Report on Calibration Observing Tests at CTIO

DES Calibration Telecon

April 1, 2009

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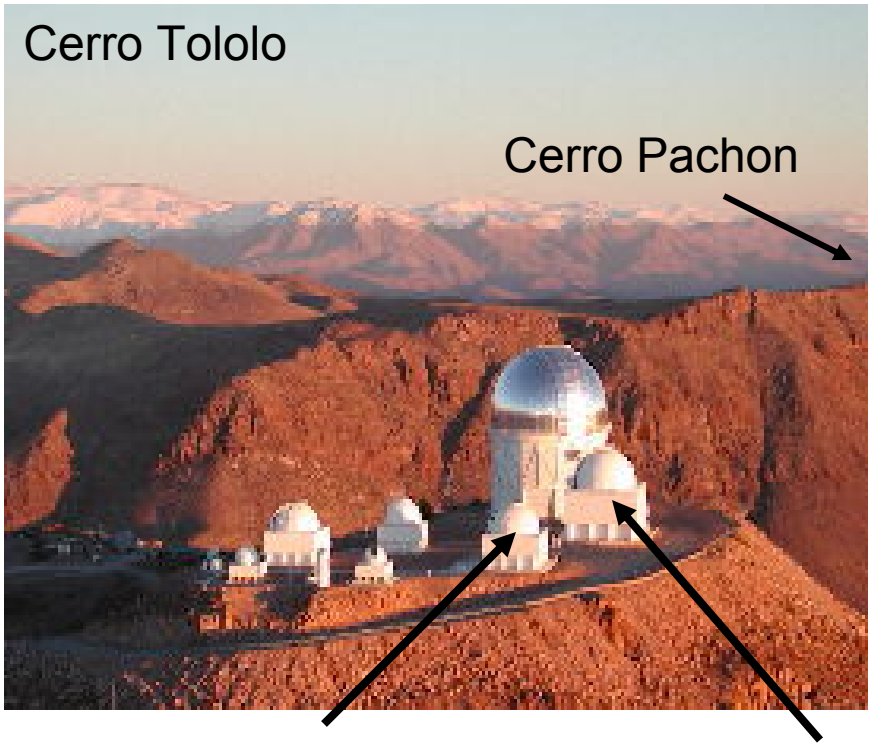
Observing Campaign at CTIO Tololo

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

Characterizing Atmospheric Absorption for Precision Photometry



2007 Studies with the 1.5m spectrograph

Establish extraction of atmospheric parameters from spectra

Done

2008 Simultaneous observing with the 1.5m spectrograph and 0.9m imager

Calibrate 0.9m stellar photometry

Done

2009 Simultaneous observing with the 1.5m spectrograph and the 4m mosiac

Calibrate 4m mosiac stellar and resolved object photometry

Scheduled (July 2009)

CTIO Observing Data Sets

Observing Run	Configuration	Spectral Wavelengths and Imaging Bands
April 24, 2007 (1 night)	1.5m RCSPEC	4000-7000Å (gr)
Nov 2-3, 2007 (2 nights)	1.5m RCSPEC	5000-10000Å (rizY4)
April 24-26, 2008 (3 nights)	1.5m RCSPEC 0.9m CFIM	5000-10000Å (rizY4) griz
July 23, 2008 (1 night)	1.5m RCSPEC 0.9m CFIM	5000-10000Å (rizY4) griz

Scheduled for 3 nights in each of these runs.
Took data about 60% of the scheduled time.

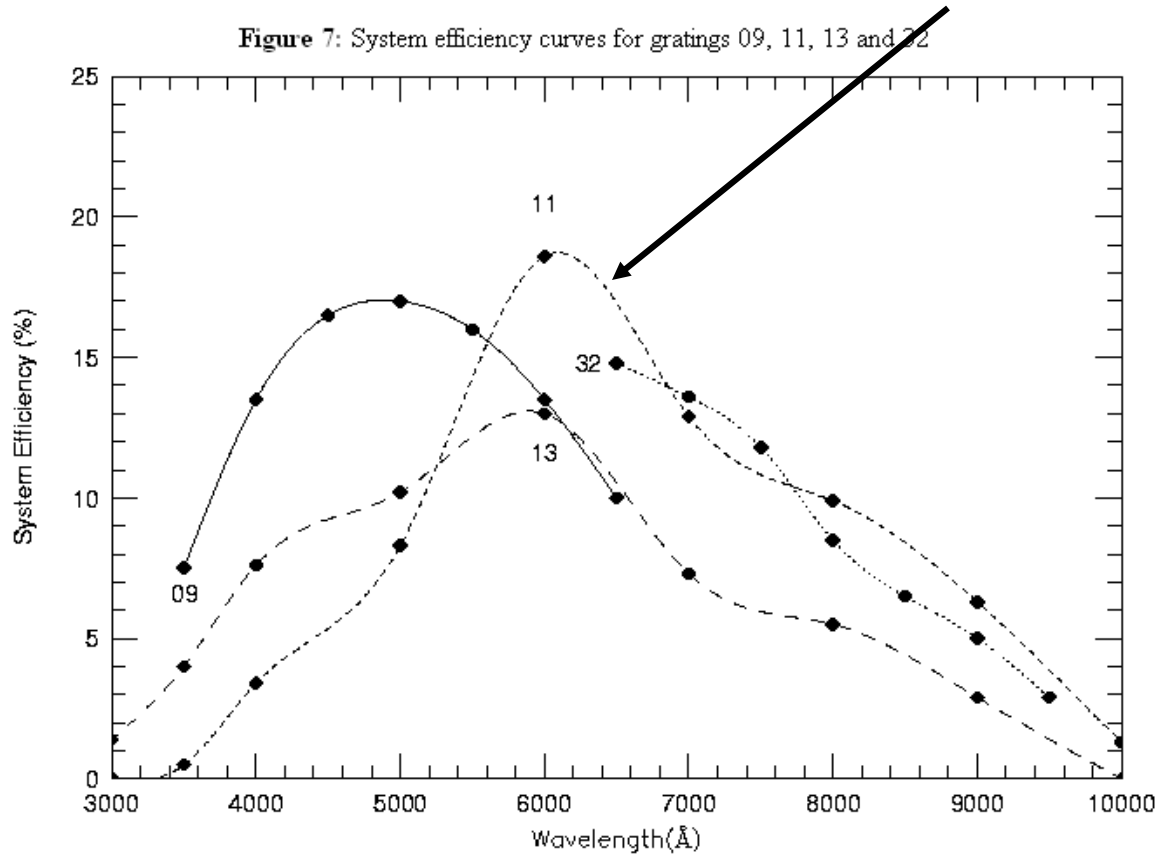
Spectrograph Set-Up and Data Reduction

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

Resolution = 16.4 Å

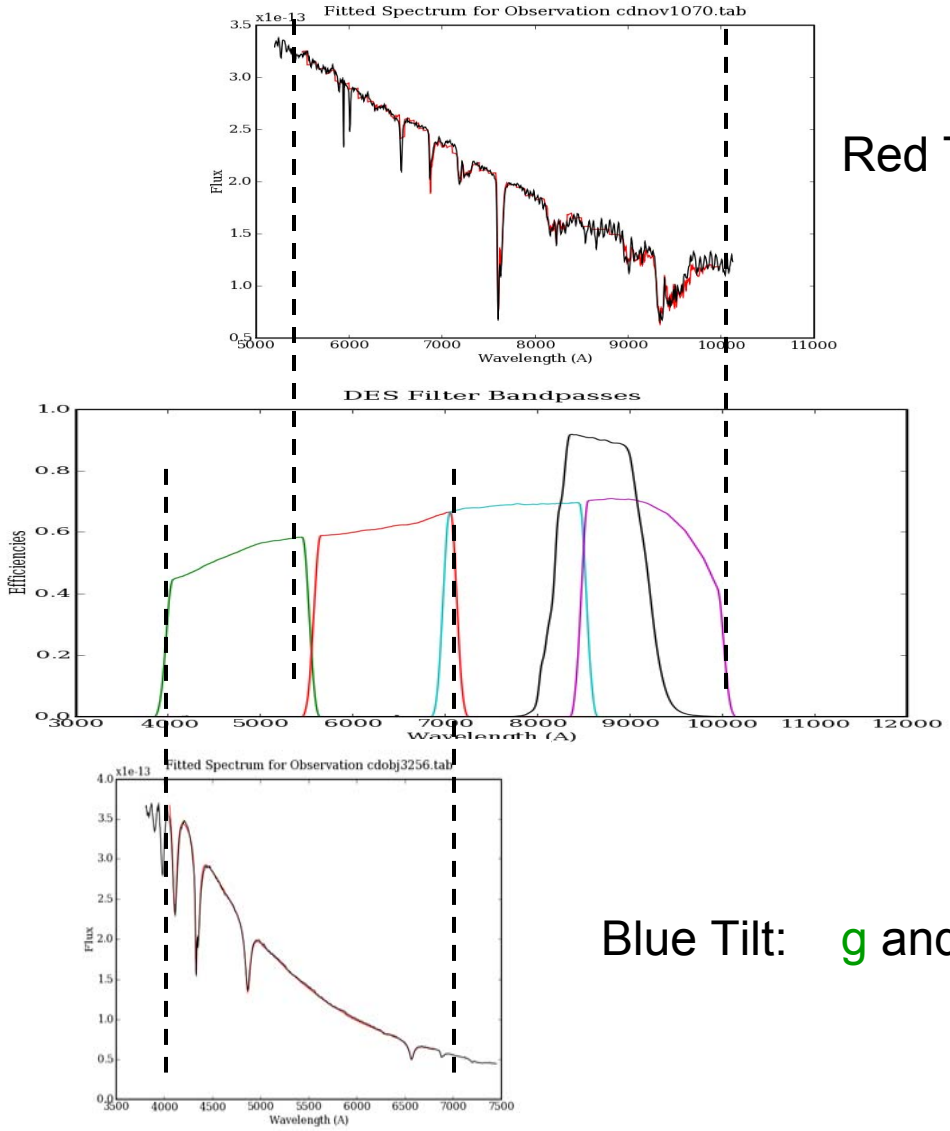
$R = \lambda / \Delta\lambda = 400$
(6500 Å)

Quartz and Ne lamps calibration of efficiency and wavelength scale.



IRAF 2D → 1D reductions (Stephane Blondin); instrument efficiency from spectro-photometric standards taken in the data sets.

DES Synthetic Photometry



Red Tilt: DES r, i, z and LSST-z bands.

Blue Tilt: g and r bands.

Calibration and “Blind” Samples

Calibration Stars – Small set of stars (4) used for calibration fits

- Each observed during at least two runs … constrain instrument calibration and compare color zero points.

Blind Test Stars – Separate set of stars used to verify calibration

- Data only “opened” after full analysis of Calibration Stars
- Fitted for spectral parameters
- Fitted for gray and H2O coefficients to support analysis

Target Lists (Calibration Stars = XX)

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

Calibration Fitting Procedure

Iteratively fit calibration observations:

1. Instrument Calibration. A single smooth function for each night

2. Target SEDs. One for each target star – fit Teff and log(g)

   Kurucz models for target A and F stars

   Blackbody with Lorentzian Balmer lines for O stars and WDs

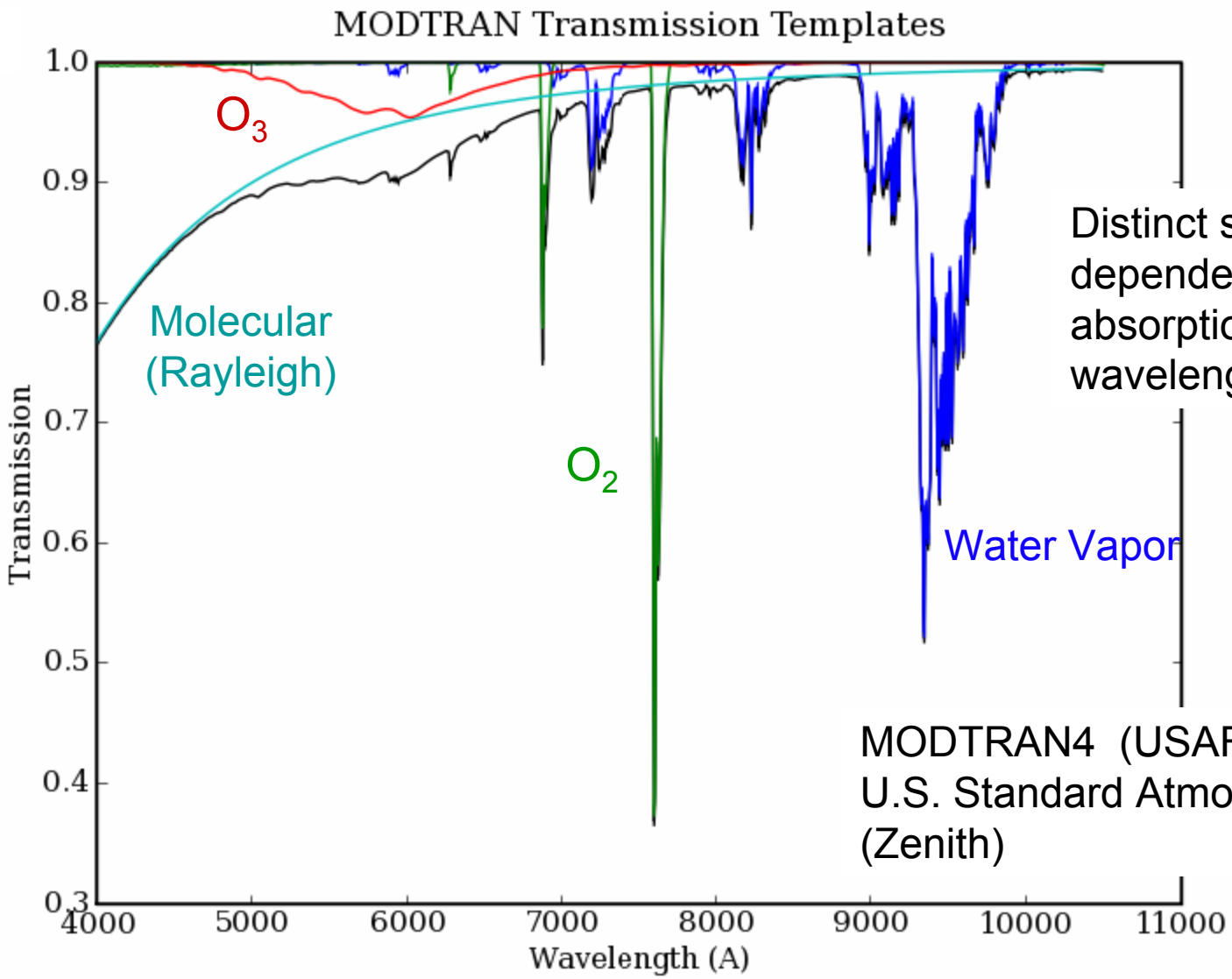
3. Atmospheric transmission:

MODTRAN templates contain all airmass and wavelength dependences.

$$S_b^{atm}(az,el,t,\lambda) = C_{gray} \times e^{(-z(alt,az)\cdot\tau_{aerosol}(alt,az,t))} \times$$
$$\times (1.0 - C_{BP} \times \text{Rayleigh scattering}(z(alt,az);\lambda)) \times$$
$$\times (1.0 - \sqrt{C_{BP}} \times \text{molecular absorption}(z(alt,az);\lambda)) \times$$
$$\times (1.0 - C_{ozone} \times \text{ozone absorption}(z(alt,az);\lambda)) \times$$
$$\times (1.0 - C_{H2O}(t) \times \text{water vapor absorption}(z(alt,az);\lambda))$$

Coefficients reflect vertical column heights when observations are made.

Atmospheric Signatures



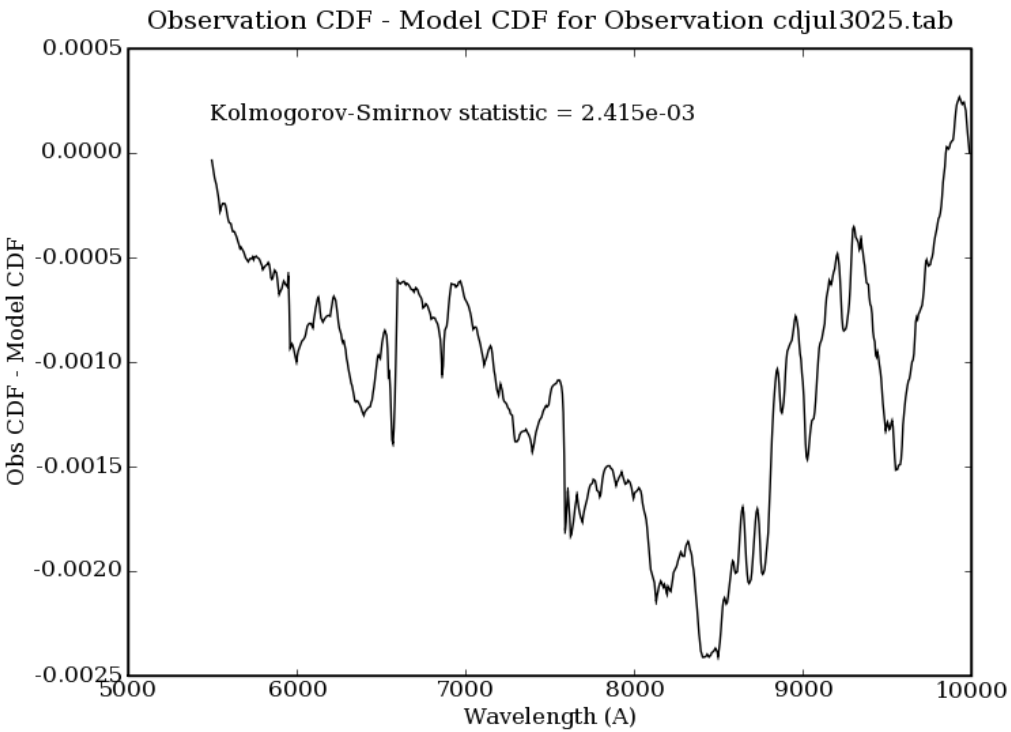
Distinct signatures from dependence of absorption on wavelength and airmass.

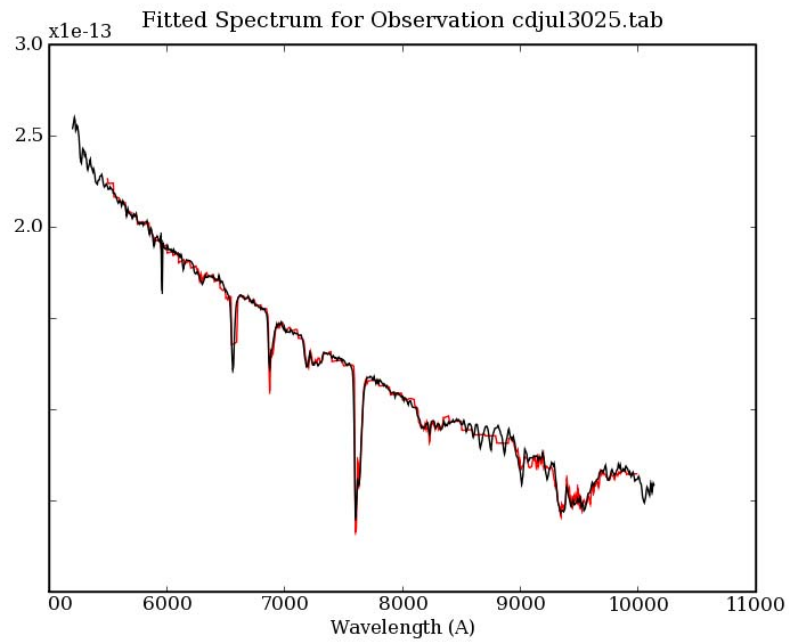
MODTRAN4 (USAF)
U.S. Standard Atmosphere (1976)
(Zenith)

Parameter Fitting – Slowly Varying

Kolmogorov-Smirnov statistic used to fit slowly varying functions …

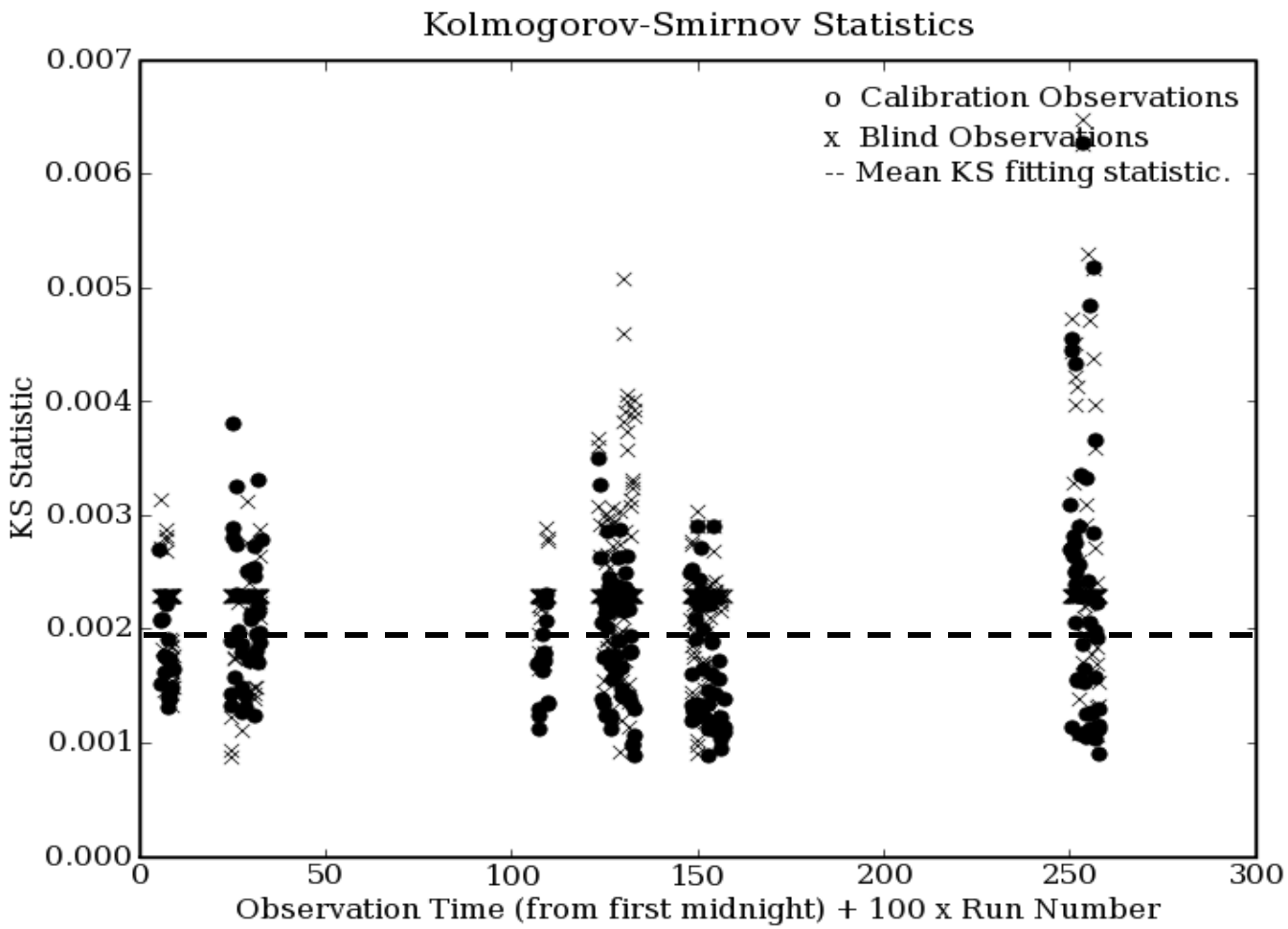
- Instrument Calibration (nightly)
- Target SEDs (once)
- Rayleigh scattering (once)
- Ozone (nightly)
- Aerosols (nightly)





Slowly Varying Fit Statistics

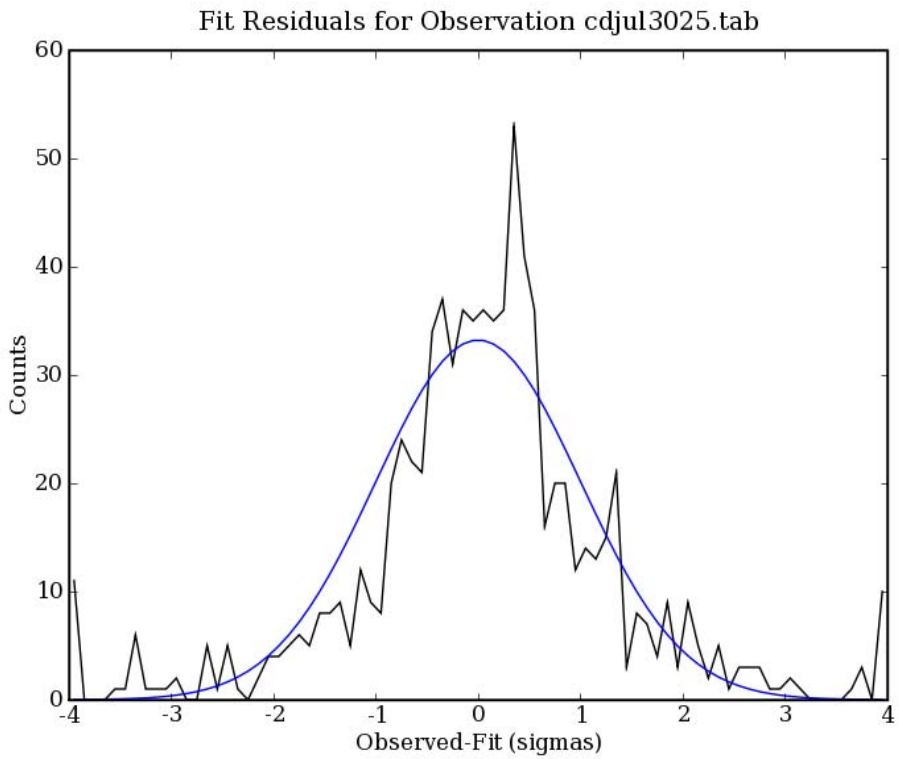
Minimize mean of KS statistic over observations being fitted.

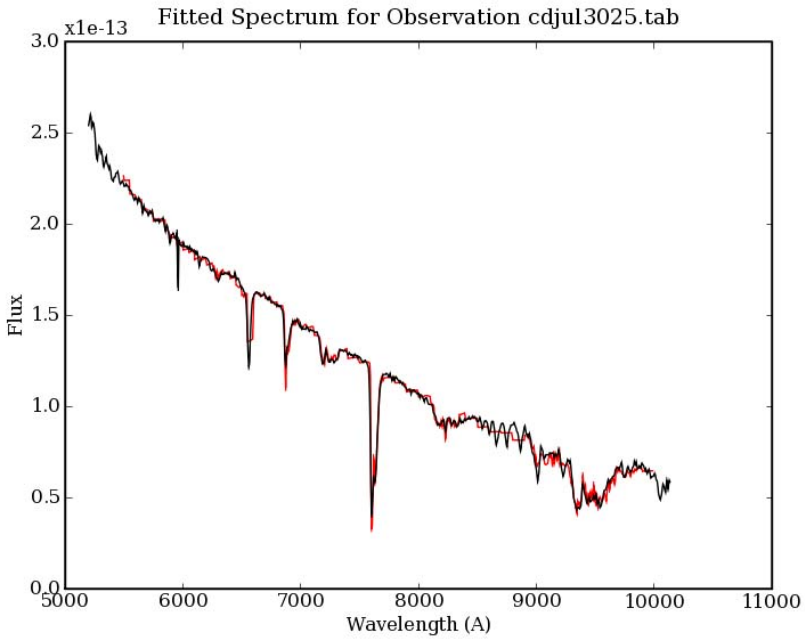


Parameter Fitting – Rapidly Varying

Chi-square used to fit water vapor and gray normalization to individual spectra

Requires an error model …





Nightly Atmospheric Parameters
Ozone and Aerosols

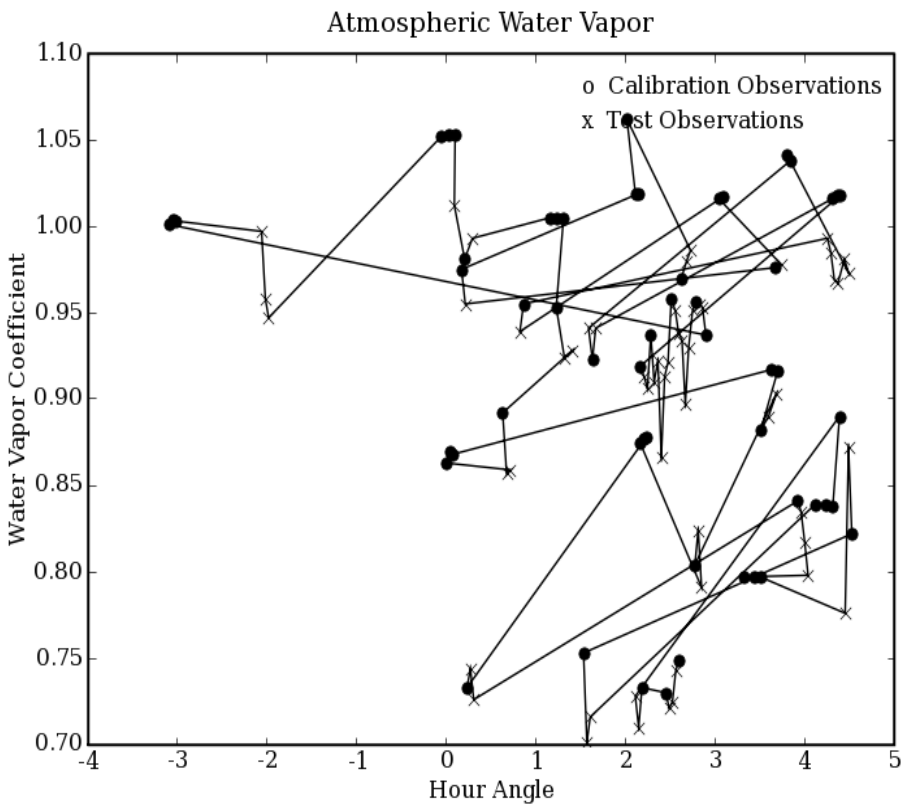
Aerosol Optical Depth

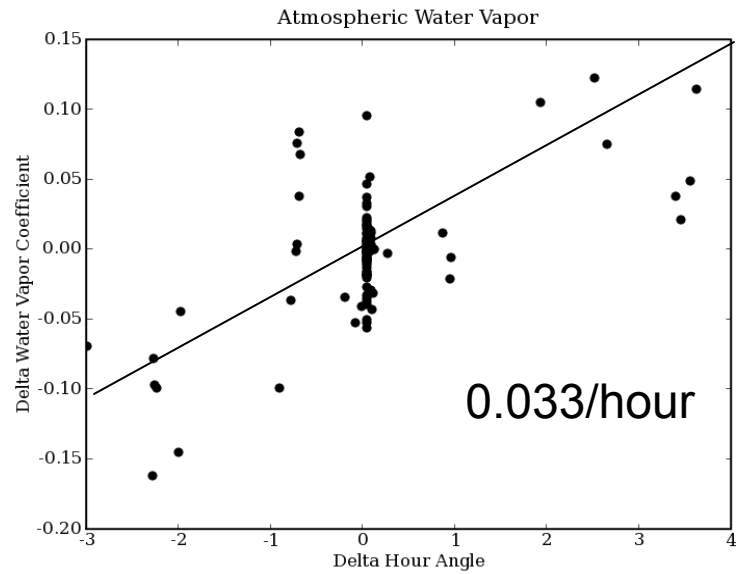
$$\tau\,(t,ha,DEC) = \tau_0(t) \cdot (1 + \tau_{EW}(t) \cdot \tan(ha) + \tau_{NS}(t) \cdot \tan(DEC\text{-}CTIO)) \cdot (\lambda/\lambda_0)^{\alpha}$$

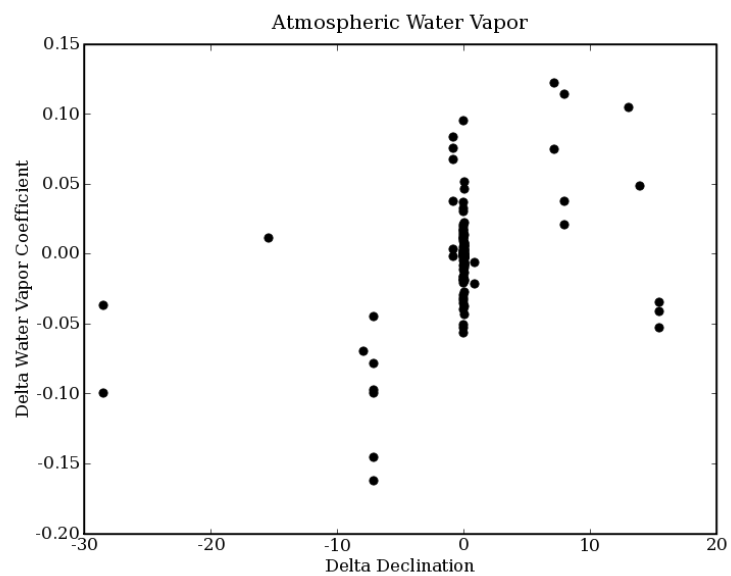
Fit one set of τ_0, τ_{EW}, and τ_{NS} and one ozone coefficient for each night.

Date	C_{ozone}	τ_0 (%)	τ_{EW} (10^{-2})	τ_{NS} (10^{-2})	α
Nov 2	0.80	3.9	- 0.1	+ 0.5	-1.70
Nov 3	0.90	5.6	- 0.3	+ 0.2	-0.95
April 24	0.86	1.2	+ 0.1	- 0.1	-0.50
April 25	1.04	0.8	- 0.1	+ 0.7	-1.10
April 26	1.46	0.8	+ 0.5	- 0.3	-1.50
July 23	1.32	0.0	NA	NA	NA

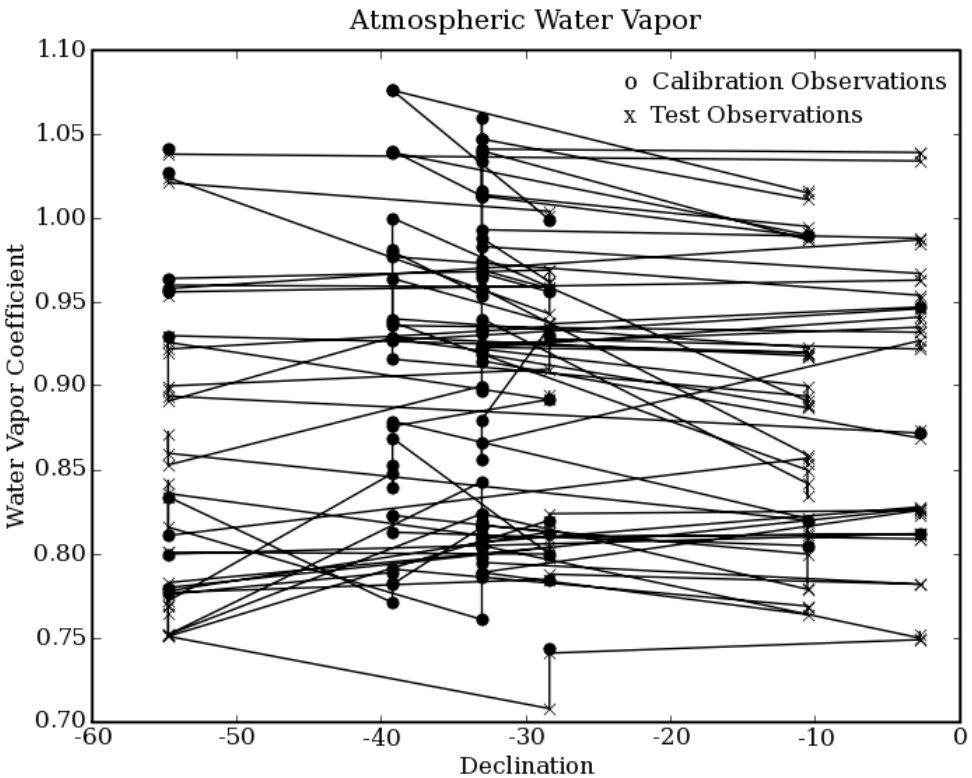
Spatial Variation in Water Vapor
November 2007

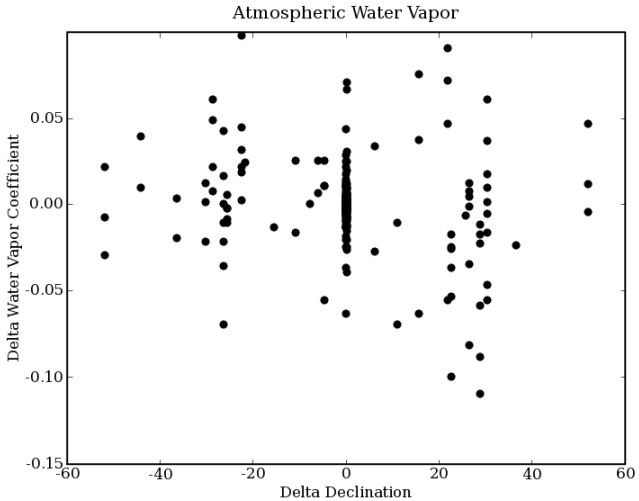


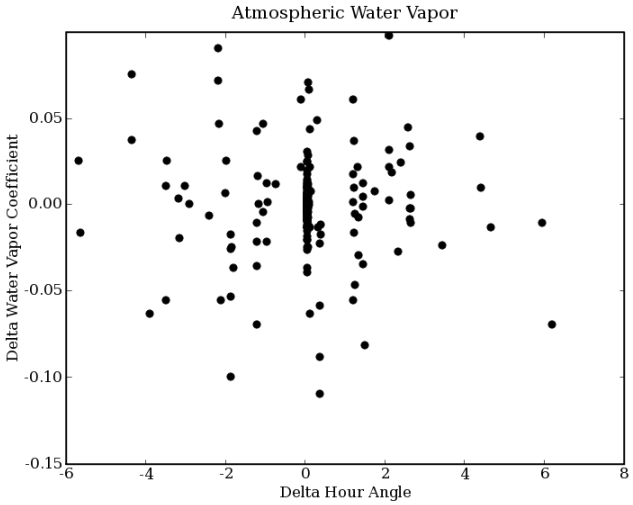




Spatial Variation in Water Vapor
April 2008

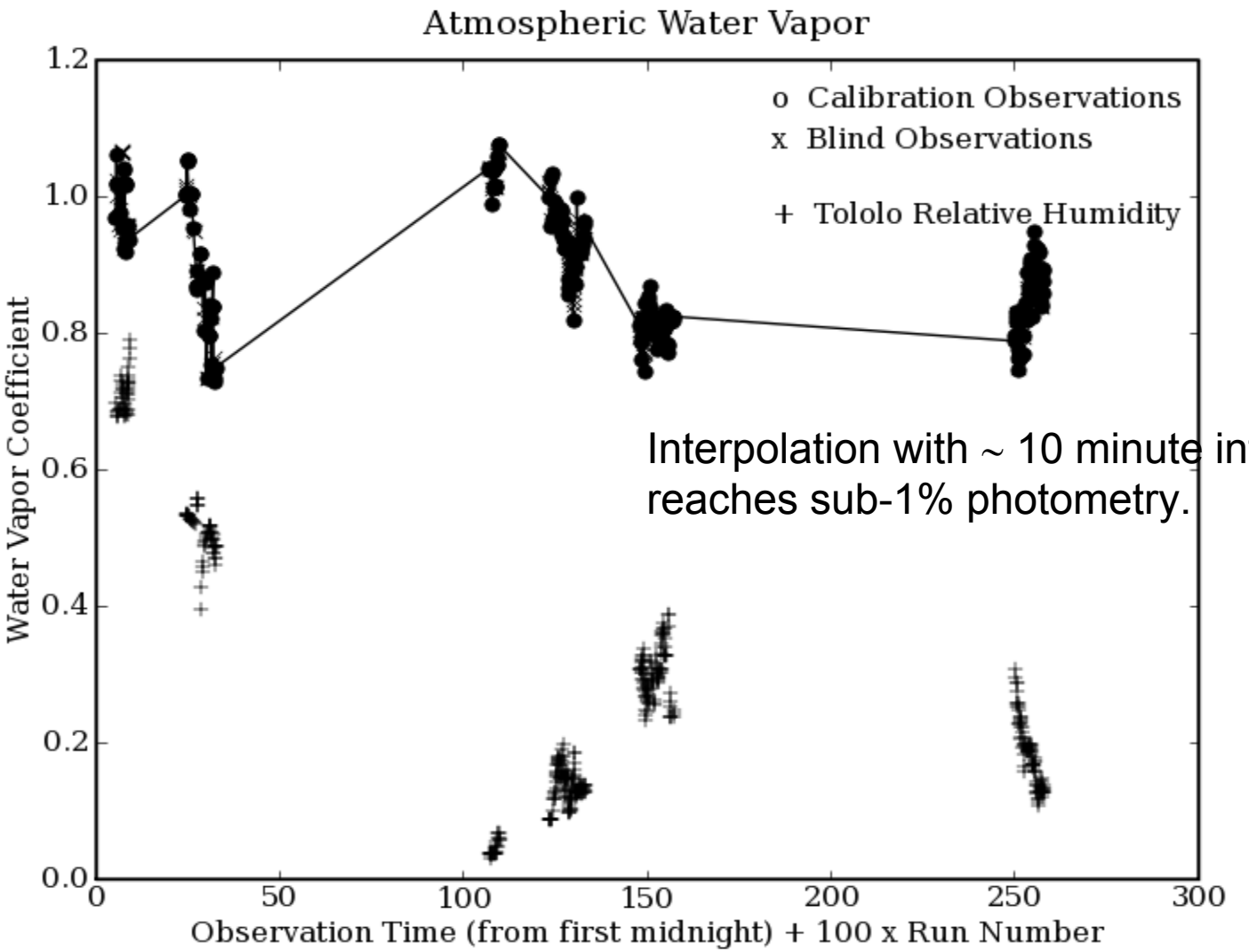






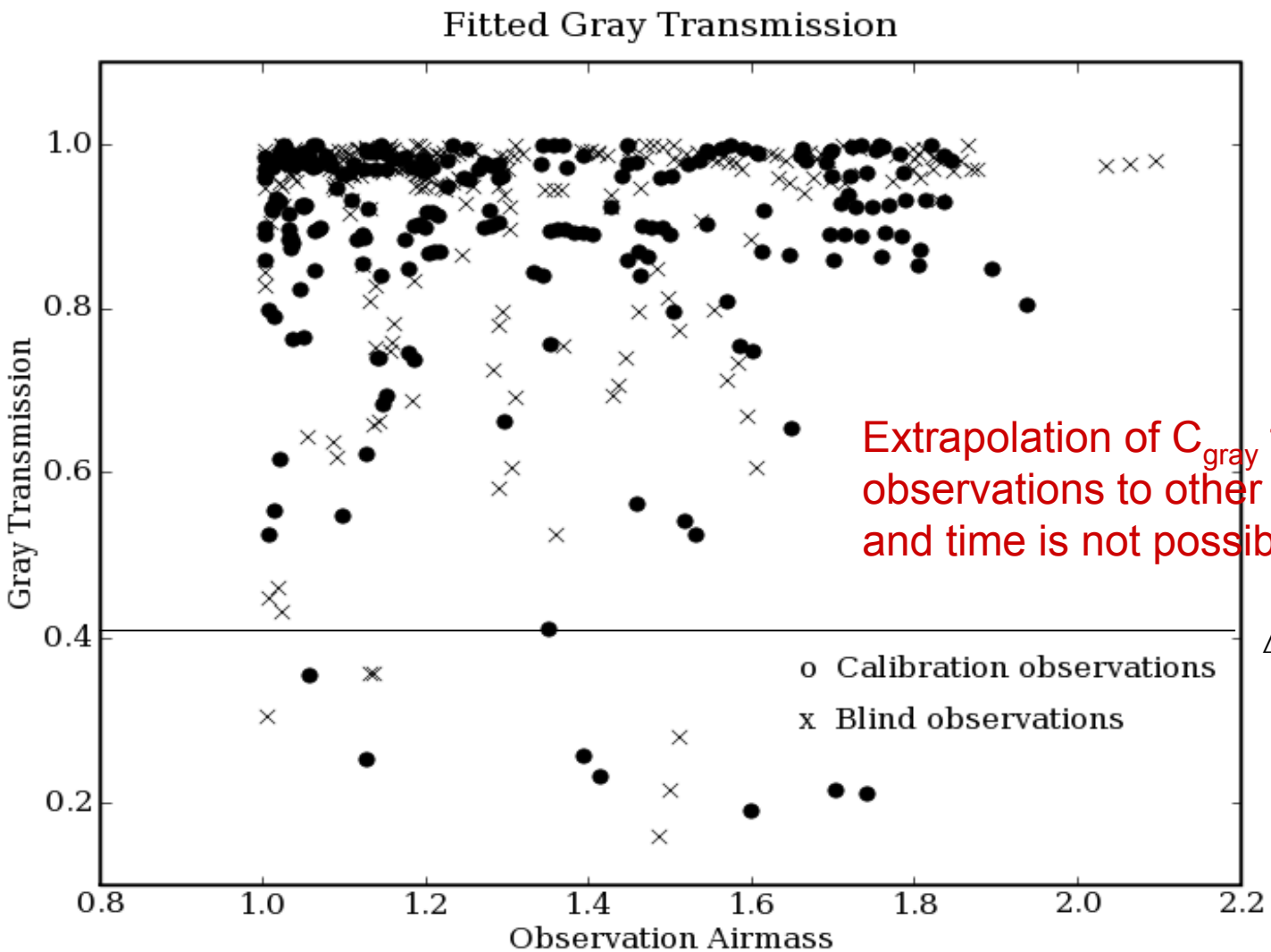
No significant spatial structure during this observing period.

Interpolated "Blind" C_{H2O}



Interpolation with ~ 10 minute intervals reaches sub-1% photometry.

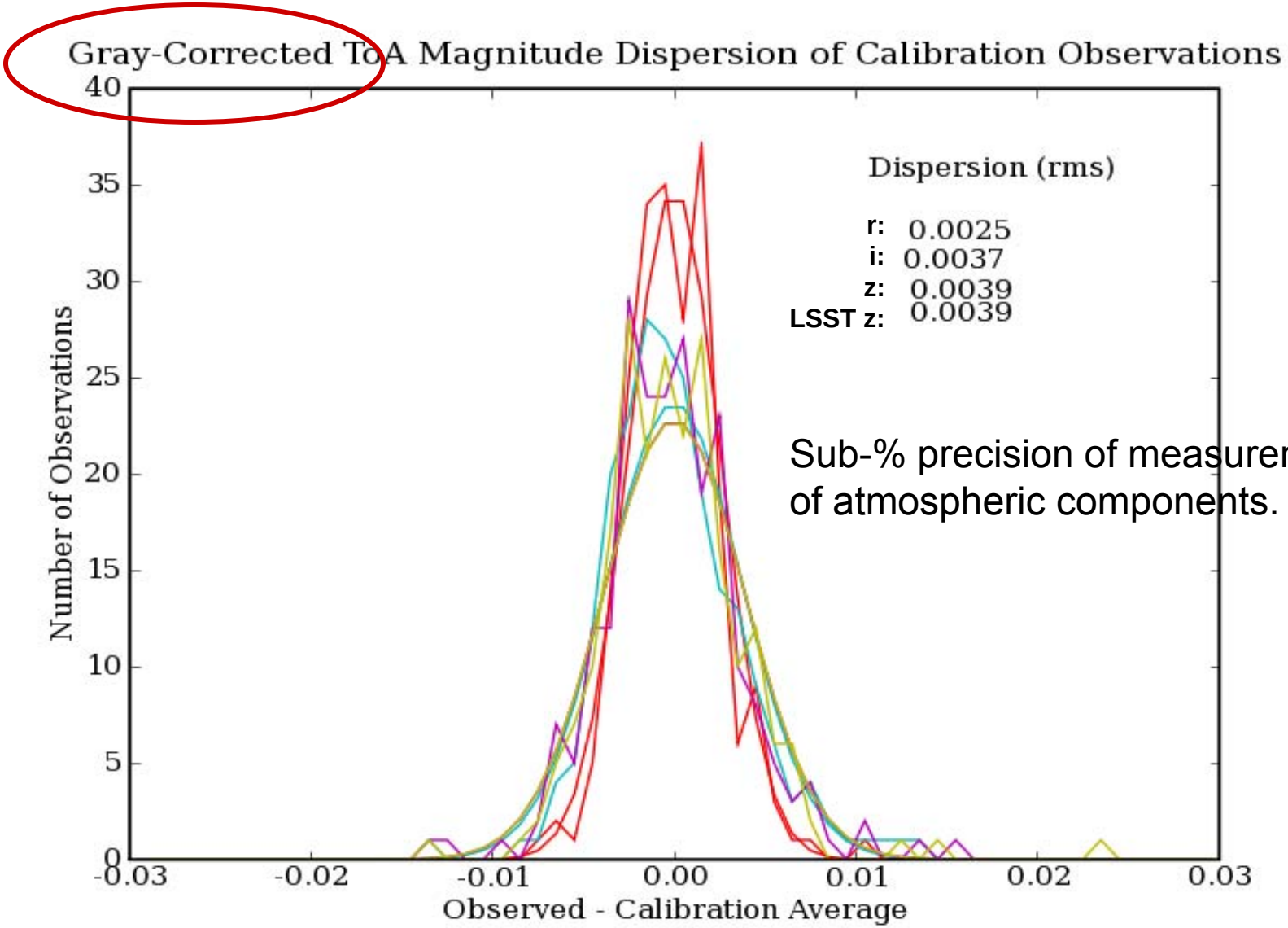
Gray Extinction (Clouds)



Extrapolation of C_{gray} from calibration observations to other points in space and time is not possible.

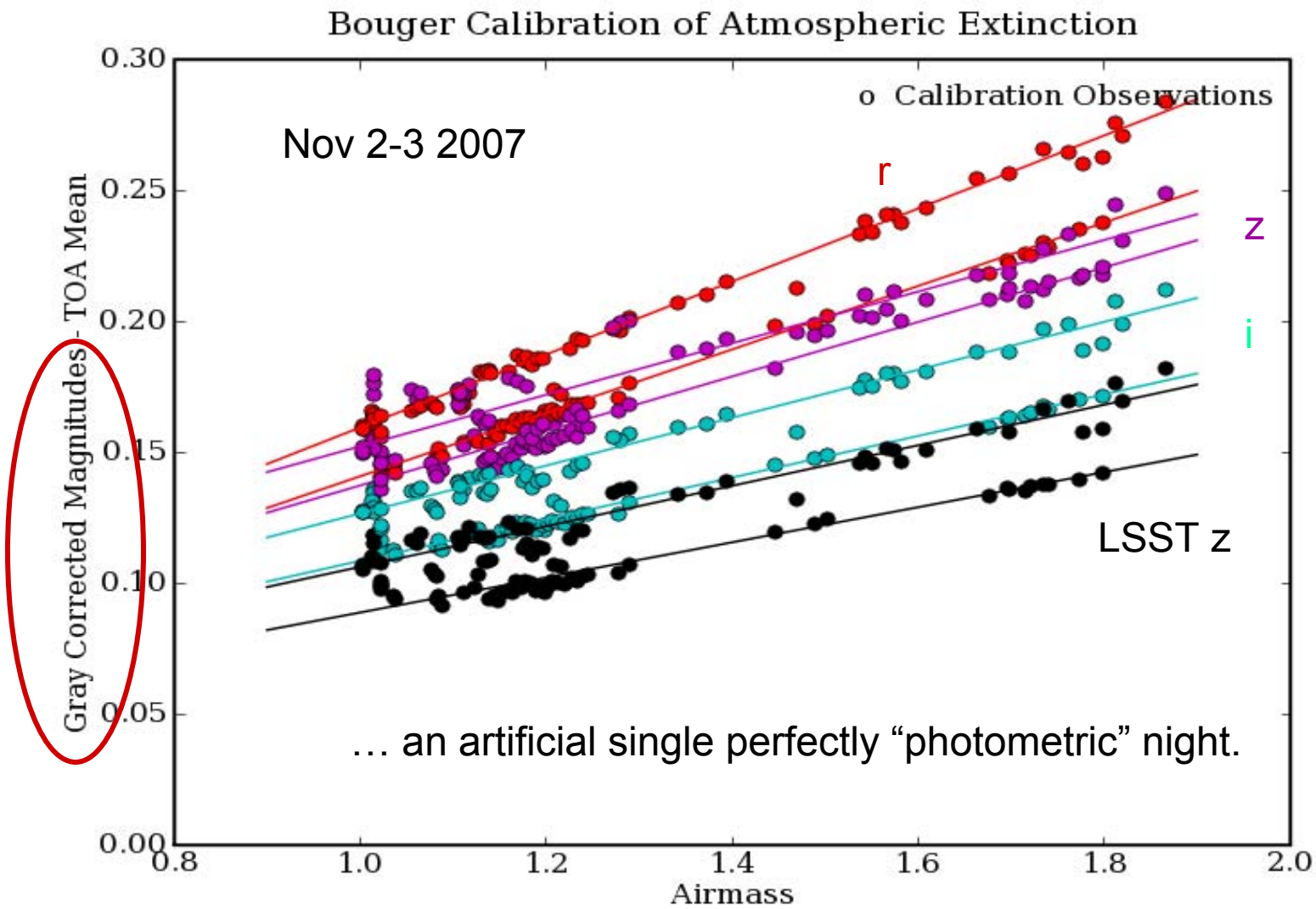
$\Delta m = 1.0$mag

Calibration Observations
(Full Data Set)



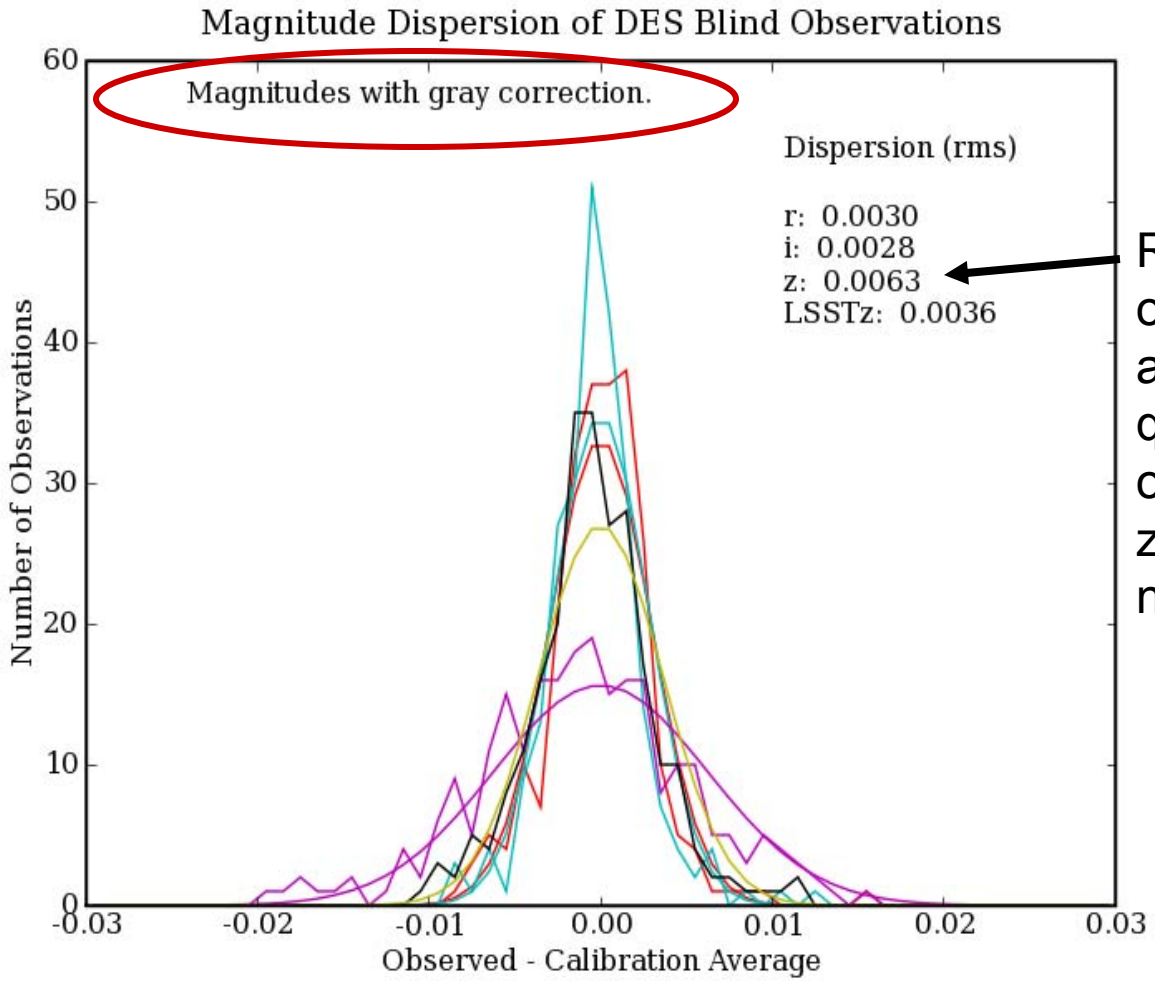
Sub-% precision of measurement of atmospheric components.

Calibration of DES Bands
Demonstration with Nov 2-3 Data



"Cheater" Blind Observations (Full Data Set)

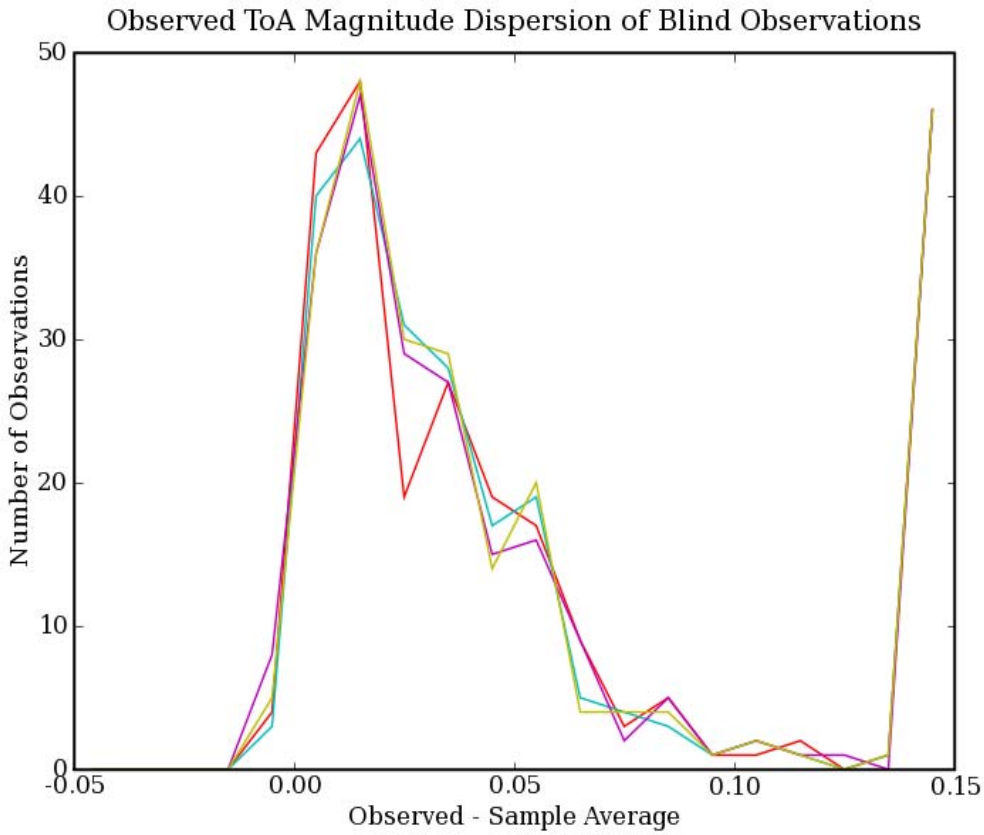
If we "cheat" and correct for gray cloud extinction, we can see what the atmosphere chemistry is doing … DES z-band looks ok for 1-2% photometry.



Ranges 0.005 – 0.010 over the six nights; the answer to the narrow question of the effect of the water vapor on z-band for these nights.

"Honest" Blind Observations (Full Data Set)

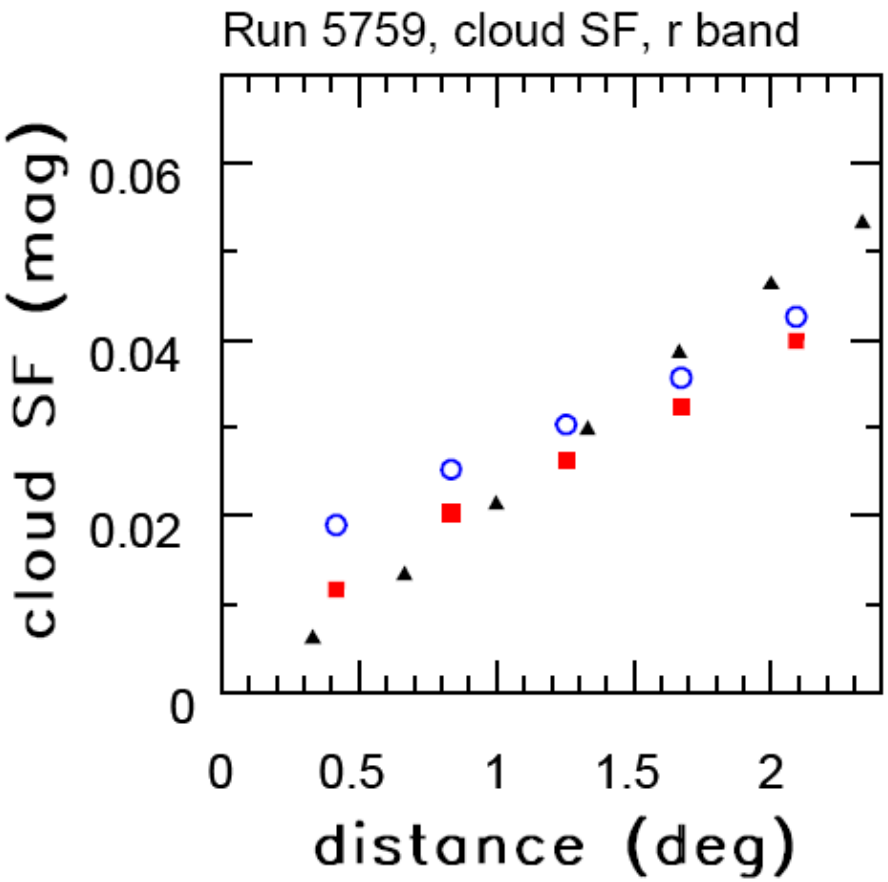
But we will actually see whatever we define "photometric" to be.



This will effect both target measurements and the calibration measurements on earlier slide.

Cloud Structure
(Data from SDSS)

Data from a run with “smooth” cloud cover of 1-2 magnitudes. **Ivezic, et al (2006)**

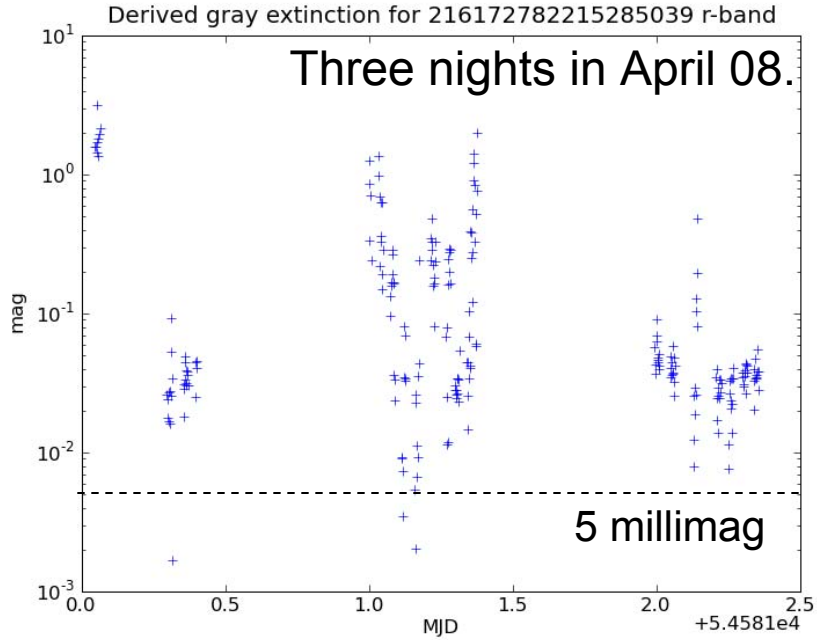


In this case, gray zero-point dispersion ≤ 0.01 mag (rms) for separations ≤ 0.25 degree (one LSST CCD 14' × 14').

Will have ≥ 100 stars on each CCD to measure pattern of gray extinction (<u>after correcting for wavelength dependent extinction</u>).

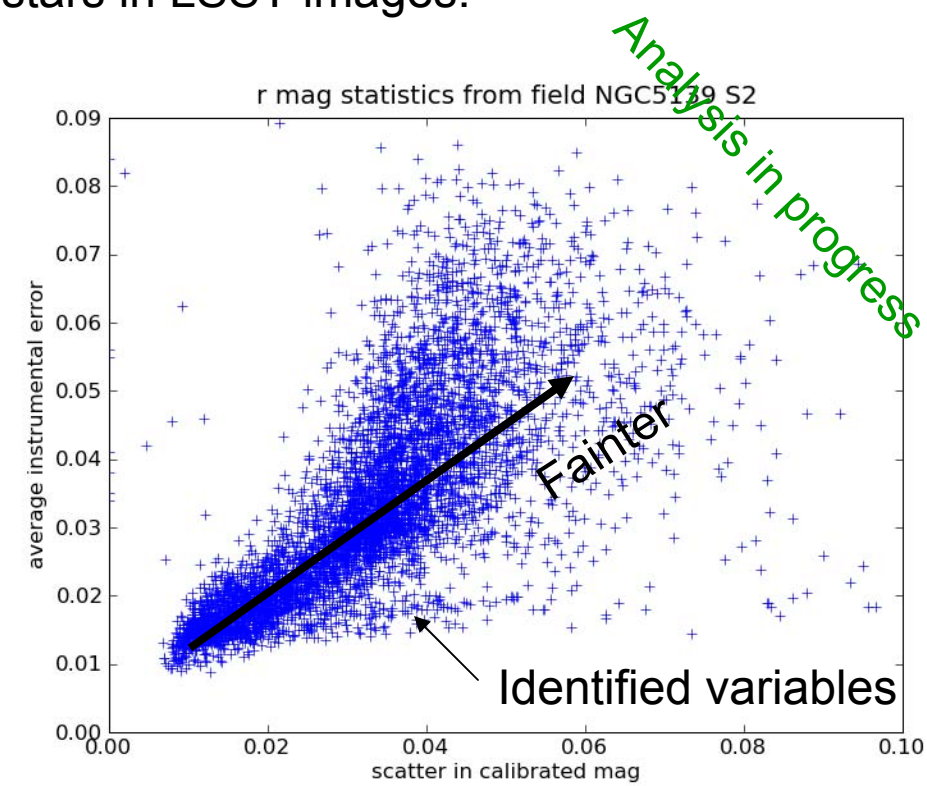
⟶ Observing tests on Tololo 0.9m imager with 13' × 13' FOV.

Calibration of Gray Extinction
Simultaneous Observing with CT0.9m Imager



Repeated observations of stars (not all bright) in 13'×13' field on outskirt of NGC5139.

Density similar to that expected for calibration stars in LSST images.



Correct for non-gray extinction, then fit pattern of spatial deviations of residuals with 2nd order polynomial.

Limited by instrumental errors through ≤ 2 mag gray extinction.

T. Axelrod (LSST/Steward Observatory)