Further development and testing of TCal: a mobile spectrophotometric calibration unit for astronomical imaging systems

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Abstract

We describe and present initial testing of TCal, a mobile spectrophotometric calibration unit that will be used to characterize imaging systems at observatories around the world. We measure transmission as a function of wavelength. This measurement helps to reduce systematic error introduced as a result of combining observations from multiple facilities/surveys. 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 with ~1% precision. In the near future TCal 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 refined design and initial testing of TCal which will make an in-situ measurement of the relative throughput of imaging systems as a function of wavelength.

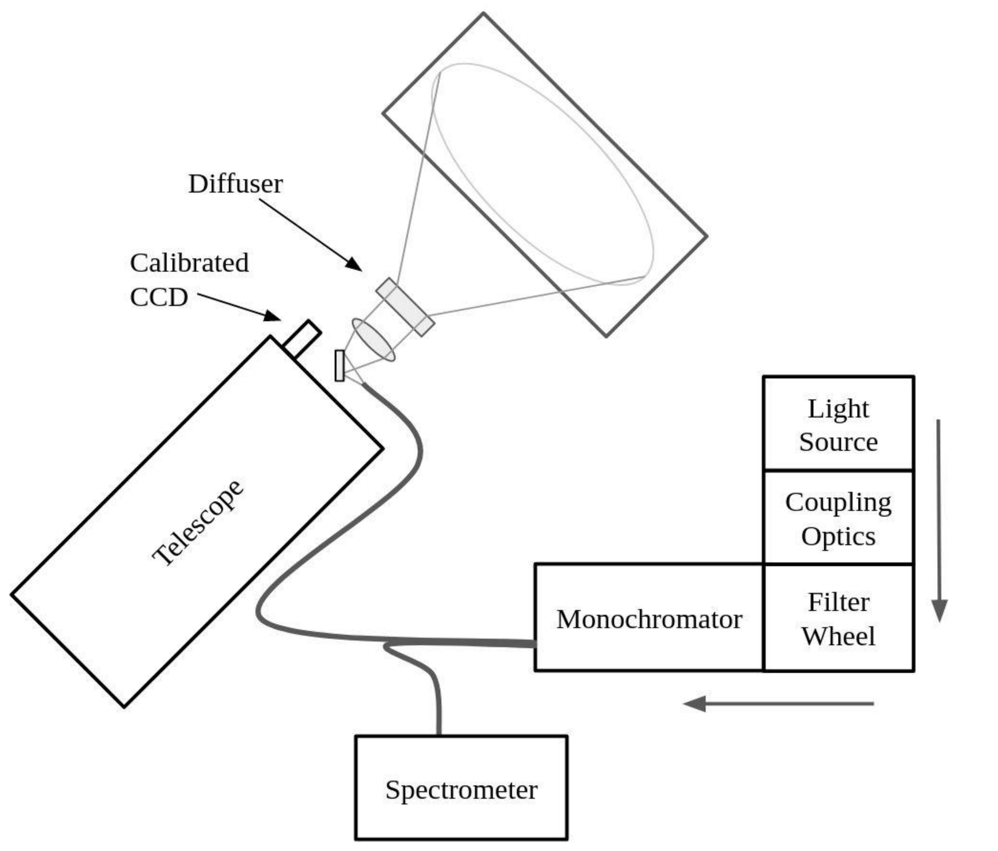


Figure 1: Schematic of the TCal system.

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 (Target CCD) and at the same time by calibrated CCD (Monitor CCD) mounted on the top of the telescope. The ratio of these two measurements provides the relative instrumental transmission at a given wavelength.

Design Details

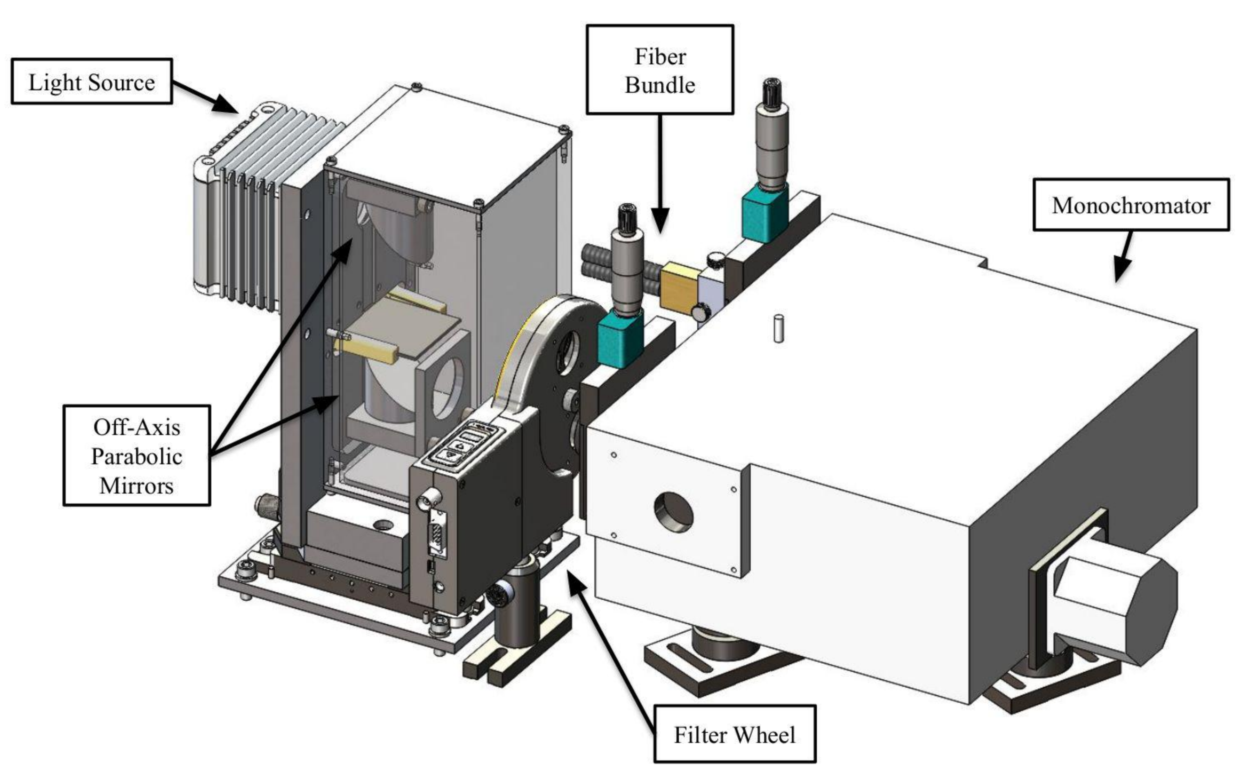


Figure 2: Model of light source, coupling optics, filter wheel and monochromator

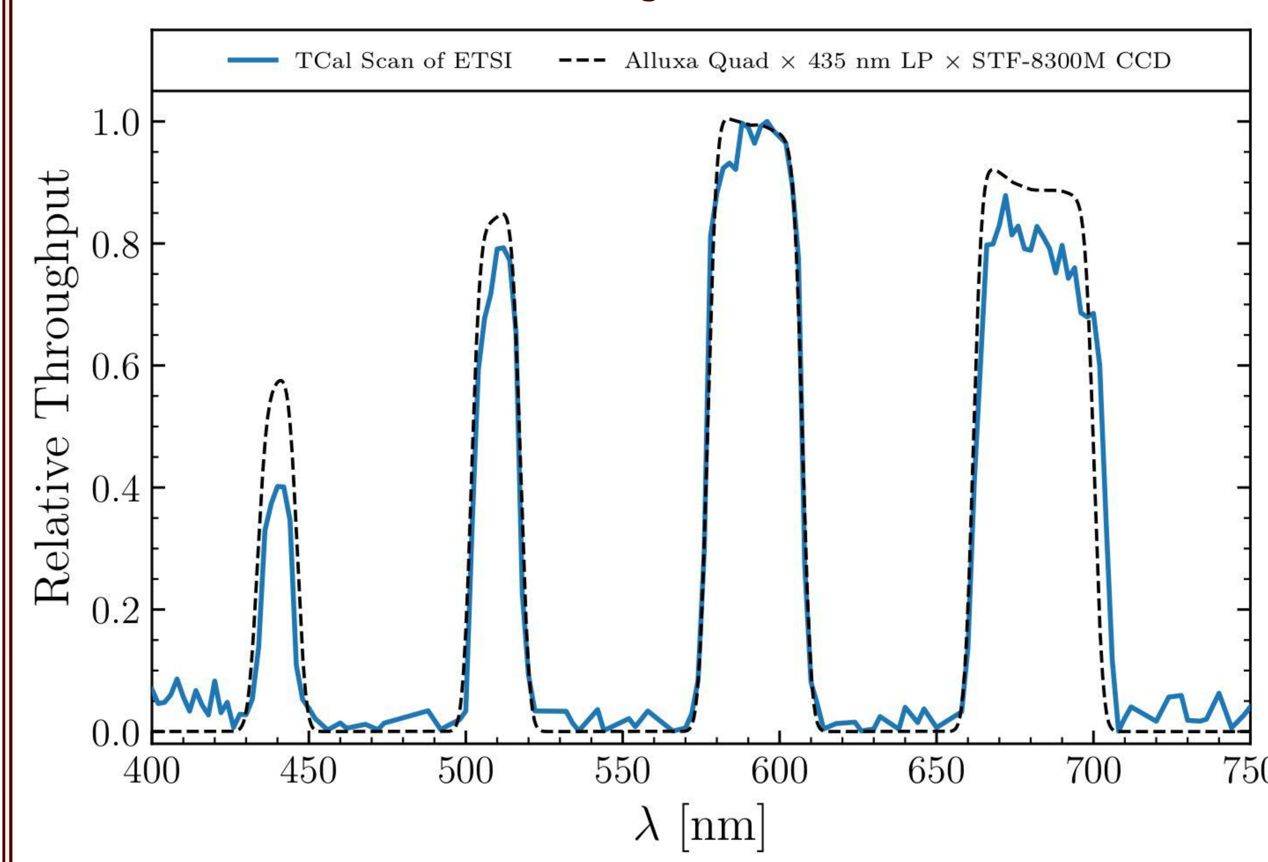
- Light Source: EQ-99x from Energetiq
  This laser driven light source provides strong emission over our whole spectral range 300 nm < λ < 1100 nm.
- Filter Wheel: FW102 from ThorLabs
  The filter wheel is used prevent out-of-band light from reaching the exit slit of the monochromator. A series of three short pass (400, 425, 450 nm) and two long pass (500, 550 nm) filters are used.
- Monochromator: iHR-320 from Horiba (f/4 Czerny-Turner style)
  The monochromator is used to easily select a narrow bandpass to feed into the fiber bundle with 1200 g/mm grating it covers our full range of 300-1100 nm.
- Projection System: polymer-on-glass Engineered Diffusers from RPC
  Depending on the size of the telescope and the size/distance of the flat field screen, different diffusers with cones of light ranging from 5° − 60° can be used to evenly illuminate the flat field screen.
- Flat Field Screen: nylon-spandex material
  We chose a material that was found to be both Lambertian and highly reflective over our spectral range. For more information on this testing see Schmidt et al. (11451-129).[1]
- Monitor CCD: STF-8300M from SBIG
  We chose to use a CCD instead of a NIST-calibrated photodiode because of how easily it integrates with the TCal software and the increased flexibility in setting up the TCal system. The Monitor CCD has been calibrated in our lab using a NIST-calibrated photodiode
- Instrument Enclosure/Stand:
  We designed and created a compact and collapsible enclosure and stand for TCal to reduce stray light and allow for easy setup and alignment of the optics.

Scan Software and Data Reduction Pipeline

We have developed a LabVIEW based fully automated scan software. This software controls of the positioning of the filter wheel and monochromator, and triggers data aquisition of both the Monitor CCD and Target CCD. This software allows one individual to easily run a scan using TCal.

Additionally we developed a python based data reduction pipeline to quickly reduce the data and concatenate all of the information needed to create our final measurement, the transmission as a function of wavelength for the system to be calibrated.

Testing of TCal



This figure shows the results of our scan of ETSI[2] (Limbach et al. 11447-100) at the McDonald Observatory 0.9 m telescope in the summer of 2019. The blue line shows our measured relative throughput as a function of wavelength, and the black dashed line shows a predicted transmission function taking only the Aluxa quad band, 435 nm long pass filters and CCD quantum efficiency into account.[3] In general our observation are in good agreement with the predictions. The small deviations showcase the need for this type of calibration to reduce errors on measurements.

Conclusion

Building on the experience gained from previous work we have continued to develop a mobile spectrophotometric calibration unit for imaging systems. We successfully tested a prototype version of TCal at McDonald Observatory and are ready to begin calibrating other systems. In the next 1-2 years we plan to calibrate various 1-8 m telescopes that expect to see significant scientific benefits from this calibration. This will serve to enhance the scientific return of LSST follow-up, benefiting the astronomical community as a whole.

References

[1] Schmidt, L. M., et al., "Characterization of the reflectivity of various white materials," Proc. SPIE, in prep (2020).
[2] Limbach, M.A., et al., "The Design of the Exoplanet Transmission Spectroscopy Imager (ETSI)," Proc. SPIE, in prep (2020).
[3] https://www.alluxa.com/

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