Spectrophotometric Calibration of the Swope and DuPont Telescopes for the Carnegie Supernova Project II

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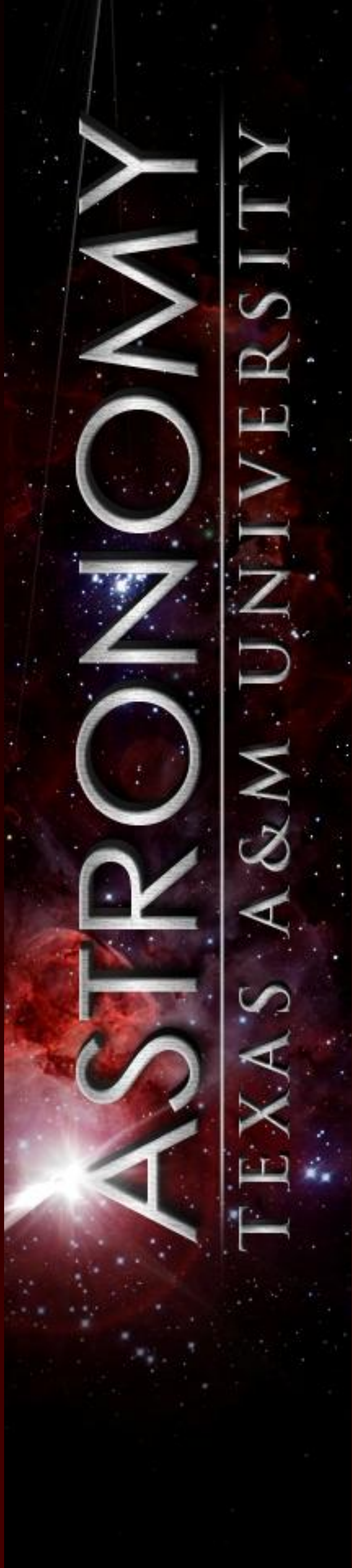


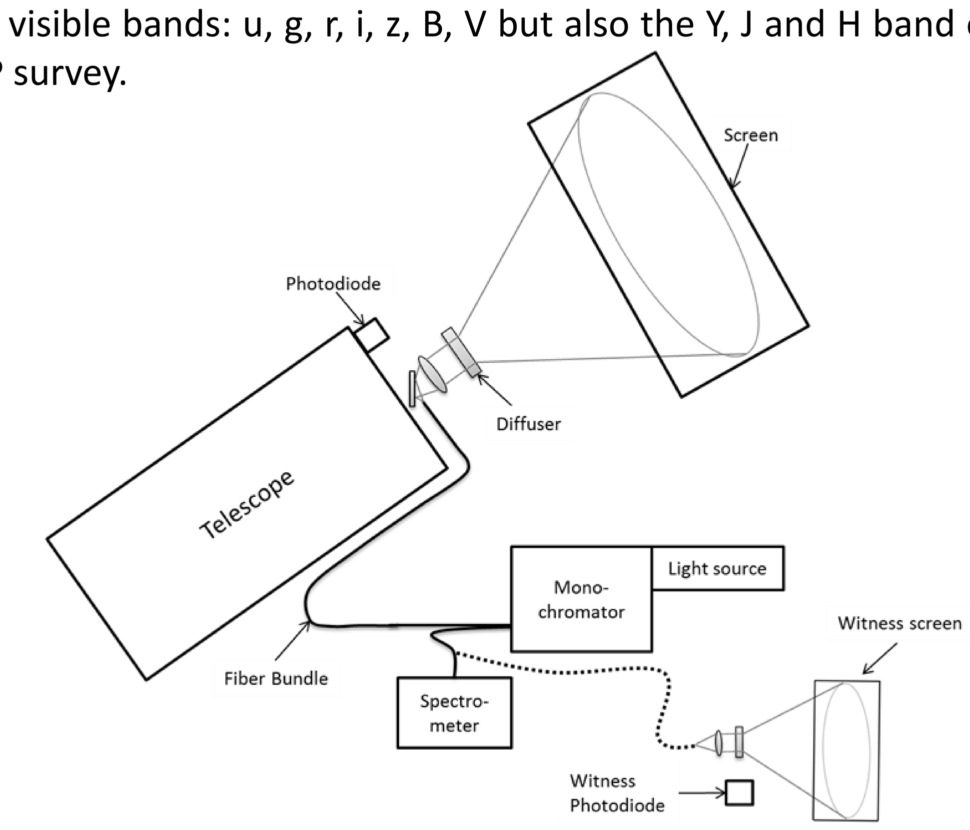
Abstract

We present results from the spectrophotometric calibration of the new E2V CCD camera on the Swope telescope and of RetroCam on the DuPont Telescope. We measured the relative sensitivity of each pixel vs wavelength over the whole wavelength sensitivity range of each camera, for all the filters that will be used during the 5 years of the CSP2 survey. We used a tunable light source and fiber delivery system conceived and built in our lab to achieve ±1% precision calibration from 300nm to 1100nm and ±3% from 1100nm to 1800nm. Achieving this relatively high precision at low light levels was made possible by using Si, Ge and InGaAs photodiodes coupled to custom high gain amplifiers. Comparison of these results to results obtained 3 years before, allowed us to confirm that the intrinsic transmission bandpass of the filters has not changed over time but that the mirror reflectivity and the introduction of a new CCD camera drastically changed the total telescope sensitivity. The analysis of the spatial response of the new E2V CCD vs wavelength also shows a slight gradient in the color response of the CCD both in the UV and Infrared.

Introduction

Current and future generations of large scale cosmological surveys will rely heavily on precise calibration of the astronomical datasets to produce precision results. The Carnegie Supernova Project II (CSP2) is one such survey that aims at achieving very high precision photometry. It is a five-year program that will obtain optical and near-infrared observations of 100-150 Type Ia supernovae located in the smooth Hubble flow.

We present telescope throughput measurements from 300nm to 1800nm performed in October and November 2013 at the Las Campanas Observatory in Chile. Our current instrument has the unique capability of performing spectrophotometric calibrations at wavelengths up to 1800nm. This allows us to characterize not only the visible bands: u, g, r, i, z, B, V but also the Y, J and H band of the CSP survey.

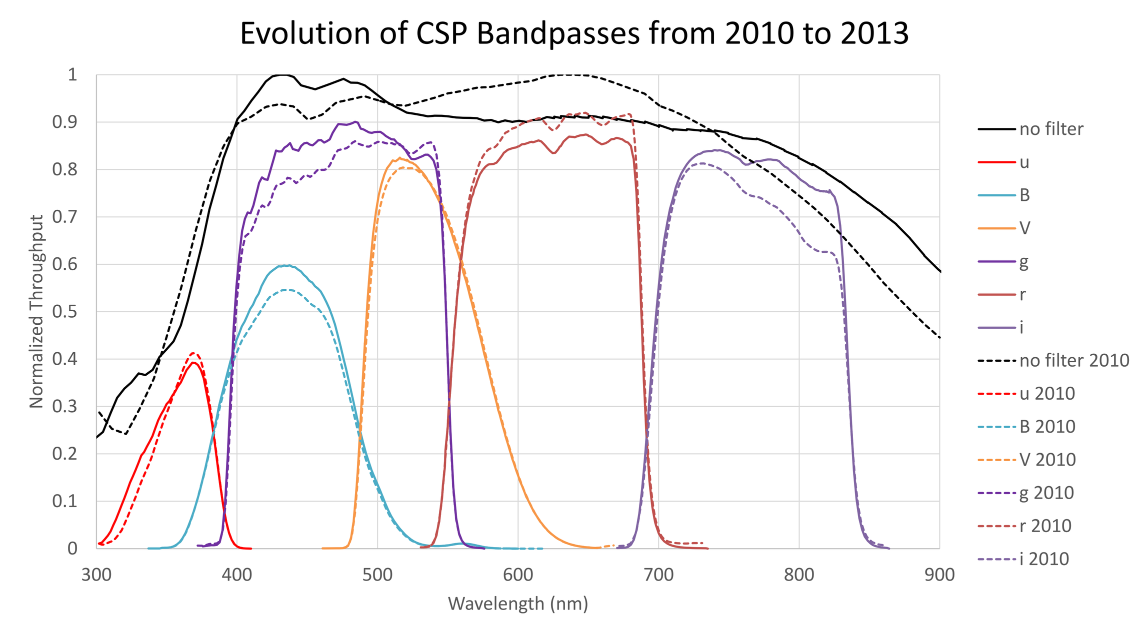


Experimental Setup

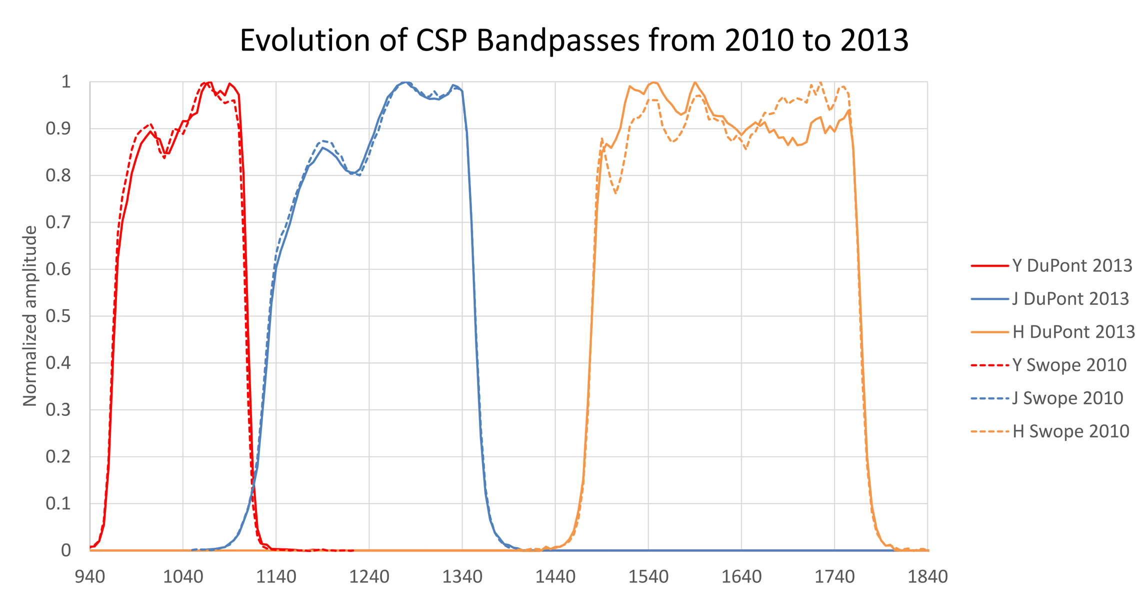
A schematic of the experimental setup is shown above. The experimental setup consists of a broadband light source from which we select a narrow bandwidth (~1-2 nm FWHM below 800nm, 10nm FWHM above 800nm) using a monochromator. The monochromator output is coupled into a fiber bundle made of 11 fibers aligned in a single row. The fiber bundle brings the light to the top of the telescope, behind the secondary mirror. Light is projected onto the flat field screen from the center of the telescope axis with beam projection optics that ensures uniform illumination of the screen. Silicon, Germanium and InGaAs NIST traceable calibrated photodiodes, also placed behind the telescope secondary mirror, measure the power on the screen. A sample of the illumination beam is fed to a spectrometer that monitors in real time the illumination wavelength with an accuracy of ~0.3nm.

Telescope transmission for each filter

The figure below shows the change in transmission of the CSP bandpasses for the Swope from 2010 to 2013. We have normalized both series of data so that the maximum transmission of the system without filter is equal to 1. A quick visual inspection of the "No Filter" curves shows that the E2V CCD (2013 –solid line) has a flatter response than the old SITE#3 CCD (2010 – dashed line). This difference in CCD response vs wavelength is the main driver of the change of the transmission response for the filters. The intrinsic filter transmission was measured on an optical bench in 2010 and 2013 and no change was detected during the 3 year period.



The figure below shows the change in the transmission function of the Y, J and H infrared bandpasses from when the RetroCam camera was on the Swope in 2010 to when it was moved to the Dupont in 2013. Both set of measurements were normalized before the comparison. The transmission function has not changed much between the measurements. In all cases, the filter edges have not shifted in wavelength. The biggest difference is in the H filter and is likely due to a difference in reflectivity of the Swope and DuPont mirrors. One thing to keep in mind is that our experiment doesn't allow us to measure an absolute transmission so a direct comparison of the amplitude of the 2010 and 2013 data is not possible. One should use standard stars to compare the absolute throughput of each filters.



Spatial and Color Dependence Analysis of E2V CCD

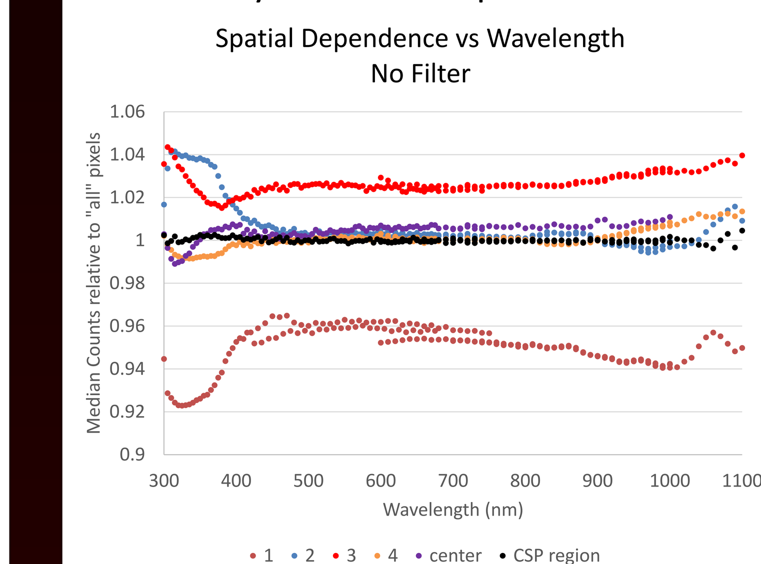
To measure the spatial dependence of the CCD, we subdivide the whole CCD into 6 regions and compare the response of each region at each wavelength step. We use the median value of all pixels in the CCD as a baseline for our calculations. The first 4 regions are the 4 different amplifiers, the "Center" region is a sub region in the center of the CCD. The "CSP" region is the region that has been chosen to position the science images for the survey.

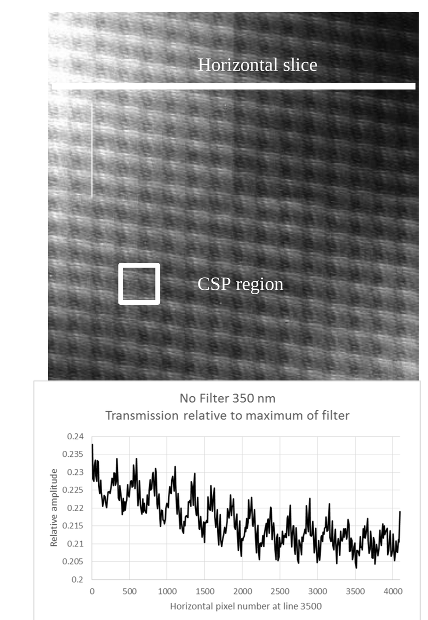
	Description	Position On CCD	Pixel location
Region 1	Amplifier 1	Upper Right	[2349:3796,2349:3796]
Region 2	Amplifier 2	Upper Left	[300:1748,2349:3796]
Region 3	Amplifier 3	Lower Left	[300:1748,300:1748]
Region 4	Amplifier 4	Lower right	[2349:3796,300:1748]
Center	Central region	Center	[1348:2749,1348:2749]
CSP	Region for CSP survey	Center of region 3	[774:1274,774:1274]
All	Whole CCD	Whole CCD	[300:3796,300:3796]

No Filter

The plot below shows the response of the telescope and CCD without filters. There is a color dependent difference of up to ±4% within the different regions on the CCD, especially below 400nm. There is also a less pronounced change in sensitivity with wavelength above 800nm, especially for region 1. Note that the CSP region (black dots) is very uniform vs wavelength.

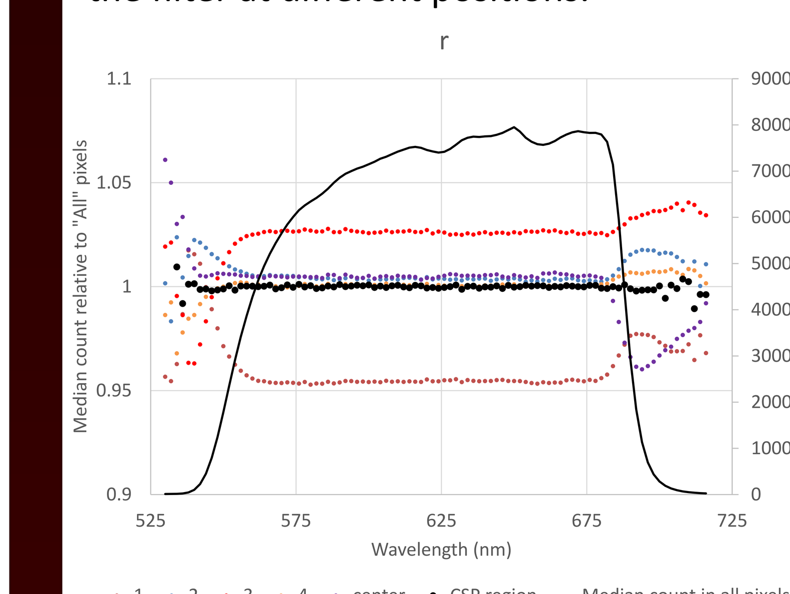
To further illustrate the color dependence of the CCD response, we show an image of the CCD response with "No Filter" at 350nm, along with an horizontal cross section. There is a diamond pattern at a level of ±1% that is caused by the manufacturing process. Also present is a large scale gradient of an amplitude of 4%. The CSP region sits in a saddle point in the wavelength dependent gradient and is thus less affected by the color dependence.

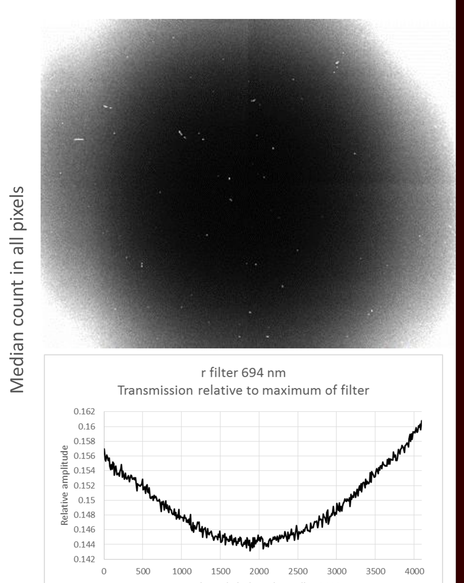




r Filter

Some filters have a spatial dependence vs wavelength at the cut-on and cut off edge of their transmission function. A prime example is the r filter transmission shown below. The response is very flat vs wavelength in the high transmission wavelength range of the filter but at the edge wavelengths, the filter transmission changes significantly between the different regions. The CCD image on the right, taken at 694 nm, exhibits a circular gradient that is centered on the optical axis of the telescope that is due to an uneven response of the filter at different positions.





Conclusion

We have measured the transmission function of the E2V camera on Swope and the RetroCam camera on DuPont and their respective filters.

In all cases, the intrinsic response of the filters has not changed since Jan 2010, although the transmission for the filter + CCD + telescope did change due to a change in the sensitivity of the E2V CCD relative to the old SITE CCD. The H filter on DuPont also changed slightly most likely due to change in the mirrors reflectivity.

The wavelength dependence vs position of the E2V CCD is responsible for up to a ~4% sensitivity dependence on the color and position. The filters are also responsible for color dependence vs position, especially where there is a sharp change in the transmission with wavelength. Confining the science images to a small region were these effects are small will reduce the color dependence of the results to much less than 1%.

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