



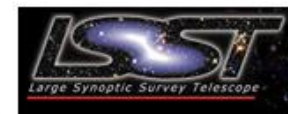
Calibrating DECam data: the DECal and aTmCam calibration systems

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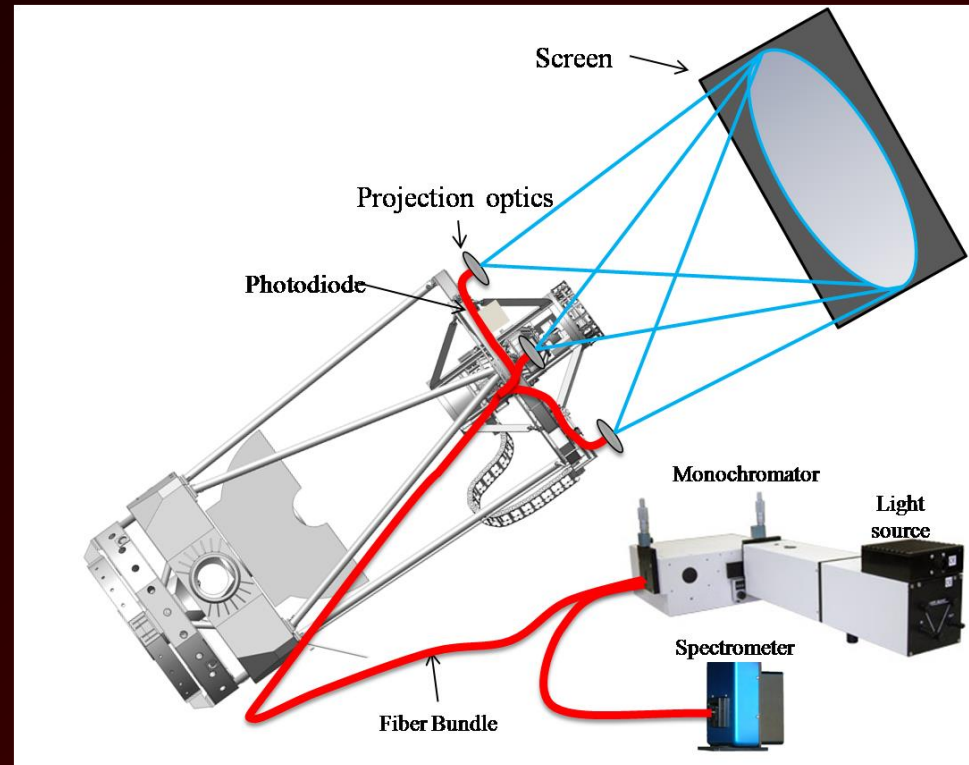
Precision photometry

- Ambitious science goals of modern wide-field imaging systems require precise measurements
 - DES has photometric precision requirement of 2% across entire survey area, with a goal of <1%
- Reaching this goal will require careful calibration of data
 - But it can be reached: see Ting Li's poster at this meeting
- We have now commissioned two instruments that can be used to measure the DECam total system response:
 - DECal: the daily flat field and spectrophotometric calibration systems
 - aTmCam: the Atmospheric Transmission Monitoring Camera



DECAL daily flat field system

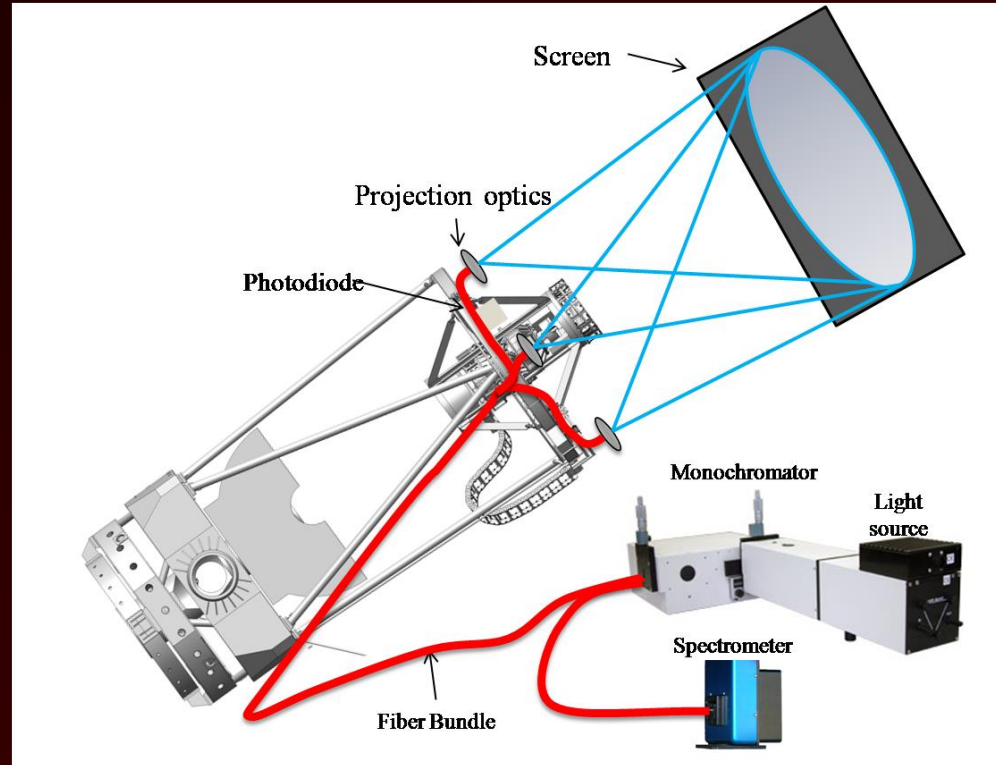
- Flat field screen
- Daily flat field system
 - LED flat field lamps
- Spectrophotometric calibration system
 - Long fiber bundle
 - Monochromator (with spectrometer monitor)
 - Monitor photodiodes





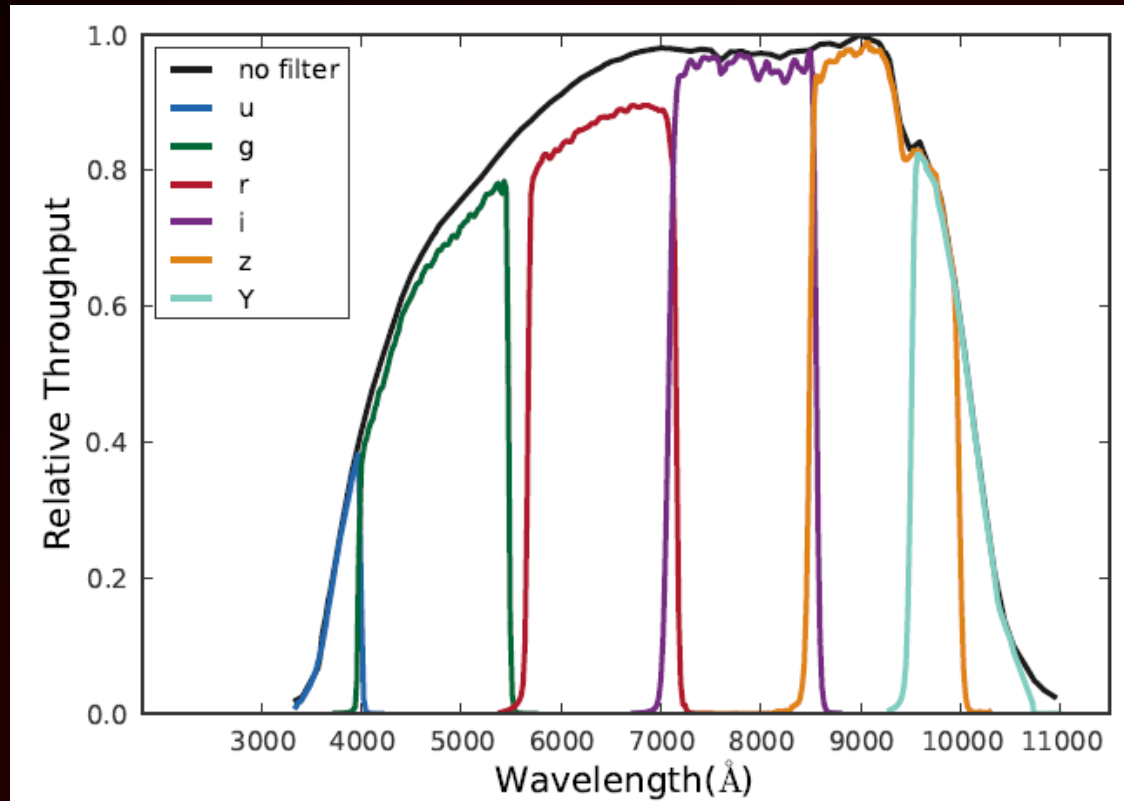
DECal spectrophotometric calibration system

- Flat field screen
- Daily flat field system
 - LED flat field lamps
- Spectrophotometric calibration system
 - Long fiber bundle
 - Monochromator (with spectrometer monitor)
 - Monitor photodiodes





Result: DES system throughput



- Measured system throughput ~5 times since Fall 2012
- Not much change in system throughput (good news!)



aTmCam

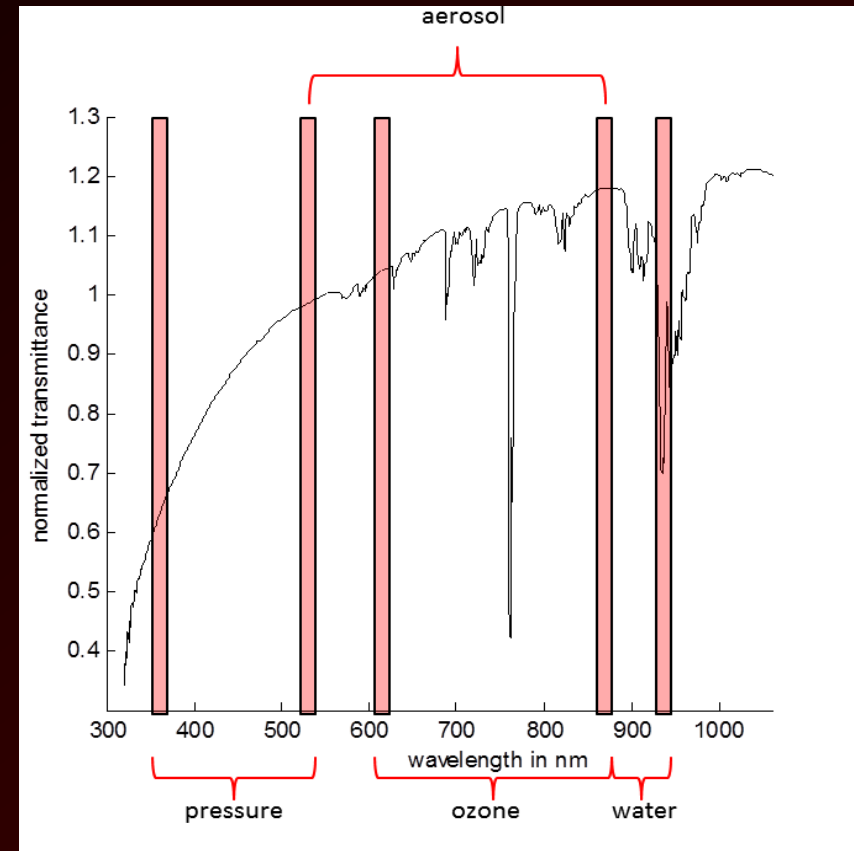
- Located on CTIO summit (next to 1m dome)
- Autonomous operation each night
- Photometrically measure atmospheric features in 4 narrowband filters
- Automatically fit atmospheric model to measurements
- Produces an atmospheric throughput model once per hour





Atmospheric transmission

- Constituents
 - Precipitable water vapor
 - Aerosols
 - (Ozone)
 - Rayleigh scattering
- Measure A stars in narrowband filters
- Fit model of atmospheric transmission to data
- Correct for atmospheric absorption to 10%
 - Enables photometric precision <1%!

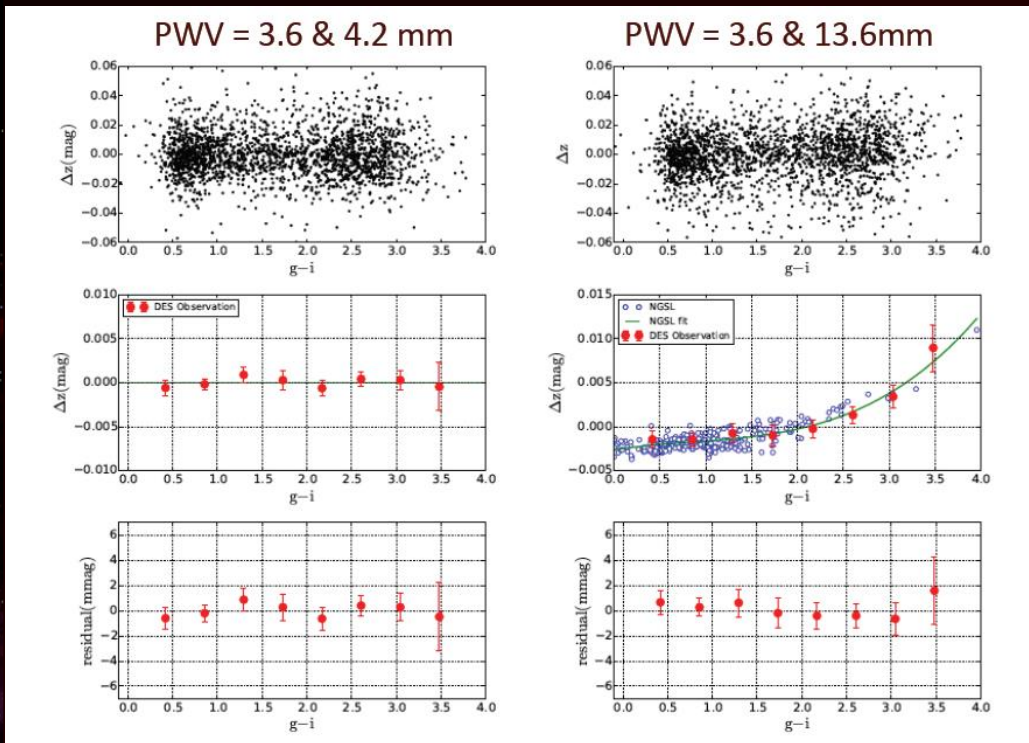


Li+2012



<1% photometric precision

- DES-calibrated photometry: nights with high water vapor



Top: Δz from two exposures on different nights

Middle: points from above averaged in bins; polynomial fit to theoretically calculated errors (based on aTmCam measurements)

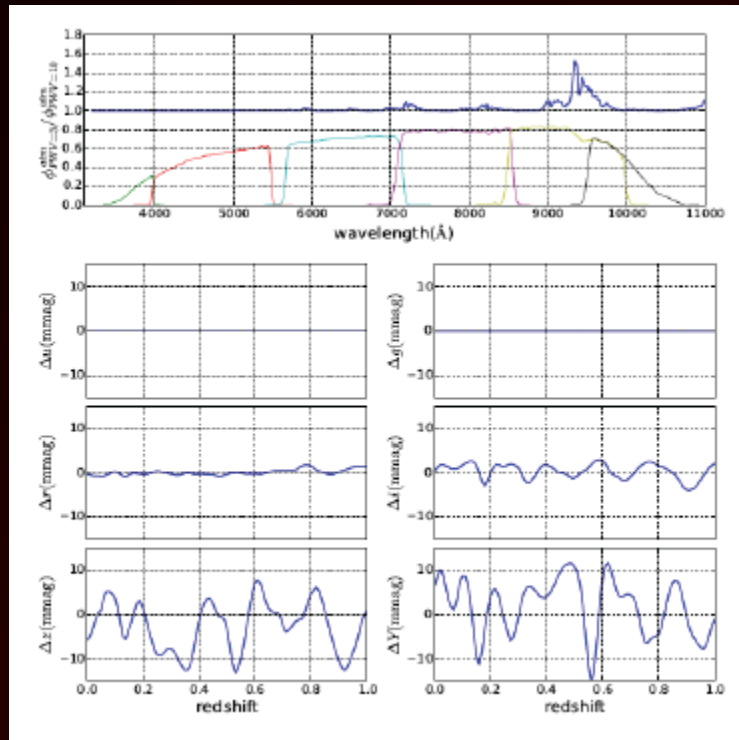
Bottom: Residuals after photometric correction are <2 mmag

- Without aTmCam calibration, photometric errors (on a wet night) are 9 mmag (M stars)
- With aTmCam, can calibrate to <2 mmag!



<1% photometric precision

- The atmosphere is also a problem for SNe:



Top: Ratio of atmospheric transmission at PWV 3mm and PWV 10mm

Bottom: Systematic errors on SN Ia photometry due to change in PWV as a function of redshift

- Change in water vapor from 3 to 10 mm results in >1% photometric errors in z and Y bands



Conclusions

- DECal+aTmCam form a complete system response measurement system for DECam
 - DECal: top of telescope down to detector
 - aTmCam: top of telescope up through atmosphere
- Together with standard photometric calibration procedures, enable $<1\%$ photometric precision of DECam photometry
- Data products available to community
 - aTmCam results may be useful to observers at other CTIO telescopes



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Stars: sources and error budget

color terms

unit: mmag / mag in g-r

10mmag ~ 1%

Sources	range	u	g	r	i	z	Y	Addition info
Instrument	center→edge		<5	5	10	5	<5	DECal
Airmass	1→2	15	20	5-10	<5	<5	<5	DECam+libRadTran
PWV	0→10(mm)	0	0	<5	5	15	15	GPS/aTmCam +libRadTran
Aerosol optical depth	0→0.2(??)	<5	15	5	<5	0	0	aTmCam+libRadTran
Ozone	260-300(??) DU	<2	<2	<2	0	0	0	No need
Pressure	772-784 hpa	<2	<2	<2	0	0	0	No need

Note: color term is JUST first order correction when assuming that error is linear to g-r color!

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Supernova: sources and error budget

SED and redshift dependent PtV errors in mmag for $0 < z < 1$ 10mmag \sim 1%

Sources	range	u	g	r	i	z	Y	Addition info
Instrument	center \rightarrow edge							DECal
Airmass	1 \rightarrow 2	60	55	15	10	10	10	DECam+libRadTran
PWV	0 \rightarrow 10(mm)	0	0	5	10	40	50	GPS/aTmCam +libRadTran
Aerosol optical depth	0 \rightarrow 0.2(??)	10	40	10	5	<2	<2	aTmCam+libRadTran
Ozone	260-300(??) DU	<2	<5	<2	0	0	0	No need
Pressure	772-784 hpa	<2	<2	<2	0	0	0	No need