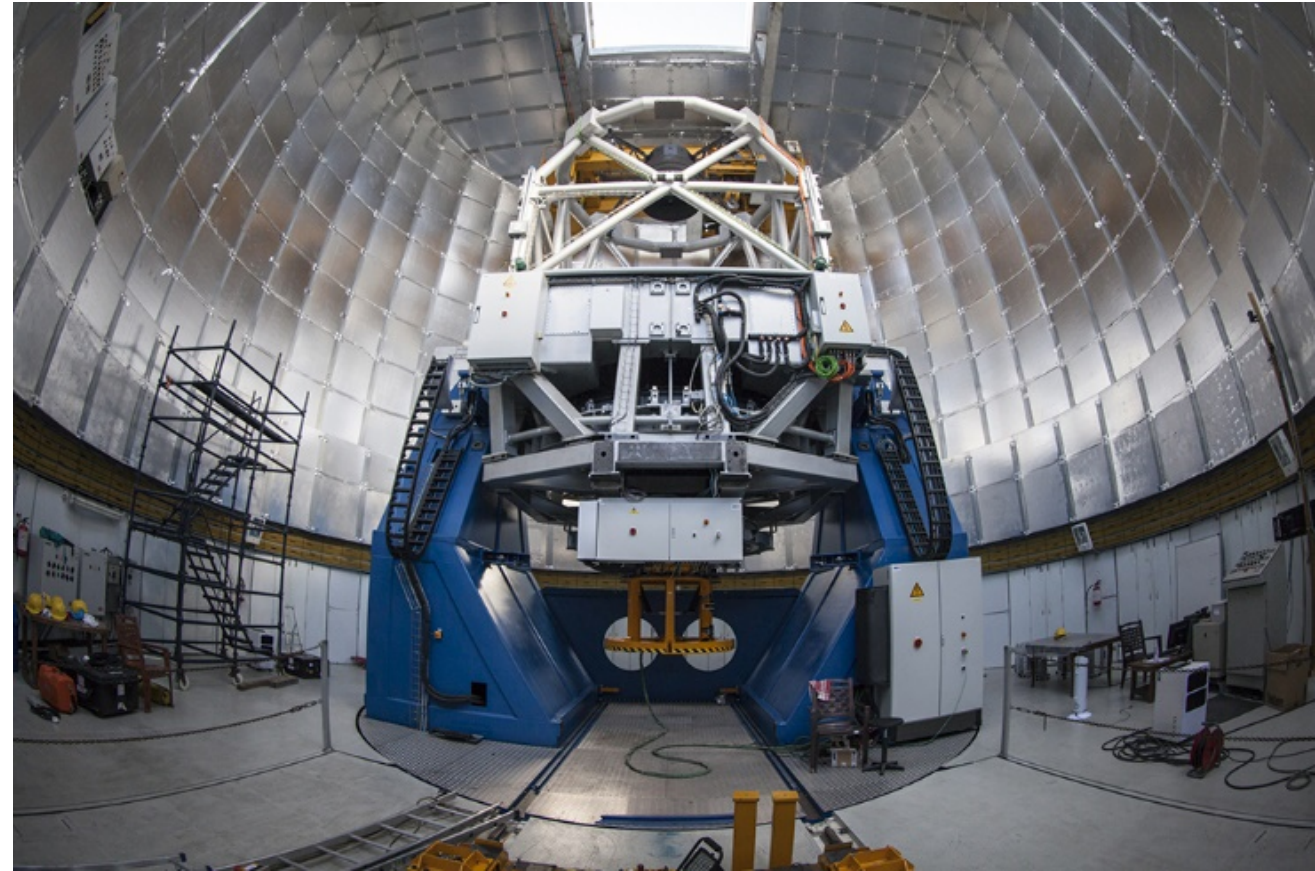


The High Resolution Spectrograph of ARIES

J. C. Pandey

Outline

- Background
- Scientific Objectives
- Technical Specification
- Realization of Instrument



Background

The Site

Parameters	Value
Location	Alt: 2424 m; Long: 79:41:40 E; Lat: 29:21:40 N
Seeing (Ground Level)	1.1 arcsec (median); 0.75 arcsec (median of 10 percentile values)
Wind	< 3 m/s for 75% of time
Air Temperature	21.5 ⁰ C to -4.5 ⁰ C (variation during year) < 2 ⁰ C (variation during night)
Rain	2 m (average over year, 80% during June to September)
Clear Nights	Out of 208 spectroscopic nights, 175 are photometric
Sky Transparency (mag/airmas)	Average: $k_U = 0.49 \pm 0.09$; $k_B = 0.32 \pm 0.06$ $k_V = 0.21 \pm 0.05$; $k_R = 0.13 \pm 0.04$ $k_I = 0.08 \pm 0.04$ Best: $k_U = 0.40 \pm 0.01$; $k_B = 0.22 \pm 0.01$ $k_V = 0.12 \pm 0.01$; $k_R = 0.06 \pm 0.01$
Relative Humidity	60% during spectroscopic nights > 90% July to September Minimum 5% is recorded

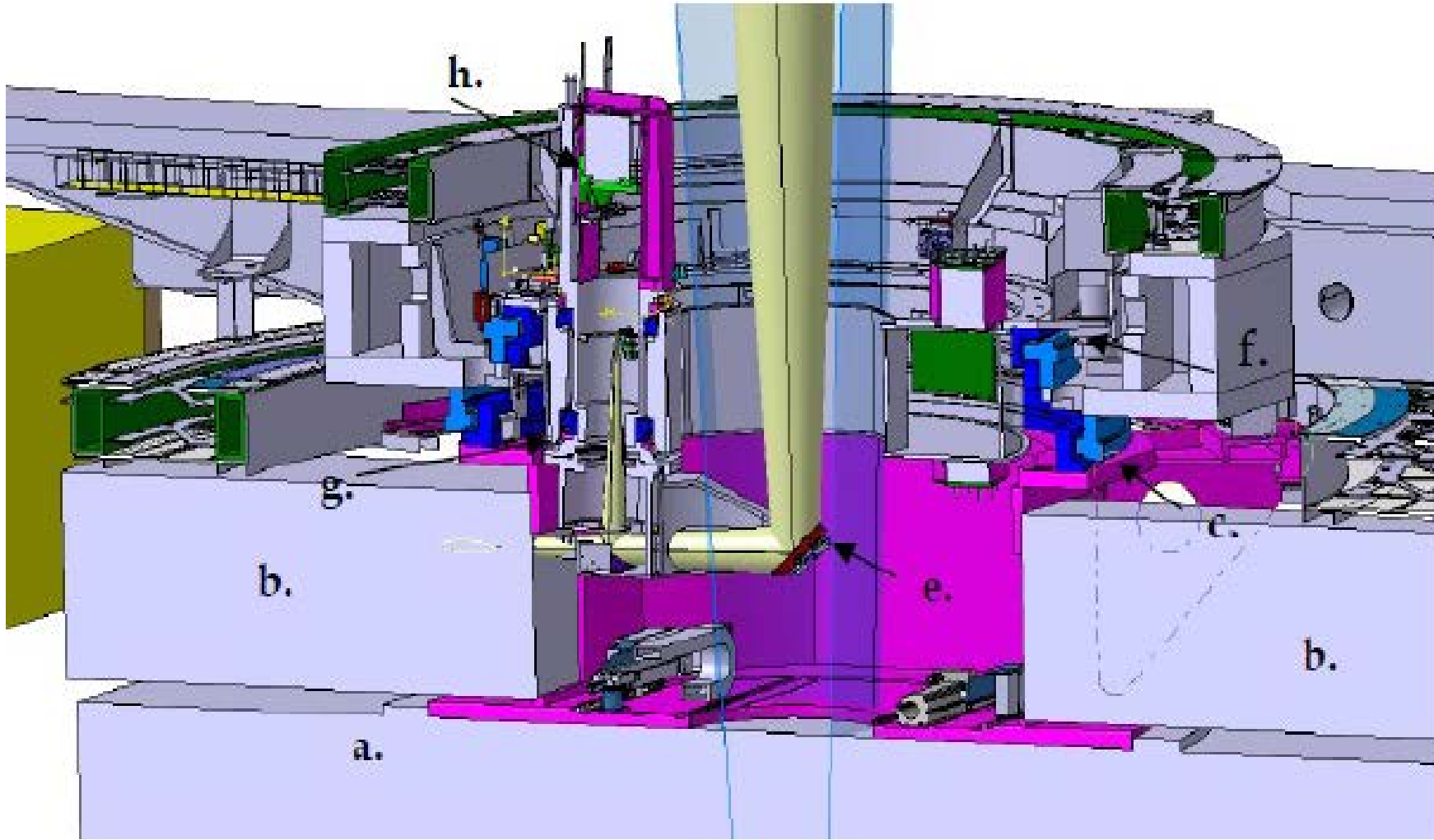
Background: The Telescope

Parameters	Values
Primary mirror clear aperture	3.6 m
Focal ratios	Primary : F/2; Effective : F/9 (0.006 arcsec/ μm)
Science Field of View:	10 arcmin on side ports, 30 arcmin on axial port, (35 arcmin for the AGU)
Operational waveband:	350 nm to 5000 nm
Optical image quality	<ul style="list-style-type: none">- Encircled Energy 50% < 0.3 arcsec,- Encircled Energy 80% < 0.45 arcsec,- Encircled Energy 90% < 0.6 arcsec, For the waveband 350 nm to 1500 nm and without corrector for 10 arcmin FOV.
Mounting	Alt-azimuth
Sky coverage	15 to 87.5° in elevation
Pointing accuracy	< 2 arcsec RMS

Background: The Telescope

Parameters	Values
Tracking Accuracy	< 0.1 arcsec RMS for 1 minute in open loop, < 0.1 arcsec RMS for 1 hour in close loop, < 0.5 arcsec Peak for 15 minutes in open loop.
Instruments' space	1 main axial port instrument: <ul style="list-style-type: none">- mass: 2000 kg- allocated room: 1.8 m X 3 m (Height X Diameter)- instrument flange: 40 cm before the focus. 2 side port instruments: <ul style="list-style-type: none">- mass: 250 kg per instrument- allocated room: 0.5 m X 0.5 m X 0.7 m (H X W X L)- instrument flanges: 10 cm before the focus.

The Telescope: Adapter Rotator Instrument Support Structure (ARISS)



a - main instrument envelope,

b - side-port instrument envelope,

c - rotator bearing,

e - pick-off-mirror,

f - adapter bearing,

g - turn table,

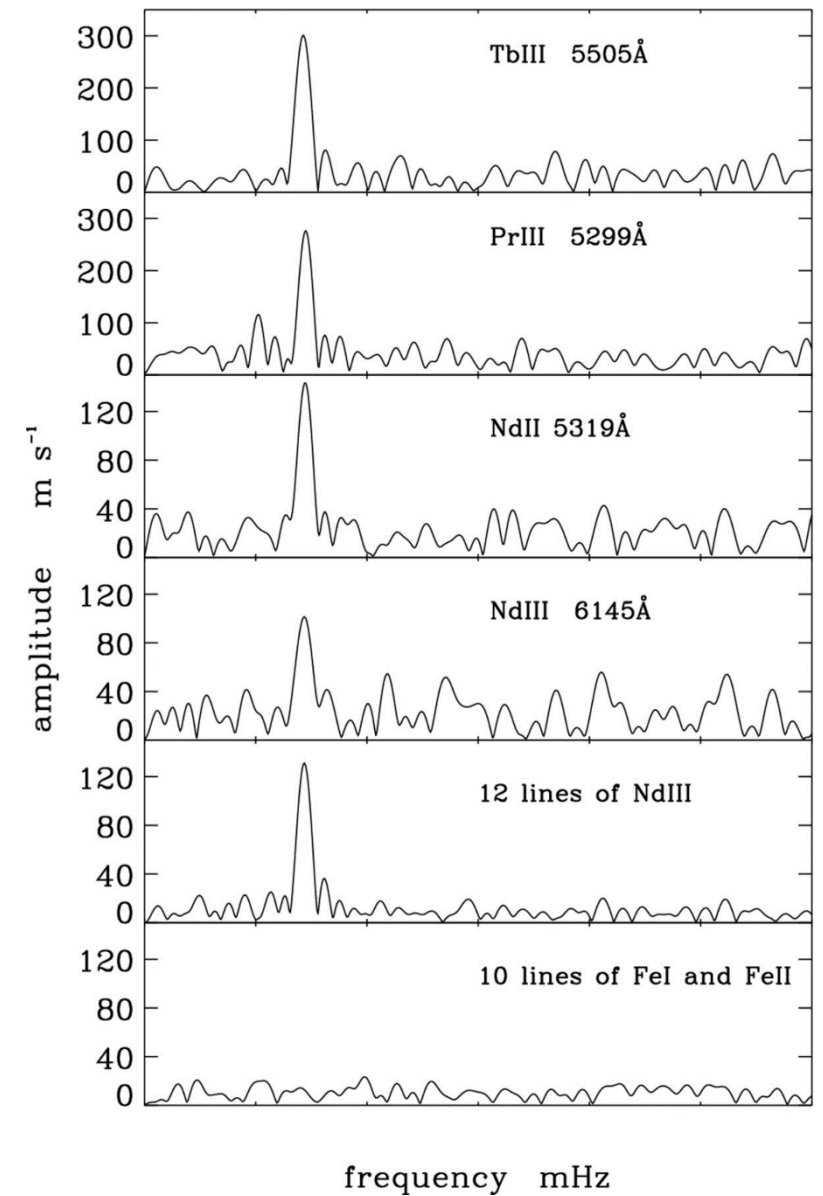
h - optical bench with guider camera and wave front sensor.

Scientific Objectives

- Asteroseismology and Chemically Peculiar Stars
- Doppler Imaging
- Abundances Studies
- Spectroscopy and Ground-based Follow-up of Exoplanet
- Extended Horizontal Branch Of Globular Cluster
- ^6Li and ^7Li isotopes in metal poor Halo stars
- Eruptive Young Stellar Object
- Supernovae

Abundances and Chemically Peculiar Stars

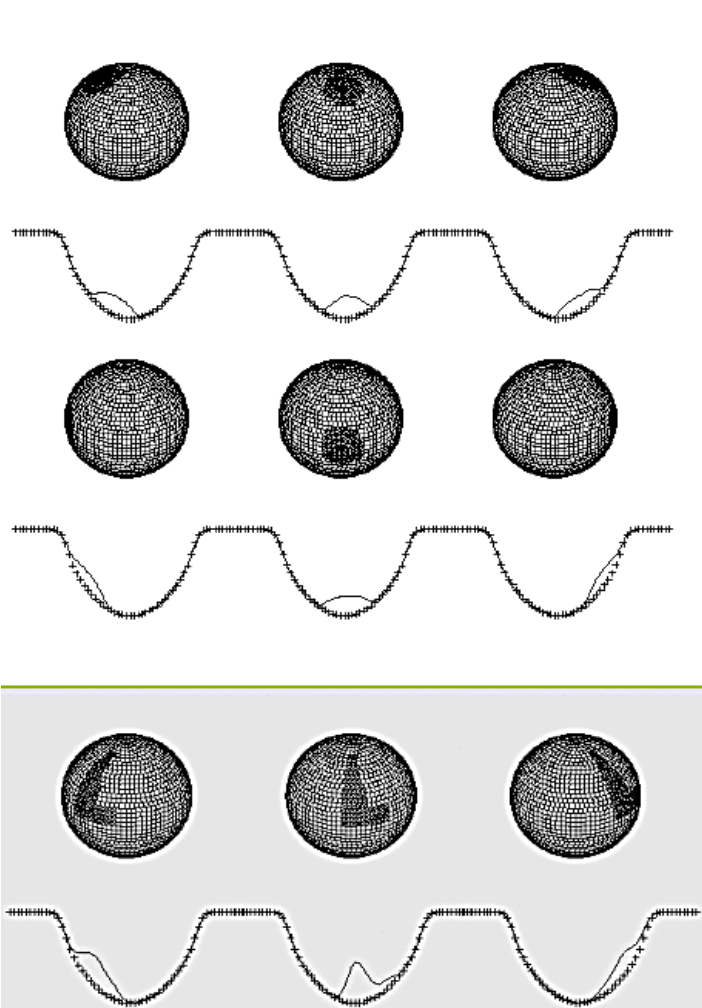
- Time resolved spectroscopy has allowed the study of wider physical aspects of the pulsating stellar atmosphere.
- A systematic study of radial velocity variations.
- Atmospheric abundances.
- Mechanism of stellar pulsation
- Modelling of stellar structure and evolution
- Physical parameters like mass, age etc.
- Requirement:
Spectral Resolution $\rightarrow > 60k$, $RV \sim 2$ m/s



Amplitude spectra for HD 213637 for individual lines and for combinations of lines of the same chemical element. Elkin et al. 2015, MNRAS, 446, 4126

Doppler Imaging

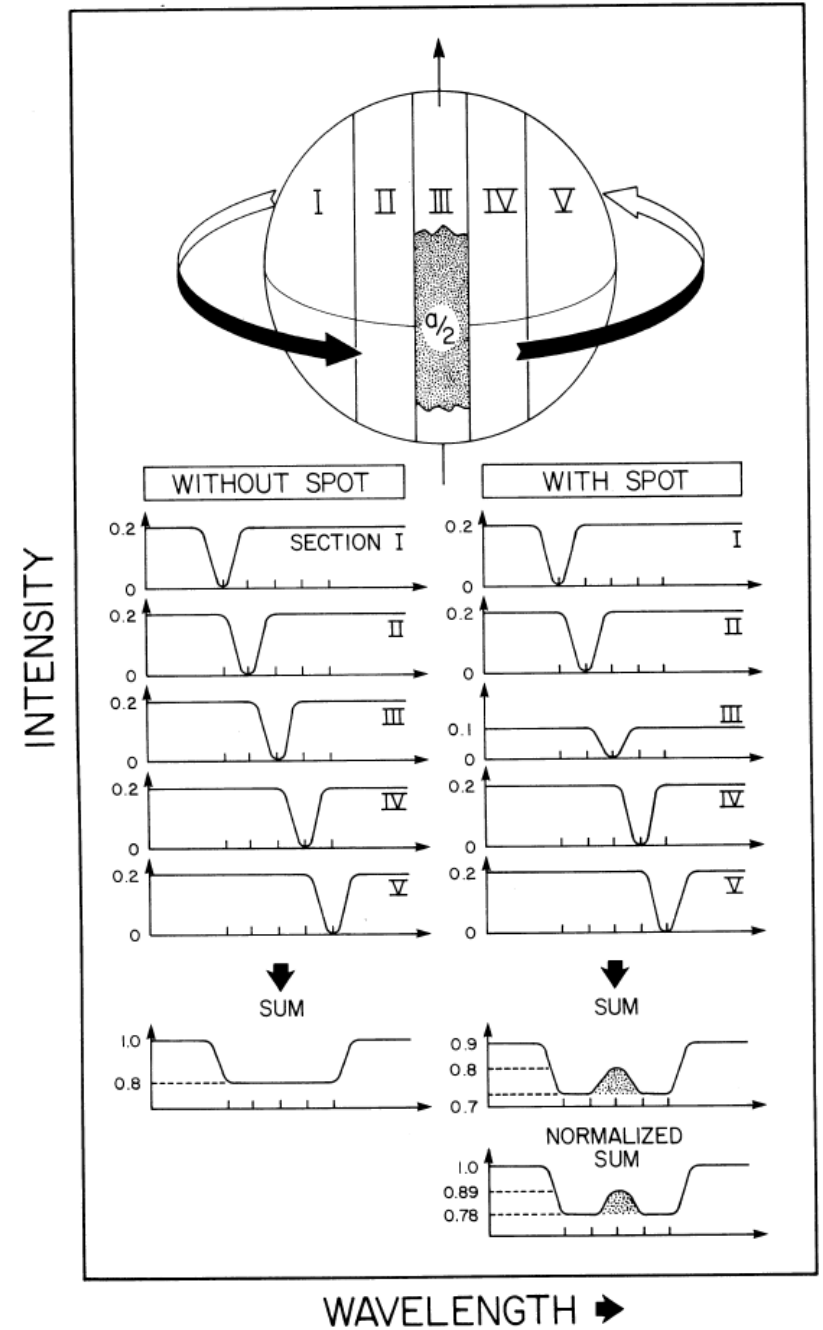
Line Profile Deformation



High Latitude

Low Latitude

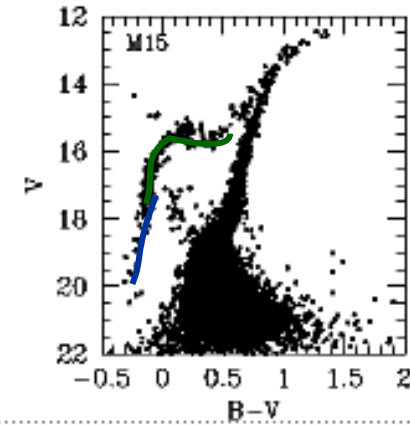
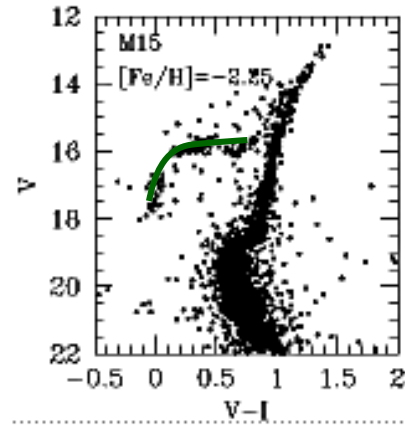
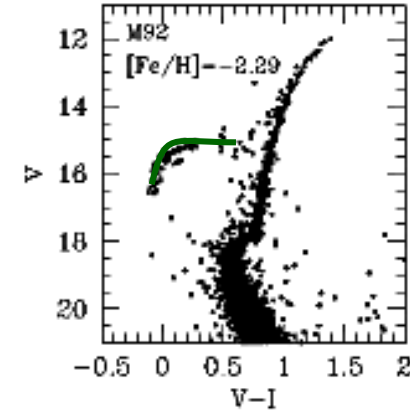
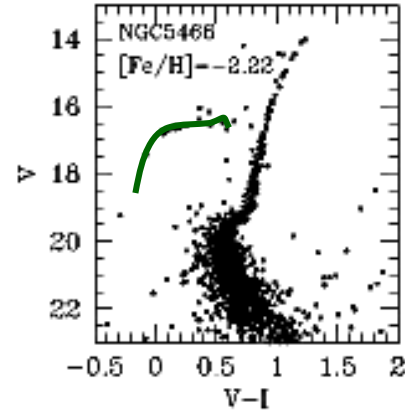
Complex Structure



Horizontal Branch (HB) in Globular Cluster

Study of HB stars have large physical impact:

- Allows to understand evolution of population II stars
- Key ingredients in any stellar population synthesis model
- Dependences of the HB morphology on metallicity
- Horizontal branch bimodality



${}^6\text{Li}/{}^7\text{Li}$ isotopes in metal poor halo stars

Signature of unstable particles that might have existed in the early universe.

Abundances of nuclides produced in big bang nucleosynthesis (BBN) suggests that primordial nucleosynthesis is good place to look for such signatures.

In context of this,

Recent observations of metal poor halo stars indicate that the primordial abundance of both ${}^6\text{Li}$ and ${}^7\text{Li}$ may not be in agreement with the prediction in standard BBN.

${}^6\text{Li}$ appears to have an abundance plateau similar to that for ${}^7\text{Li}$ in very low metallicity stars. This suggests a primordial abundances.

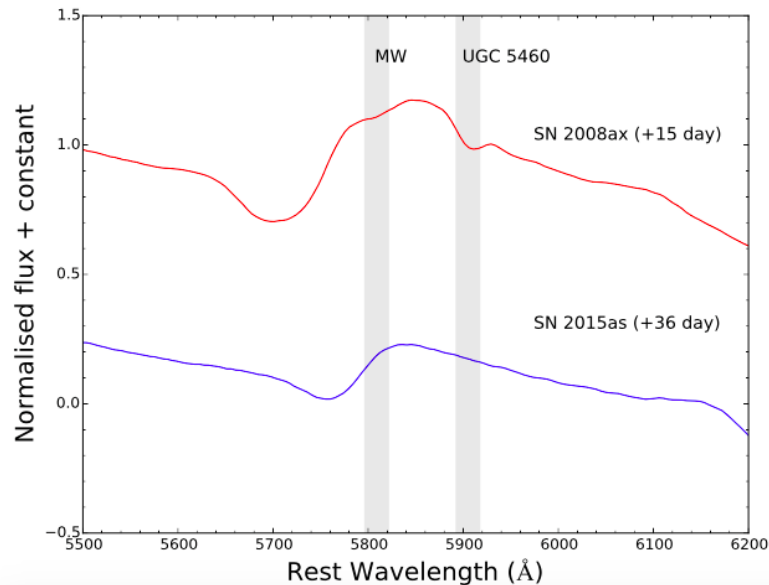
A number of solution have been suggested for ${}^6\text{Li}$ results: e.g. possible epoch of enhance cosmic ray nucleosynthesis via $\alpha + \alpha$ reaction (Rollinde et al. 2008).

Spectroscopy and Ground-based Follow-up of Exoplanets

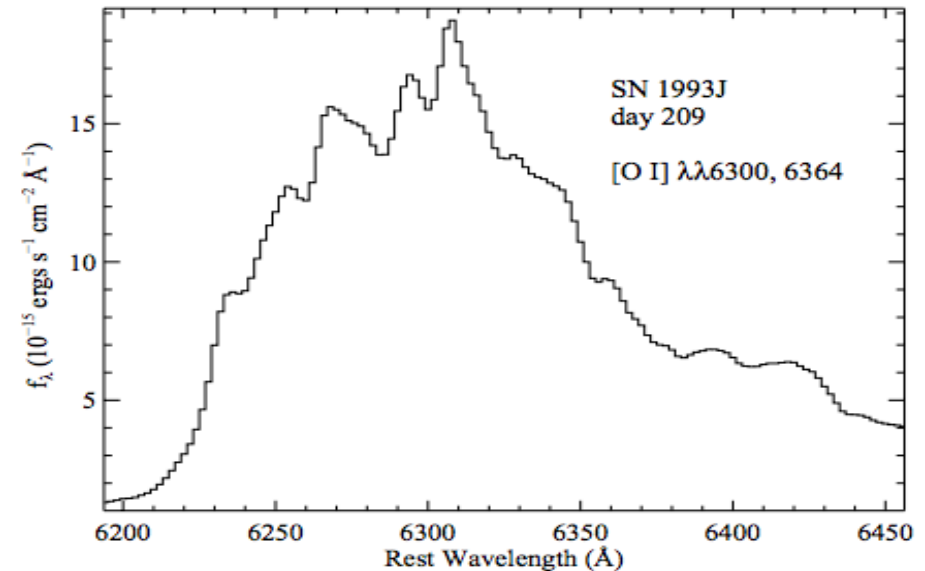
- Exoplanet research → an established and cutting-edge branch of astronomy and planetary sciences.
- The transit spectroscopy → a powerful tool for the characterization of planetary atmospheres.
- The wavelength-dependent absorption during the transit is indicative of the composition of its atmosphere such as gases, hazes, and clouds.
- The higher C/O abundance ratio in high-metallicity stars with planets → Indicative of existence of terrestrial planets with a carbon-dominated composition → very different from the composition of the Earth.
- High dispersion spectroscopy on a large telescope such as DOT can overcome the difficulty inherent to the many orders of magnitude that separate the brightness of a planet and that of its stellar host to get high signal-to-noise ratio observations.

Supernovae

- Estimation of total extinction (Galactic and Host)
- Sawtooth profiles of Oxygen and Calcium



The milky way and host galaxy Na 1D component in the spectra of two type-IIb supernovae.



The sawtooth profile of the OI line superimposed on the global line profile seen in a late-time spectrum of a type-IIb supernova indicating the clumpy nature of the ejecta.

Technical Specifications

- Spectral coverage

The instrument must yield a complete wavelength coverage in the optical domain from 380 to 900 nm in a single exposure.

- Spectral Resolution:

Two modes of spectral resolution required

Lower Spectral Resolution mode: 40,000

Higher Spectral Resolution mode: 80,000

Technical Specification

- Two interleaved spectra

The spectrograph should be able to record simultaneously the spectra an object and/or sky. Alternatively, it should have the possibility to interleave the object spectra and that of the calibration spectra. The instrument should also be able to record at the same time the spectrum of the faint object along with that of the adjacent sky.

- Radial Velocity Stability

The variety of science program needs different radial velocity (RV) stability. There are certain programs which need RV stability as low as 2 m/s

- Throughput

A peak throughput between 15-25% is necessary to get good S/N spectra of stars up to 12-15 mag.

Technical Specification

- Stray Light

Inter-order light level $< 2\%$ of signal within orders for flat-field observations

- Focusing

Fully automated focusing, observing, and calibration functions.

Proposed Design

- Three main units

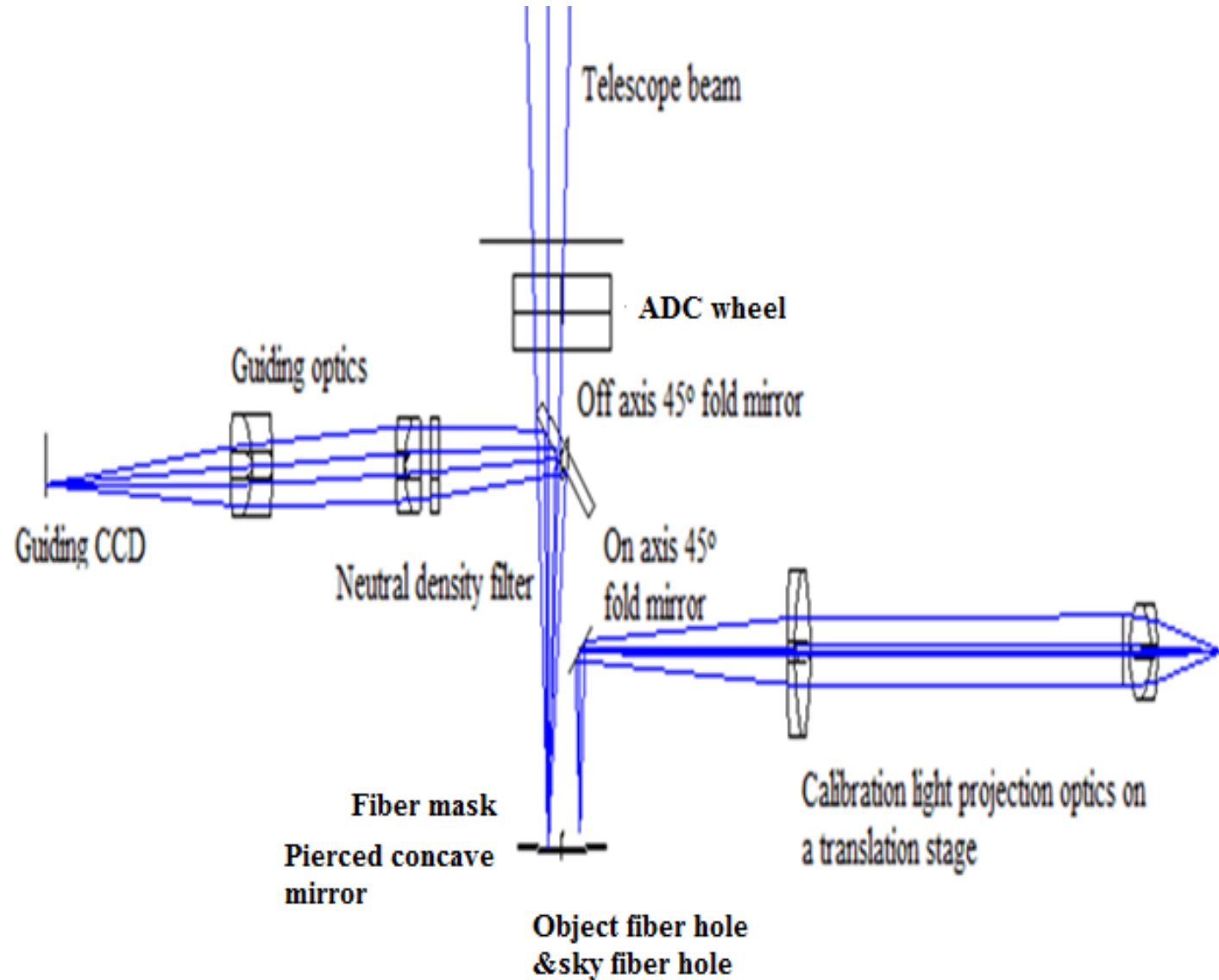
Interface

Spectrograph

Detector

Interface Unit

Optical layout of the telescope interface unit



Interface Unit

- Atmospheric Dispersion Corrector (ADC)

- Refractive index of the atmosphere is dependent on wavelength.
- So when we observe near horizon image will be vertically dispersed. So most of the blue and UV flux will be lost for the spectrograph.
- ADC will be used to neutralise the effect of atmospheric dispersion.

- Calibration Unit

- Two types light source are required
- One continuous source for order location for correction of pixel to pixel variation over the detector.
- Second is the rich emission line sources for wavelength calibration.

Interface Unit

- **Guiding Unit**

- A pierced concave mirror will be used just in front of the fiber.
- This mirror will be slightly tilted. The star light will pass through the holes in the mirror to the fiber entrance and rest of the light will be directed by another folding mirror towards the fiber viewer

- **Exposure meter**

- An exposure meter is planned to use for continuous monitoring of flux for deciding the exposure time with the desired SNR.
- The exact mean time of exposure is required to apply correction to the observed radial velocity.

- **Optical Fiber**

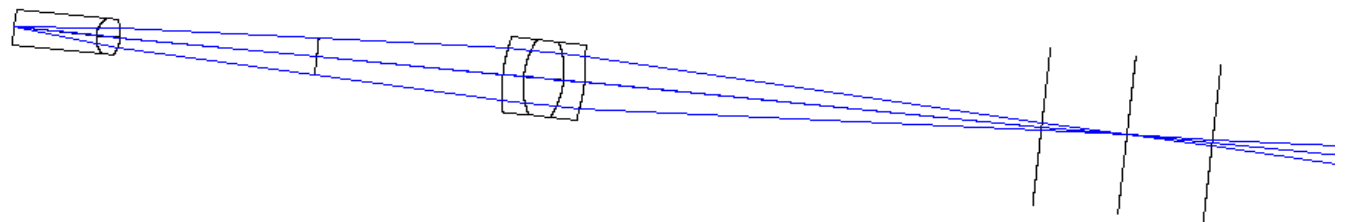
- Two optical fibers at the telescope focal plane will be used. One fiber captures the star light for producing the science spectra and called the 'science fiber'. The other fiber will be used to image the sky for sky intensity subtraction and called 'sky fiber'.

Focal Ration Adaption (FRA) Optics

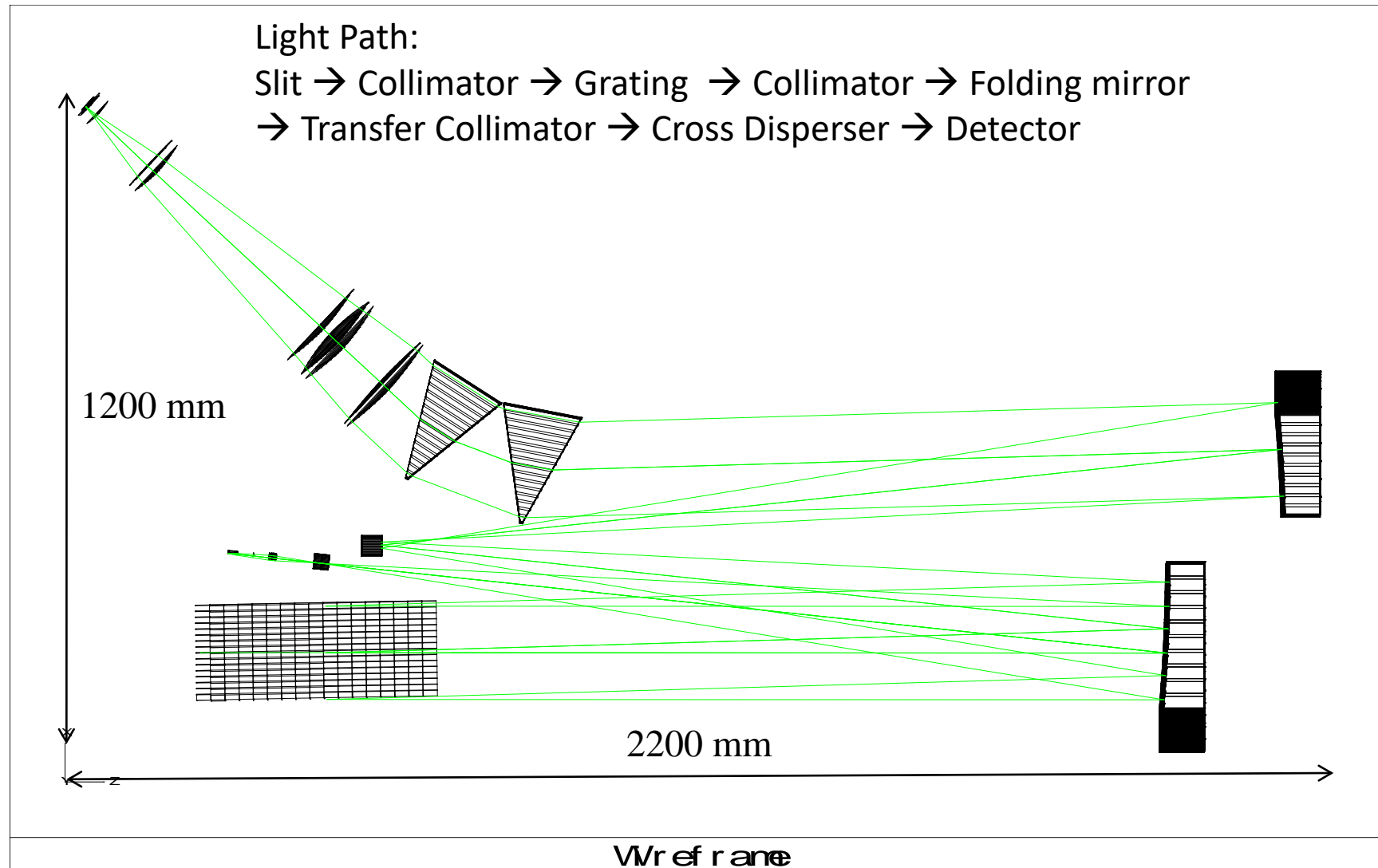
f-ratio of light existing fiber $\sim 3.44 \rightarrow$ spectrograph optics requires a much larger focal ratio.

FRA optics will be used to increase the f-ratio of the beam by a factor of 2.6, resulting in the required f/9.15 spectrograph beam.

The FRA optics consists of one doublet and one triplet. The doublet will be directly cemented on the fiber exit. This increases mechanical stability and limits the number of glass-air interface, thereby reducing the reflection losses.



Spectrograph Unit: Concept Design



Collimators and Flat Folding Mirror

- The parabolic mirror is the obvious choice for the collimators
- The spectrograph design will be used two off-axis parabolic mirror as the main and transfer collimator
- Both the collimators are the segments of a single parabolic mirror of diameter 660 mm.
- The collimators have a focal length of 1475 mm and diameter 660 mm and provide a collimated beam of diameter 161.3 mm, this result in a spectrograph focal ratio of about 9.15.
- **Flat folding mirror** will be used in the vicinity of the intermediate focal plane of the main and transfer collimator. As all the superposed orders are made to fall on the flat folding mirror, so it's a long component covering all the orders. The physical dimension of the flat folding mirror is 224x55x32 mm.

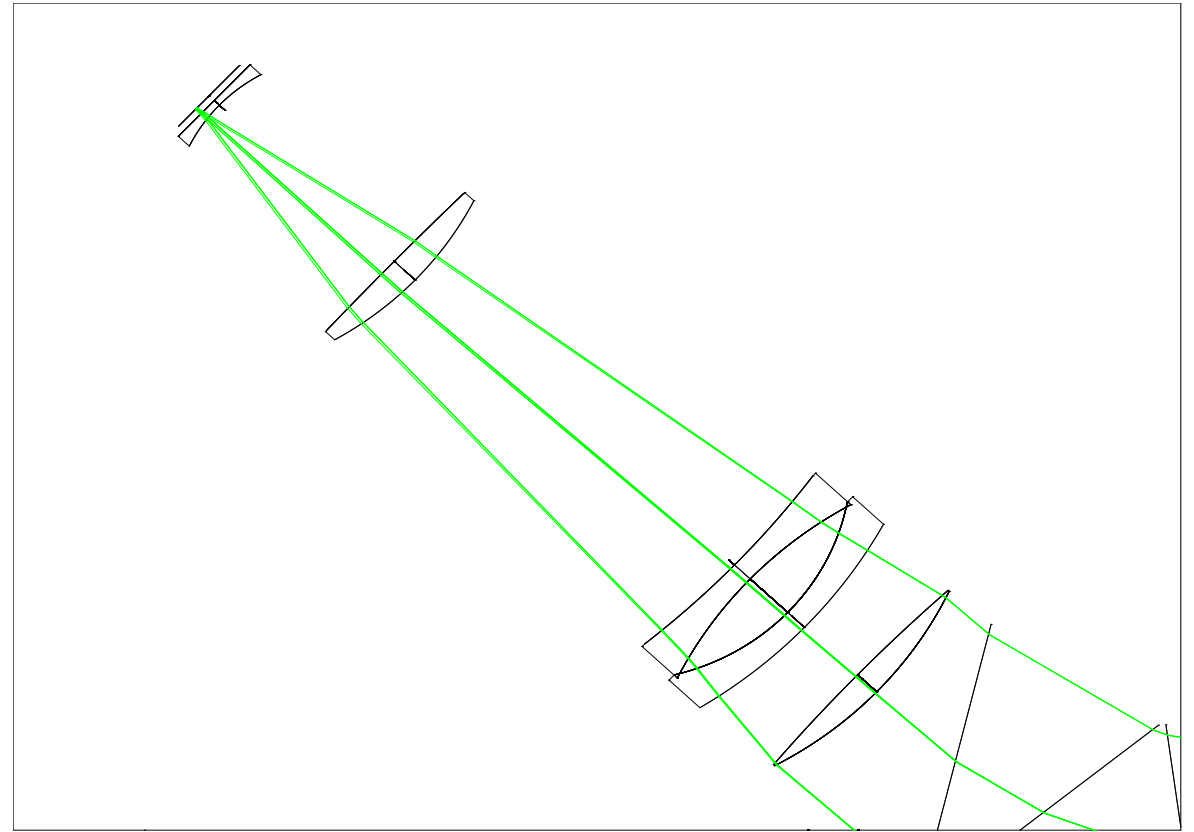
Cross Disperser

- Prism gives larger separation at shorter wavelength, which is desirable.
- Prism (> 90%) has more efficiency than grating (60-70%).
- Prism can comfortably cover the large wavelength range.
- Prism gives a more uniform order separation.
- Two PBL1Y prism with apex angle= 37.4° is used giving a separation of about 50- 21 pixels for wavelength 377-900 nm.

Camera

6 lenses in 4 groups (3 singlet and 1 triplet).

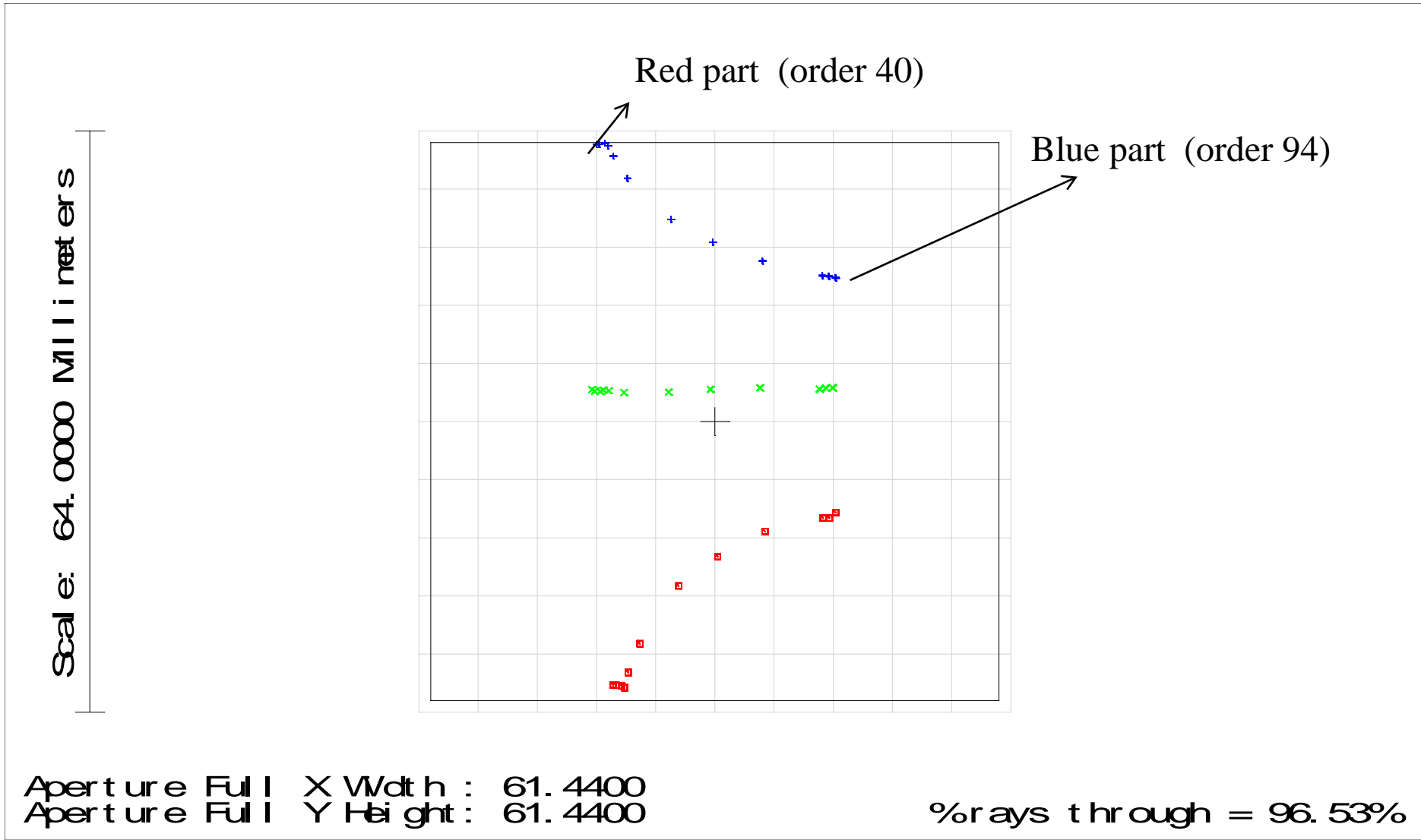
- Camera is designed to give the final focal ratio of 2.8 with good image quality.
- Last surface of the lens is a cylindrical surface to correct the field curvature.
- The last lens of the camera will serve as the detector window.



Detector

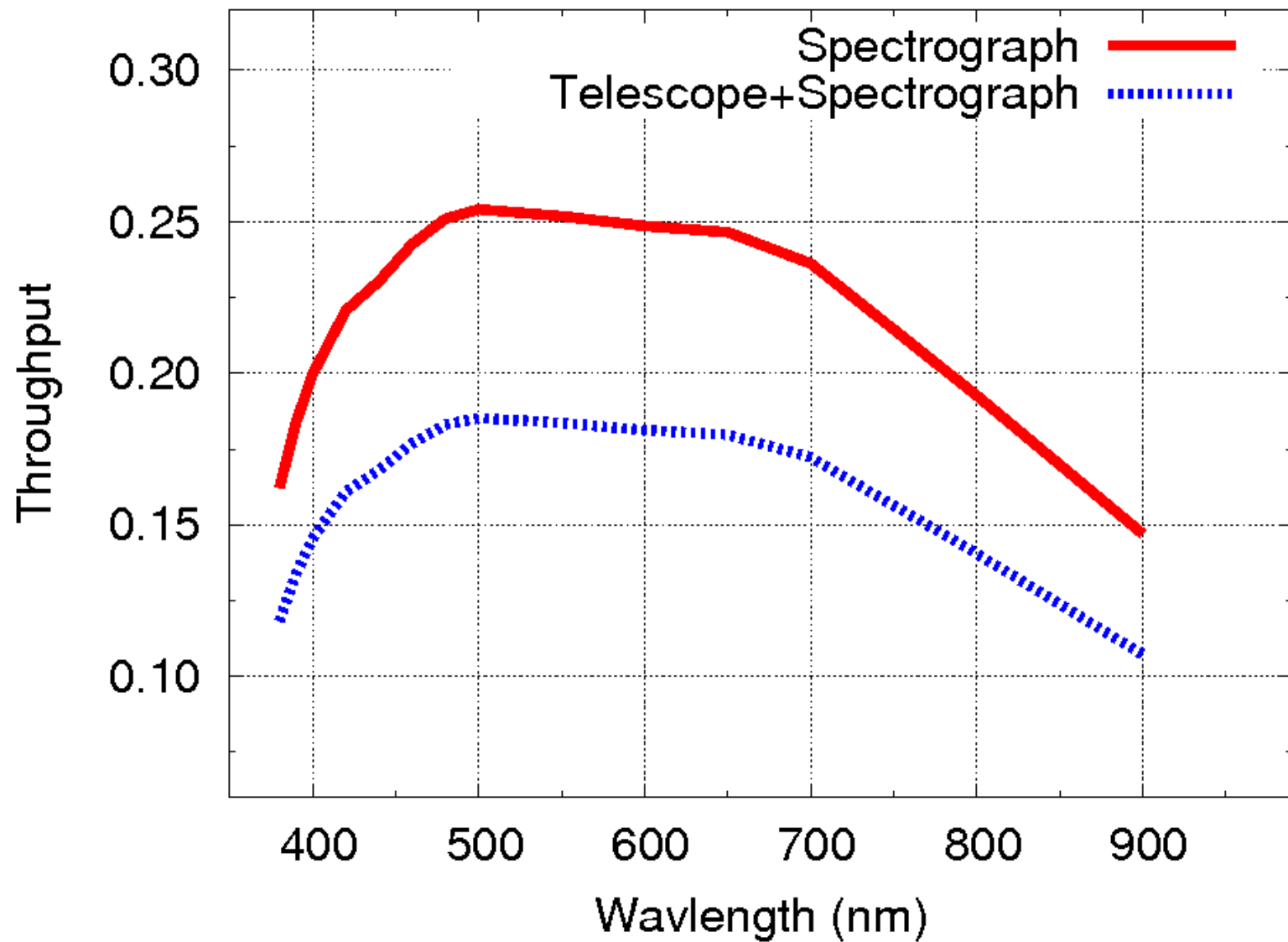
- The detector should cover the required spectral orders with interleaved spectra without any vignetting.
- A 4kx4k CCD with 15 micron pixel size may be used.
- CCD must have a low thermal and read out noise along with high quantum efficiency over the specified wavelength range.

Shape of spectrum at CCD

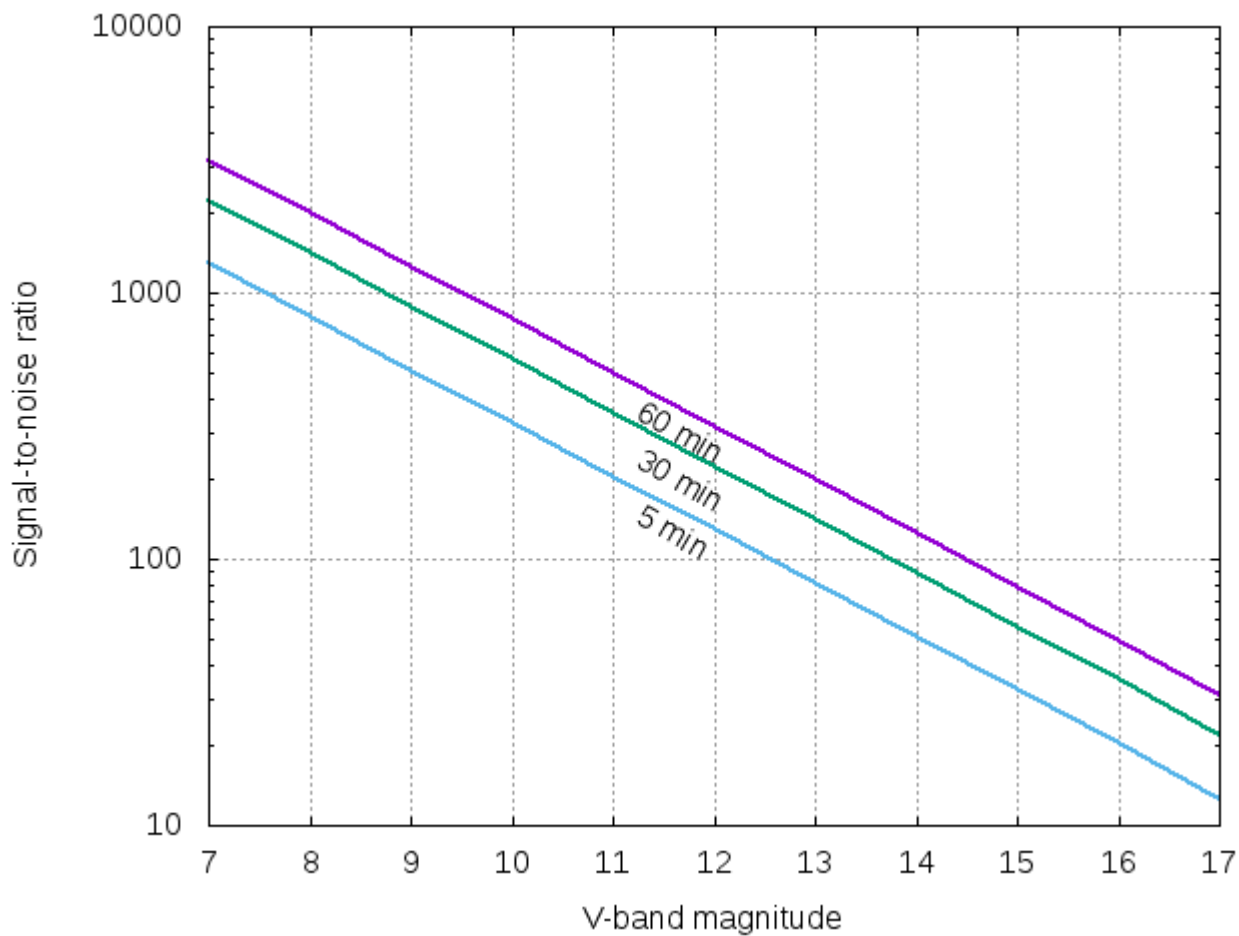


Foot print Diagram

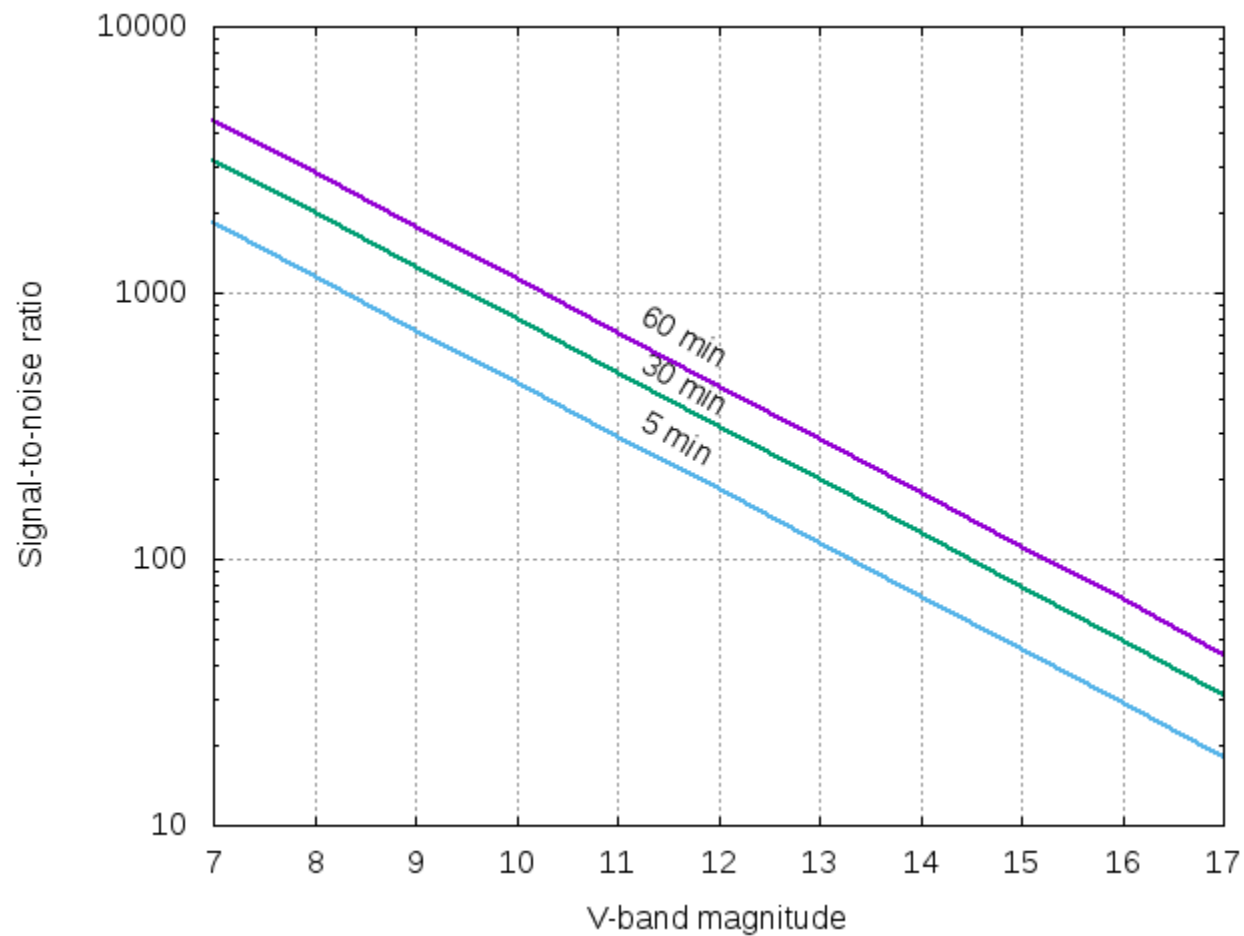
Throughput



Signal-to-Noise Ratio

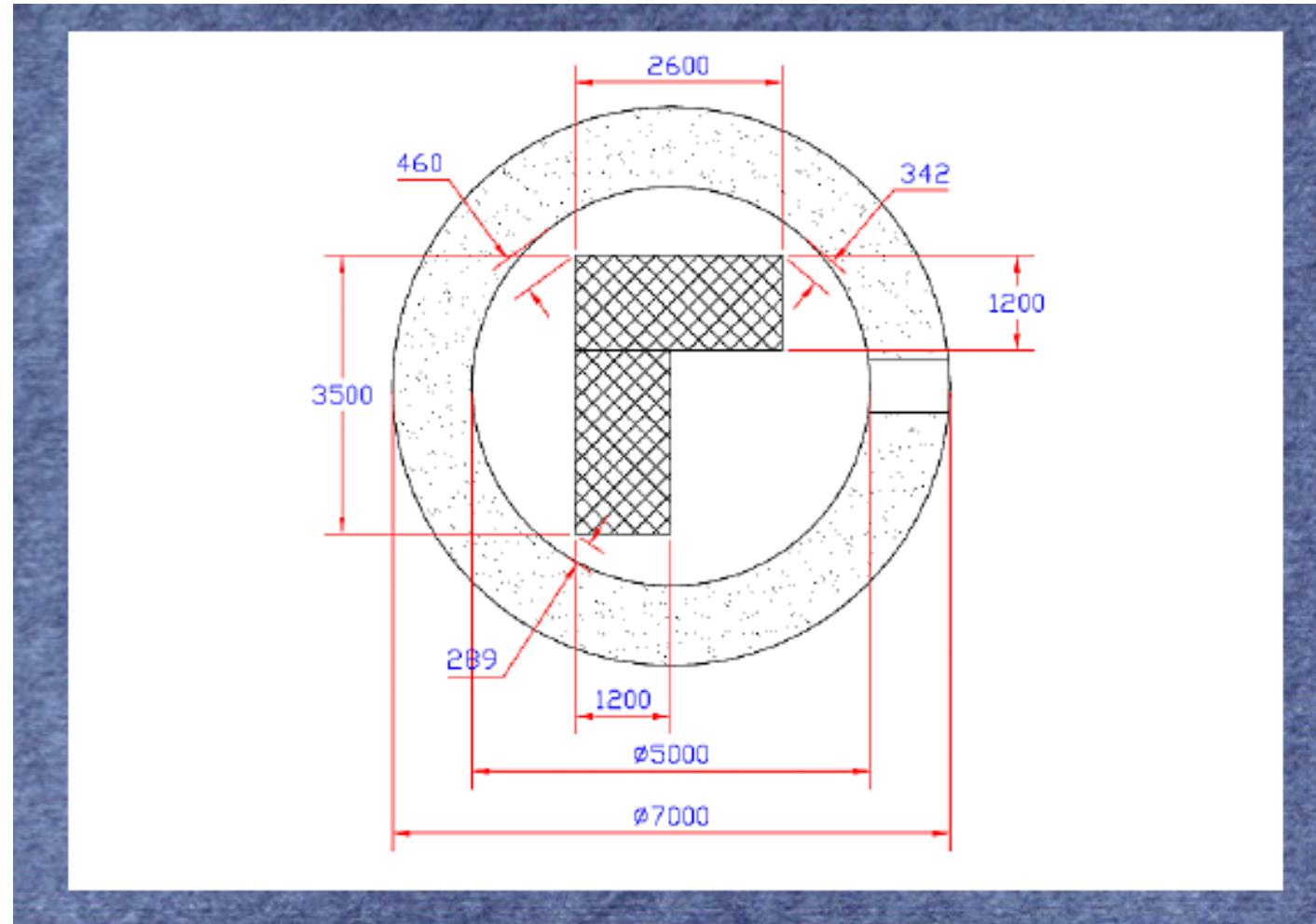


For 80 k spectral Resolution



For 40 k Spectral resolution

Location of Spectrograph



National Status of Design

Spectrograph	Telescope	Spectral coverage	Spectral Resolution	Throughput (Tel+Det.)	Observing Limit	RV Accuracy
HESP	2.0 HCT	350-900	60,000 30,000	20	12	20 m/s
PARAS	Mt. Abu	370-860	63,000	1-2 m/s
ARIES-HRS	3.6-m DOT	380-900	80,000 40,000	25	14	2 m/s

International Status of the Design

Spectrograph	Telescope	Spectral coverage (nm)	Spectral Resolution	Throughput (Tel+Det.)	Observing Limit (1hr, SNR=100)	RV Accuracy (m/s)	Reference
HIRES	10-m Keck	300-1100	80000	8%			Vogt et al.
UVES	8.2-m VLT	300-500 420-1100	80000 (B) 110000 (R)	12-14%	18.0 (B) 19..5 (R)		Dekker et al, (2000)
HARPS	3.6-m La Silla	378-691	115000	~10%		1 m/s	Pepe et al,(2000)
ESPaDOs	3.6-m CFHT	380-900	63000	12%			Donati (2006)
TOU	2.1-m KPNO/AST	380-900	100000			1m/s	Ge et al. (2016)
HERMES	1.2-m La Palma	380-900	85000 63000	22% 15%	10	2.5 m/s	Raskin et al.(2011)
ARIES-HRS	3.6-m DOT	380-900	80000 40000	20	14	2 m/s	

Time Schedule of Activities and Milestone

First Year

- Preliminary design review of spectrograph and interface unit (optical+mechanical+ Thermal enclosure design+ electronics+software)
- Critical Design review of spectrograph and interface unit (optical+mechanical+ Thermal enclosure design+ electronics+software)
- Procurement of optical components

Second Year

- Procurement of optical components
- Tool and melt adaptation of optical design
- Start of Optics Fabrication
- Start of Mechanical and electronics components procurement/fabrication
- Thermal and vacuum enclosure fabrication
- Development of software

Time Schedule of Activities and Milestone

Third Year

- Completion of optics fabrication
- Completion of mechanical and other components manufacturing/procurement
- Thermal and vacuum enclosure fabrication complete
- Integration, test of components and sub assemblies
- Final assembly, testing, and integration of complete instrument at Devasthal, ARIES
- Acceptance Test

THANK YOU