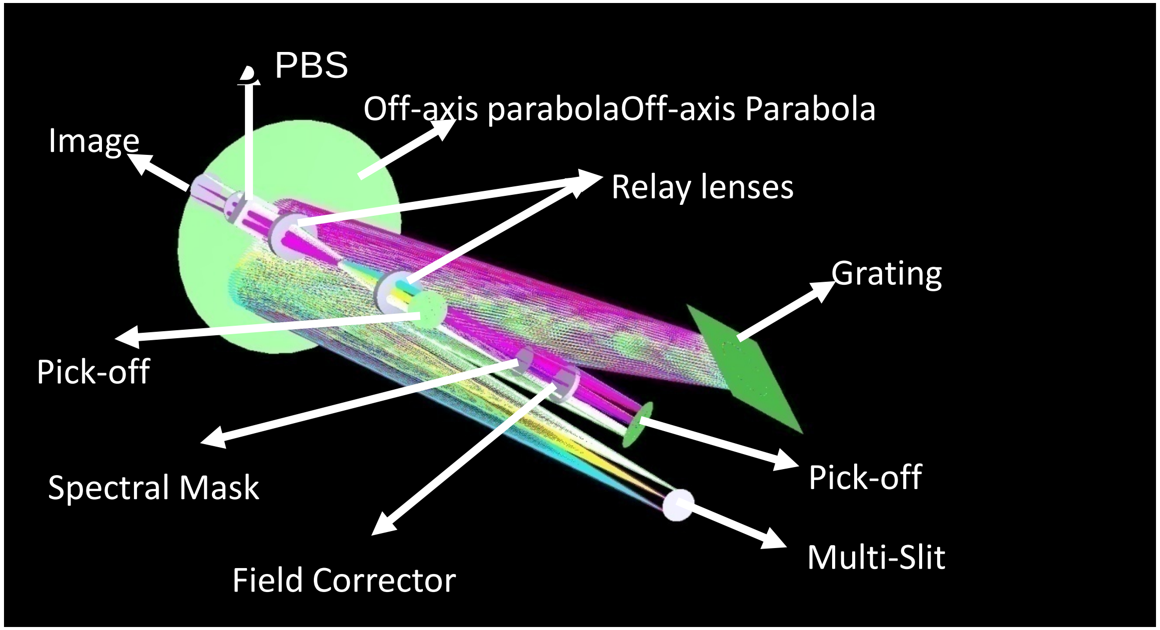
Proto type Spectrograph with MAST



Specification	Prototype with MAST
Slit width	27 μ
Collimator Lens focal length	1950 mm
Grating – groove density	31.6 lines/mm
Blaze angle	71.0°
Grating Size	408 mm
CCD Pixel Size	6.5 micron (617.3 nm) 6.5 micron (630.2 nm) 6.5 micron (854.2 nm)
Total FOV along the Slit	~ 90 arcsec
Spatial Sampling in CCD	0.07 arcsec (617.3 nm) 0.07 arcsec (630.2 nm) 0.07 arcsec (854.2 nm)
Spectral Sampling	3.10 mÅ (617.3 nm) 3.17 mÅ (630.2 nm) 4.13 mÅ (854.2 nm)
Total Wavelength Coverage	nearly 7 Å

MUSIC or MSSP Requirements & Optical Design

Courtesy: Raja Bayanna, USO



- Spectral resolution > 200,000
- Dispersion: 15 mA/pixel
- Wavelength coverage: ~ 3A
- SNR: about 1000 (or 0.1% noise level in polarization)
- Exposure time ~ 10sec at the diffraction limit
- Two beam simultaneous measurement is a must in order to avoid seeing induced polarization cross-talks.
- Detector: CCD. Larger and faster is better

Prototype instrument already made by Sankar & his team. Ready to be installed at MAST

Design Specs:

- **Spectral Resolution = 210,000**
- **Dispersion = 15.7 mA/pixel**
- **Wavelength Coverage = 4 A**
- **CCD Size = 2K X 2K**
- **No. of Slits = 4**
- **Filter Passband = 9 A**
- **Design optimized for 3-wavelengths**

Status of the project

- The Department of Science and Technology accepted the Detailed Project Report submitted by IIA and termed it as one of the mega projects in the current five year plan.
- The Expenditure Finance Committee (EFC) report has been submitted to DST. One level of review is over. At the next level, it gets circulated to other departments.
- Financial allocation is awaited. DST has asked for international collaboration in the same lines as that of USA's Thirty Meter Telescope project.
- In the mean time IIA has allocated some seed money for prototype instrument development and this work is in progress.

Collaborations

- NSO and HAO have agreed to give support.
- MPS may collaborate with Indian institutions on making backend instruments
- KIS, Freiburg with Dirk Soltau is designing the optics including the AO.
- Several Indian institutions like USO, ARIES and ISRO are involved.
- MTM, Germany may be executing the project in consortium with Indian industry.

Conclusion

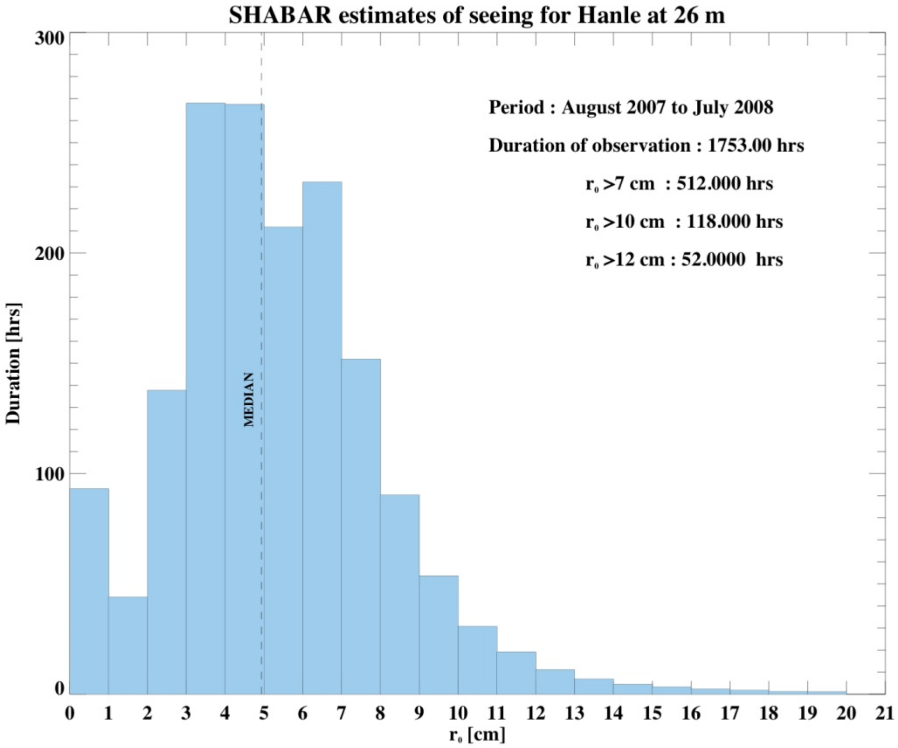
NLST will be a good state of art technology solar telescope which will serve Solar community for a long time to come if funded.

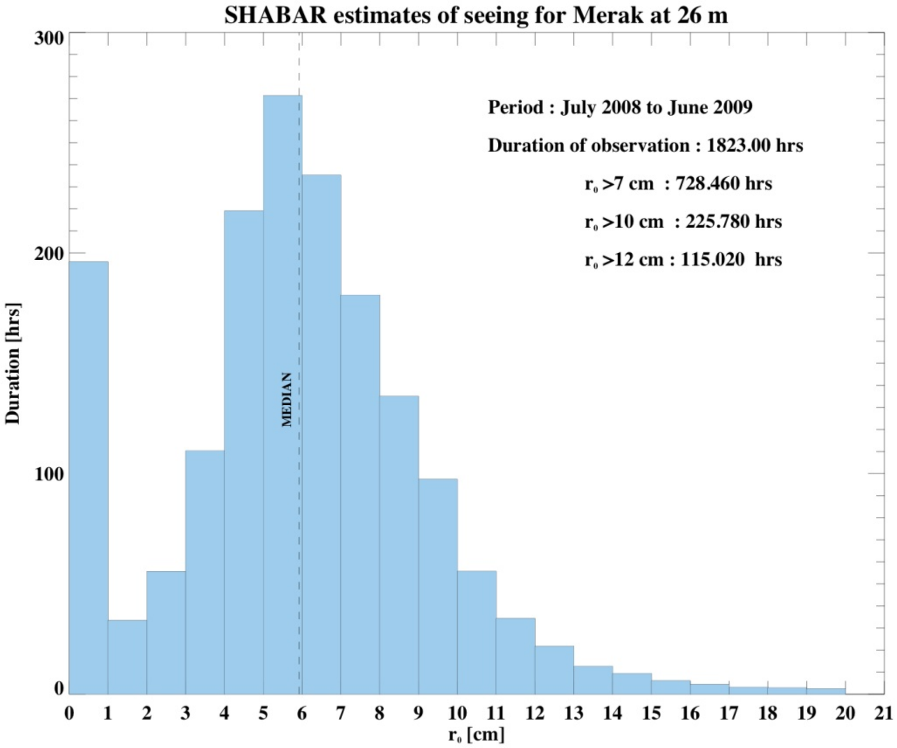
It will also generate job opportunities for young scientists and engineers and keep them occupied in the pleasant job of studying the Sun.

One of the aims is to train young people and allow them to continue the tradition set up by John Evershed nearly a century ago in Kodaikanal observatory, India.

Thank you for your patience and attention

SEEING CONDITIONS AT HANLE AND MERAK





SDIMM/SHABAR data for 26/28 meters	Hanle	Merak	Big Bear	Haleakala
Corrected Annual Hours $r_0 > 7$ cm	514	731	1053	997
Corrected Annual Hours $r_0 > 12$ cm	74	108	136	399
Corrected Annual No. 2-hr blocks $r_0 > 7$ cm	38	72	83	82
Corrected Annual No. 2-hr blocks $r_0 > 12$ cm	1	6	1	10