Utilizing a High Power Broadband Light Source to Characterize the Throughput Ratio of Fiber Optics

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Abstract

Accurately measuring the night sky is imperative for large, ground-based astronomical telescopes; the goal is to subtract the spectrum of the sky background from the target spectrum and effectively reach reliable scientific results. The Fiber Optic Characterization for Unprecedented Sky Subtraction (FOCUSS) project aims to measure the throughput efficiency and focal ratio degradation (FRD) in multiple fiber optic cables to inform design choices for future fiber-fed astronomical spectrographs. Throughput efficiency measures absorption as a function of wavelength in a fiber optic, while FRD measures the change in angular distribution of the light after passing through a fiber as a function of the initial incident angle. The FOCUSS project measures these two parameters between wavelengths of 400nm and 1000nm with 18nm step sizes, equal to the band-pass of the monochromator. The measurements of the throughput and FRD are acquired between two respective tests, one to measure the FRD where a photo-diode, CMOS sensor, and a five-axis motor are utilized to align and step through incident angles and wavelength. The transmission test measures throughput efficiency by utilizing two identical CMOS sensors and an integrated sphere of light capturing images of similar periods of light. The Python programming language is used to interface with the testing hardware and automate the data collection and reduction process. With the validation of the experimental setup completed, we've begun testing various samples comparing the desired characteristics between fibers, and this presentation will primarily focus on the transmission portion of the project.

Introduction

When deciding to utilize a fiber optic cable within a setup, it's imperative to ensure the performance of the chosen fiber is up to par, and one of the most efficient methods of measuring performance is by the transmission rate, or throughput efficiency, of the fiber. The definition of transmission in this sense is fairly simple; what is the amount of light recovered through a fiber compared to the amount emitted? Measuring this ratio has its challenges, but by utilizing detectors such as CMOS imagers and an integrated sphere we're able to capture results from our control and from our specimen during the same instance of light. By summing together the intensity values of each pixel for each detector, we're able to compare the results by dividing the total counts of our Fiber detector and the total counts of out Pinhole detector providing us with the Fiber-to-Pinhole ratio. Although the concept is fairly simple, the process has proved to be a challenge all on it's own.

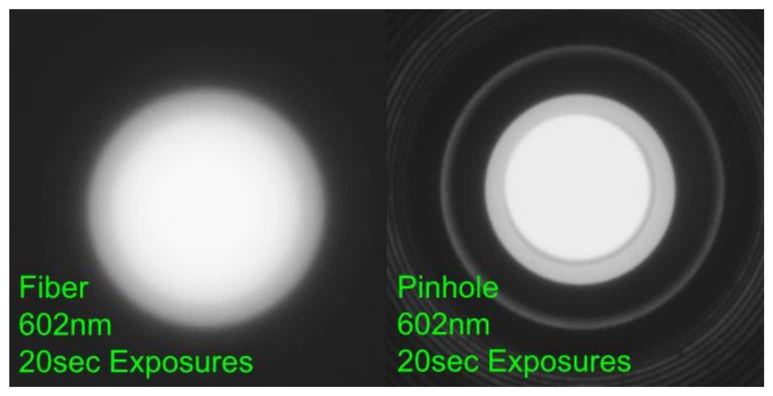

FIG. 1 Depicted above are separate exposures of our Fiber detector (Left) and our Pinhole detector (Right). In this current setup we placed a fiber optic cable in between the integrating sphere and the Fiber detector with the purpose of running a full Transmission Test, acquiring the Fiber-to-Pinhole ratio

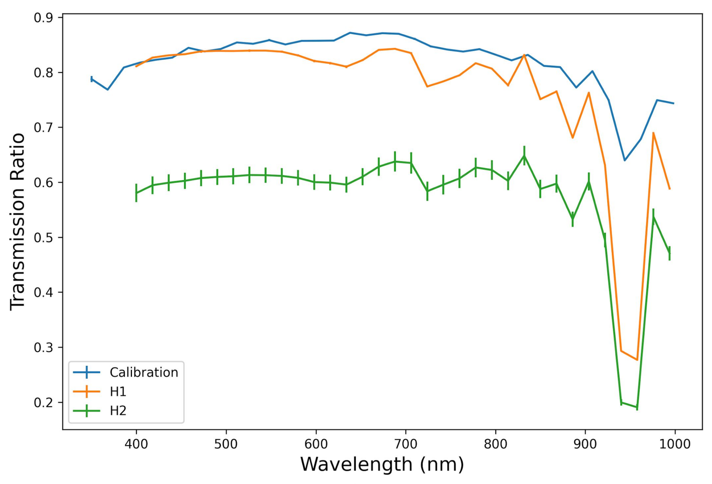

FIG. 2 Depicted above are final transmission results for three fibers, our calibration fiber and two different Optran UV fibers labeled as H1 and H2. We weren't given exact specifics on H1 and H2, however, we believe one is the Optran UV-Wide Field and the other to be the Optran UV-Vis but remains unconfirmed.

References

1. Vega, E. G., Menon, S. V., Andrade, S. D., et al. 2022, Texas A&M University, "Fiber Optic Characterization for Unprecedented Sky Subtraction (FOCUSS)"
2. Zhang, K., Zheng, J. R., Saunders, W., 2016, "High numerical aperture multimode fibers for prime focus use," Proc. SPIE 9912, 99125J
3. Assen, V., Verheijen, W., 2011, Kapteyn Astronomical Institute, University of Groningen, "Focal Ratio Degradation in Optical Fibres"

Methods and Discussion

Setup

Utilizing a high-power broadband laser-driven light source and a monochromator to isolate wavelengths, we illuminate an integrating sphere, homogenizing the input light and reducing inconsistencies. By taking advantage of the zwoasi python package and CPU threading, we interface with the two CMOS detectors, capturing images at the same time of the same instance of light, reducing the impact of variations within the light source. Furthermore, we apply an annulus-based background subtraction to accurately analyze the images' count values, representing the results as a Fiber-to-Pinhole ratio of these acquired counts for each desired wavelength. We calibrate the system with two identical pinholes or test a fiber against the previously calibrated pinhole depending on the configuration and desired results.

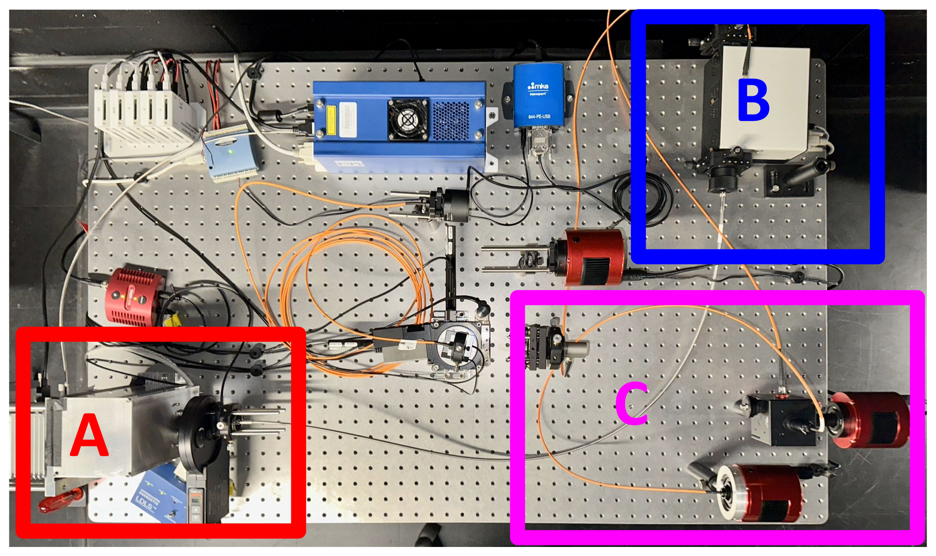

FIG. 3 Depicted above is the configuration of the FOCUSS setup with a focus on the Transmission Test. Our light source in section A (Red) is connected by a fiber optic to our monochromator, section B (Blue), who's output travels by fiber to section C (Magenta) containing our integrating sphere and the two CMOS detectors setup with a pinhole (control) and fiber optic (specimen).

Calibration

Our first major concern when designing the transmission test was ensuring that both detectors viewed the incident light with the same degree of accuracy. To remedy this issue we designed a test to calibrate the two detectors and create correction factors to apply when testing.

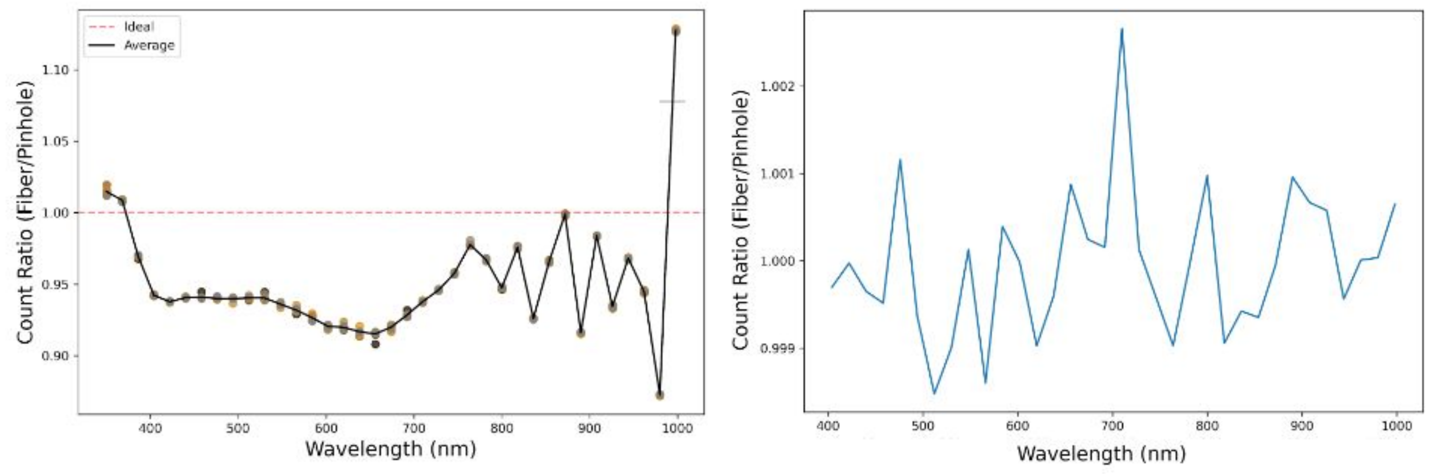

FIG. 4 Depicted above are pre (Left) and post (Right) calibration results from our efforts, the data from the pre-calibration was extracted and utilized as the correction factors producing the post-calibration results, calibrating the detectors to within three-tenths of a percent. Both results utilize two identical pinhole for both detectors rather than the dedicated Fiber detector utilizing a fiber as depicted in FIG. 1.

Despite the moniker of the Fiber detector, we simulated a perfect fiber utilizing a pinhole within the dedicated Fiber detector against an identical pinhole within the dedicated Pinhole detector. The advantage of utilizing these two identical pinholes allows the system to view the input light to near identical degrees, ensuring that both detectors are within one percent to one-tenth percent of each other in count values per wavelength. This is done by taking an average of multiple uncalibrated tests and using these Fiber-to-Pinhole ratios to multiply against future Pinhole counts (depicted in FIG. 4), adjusting our control so that when a fiber is introduced the decrease of light is observable and accurate.

Optimization

In addition to our concern about accuracy when implementing our calibration efforts, another major cause of contention when designing the test has been the duration of the total test time. To remedy this issue of test length, we attempted to optimize for the shortest exposure time while retaining high accuracy per wavelength by testing a pinhole and a known fiber and collecting ten images from multiple exposure lengths at each necessary wavelength. Once the data was collected, we analyzed the Fiber to Pinhole ratio, monitoring the resulting value and its accuracy, and analyzed the well usage (depicted in FIG. 5) optimizing for a count ratio standard deviation within one percent and/or a maximum of 40% well usage. With this optimization method, we were able to achieve a total test time of just above 30 minutes for a test between 350nm-998nm at 18nm step sizes and a test time of 20 minutes for a more brief test between 404nm-998nm.

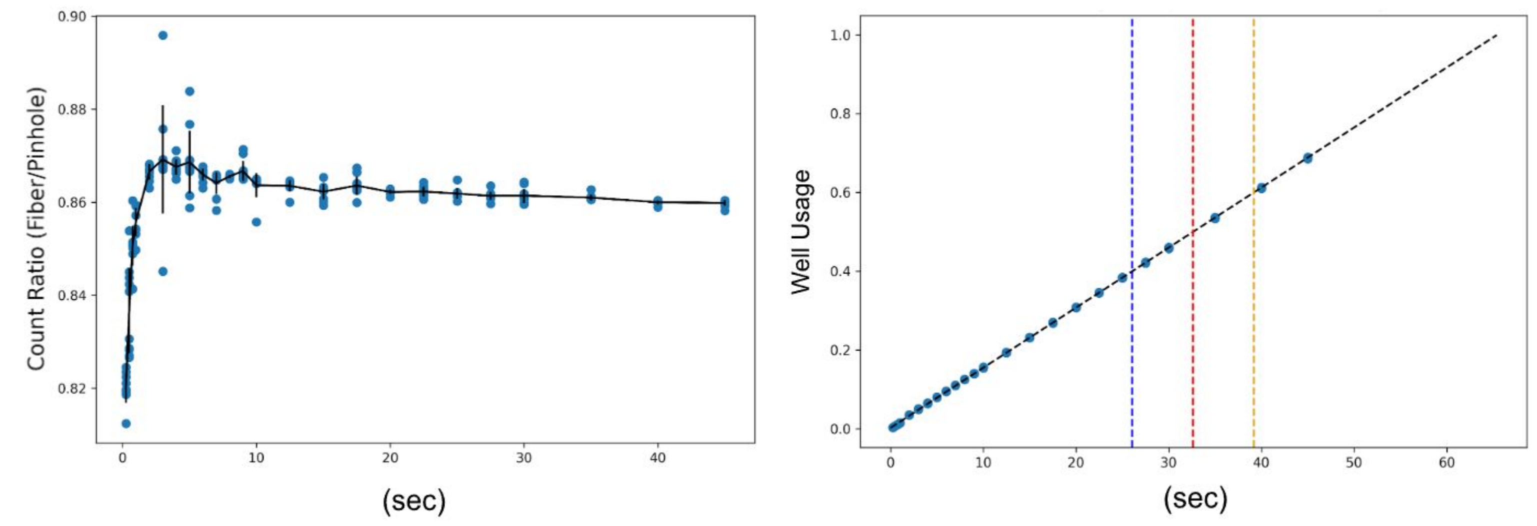

FIG. 5 Depicted above are the results of the optimization efforts of 550nm light where one graph visualizes the Count Ratio vs Exposure Time (Left) and the other depicts Detector Well Usage vs Exposure Time (Right). The left graph was utilized to optimize for one-percent accuracy while the right was utilized to optimize for 40% well usage and the Blue, Red, and Yellow dotted lines represented the exposure time for 40%, 50%, and 60% well usage respectively.

Results and Conclusion

With all current aspects of the transmission test developed, calibrated, and optimized, we re-calibrated and began preliminary testing with our calibration fiber between wavelengths of 404nm to 998nm with stepsizes of 18nm with great success. Since preliminary testing, we've tested our calibration fiber and two different Optrran UV fiber optic cables as depicted in Figure 2. An interesting result presents itself as an absorption feature between the wavelengths of 944nm to 962nm that's so far consistent within all fibers, this feature is consistent with a known absorption feature of water. Future testing would be required, but limiting this effect of this absorption would be preferred, hopefully by temperature control or dehumidifying the ambient air around the system. The acquired results so far are consistent and accurate, proving the steps taken towards innovating and improving the test have been a worthwhile undertaking. We're excited to continue improving our procedure and testing future fibers to provide the community with accurate and precise results of various fibers to suit their desired needs.

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