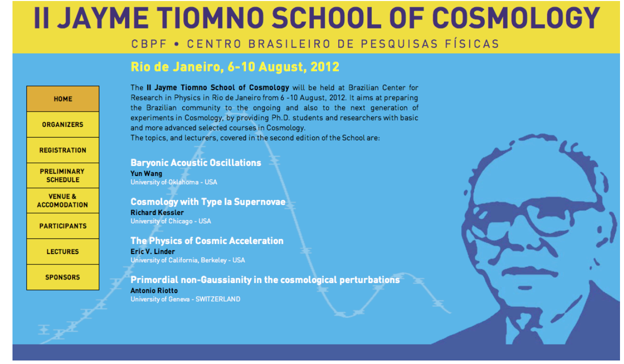
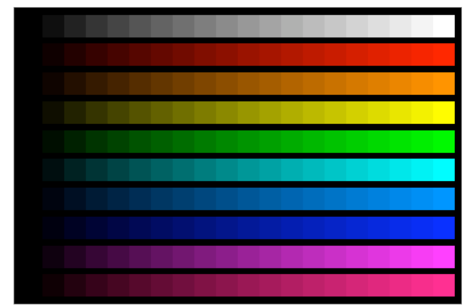


Lectures on Cosmology with Type Ia Supernovae: **CALIBRATION**



R.Kessler (U.Chicago)

II Jayme Tiomno School of Cosmology

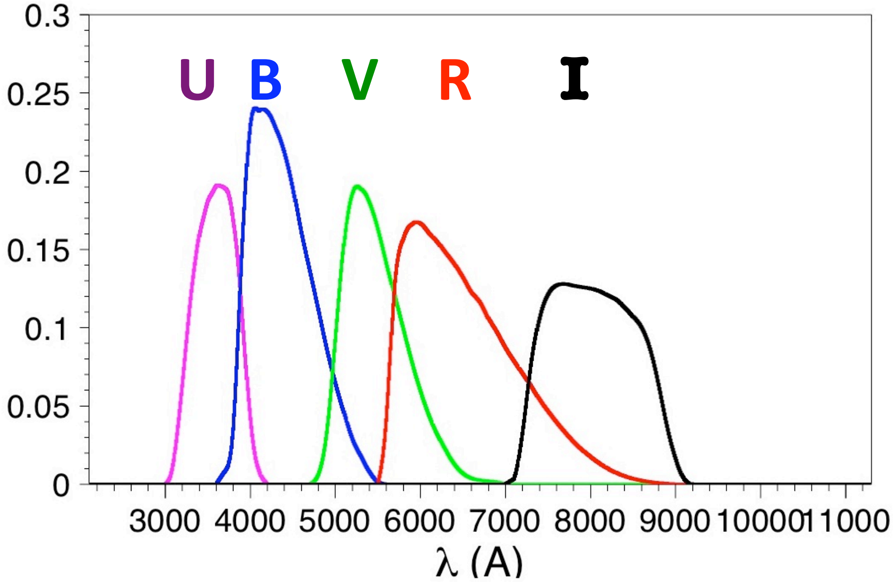
Rio de Janeiro, Brazil

Aug 6-10, 2012

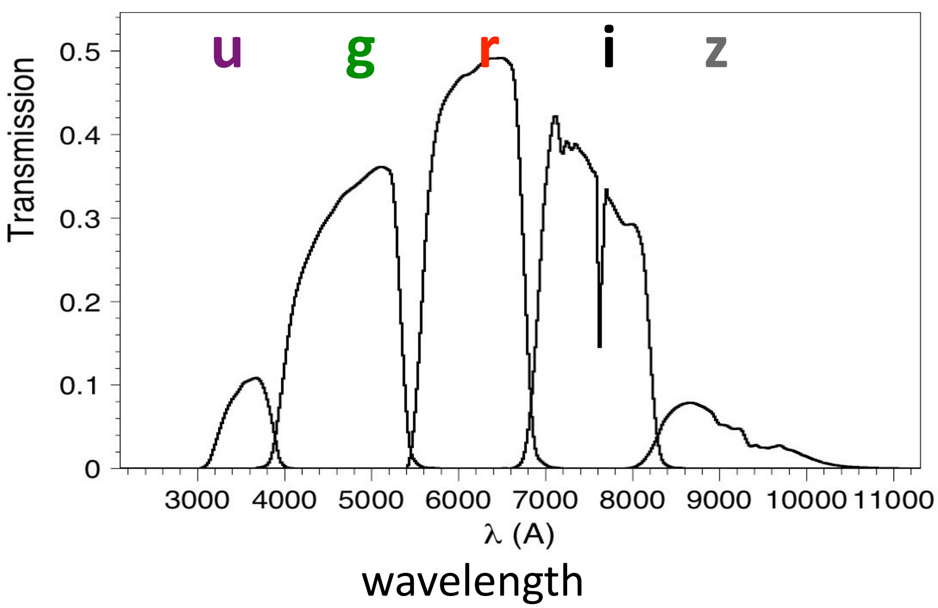
Why?

- Because calibration uncertainties currently dominate the systematic error budget for SNIa cosmology.

Filters



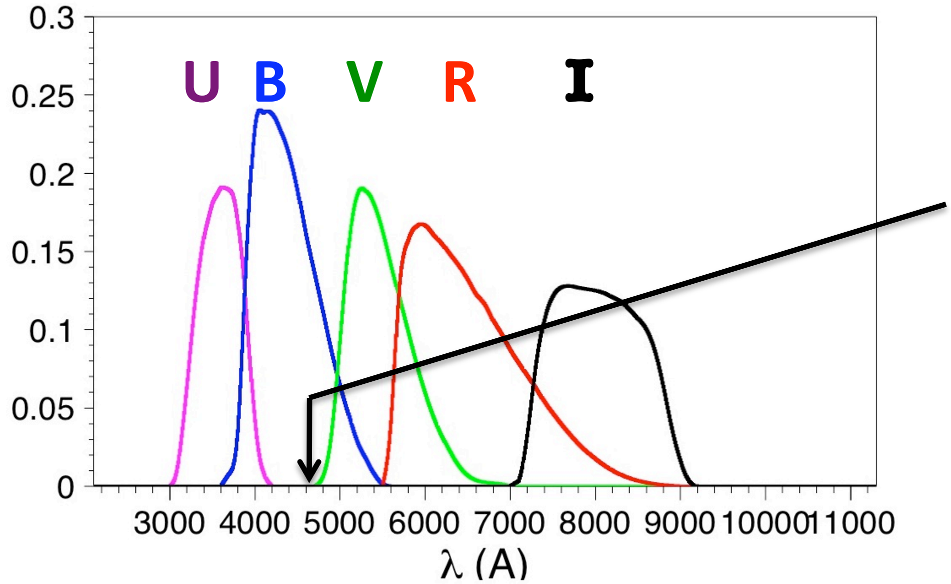
Bessell (1990):
Used for most nearby
SNIa (CfA)



SDSS ugriz:
Similar filters used for
SNLS, PS1, HSC, DES, LSST ...

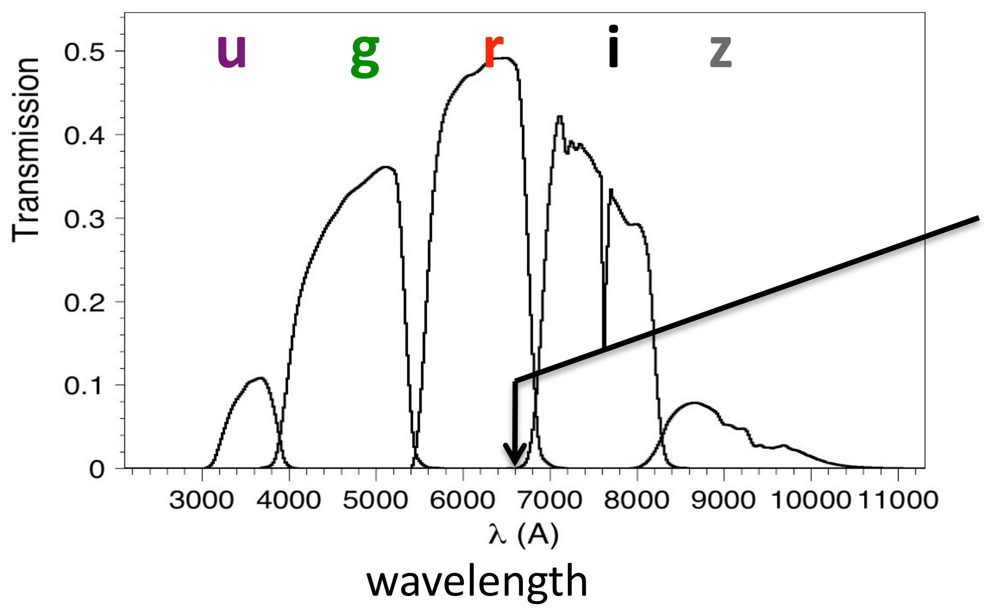
and CSP (nearby)

Illustration of Calibration Challenge



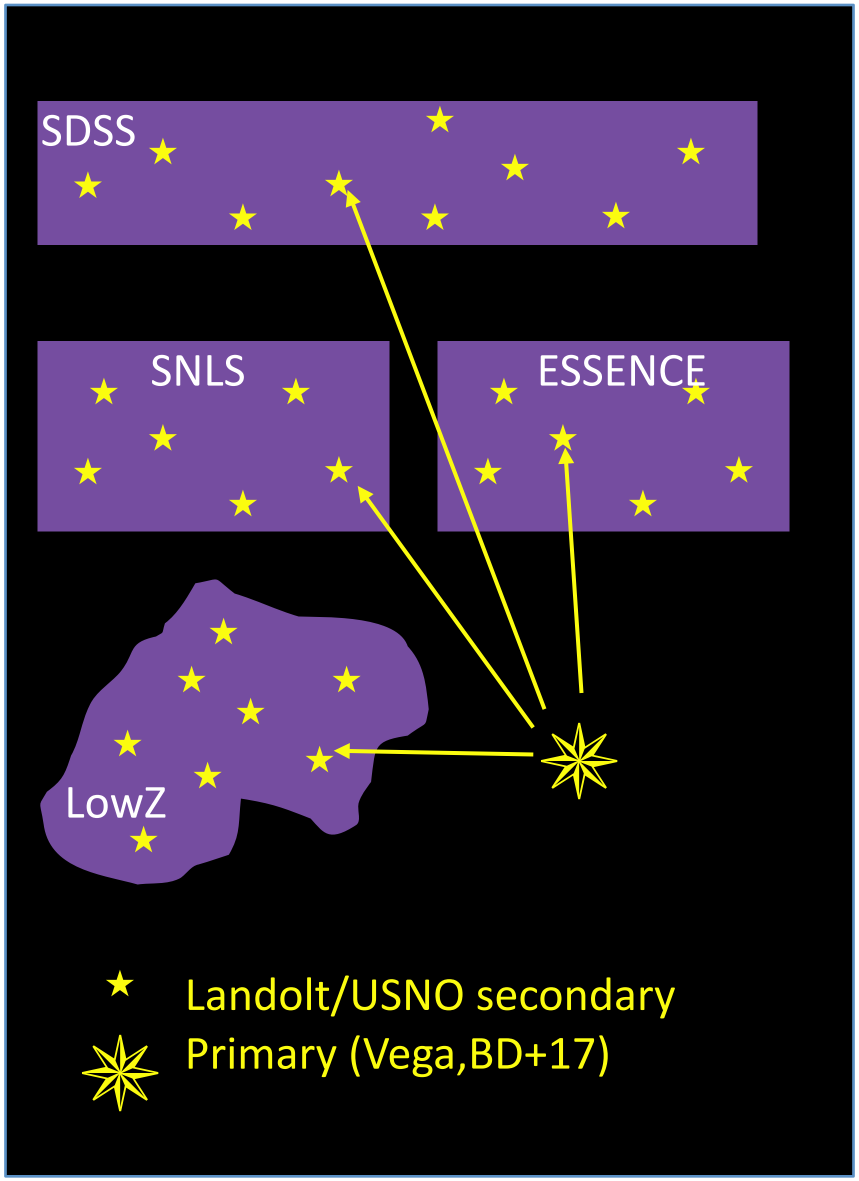
Compare rest-frame Flux(4400 A) at z=0.05 using B band

to



same rest-frame Flux at z=0.5, but using r band on different telescope …
and NO overlapping measurements with nearby SN fields !!!

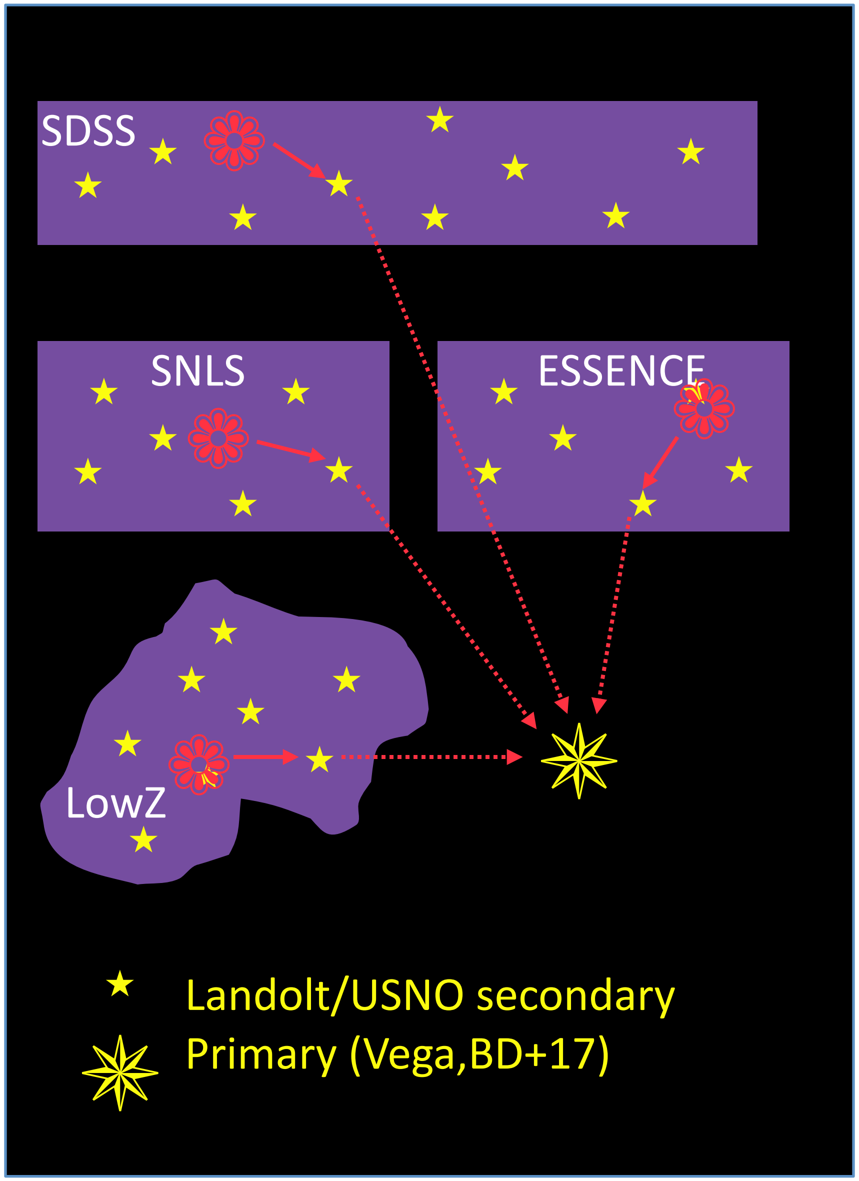
Calibration: Overview



Each SN sample is calibrated to Landolt or USNO stars within (or near) their survey field.

SDSS,SNLS filters ugriz require large color transformations to Bessell UBVRI.

Current Calibration with SNe



Comparing SNe (❁) in different surveys involves a complex calibration path.

SN Flux-Model with Reference

$$F_{e,f} = x_0(1+z)\frac{\int d\lambda\,[\lambda f_{\mathrm{SN}}(e,\lambda)T_f(\lambda(1+z))]}{\int d\lambda\,[\lambda f_{\mathrm{REF}}(\lambda)T_f(\lambda)]}$$

Reference:
(Vega or BD17)

Filter
transmission

SN Flux-Model with Reference

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- **Ideally $T_f(\lambda)$ is measured and $f_{\mathrm{REF}}(\lambda)$ is known, such as from HST CALSPEC.**
- **However, $T_f(\lambda)$ is not known for most of the nearby SNe Ia.**

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- However, $T_f(\lambda)$ is not known for most of the nearby SNe Ia.
- For nearby SNe Ia we know that
  - $T_{U,B,V,R,I}$ are approximately Bessell-90 U, B, V, R, I filters.
  - SN magnitudes are reported in the "Landolt" system,

$$F_{U,B,V,R,I} = 10^{-0.4m} = \frac{\int d\lambda\,[\lambda f_{\mathrm{SN}}(\lambda) T_{U,B,V,R,I}(\lambda)]}{\int d\lambda\,[\lambda f_{\mathrm{Land}}(\lambda) T_{U,B,V,R,I}(\lambda)]}$$

SN Flux-Model with Reference

$$F_{e,f} = (1+z)\frac{\int d\lambda\,[\lambda f_{\rm SN}(e,\lambda)T_f(\lambda(1+z))]}{\int d\lambda\,[\lambda f_{\rm REF}(\lambda)T_f(\lambda)]}$$

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- **Assume $T_{U,B,V,R,I}(\lambda) = T^{\rm Bess}_{U,B,V,R,I}(\lambda - \delta\lambda_{U,B,V,R,I})$ (each filter is a shifted Bessell-90 filter) $\longrightarrow$ no solution using published SN info !**

Can solve for $\delta\lambda_{U,B,V,R,I}$ using standards stars that have both Landolt mags and HST spectra.

$$m_U = -2.5\log_{10}\left\{\int d\lambda \left[\lambda f_{\rm Land}(\lambda) T_U^{\rm Bess}(\lambda - \delta\lambda_U)\right]\right\}$$

$$m_B = -2.5\log_{10}\left\{\int d\lambda \left[\lambda f_{\rm Land}(\lambda) T_B^{\rm Bess}(\lambda - \delta\lambda_B)\right]\right\}$$

$$m_V = -2.5\log_{10}\left\{\int d\lambda \left[\lambda f_{\rm Land}(\lambda) T_V^{\rm Bess}(\lambda - \delta\lambda_V)\right]\right\}$$

...

Landolt mags

HST-measured SEDs on Landolt stars

Solve for δλ

Star
BD+17°4708
Vega
G191B2B
GD71
GD153
AGK+81°4211
BD+28°4211
BD+75°325
Feige 110
Feige 34
GRW+70°5824
HZ21
HZ44
HZ4

Filter Shifts, $\delta\lambda_{U,B,V,R,I}$

Wavelength Shifts for Bessell (1990) Filters

	filter shift in Å for:	
Bessell filter	HST standards	Astier et al. (2006)
U	$+13 \pm 4$	–
B	-15 ± 4	-41
V	$+12 \pm 6$	-27
R	$+7 \pm 9$	-21
I	-45 ± 21	-25

by J. Marriner
(in Kessler et al, 2009)

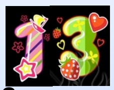
Uses ground-based spectra

Comments on UBVRI Filter Shifts

- Discrepant filter shifts depending on choice of spectro-photometric standards.
- Simple wavelength shift is likely too naïve
- Better solution is to collect new nearby SNIa with known filter transmissions:

  CSP (Stritzinger et al., 2011)

  CfA3 (Hicken et al., 2009)

Exercise 

:

For a 10 Å shift in the V band central wavelength, what is the peak SN magnitude shift at z=0 ? at z = 0.5 ? Use BD17 SED as the reference.

SNIa spectral template vs. epoch:
http://supernova.lbl.gov/~hsiao

BD17 HST spectrum:
http://www.mmnt.net/db/0/1/ftp.stsci.edu/cdbs/testcdbs/calspec

Bessell UBVRI Filters:
http://supernovae.in2p3.fr/~guy/salt/download_instruments.html
(then click SNLS3-Landolt-model-5A.tar.gz)

Exercise 14

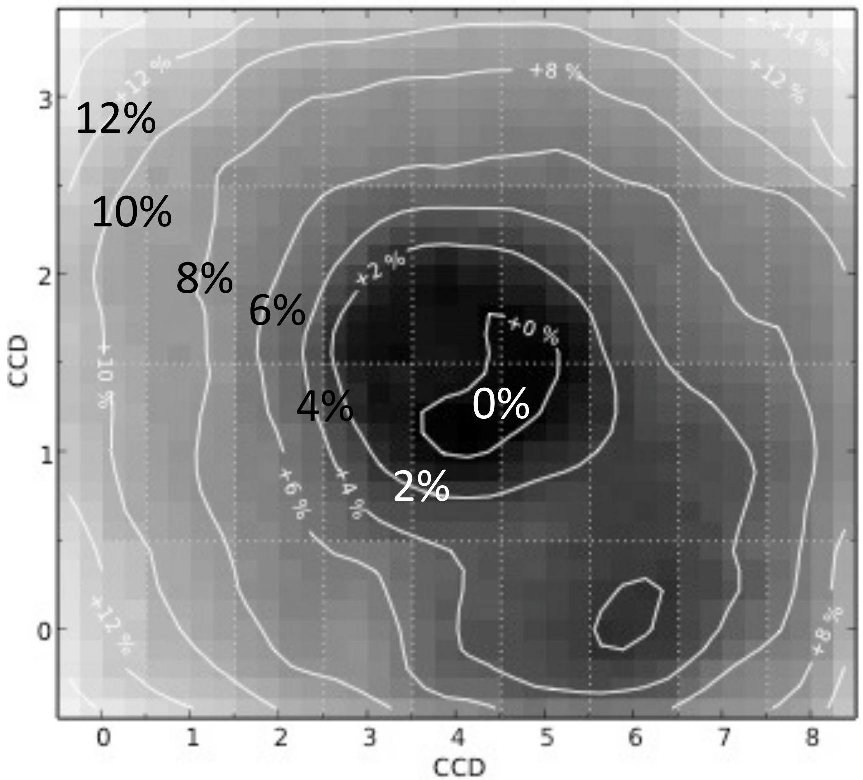
Suppose we measure the filter transmission in 50 Å steps using a nearly monochromatic beam with a Gaussian profile (σ_λ = 50 Å). We simply connect the measurements with straight lines to estimate the filter response.

For U, V, I bands, what is the error on the synthetic SN mag at peak (z=0) ?

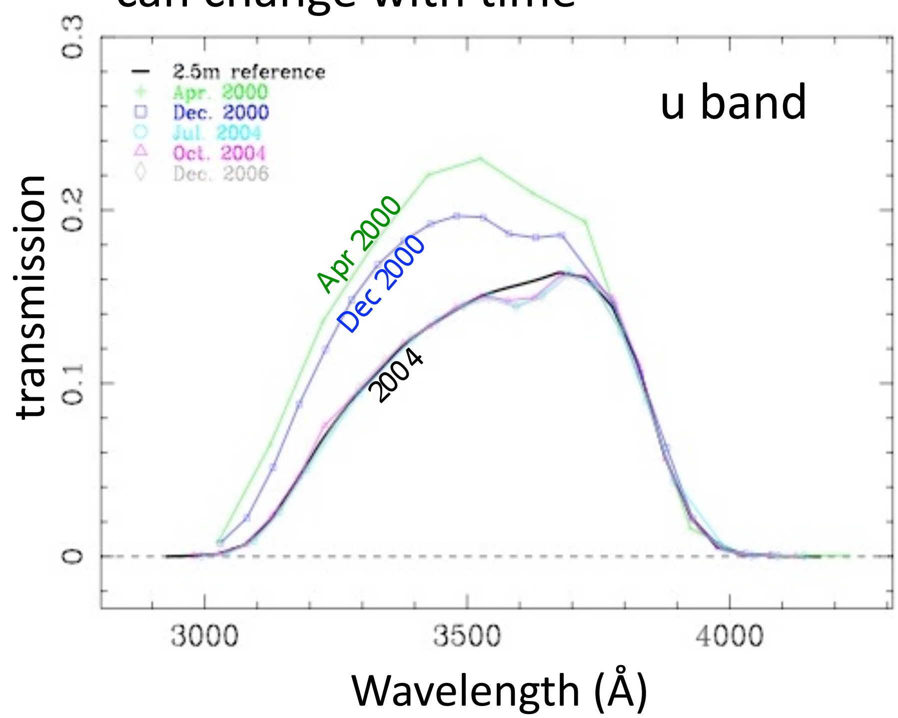
Repeat for 200 Å steps and σ_λ = 200 Å.

Miscellaneous Complications

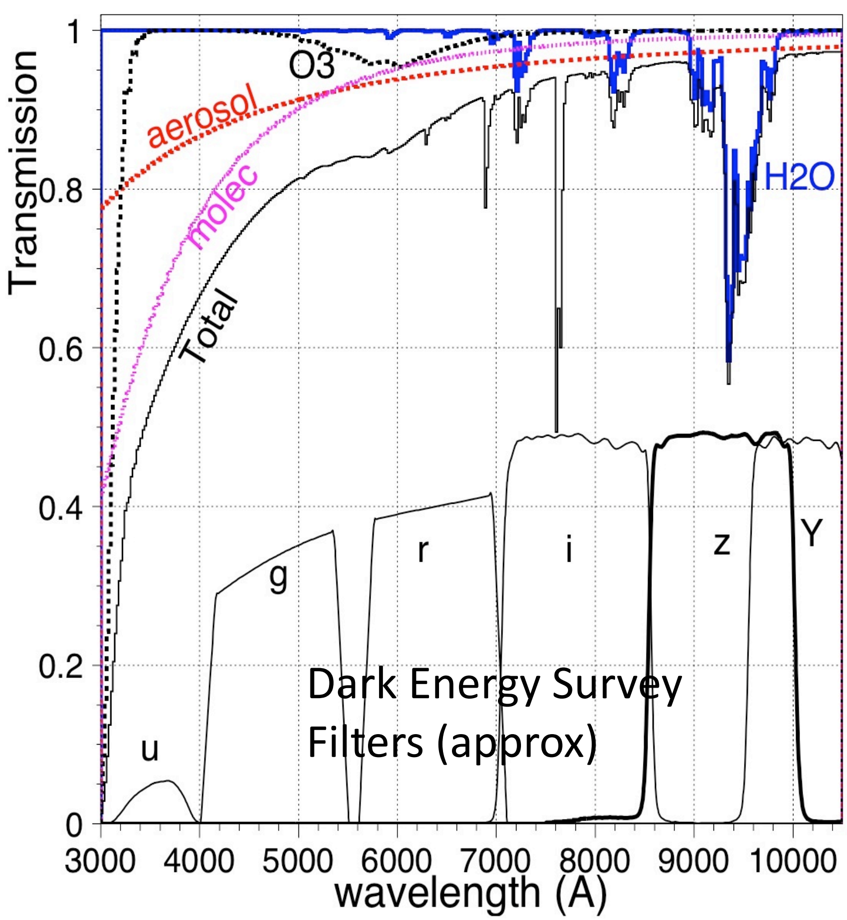
SNLS: Regnault et al, A&A 506, 999 (2009)
Filter transmission is not uniform over focal plane



SDSS: Doi et. al., AJ 139, 1628 (2010)
Filter transmission can change with time



Miscellaneous Complications: Atmosphere Transmission



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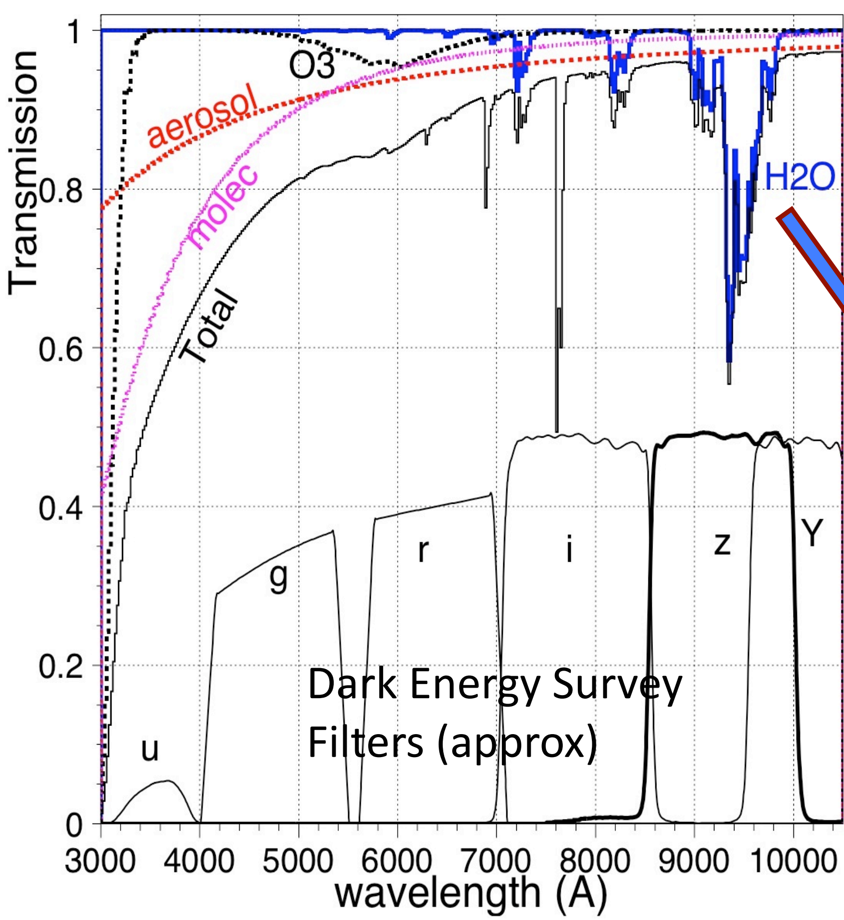
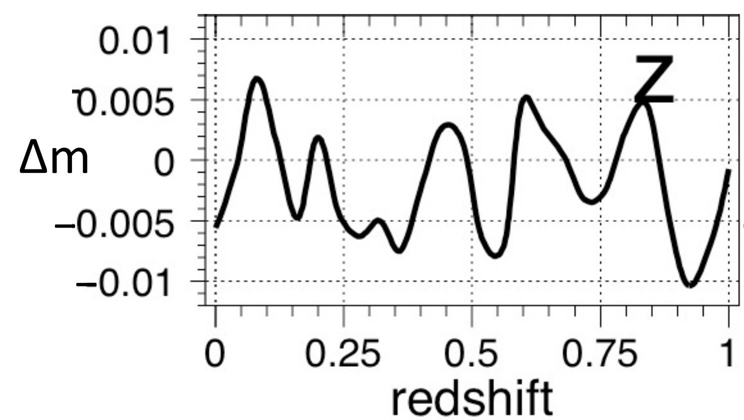


For SNIa at peak, z band mag error (Δm) vs. redshift from ignoring a 50% increase in H2O.



Simulation for DES
(by RK & V.Braganca)

Inter-calibration Between Surveys

- Combining SN from different surveys requires precise inter-calibration without crosschecks.
- Inter-calibration efforts have recently started, where independent telescopes observe the same objects within their fields (beyond Landolt stars)

CSP vs. SDSS Mosher et al, AJ 144, 17, (2012)

- CSP & SDSS simultaneously observed 9 live SN Ia. Use measured filter transmissions to correct and compare mags.

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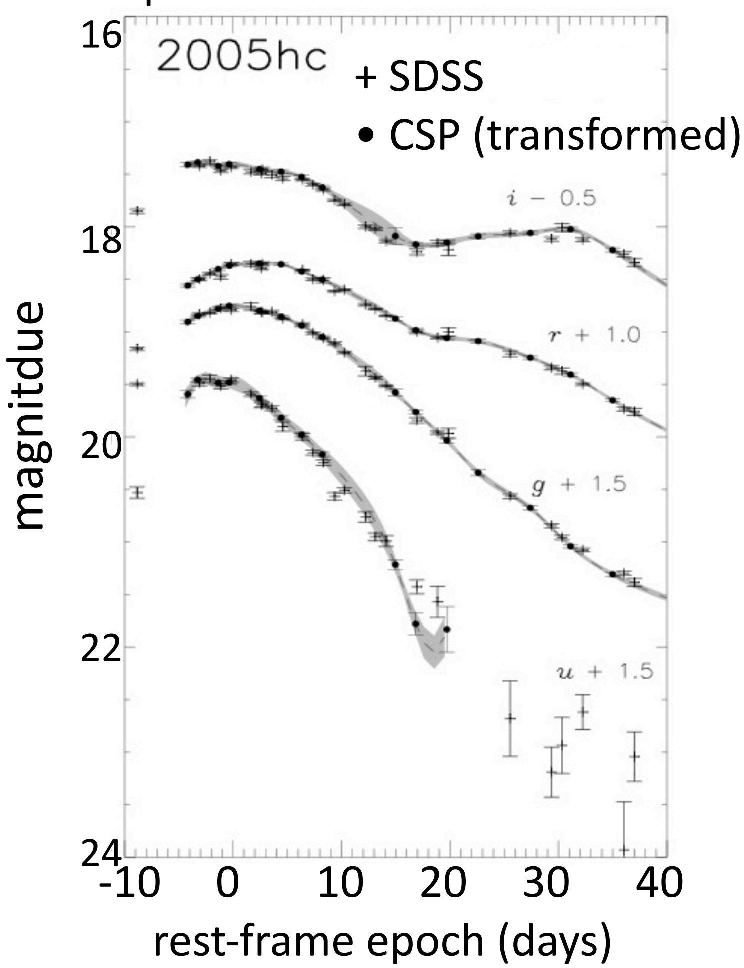
Interpolate SDSS obs to CSP obs



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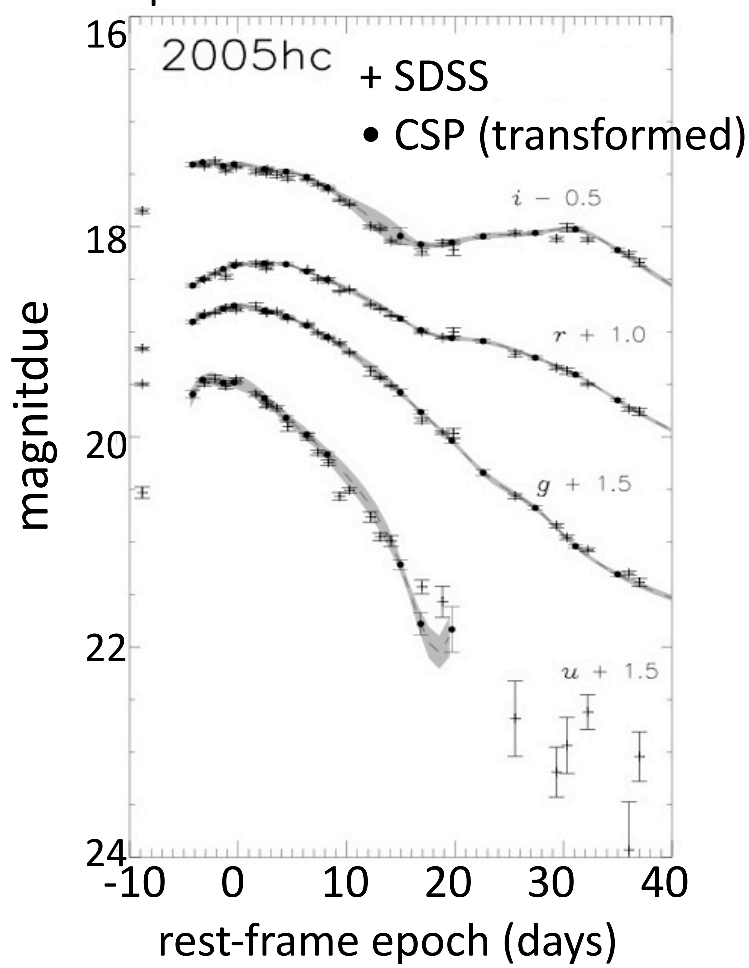


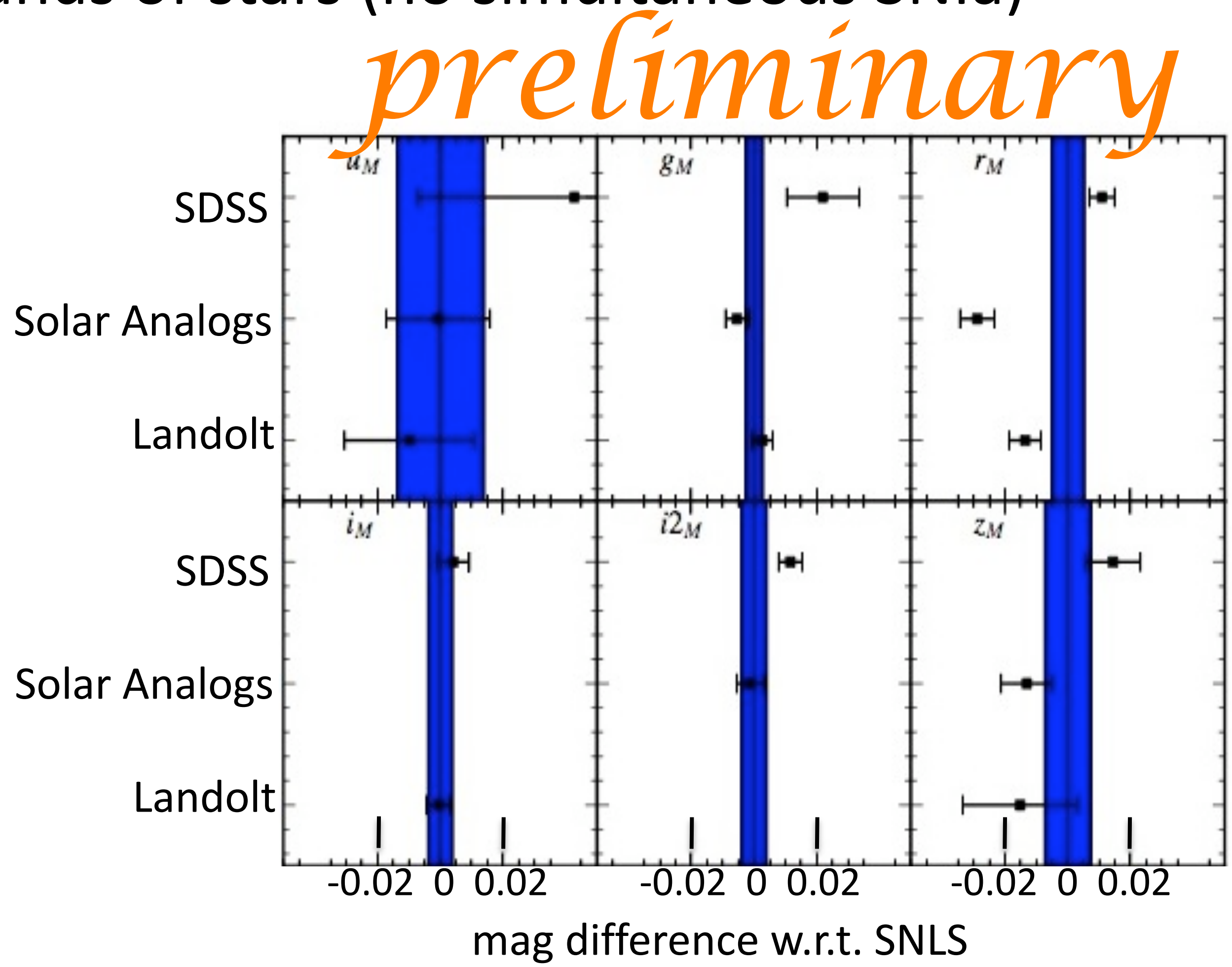
Table 6. Magnitude agreement statistics: pooled data

		residual		
band	N	mean [mags]	scatter[mags]	scatter[σ]
u	32	0.001 ± 0.014	0.077	1.01
g	62	-0.002 ± 0.006	0.043	0.97
r	60	-0.002 ± 0.005	0.049	1.24
i	59	-0.011 ± 0.005	0.050	1.32

Note. — Residual is defined as CSP magnitude minus interpolated SDSS magnitude. CSP magnitudes have been S-corrected onto the SDSS photometric system. Residual mean and scatter have been calculated using the inverse variance as weight. To test gaussianity of the statistical errors, we have also calculated the scatter in units of the error $\equiv \Delta m/\delta m$. If errors are random, we expect this quantity to be 1.

SDSS vs. SNLS (M. Betoule et al, in prep)

- SNLS observed SDSS fields to compare mags for thousands of stars (no simultaneous SNIa)



Calibration: Old vs. New

	Old surveys: SNLS,ESSENC,SDSS	**New Surveys: PS1, DES, LSST …**
Filter transmission	Once every few years in a lab	weekly/monthly in-situ
Filter uniformity	Whatever they got	Strict specifications

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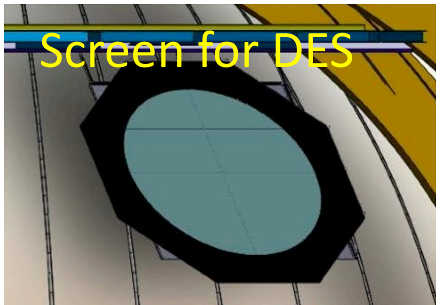
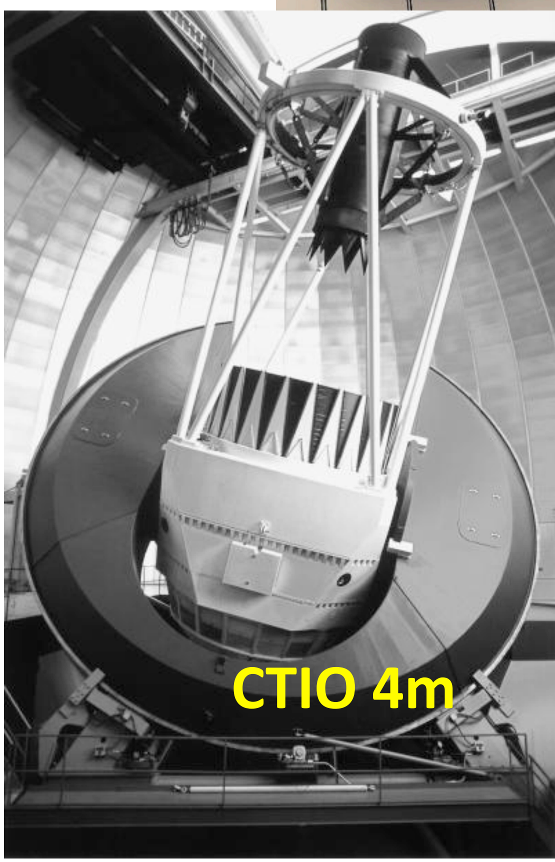
Filter transmission	Once every few years in a lab	weekly/monthly in-situ
Filter uniformity	Whatever they got	Strict specifications
Atmosphere	Photometric night by visual inspection or 10um camera	Monitor bright stars with multi-band camera or spectrograph. GPS for water vapor.
Spectrophotometric standards	HST CalSpec, White Dwarf Models	Same, but more White Dwarfs

In-Situ Measurement of Telescope Efficiency





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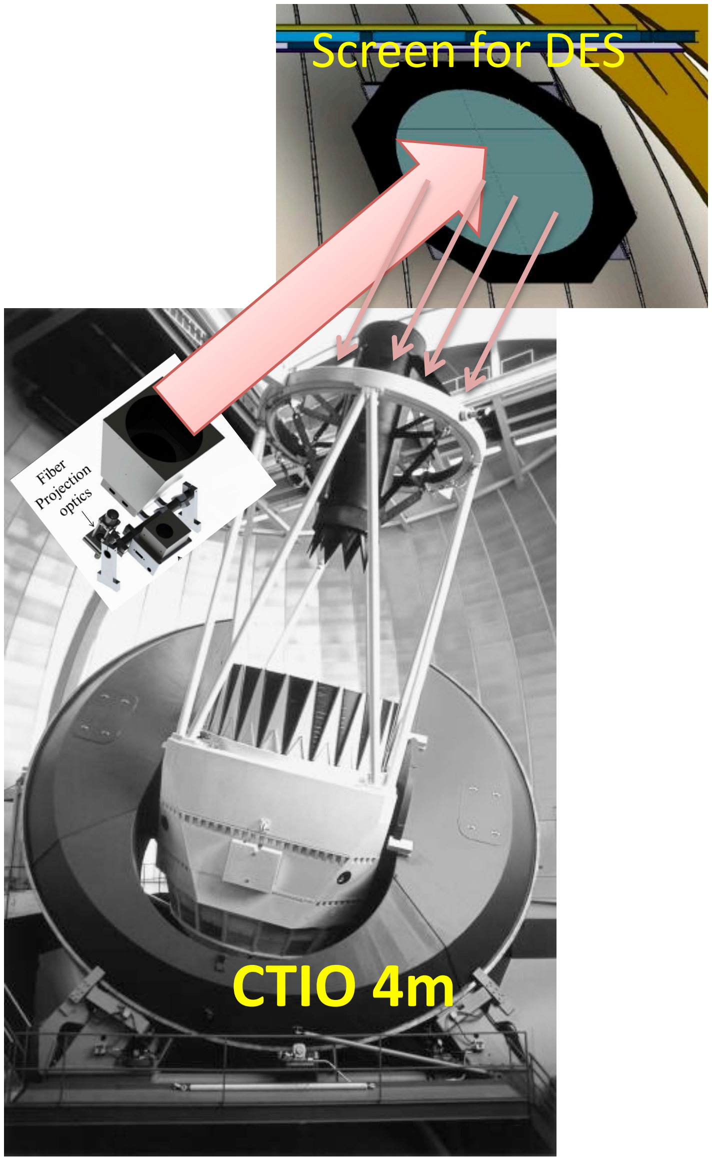


Monochromatic light source illuminates screen

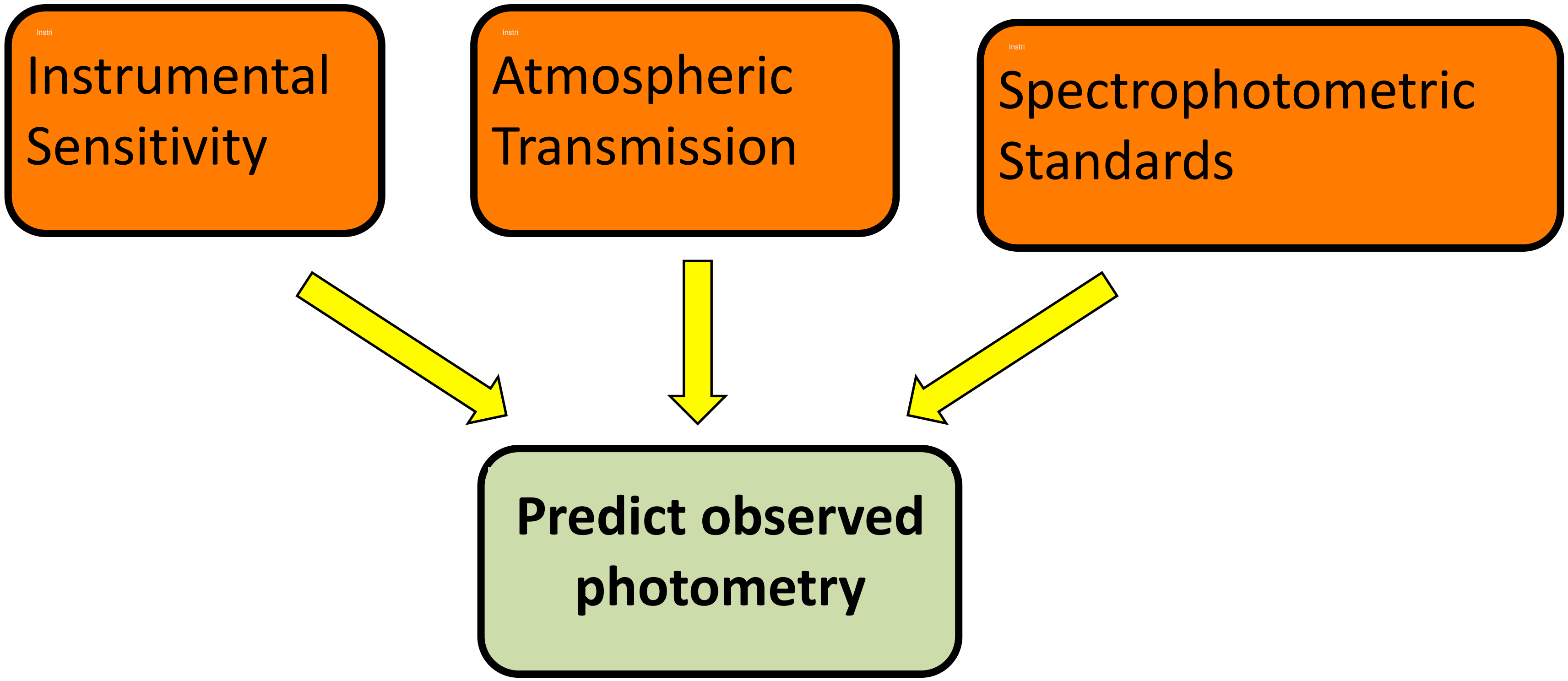
Reflected light goes into telescope and into PIN diode.
Eff = $N_\gamma^{tel} / N_\gamma^{PIN}$

Map out efficiency vs. λ

Several existing systems built by C. Stubbs and D. Depoy.

Holy Grail of Calibration

(from C. Stubbs talk at FNAL Calib conf, April 2012)



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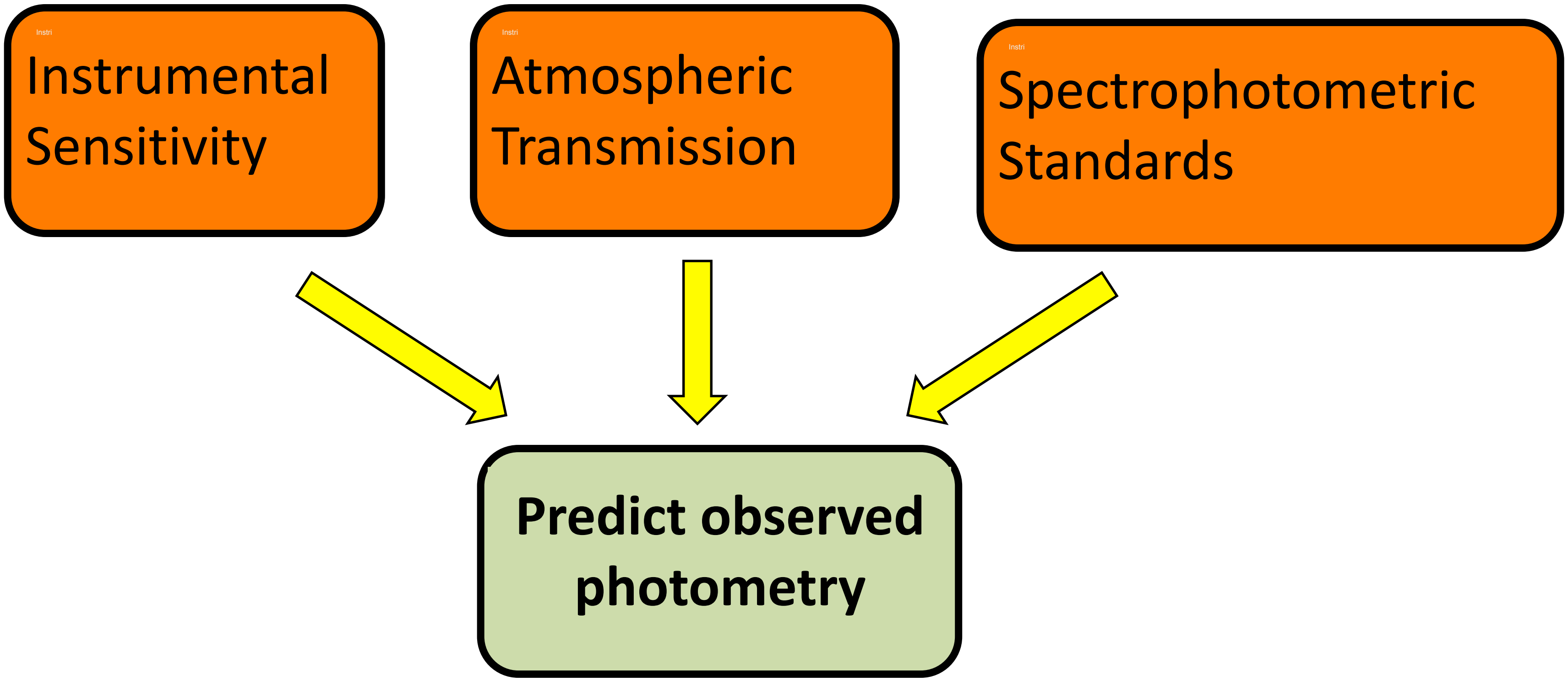

PanStarrs-1 comes within 5% rms
Tonry et al., AJ 750, 99, (2012)
Long-term goal is sub-percent.