Designing and building an ultra-stable single mode fiber spectrograph for adaptive optics assisted observation in the infrared

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INTRODUCTION

The prototype of a single mode fiber fed ultra-stable spectrograph for the infrared is taking shape at Macquaire University. Here, we characterize the infrared detector as well as detail the fiber input design and update progress on the elements designed in 2016[1].

Spectrograph Specifications:

- **Richardson Grating Labs R6 Echelle**
- **blaze angle 80.7 degree**
- **13.33 lines/mm**
- **152.4 mm primary mirror, f/3.8 - zerodur**
- **PIRT 1280 SciCam InGaAs detector**

DESIGN

The optical design is a cross-dispersed Echelle spectrograph based on a white pupil layout. The pupil relay design is shared with the TARdYS spectrograph[2]. The echelle is mounted with the grating surface facing the bench, a method which will carry over to the vacuum sealed version.

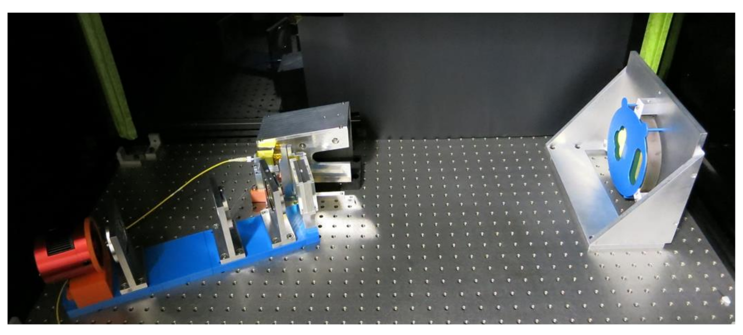

Fig. 1 Optical bench setup showing mounts machined at Macquarie and 3D printed protoypes being tested.

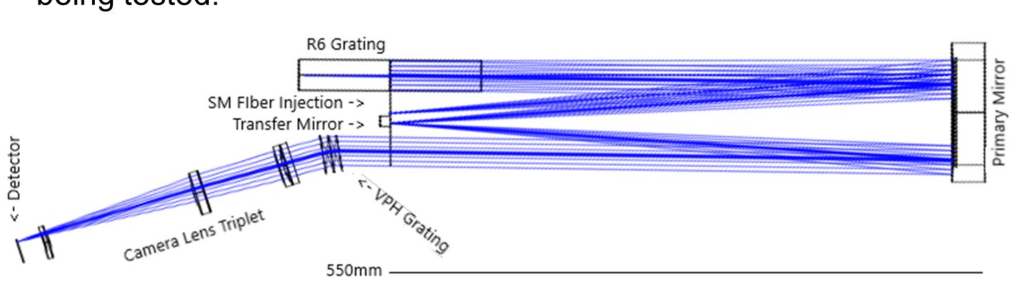

Fig. 2 Zemax model of optical design.

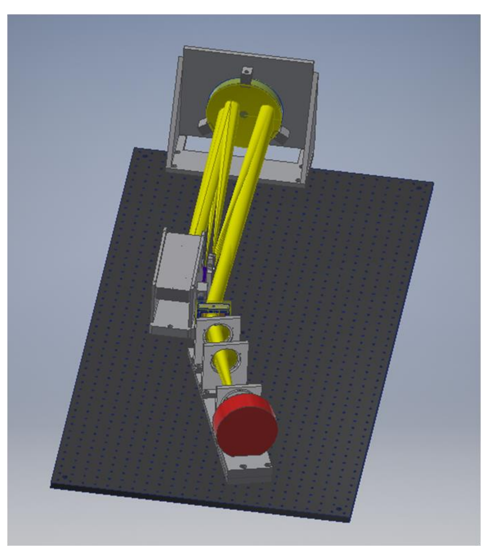

Fig. 3 CAD drawing with all elements, a different detector shown in drawing instead of the PIRT unit.

INFRARED DETECTOR

The detector chosen for the setup is a Princeton Infrared Technologies 1280 SciCam which uses Indium gallium arsenide photodiodes.

Detector Specifications: [3]

- **1280x1024 pixels**
- **12 micron pixel size**
- **15.4 x 12.3 mm approximate frame dimensions**
- **cooling settings: 0 C, -20 C, -40 C, -60 C (water cooling)**
- **4.2 e⁻/count gain at -60 C (measured by PIRT)**
- **14 bit analog to digital converter**
- **Frame grabber: National Instruments PCIe-1427**
- **400 nm to 1700 nm range**
- **Readout Noise: 58.99 e⁻/pixel (-40 C 1 ms int. time)**

Dark Frame exposure at -40 C

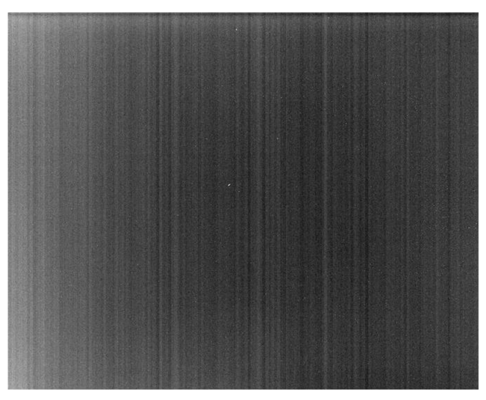

Fig. 4 Dark frame at 1 sec integration time.

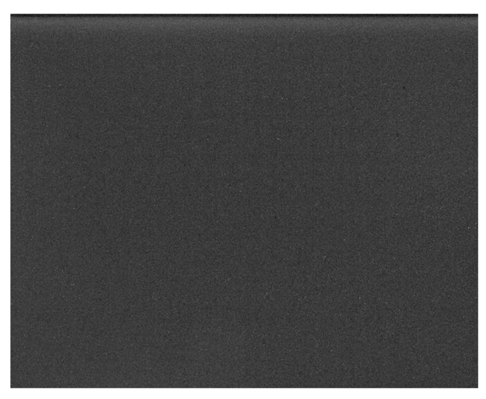

Fig. 5 Dark frame from Fig.4 with master bias subtracted. Master bias averaged from 20 bias frames at 1 ms integration time.

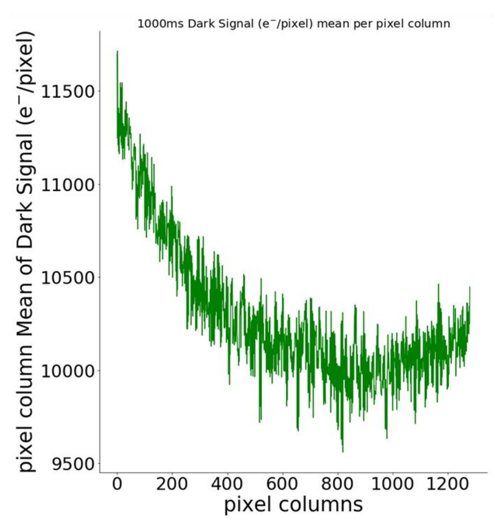

Fig. 6 e⁻/pixel average by columns in uncorrected frame from Fig 4.

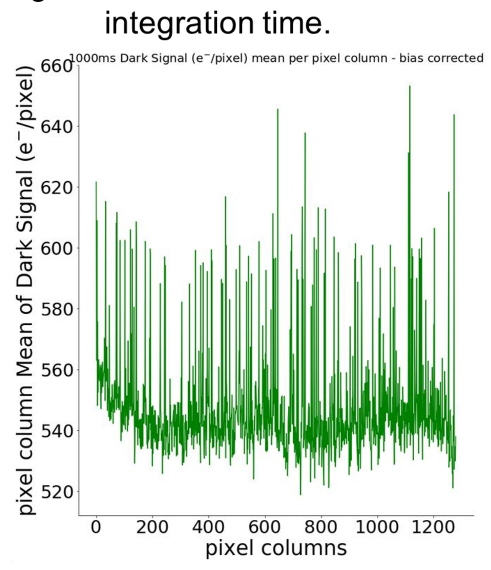

Fig. 7 e⁻/pixel average by columns in corrected frame from Fig 5.

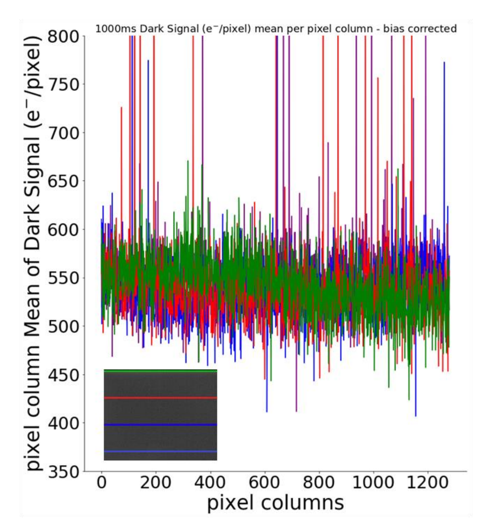

Fig. 8 e⁻/pixel average by columns of 20 pixel tall horizontal strips in corrected frame from Fig 5.

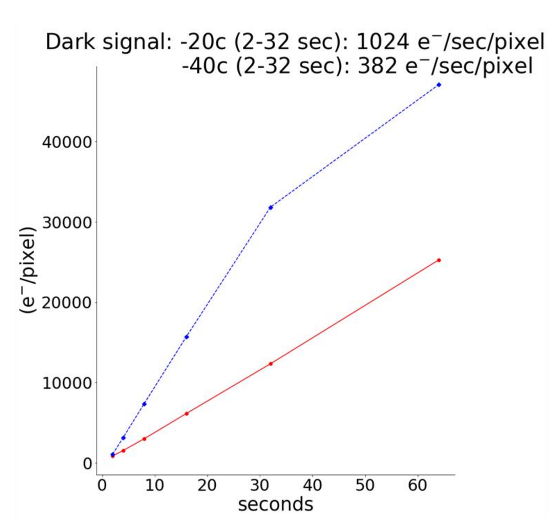

Fig. 9 Dark Signal from 2 to 64 s for -20 C and -40 C.

FIBER INPUT DESIGN

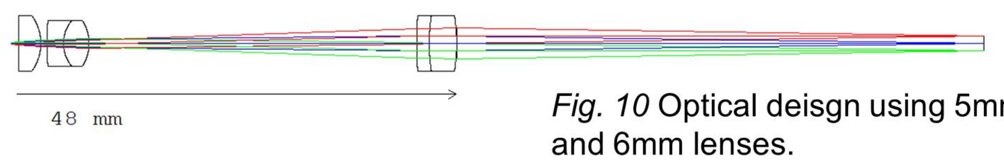

Fig. 10 Optical deisgn using 5mm and 6mm lenses.

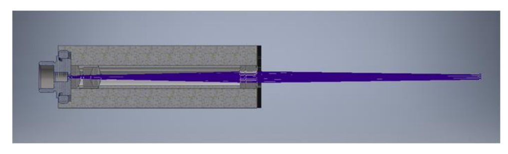

Fig. 11 Cutaway of the nested barrel mechanical design, given the optical design parameters.

The near tele centric design is using off-the shelf components that is diffraction limited throughout the relevant range, 800 -1500 nm. The 3 lenses used are a Thorlabs 6mm diameter LA1116, a 5 mm Thorlabs AC050-008-B and a 6 mm Edmunds 45789.

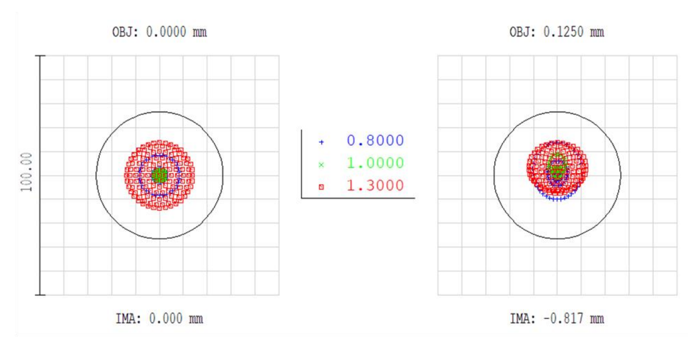

Fig. 12 Spot diagrams at intermediate focus for two single mode fibers, one spot on axis and one 125 μm off axis. Wavelengths at 800, 1000 and 1300 μm. Airy disk radius is 26.57 μm.

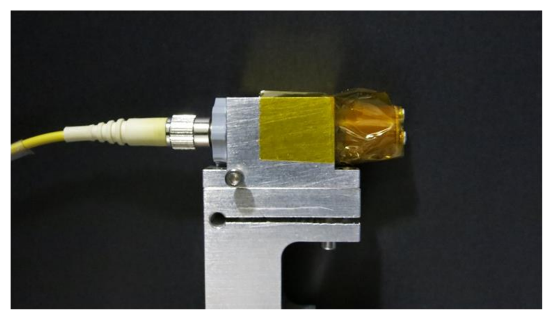

Fig. 13 Fiber input, 3D printed for testing.

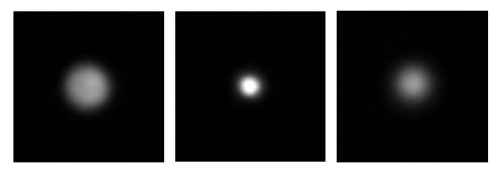

Fig. 14, 15, 16 Spot from a 532 nm HeNe laser coupled to the printed barrel design by SMF, short of focus (left), in focus (center), long of focus (right).

CONCLUSIONS

To integrate the components into an ultra-stable instrument, we will continue characterizing the detector at it's max cooling of -60 C, machine the rest of the mechanical designs, and mount the echelle grating. The next challenge will be designing a vacuum chamber for the setup and stabilizing through rigorous temperature control.

REFERENCES

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2. Rukdee, S., Vanzi, L., and Schwab, C., "Optical Design and Tolerance Analysis of a high resolution near IR spectrograph for astronomy," (2016).
3. Princeton Infrared Technologies, "Interface Control Document," (2017).

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Code for reading detector raw file into fits: https://github.com/blaisekuo/pirt-1280cam