Characterization of Focal Ratio Degradation in Optical Fibers for Use in Astronomical Instruments

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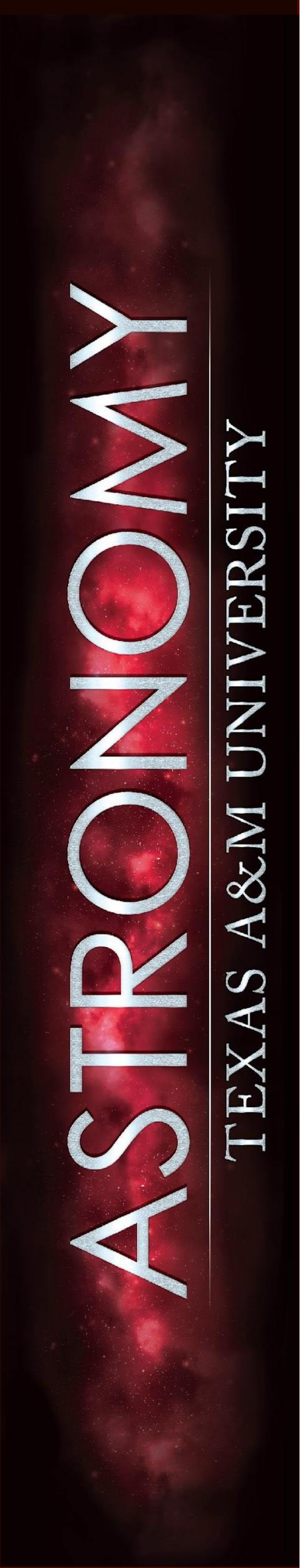

Abstract

In order for the future large, Earth-based, fiber-fed astronomical spectrographs to function precisely and efficiently, the background sky spectra must be removed without compromising the target spectra. The Fiber Optic Characterization for Unprecedented Sky Subtraction (FOCUSS) project aims to automate the examination of multiple fiber optic cables in order determine their respective throughput efficiency and focal ratio degradation (FRD). The throughput efficiency simply measures the percentage of light that enters the fiber and ends up at the detector, while the FRD test measures the angular spread of light out of the fiber as a function of incident angle. FOCUSS tests within the 400-1000 nm regime, limited by the bandpass of the monochromator, which is 18 nm. Our experimental assembly consists of a laser-driven light source, a monochromator, an integrating sphere, a photodiode, a five-axis motor for fiber positioning, and three CMOS (Complementary Metal-Oxide-Semiconductor) detectors for data acquisition (depicted in Figure 1). Our results will be used to guide future astronomers as to which fibers should be used within spectrographs for the best data quality and sky subtraction. The Python programming language was utilized for data collection, reduction, and analysis. This work will primarily focus on the FRD aspect of the FOCUSS project.

Introduction

Data quality and ease of acquisition are of utmost importance when taking observations with astronomical instruments. In order to maximize both, the transmission and focal ratio degradation must be characterized for the chosen fiber. FRD occurs due to small imperfections within the fiber's core-cladding interface, called microbends, which cause the light to be scattered at a different angle than intended [1]. This results in an annulus, or ring shape, at the detector (depicted in Figure 2). Focal ratio itself can be described as the speed of an optic, where a faster f/# implies that the light collecting area is large compared to the focal length. In this case, since the focal ratio degrades (f/# decreases) as the light travels through the fiber, the light is effectively being spread out more than expected. This results in the CMOS detector measuring fewer counts per pixel within the annulus when compared to an optical fiber with better FRD. To clarify, a fiber with poor FRD will have more light spread radially, whereas a better fiber will instead spread the light azimuthally (depicted in Figure 3). Focal ratio degradation can be easily measured using our experimental assembly by analyzing the size and shape of the annulus, as well as the counts within. For the future of astronomical spectrographs, choosing a fiber with the best optical properties and characterizing said fiber is necessary to prevent loss of both signal and spectrograph resolution.

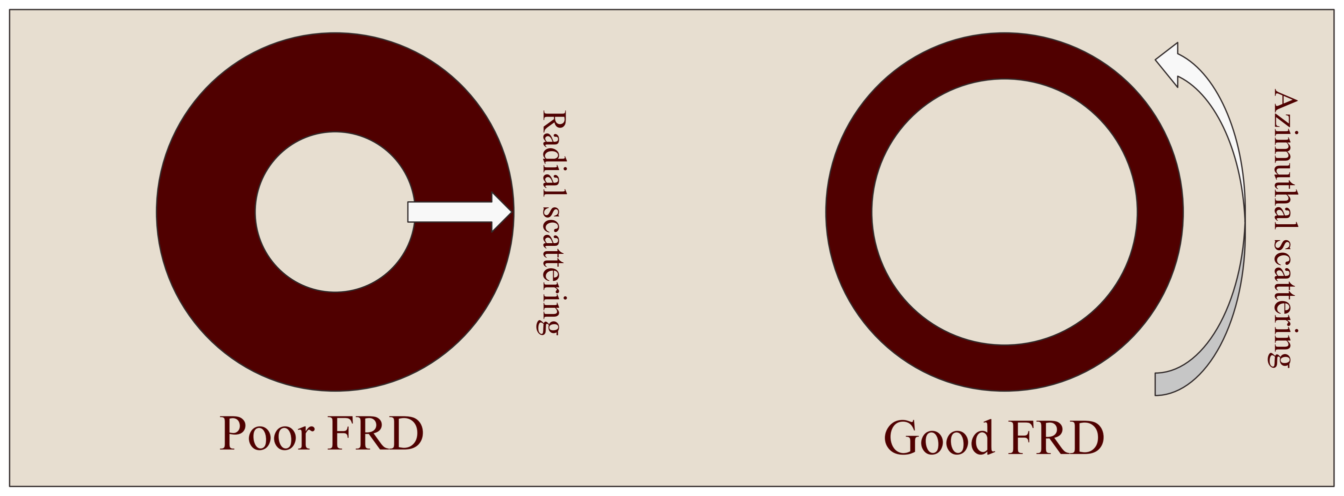

Figure 3, A comparison of FRD between two different fibers, assuming that incident angle and wavelength is held constant between the fibers.

References

1. Monty, S., Jahandar, F., Lee, J., Venn, K. A., Bradley, C., et al., 2018, "Automated testing of optical fibres: towards the design of the Maunakea Spectroscopic Explorer Fibre Transmission System," Proc. SPIE 10702, 107027I
2. Zhang, K., Zheng, J. R., Saunders, W., 2016, "High Numerical Aperture Multimode Fibers for Prime Focus Use," Proc. SPIE 9912, 99125J

Methods and Discussion

The FRD test begins with aligning the collimated light beam so that the light beam is normal to the fiber end face. This is done by slewing about each axis to find where the photodiode reads its maximum value. Once aligned, the CMOS detector completes its cooling procedure (around -12ºC) and takes several dark frames at varying exposure times, which will later be used to calibrate the images. After moving the fiber from the photodiode to the CMOS detector, the program begins taking exposures of each wavelength at varying incident angles, ranging from 400-1000 nm and 0º to 12º respectively. The .fits files are then analyzed using a script which first applies a gaussian blur (in order to find the center of the annulus) then takes a slice across each image and plots it on a pixel value (counts) vs. pixel position graph, allowing us to measure of the full width at half maximums (FWHMs) on each side of the annulus (depicted in Figure 4). The image is then rotated and this process is repeated to ensure precise measurement. The peak of each FWHM is found, and the difference between their pixel position is used as the diameter. The FRD proxy is then calculated by dividing the sum of the FWHMs by the diameter and multiplying by the incident angle [2]. Due to the nature of the FRD test, it is only possible to characterize FRD when the incident angle of light is greater than 4º. This is because the annulus is too compact for the script to distinguish between the two peaks, and it is seen as a single peak (depicted as a spot in Figure 5). Once the exposure for each wavelength and incident angle is analyzed, the script produces a graph of FRD vs. wavelength (depicted in Figure 6). This process allows for quick and efficient FRD characterization, enabling us to identify which optical fibers are well suited for use within fiber-fed spectrographs.

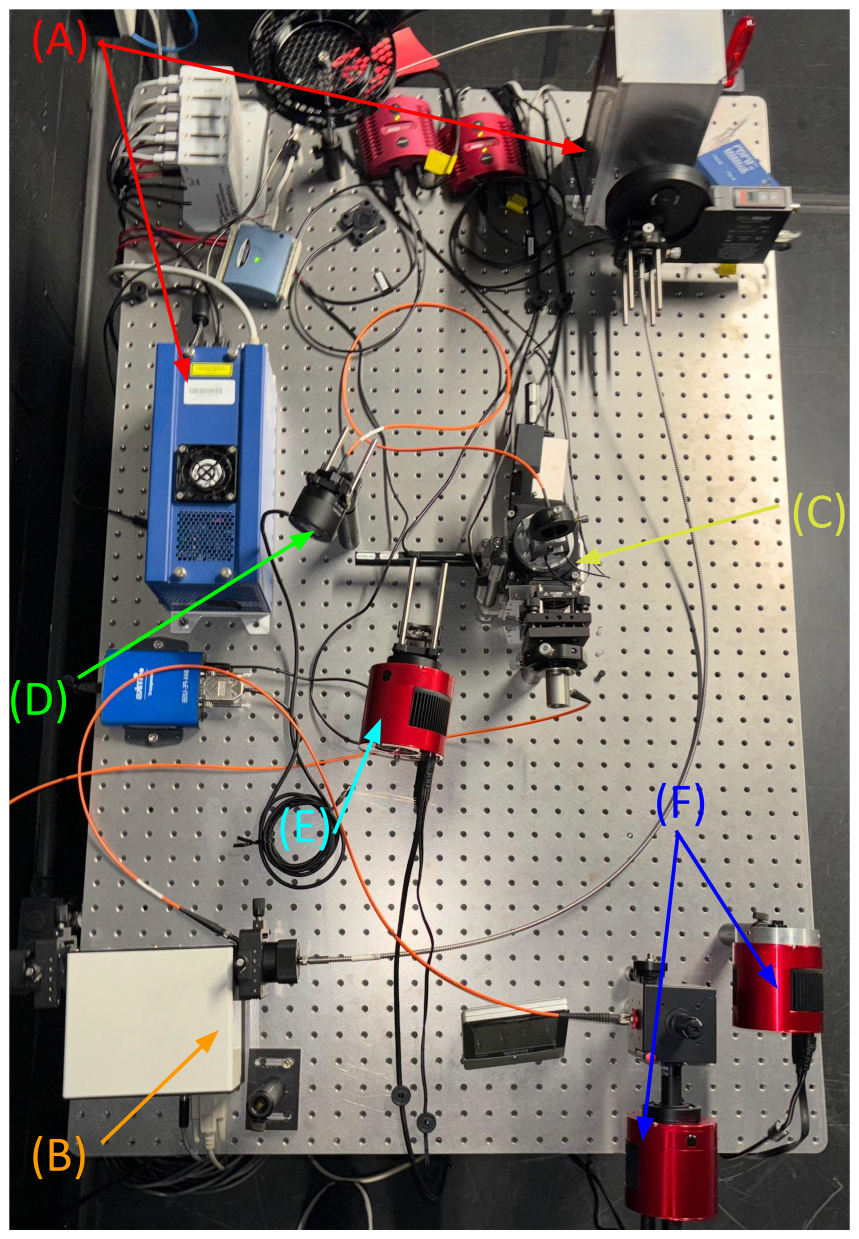

Figure 1, Depicted is the experimental assembly in FRD test configuration, consisting of a laser driven light source and power supply (A), monochromator (B), five-axis fiber positioner (C), photodiode (D), one CMOS detector for the FRD test (E), and two CMOS detectors for the transmission test (F), and connecting fibers.

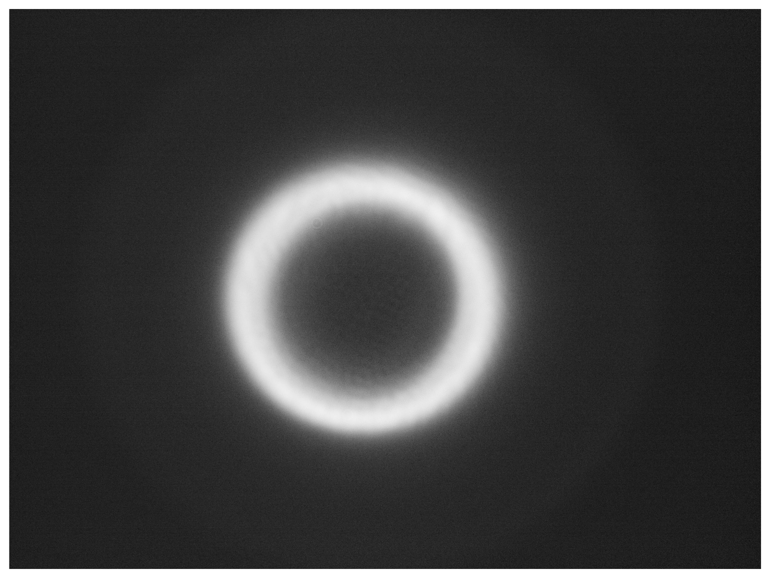

Figure 2, Resulting annulus from FRD test at an incident angle of 6º at a wavelength of 764 nm using ZWO ASI-1600MM PRO CMOS detector with an exposure time of 0.5 seconds.

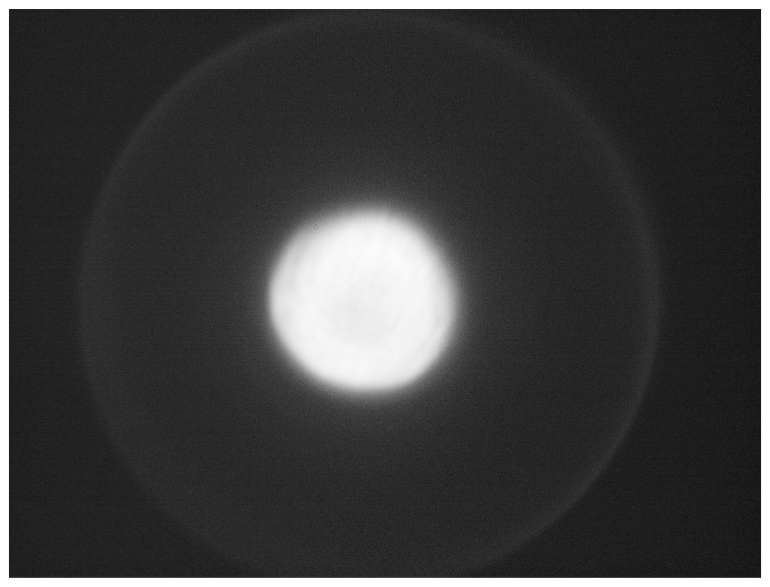

Figure 5, Resulting spot from FRD test at an incident angle of 3º at a wavelength of 512 nm using ZWO ASI-1600MM PRO CMOS detector with an exposure time of 0.15 seconds.

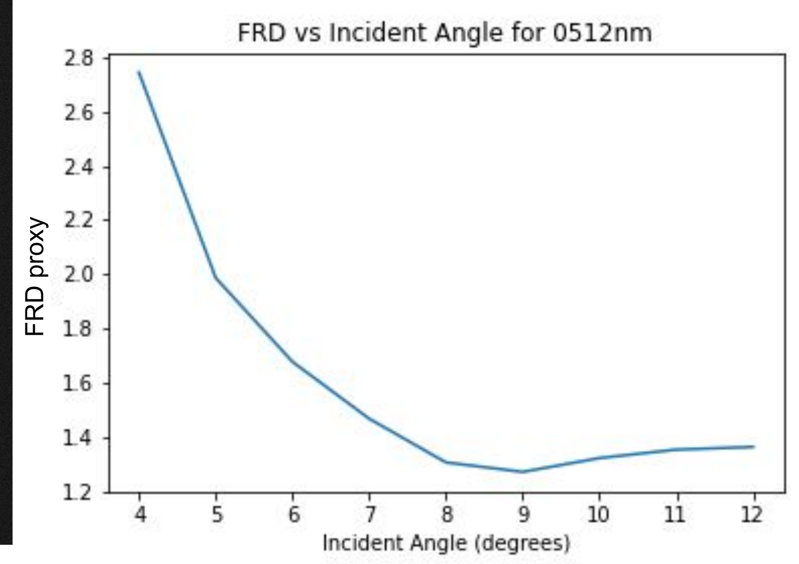

Figure 6, Graph of FRD proxy vs. Incident Angle for 512 nm light ranging from 0º-12º.

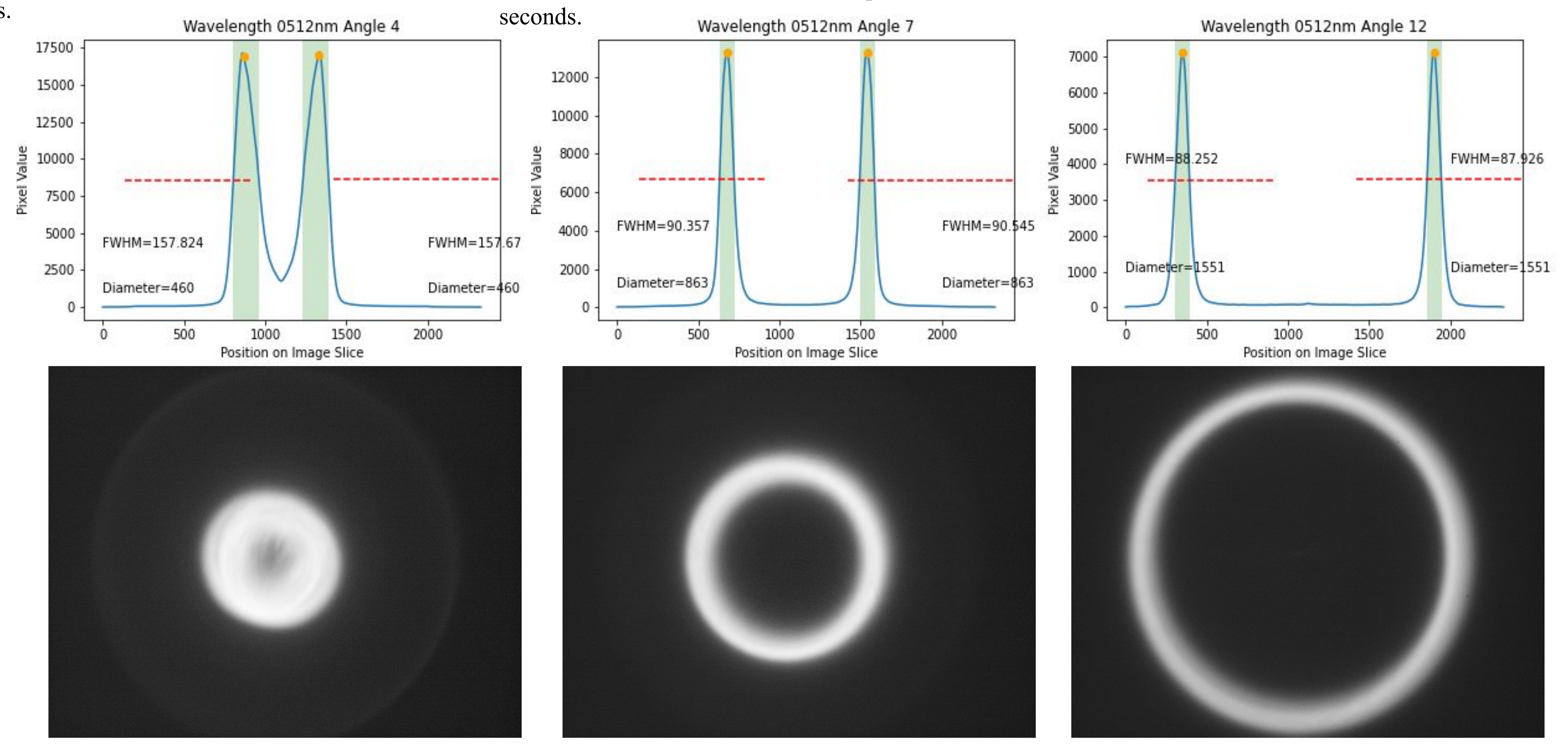

Figure 4, Pixel Value (counts) vs Pixel Position graphs with incident angle ranging from 4º to 12º at a wavelength of 512 nm depicting both FWHM and diameter measurements (top row) and corresponding image of annulus at each angle, with exposure time of 0.15 seconds taken with ZWO ASI-1600MM PRO CMOS detector (bottom row).

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