Injecting Starlight into a Single-Mode Fiber

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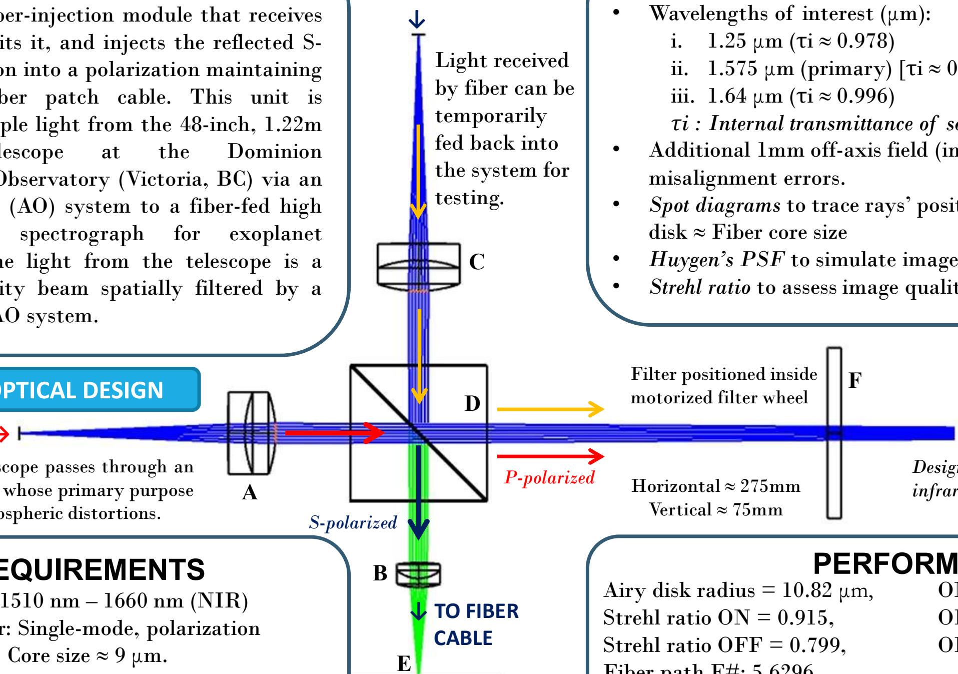
INTRODUCTION

Design for a fiber-injection module that receives input light, splits it, and injects the reflected S-polarized portion into a polarization maintaining single-mode fiber patch cable. This unit is required to couple light from the 48-inch, 1.22m McKellar telescope at the Dominion Astrophysical Observatory (Victoria, BC) via an adaptive optics (AO) system to a fiber-fed high contrast gas spectrograph for exoplanet detection[1]. The light from the telescope is a uniform intensity beam spatially filtered by a pinhole in the AO system.

THE OPTICAL DESIGN



*AR coating reduces Fresnel losses for the air/glass interface

REQUIREMENTS

- Bandwidth: 1510 nm – 1660 nm (NIR)
- Type of fiber: Single-mode, polarization maintaining. Core size ≈ 9 μm.
- Polarization: Extinction ratio ≥ 1:100
- F#: F/6 – F/7 beam for the fiber path
- Flux: >5pW (stability: up to ≈ 100Hz)

PRIMARY COMPONENTS

A. Ø1/2" Achromatic Doublet, f = 30 mm
B. Ø6.35 mm Achromatic Doublet, f = 15 mm
C. 12mm Achromatic Doublet, f = 30 mm
D. 20mm Polarizing Beamsplitter Cube
E. AR Coated* Fiber-cable (1440 - 1620 nm)

SECONDARY COMPONENTS

F. NIR Filter
G. Science Camera

MODELLING & SIMULATION

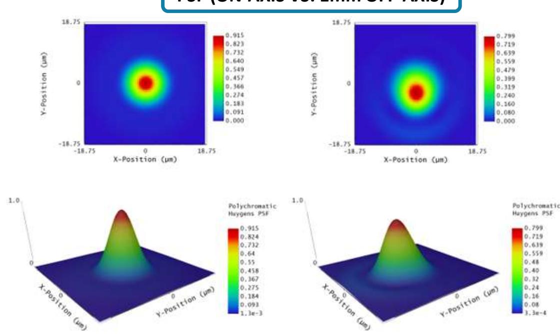
- Wavelengths of interest (μm):
  i. 1.25 μm (τi ≈ 0.978)
  ii. 1.575 μm (primary) [τi ≈ 0.978]
  iii. 1.64 μm (τi ≈ 0.996)
  τi : Internal transmittance of selected 20mm beamsplitter cube
- Additional 1mm off-axis field (in y plane) to test sensitivity to misalignment errors.
- *Spot diagrams* to trace rays' positions at the image surface. Airy disk ≈ Fiber core size
- *Huygen's PSF* to simulate image at the image surface.
- *Strehl ratio* to assess image quality. Ideally ≥ 0.8.

PERFORMANCE

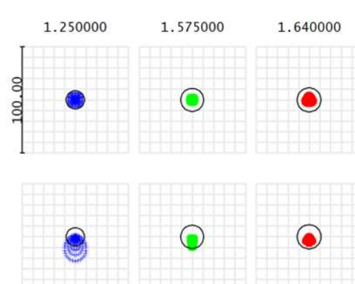
Airy disk radius = 10.82 μm,
Strehl ratio ON = 0.915,
Strehl ratio OFF = 0.799,
Fiber path F#: 5.6296,
ON Total transmission = 0.45989,
OFF Total transmission = 0.45984,
OFF Decenter = 0.46859mm,

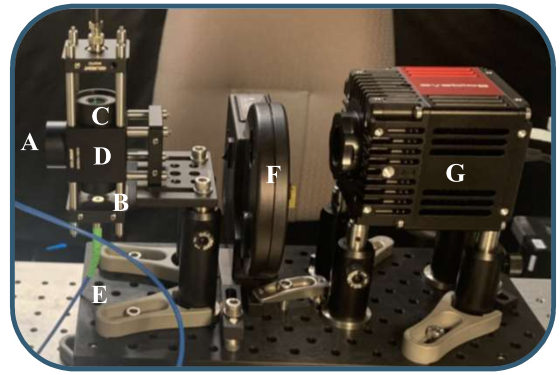
N.B: ON = On-axis field, OFF = 1mm off-axis field

PSF (ON-AXIS VS. 1mm OFF-AXIS)



SPOT DIAGRAM





Module setup in the lab

ANALYSES

Diffraction limited performance achieved.
Airy disk larger than fiber core size∴ MFD of selected cable should be as close to this as possible to maximise the coupling efficiency.
Off-axis field:

- Coma aberration present in spot diagrams.
- Strehl ratio decreases by ≈ 12%. No longer diffraction limited.
- As wavelength increases, the number of rays traced within the airy disk increases.
- Total transmission decreases by ≈ 0.01%

NEXT STEPS

i. Assess initial throughput & coupling efficiency results (acquired via simulated light source)
ii. Test module on sky using AO corrected light
iii. Feed module to high contrast gas spectrograph

REFERENCES

1. Cheriton, Densmore, et al. (2022) – *High Contrast Spectroscopy of Exoplanet Atmospheres Using Photonic Chips*, NRC-AEP.