Development of TCal: a mobile spectrophotometric calibration unit for astronomical imaging systems

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Abstract

We describe a TCal, a mobile spectrophotometric calibration unit that will be used to characterize imaging systems at observatories around the world. We will measure transmission as a function of wavelength, and place all calibrated systems on a common photometric baseline. Our calibration system uses a ~1 nm wide tunable source to measure the instrumental response function of the telescope optics and detector from 300 nm up to 1100 nm. The system consists of a monochromator based tunable light source that illuminates a flat field screen. This screen is monitored by calibrated photodiodes allowing us to measure the telescope throughput as a function of wavelength. This system will be taken to various 1-8m telescopes that expect to devote time to wide field/synoptic survey follow-up.

Introduction

Current and future generations of wide field/synoptic surveys with high precision photometry will rely heavily on follow-up efforts from other telescopes to enhance the surveys' scientific yield. These follow-up observations will have to be precisely calibrated to reduce systematic errors when combining data from multiple observatories. To that end we have developed a mobile spectrophotometric calibration system, TCal. Here we present the experimental design of TCal which will make an in-situ measurement of the relative throughput of imaging systems as a function of wavelength.

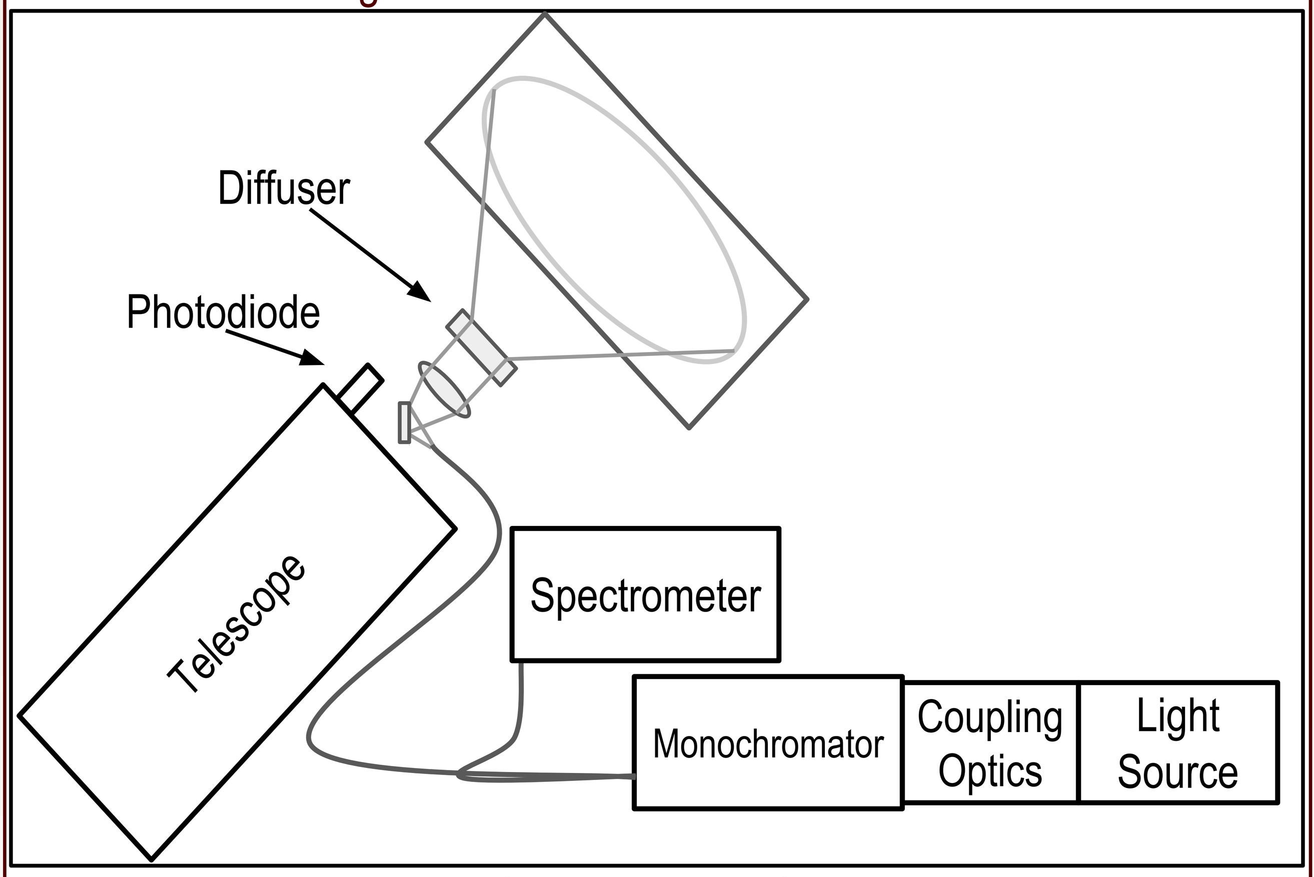

Figure 1: Schematic of the TCal system.

Experimental Setup

A schematic of the TCal system is shown in Figure 1. Briefly summarizing the system, a broadband light source is fed into a monochromator that selects a narrow bandwidth (~1 nm FWHM). This narrowband light is fed into a fiber bundle with one of the fibers leading to a monitoring spectrometer. The rest of the bundle brings the signal to a diffuser at the top of the telescope. The monitoring spectrometer allows us to measure and verify in real time the central wavelength and bandwidth of the signal. The diffuser uniformly projects the light onto a mounted flat field screen. This signal, coming off the flat field screen, is measured by the system to be calibrated and at the same time by calibrated photodiodes mounted on the top of the telescope. The ratio of these two measurements provides the relative instrumental transmission at a given wavelength.

Light Source

TCal operates continuously over a very wide wavelength range (300 nm < λ < 1100 nm). We find that a laser driven light source (Energetiq, EQ-99x) provides strong emission over the entire spectral range that is roughly 10 times that of a traditional quartz lamp. The spectral radiance as measured by Energetiq is shown in Figure 2.[1]

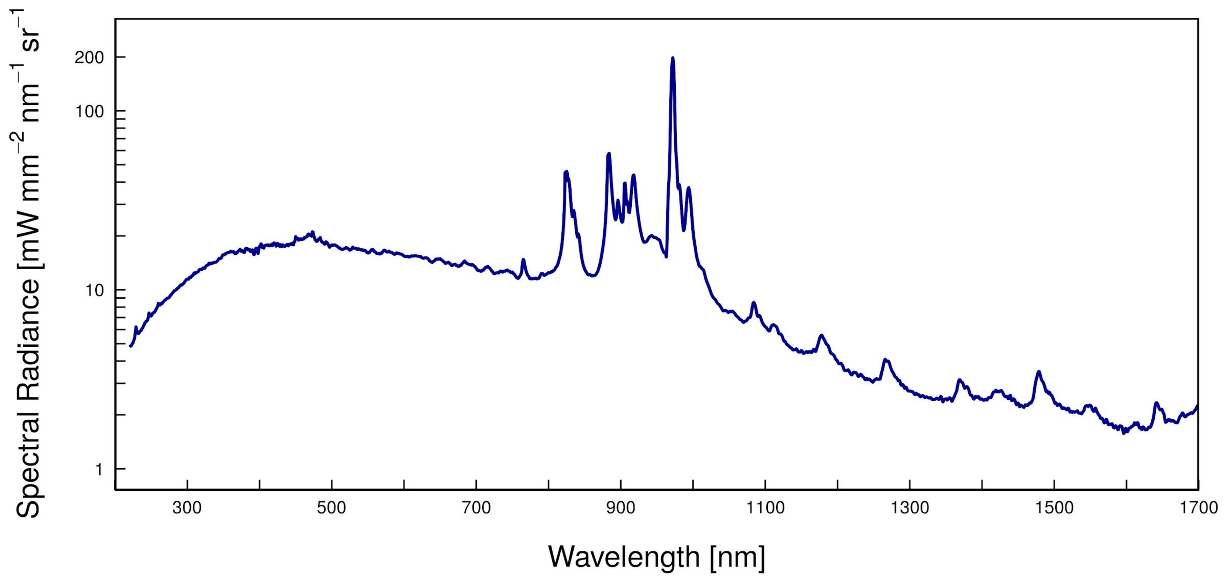

Figure 2: Spectral radiance of the laser driven light source (EQ-99x) as measured by Energetiq.

Monochromator

We use a fully automated f/4 Czerny-Turner monochromator (Horiba, iHR-320) having a high reciprocal dispersion of 4.2 nm/mm when used with a 1200 g/mm grating. This allows us to create the desired ~1 nm bandpass and scan from 300-1100 nm without switching gratings.

Fiber Bundle

A custom 8.5 m long fiber bundle assembled by Fibertech Optica is used. This is a broad spectrum fiber that transmits well both in the UV and IR. The bundle contains 10 fibers with 600 micron cores arranged in a line at the monochromator output. One of the fibers is split off and illuminates the monitoring spectrometer. The rest of the fibers are arranged in a circular output that feeds into the diffuser mounted on the telescope.

Projection System

We use polymer-on-glass Engineered Diffusers (RPC Photonics, EDC) to project the light onto the flat field screen. Depending on the size of the telescope and the size/distance of the flat field screen, different diffusers with cones of light ranging from 30° − 60° can be used to evenly illuminate the screen.

Photodiodes

We use a calibrated reference photodiode (Gentec PH100-SiUV) to measure the light reflected by the screen. The photodiode will be mounted on the side of the telescope and baffled so as to only be a measure of light reflected by the screen. This photodiode provides a relative measure of the light incident on the telescope as long as the field of view and diffusion pattern are wavelength independent.

Monitoring Spectrometer

We feed one of the fibers from the bundle into a spectrometer. This monitoring spectrometer records a spectrum for each exposure that is a direct measure of the central wavelength and FWHM of the light leaving the monochromator. We use a spectrometer with high enough resolution to characterize the central wavelength and FWHM with a precision of ~ 0.1 nm.

Flat Field Screen

A mixed nylon-spandex material from *stretchyscreens.com* was found to be both relatively Lambertian, and highly reflective as seen in Figure 3. More information on this and other measured white materials can be found Schmidt et al. (*10706-196, Thursday June 14*).[2] Also shown is a photograph of a 1.2 m flat field screen mounted in a commercial frame (also provided by *stretchyscreens.com*).

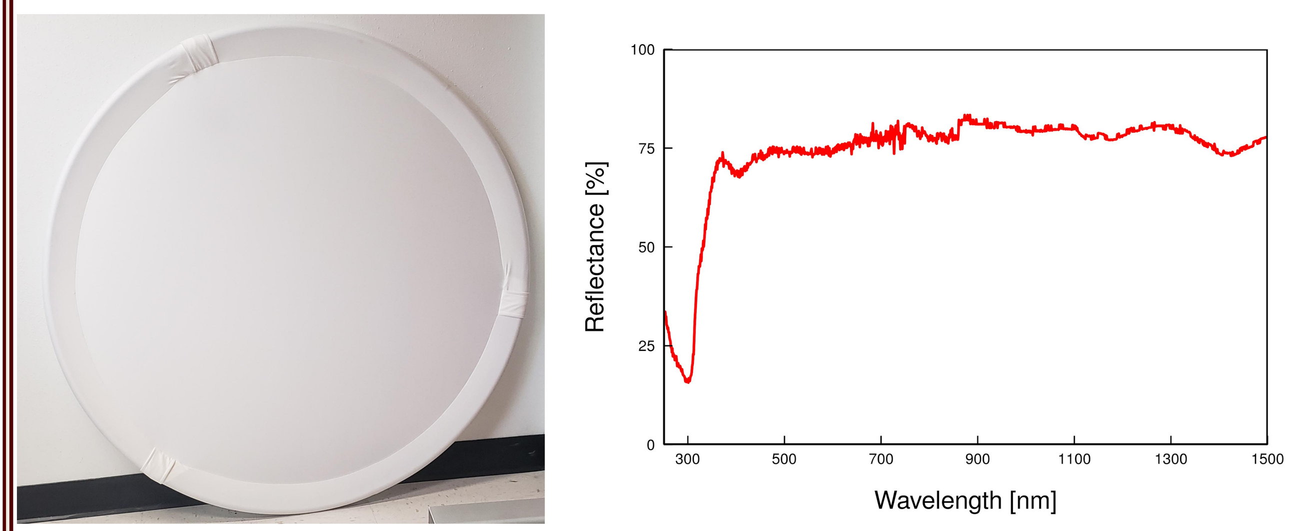

Figure 3: *Left*: Image of 1.2 m screen,
Right: Reflectance measurements for the mixed nylon-spandex material.

Software and Expected Data Product

We plan to develop an almost fully-automated LabVIEW interface to communicate will all components of TCal and execute a scan with minimal intervention. The end data product will be similar to previous work (Figure 4) characterizing RetroCam on the Swope telescope used in the Carnegie Supernova Project.[3,4]

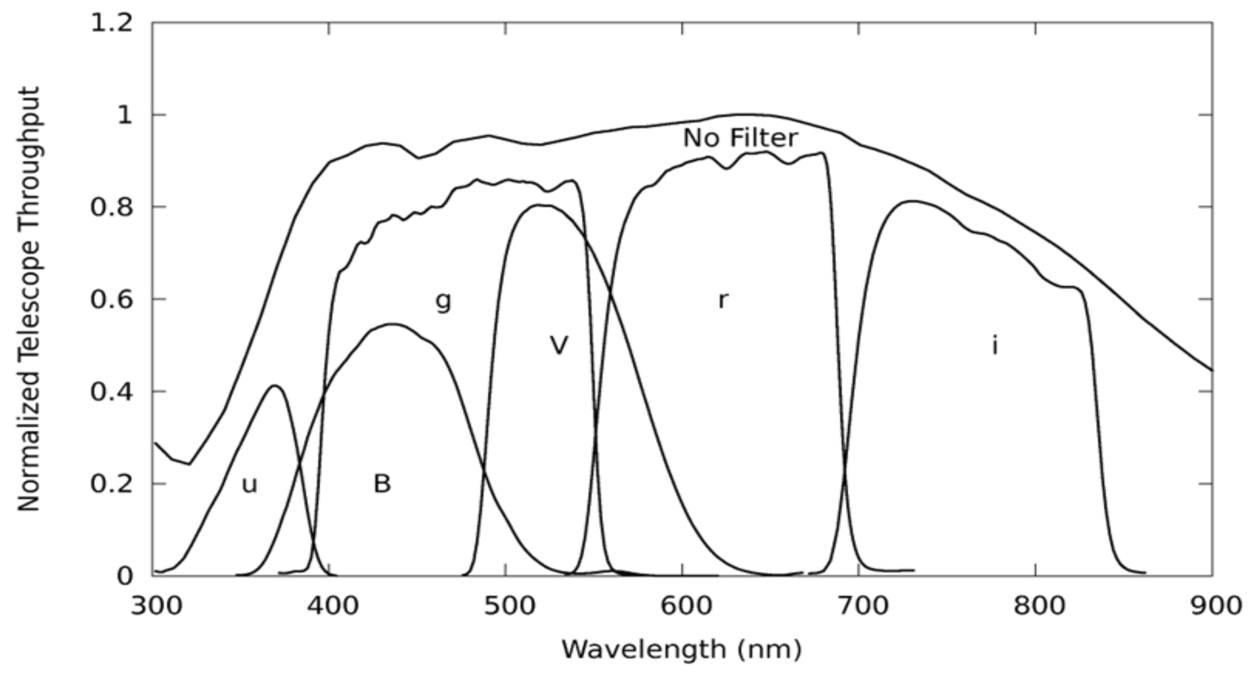

Figure 4: Scan of optical filters used in the Carnegie Supernova Project.

Conclusion

Building on the experience gained from previous work we have developed a mobile spectrophotometric calibration unit for imaging systems. In late 2018 we plan to take TCal to McDonald observatory in Texas to refine and finalize the design. Then in the next 2-3 years we plan calibrate various 1-8 m telescopes around the world that expect to see significant scientific benefits from having their transmission function precisely characterized. This effort will serve to enhance the scientific return of follow-up efforts, which will benefit the entire astronomical community in the next decade and beyond.

References

[1] www.energetiq.com
[2] Schmidt, L., et al., "Characterization of the reflectivity of various white materials," Proc. SPIE, in prep (2018).
[3] Marshall, J. L., et al., "DECal: A Spectrophotometric Calibration System for DECam," ASPC 503, 49 (2016).
[4] Rheault, J.-P., et al., "Spectrophotometric calibration of the Swope and duPont telescopes for the Carnegie Supernova Project 2," Proc. SPIE 9147, 91475L (2014).

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