Cross-Calibration: Dovekie

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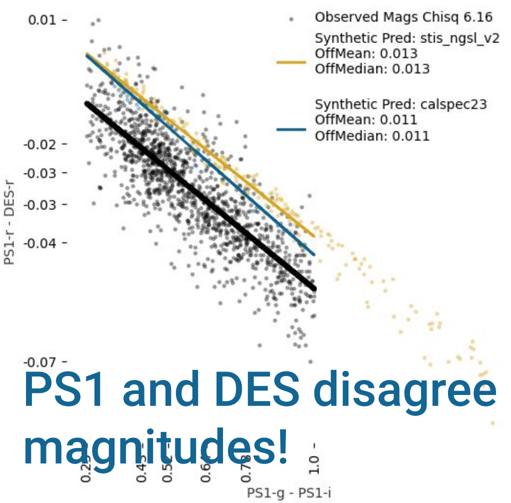
What is Dovekie?

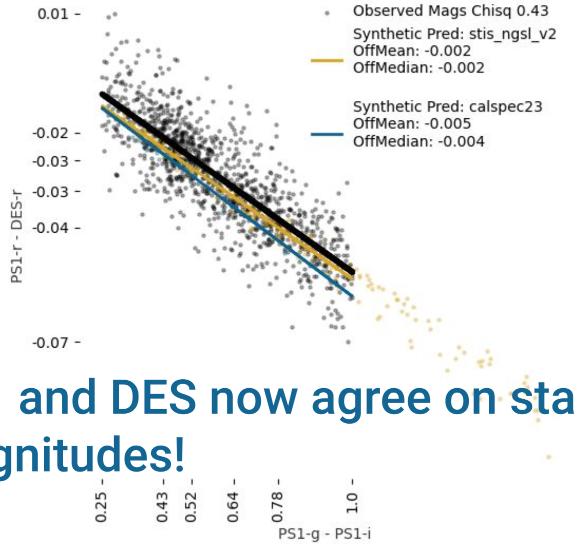
- Doesn't stand for anything
  - (I don't like acronyms!)
- Open-source, multi-modal methodology to cross-calibrate any **arbitrary** surveys
  - Pan-Starrs
  - Gaia
  - DA WD observations
- Includes many (hopefully) useful tools for the community
- **The goal is twofold:**
  1. Ensure filter measurements match our expectations.
  2. Align all telescopes on a single calibration system for precision cosmology.

What is Dovekie?



PS1 and DES disagree on star magnitudes!

Cross calibration



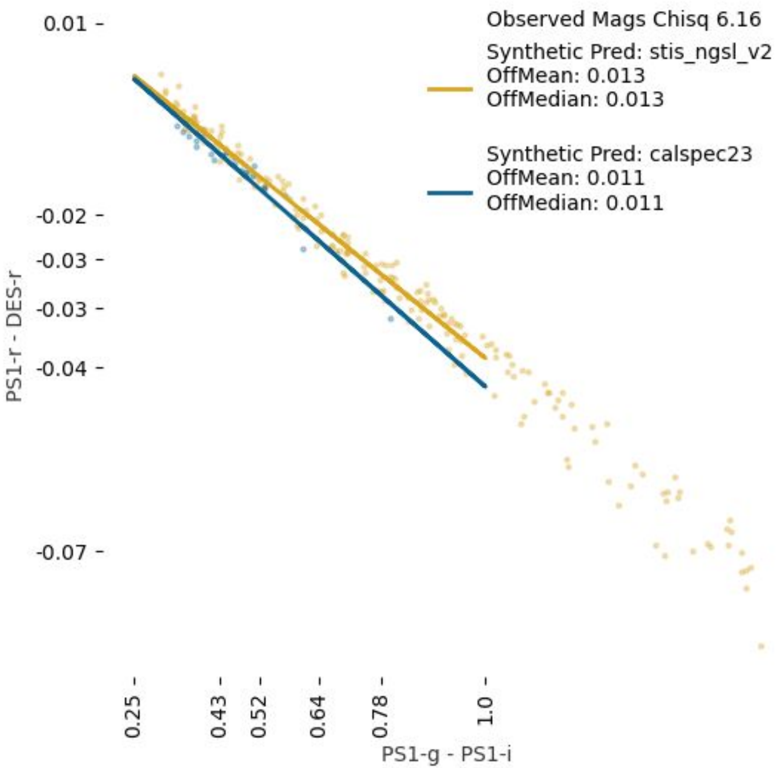
PS1 and DES now agree on star magnitudes!

- **The goal is twofold:**
  1. Ensure filter measurements match our expectations.
  2. Align all telescopes on a single calibration system for precision cosmology.

What is Dovekie?

1. PS1
2. Gaia
3. Filter Uncertainties

Perfect Calibration



We observe all of our calibrator stars, of every different library, with our two telescopes directly.

From this we have direct differences in magnitudes as a function of colour.

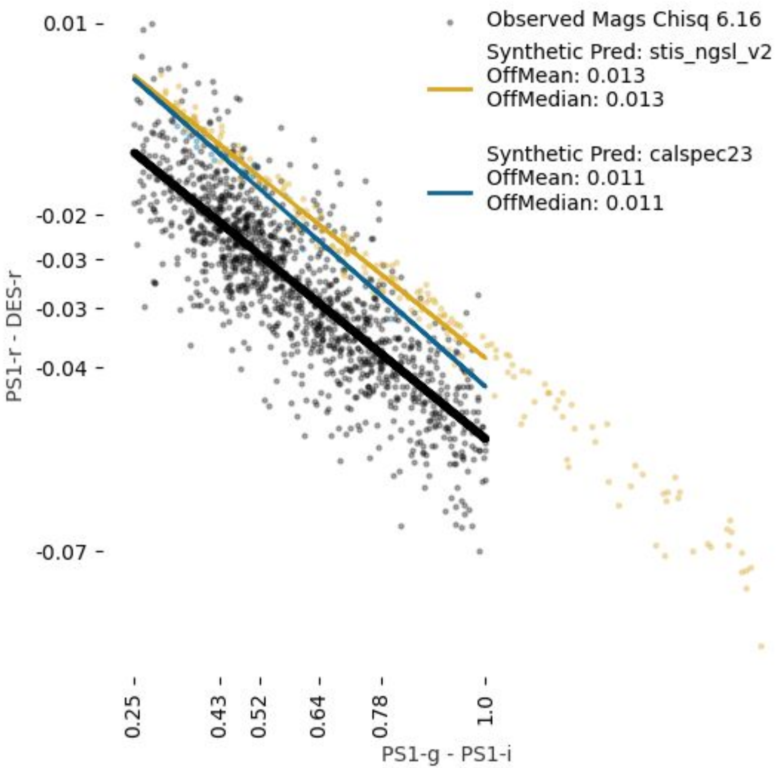
Pros:

- Best case scenario
- No middle men
- Removes additional sources of systematic uncertainty

Cons:

- Impossible

Actual cross-calibration is much uglier

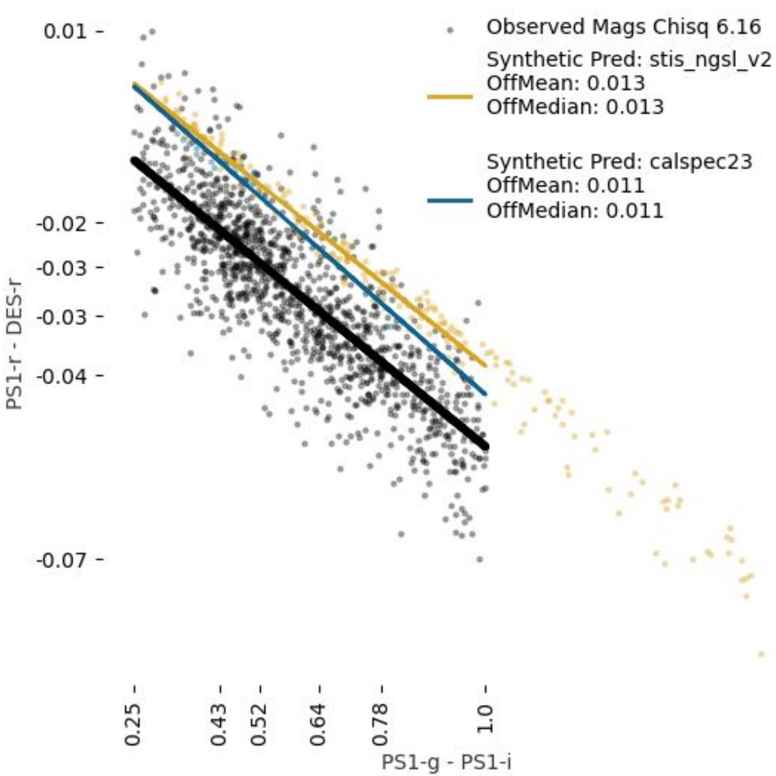


We start with spectral libraries of calibrator stars. These spectra are integrated through our filters to give magnitudes.

Multiply libraries are used to represent our uncertainty on which set of calibrators is ideal.

These are the blue and gold points and lines

Actual cross-calibration is much uglier

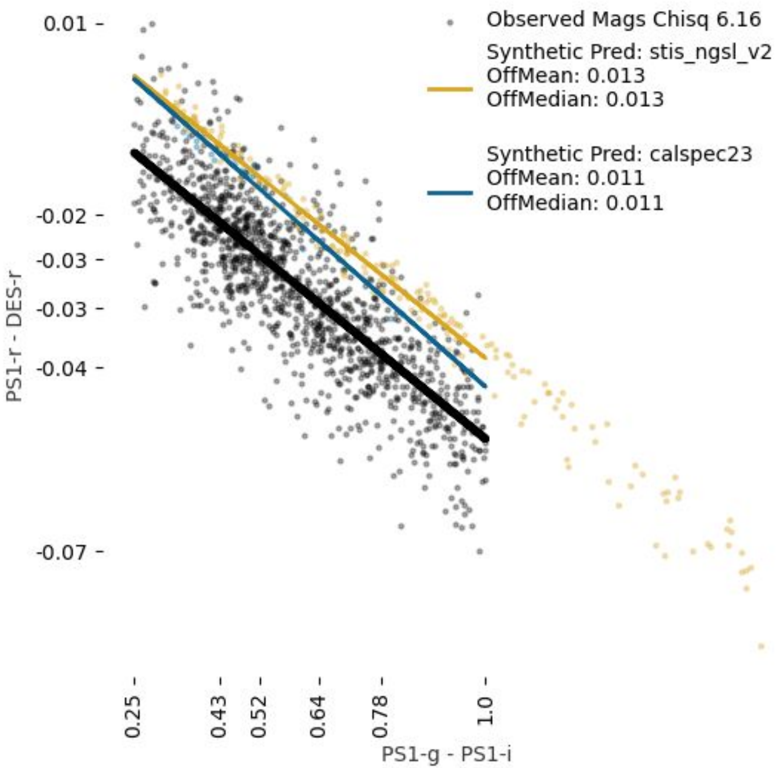


We use field stars to cross calibrate:

1. Collect stars in desired system (let's say DES), with magnitudes, RA, and DEC
2. Observe these stars with PS1 aperture photometry
3. Integrate our spectral libraries through DES filters.

Only two data products are needed: stars and filter transmission functions

Aim for matching slopes



At this stage, we are concerned with ensuring that the slope of our blue and gold lines matches that of the data.

Pros:
Well-calibrated and precise
No suspicious biases

Cons:
Only provides photometric products
Use of middle-men spectral libraries

Only two data products are needed: stars and filter transmission functions

What is Dovekie?

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2. Gaia
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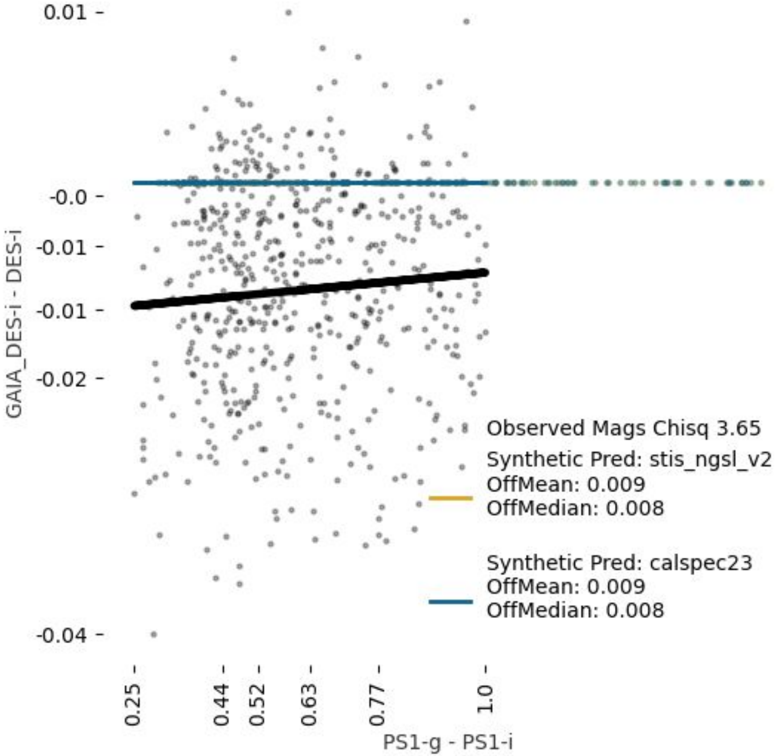
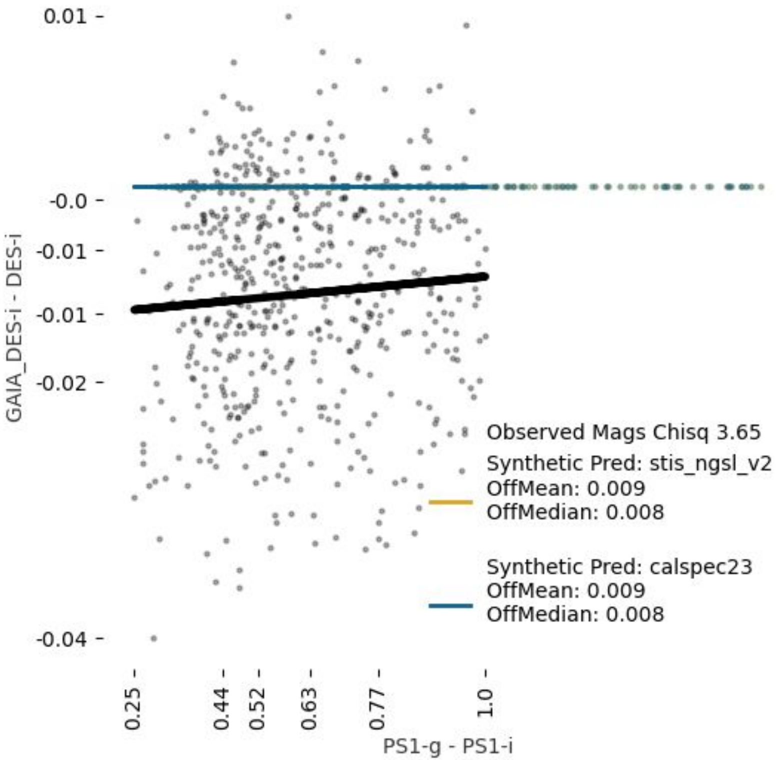
Cross calibration with Gaia



We can use Gaia to cross-calibrate as well - by observing DES stars with Gaia, we capture the spectra and can integrate it through our filters for a direct magnitude measurement.

Slope should be zero.

Aim for matching slopes



At this stage, we are concerned with ensuring that the slope of our blue and gold lines matches that of the data (0).

Pros:
Spectral information
Direct magnitude comparison

Cons:
Not trusted for g-band
Gaia calibration has not been used for calibration before

Only two data products are needed: stars and filter transmission functions

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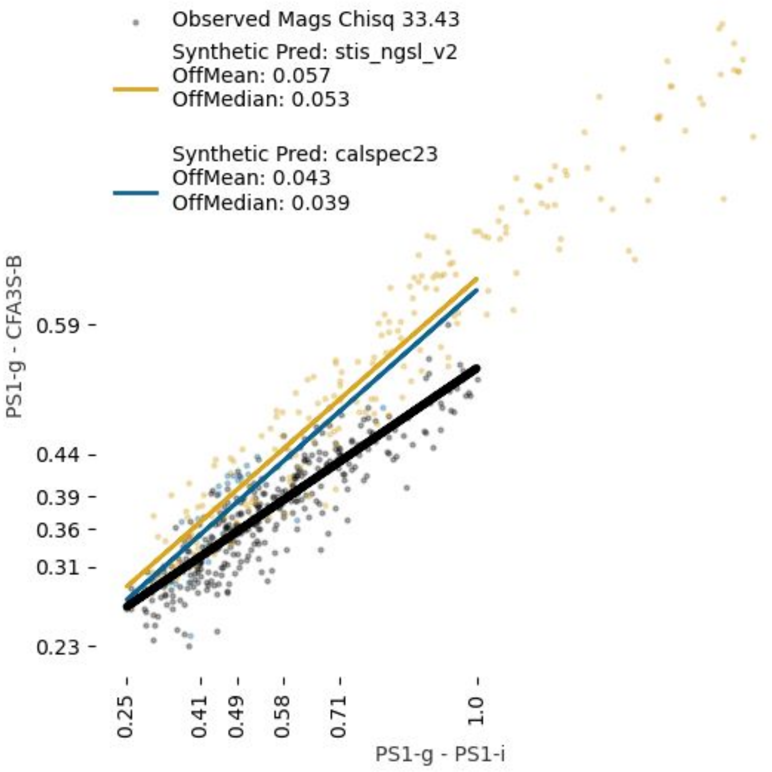
Filters don't always match data



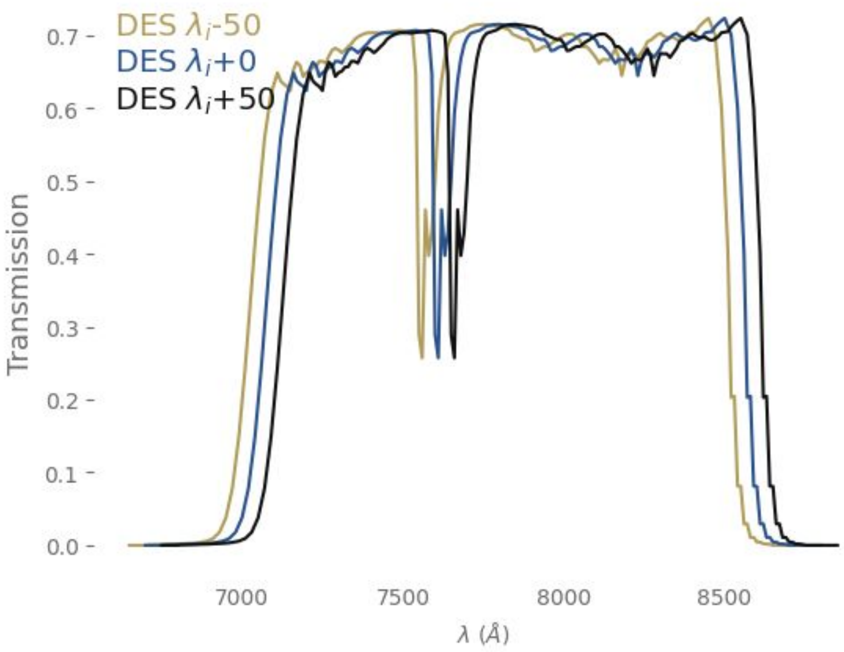
CfA3S-B band, for instance, sits at 5sigma disagreement between the published filter and calibrator stars.

Some filters are well-measured; others, not so much

How do we address this mis-match ?

Using Gaia and PS1, we have independent checks of this

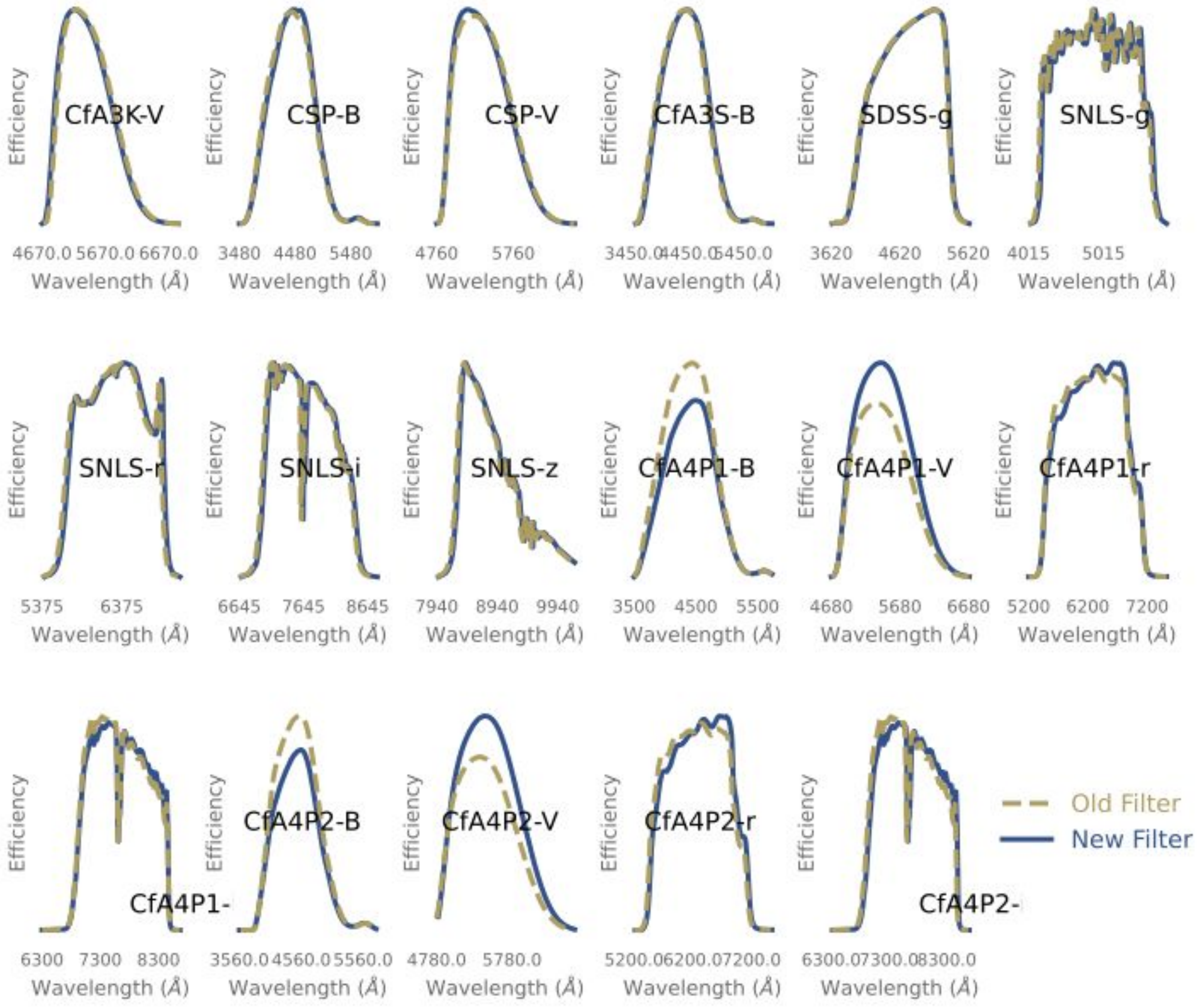
Filter transmission shifts



Shifting the transmission function by some number of Angstrom is an effective way to tweak the colour-magnitude slope - which we need to match our data.

Oftentimes, the required changes are “small”.

But what is a *significant* filter shift?



How well do we understand our filters ?

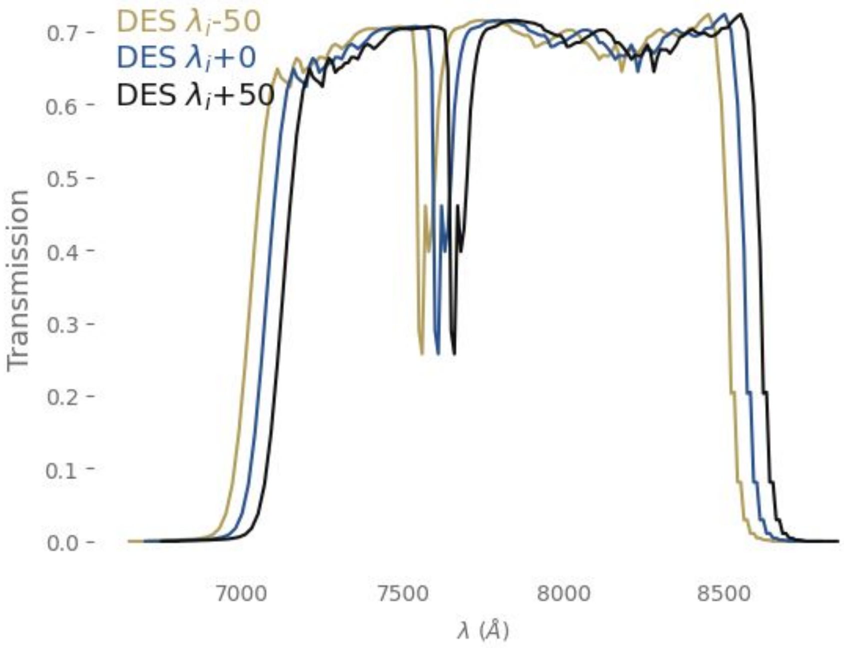
Sample	Filters	Wave. Uncertainty (Å)
Calan/Tololo	U, B, V, R, I	20,20,20,20,20
CfA1	U, B, V, R, I	20,20,20,20,20
CfA2	U, B, V, R, I	20,20,20,20,20
CfA3-Keplercam	U, B, V, r, i	20,10,10,10,10
CfA3-4Shooter	U, B, V, r, i	20,10,10,10,10
CSP	u, B, V, g, r, i	8,7,3,8,4,2
SDSS	u, g, r, i, z	6,6,6,6,6
SNLS	g, r, i, z	3,10,10,6

Conventional filter uncertainties are on the order of ~5-10 Angstrom - but what does this mean ?

If we shift SDSS by 6A, *what* moves by 1sigma?

	$\sigma(Z)$ (*mmag*)	$\sigma(\lambda^{eff})$ (*nm*)
MEGACAM (SNLS)		
g	3	0.3
r	6	3.7
i	4	3.1
z	8	0.6
SDSS		
u	8	0.6
g	4	0.6
r	2	0.6
i	3	0.6
z	5	0.6
STANDARD		
U	100	2.5
B	15	1.2
V	15	1.2
R	15	2.5
I	15	2.5
4SHOOTER (CfAIII)		
Us	70	2.5
B	11	0.7
V	7	0.7
R	8	0.7
I	20	0.7
KEPLERCAM (CfAIII)		
Us	31	2.5
B	11	0.7
V	7	0.7
r	25	0.7
i	8	0.7

An initial attempt to characterise our filters

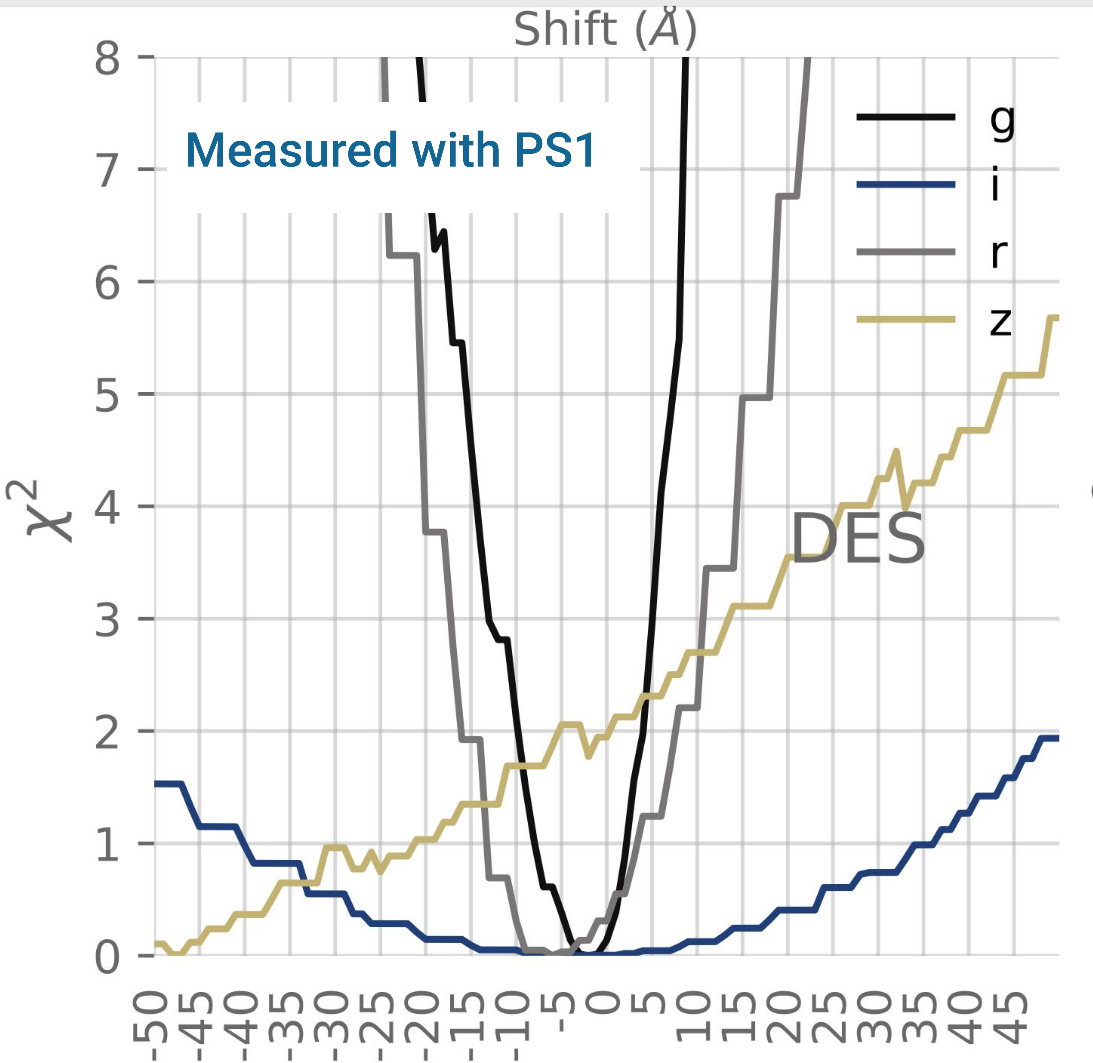


If we repeatedly measure our filters at each shift, we can get posteriors on how the colour-magnitude slope is impacted by a changing filter.

Is this the uncertainty associated with the filters for our cosmological analysis?

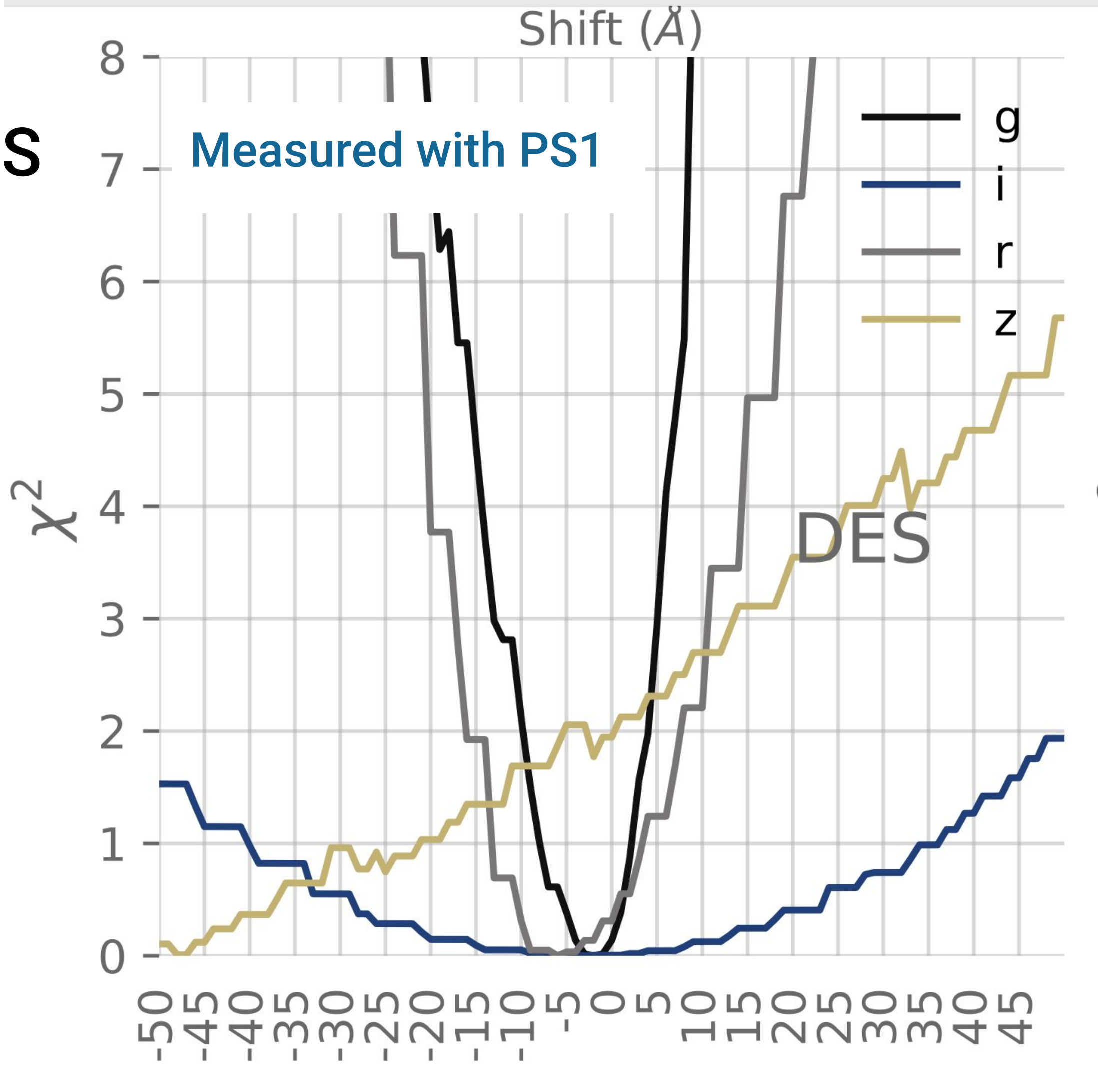
Posteriors are scary

1. Shift each filter by -50 A, and measure the colour/magnitude relationship
2. Shift filter up to -50+1, repeat measurement.
3. Repeat in steps of 1A until we reach +50A



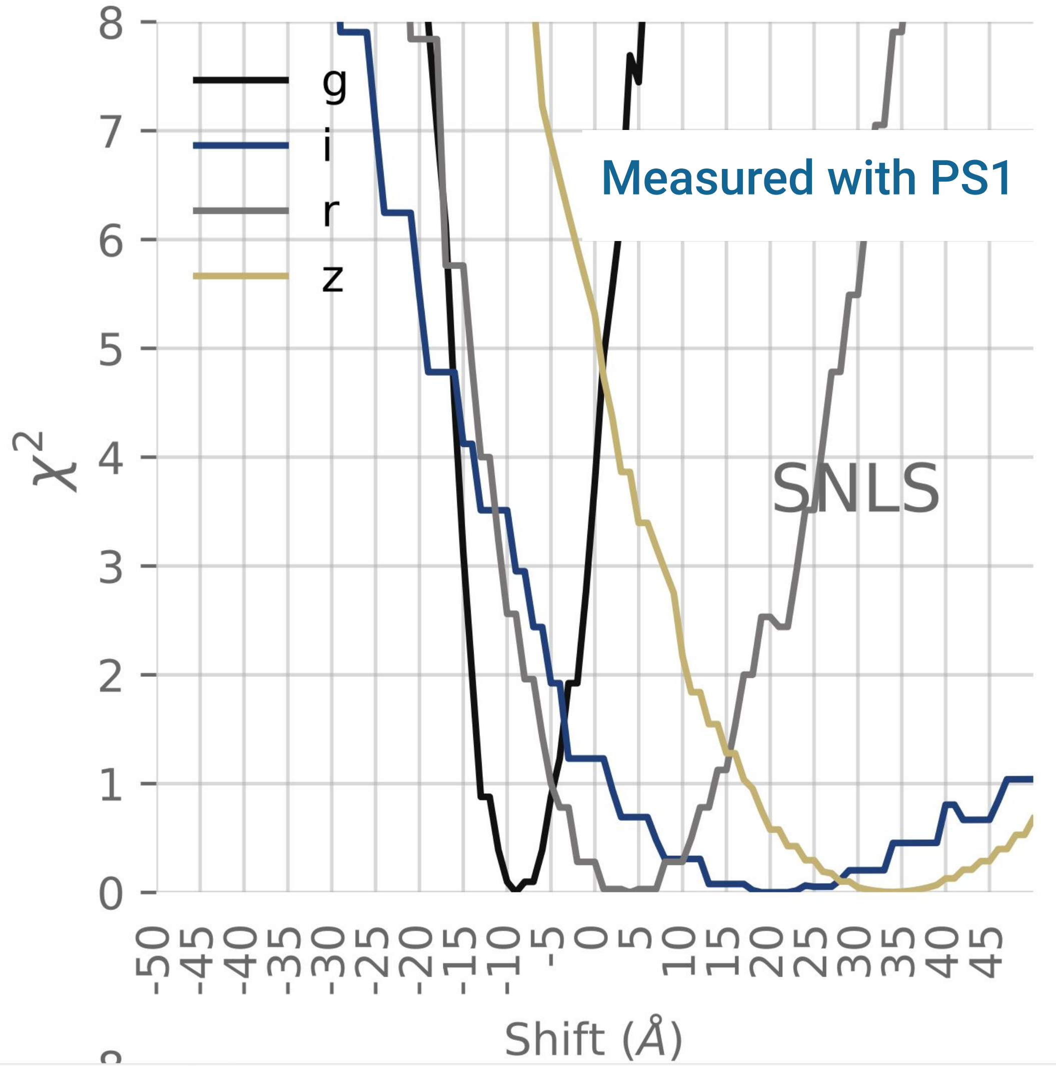
Posteriors are scary - DES

Filter	Published Value	Dovekie Value
g	6	5
r	6	8
i	6	40
z	6	20



Supernova Legacy Survey

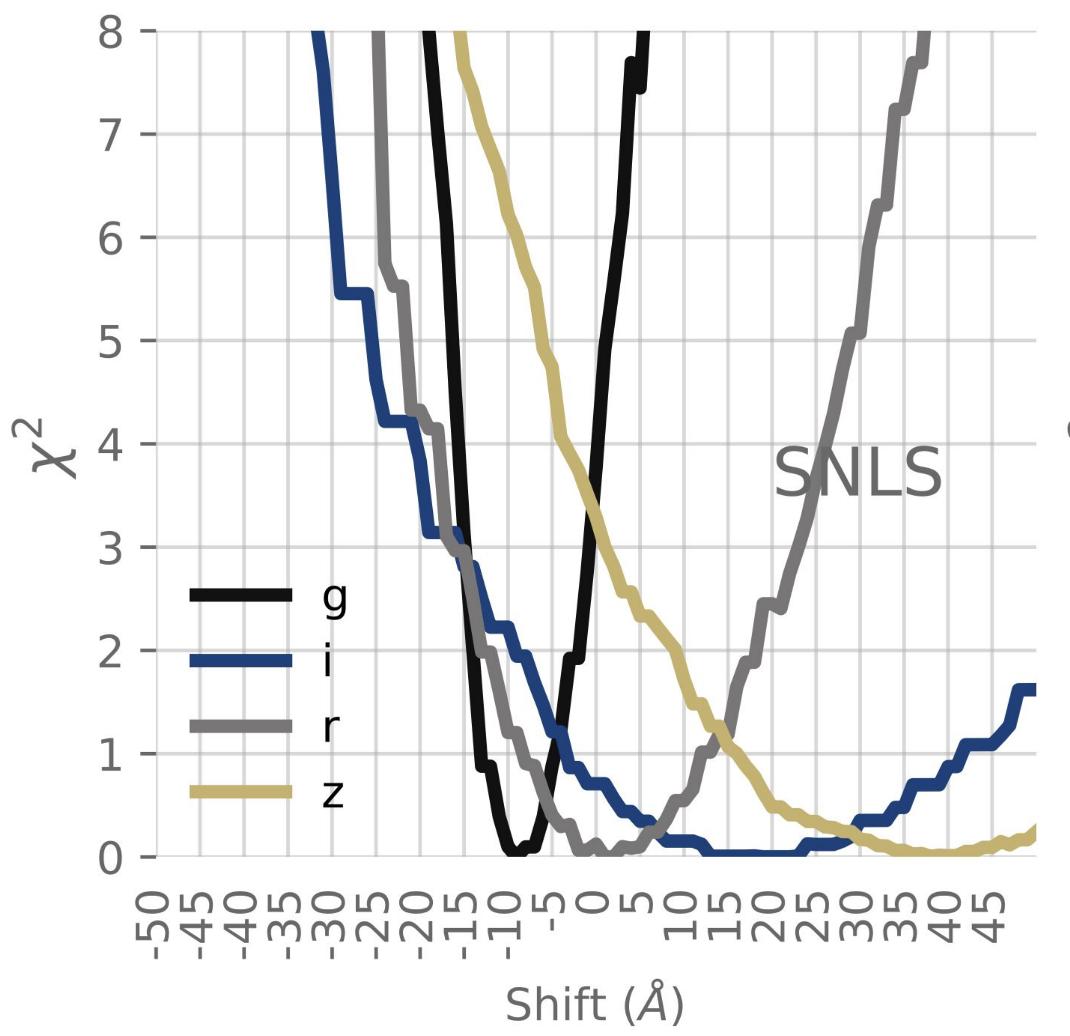
Filter	Published Value	Dovekie Value
g	3	3
r	10	10
i	10	15
z	6	20



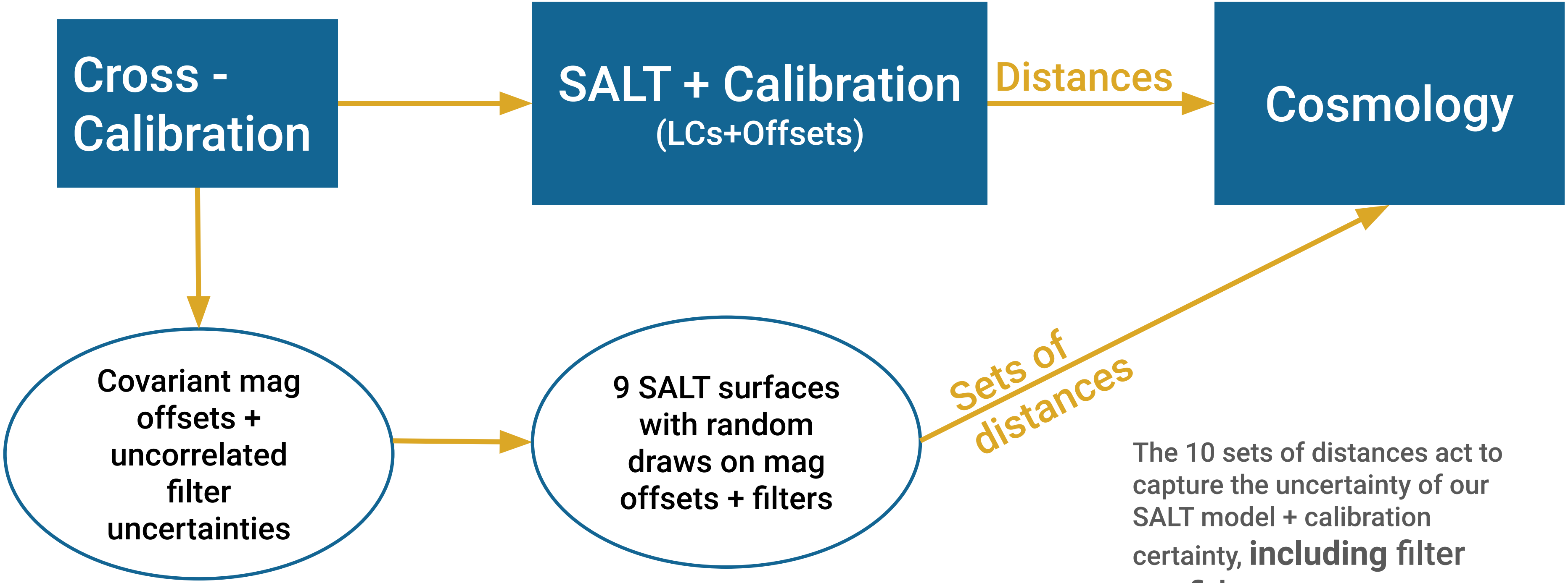
SNLS Combined Constraints

Filter	Published Value	Dovekie Value
g	6	5
r	6	10
i	6	15
z	6	20

No noticeable improvement…

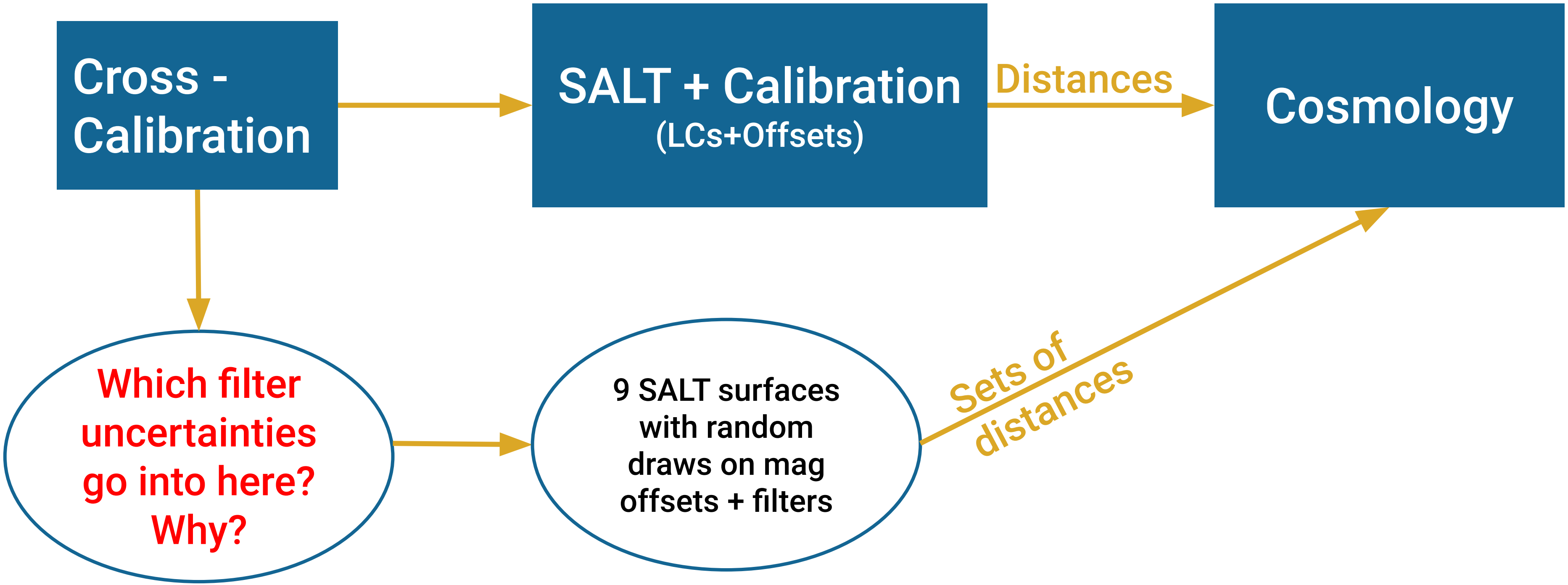


Why does this matter?



The 10 sets of distances act to capture the uncertainty of our SALT model + calibration certainty, **including filter confidences**

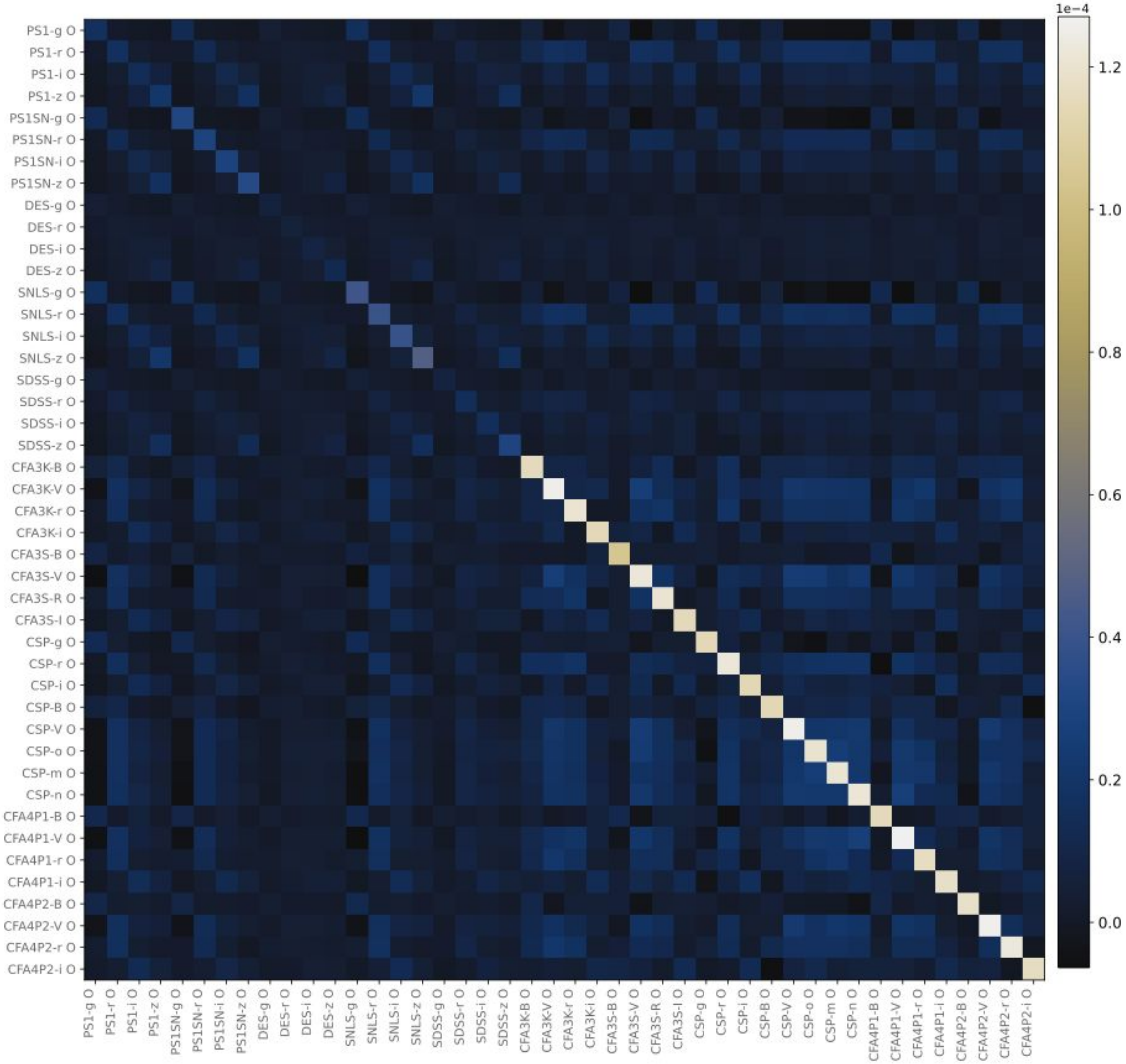
Why does this matter?



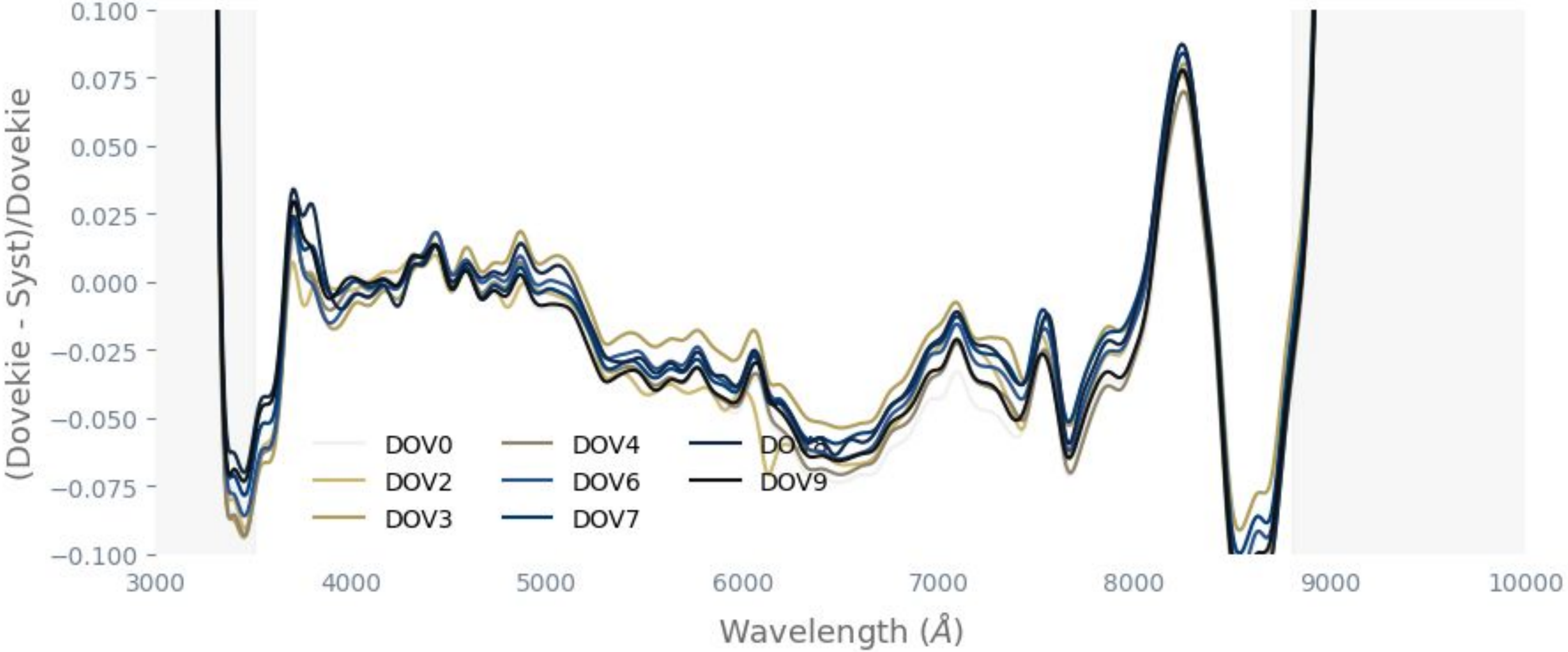
Magnitude Offsets are correlated with filters

Worst performers are low-redshift surveys, further highlighting the need for ZTF.

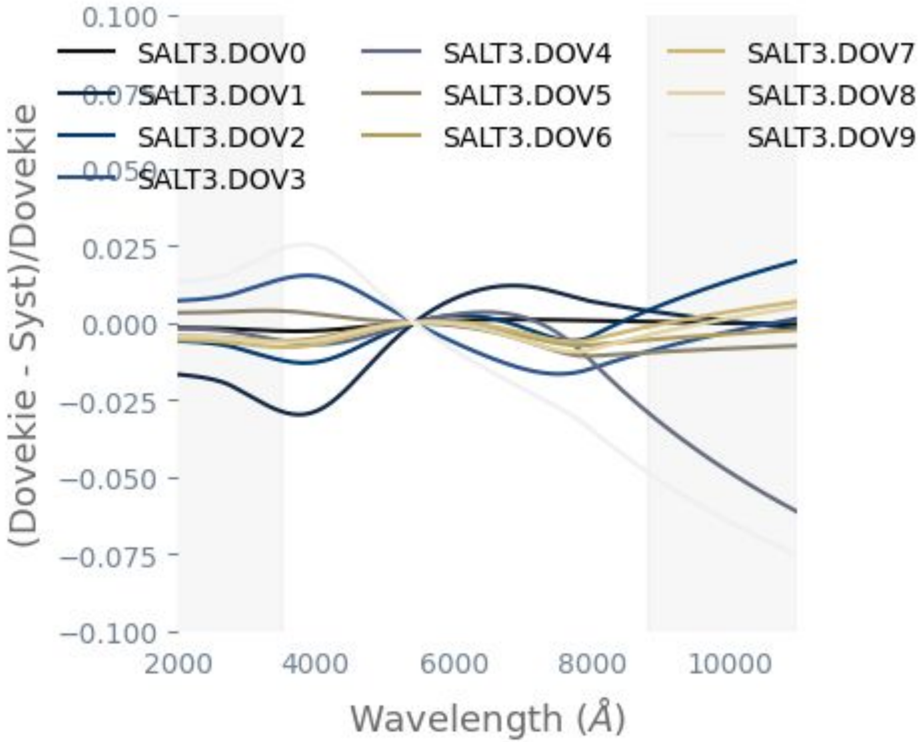
SDSS, PS1, DES, SNLS, CFA3, CSP, CFA4 all calibrated here - trivial to add more



Propagate this to SALT surfaces…



Propagate this to SALT surfaces…

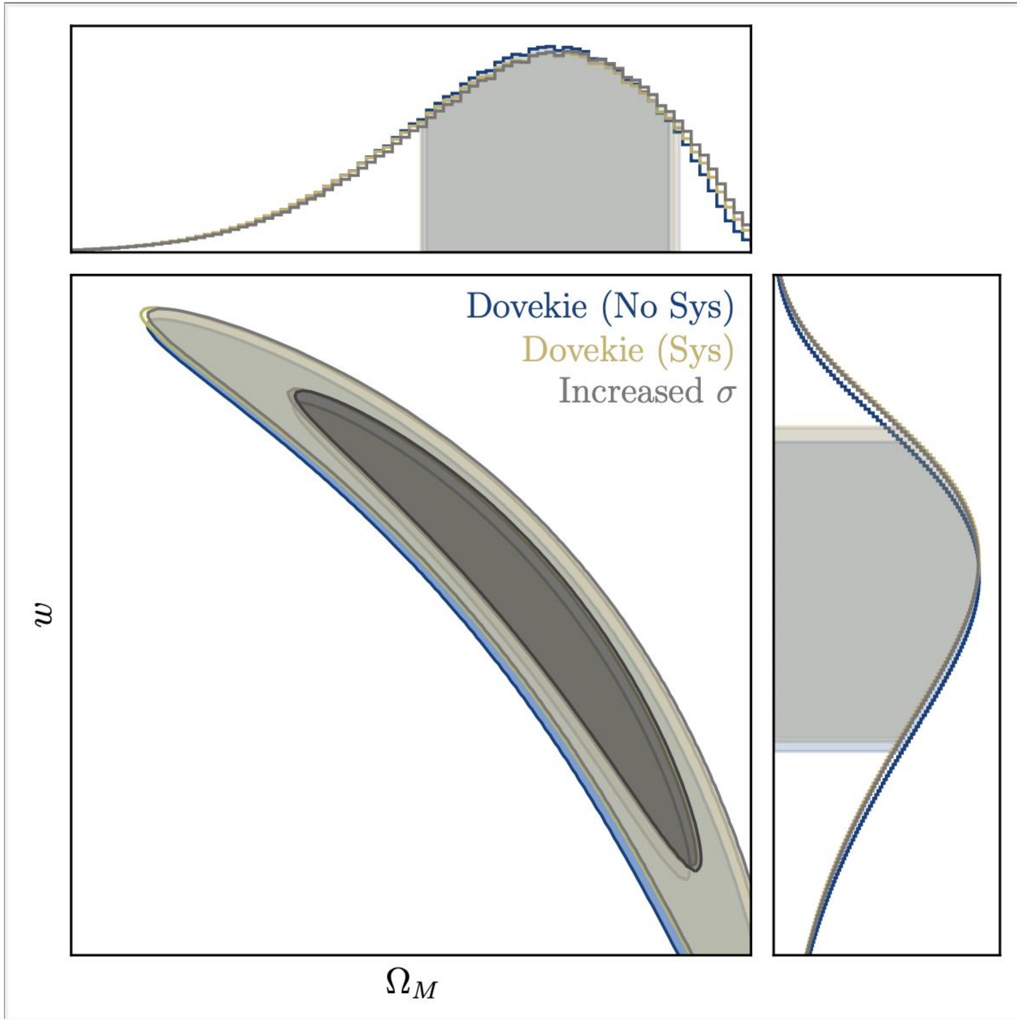


Systematic Uncertainties

Photometric Systematic Uncertainties are at 0.04 in *w*.

This increases to 0.06 with the larger filter uncertainties.

(Consistent enough with P+/DES values)

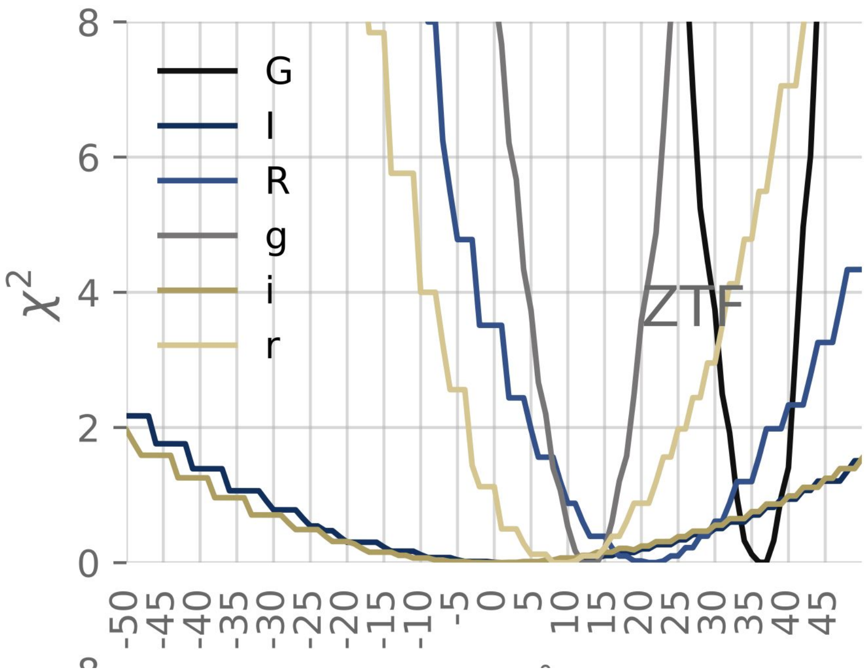


In review

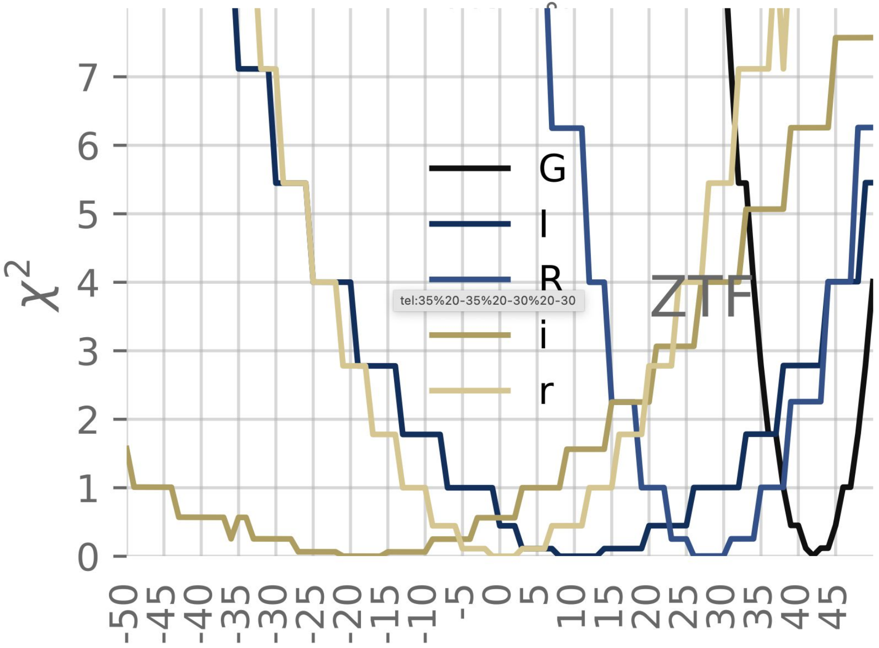
1. Proper filter uncertainties are necessary to understand our systematic uncertainties associated with photometric calibration
2. Our current methods are unable to discern the quoted 1-sigma uncertainties in the colour-magnitude relationship
3. This may be fixed with more stars, but with many surveys, this is simply not possible.
4. What are our 1-sigma uncertainties ?
5. Using these new 1-sigma uncertainties gives a x1.4 increase in the quoted photometric uncertainties


Fin

ZTF Filter characterisation



Measured with PS1



Measured with Gaia