aTmcam: A Simple Atmosphere Transmission Monitoring Camera For Sub 1% Photometric Precision

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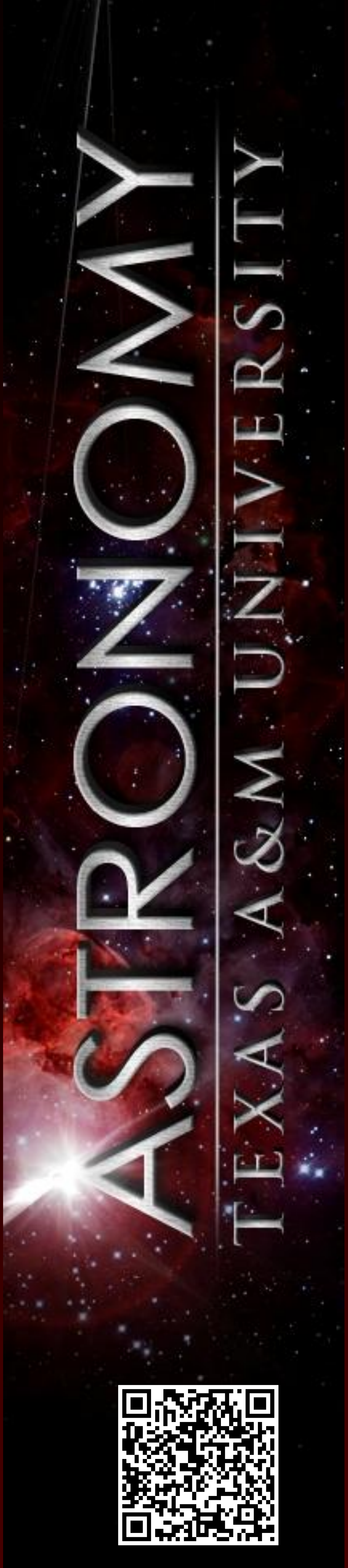
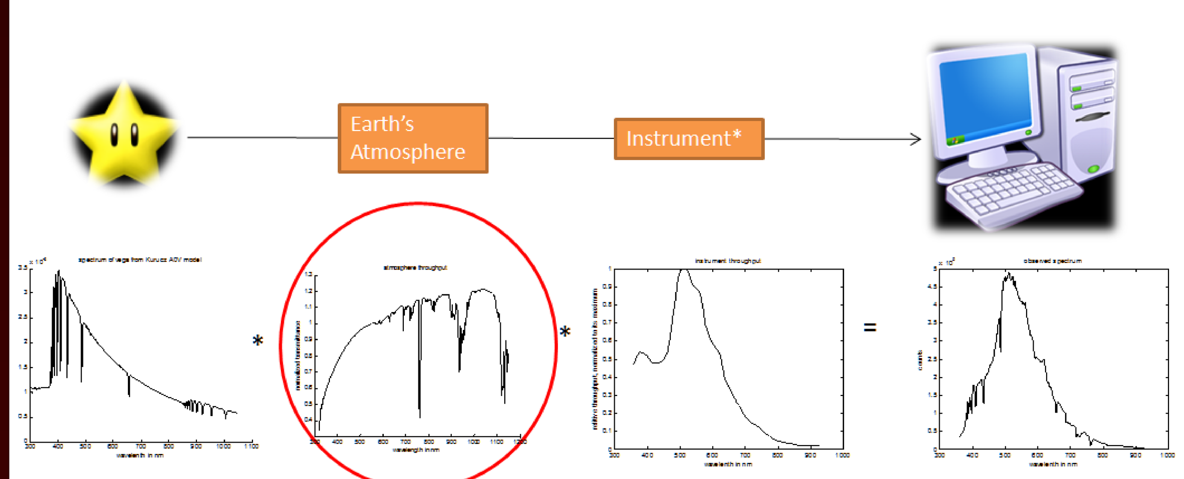


Abstract

Traditional color and airmass corrections can typically achieve ~0.01mag photometric precision. A major limiting factor is the variability in atmospheric throughput, which changes on timescales of less than a night. We present preliminary results for a system to monitor the throughput of the atmosphere, which should enable photometric precision when coupled to more traditional techniques of less than 0.5%. The system, aTmCam, consists of a set of imagers each with a narrow-band filter that monitors the brightness of suitable standard stars. Each narrowband filter is selected to monitor a different aspect of the atmospheric transmission, including the amount of precipitable water, aerosol optical depth, etc. We present performance modeling results and comparison of narrowband photometric measurements with spectroscopic measurements of the atmosphere; we show that the narrowband imaging approach can predict the throughput of the atmosphere to better than ~10% across a broad wavelength range.

Introduction

The Dark Energy Survey (DES) requires a photometric precision of 0.02 mag for a wide variety of targets (SN, galaxies, stars, etc.) to achieve its science objectives. However, improved precision can in principle give improved results, so DES has a goal of reaching 0.01 mag precision. Due to the variability in atmospheric throughput, which changes on timescales of less than a night, unmonitored changes in the atmospheric throughput ultimately limit survey photometric precision to ~0.01 mag. Therefore, real time atmospheric transmission monitoring is required to substantially improve photometric precision.



The spectrum of the object observed on Earth should be the stellar spectrum convolved with both the atmospheric throughput and instrument response function, as shown in the figure above. The atmospheric transmission is a mix of Rayleigh scattering, aerosol and dust scattering, water vapor absorption, etc. We can derive the atmospheric transmission with suitable observations of known stars with well-calibrated instrumentation.

Proposed System

We have proposed a simple system based on an imager with different narrow-band filters that monitor the brightness of suitable calibration stars. The imagers will have a field-of-view and aperture large enough to enable automatic pointing and tracking of a catalog of stars (i.e. robotic operation). Each narrowband filter will be selected to monitor a different aspect of the atmospheric transmission. We show below that a system based on images through several narrow-band filters will be sufficient to constrain a model that will be precise to better than 10% across the DES filter range. We assume that our goal will be to determine the relative transmission across the DES wavelength range; observations with DECam itself will be used to determine exposure by- exposure grey terms, for example, and that standard calibration procedures for multi-color extinction terms and color-corrections will be in place. Below we describe a prototype system, show the results of modeling to predict performance, and present preliminary results.

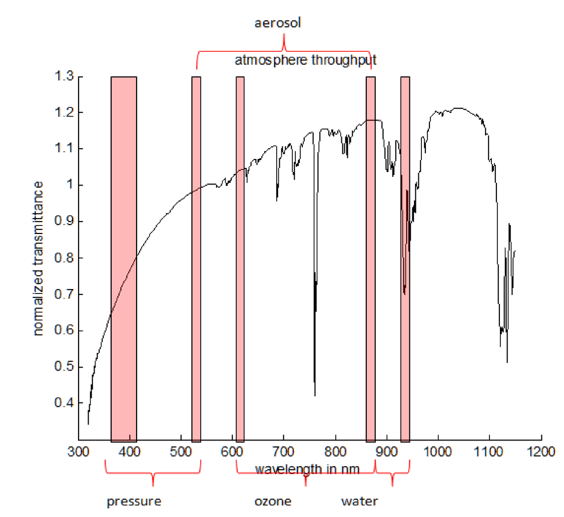
Prototype System Setup

The figure below shows the prototype setup. There are two 8-inch telescopes: one with a fiber at the focal plane that feeds an Ocean Optics JAZ spectrograph, another with an SBIG ST-402ME CCD at the focal plane. The imaging telescope has a cap on the front that holds five filters, each coupled to a "wedge prism" that diverts a ~40mm part of the telescope pupil by ~2 arcminutes. This creates five individual images on the CCD of the same star. The two telescopes are co-mounted on a tripod and are aligned to look at the same star, so we simultaneously obtain a spectrum and five narrow-band images of a star.

We have selected five filters that span 390nm to 940nm as the prototype monitoring system. They are chosen to monitor the water, aerosol, Rayleigh scattering, and ozone components of the atmosphere. These filters had central wavelengths and bandpasses as shown in the table and the figure below on a fiducial atmospheric throughput model.

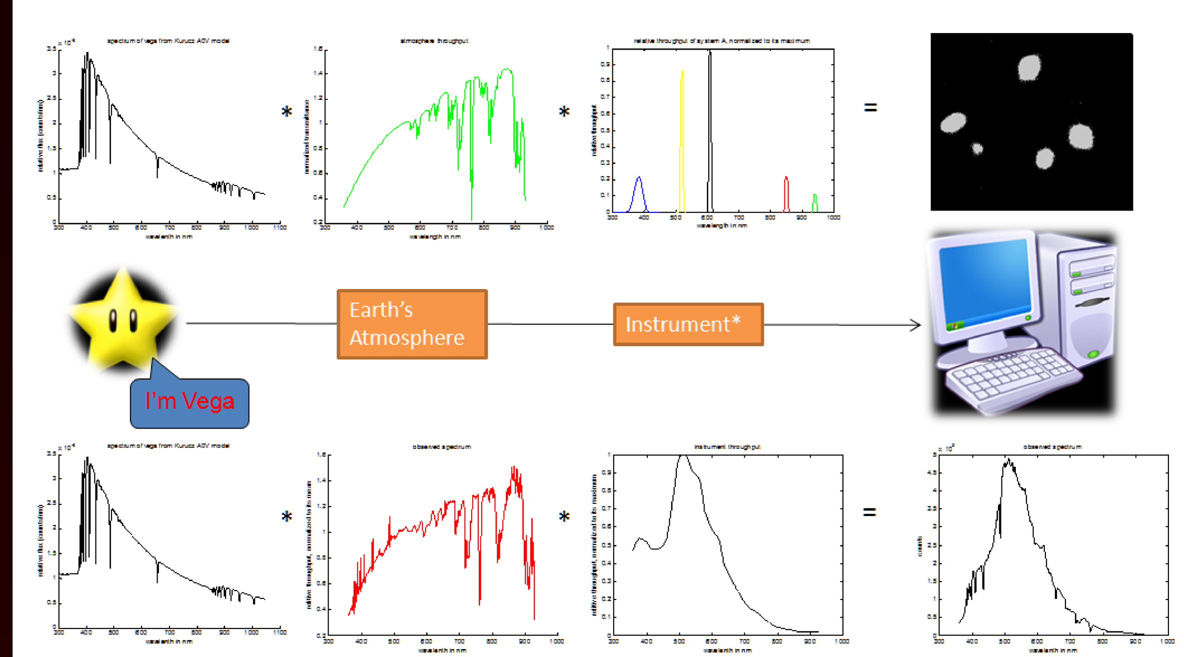
Filter central wavelength	Filter FWHM
390 nm	~50 nm
520 nm	10 nm
610 nm	10 nm
852 nm	10 nm
940 nm	10 nm

Table 1: Central wavelengths and bandpasses of the prototype filters.

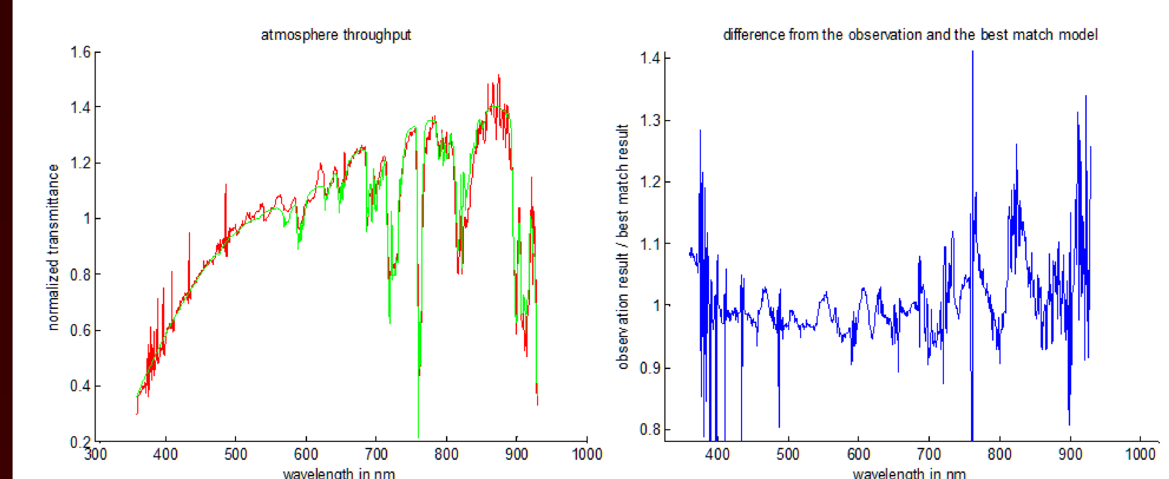


Preliminary Result

We have made photometric and spectroscopic measurements simultaneously with the prototype system described above at both TAMU observatory and McDonald observatory and we take one measurement as an example hereafter. We used Vega (A0V) as our standard star since the absolute flux of Vega is reasonably well determined. However, we can observe any star if we know the spectrum and it has adequate UV and NIR flux.



As shown in the figure above, the top row is the measurement from the narrow-band imager; the bottom row is from the spectrometer. The four columns represent, in order, the stellar spectrum of Vega, the derived atmospheric throughput, the instrument response function, and the observed image and spectrum from the prototype system. We obtained the red curve from the spectroscopic measurement, which is the observed spectrum after removal of both the instrumental response function and Vega spectrum. The green curve is from a model selected to represent the colors measured by the narrow-band imaging system. The model has residuals compared to the spectroscopically-derived atmospheric throughput of less than ~10% at all wavelengths, as shown in the figure below. Smoothed over a wide bandpass, these relatively small deviations produce very small photometric precision errors.



Conclusion

We have used a relatively simple narrowband imaging system that should allow derivation of an atmospheric transmission model that could improve photometric precision to less than 1%. We have tested a prototype of the system and confirmed, using simultaneous spectroscopic measurements, that the principle works adequately well.

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