Fiber Optic Characterization for Unprecedented Sky Subtraction (FOCUSS)

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Abstract

The Fiber Optic Characterization for Unprecedented Sky Subtraction (FOCUSS) project aims to obtain an accurate subtraction of the sky background using calibrated fiber-fed spectroscopic instruments for the next generation of spectroscopic facilities such as the Maunakea Spectroscopic Explorer (MSE). The goal of FOCUSS is to develop techniques to test various fiber characteristics that are the most relevant to astronomical instrumentation, such as: focal ratio degradation (FRD), fiber transmission vs. wavelength, sensitivity to stress and strain, the relevance of fiber profile shape, and the injection efficiency as it relates to fiber positioner architecture.

Introduction

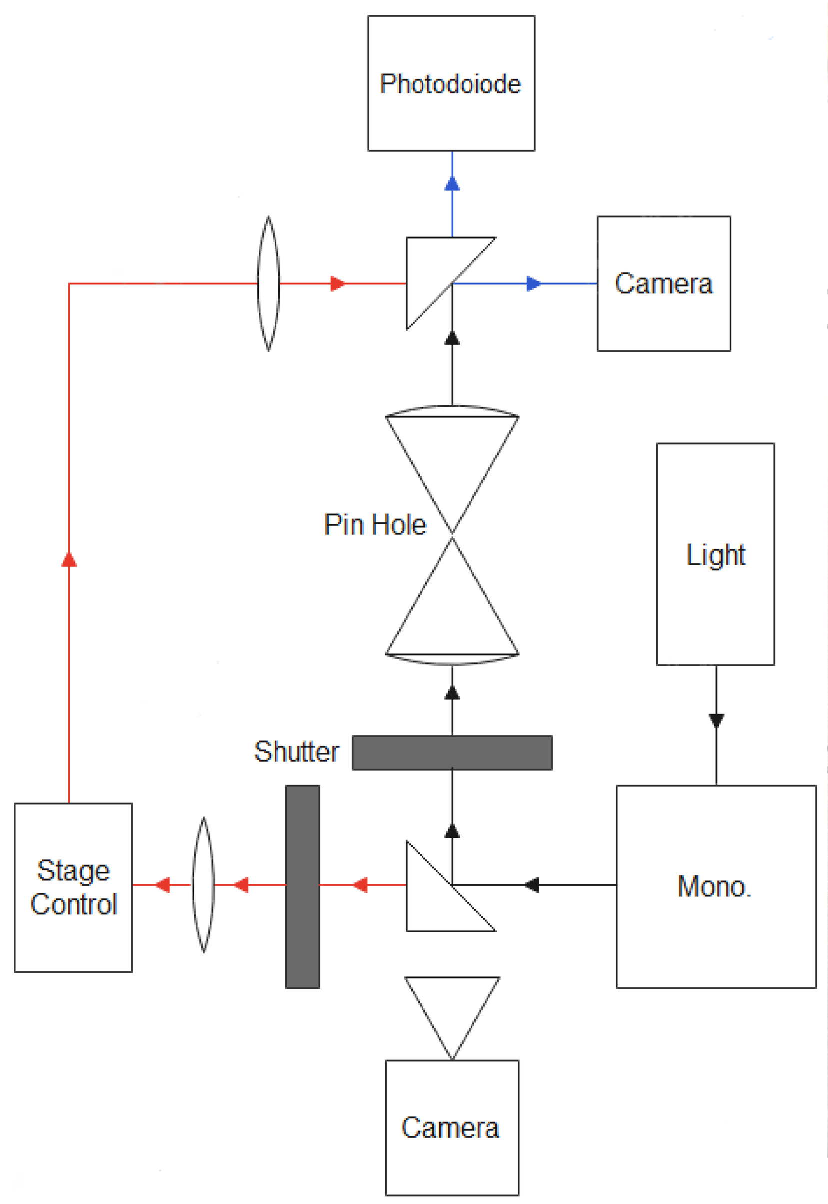
Observations taken from ground-based telescopes and large spectroscopic facilities are contaminated by emission from the Earth's atmosphere and must be subtracted from astronomical measurements to recover the true target spectrum.

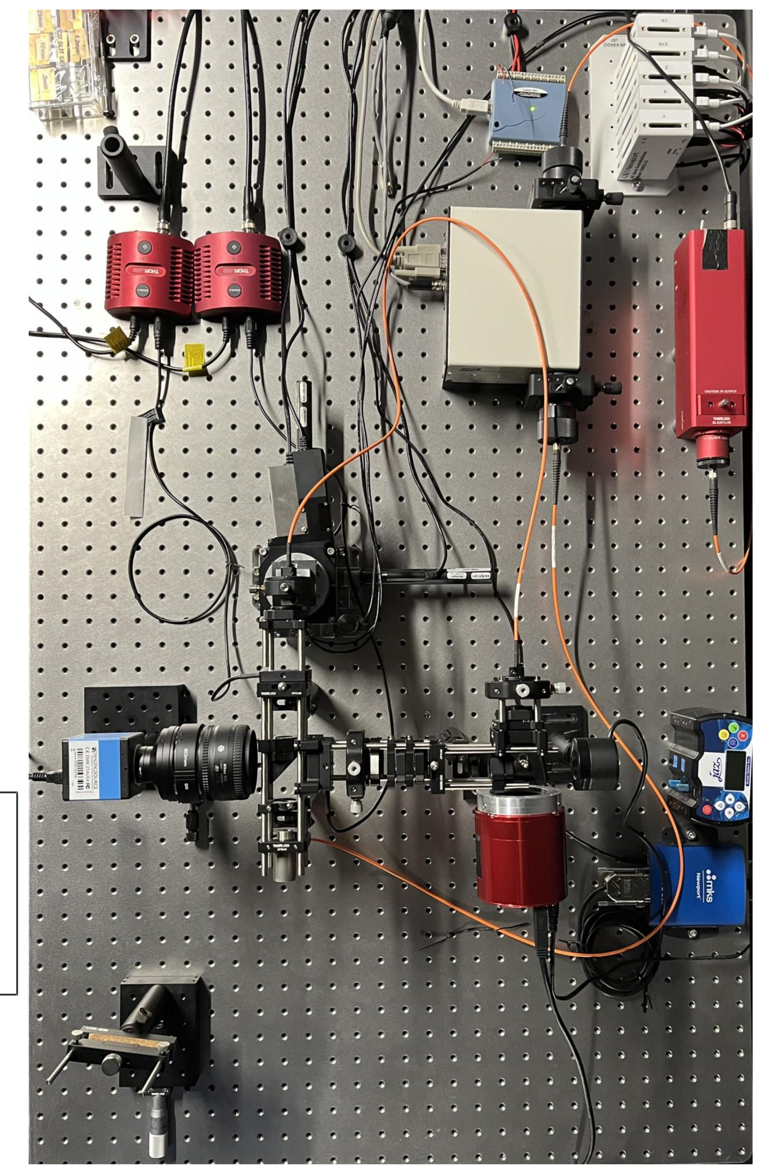
Precise and accurate sky subtraction is imperative to achieving reliable science results since many astronomical objects are fainter than the sky background. Fiber-fed spectroscopic instruments are additionally affected by the variable transmission of individual fibers due to an individual fiber's material composition and the normal stress and strain from instrument operation. Although current multi-fiber spectroscopic facilities have minimized these effects, the quality of data collected and the capabilities of the next generation of more sensitive spectroscopic facilities will be severely limited[1].

The fundamental basis of FOCUSS is to take detailed measurements of individual fibers that will be used in these spectroscopic facilities, locate and analyze the primary of depreciator of fiber performance, and identify solutions and techniques to limit these effects[2]. Ultimately, we should be able to choose a group of fibers for any spectroscopic facility that effectively minimize the effect of fiber differences to achieve accurate sky subtraction and maximize the accuracy of the spectroscopic data collected.

Setup

Figure 1: The theoretical setup (left) and lab setup (right) for FOCUSS testing. The testing setup consists of a laser, a monochromator, photodiode, various optical components, movement stages, two testing optic fibers, and two shutters. Light passes from the laser through the monochromator (which allows for characterization across various wavelengths) to a beam splitter that splits the light into two paths containing a variety of optical components that allow us to gather data for a given test.





Characteristics

- **Focal Ratio Degradation (FRD)**: FRD is the decrease of light's focal ratio between the input and output of an optical fiber caused by fiber optics[3]. This effect makes calibrating spectrographs much more difficult because it reduces their resolution, making it a dominant factor in assessing fiber performance.
- **Relative Transmission**: Measuring the relative transmission of fibers allow us to analyze their stability and spectrophotometric performance. This helps us characterize fibers with respect to the requirements of a given spectroscopic instrument.
- **Flexure Impact**: Focal ratio degradation is sensitive to the stress and strain of fibers. The fibers can be manipulated by a robotic stage control in a manner that helps to evaluate these effects on focal ratio degradation. This would allow us to find the optimal fiber path for spectroscopic facilities.
- **Fiber Shape and Scrambling**: Groups of fibers that take different paths to a spectrograph experience different bends and levels of strain, which causes inconsistent spectrograph line spread functions. Solutions to fiber scrambling would help produce more stable output and better sky subtraction.
- **Tilting Spine Characterization**: Many large spectroscopic facilities use a tilting spine fiber positioner[4]. The position and angular orientation of the fiber along with the position of the spine influence the FRD and the relative transmission of the fiber.

Projected Results

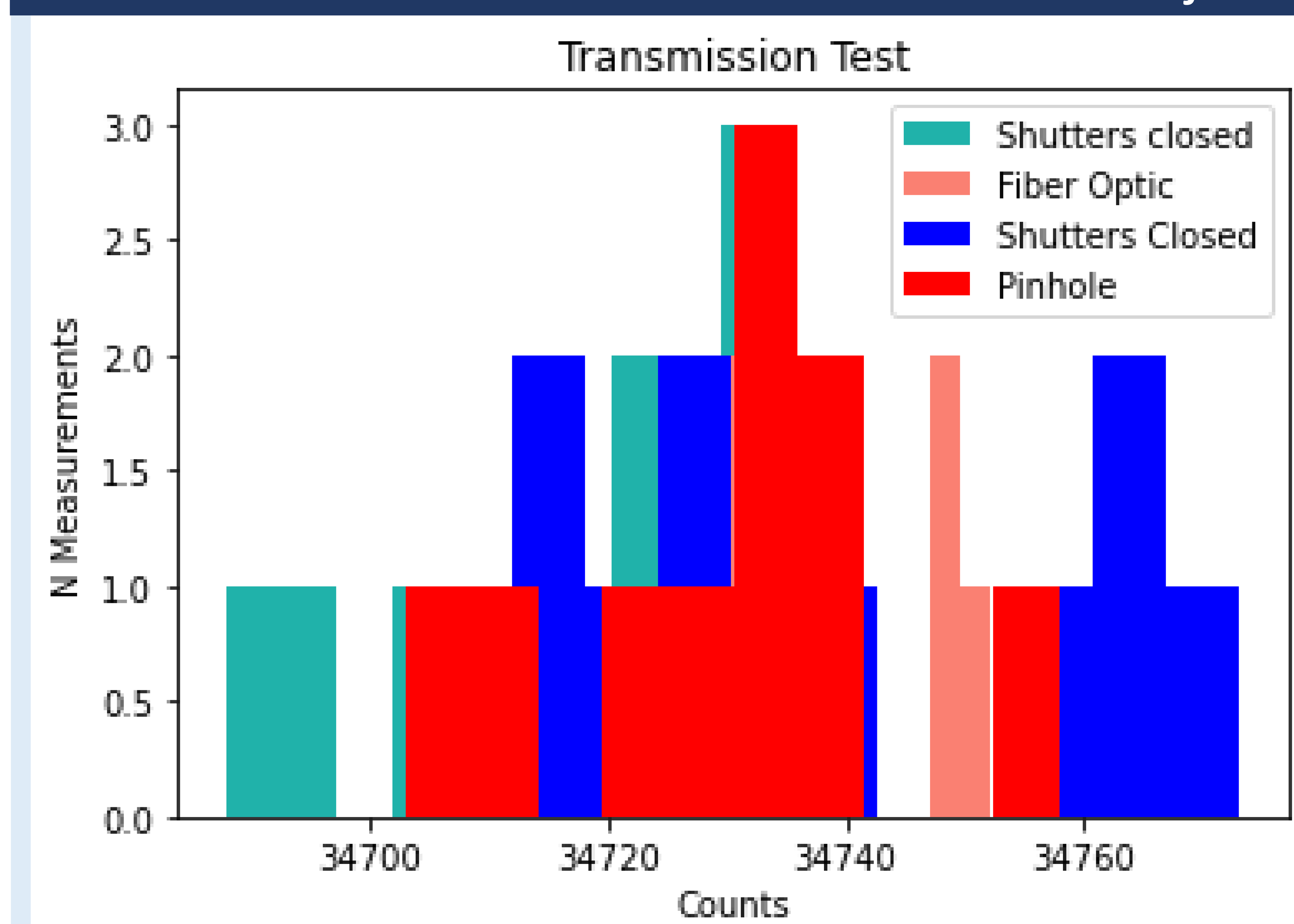


Figure 2: Data gathered for four different transmission states: Shutters Closed, Fiber Optic only transmission, Shutters Closed for a second time, and only Pinhole transmission.

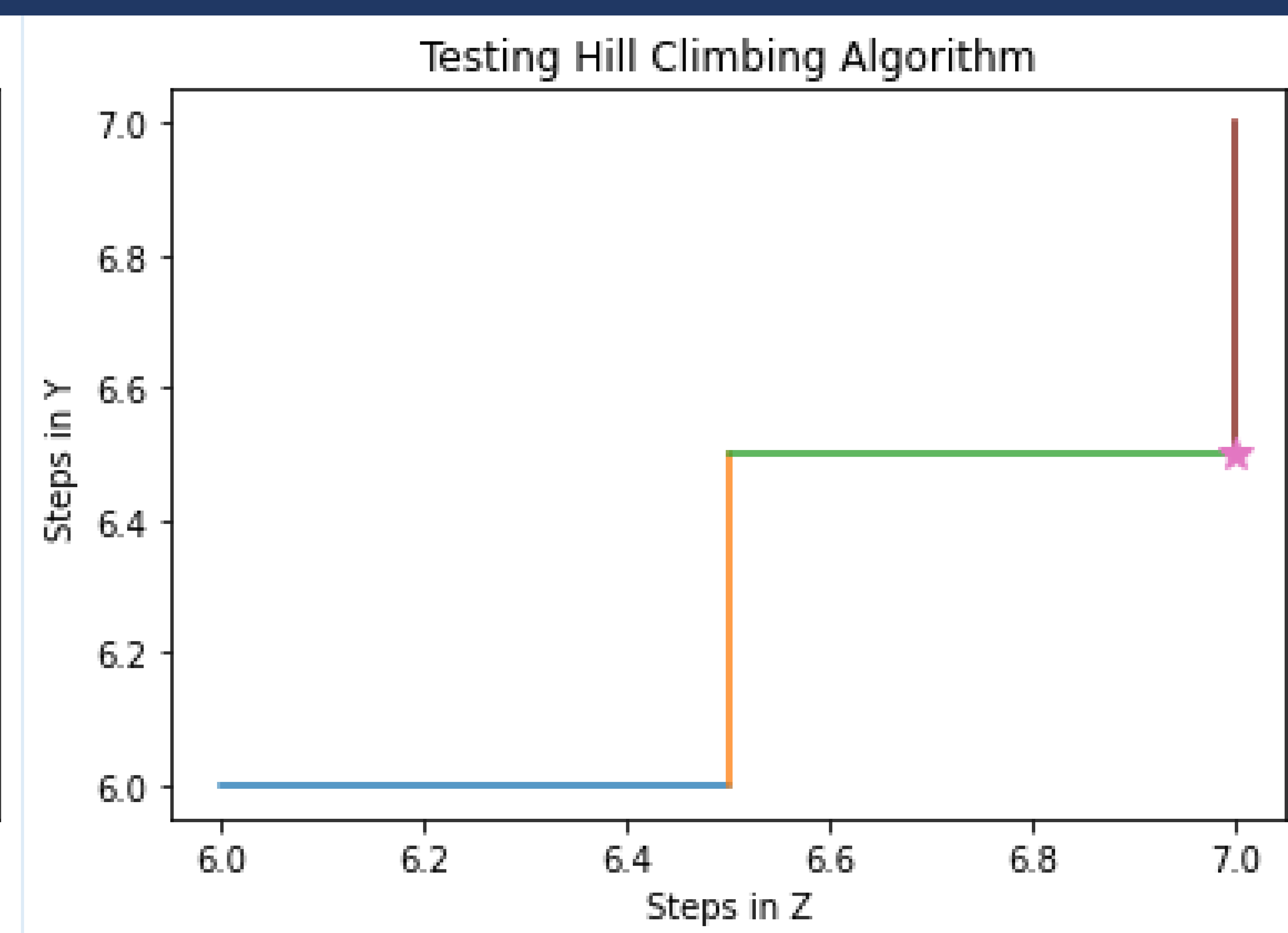
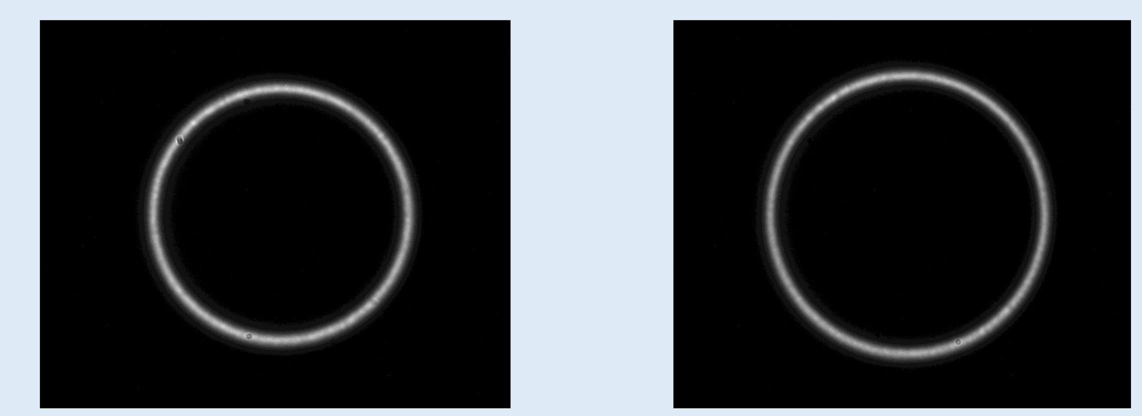


Figure 3: Visual representation of steps taken in the Hill Climbing algorithm for the Y-axis and the Z-axis. The star represents the final position in our controlled stages.

Discussion

Transmission Test: We find that the data gathered for each different transmission state is inaccurate. Each transmission state was controlled by two shutters, creating three different states: Shutter 1 open, while Shutter 2 closed; Shutter 2 open, while Shutter 1 closed; and finally, both shutters will stay close and gather data. Our setup did not allow for these states to happen, as our shutter would only blink and remain open for the rest of the data gathering. We believe this created flawed data in each transmission stage. We believe the best solution is to create our own Python code to manually control the shutter states instead of the default programming. This should give provide control of each state and data gathering.

Ring Test: We searched for the FRD by using a series of Ring Tests for an optic fiber. This test uses the Hill Climbing Algorithm, which allows us to view different position angles for the optic fiber. For now, only two axis are implemented in our Hill Climbing algorithm, Y and Z. We plan to implement three other axis, X, XZ and Y-Ramp in future work.



Conclusion

FOCUSS sets forth a guide for characterizing and evaluating fibers, to optimize sky subtraction and improve the observations of fainter targets with future large spectroscopic facilities. The testing techniques described in this work can be used to calibrate a wide range of devices and can greatly benefit the astronomical instrumentation community[5].

References

- [1,2,4,5] ATI Proposal, Jennifer Marshall, 2019
- [3] Studying focal ratio degradation of optical fibers for Subaru's Prime Focus Spectrograph, Jesulino B.

Acknowledgements

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