Monitoring the atmospheric throughput at Cerro Tololo Inter-American Observatory with aTmCam

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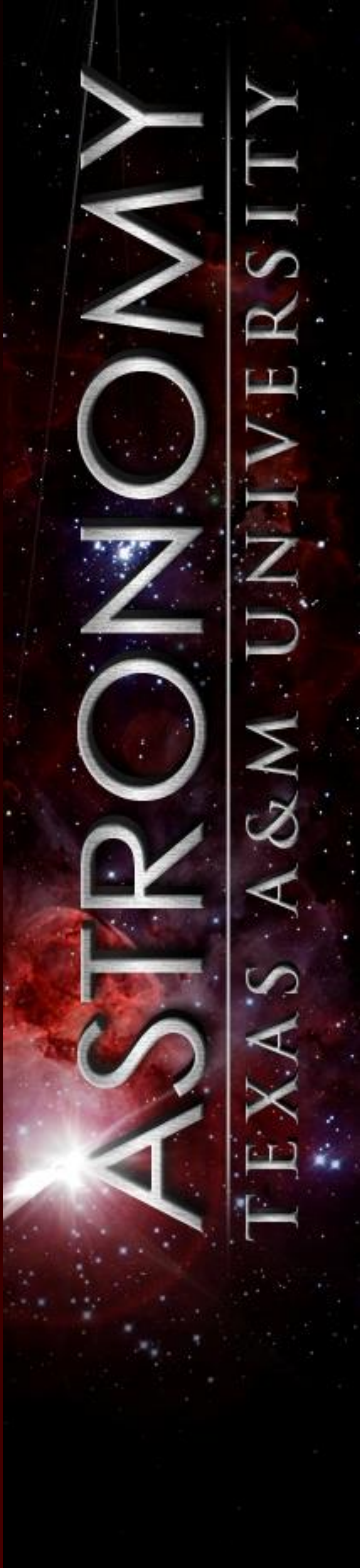

Abstract

We have built a prototype of the Atmospheric Transmission Monitoring Camera (aTmCam), which consists of four telescopes and detectors each with a narrow-band filter that monitors the brightness of suitable standard stars. Each narrowband filter is selected to monitor a different wavelength region of the atmospheric transmission, including regions dominated by the precipitable water vapor and aerosol optical depth. The colors of the stars are measured by this multi narrow-band imager system simultaneously. The measured colors, a model of the observed star, and the measured throughput of the system can be used to derive the atmospheric transmission of a site on sub-minute time scales. We deployed the system to the Cerro Tololo Inter-American Observatory (CTIO) and executed two one-month-long observing campaigns in Oct-Nov 2012 and Sept-Oct 2013. We have determined the time and angular scales of variations in the atmospheric transmission above CTIO during these observing runs. We also compared our results with those from a GPS Water Vapor Monitoring System and find general agreement. The information for the atmospheric transmission can be used to improve photometric precision of large imaging surveys such as the Dark Energy Survey and the Large Synoptic Survey Telescope.

Introduction

The Dark Energy Survey (DES) has a photometric precision goal of 0.01 mag for a wide variety of targets (SN, galaxies, stars, etc.) to achieve its science objectives. Although traditional photometric observing techniques can produce photometric precision at these levels, assembling a large survey with such precision is very challenging. Due to the variability in atmospheric throughput, which changes on timescales of less than a night, unmonitored changes in the atmospheric throughput are the largest source of photometric precision error. Therefore, real time atmospheric transmission monitoring is required to substantially improve photometric precision.

Atmospheric transmission in the optical wavelengths (~300nm-1100nm) is mainly determined by 3 processes: Rayleigh scattering from molecules, aerosol and dust scattering from small particles, and molecular absorption (principally by O_2, O_3, and H_2O). There have been relatively few systematic, long-term studies of the detailed atmospheric transmission at any major astronomical observatory. Here, we describe a simple system that rapidly monitors the transmission of the atmosphere. We have built a prototype version of such system and used it at CTIO for ~40 nights of observing in 2012 and 2013. We have determined (over these particular nights) the angular and temporal scale of meaningful changes in the atmosphere.

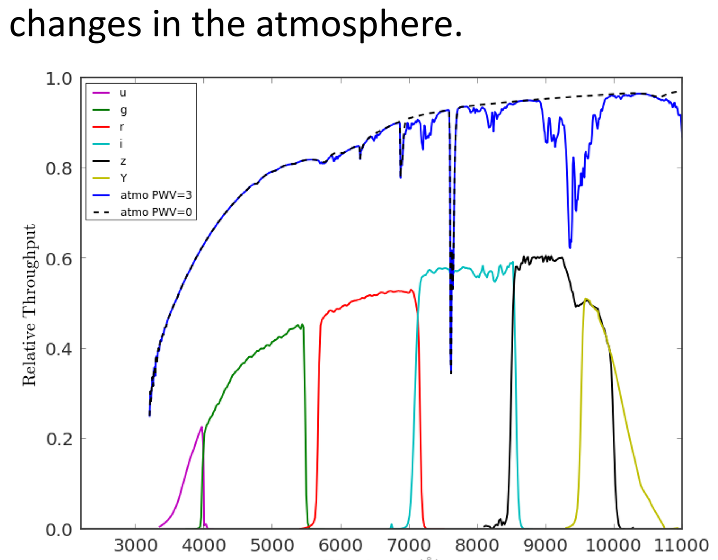

Figure 1. A model of fiducial atmospheric transmission at CTIO is shown, with altitude 2.24km, barometric pressure P = 780mbar, aerosol optical depth tau=0.05 at 550nm, and precipitable water vapor PWV=3mm at airmass X=1.3, generated by libRadTran[a]. Another PWV-free atmospheric model is plotted as contrast to see where the absorptions from H_2O. For reference, the system response function of ugrizY bandpasses currently installed in DECam are shown.

[a] http://www.libradtran.org/

Description of the System

We have built and deployed a prototype of the atmospheric transmission monitoring system (aTmCam) based on simultaneous measurement of the brightness of a star (with well-understood SED) through narrow-band filters using a well-calibrated system. The aTmCam currently consists of four Celestron f/10 8-inch telescopes mounted on two Celestron CGEM mounts. Each telescope is fitted with an SBIG ST-8300M CCD and a filter centered near a part of the spectrum sensitive to a particular component of the atmospheric throughput, with a different filter in each telescope.

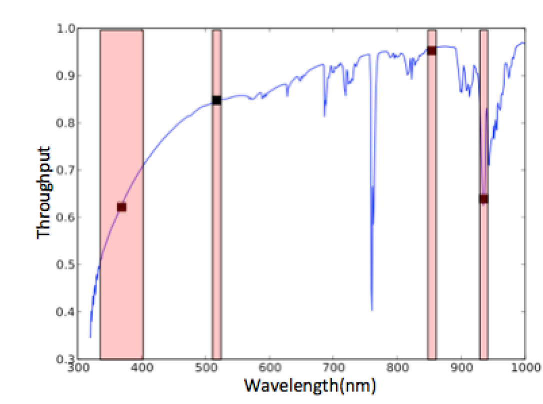

Figure 2a. Photograph of one of the prototype systems being installed at CTIO in November 2012. The prototype used a tent with a removable top as a temporary shelter during the observing campaign. Figure 2b. The central wavelengths of the four filters we used in this study overplotted on a fiducial atmospheric model.

Simultaneous observations of the brightness of a star with each telescope allow determination of "colors" that measure the atmospheric transmission.

We generated a grid of models of the Earth's atmospheric transmission with different column densities of precipitable water vapor (PWV), aerosol optical depth τ (AOD) at 550nm, and barometric pressure using libRadTran. We calculated the synthetic color with those models, the expected throughput of the system, and the SED of an A0V star. Then a "best fit" model was determined by minimizing χ^2 between the model and data values. A unique PWV and AOD is taken from the best fit model.

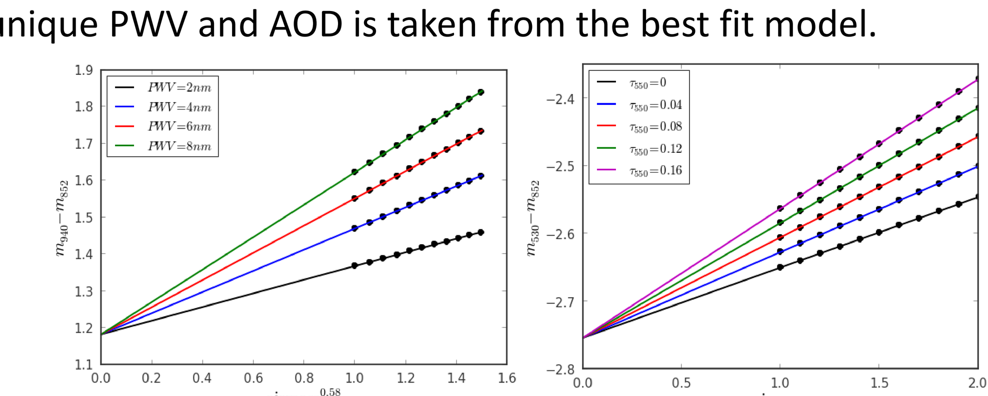

Figure 3. Synthetic color indices vs. airmass at various PWV (left) and AOD (right).

Clouds are Grey

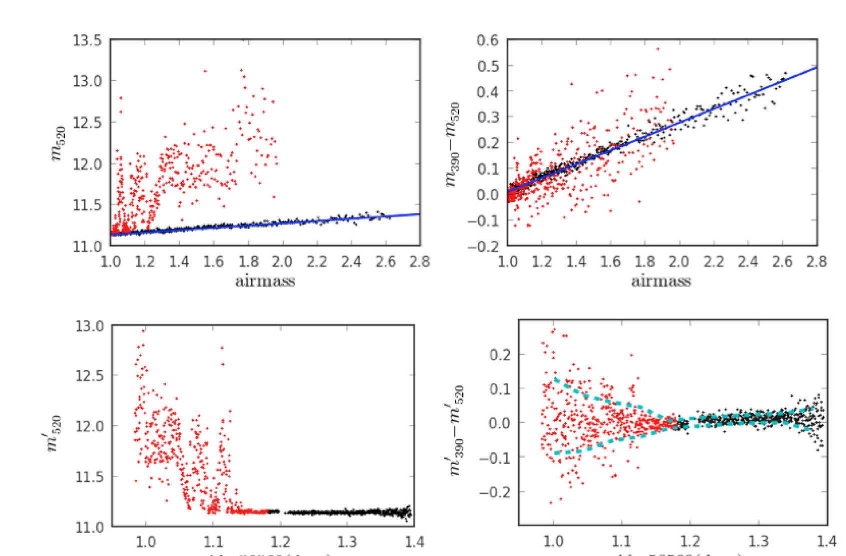

Figure 4. On the night of Sep 25, 2013, the sky was partly cloudy for the first half of the night and later cleared. We spent the entire night monitoring one star as it crossed the sky. Red dots show the measurements from the first half the night and black dots are from the second half of the night. We derived an airmass extinction term of each filter using the data from the second half of the night as show in the top left panel. The bottom left panel shows the airmass extinction-corrected magnitude in filter 520nm, m'_{520}, as a function of time. At the beginning of the night, the clouds caused as much as 1.5 mag of extinction. We also calculated the color index after the extinction correction, m'_{380}-m'_{520}, as a function of time, shown in the bottom right panel. m'_{380}-m'_{520} is constant on average over time, suggesting that clouds are grey. The cyan line shows the 1-σ scatter from the mean.

Results

For each measurement obtained during both observing runs, we derive a best-fit aerosol optical depth (AOD) and precipitable water vapor (PWV). We show five nights of the results from the 2013 observing run in Figure 5. It can be seen that the PWV (left column) can change by a few millimeters over one night and mostly decreases over time on any given night. The scatter is mainly the statistical error due to the photon noise. The 1-σ error is ~0.6mm in PWV and ~0.03 in AOD.

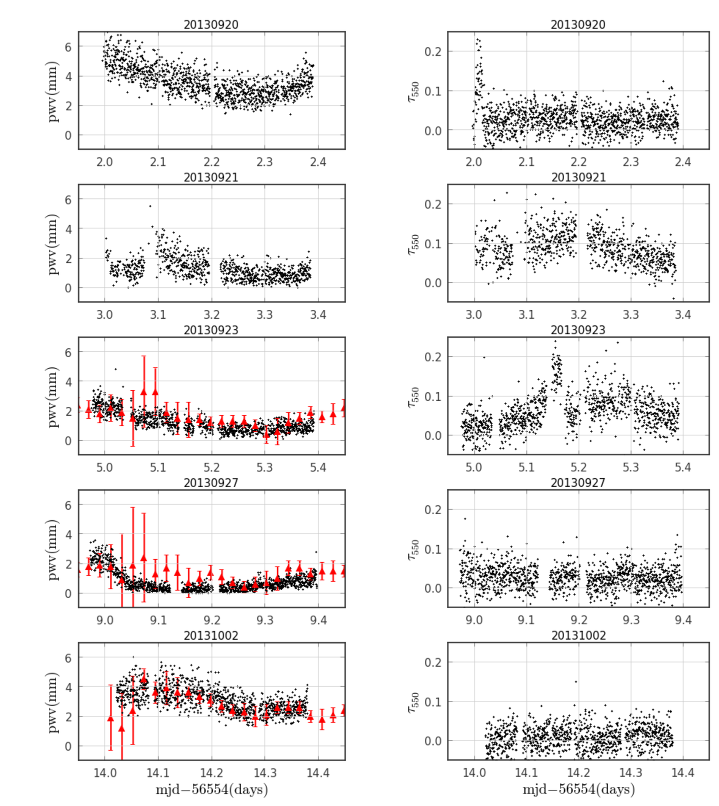

Figure 5: An example of 5 nights of the results from 2013 observing run. The left (right) column shows the PWV (AOD) as a function of time in MJD. The number on the top of each panel is the date of the night that the observation started, in the format of YYYYMMDD. Overplotted red triangles are the PWV measured by a GPS Water Vapor Monitoring System.

We probe the time and angular scales of the variation of the precipitable water vapor. we calculated the change of the PWV, ΔPWV, at different time interval, Δt, and at different separation angle, θ. Our analysis shows that the PWV decreases by about 1mm over ~9 hours on average. We observe no significant PWV variation up to ~90° across the sky, which indicates that the PWV was angularly homogeneous during our observing run.

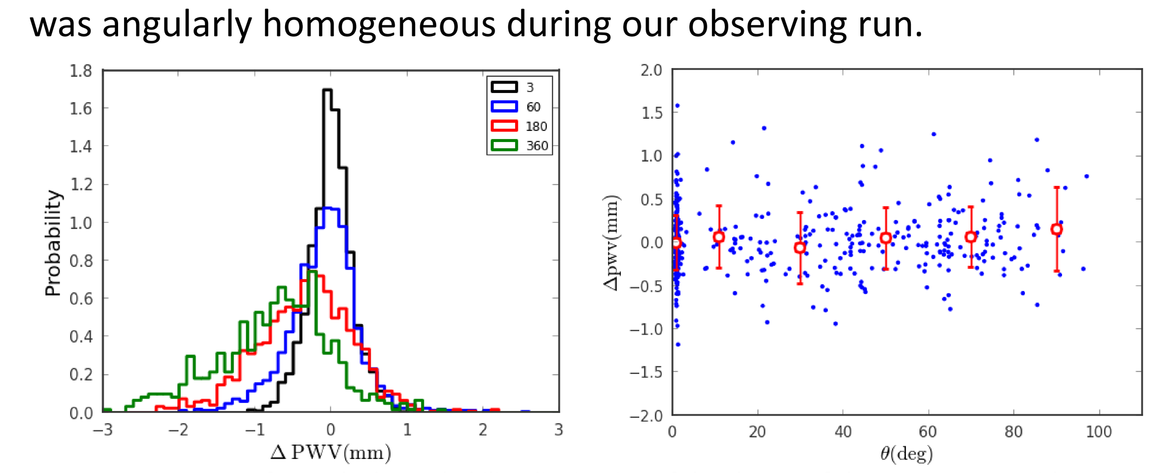

Figure 6. Left panel: The probability distribution of the change of the PWV, ΔPWV, with a time scale of 3 minutes, 1 hour, 3 hours, and 6 hours. Right panel: ΔPWV as a function of the separation angle ϑ of two consecutive measurements.

Conclusion

We present results from a simple system that has been used to monitor the transmission of the atmosphere above the CTIO site. This system, aTmCam, consists of four telescopes and detectors each with a narrow-band filter that monitors the brightness of suitable standard stars simultaneously. We deployed this system to CTIO for ~40 nights of observing in 2012 and 2013 and we have derived the precipitable water vapor and aerosol optical depth from the measured color of the star. We see that the precipitable water vapor can change over one night (typically decreasing), while aerosol optical depths are generally quite stable. We probe the time and angular scales of the variation of the precipitable water vapor. During our observing runs, we conclude that we need to measure the PWV only once per hour if we require PWV estimates accurate to 1mm. We also observe no significant PWV variation over an angle of ~90° on the sky.

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HETDEX Illuminating the Darkness — Hobby-Eberly Telescope Dark Energy Experiment

LSST — Large Synoptic Survey Telescope

DARK ENERGY SURVEY

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