Absolute and Relative Photometric Calibration of Optical Surveys

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PACCD Meeting

My day job is to measure cosmological parameters with Type Ia Supernovae

But the top systematic uncertainty for our dark energy measurement is due to calibration.

So I spend a lot of time working on calibration of past (Pan-STARRS), current (DES) and future surveys (WFIRST)

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But the top systematic uncertainty for our dark energy measurement is due to calibration.

So I spend a lot of time working on calibration of past (Pan-STARRS), current (DES) and future surveys (WFIRST)

PS1 work with Chris Stubbs, Doug Finkbeiner

DES work with James Lasker, Ting Li

WFIRST Photometric Calibration Working Group Leads:
Dan Scolnic
Stefano Casertano
and work with Chris Hirata, Chris Stubbs, Charles Shapiro

Some definitions:

There is relative and absolute calibration.

Absolute - how close are the number of counts per second to real physical value.

Relative [spatial/temporal] - If same exact star is observed on different parts of filter plane, or different parts of sky or on different seasons, how consistent would measurements be.

Relative [colors] - How accurate are filters/system-throughput known and how well is this tied to observations

These are top calibration concerns (in no particular order)

1) Spatial uniformity of photometric response (relative fluxes, colors)

2) Field-dependent bandpass effects

3) Temporal photometric stability

4) Persistence and saturation effects

5) Accuracy of relative flux across filters (i.e., absolute slope of photometric response)

6) Characterization of detector non-linearity effects

7) Laboratory characterization of component response and system throughput

8) Cross-survey photometric calibration

9) Understanding PSF issues esp. in image-subtraction search and photometry.

This is the PS1 SN Cosmology Analysis Error Budget

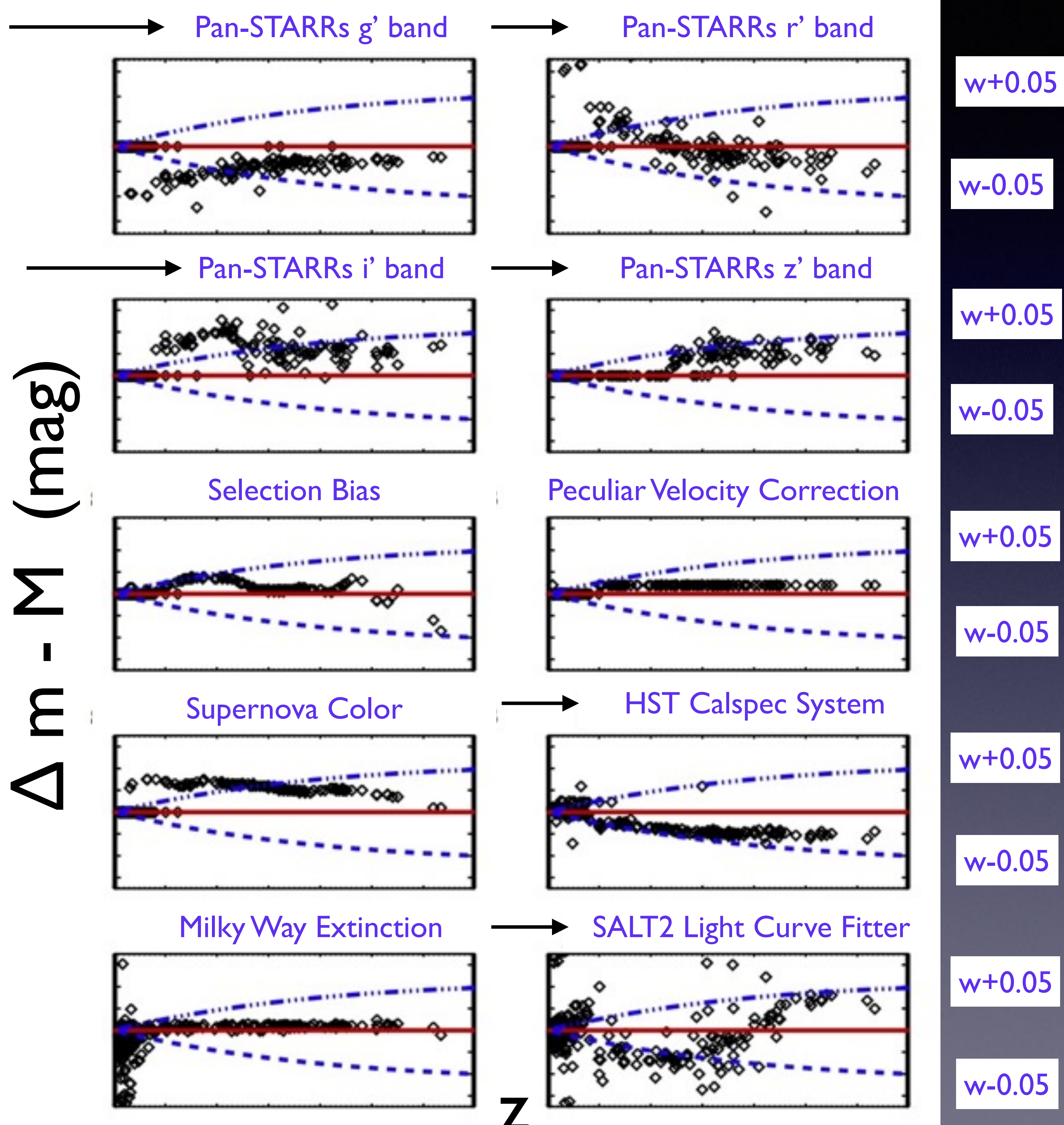
	dw
Calibration:	0.045
SN Color Model:	0.023
Host Galaxy Dependance:	0.015
MW Extinction:	0.013
Selection Bias:	0.012
Coherent Flows:	0.007

Top issue, by far, is calibration.

To measure w to 10%, we need careful accounting of systematics

Here we show Hubble diagram differences when we change our biggest systematics by 1σ

w is equation of state of dark energy



Systematic uncertainties are of similar size to statistical uncertainties. Propagate systematic uncertainties to covariance matrix.

Based on Scolnic et al 14b

Common Path to Calibrating Recent Large-Area Photometric Surveys

1. Measure throughput. For select fields, tie [arbitrarily] observed magnitudes in each band to some system (use another survey or small set of standard observations)
2. From [flat-fielded] observations over a large area of sky, tie observations together to form full sky relative calibration
3. Use full-sky calibration to set zeropoints of observations of spectral standards
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For full-sky calibration, there are two different methods.

1. The Ubercal Method

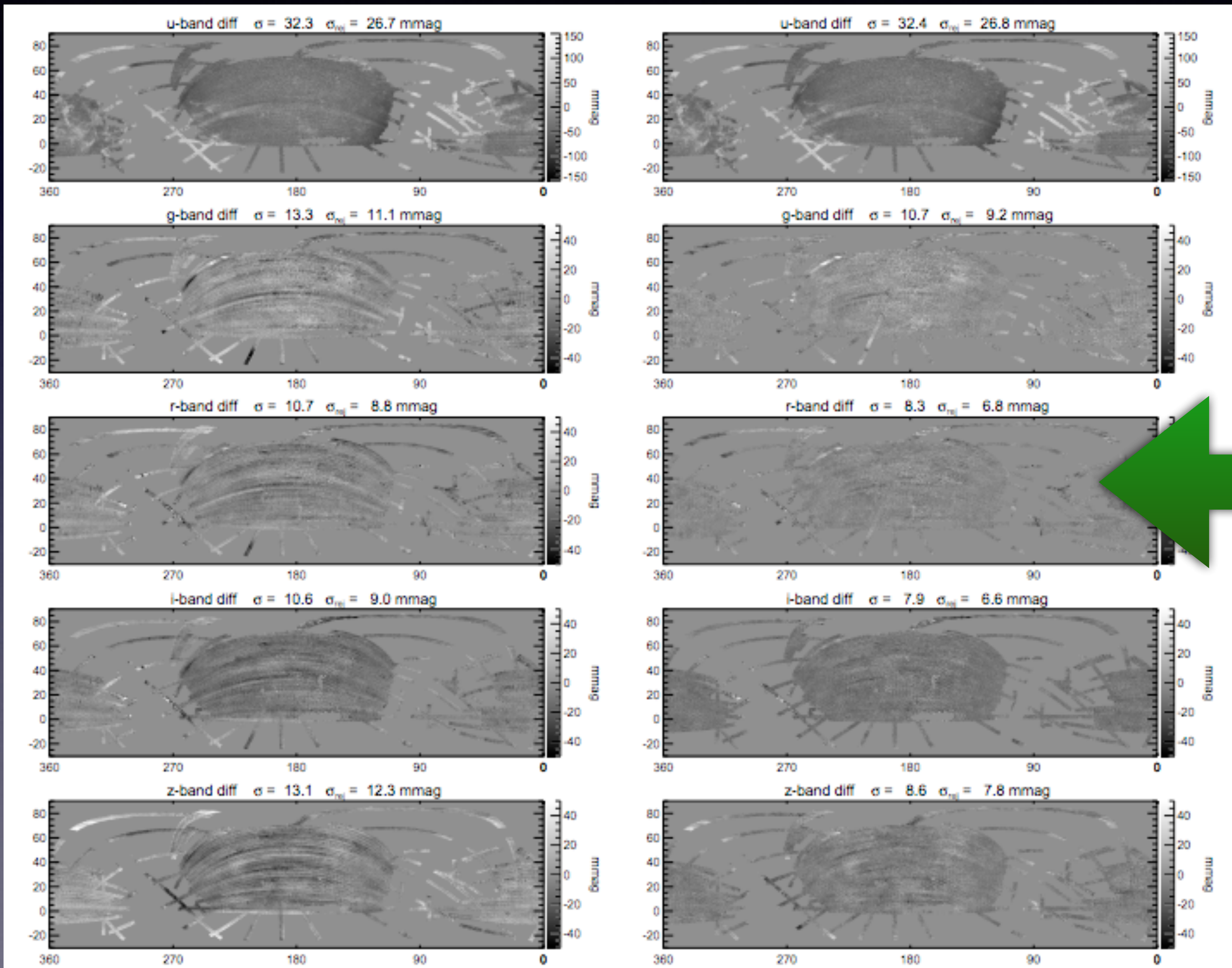

FIG. 1.— The mean difference (PS1 minus SDSS) in 15 arcminute

FIG. 2.— Same as Fig. 1, but after recalibration. The cali-

Padmanabhan et al. SDSS
Schlafly, Finkbeiner et al. PS1 Ubercal,
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relative calibration across sky <5mmag
<3 mmag for MD fields

Compared PS1 to SDSS, found SDSS issues

Use repeat observations to simultaneously solving for the system throughput, the atmospheric transparency, and the large-scale detector flat field with numeric matrix solutions

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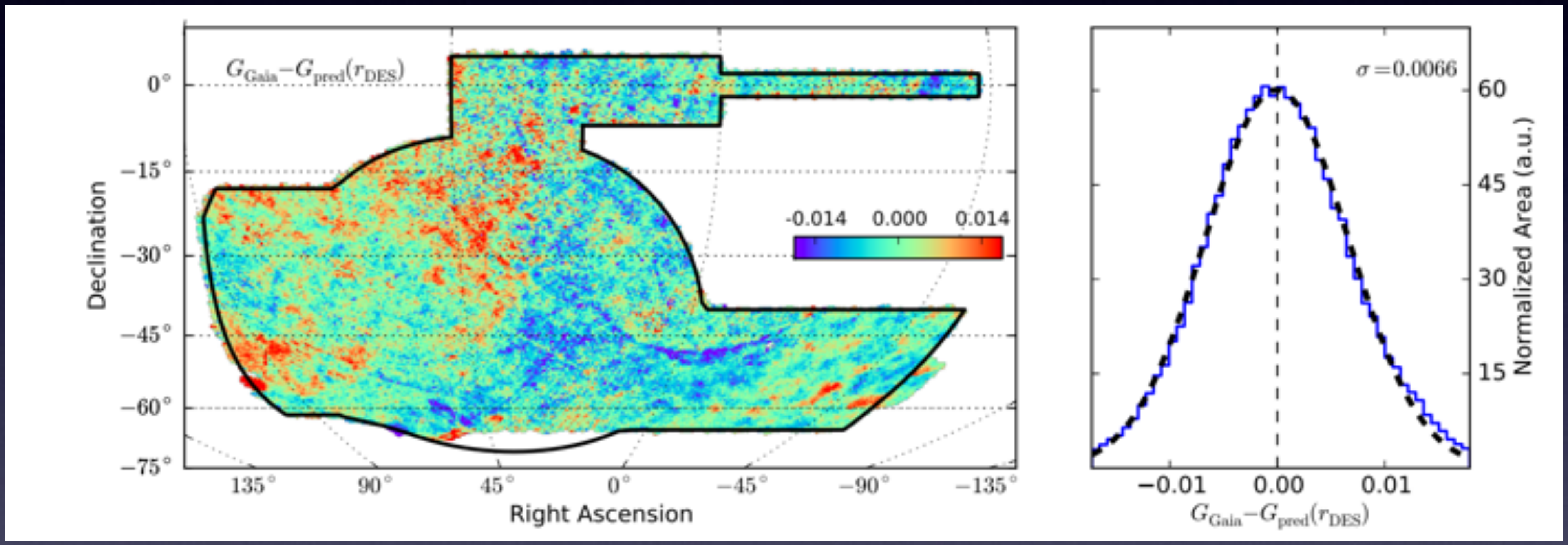
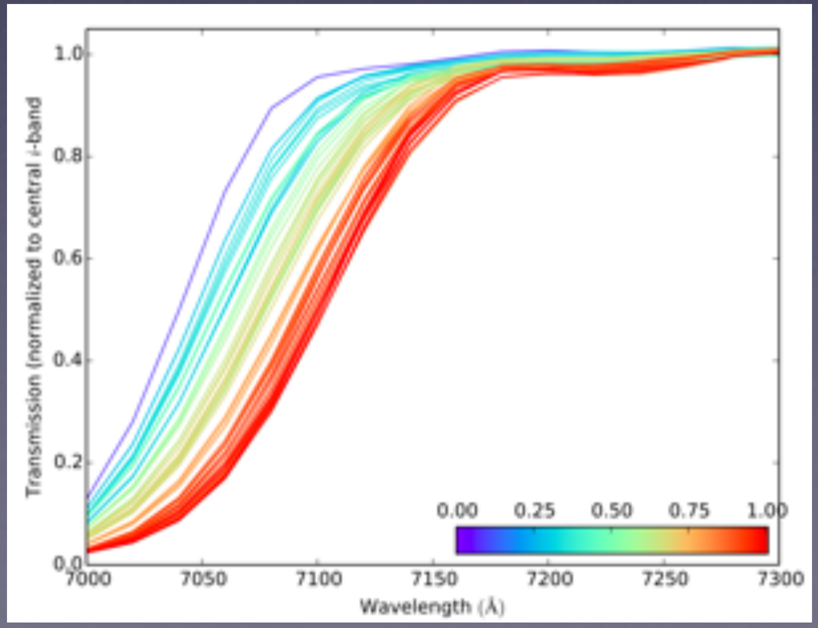
II. Forward Global Calibration



Rykoff, Burke et al. in prep for DES



The FGCM approach is to 'determine the full atmospheric and instrumental passbands through which observations are made at the time they are made.'

Ongoing work by James Lasker to compare DES and PS1
See Ting Li's talk for similar analysis

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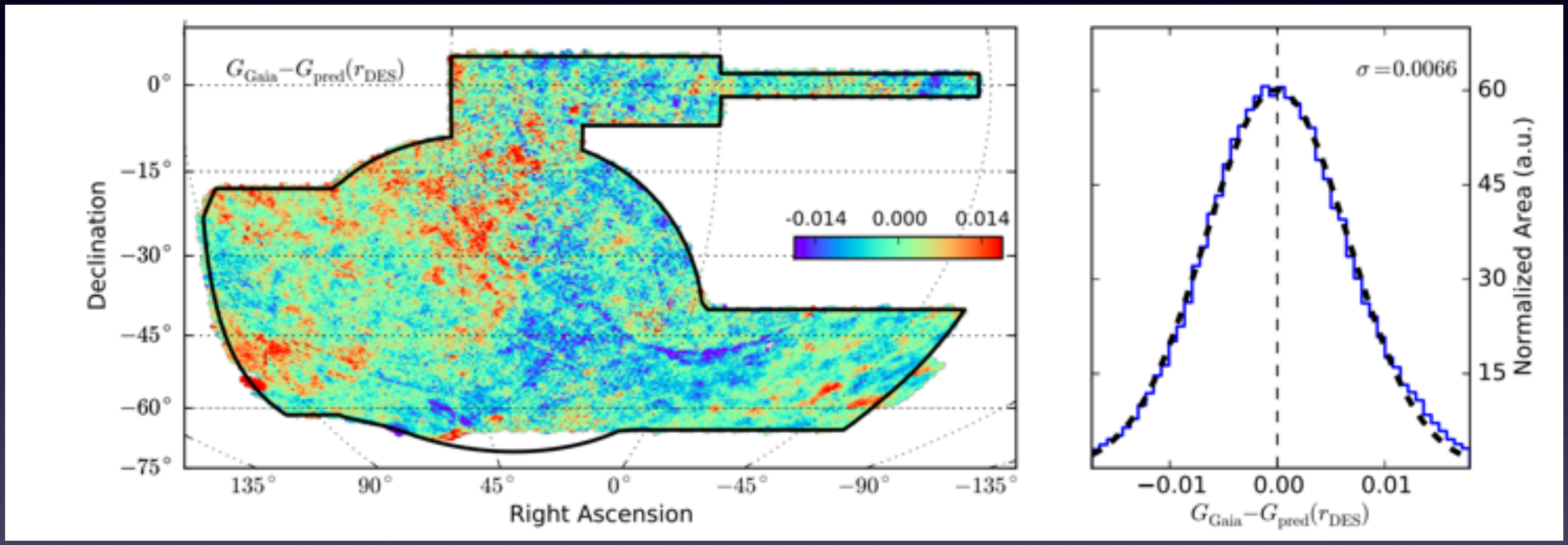

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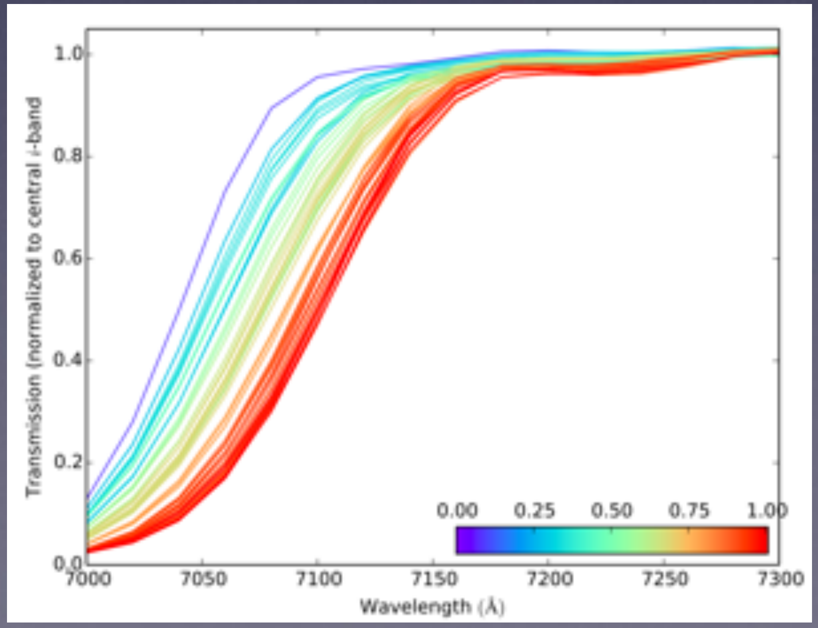

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Ongoing w

Target goal: 1-2 mmags

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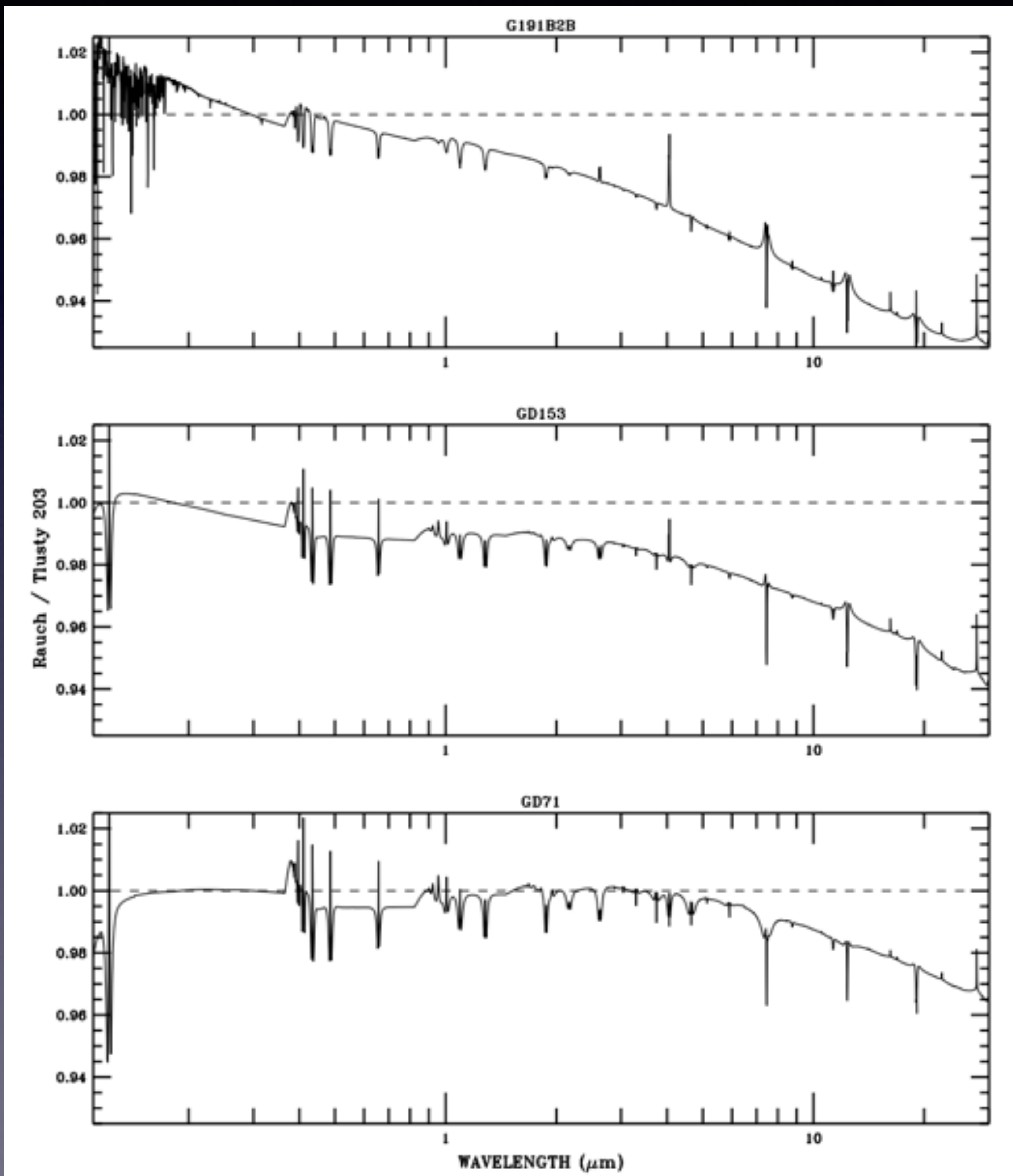
There are two methods for determining the absolute/color zeropoints of system.



Method 1: WD models

-Current state of the art: HST, 5 mmag per 7000 A

-Concerns: Models of WD standards still have sizable uncertainties, especially in IR.

-Improvement with self-calibration: No.

G. 11.—Ratio at R = 500 of the new Rauch model fluxes to the pure-hydrogen Tlusty 2003 models that previously defined the three primary WD SEDs. NLTE models.Bohlin+ 2014

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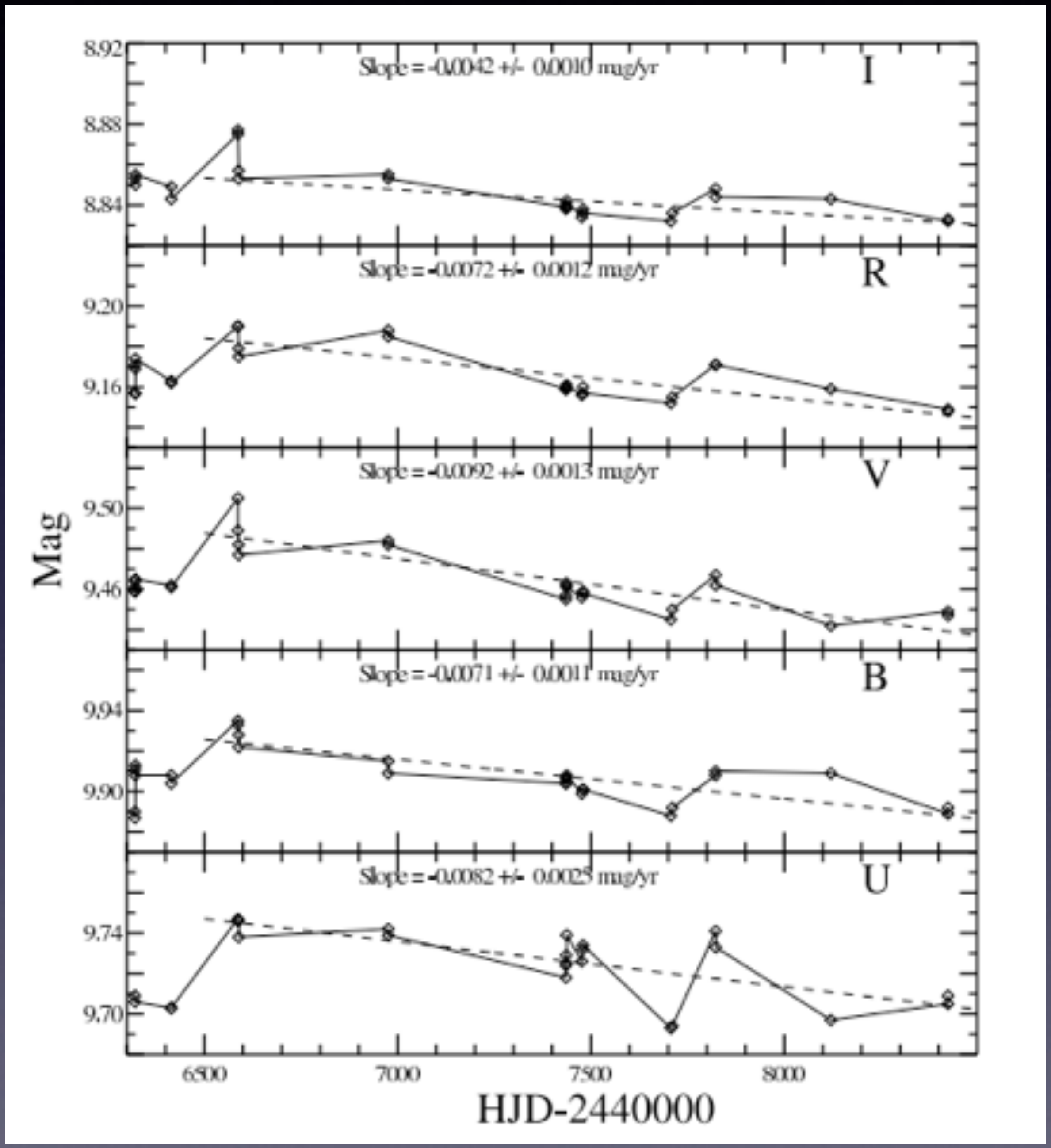


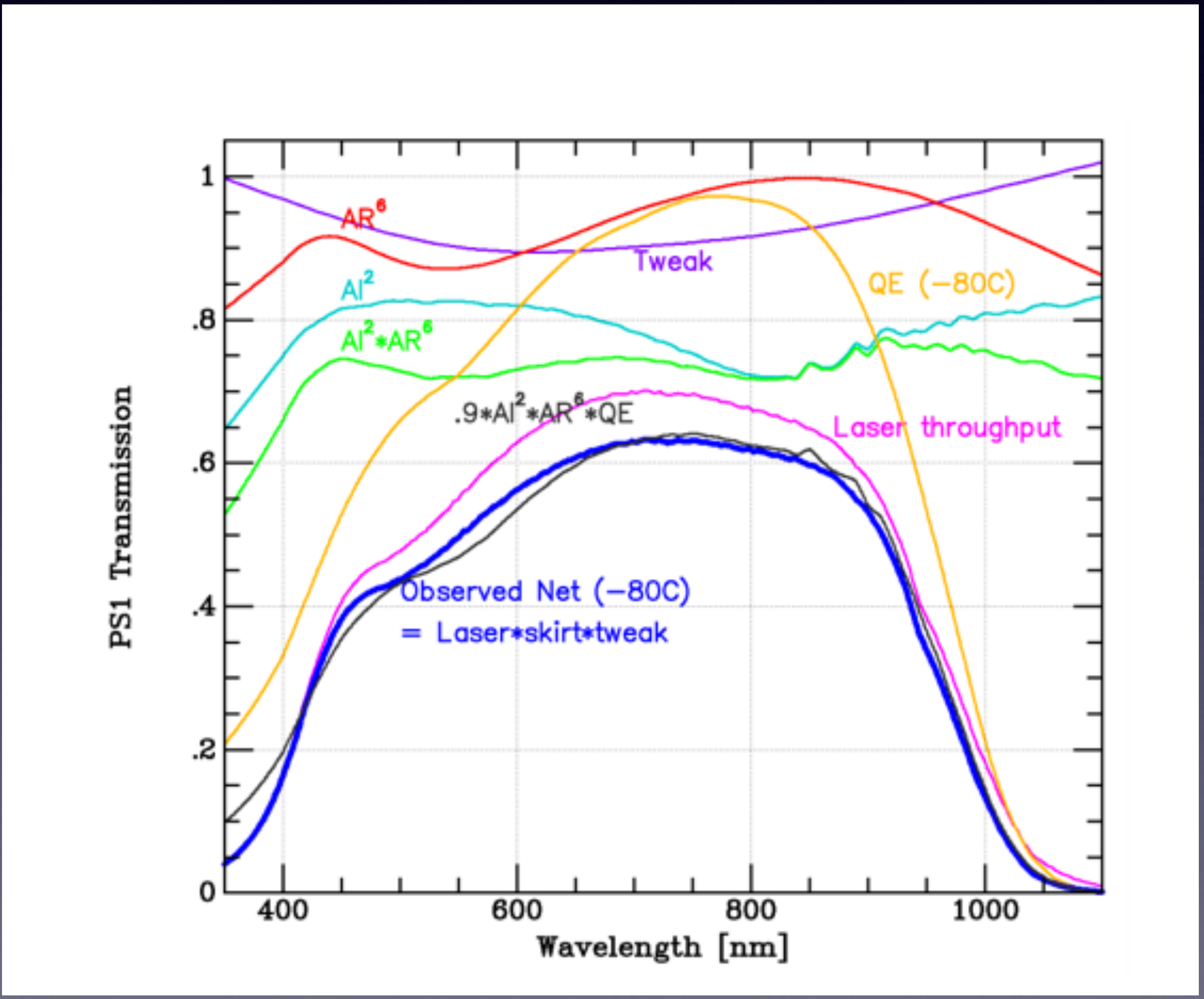
Method 1: WD models

A number of past systems are defined by the flux of one standard, BD17, which is changing with time!! [Bohlin+Landolt 2015]

New programs to create larger database of fainter WD standards [Narayan 16]

There are two methods for determining the absolute/color zeropoints of system.

Method 2: Lab based metrology



Plan to use precision calibrated photodiode as the fundamental metrology reference in order to determine the relative throughput of the PanSTARRS telescope and the Gigapixel imager. Technique ses a tunable laser as a source of illumination on a transmissive flat-field screen.

[Stubbs 2010, Tonry 2012]

Hasn't yet worked to 1% level

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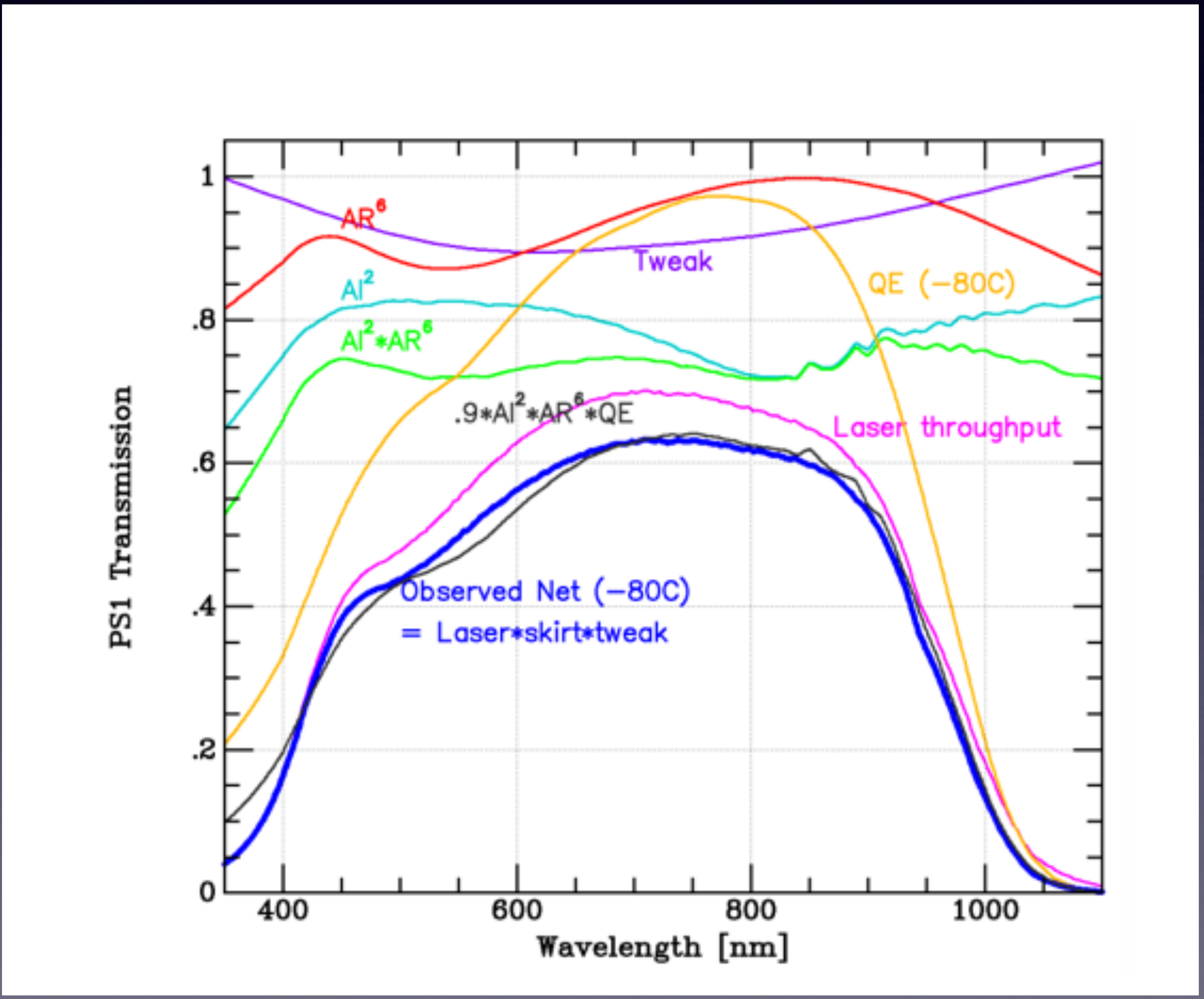

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[Tonry, Stubbs et al. 2012]

Hasn't

Relative calibration target: 3 mmag/7000
Absolute calibration target: 2%

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When comparing photometry of standards to synthetic predictions, must check

-> Field dependent bandpass effects

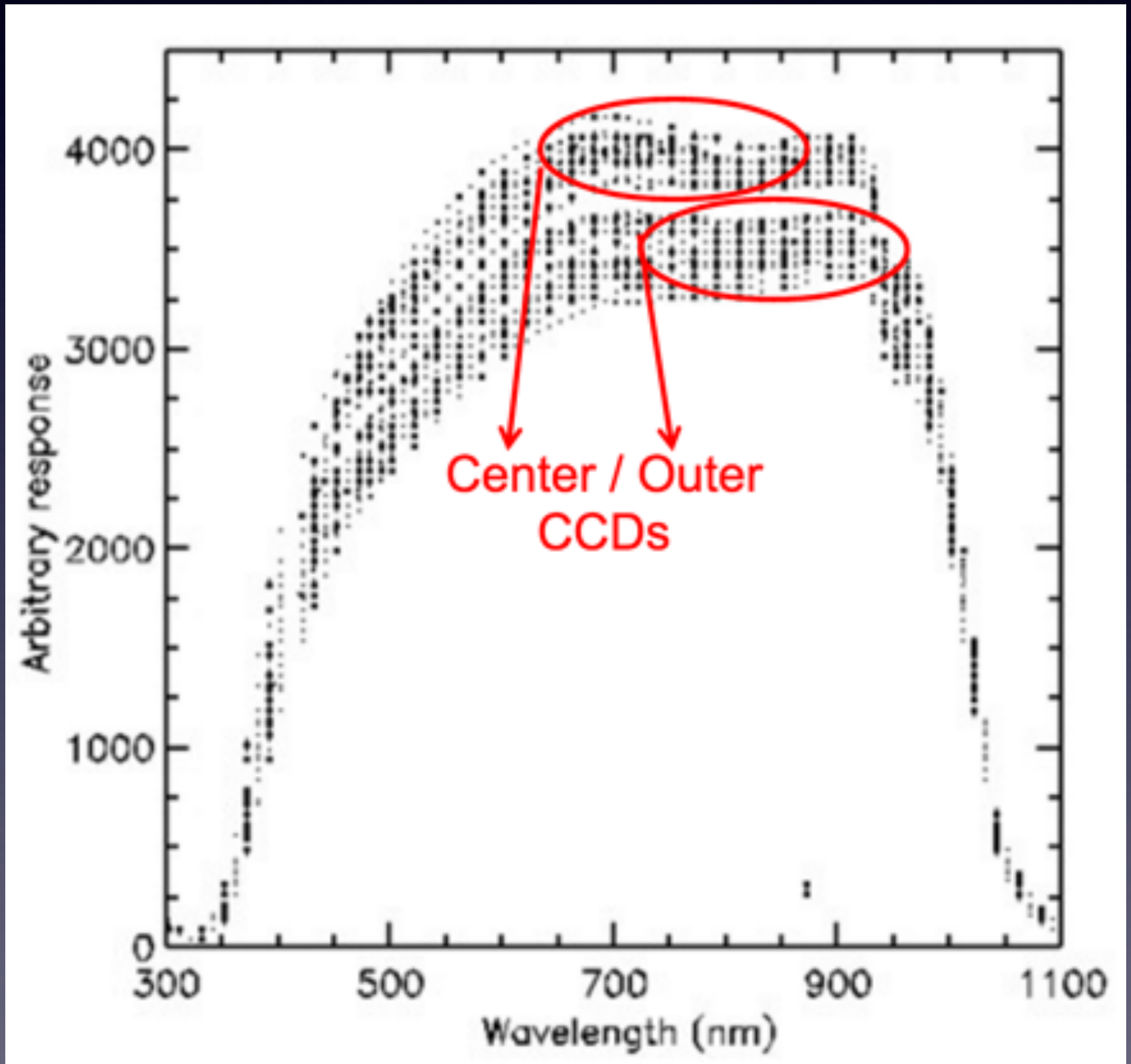
Target goal: 1 mmag

-> Temporal stability

Target goal: 1 mmag

-> Non-linearity

Target goal: 3 mmag/dex



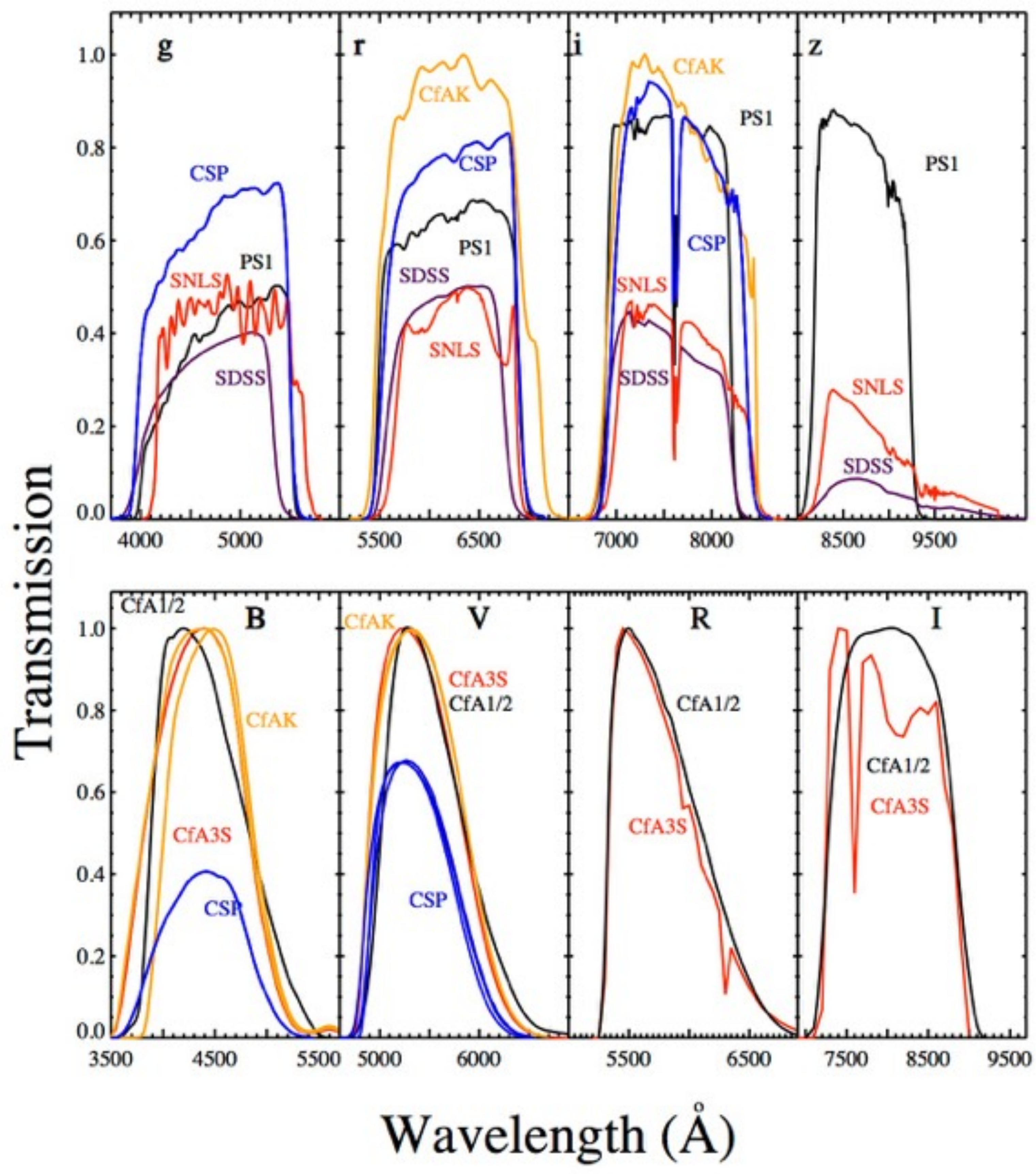
For set of standards, for each passband, measure, e.g. AB-offset=Mean(Phot-Synthetic)

DES Filter Differences from Marshall et al. 2013

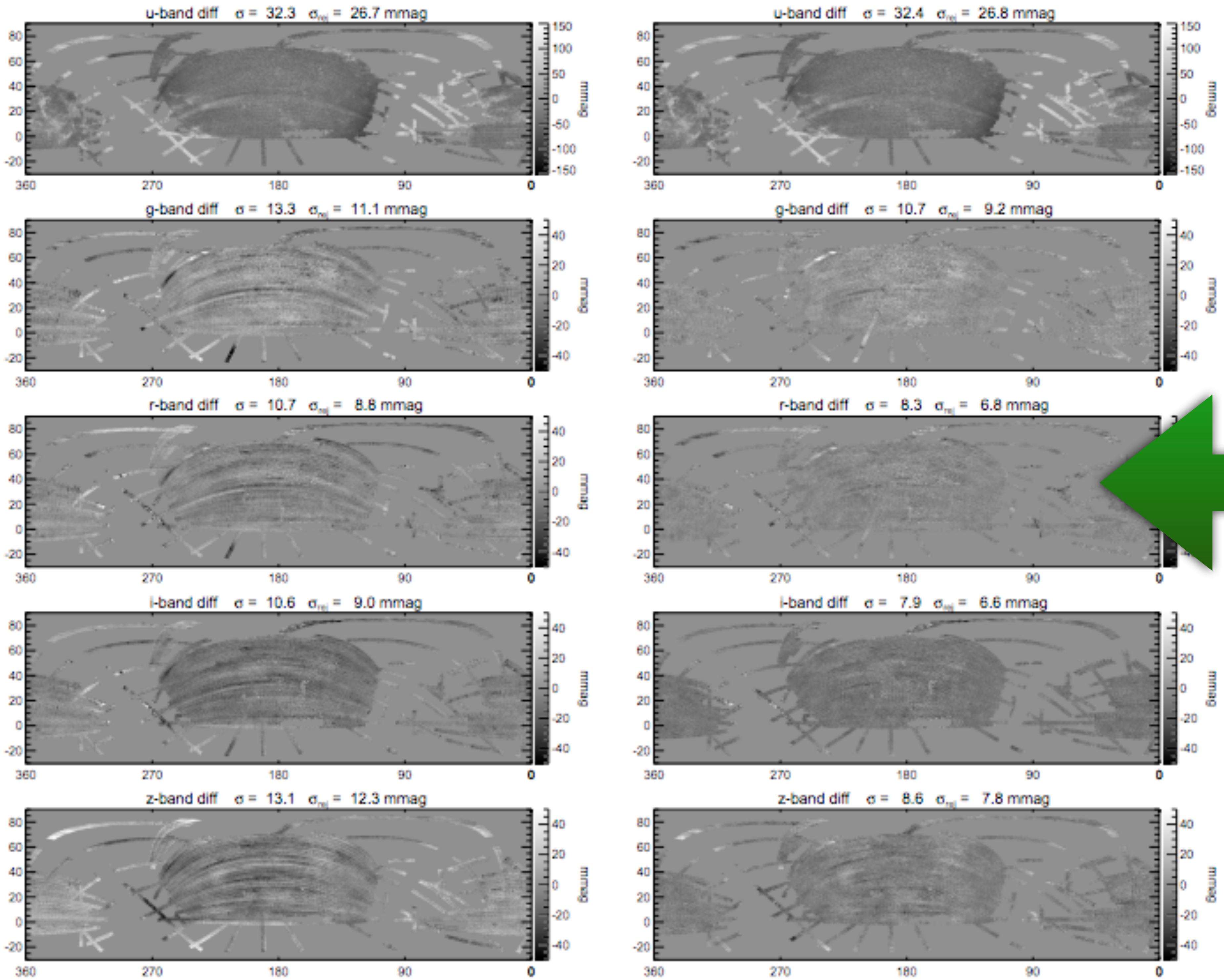
The spectrophotometric calibration system consists of a monochromator-based tunable light source that is projected onto the flat field screen using a custom line-to-spot fiber bundle and an engineered diffuser. Several calibrated photodiodes positioned along the beam monitor the telescope throughput as a function of wavelength.

So every survey does this and defines its own system, can we combine all of them?

Different surveys on different systems (AB system, standard system) with different filters..



We can take advantage of large sky surveys to compare calibration of multiple surveys



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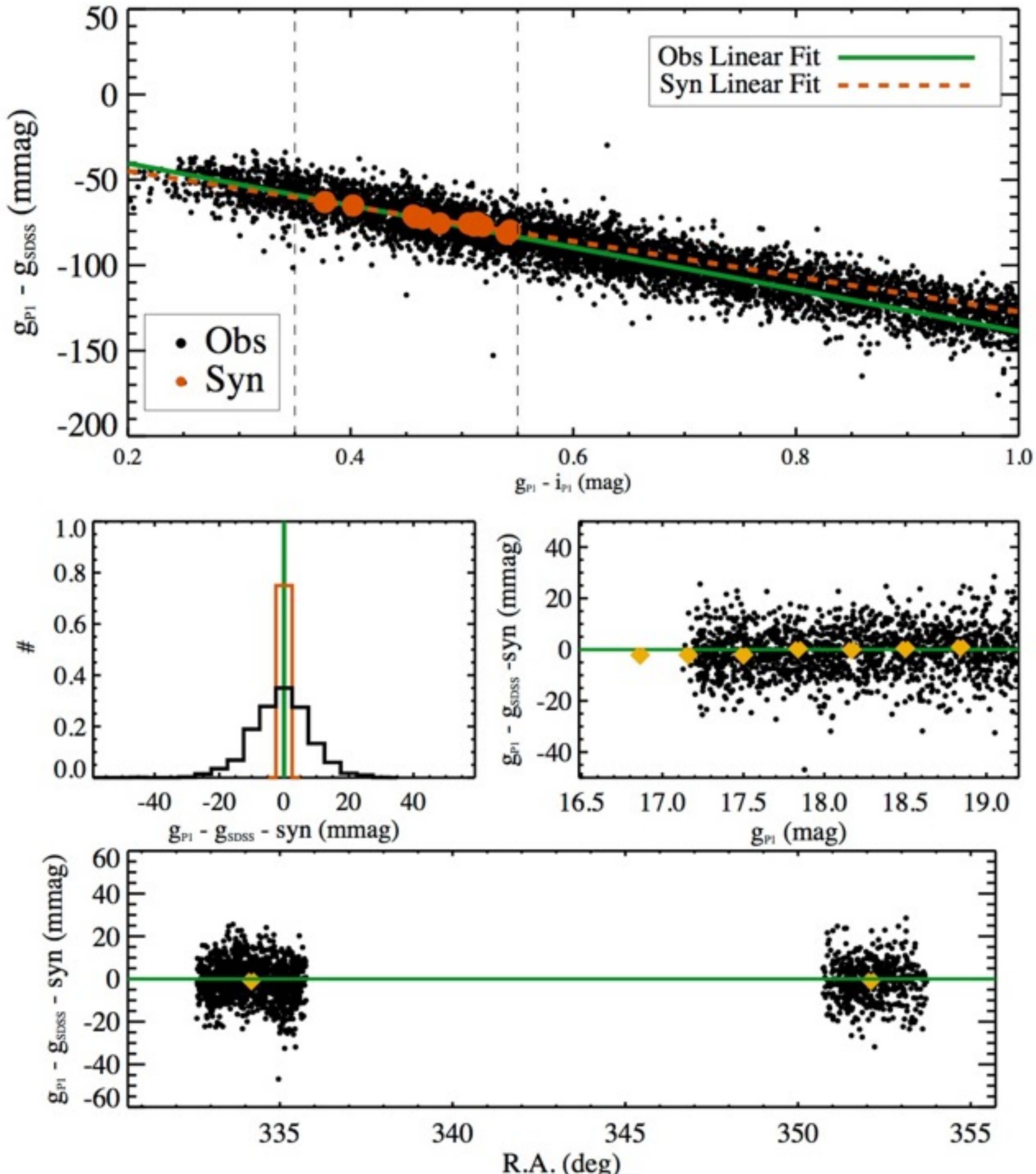
Compared PS1 to SDSS, found SDSS issues

Can invert this process and try to find system offsets for every survey

Based on Scolnic Supercal 15

For any system, for any patch of sky, can measure differences between PS1 observations and other survey's observations of same stars, and then compare to expectations from synthetic spectral library



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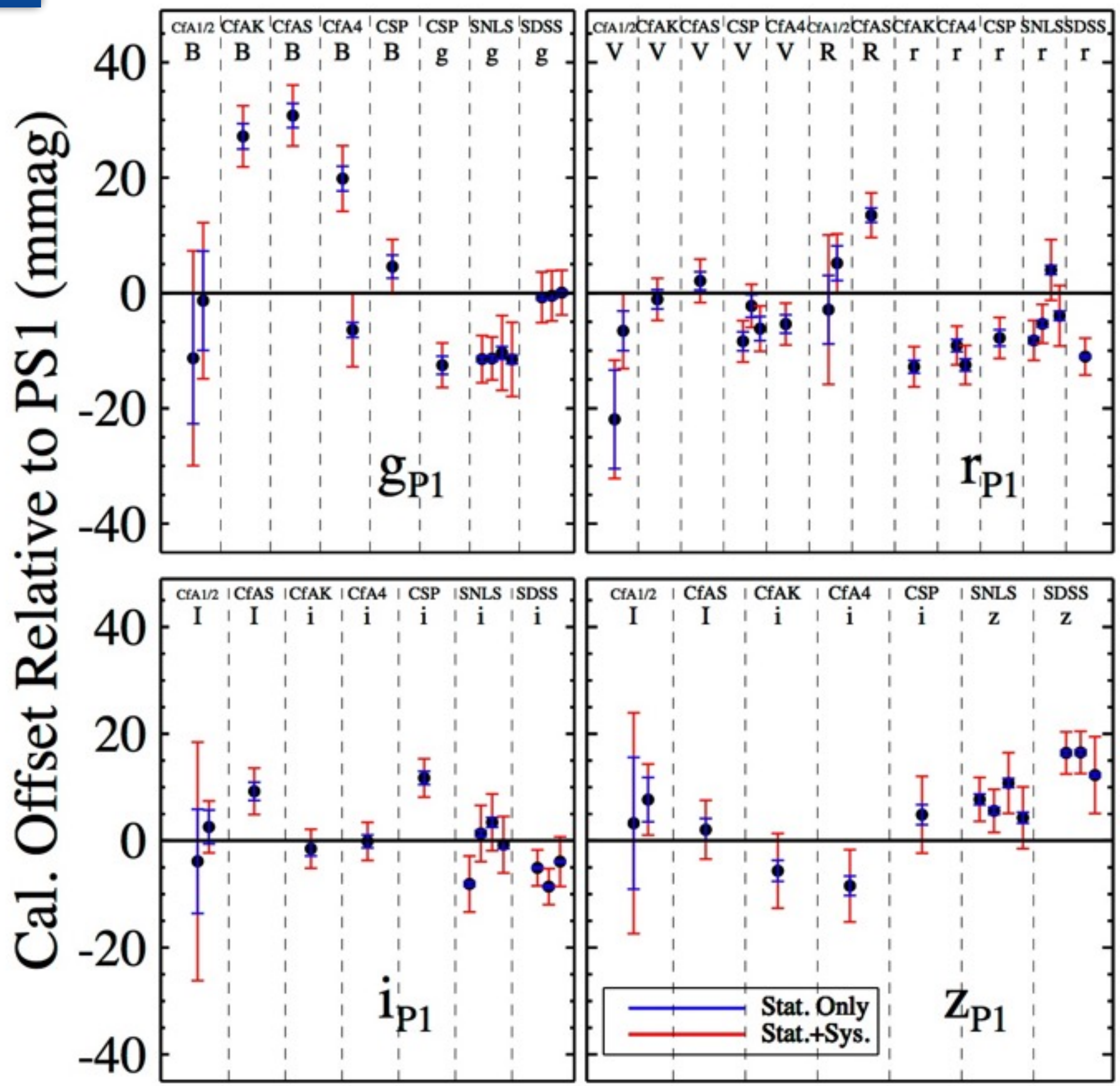
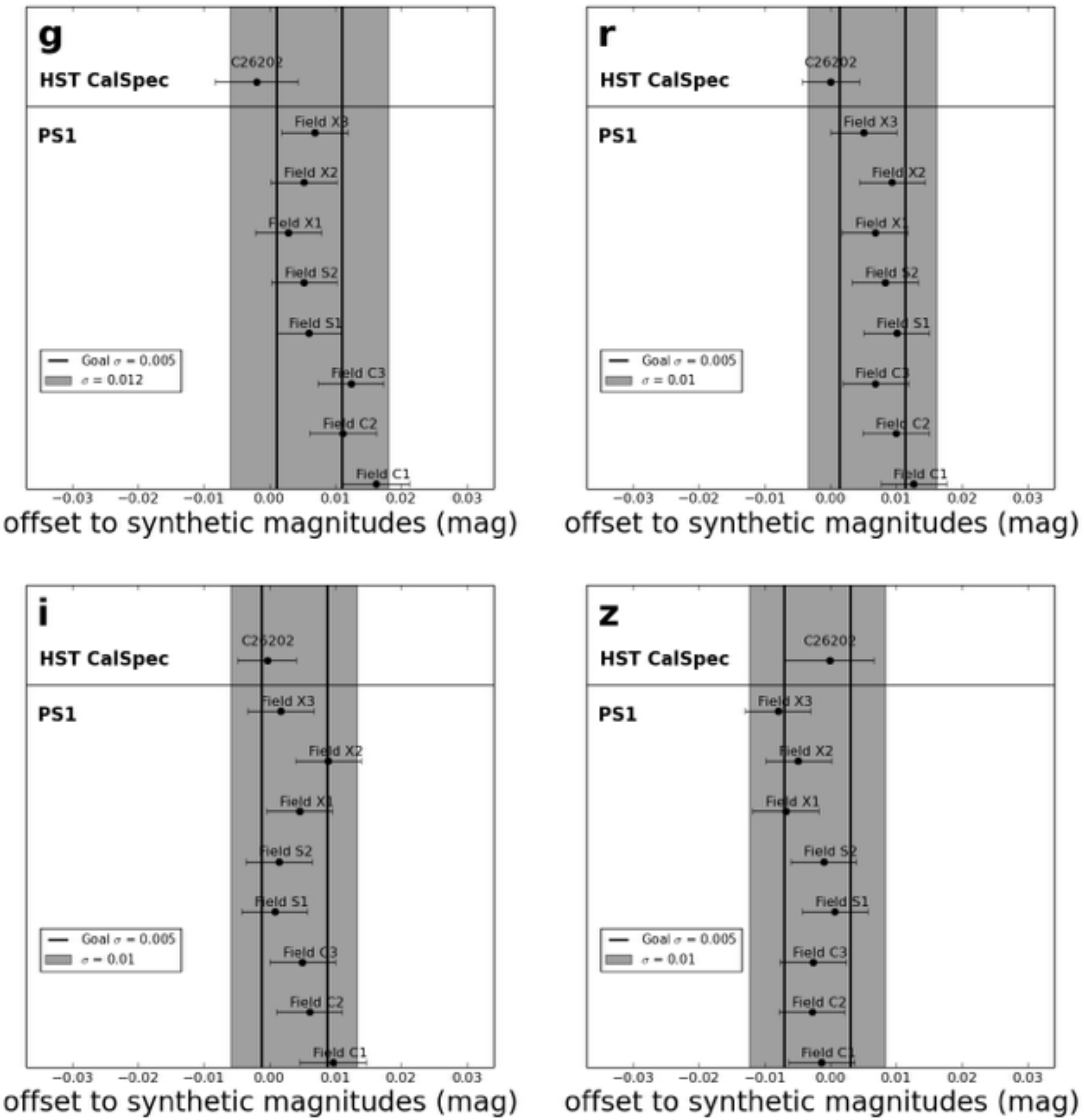
Doing this for all available public data, measure an offset for each filter for each system.



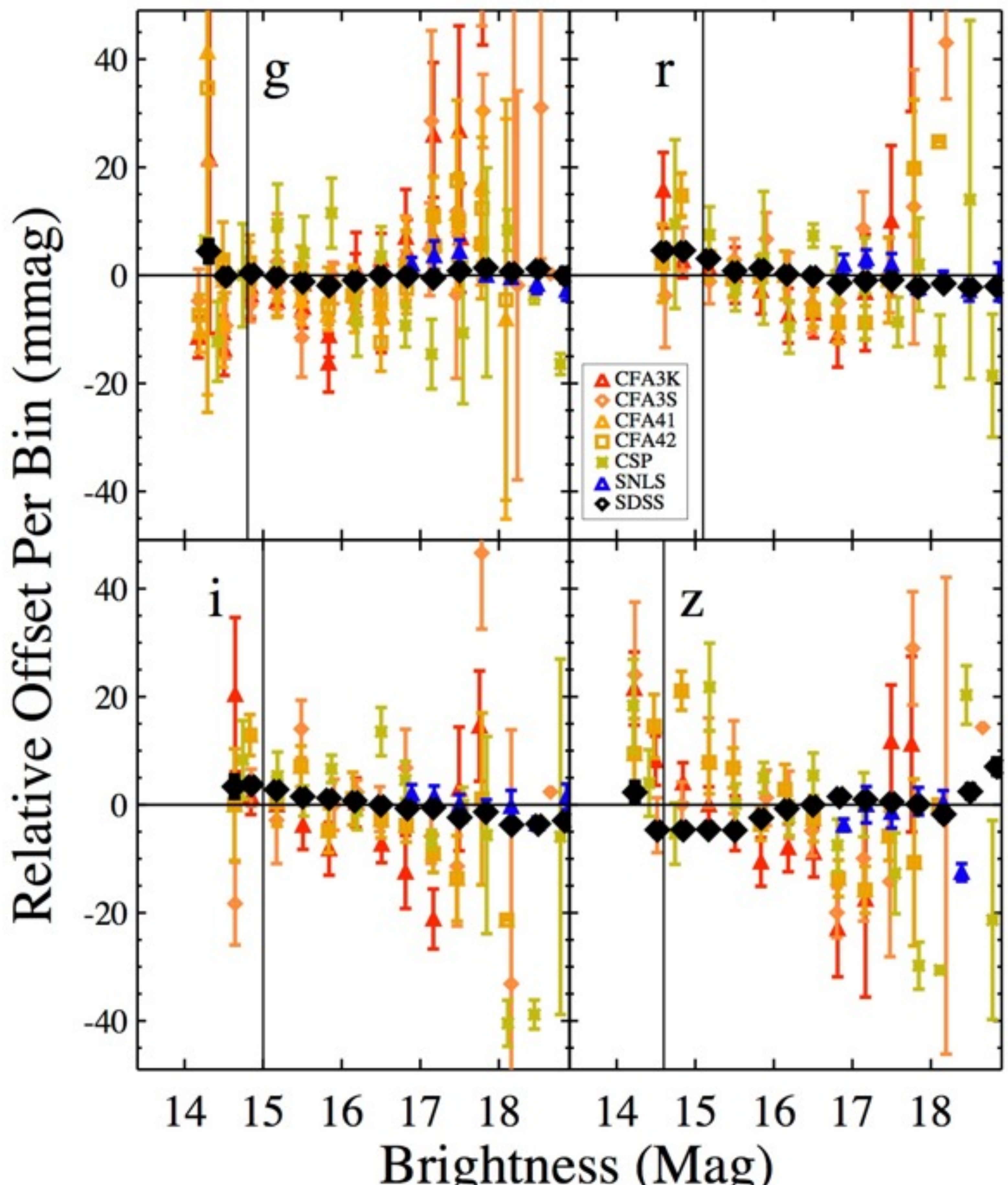
Can do same process with DES, using HST Calspec standard and PS1 to tie calibration

[Lasker in prep]



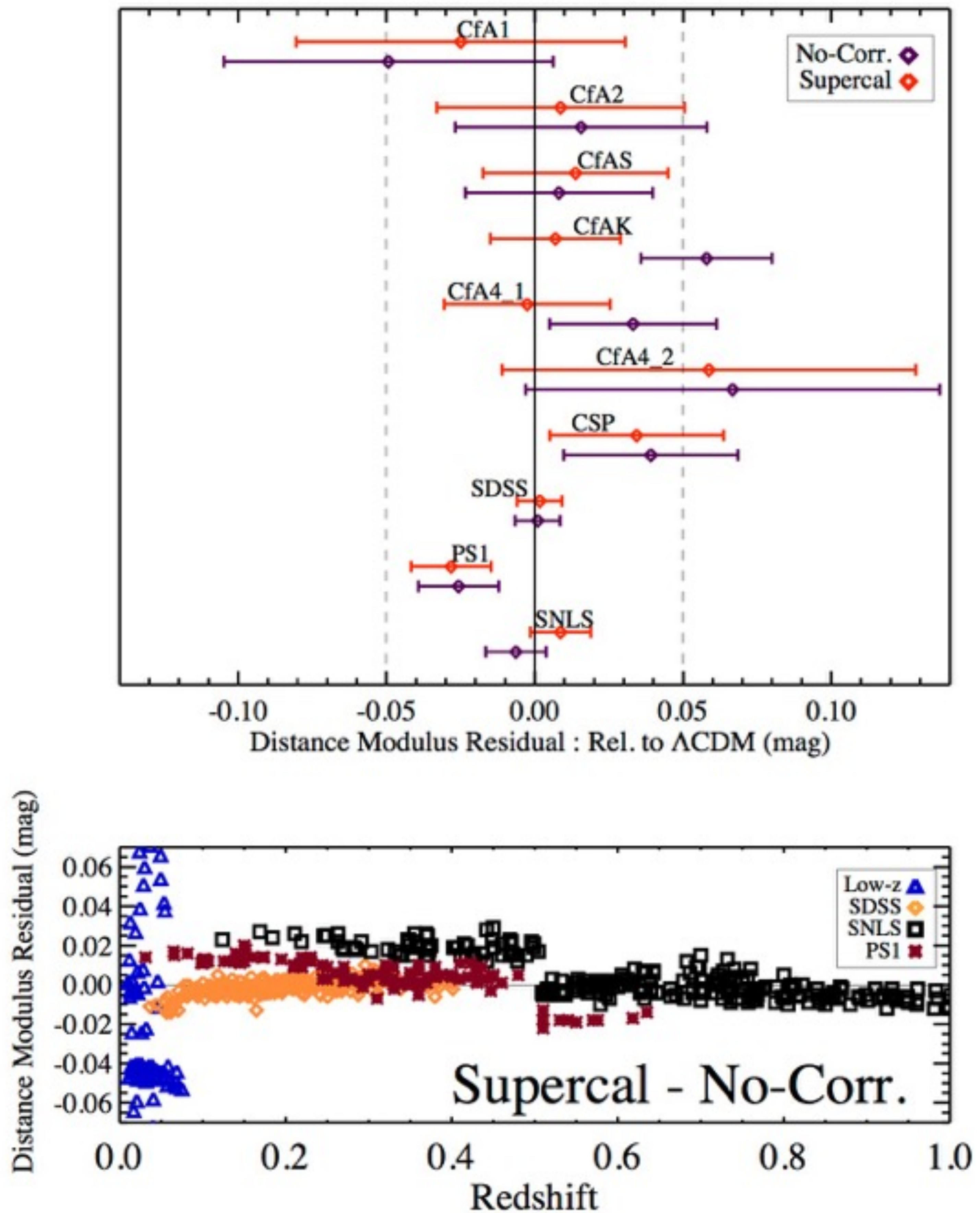
We checked a number of systematics of this approach, most significant is a linearity bias with PS1.

Overall we find this to be smaller than any of the offsets between surveys.



We can then remove these systematic offsets from each sample and measure new distances.

Overall, this is a 3% systematic uncertainty (compared to 5% statistical constraints)



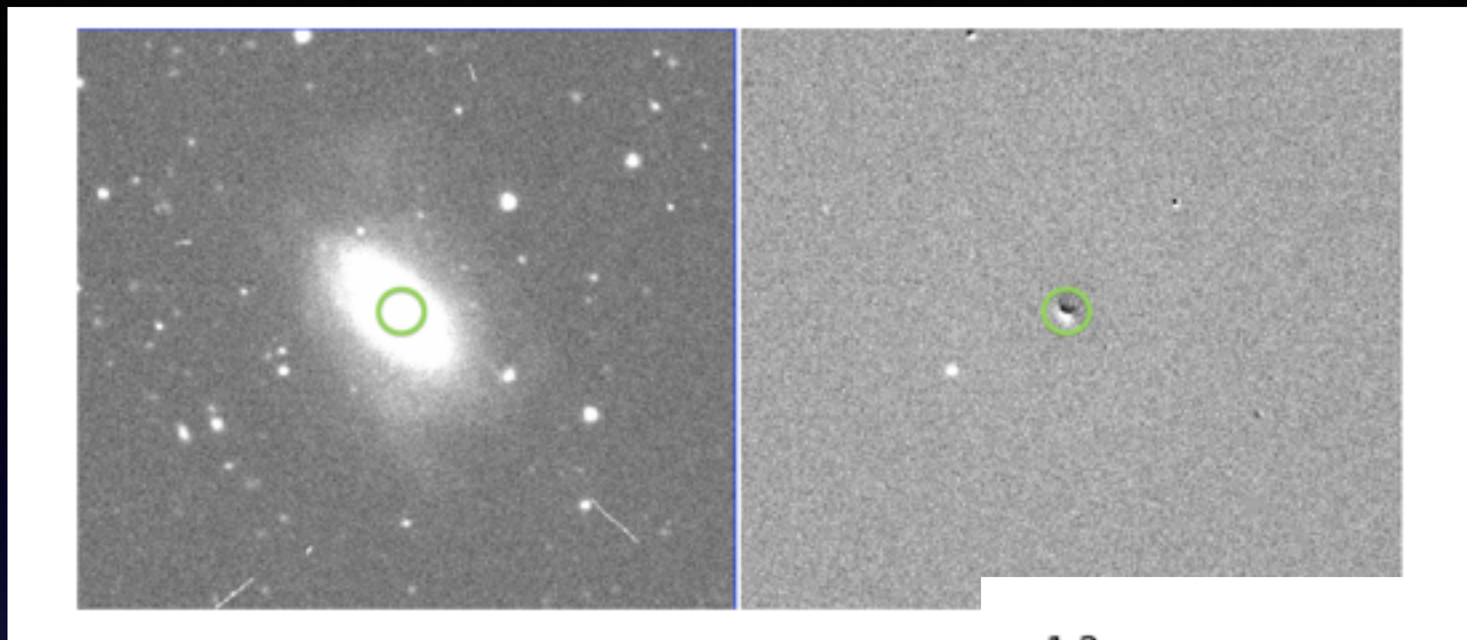
There's a lot of room for root(N) improvement of calibration systematics

- Can compare multiple systems
- Can calibrate systems using different methods, both spatial and color calibration
- Surveys can use more spectrophotometric standards (<10)
- Can have different networks of standards
- Can improve lab based metrology for relative throughput

Summary of WFIRST requirements

Requirement Description	Target Value	Science Driver	Notes
Spatial Uniformity of response	~3 mmag on ~ degree scales	Avoid correlated effects in sample selection for weak lensing, other photometric probes	Detailed simulations needed to quantify effects
Spatial Uniformity of response	~2 mmag across fields	Supernova measurements	Does this apply to mulitple measurements of same supernova (i.e., light curve) or for different SNe as well?
Spatial Uniformity of response	2.5 mmag over FOV	Stellar population age error < 1 Gyr	Trade-off with bandpass effects
Bandpass variation	2.5 mmag over FOV	Stellar population age error < 1 Gyr	Trade-off with spatial uniformity
Temporal stability	1 mmag over 10-60 min	Error on planet mass < TBD	Simulations ongoing
Persistence	< 1 e/s/pix for signal 5 10^5 e/s/pix	Limit the loss of potential events	Sufficient, but not fully established as a requirement.
Absolute photometry	5 mmag	Calibrate photometric response with spectrophotometry; match to other surveys with different filters	Need for **absolute** calibration (in erg/cm^2/s) not fully justified at present. May be driven by GO science.
Absolute photometric slope	0.3%/700 nm	FOM impact as accuracy degrades	Detailed simulations already exist
Detector non-linearity	0.3%/dex	Comparison of bright and faint sources (e.g., SNe at different z)	
Cross-survey calibration	2 mmag	Joint analysis of multiple surveys (e.g. WFIRST and LSST)	More detailed study of joint analysis needed
PSF size	0.1%	Shape measurement for weak lensing	
PSF encircled energy	0.05%	Shape measurement for weak lensing, crowded field photometry	Absolute encricled energy needed

If we have a little extra time..



These have impact on SNIa science, and huge impact on potentially finding Kilonovae
Doctor et al. 2016 - DES

In every survey I’ve worked on, subtracted bright galaxies/stars leave strong dipoles