Spectrophotometric Calibration System for DECam

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INTRODUCTION

The discovery that the universe is *accelerating*, not slowing down from the mass it contains, is the surprise that sets the initial research program of 21st Century cosmology. The Dark Energy Survey is a next generation sky survey aimed directly at understanding this mystery. The survey will rely on DECam, an extremely red sensitive 520 Megapixel camera that has a 1 meter diameter, 2.2 degree field of view prime focus corrector, and a data acquisition system fast enough to take images in 17 seconds. DECam will be installed at the prime focus of the Blanco 4-meter telescope at CTIO, a southern hemisphere NOAO telescope.

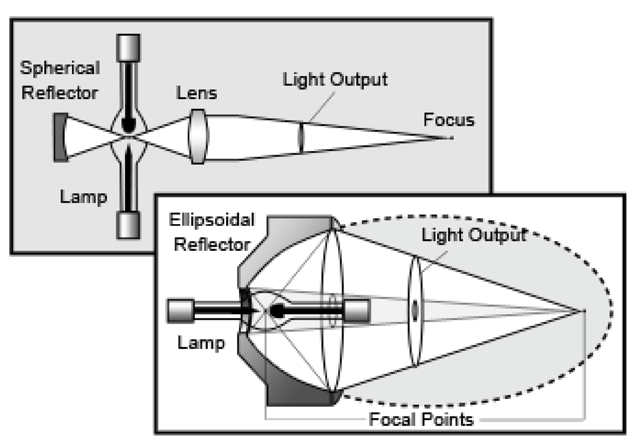
We are building a spectrophotometric calibration system for this camera that will measure the total instrument throughput versus. wavelength. The system will be installed permanently at the telescope. The goal is to monitor the throughput of the telescope at regular intervals (~every 1 month) during the 5-year survey to monitor the instrumental performance. The data from our calibration will also provide accurate knowledge of the filter transmission functions that can be used to calculate more accurately photometric redshifts, supernovae k-correction transformations and other valuable precision photometric results.

We have successfully deployed a prototype of our system at the Swope and DuPont telescopes located at Las Campanas Observatory in Chile. We measured the throughput of the u, B, V, g, r, i,Y, J, H and K filters used during the Carnegie Supernova Project. This was the first time such a calibration was performed in the Infra-red. We present here the results of this calibration that was performed in January and July 2010. We also present the final design of the permanent DECam system we will implement at the CTIO Blanco telescope this summer.

Monochromator and Light Source

We will use a fully automated F/4 Czerny-Turner monochromator with a high reciprocal dispersion of 2.3 nm/mm. This will allow us to open the slits to 1mm and still keep a relatively narrow bandwidth of 2nm FWHM with a 1200g/mm grating. We will use 3 gratings, 5 order sorting filters and two light sources to maximize the throughput over the whole wavelength range of 300 to 1100nm. All of these will be remotely controlled by a Labview based calibration program.

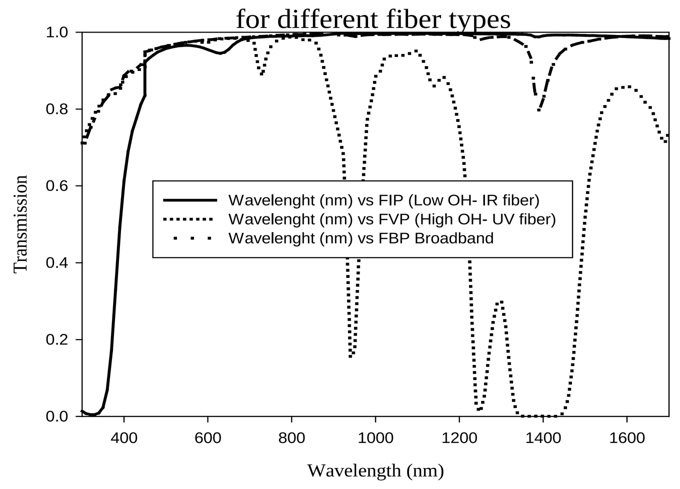
We use two light sources to cover a broad wavelength range. A 150W compact xenon light source covers the region from 300 to 800nm; a 250W quartz Tungsten Halogen (QTH) is used to cover the infrared from 800nm to 1100nm. Efficiently coupling the light from extended sources into a 1mm wide monochromator input slit is challenging. Our xenon light source is equipped with an ellipsoidal reflector that envelops the lamp and collects 70% of the light output as opposed to 20% for a regular reflector. Because of the large size of the QTH lamps, an elliptical mirror is inefficient and a simple spherical mirror is simpler and provides better results.

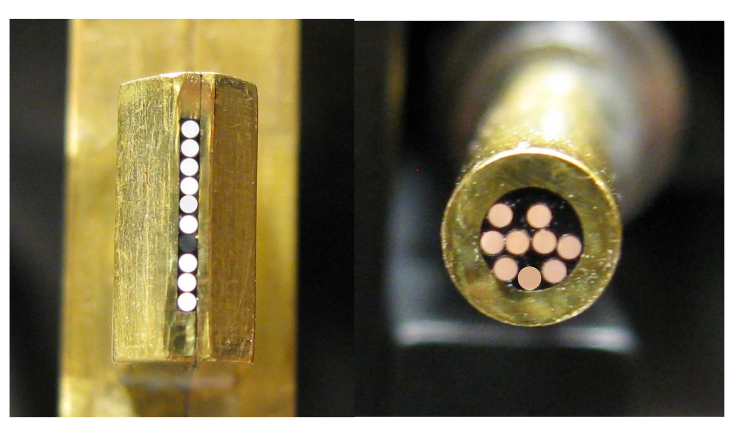


Fiber Bundle

We will use a custom 75mm long fiber bundle made with special broad-spectrum fiber. This fiber has excellent transmission both in the UV and the IR. This contrasts with most fibers where good transmission is only available in the infrared (low OH^- content) or in the UV (high OH^- content) but never at both end of the spectrum simultaneously (see figure at right).

Internal transmission over 10 meter for different fiber types





10 fiber prototype bundle used at LCO. The final bundle will consist of 87 fibers arranged in 3 vertical lines at the slit end and will be split into 5 branches at the top of the telescope.

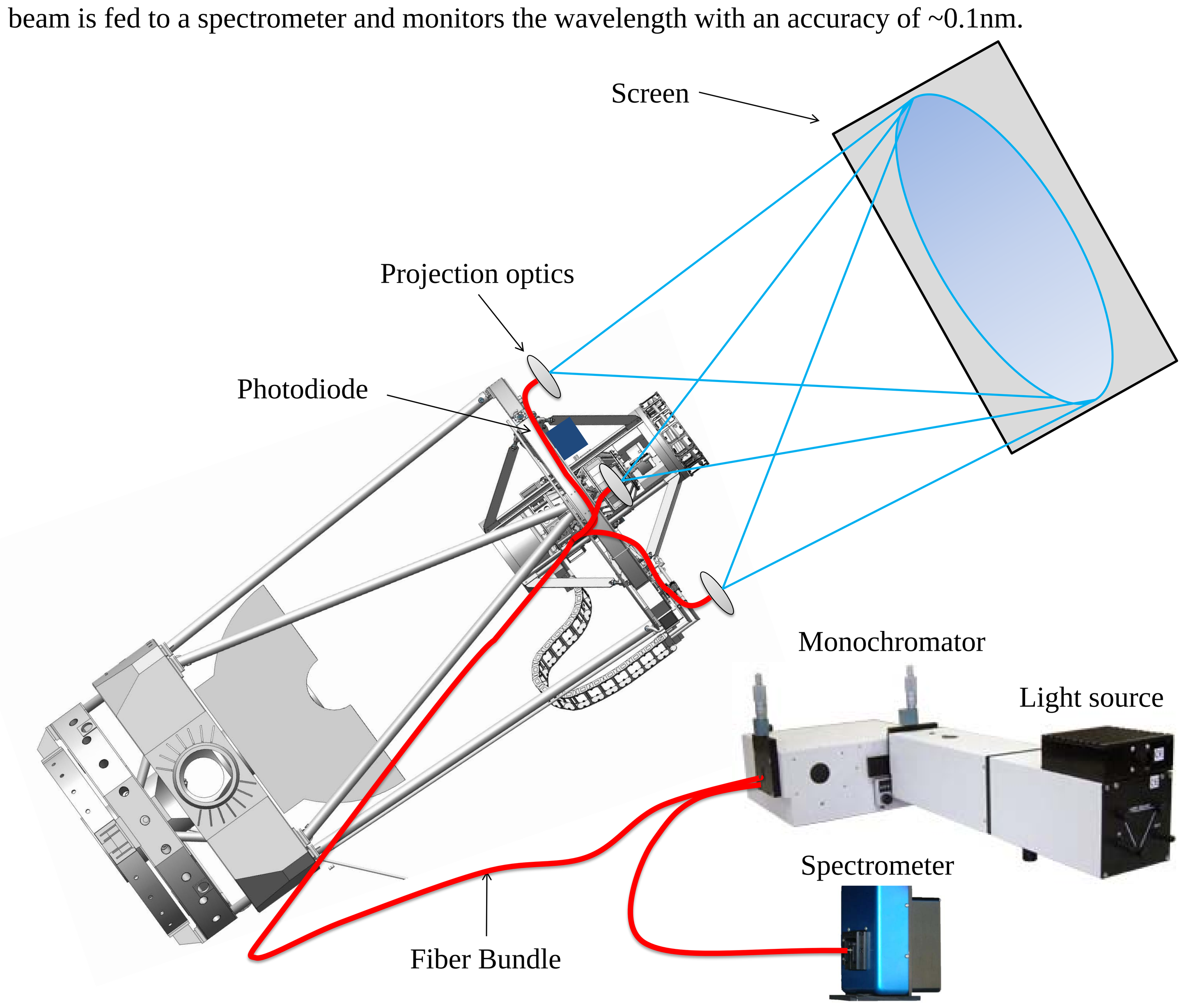
The bundle will consists of 87 fibers with 300 micron cores arranged in a 3 vertical lines by 29 rows at the input end (monochromator). The bundle is separated in 5 branches, 4 of which go to the top of the telescope to illuminate the screen. The 5^{th} branch is fed into a spectrometer to monitor the central wavelength and FWHM of the illuminating beam in real time.

ABSTRACT

We present a spectrophotometric calibration system that will be implemented as part of the DES DECam project at the Blanco 4 meter at CTIO. Our calibration system uses a 2nm wide tunable source to measure the instrumental response function of the telescope from 300nm up to 1100nm. This calibration will be performed regularly to monitor any change in the transmission function. The system consists of a monochromator based tunable light source that provides illumination on a dome flat that is monitored by calibrated photodiodes and allow us to measure the throughput as a function of wavelength. Our system has an output power of 2 mW, equivalent to a flux of approximately 800 photons/s/pixel on DECam. We also present results from the deployment of a prototype of this system at the Swope and DuPont telescopes at Las Campanas Observatory for the calibration of the photometric equipment used in the Carnegie Supernova Project.

Experimental Setup

A schematic of the experimental setup is shown below. The experimental setup consists of a broadband light source from which we select a narrow bandwidth (2-5 nm FWHM) using a monochromator. The monochromator output is coupled into a fiber bundle and brought to the top of the telescope behind the secondary and then projected onto the flat field screen using beam projection optics that ensure uniform illumination of the screen. 4 NIST traceable calibrated photodiodes, also placed on the back of the secondary, measure the power on the screen. A sample of the illumination beam is fed to a spectrometer and monitors the wavelength with an accuracy of ~0.1nm.



Diffuser

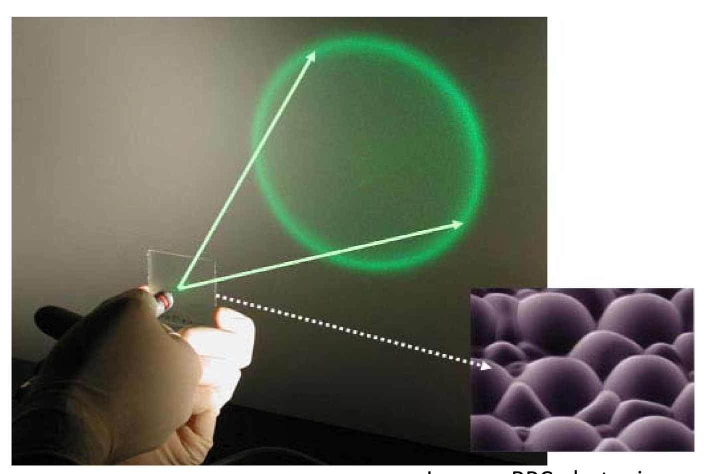
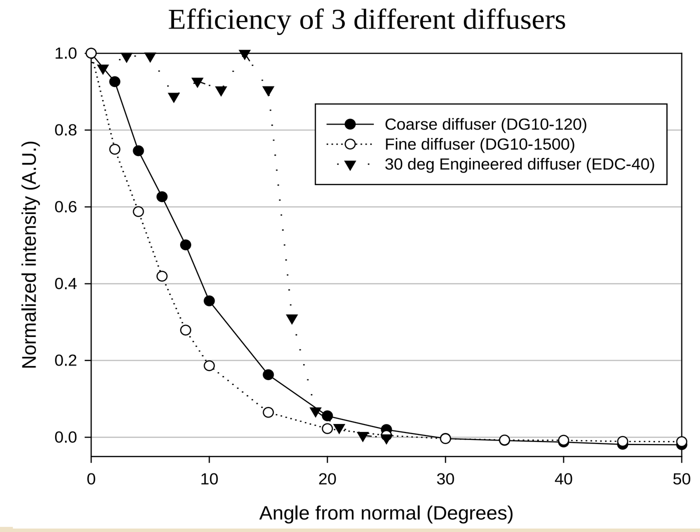


Image : RPC photonics

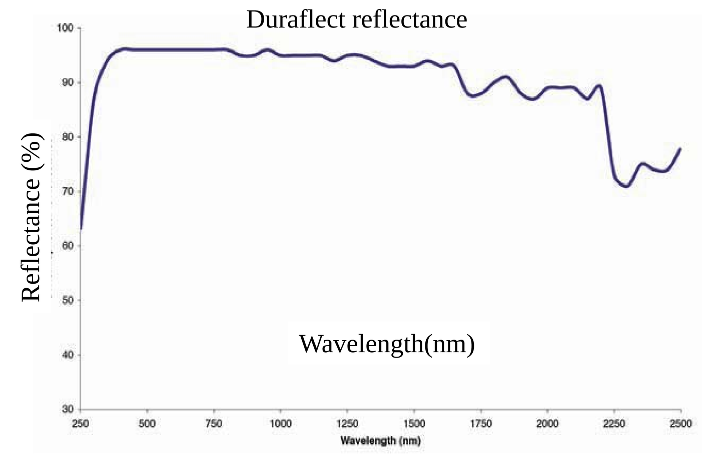
To ensure a uniform illumination of the focal plane area, we use an Engineered Diffuser from RPC Photonics to project the light from the fibers on the screen (see example at left). Our diffuser is a 30° angle cone diffuser that projects the light in a top hat shape with a diverging angle of 30 degrees.

The uniformity of the illumination on the screen is measured to be around +/-10% within the 30° angle. Furthermore, more than 80% of the light exiting the fiber bundle ends up within the 30° cone of light. This method is far superior to the use of a regular diffuser where most of the light would be scattered away from the screen if we used a diffuser aggressive enough to achieve a +/-10% uniformity in a 30° cone.

Efficiency of 3 different diffusers



Flat Field Screen



The screen we use is made of a lightweight aluminum honeycomb panel coated with a highly reflective and almost perfectly Lambertian coating called Duraflect from Labsphere. It is a coating that was developed for use in integrating spheres. The spectral reflectivity of the Duraflect coating is excellent with reflectivity over 95% from 350 to 1200nm and over 85% from 300 to 2200nm. This is shown in the figure at left.

Photodiode Monitoring

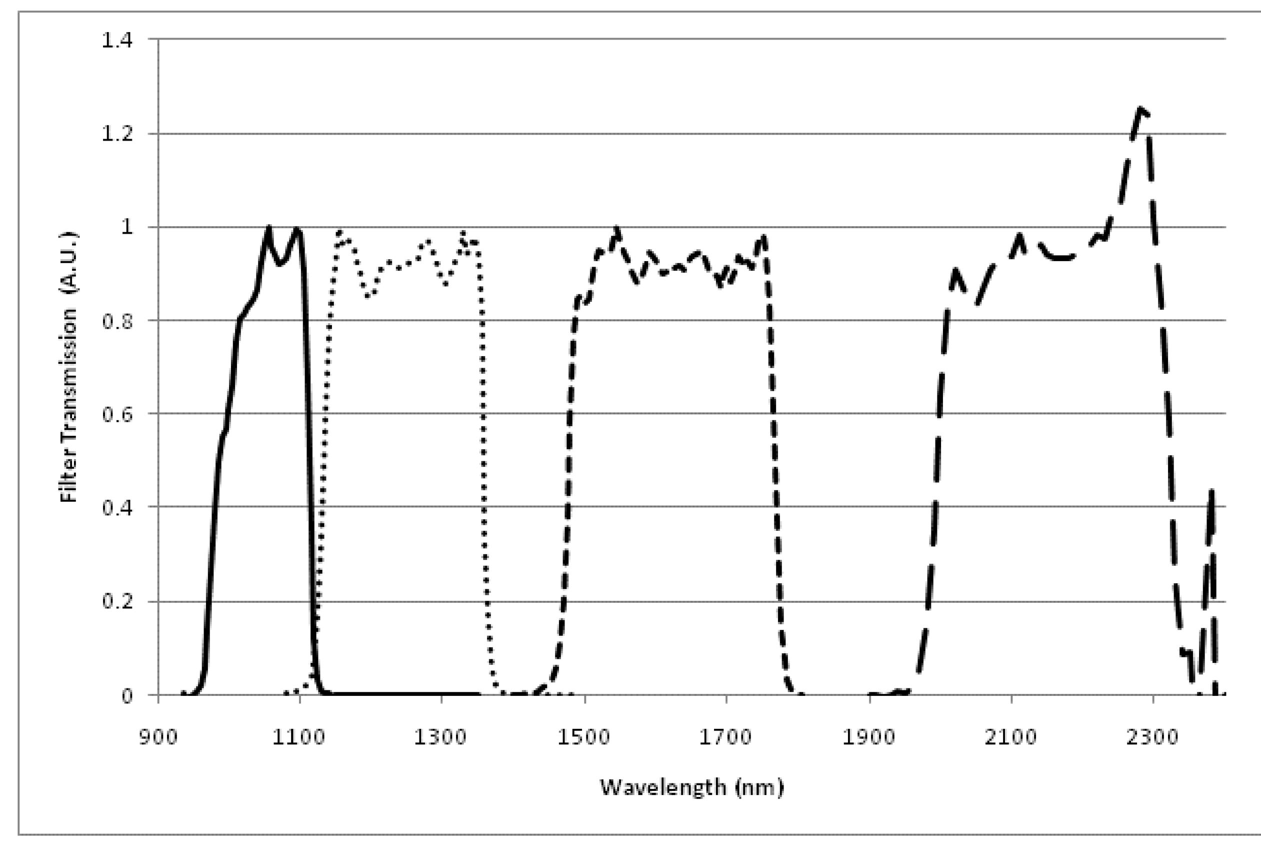
Reference photodiodes measure the amount of light reflected off the screen. They are positioned behind the secondary, facing the screen. They have a baffle that limits their field of view to the screen only so they don't receive any light reflected from the dome. We use 10mm Ø silicon photodiodes that are sensitive from 300nm to 1150nm to measure the light. 6mm Ø Germanium photodiodes were used for the infared (900nm to 1650nm). We measured signals on the order of 1 nW on the photodiode. These signals were amplified by a low noise trans-impedance amplifier with a selectable gain of 10^9 or 10^{10}. The amplifier has a cut-off frequency around 20 Hz to reduce noise levels. The amplified signal was read by an analog to digital converter acquiring signal at 10kHz. The signal was averaged down to 5 Hz for analysis. The photodiodes were calibrated in our labs using reference photodiodes from Gentec-EO that are NIST traceable.

Wavelength Monitoring

One of the fibers in the bundle is bifurcated toward a spectrometer to measure in real time the spectral content of the illumination source. The spectrometer measures both the central wavelength and the FWHM of the source. A spectrum is saved for every exposure and subsequently reduced to get the FWHM and central wavelength to 0.1nm. The spectrometer is calibrated every night with a Mercury calibration lamp. We use an echelle spectrograph from Optomechanic Research (SE-100) that covers the whole wavelength range in a single scan while keeping a high resolution of 3500.

Results: Infra-Red Calibration at the duPont Telescope

The relative throughput of the telescope, including losses by the primary and secondary mirrors, filter, dewar window and CCD quantum efficiency, is shown below. The data has been normalized for each filter. The data is not reliable upwards of 2100nm because the signal from our source falls off rapidly in the mid-infrared.



Conclusion

We have demonstrated our capacity to use a monochromator based light source to perform an accurate spectrophotometric calibbration. We will make improvements to the system to implement it on the CTIO Blanco 4 meter telescope as part of a permanent calibration system. These improvements will include increasing the light throughput of the system by using a monochromator with a higher dispersion and a fiber bundle with twice the collecting area. We will fully integrate the controls of the calibration system (light source, data acquisition and wavelength monitoring) to the DECam control software for a convenient user friendly operation.

ACKNOWLEDGEMENTS

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LSST Large Synoptic Survey Telescope

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