Calibration Tests at CTIO and the LSST AuxTel Observing Strategy

D. Burke

LSST DESC PC Telecon

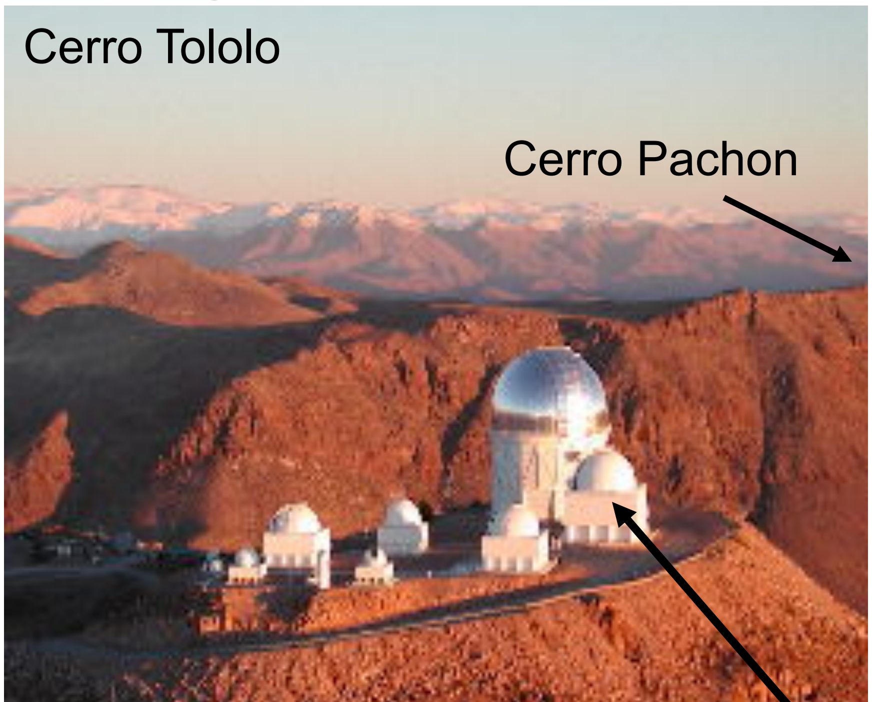
February 8, 2019

(Adapted from report at LSST AHM Tucson 2012)

Observing Campaign at CTIO Tololo

NOAO Observing Proposal *Standard proposal* Panel: *For office use.*
Date: October 2, 2006 Category: EGAL - Other

Characterizing Atmospheric Absorption for Precision Photometry



1.5m Spectrograph

Report on 3 three-night runs

2007 November

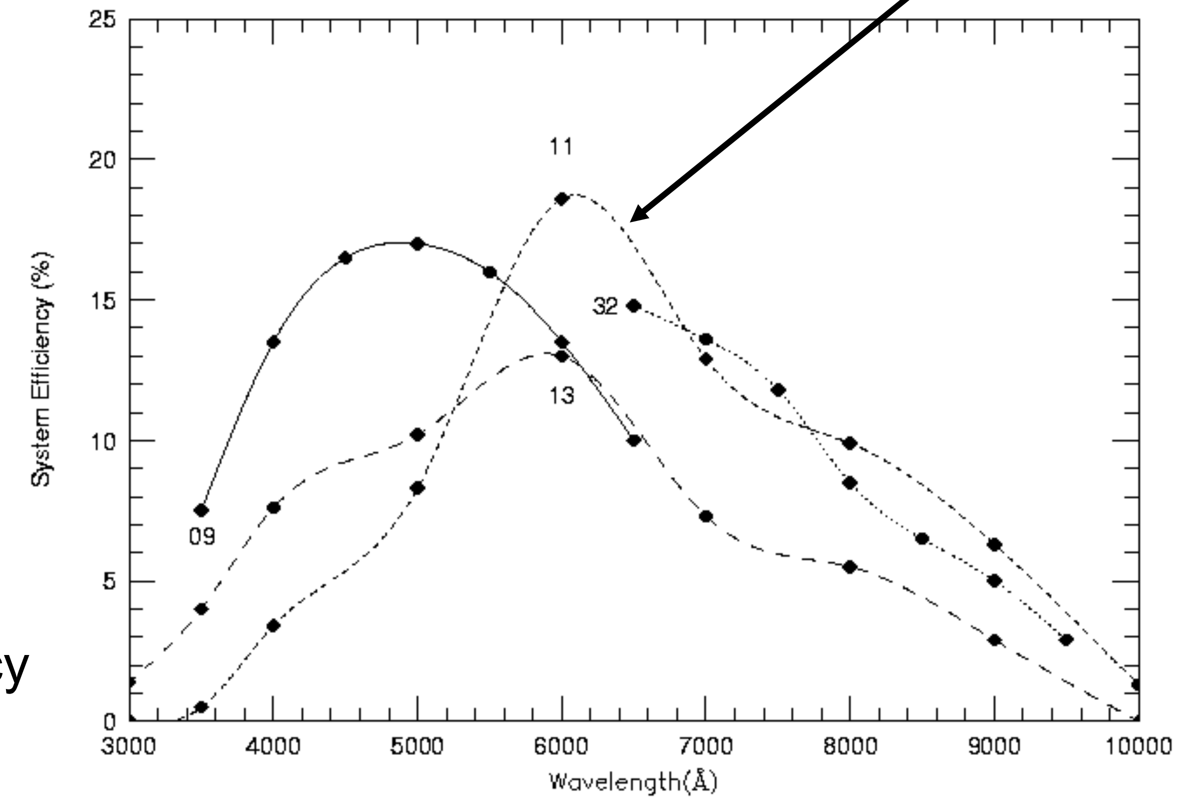
2008 April and July

Results published in 2010
(Burke, et al., 2010, ApJ. 720, 811)

Spectrograph Set-Up and Operation

Spectrograph operated in first order with low resolution grating (#11 at 8000Å blaze).

Figure 7: System efficiency curves for gratings 09, 11, 13 and 32



Resolution = 16.4 Å

R = λ / $\Delta\lambda$ = 400 (6500 Å)

Quartz and Ne lamps calibrations of efficiency and wavelength scale.

Slew and acquire calibrations and 2 spectra required ~ 10 minutes.

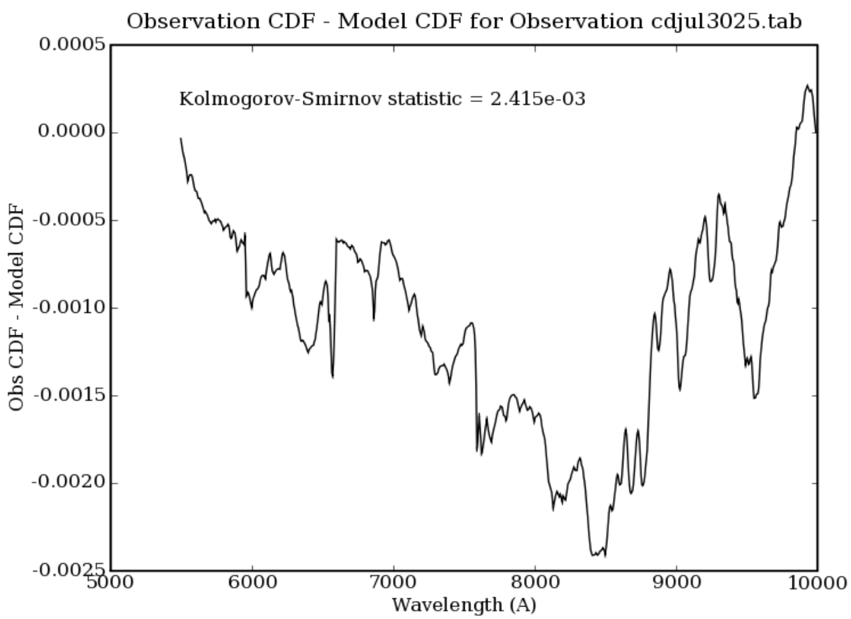
Target List
XX = Calibration of Slowly Varying Parameters

Star	Type	RA	DEC	Nov07	April08	July08
CD 34 241	11.2F	00 41 47	-33 39 08	X		
CD 35 534	10.0F	01 32 04	-34 29 15	XX		XX
HD 24954	9.9F	03 56 10	-41 35 42	X		
CD 277546	9.5F	10 35 08	-28 22 38		X	
HD 103441	9.4F	11 54 36	-54 43 57		X	
HD 113815	9.7F	13 06 21	-02 46 33		X	
CD 329927	10.4A	14 11 46	-33 03 14		XX	XX
HD 145330	9.9F	16 10 45	-10 32 18		X	
EG 274	11.0DA	16 23 34	-39 13 46		XX	XX
LTT 7379	10.2G	18 36 26	-44 18 37			X
HD 189910	9.6F	20 03 18	-25 08 45			X
HD 207474	9.6F	21 49 10	-02 02 24			X
LTT 9239	12.1G	22 52 41	-20 35 33	XX		XX
Feige 110	11.8DA	23 19 58	-05 09 56	X		
CD 761164	10.1A	23 26 55	-75 38 29			X

Parameter Fitting

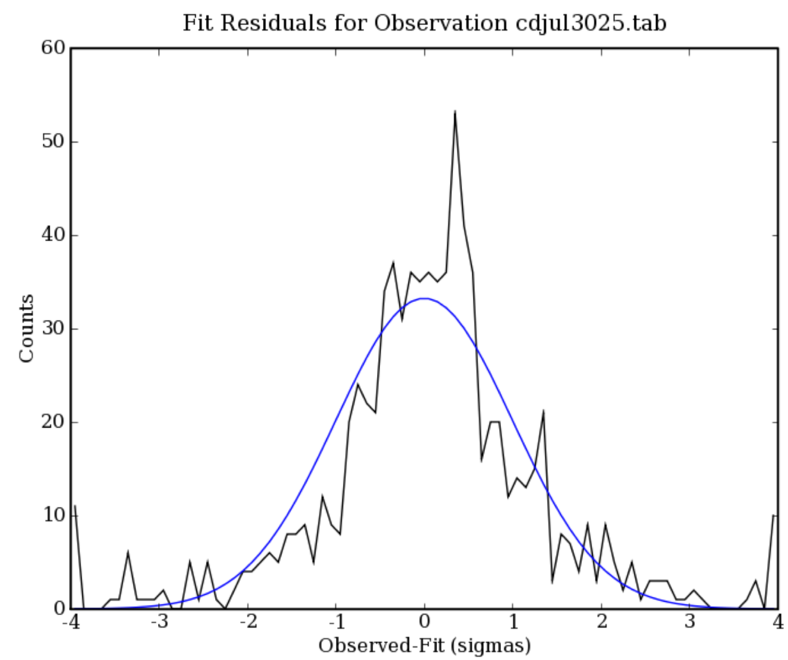
Kolmogorov-Smirnov statistic to fit slowly varying functions (4 stars) …

Instrument Calibration (nightly)
Target SEDs (once)
Rayleigh scattering (once)
Ozone (nightly)
Aerosols (nightly)

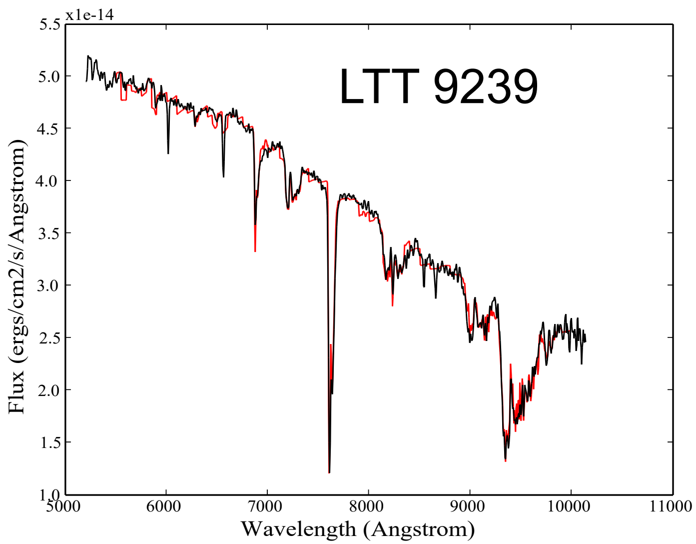


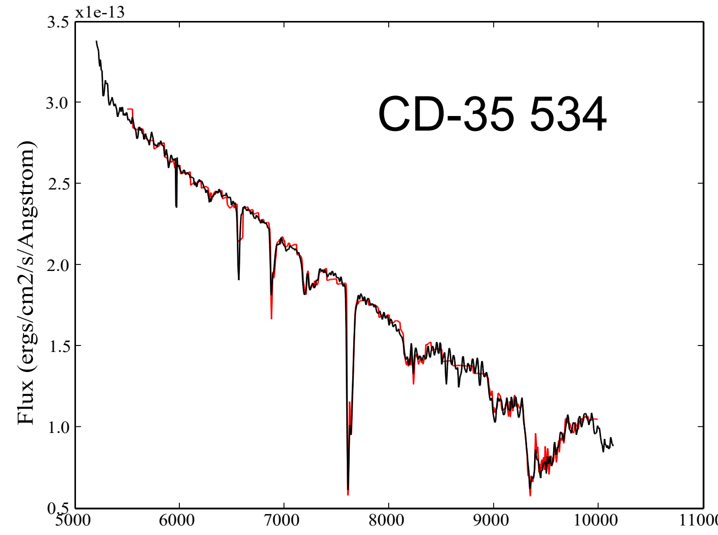
Chi-square used to fit water vapor and gray normalization to individual spectra … requires an error model.

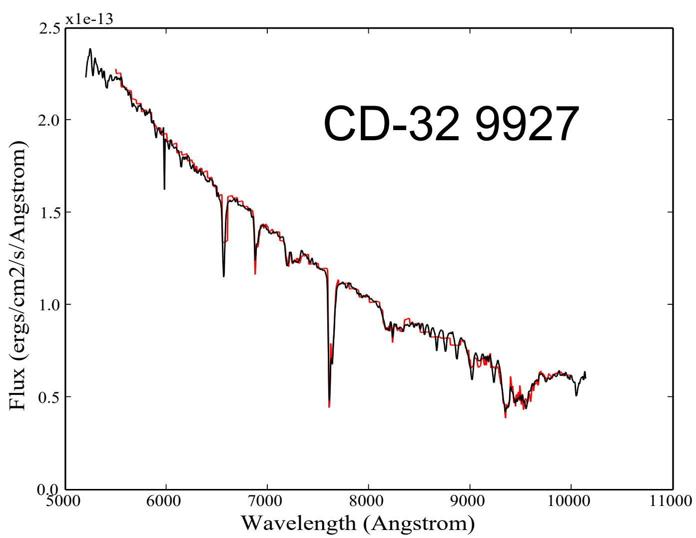
Fit "pull" with Gausian ($\sigma = 1$) overlay …

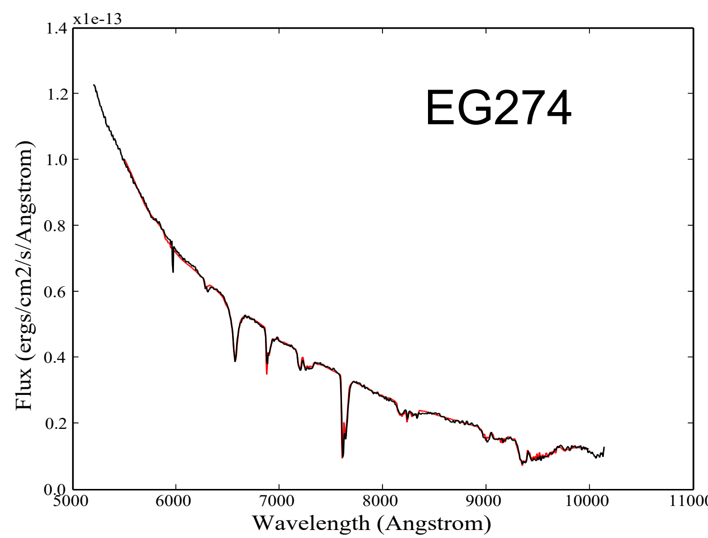


Examples
The Four Calibration Stars





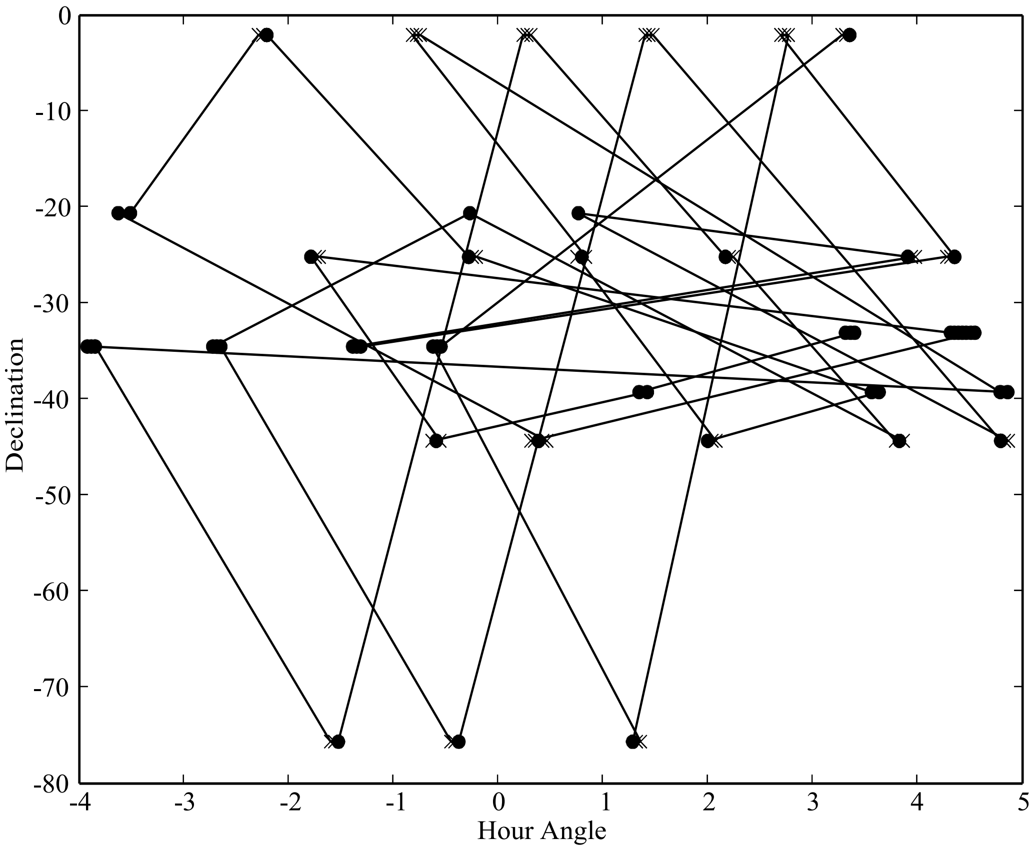




Observing Strategy
Getting the Most Out of Airmass

Large slews control the independent variable --- airmass!

Observing pattern one night in July 08 …



Fixed airmass (e.g. HA = -4 hrs → +4 hrs) samples spatial variation at fixed time.

Varied airmass (e.g. HA = -4 hrs → zenith → + 4hrs) is a powerful sequence.

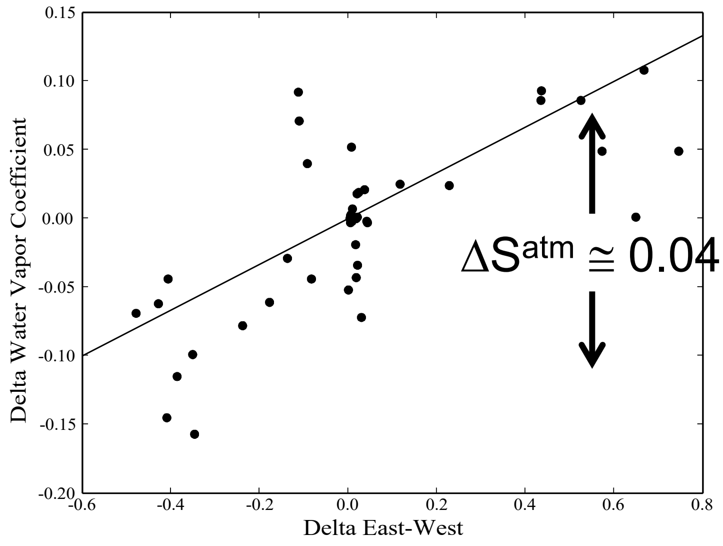
Spatial Variation in Water Vapor

Write water vapor coefficient as,

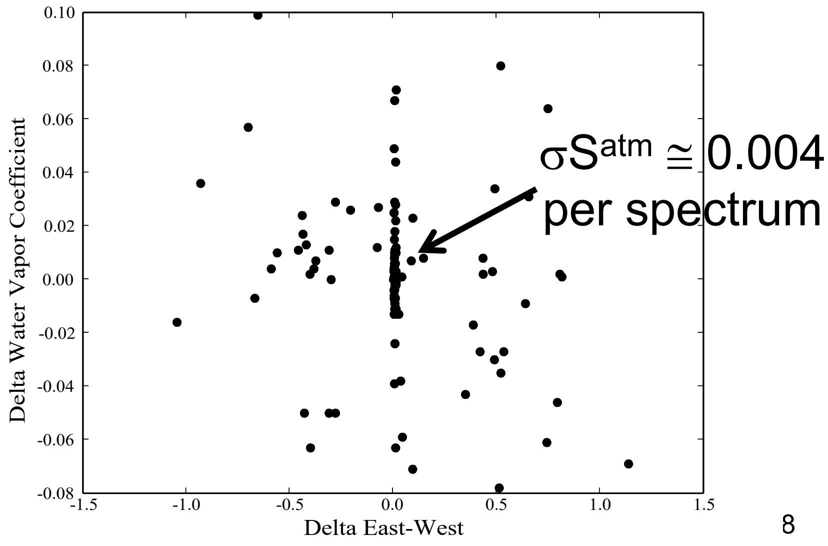
$$C_{\mathrm{H_2O}}(alt, az, t) = C_{\mathrm{H_2O}}(t) + \frac{dC_{\mathrm{H_2O}}}{d\mathrm{EW}}\Delta\mathrm{EW} + \frac{dC_{\mathrm{H_2O}}}{dNS}\Delta\mathrm{NS}$$

where $\mathrm{EW} = \cos(alt)\sin(az)$ and $\mathrm{NS} = \cos(alt)\cos(az)$

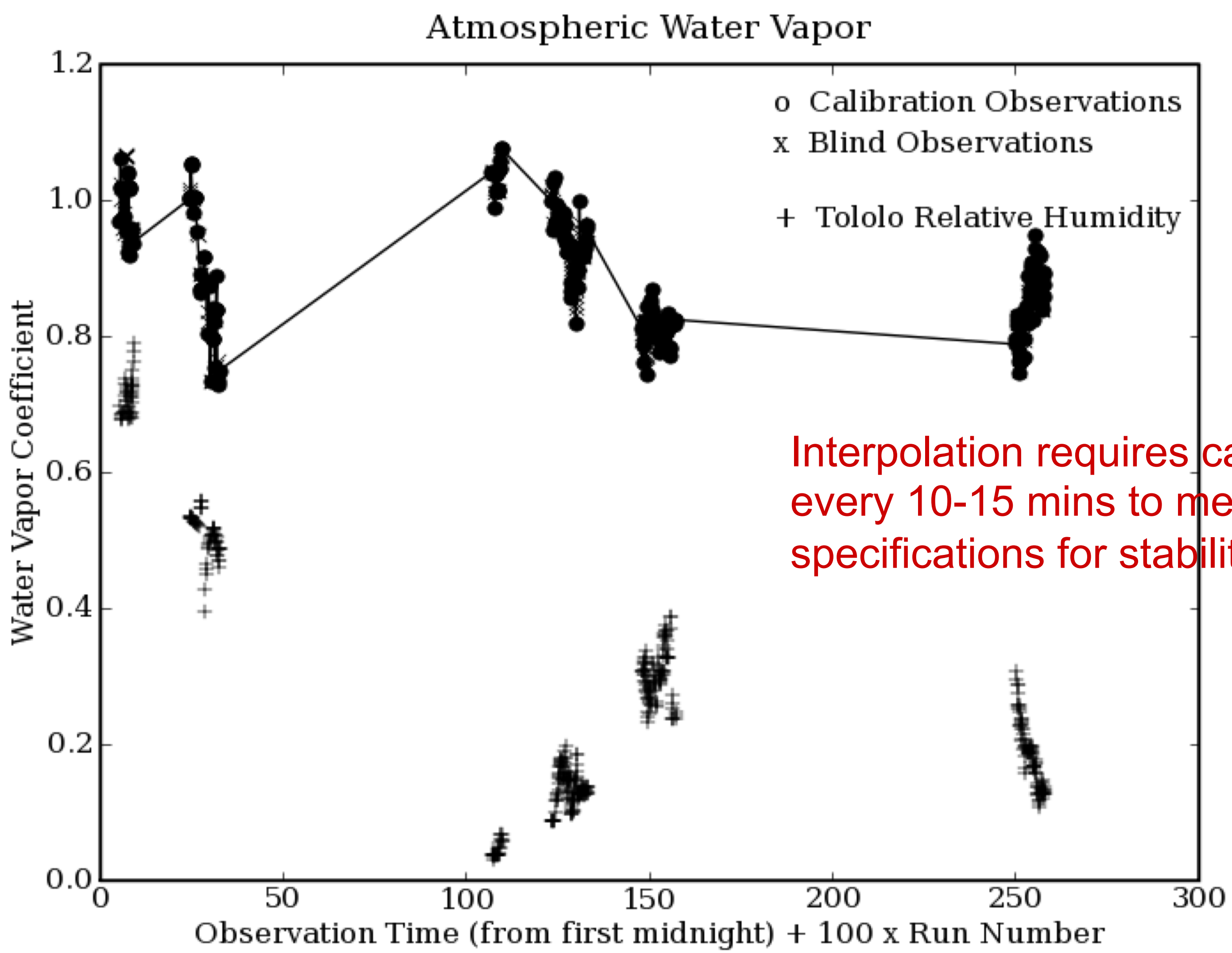
Nov 2007: $\Delta C_{H2O} / \Delta(\cos(alt)\sin(az)) = 0.166$



April 2008: No spatial variation

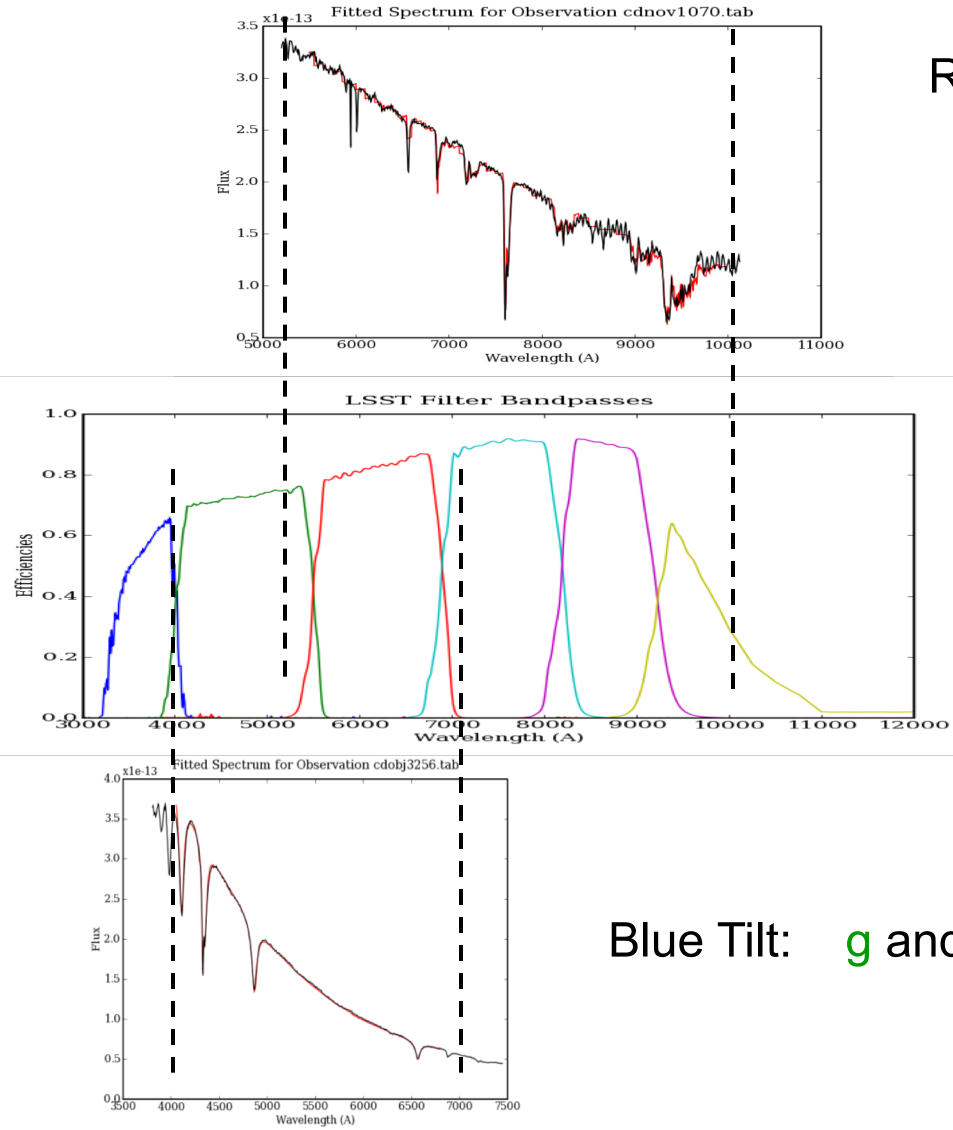


Interpolate C_{H2O} in Time



Interpolation requires calibration point every 10-15 mins to meet SRD specifications for stability in Y4 band.

LSST Synthetic Photometry



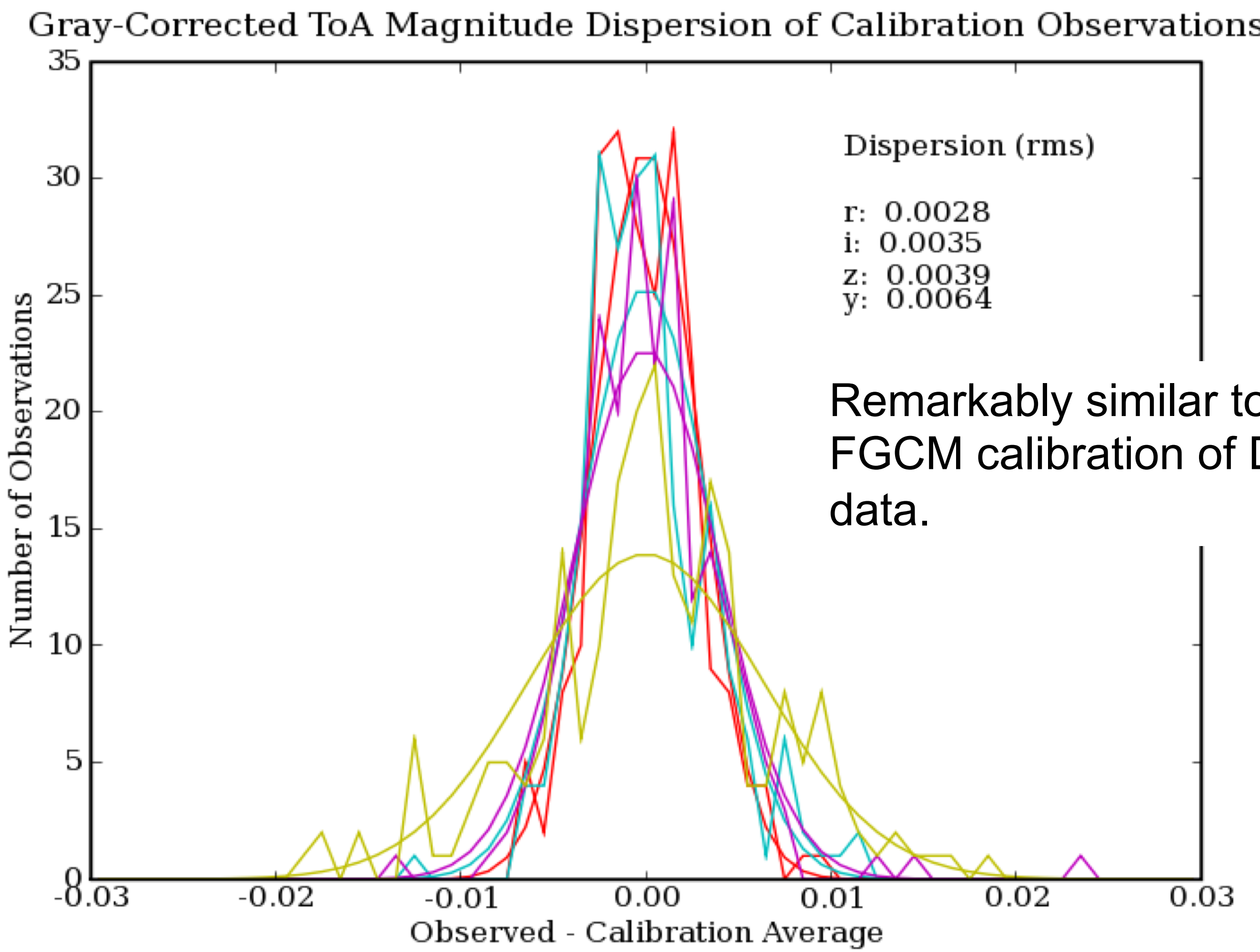
Red Tilt: r, i, z, and y4 bands

Note y4

No measurements in u-band.

Blue Tilt: g and r bands

Calibration Observations
(Full Data Set)



Remarkably similar to results of FGCM calibration of DES imaging data.

Summary of Key Conclusions

1. Do not need many stars. A grid spaced every 2 hours in ra and ±30° in dec will do. (Only 4 calibration stars were used to fit slowly varying parameters.)

2. Need to know well the signatures of atmospheric extinction – MODTRAN.

3. Do not need to know stellar spectra or instrument throughput exceptionally well – they don't depend on airmass (but can add noise to fit)!

4. But, in the presence of systematic errors in extinction model, fit results will be better if reasonable models for spectra and throughput are used.

5. Use an observing strategy that separates spatial and temporal variations – large slews in ra and dec at constant versus different airmass.

6. Best to not look too closely – narrow saturated lines are not easily analyzed.

Comments on AuxTel Observing Strategies

LSST Synchronous Approach (AuxTel spectrum for each LSST pointing)

- Directly determine atmospheric transmission $S^{atm}(t, \lambda)$ for each LSST image for which there is an AuxTel spectrum
- May not need intermediate separation into atmospheric components … just measure $S^{atm}(t, \lambda)$?
- Requires coordinated TelOps
- Requires sufficient speed and accuracy of AuxTel acquisition
- Limited range in airmass … little variation of the key independent variable
- Missing AuxTel data – interpolate or fall back to parallel FGCM-like calibration?

Comments on AuxTel Observing Strategies

Independent Sky Approach

- Determine atmospheric transmission $S^{atm}(HA, DEC, t, \lambda)$ independently of LSST
- Independent TelOps and analyses
- Large rapid variations in airmass of AuxTel observations … maximum sensitivity to atmospheric signatures
- Requires sufficient speed and accuracy of AuxTel measurements to track atmospheric changes and interpolate to LSST pointing
- FGCM calibration code incorporates LSST imaging and AuxTel spectra into common fit … naturally accommodates missing data

  (Note: no auxiliary data are used in DES calibrations.)