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DOTIFS: Spectrograph optical and opto-mechanical design

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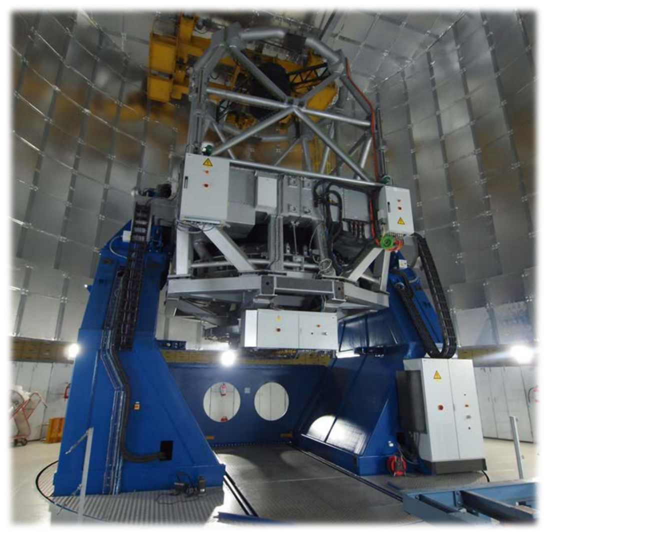
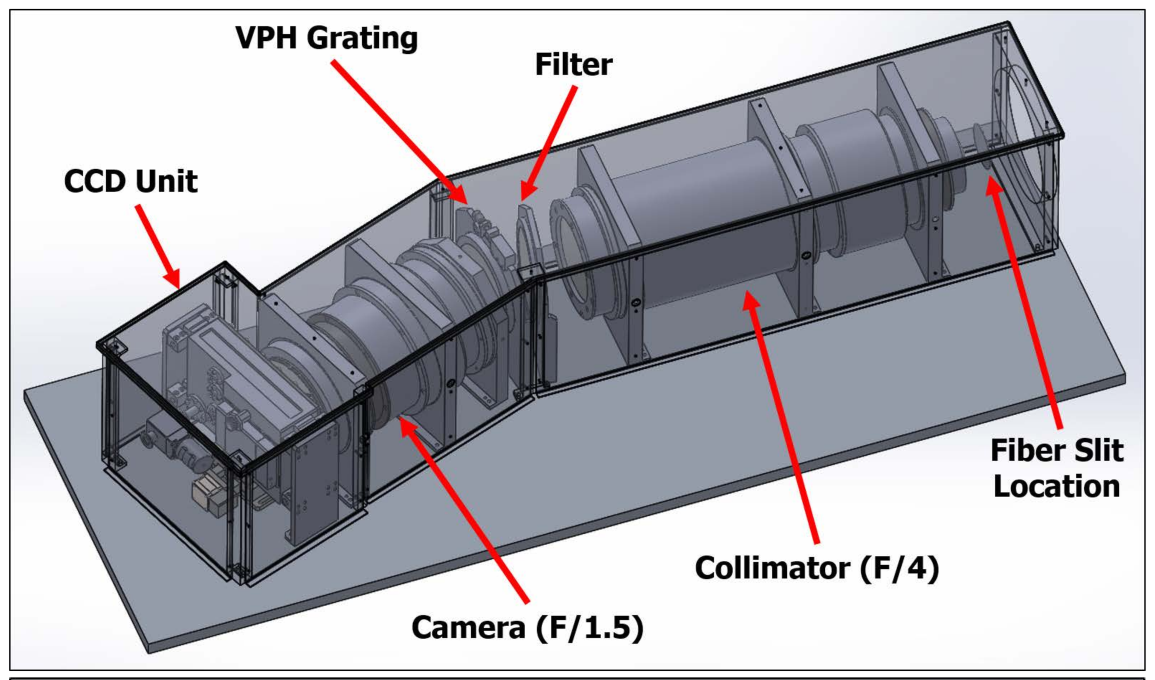
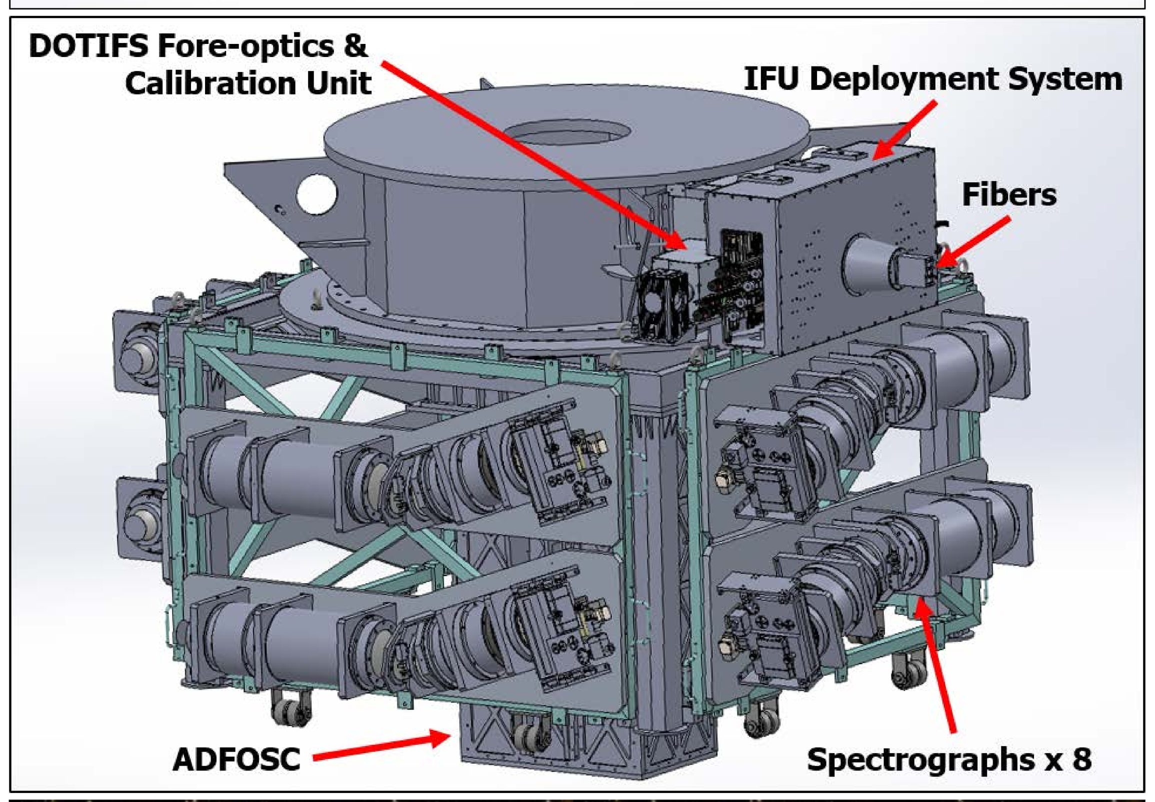


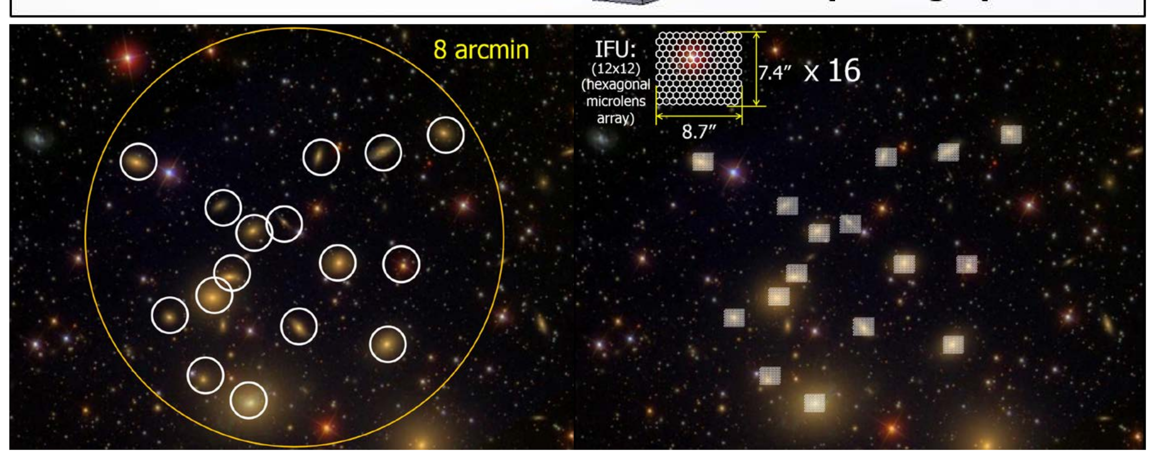
Introduction

Devasthal Optical Telescope Integral Field Spectrograph (DOTIFS)[1] is an optical multi-Integral Field Unit (multi-IFU) spectroscopic instrument being built by Inter-University Centre for Astronomy and Astrophysics (IUCAA). It is planned to be mounted on the 3.6m Devasthal Optical Telescope (DOT)[2] at Devasthal peak, Uttarakhand, India. Korea Institute for Advanced Study (KIAS) and Seoul National University (SNU) are involved in this project as international collaborators.

The instrument is designed for 2-dimensional spatially resolved spectroscopy in the entire visible range with medium spectral resolution with multi-object capability. It has **16** deployable IFUs over an **8'** focal plane. Each IFU has **8.7" x 7.4"** field of view sampled with a 12x12 hexagonal aperture microlens array. The light coming from the **2,304** spaxels through optical fibers are dispersed by **8** identical spectrographs over a **370 to 740nm** wavelength range simultaneously with **R=1200-2400** in a single exposure. We show the overall structure of the instrument and working concept as below. In this work, we present spectrograph optics and opto-mechanical design with the result of thermal & tolerance analysis.

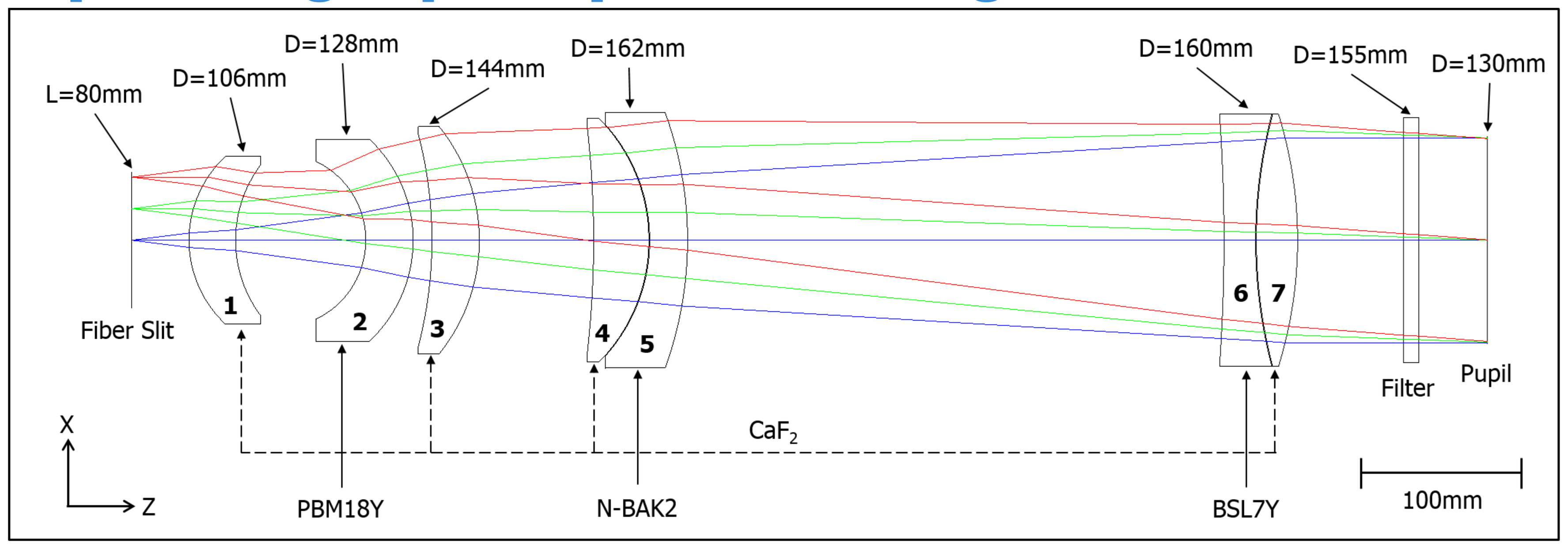


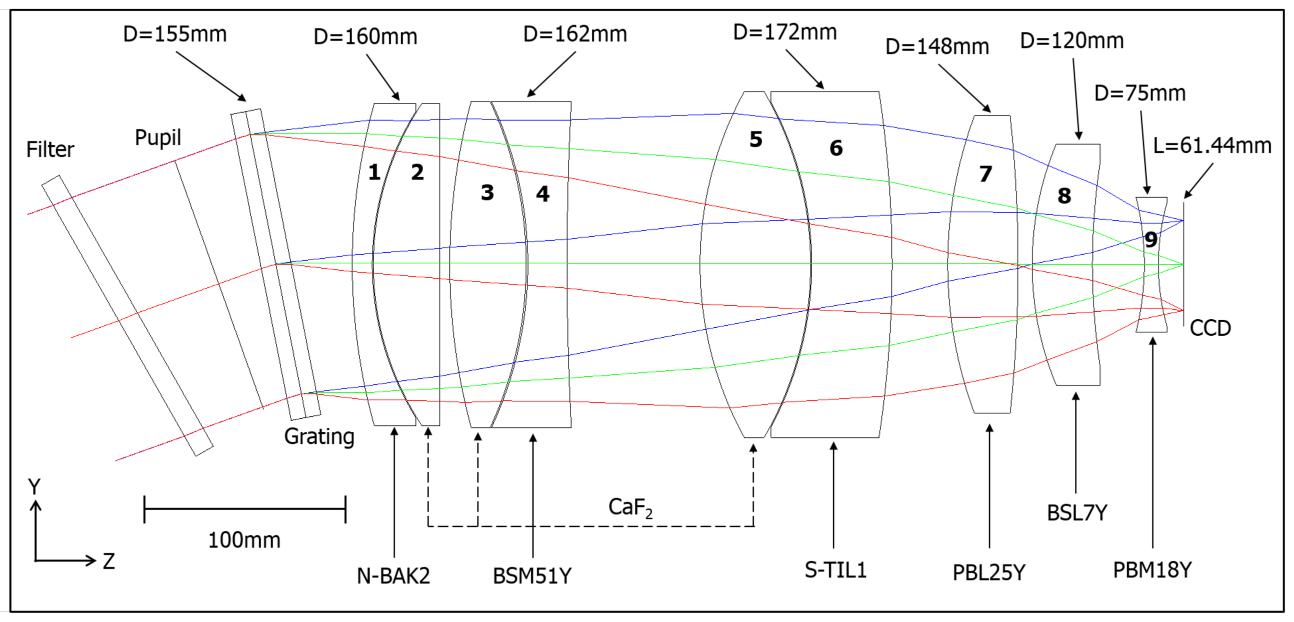




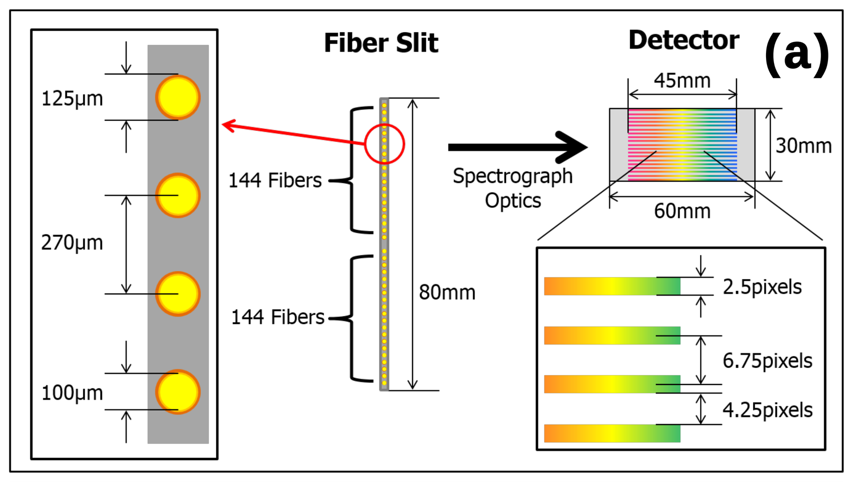
We designed opto-mechanics using Solidworks 2015 software. **(Top)** Opto-mechanical structure of the spectrograph is shown. It is designed to hold optical elements rigidly within alignment tolerance budget. **(Middle)** Overall structure of the entire DOTIFS system up to date. **(Bottom)** Conceptual diagram of how DOTIFS works. The background image is obtained from SDSS DR10 navigator[3].

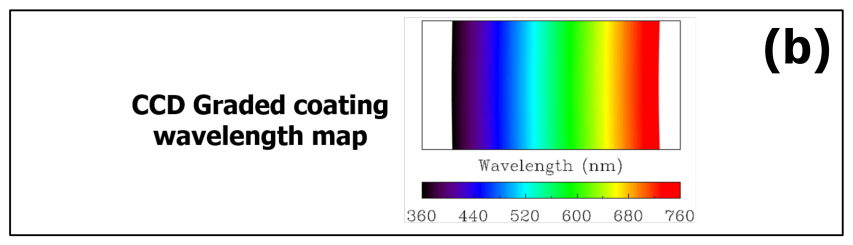
Spectrograph Optical Design & Performance

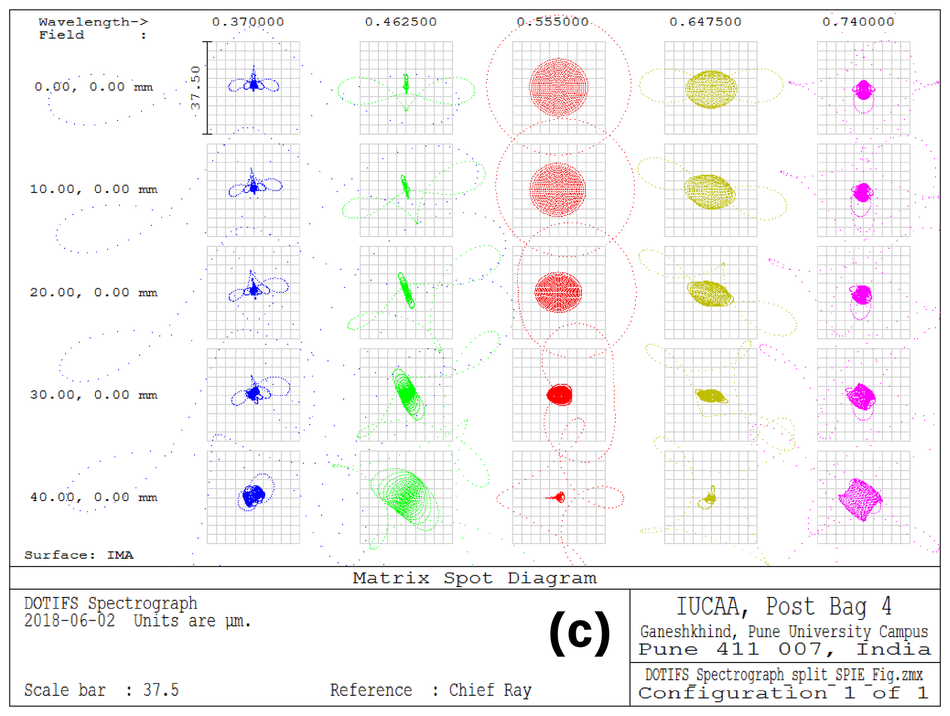


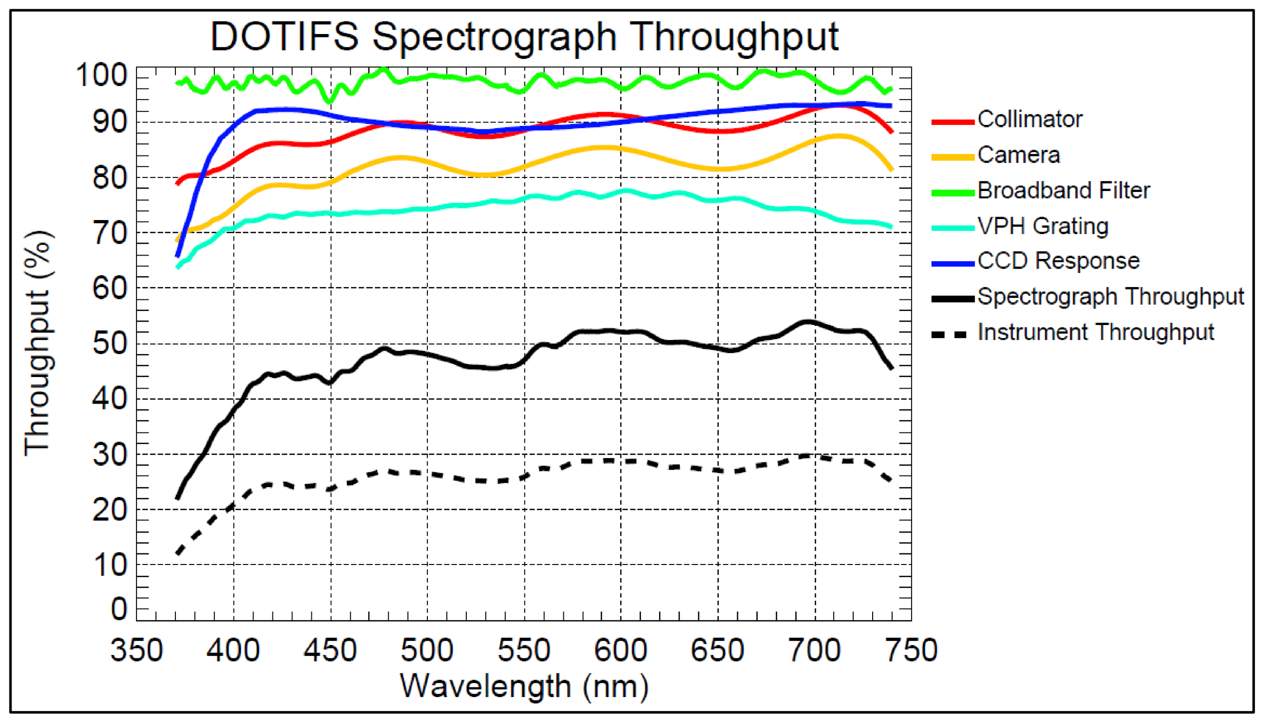


We design DOTIFS spectrograph using ZEMAX optical design software, version 13. Collimator optics layout **(Left)** and camera optics layout **(Right)** are shown in above figures. The light coming out from 80mm fiber slit is refracted by the collimator (F/4) and forms 130mm diameter pupil. Light other than working wavelength range is filtered out by broadband filter located just before the pupil position. Collimated light is dispersed by Volume Phase Holographic (VPH) grating and focused on the CCD through camera optics (F/1.5). This optics is designed based on South African Large Telescope Robert Stobie Spectrograph[4] due to its similar optical specifications. We initially designed the close pairs as doublets, but later we decide to separate them to avoid possible risk during fabrication and delivery of optics. We use CaF_2 and Ohara i-line glasses to improve throughput at near-UV range (370-400nm). Every optics elements has spherical surface. VPH grating has line density of 615 lines/mm, and it is designed to have maximum efficiency at 480nm.



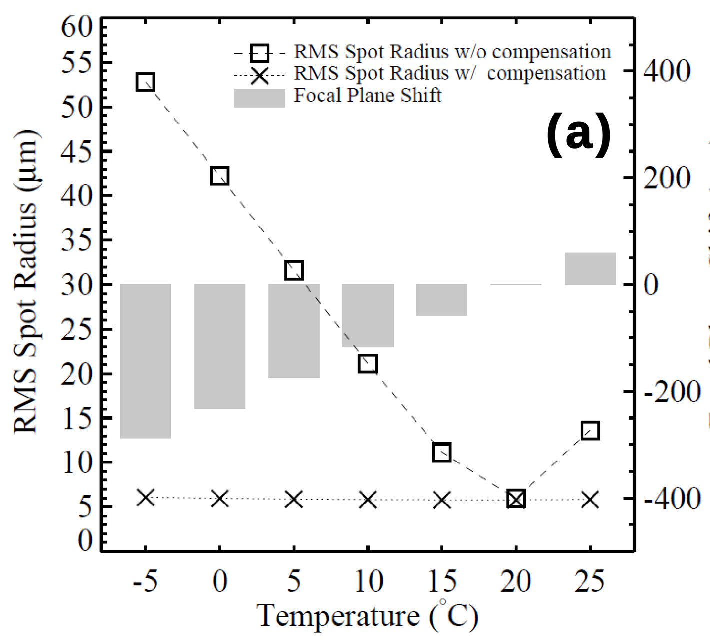


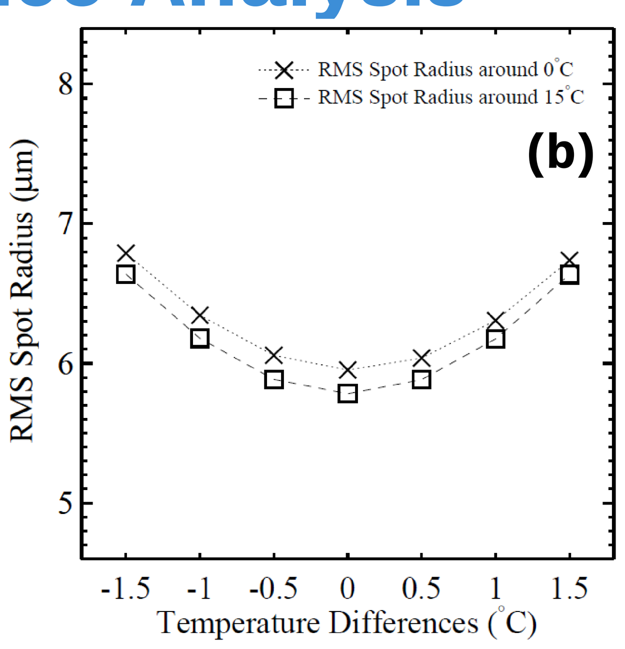




(a) Conceptual diagram of fiber slit and fiber images on the detector is shown. Each spectrograph accommodates fibers from 2 IFUs (144 fibers x 2). We choose F/4 collimator and F/1.5 camera to focus light from 100μm fiber to 37.5μm image, which correspond to 2.5 pixels. Separation between fibers is set as 270μm to minimize the cross-talk between fiber images as well as to maximized total number of fibers in a fiber slit. 2048 x 4102 pixels E2V CCD44-82 is chosen as a detector. Detector will be graded coated to maximize quantum efficiency. **(b)** Graded coating wavelength map of CCD. **(c)** ZEMAX matrix spot diagram of the DOTIFS spectrograph optics. Box size is 37.5μm which is matching with the size of fiber image scale. **(d)** Throughput of DOTIFS spectrograph and sub-components. Due to high-throughput optical glasses, throughput loss from collimator and camera optics are mainly attributed from AR coating. Curve of broadband filter, VPH grating and CCD response are from simulated or fitted data. Average throughput of the entire DOTIFS is 26.0%.

Thermal & Tolerance Analysis





(c) Lens fabrication requirements

Center thickness	±50μm
Radius of curvature	±0.1%
Surface tilt	±2 arcmin
Surface decenter	±50μm
Surface irregularity	λ/4 @ 632.8nm
Refraction index	±0.0003
Abbe No.	±0.5%

(d) Optics alignment requirements

Center distance	±50μm
Element tilt	±2 arcmin
Element decenter	±50μm

(e) Result of sensitivity analysis

	Design	Fabrication	Alignment	Total
RMS spot radius (μm)	5.79	10.44	8.99	11.43
Change (μm)		4.65	3.20	5.64

(f) Result of Monte-Carlo analysis

RMS spot radius (μm)		Compensator (mm)	
Nominal	5.8	Minimum	25.261
Worst case	35.4	Maximum	26.293
Mean	11.0	Mean	25.807
Standard deviation	3.0	Standard deviation	0.128

(a) Thermal analysis on temperature variance over telescope site yearly temperature range (-5 to +22°C) is performed. The distance between the last and the second last camera element is used as a compensator. Result shows that the optics is well compensated at the different temperatures by the compensator movement. **(b)** Analysis on temperature variance over intra-night variance (less than 2°C) is also performed. First, we compensated optics at two nominal temperatures and measured RMS spot radius variance over small temperature range without compensation. It shows that within intra-night temperature variance there is no significant RMS spot radius change. **(c)**, **(d)** These tables show lens fabrication and optics alignment requirements of the optics. **(e)** It shows result of ZEMAX sensitivity analysis on fabrication and alignment requirements. **(f)** We performed 100,000 Monte-Carlo analysis assuming normal distribution statistics of tolerance requirements. The result shows that in most cases spectrograph is expected to yield acceptable performance with reasonable displacement of the compensator.

Current Status

We are going to assemble two spectrographs first and commission the instrument, and add six more spectrographs in future to complete the instrument. As of 2018 May, we finalized spectrograph optics design and ordered two sets of lens components to the lens fabricator. We expect to receive actual elements within 2018. We ordered and received most of the other components (broadband filter, VPH grating, and CCD) and opto-mechanical parts. Currently, we are doing performance verification of received components. We will start assembly of spectrograph optics when all parts arrive.

References

[1] Chung, H., Ramaprakash, A. N., Omar, A., Ravindranath, S., Chattopadhyay, S. et al. Proc. SPIE 9147, 91470V-70V-8 (2014)
[2] Sagar, R., Kumar, B., Omar, A., Pandey, A. K., Proc. SPIE 8444, 84441T-41T-12 (2012)
[3] C.P. Ahn et al., The Tenth Data Release of the Sloan Digital Sky Survey, Astrophysical Journal Supplement Series, 211, 17 (2014)
[4] Burgh, E.B., Nordsieck, K.H., Kobulnicky, H.A., Williams, T.B., O'Donoghue, D. et al. Proc. SPIE 4841, 1463-71 (2003)