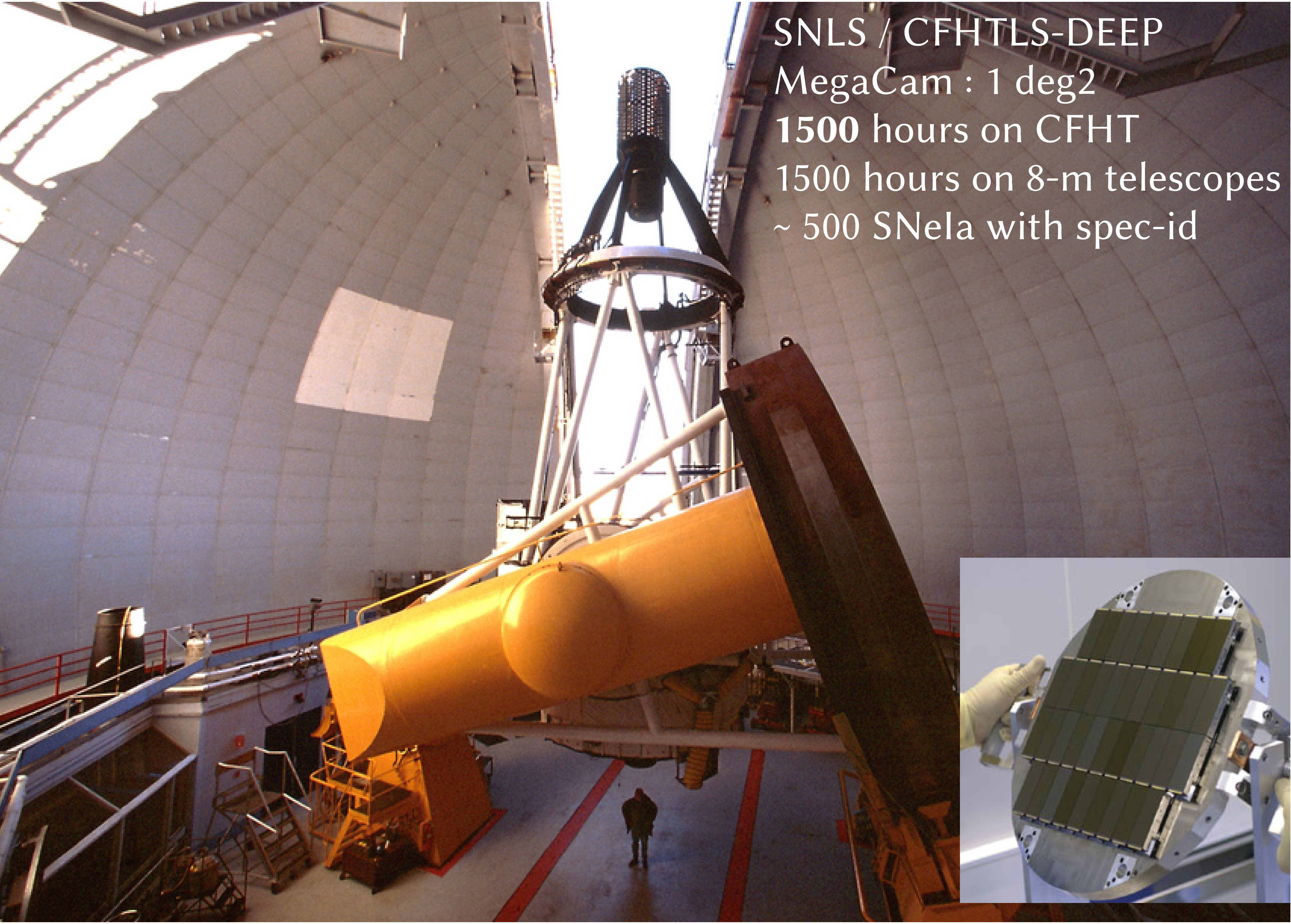
# Photometric calibrations

*Lessons learnt from CFHTLS*

N. Regnault

(LPNHE, Paris)


SNLS / CFHTLS-DEEP
MegaCam : 1 deg2
**1500** hours on CFHT
1500 hours on 8-m telescopes
~ 500 SNeIa with spec-id

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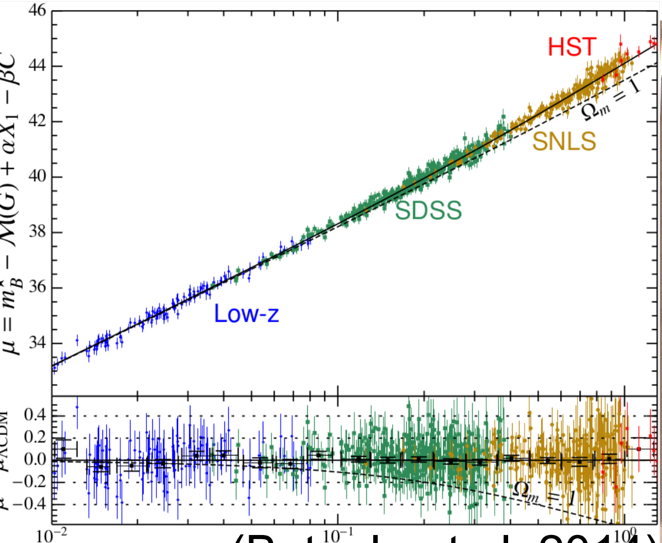
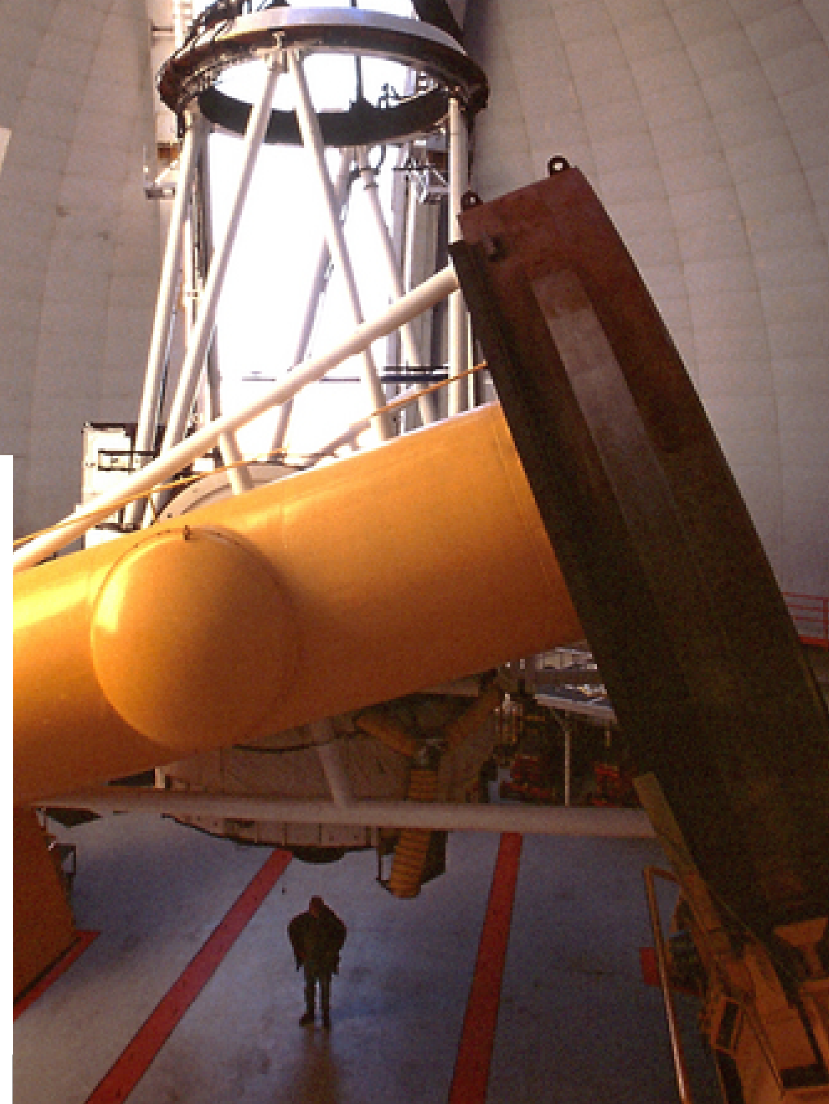
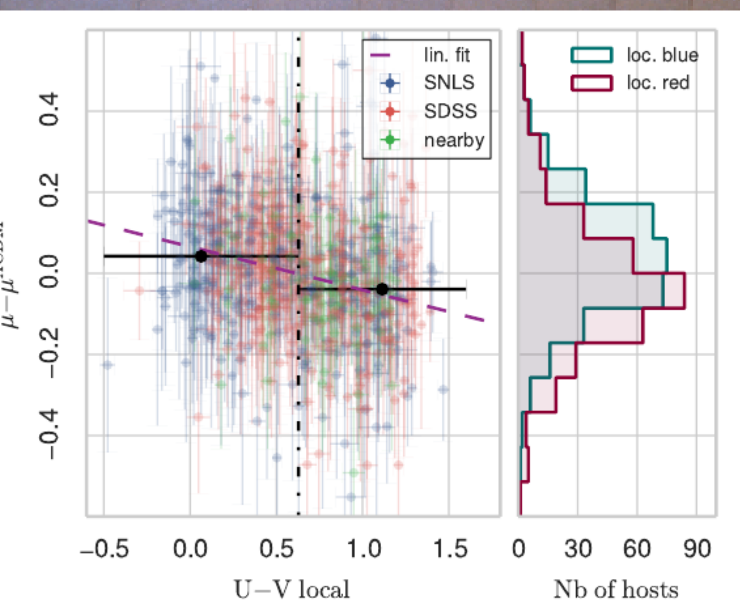
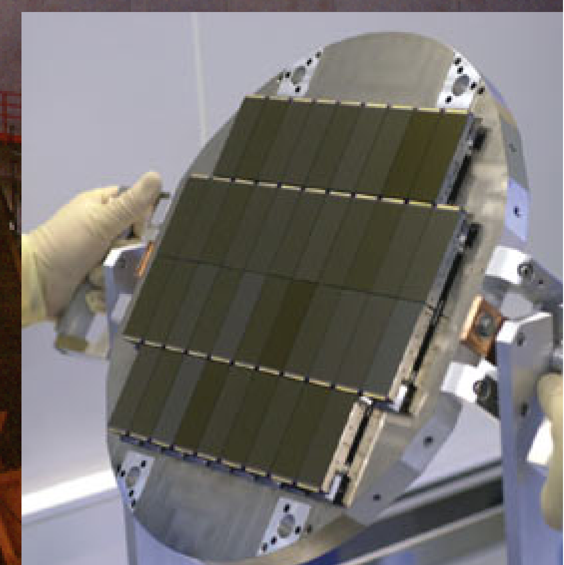


(Betoule et al, 2014)

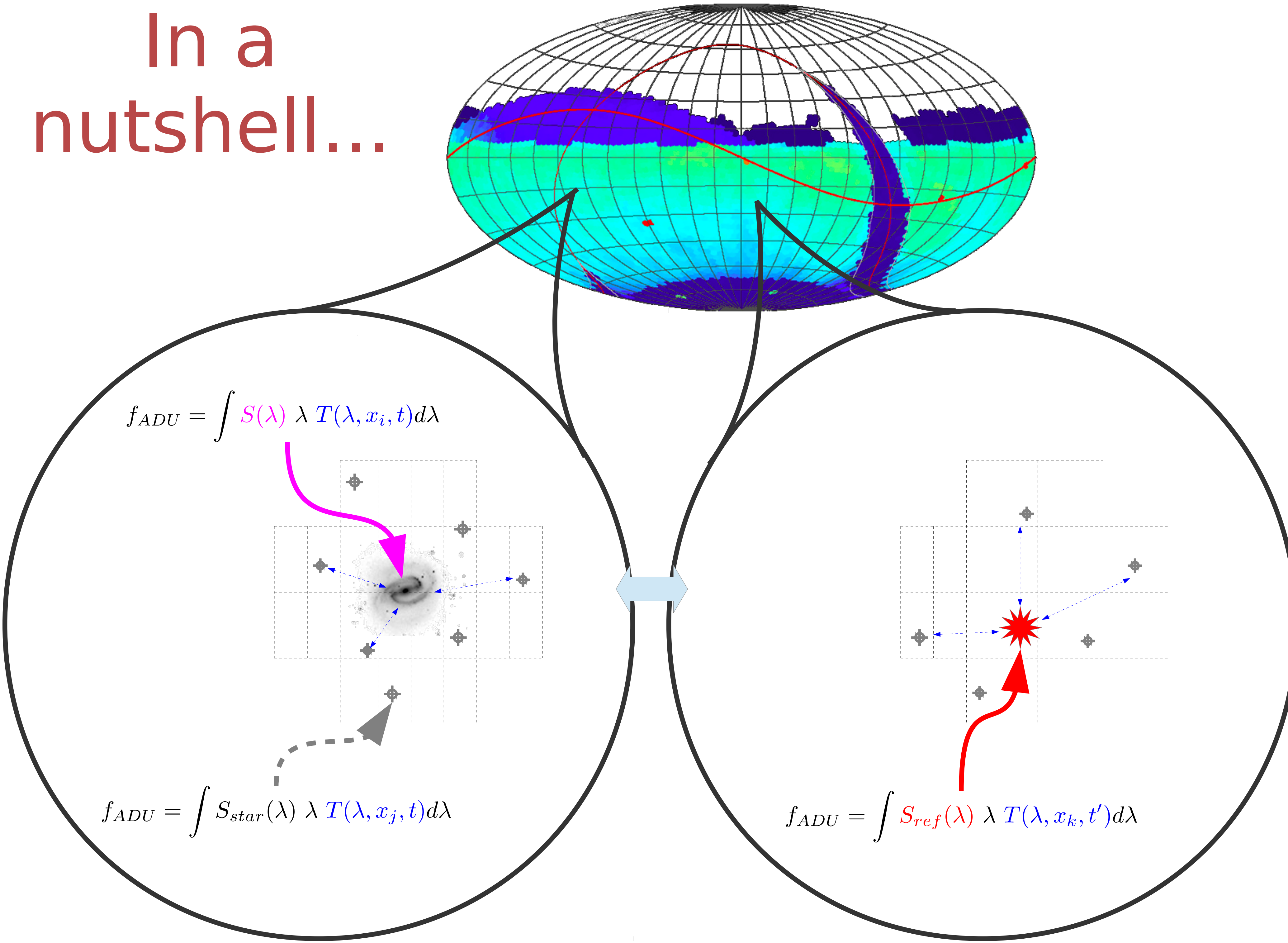




(M. Roman et al, 2017)



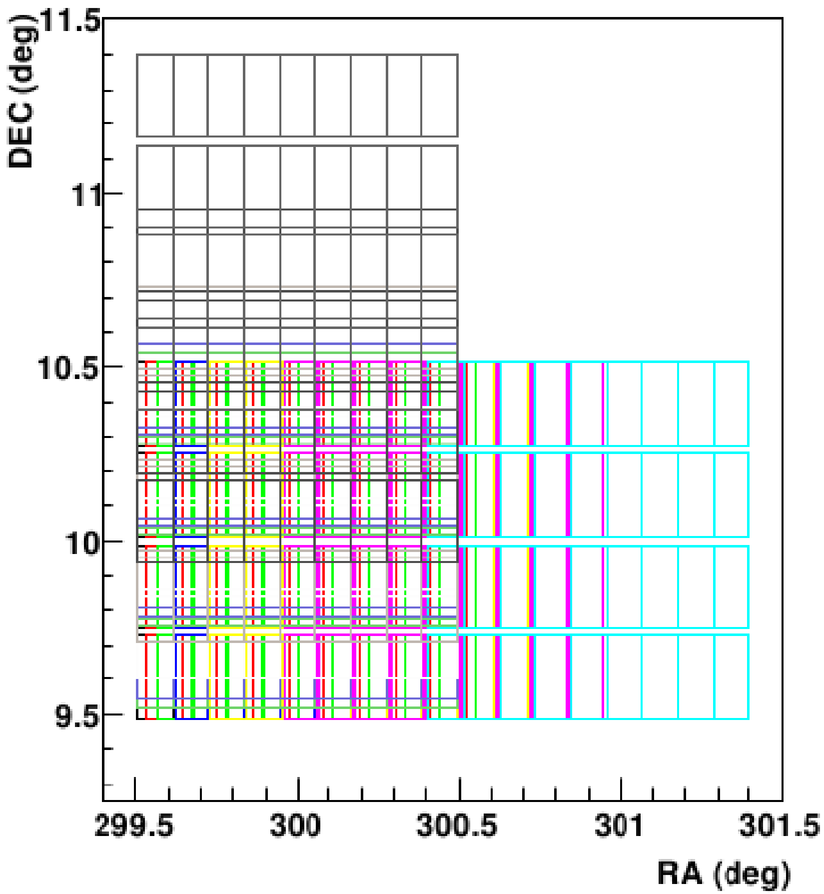
# In a nutshell...



# Ingredients

- Uniformize measurements
  - i.e correct for spatial / temporal variations of throughput
  - ... without breaking measurement model (SED independent scales)
- Map variability of passbands – $T(\lambda, x, t)$
  - As a function of position on focal plane
  - ... and time (atmospheric variations)
- Metrology chain $\longrightarrow$ primary flux reference (s)
  - Star(s), e.g. DA white dwarfs
  - or NIST calibrated lab standard
  - Control of photometry biases: bright standards $\leftrightarrow$ faint targets (see Astier et al, 2013)
- Assess accuracy of primary flux reference(s)

# Mapping the instrument response




- Dithered observations of dense stellar fields
  - Logarithmically Increasing steps (1.5' ⟶ 0.5 deg)
  - Observed every ~ 6 months
- Model

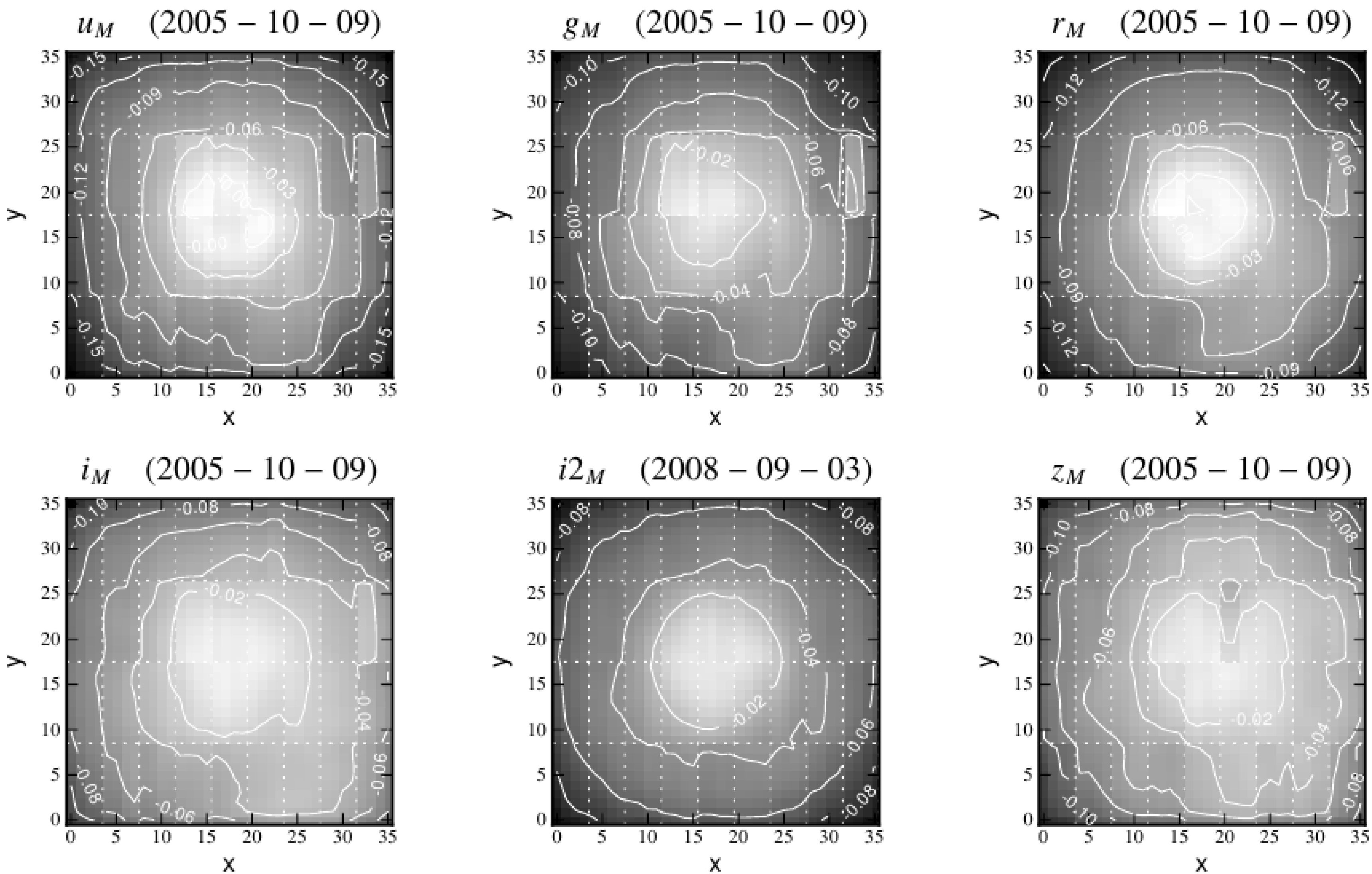
$$m(x) = m(x_0) + \delta zp(x) + \delta k(x) \times col$$

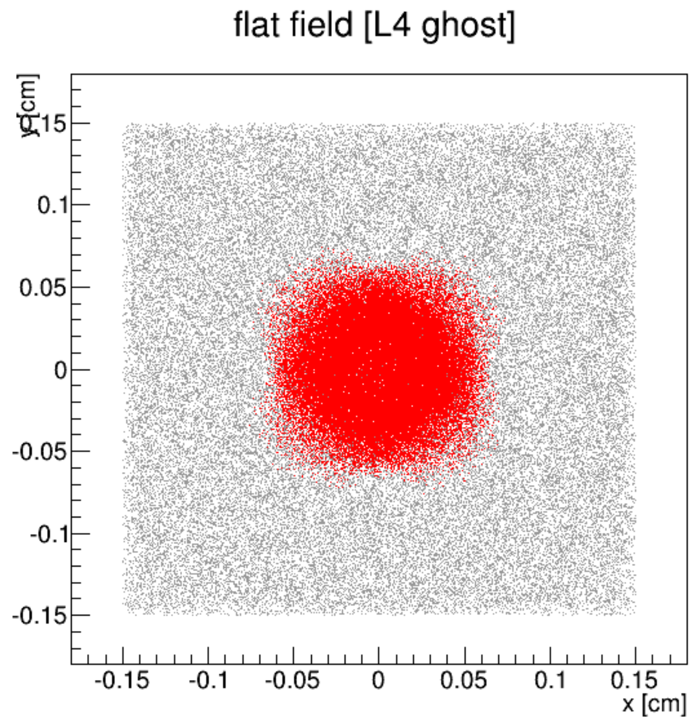
Star mags @ center (~ 100,000 pars)

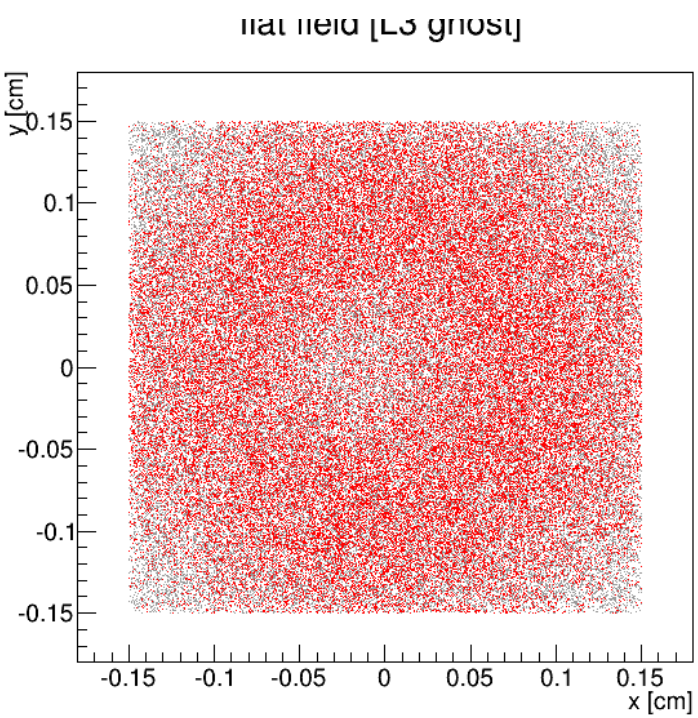
Maps (~ 100 pars)

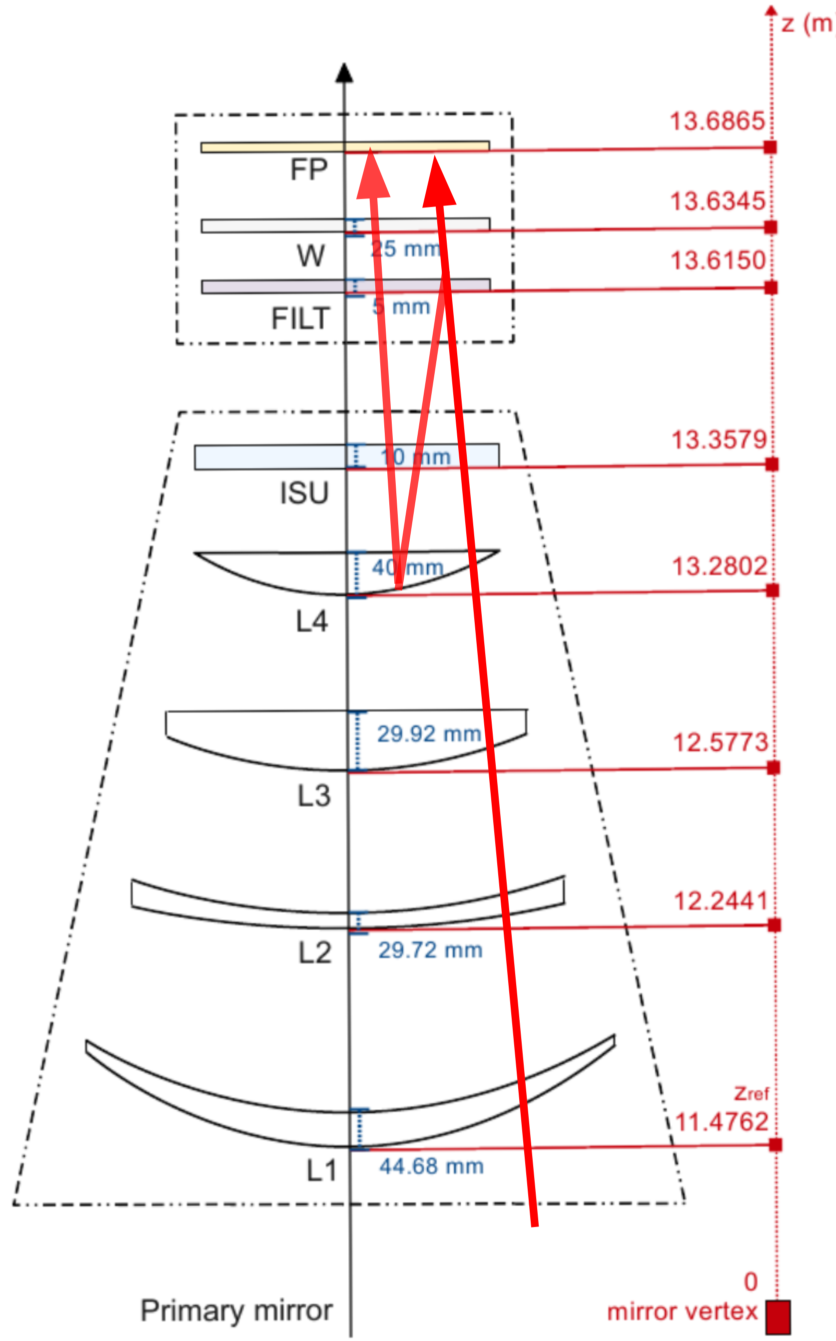
(Magnier & Cuillandre, 2004; Regnault et al, 2009; Betoule et al, 2013, Rykoff et al, 2017)

# Plate scale + ghosts

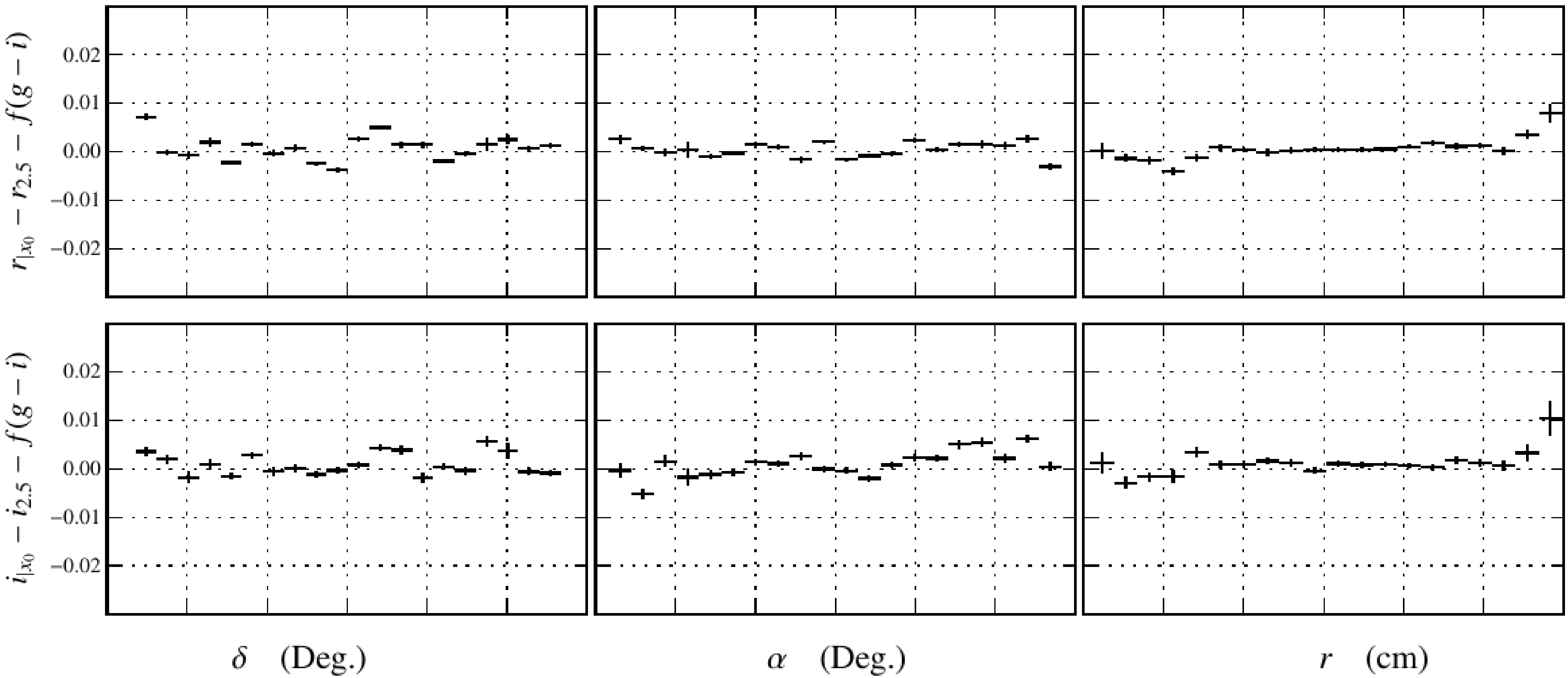



flat field [L4 ghost]
y [cm]
x [cm]
0.15
0.1
0.05
0
-0.05
-0.1
-0.15


y [cm]
x [cm]
0.15
0.1
0.05
0
-0.05
-0.1
-0.15


z (m)
FP
13.6865
W
25 mm
13.6345
FILT
5 mm
13.6150
ISU
10 mm
13.3579
L4
40 mm
13.2802
L3
29.92 mm
12.5773
L2
29.72 mm
12.2441
L1
44.68 mm
Zref
11.4762
0
mirror vertex
Primary mirror

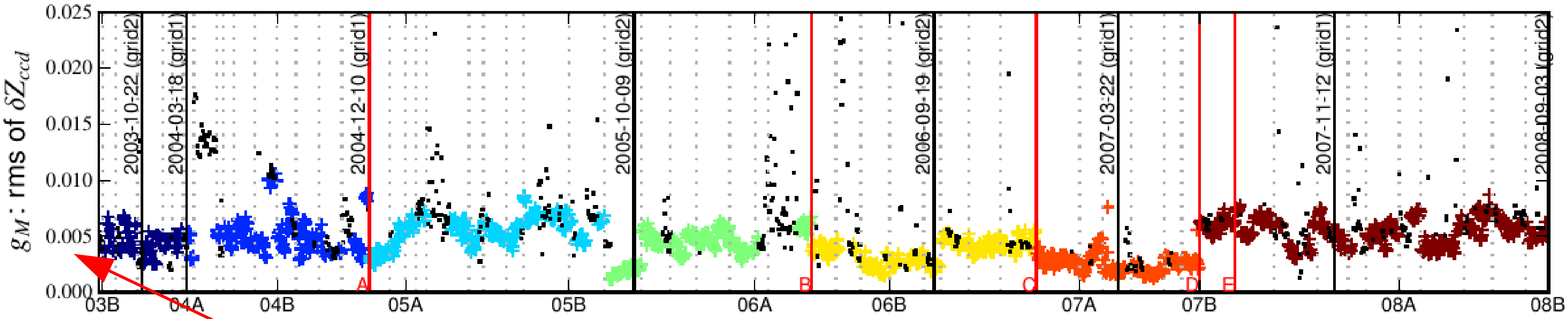
# Uniformity (vs. SDSS)




- rms < 3 mmag

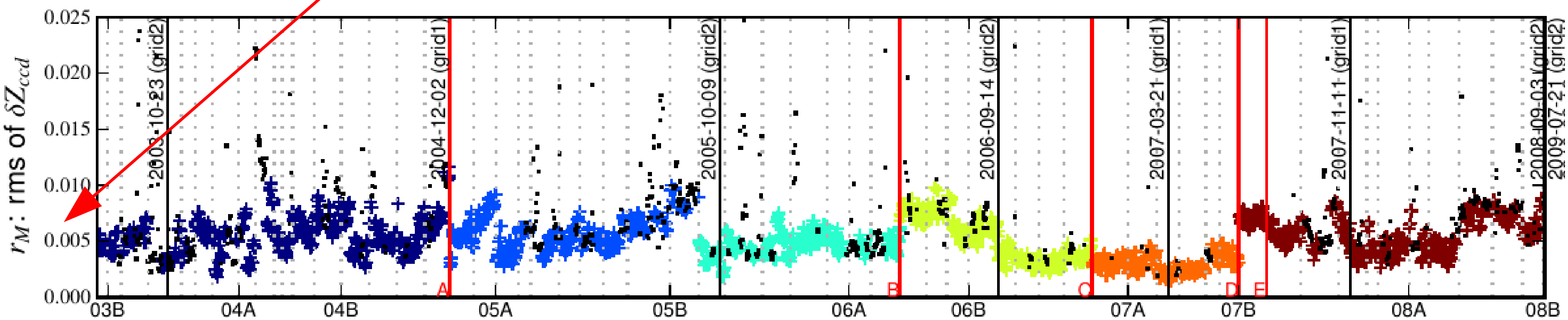
# Internal consistency of obs.

RMS of ZP variations across focal plane in each of the 5 year SNLS exposures w.r.t average




**~ 5 mmag**

Ubercal / FGCM allow to build star flat corrections (see 1706.01542)

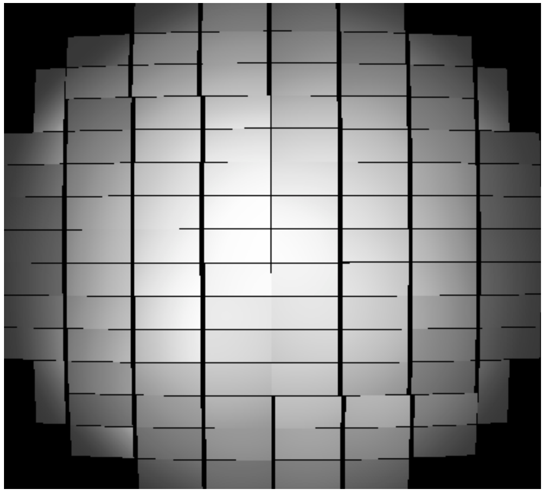


# HSC

- Large distortions

  → plate scale variations ~ 20% center → corner

  → well determined; included in the model



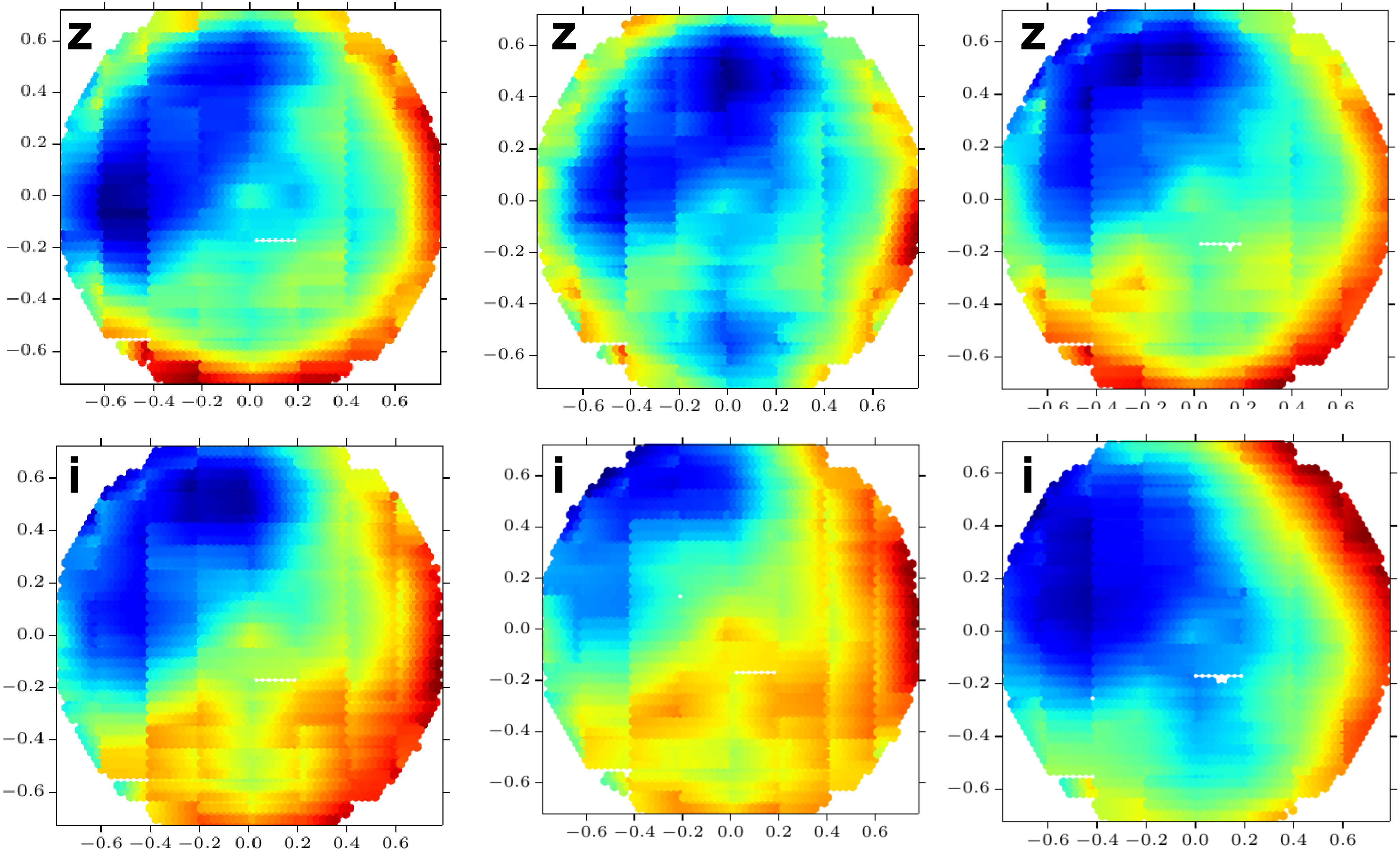
- Model

$$m(\vec{x}) = m_s(\vec{x_0}) + PS(\vec{x}) + zp(\vec{x}) + \vec{k}_{ccd} \cdot \vec{x} + \ldots$$

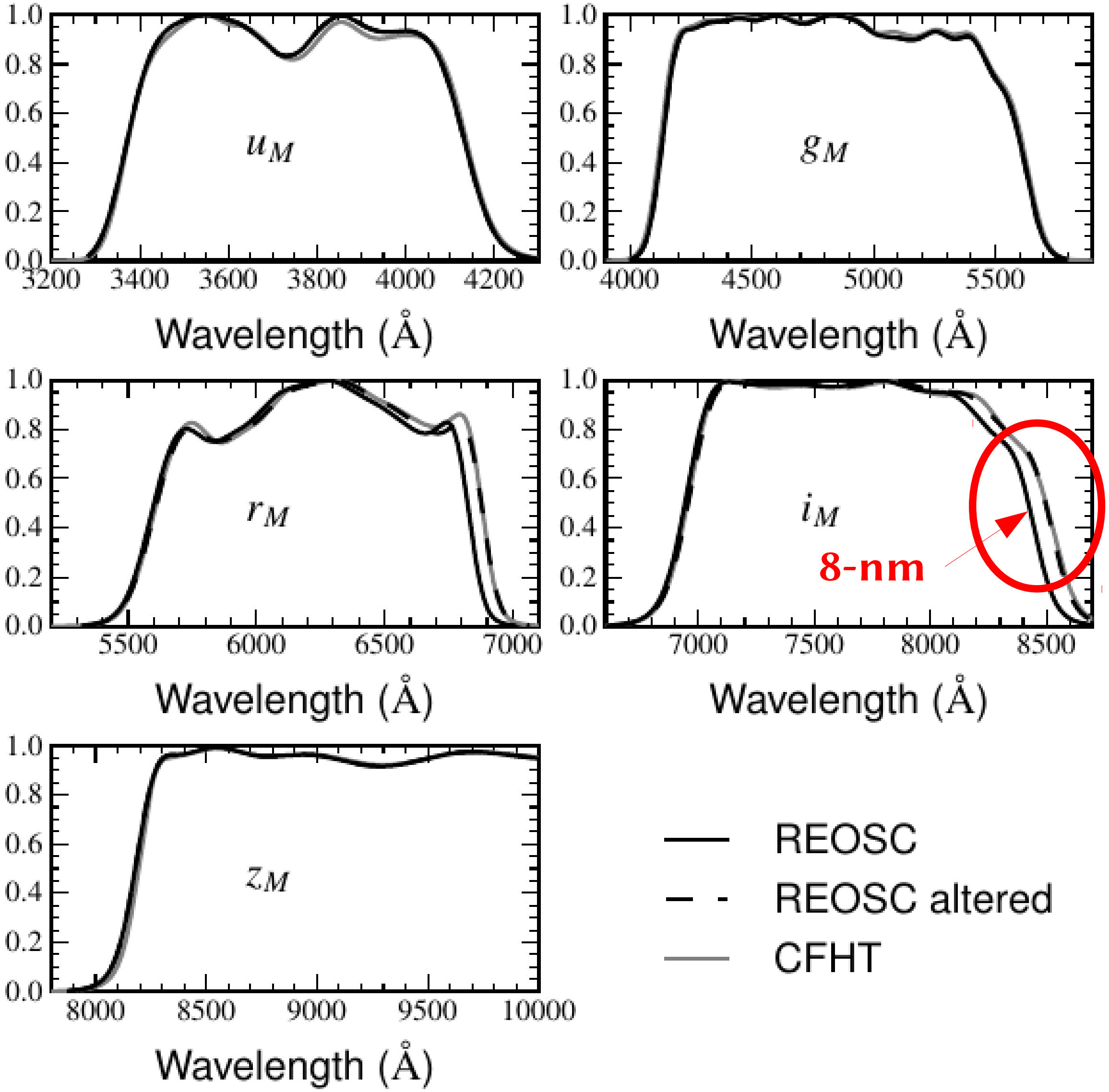
Still too rigid. $X^2$ degrades at edge of FP

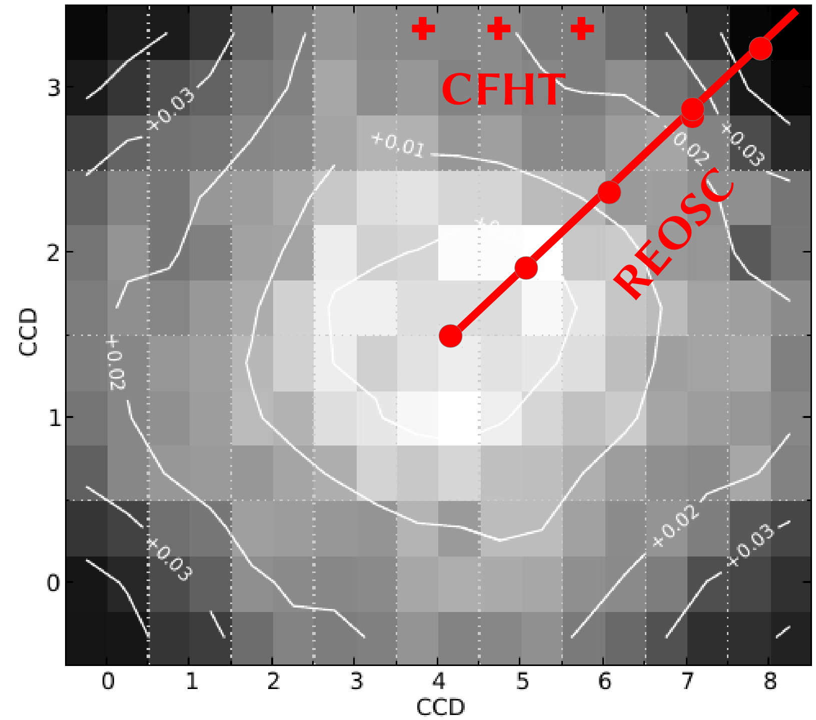
- Fit on each COSMOS visit
  - Taking advantage of the large dithers

# HSC



# Filters




(c) $\delta k_{i,r-i}(x)$

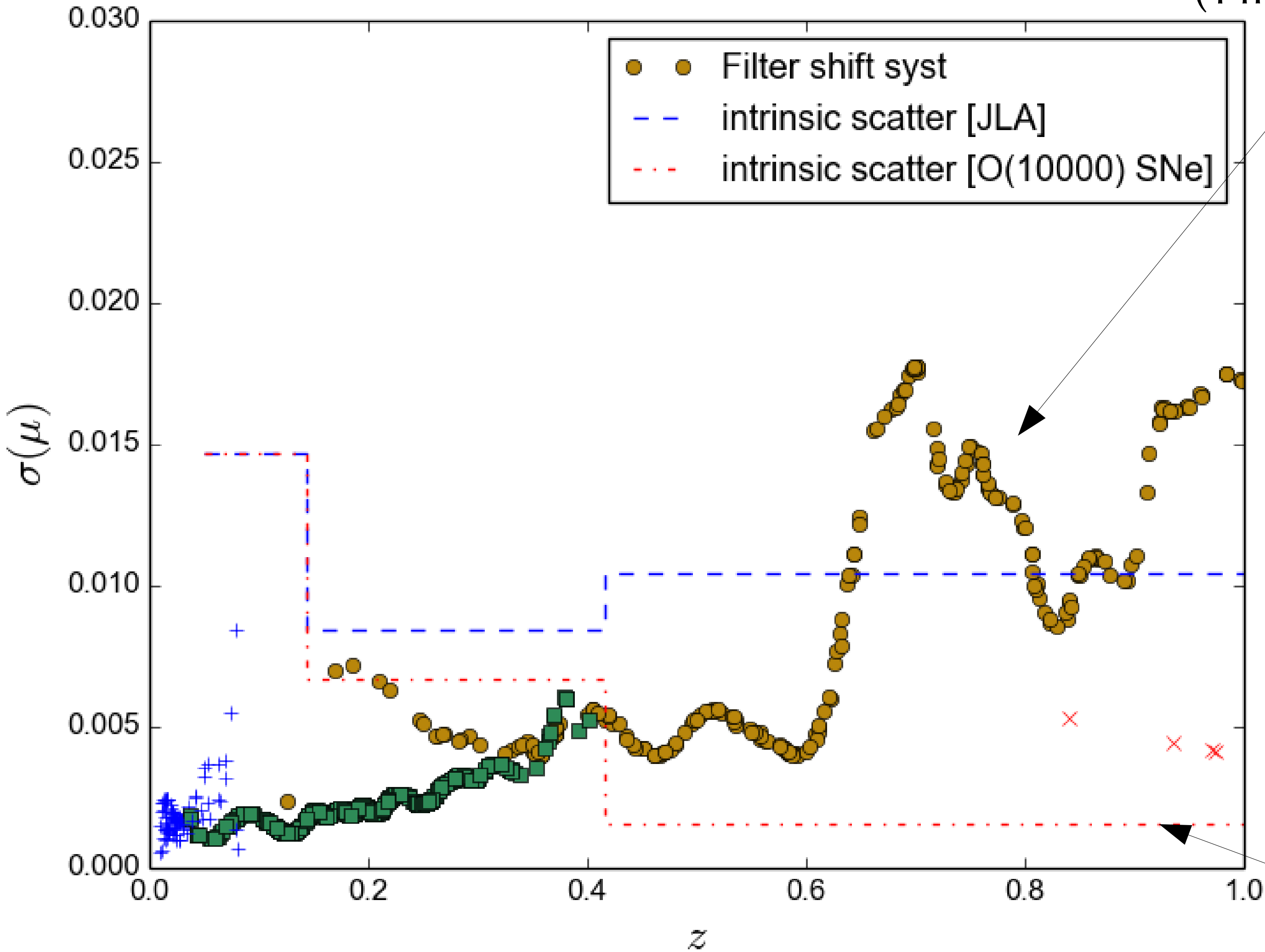
- Scans
  - by manufacturer (2002)
  - at CFHT (2006)
- Slow ageing excluded
- Evolution ~ just after installation ?

# Impact on cosmology

- Uncertainties in filter transmissions impact
  - Interpretation of flux measurements
  - SN empirical light curve model
  - Distances to SNe
- Improperly mapped filter non-uniformities impact
  - Photo-z
  - Introduces a scale ~ imager FOV in LSS studies

# Sensitivity to filter positions

JLA : propagation
of filter position *target* uncertainties
(1 nm, uncorrelated)

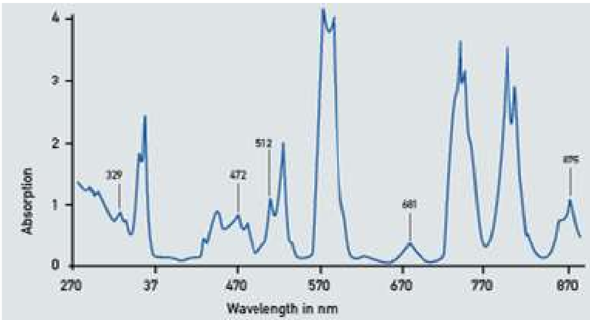


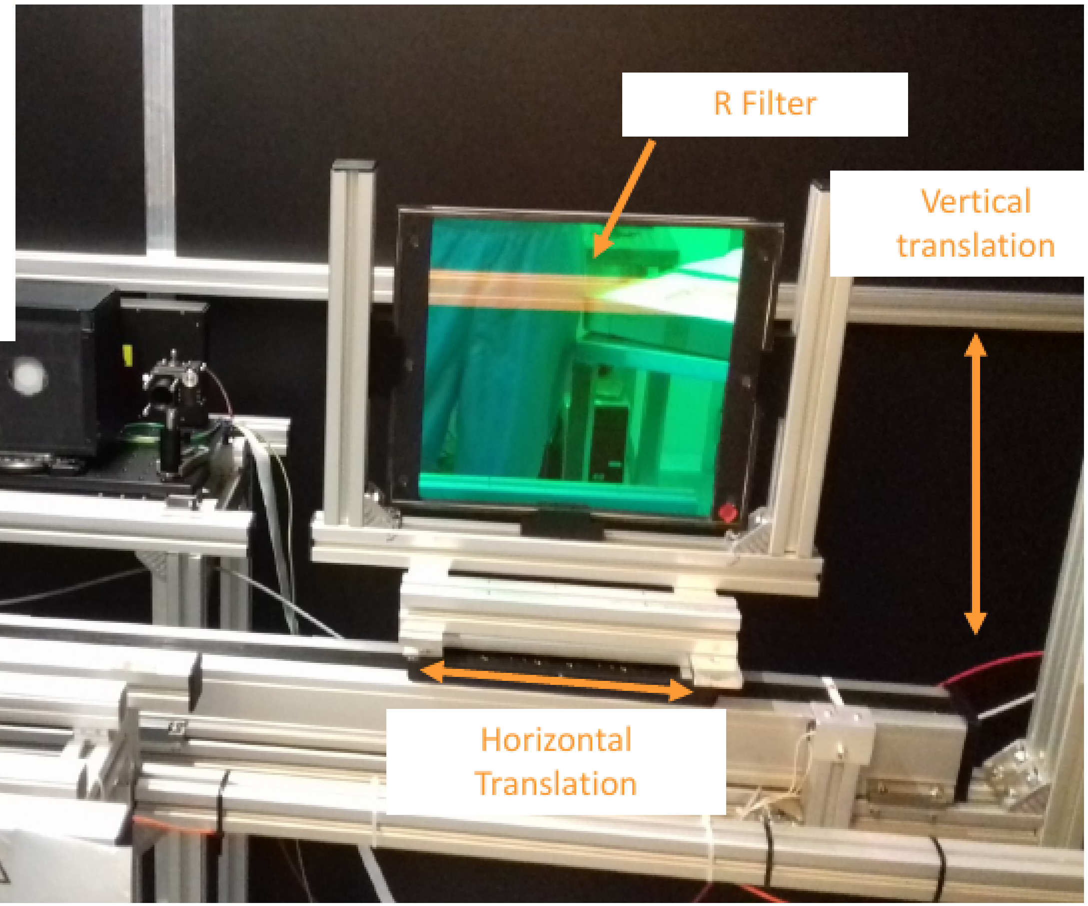

Level of statistical
uncertainties expected
with $O(10^4)$ SNe

# Filter scans @ LMA

- CFHT-LS filters have been decommissioned
- CFHT has agreed to send filters to LMA
- Goals:
  - Full scans of all filters on a grid
  - wavelength accuracy goal < 5 Å
  - At least 4 incidence angles
    - reconstruct effective passbands
  - Look for out-of-band light
  - Environmental studies to check sensitivity of filter coatings to temperature / hygrometry

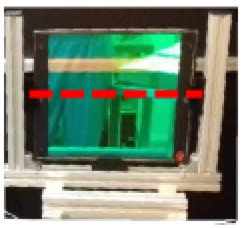
# Filter scans @ LMA (Lyon)

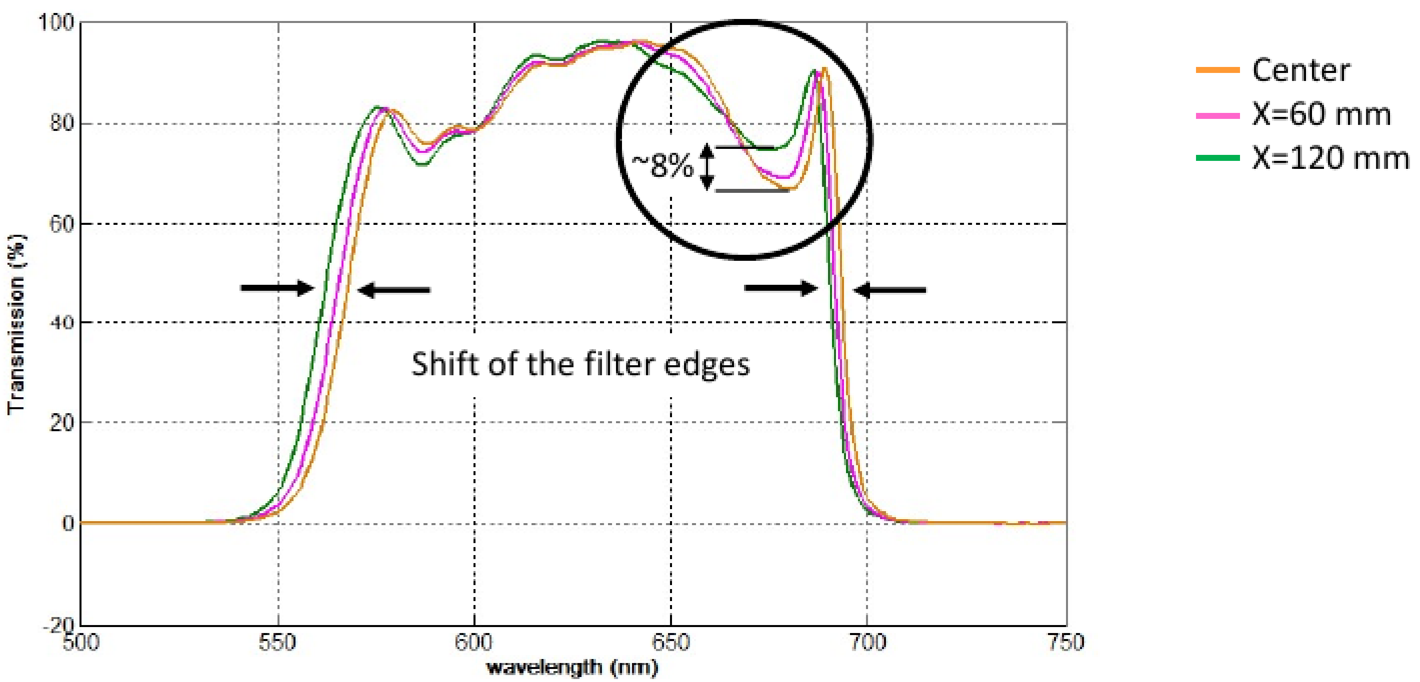



# Preliminary results

**AOI 0°**

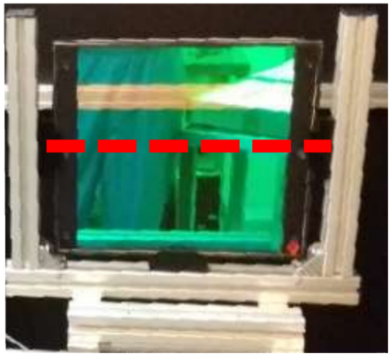


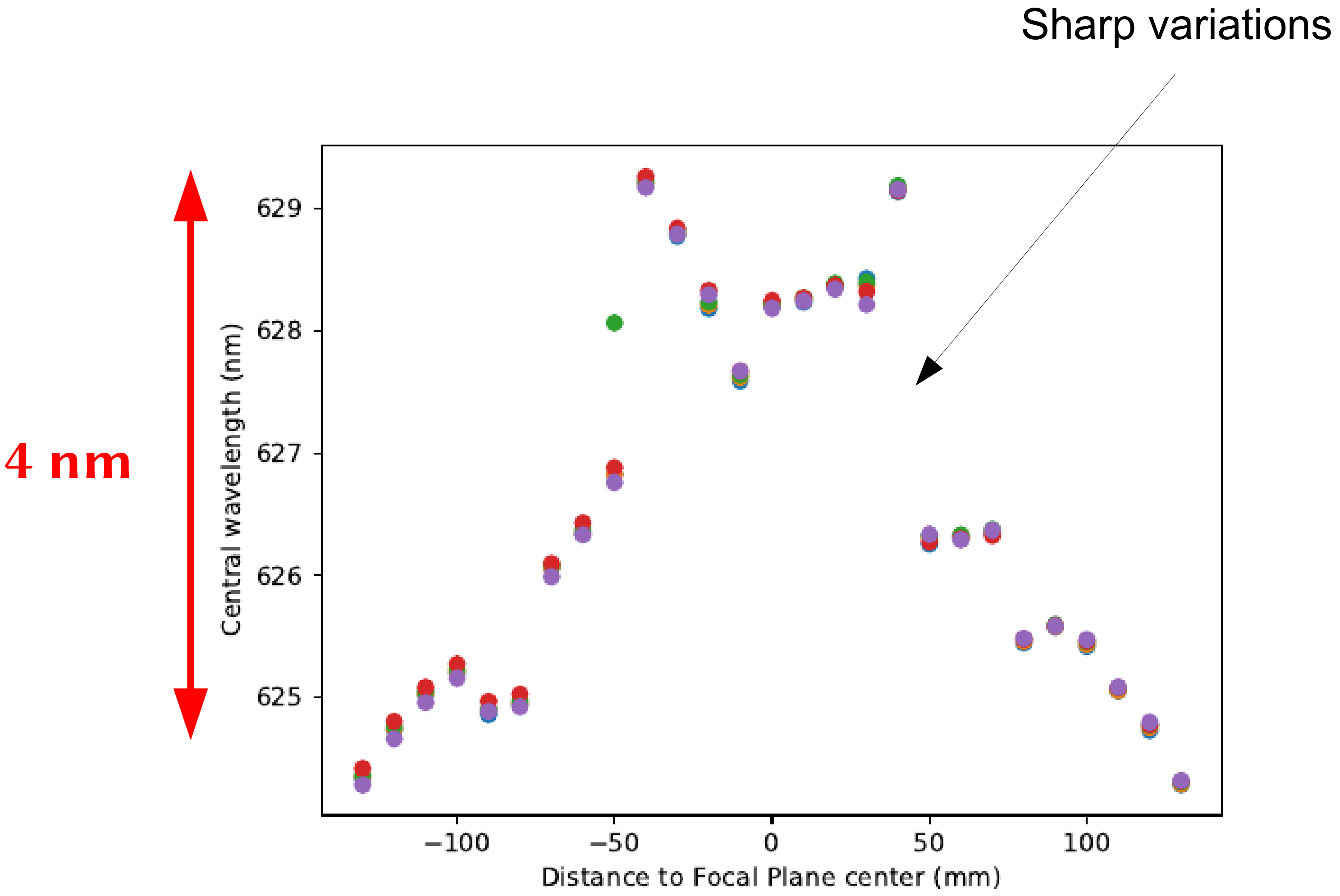
Deformation of the bandpass



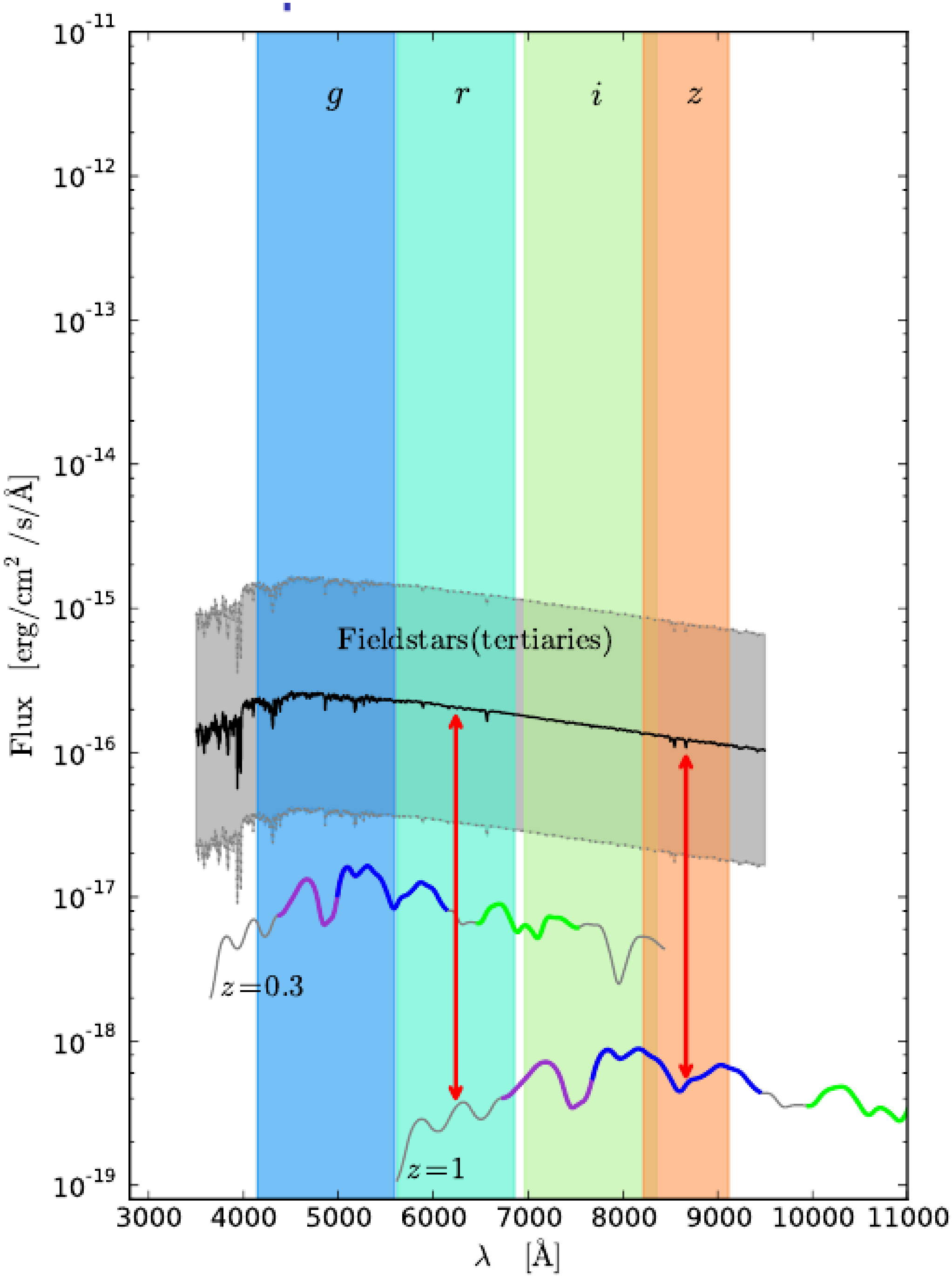

In addition to the shift of the filter edge, there is a deformation of the bandpass

# Scan along an axis

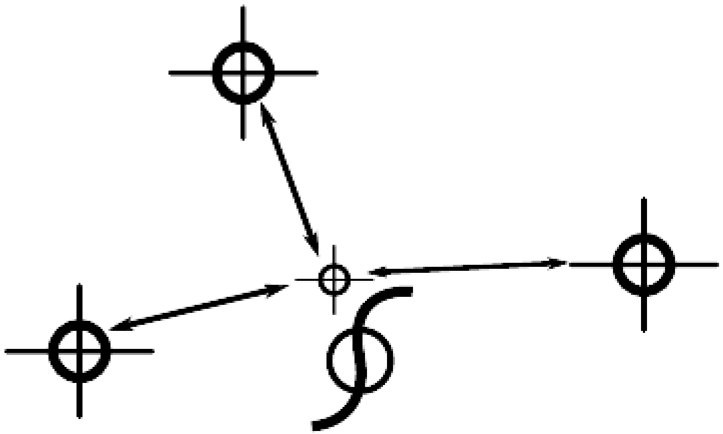




# Flux metrology chain




- Instrument response
  - Measure flux ratios in a single image



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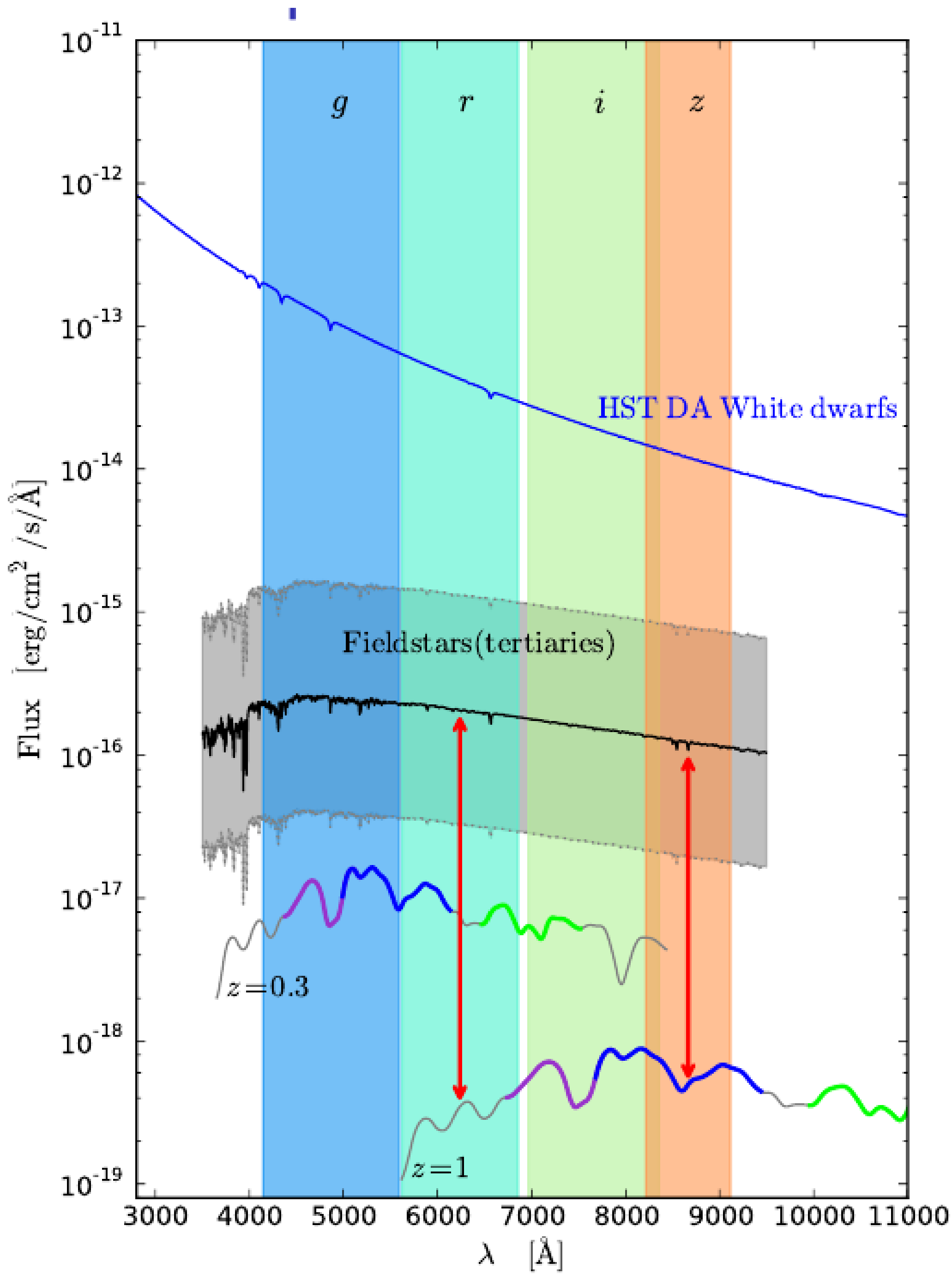


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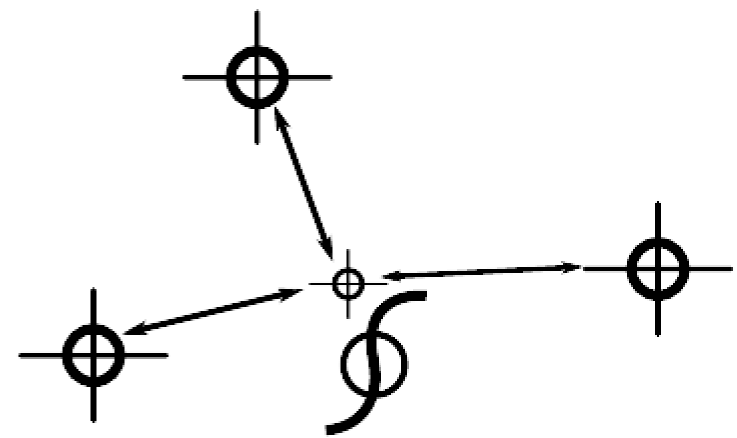
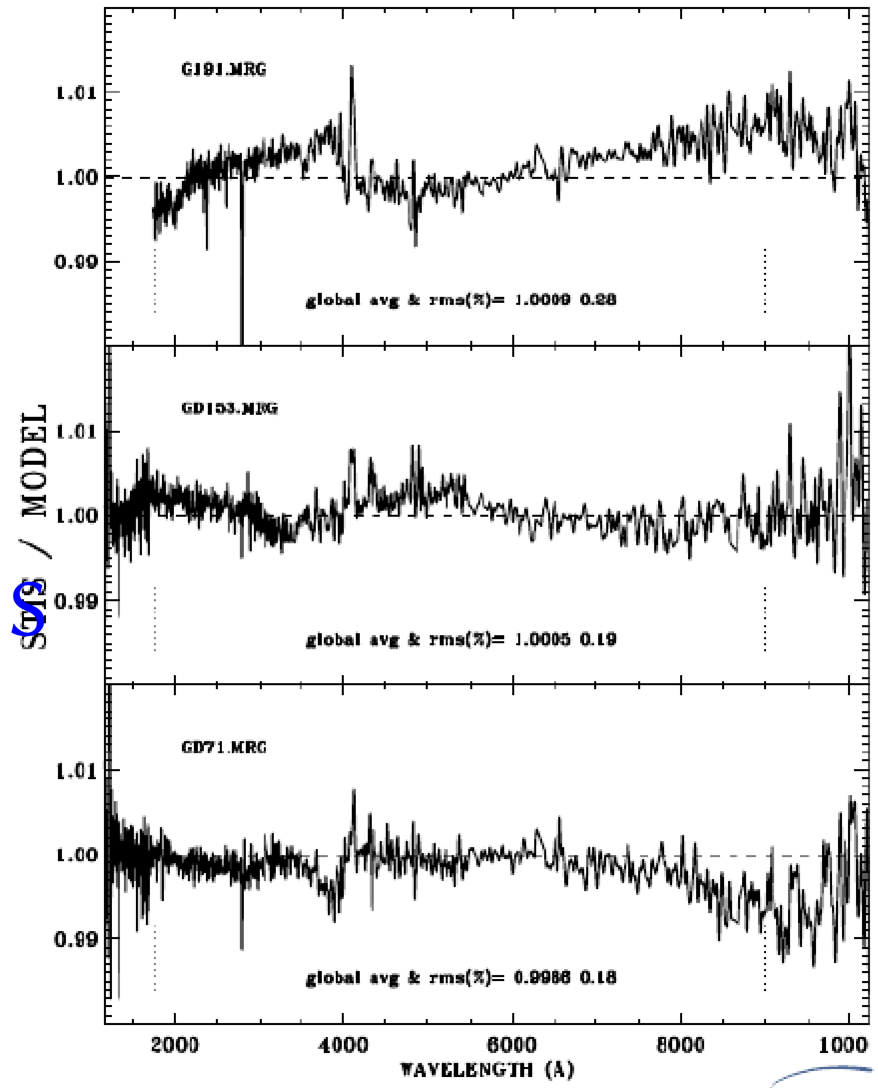


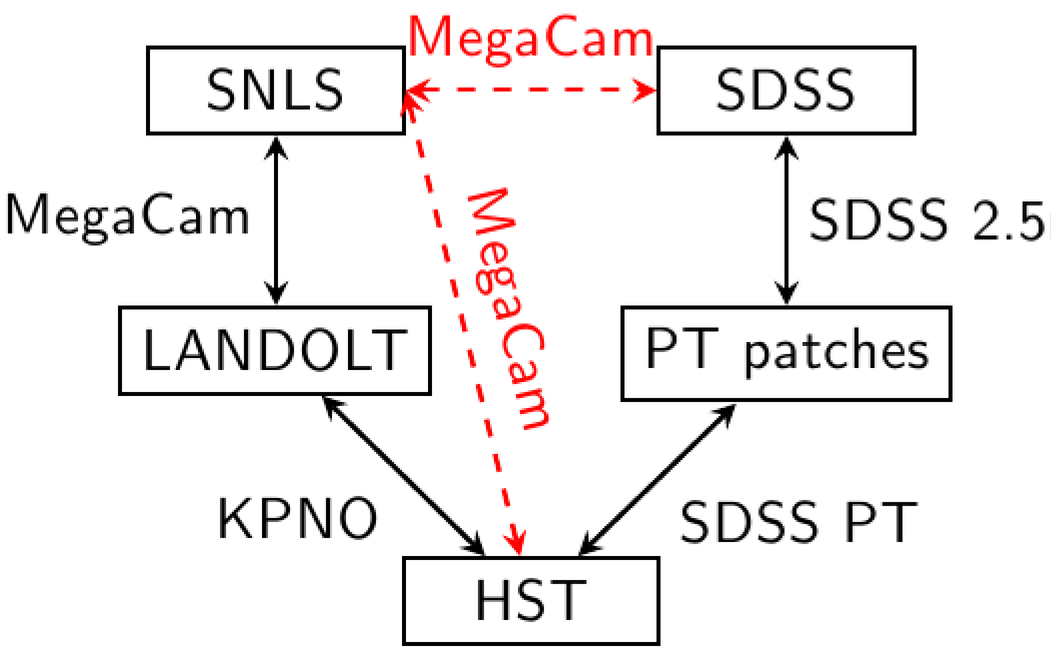
- Calibration transfer
  - HST standard as a primary calibration flux

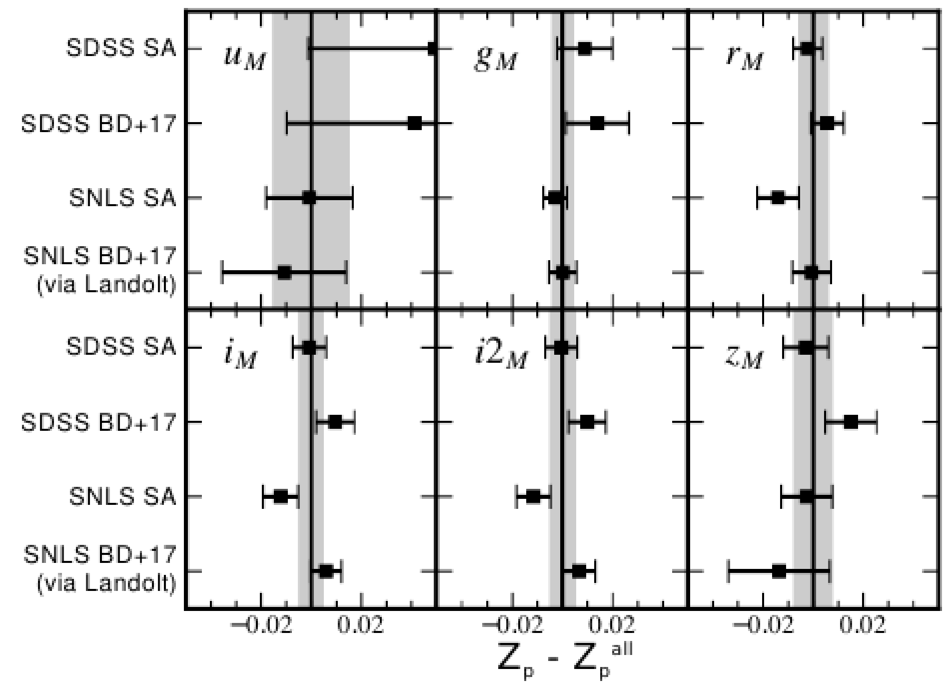
# CALSPEC

- Bohlin, Gordon, Tremblay, 2014
  - 3 DA white dwarfs : G191B2B, GD153, GD71
  - Rauch et al, 2013, NLTE models
- The average defines the HST/STIS calibration
  - Residuals at the ~ 1% level (in the visible)



# SNLS/SDSS (JLA) calibration paths

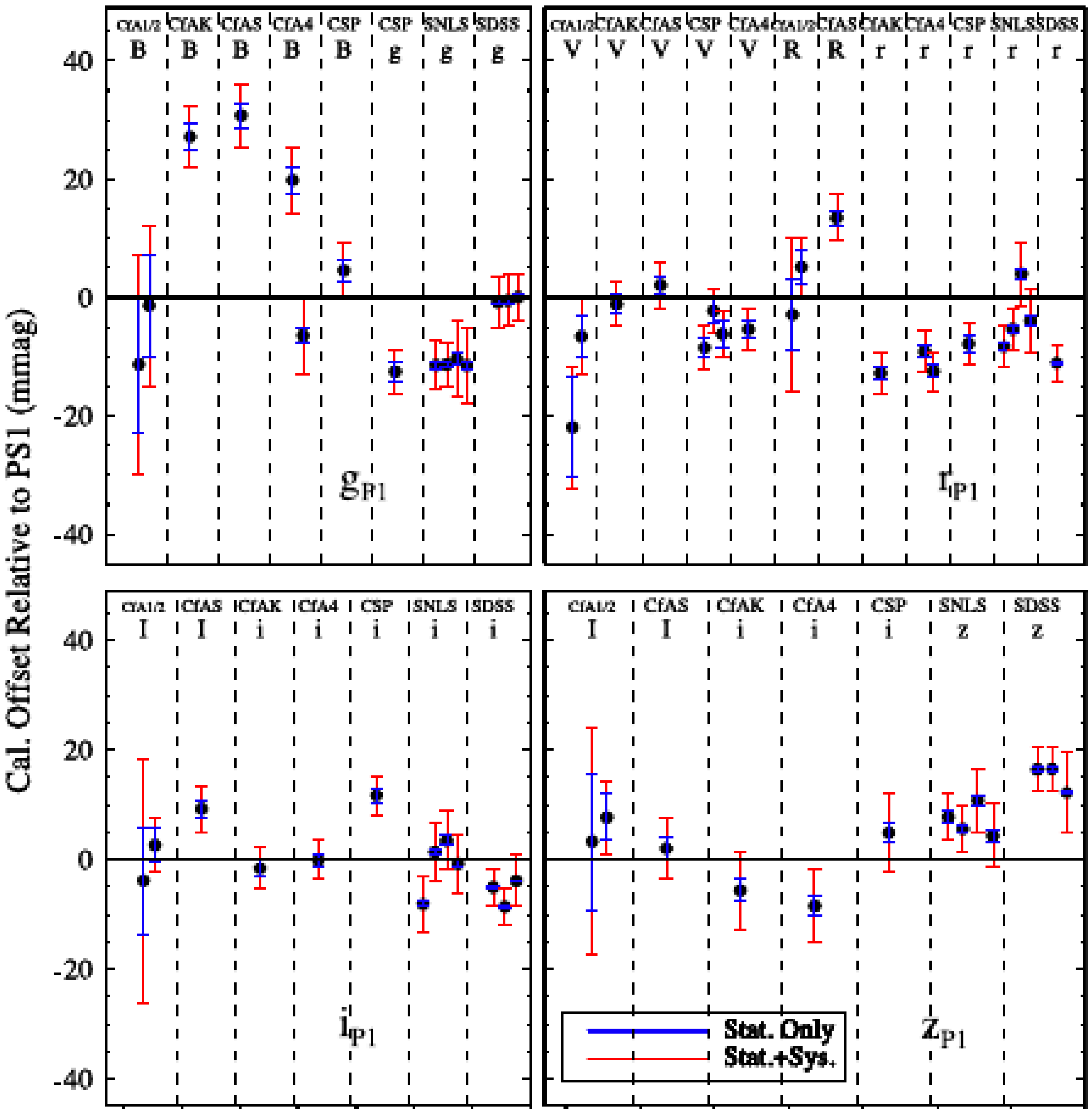



- Direct observations of SDSS & HST stars
- Several calibration paths
- 0.3% accuracy in gri

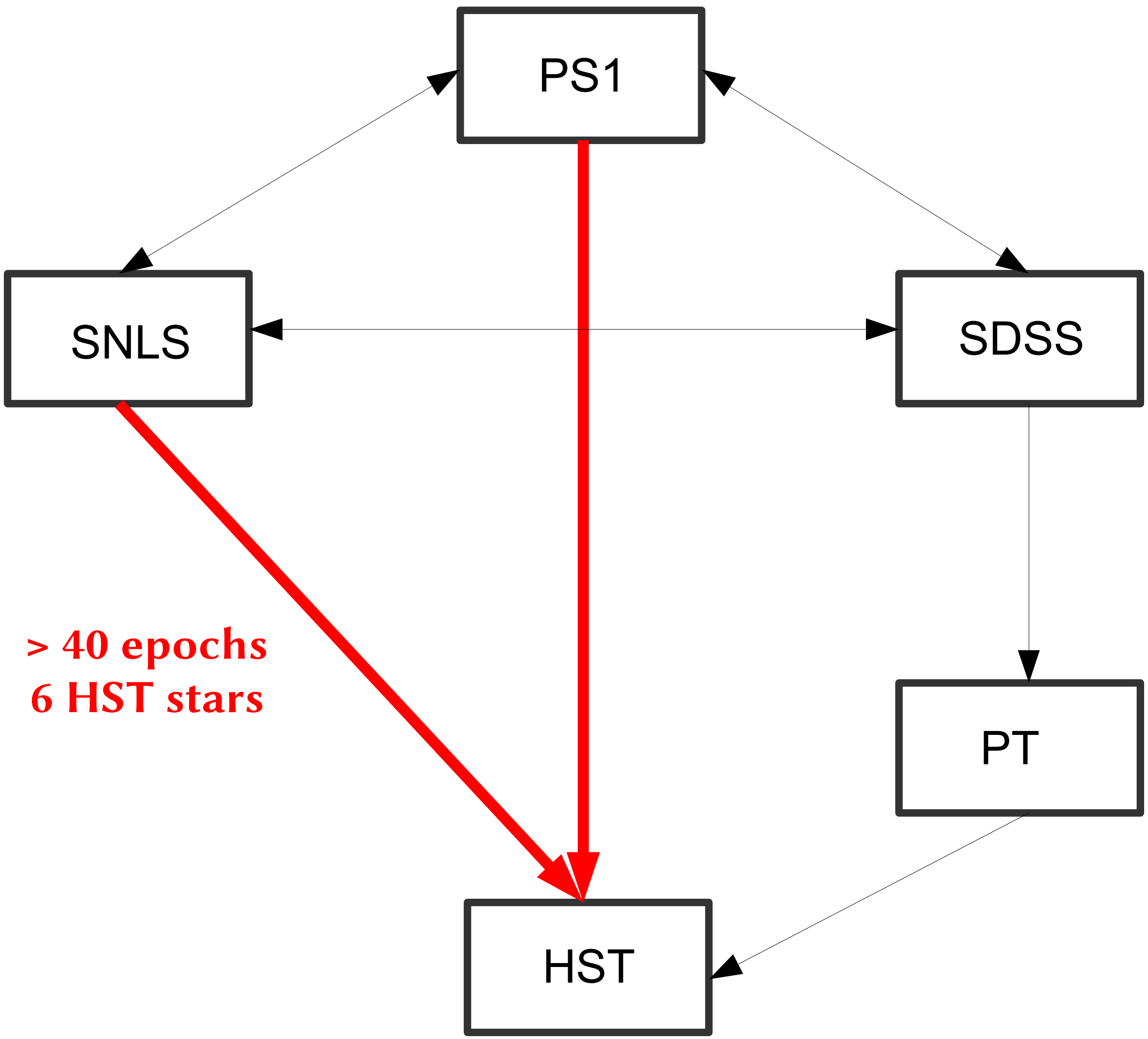
(Betoule et al, 2013)

# “Supercal” (Scolnic et al, 2015)



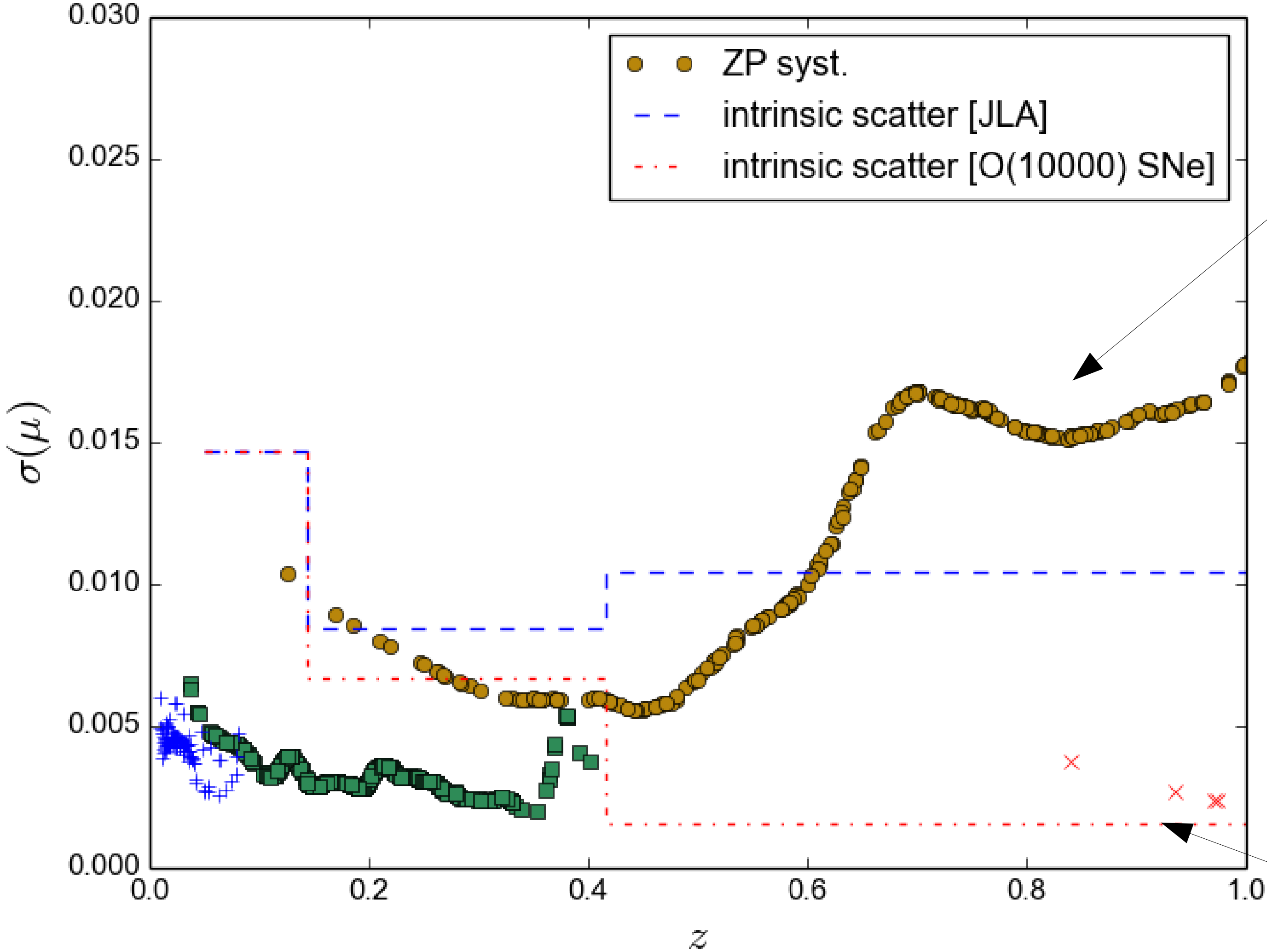

- Uses PS1 Full Sky sample as a reference

  (Schlafly et al, 2014)
- Recalibrate SN surveys using stars in common with PS1
- Independent path in metrology chain → CALSPEC
- Prefiguration of LSST calibration chain.


PS1
SNLS
SDSS
PT
HST
> 40 epochs
6 HST stars

# Sensitivity to Flux scale

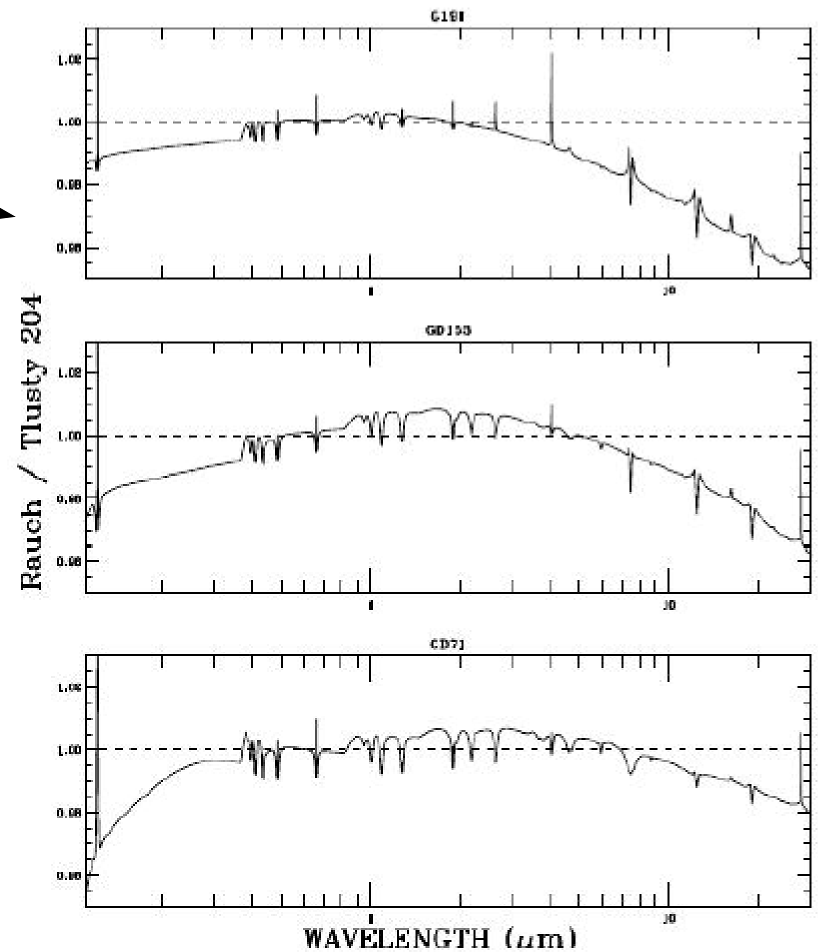
JLA : propagation
of MegaCam ZP uncertainties
(5 mmag)




Level of statistical
uncertainties expected
with $O(10^4)$ SNe

# Uncertainties ?

- 2 models implementing the same physics
  - ~ 4 mmag 300 < λ < 1000
- What about physics unaccounted for ?
  - Metal lines found in high-resolution spectra of G191B2B
  - Lyman / Balmer line problem
  - Others ?

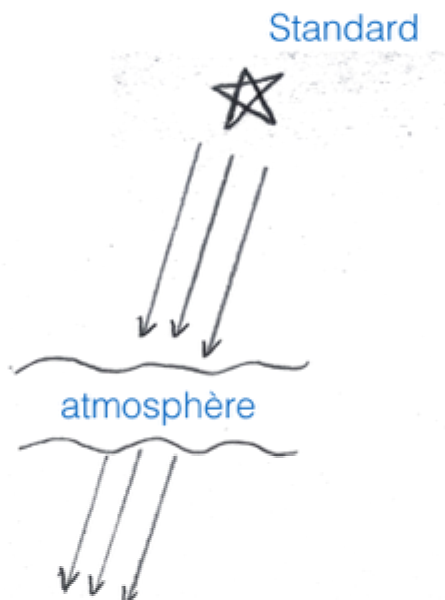



(Bohlin, 2014)

# How can we improve on that ?

- Add more DA white dwarfs to CALSPEC
  - Narayan et al, 2016
- Use a different type of standard ?
  - Instrumental calibration
    - COBP
    - StarDICE
    - ACCESS (e.g. Kaiser et al, 2014)
    - ...

# Methodology

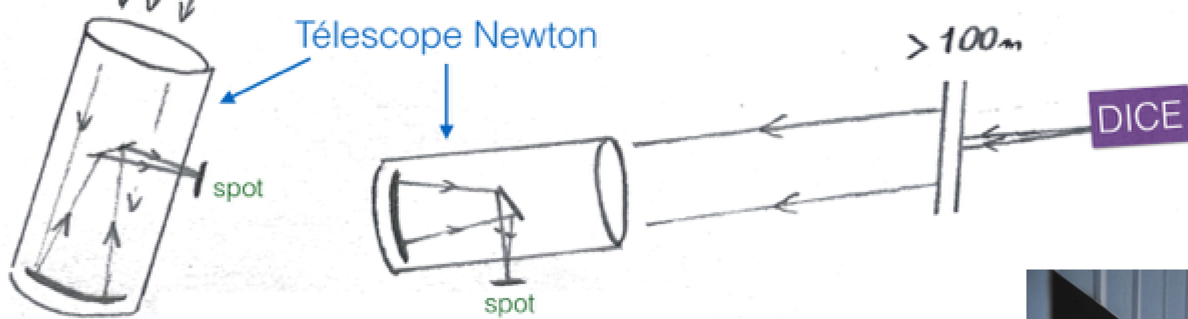



- Observe alternatively
  - The calibrated source (⟶ star on the focal plane)
  - A selection of bright (and faint) CALSPEC standards

Challenges :

Generate a stable artificial point source

Account for the differential extinction



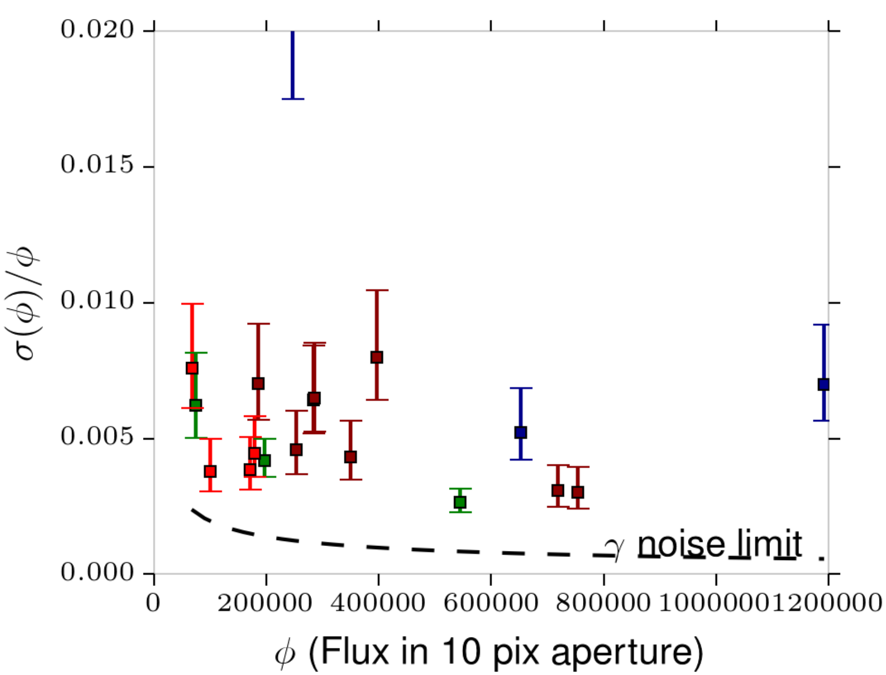

# First results

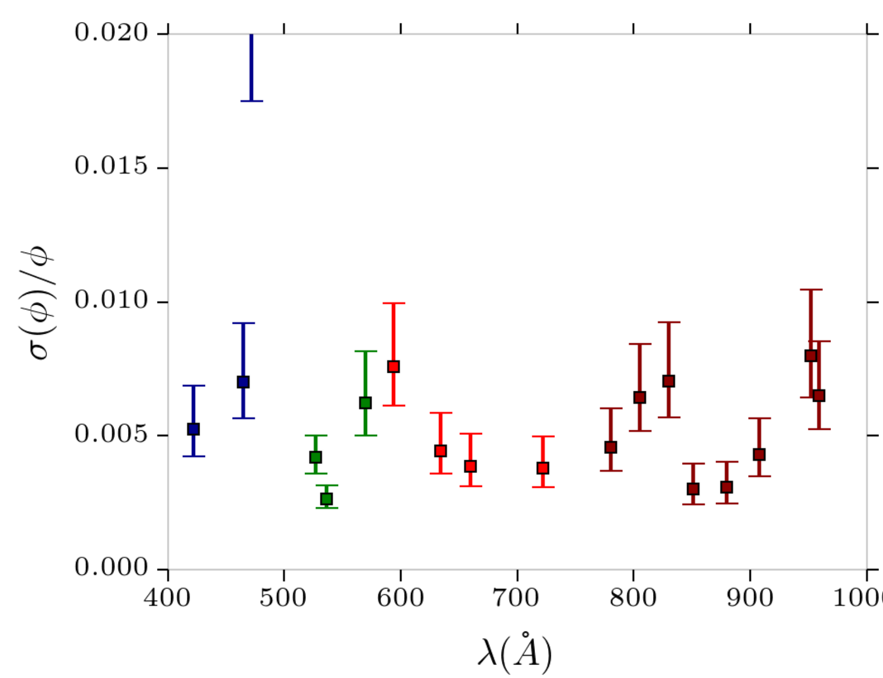
- Stability of (source + atmosphere + telescope)

  ~ 0.5% - 0.7% over ~ 10 – 20 minutes

- Target recision of ~ 0.1% within reach

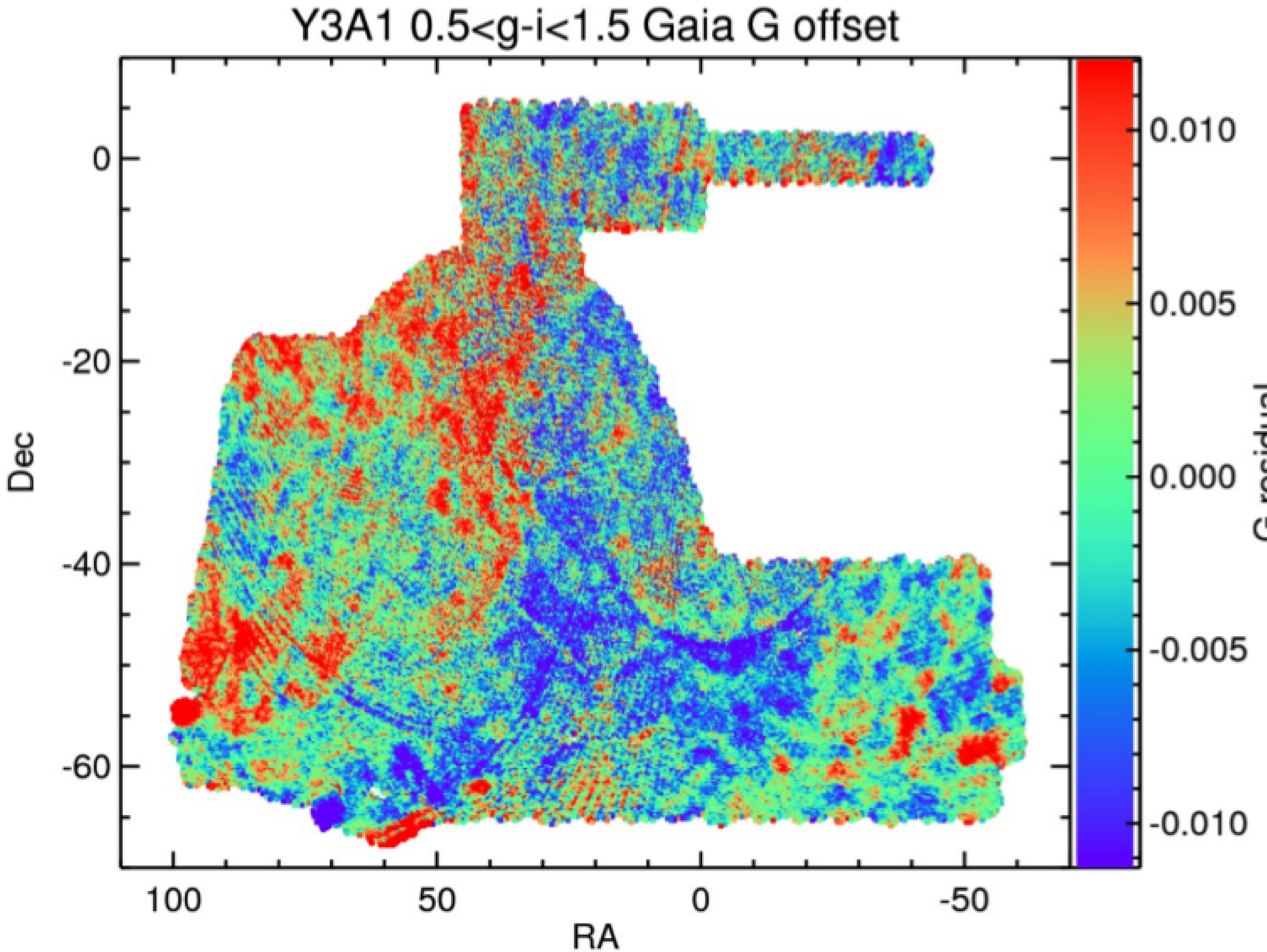
  ⟶ if one can accumulate ~ O(50-100) visits per star



# Conclusion

- Important redundancy in LSST obs. Strategy
  - Calibration transfer will be easier (FGCM + GAIA)
- Potential key issues
  - Filter characterization and follow-up (COBP?)
  - Primary flux reference




E. Rykoff, DES collaboration