Calibrer une caméra grand champ : l'expérience de SNLS

N. Regnault et al

(LPNHE, Paris)

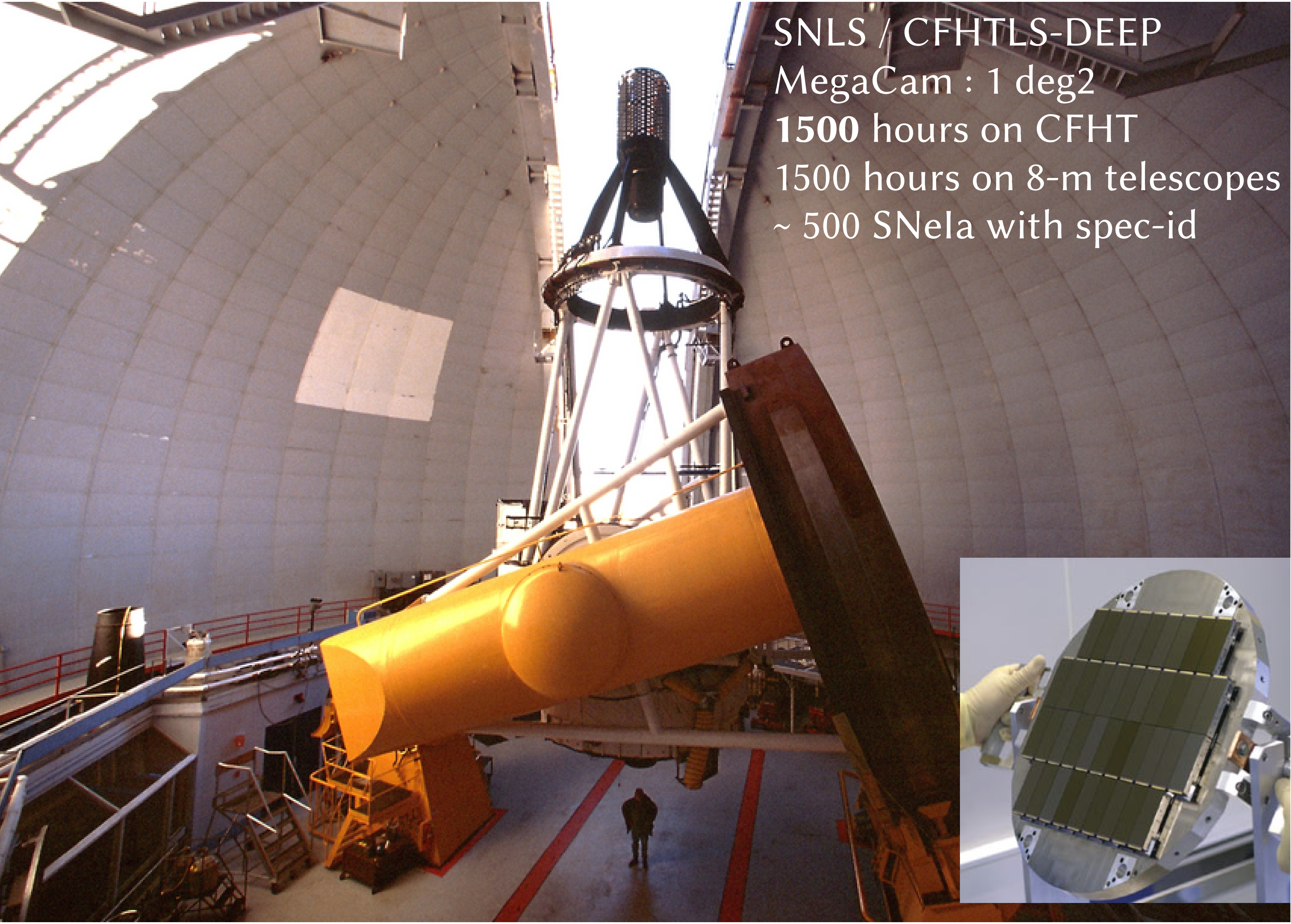
SNLS / CFHTLS-DEEP

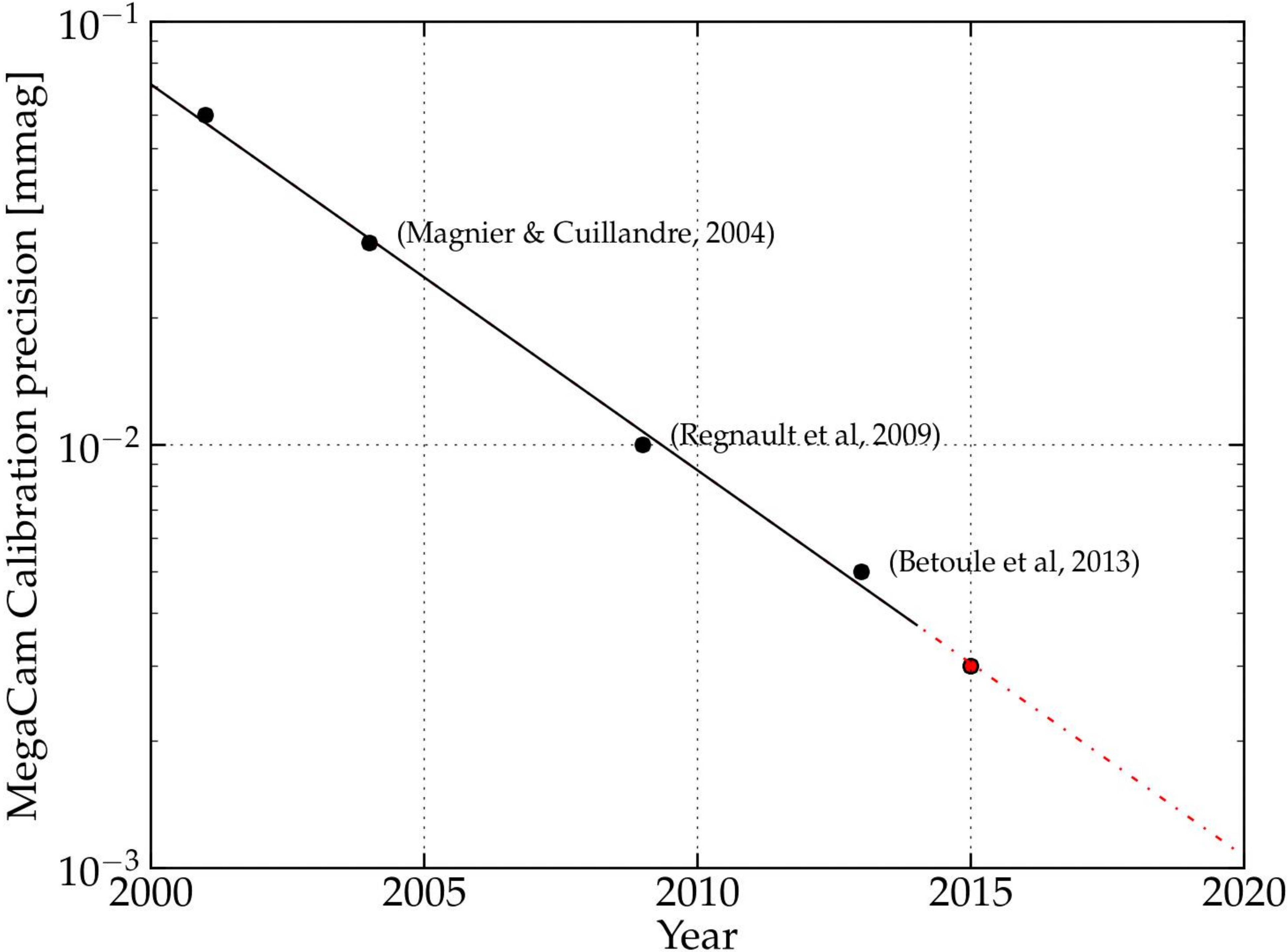
MegaCam : 1 deg2

1500 hours on CFHT

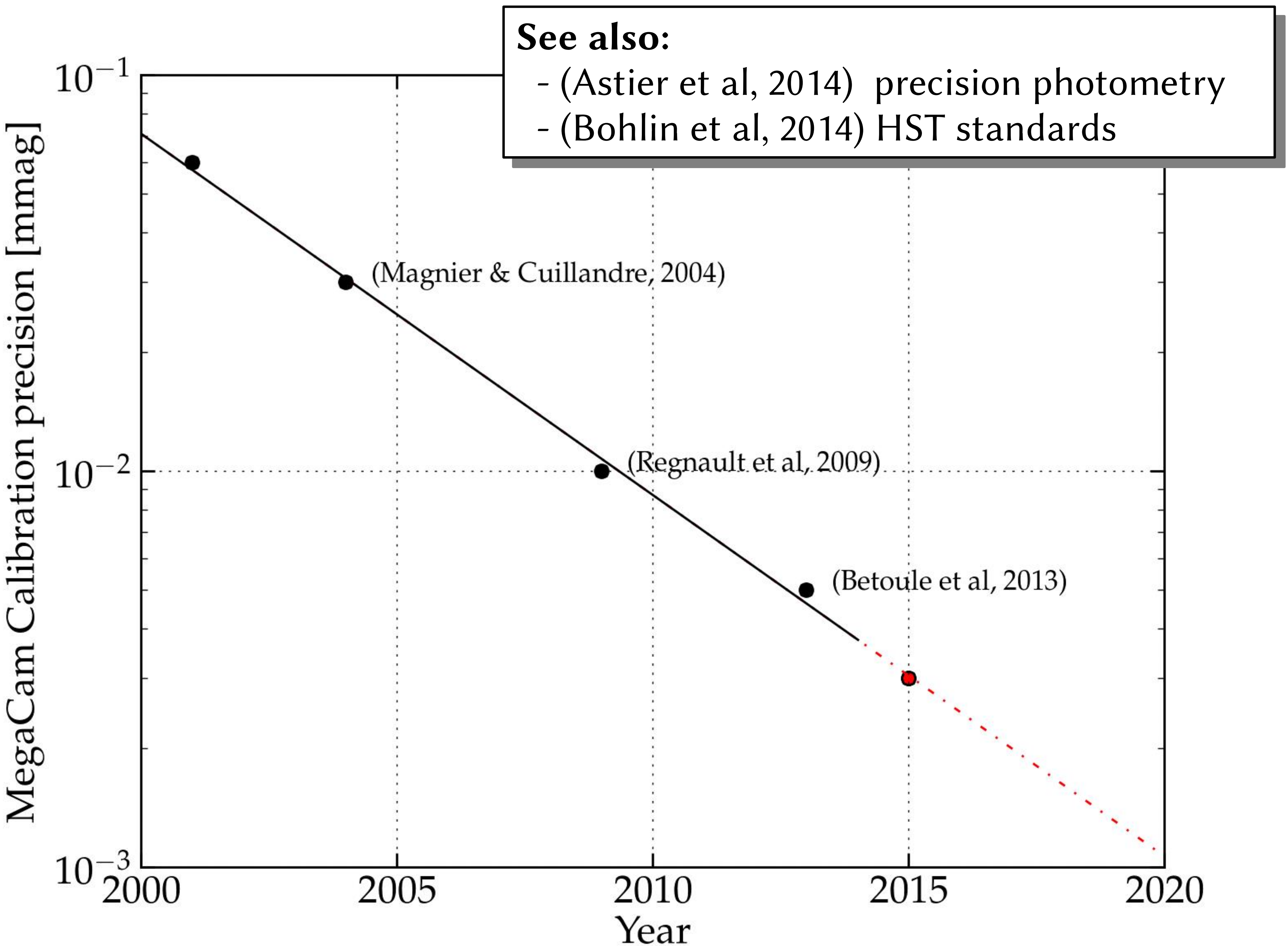
1500 hours on 8-m telescopes

~ 500 SNeIa with spec-id





MegaCam Calibration precision [mmag]
Year
10^{-1}
10^{-2}
10^{-3}
2000
2005
2010
2015
2020
(Magnier & Cuillandre, 2004)
(Regnault et al, 2009)
(Betoule et al, 2013)



See also:
- (Astier et al, 2014) precision photometry
- (Bohlin et al, 2014) HST standards
10^{-1}
10^{-2}
10^{-3}
MegaCam Calibration precision [mmag]
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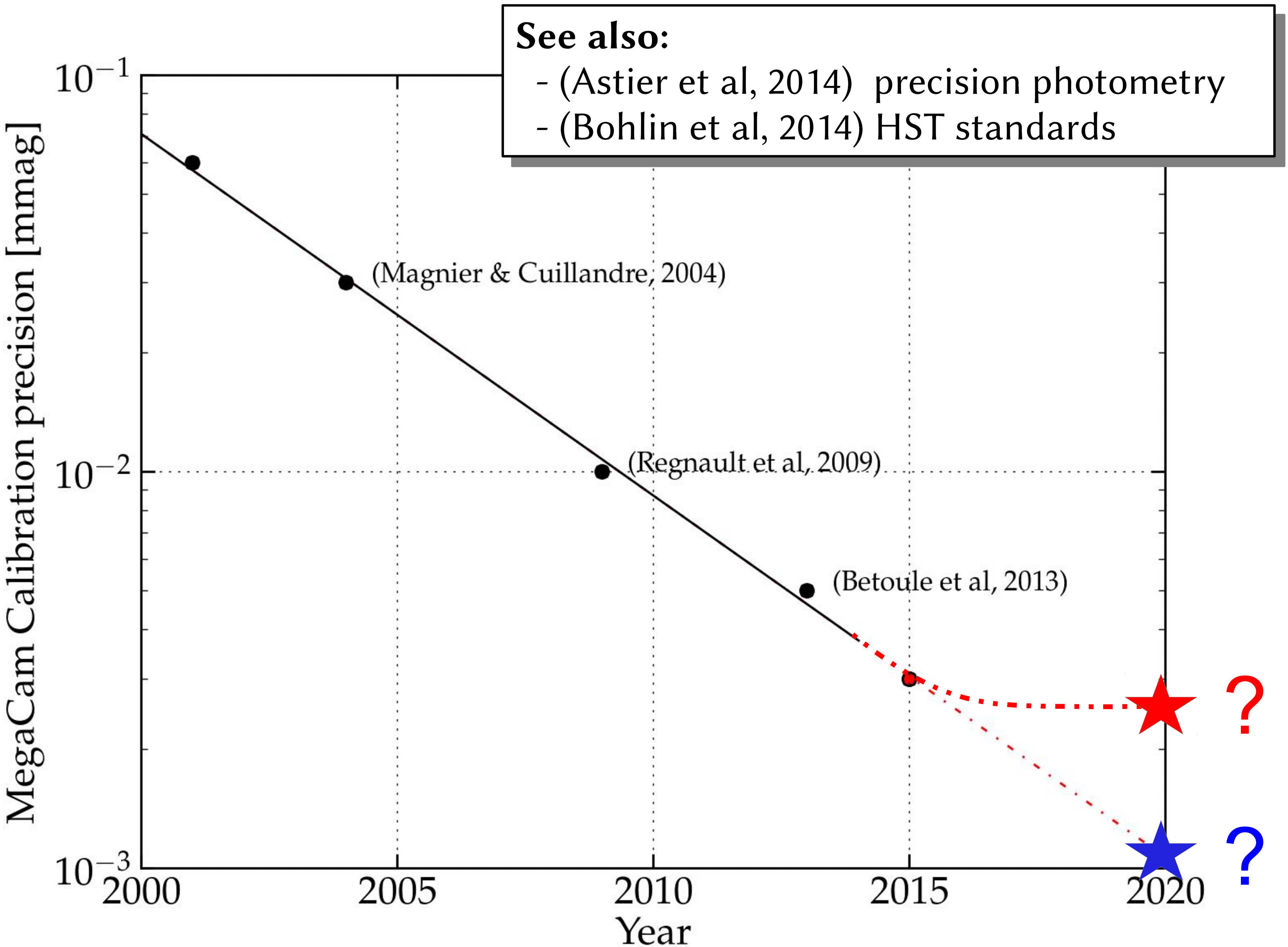
Year



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10^{-1}
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(Magnier & Cuillandre, 2004)
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(Betoule et al, 2013)
?
?
2000
2005
2010
2015
2020
Year

Outline

- Imager Uniformity
  - Response maps / “grids” / star flats
- Flux metrology chain
  - Fundamental flux standards
  - Building robust metrology chains
- Instrumental calibration

Instrument response

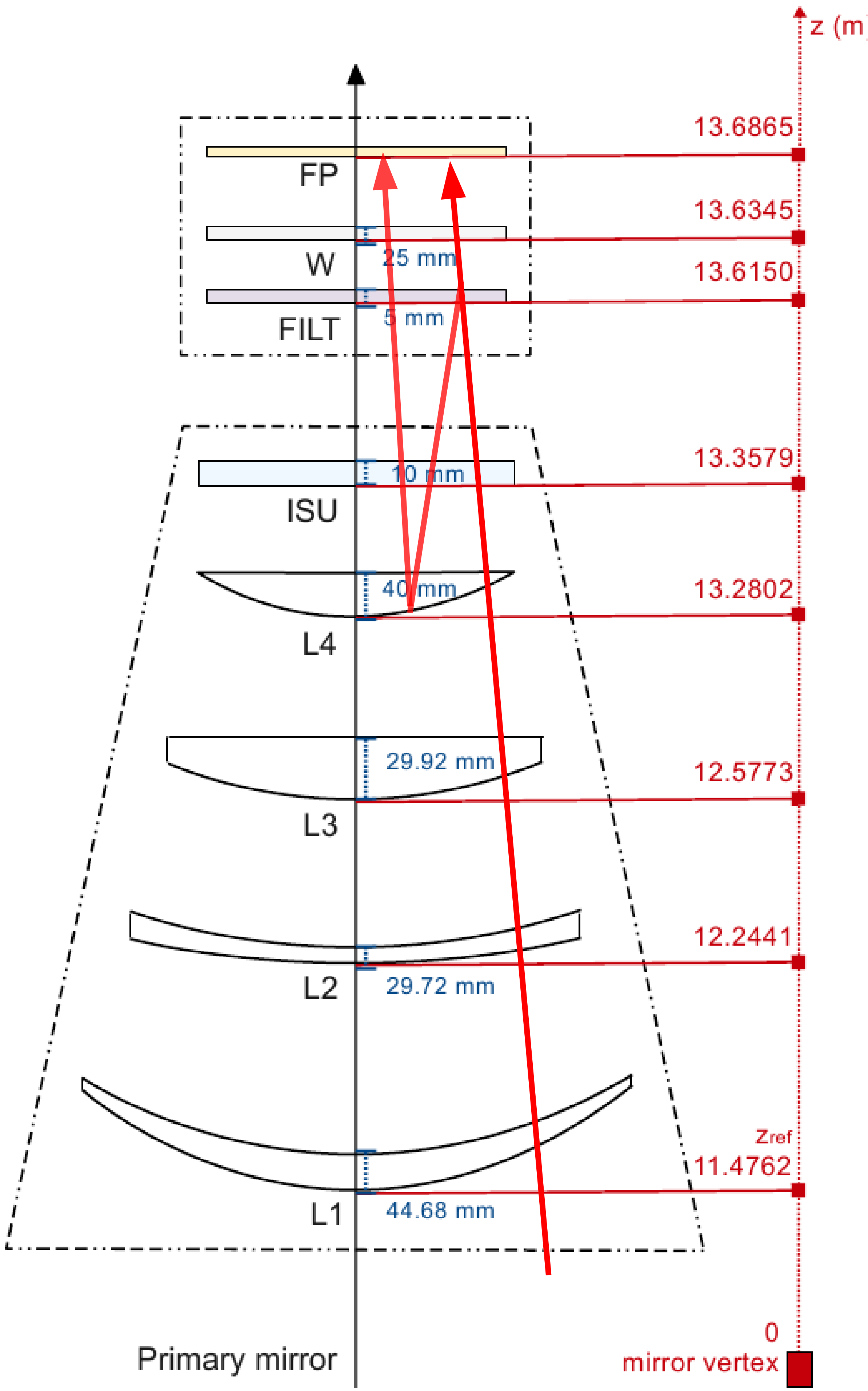
- Flat fields
  - Affected by plate scale variations (well measured $\leftrightarrow$ astrometry)
  - contaminated by ghosts (reflections in the WFC)

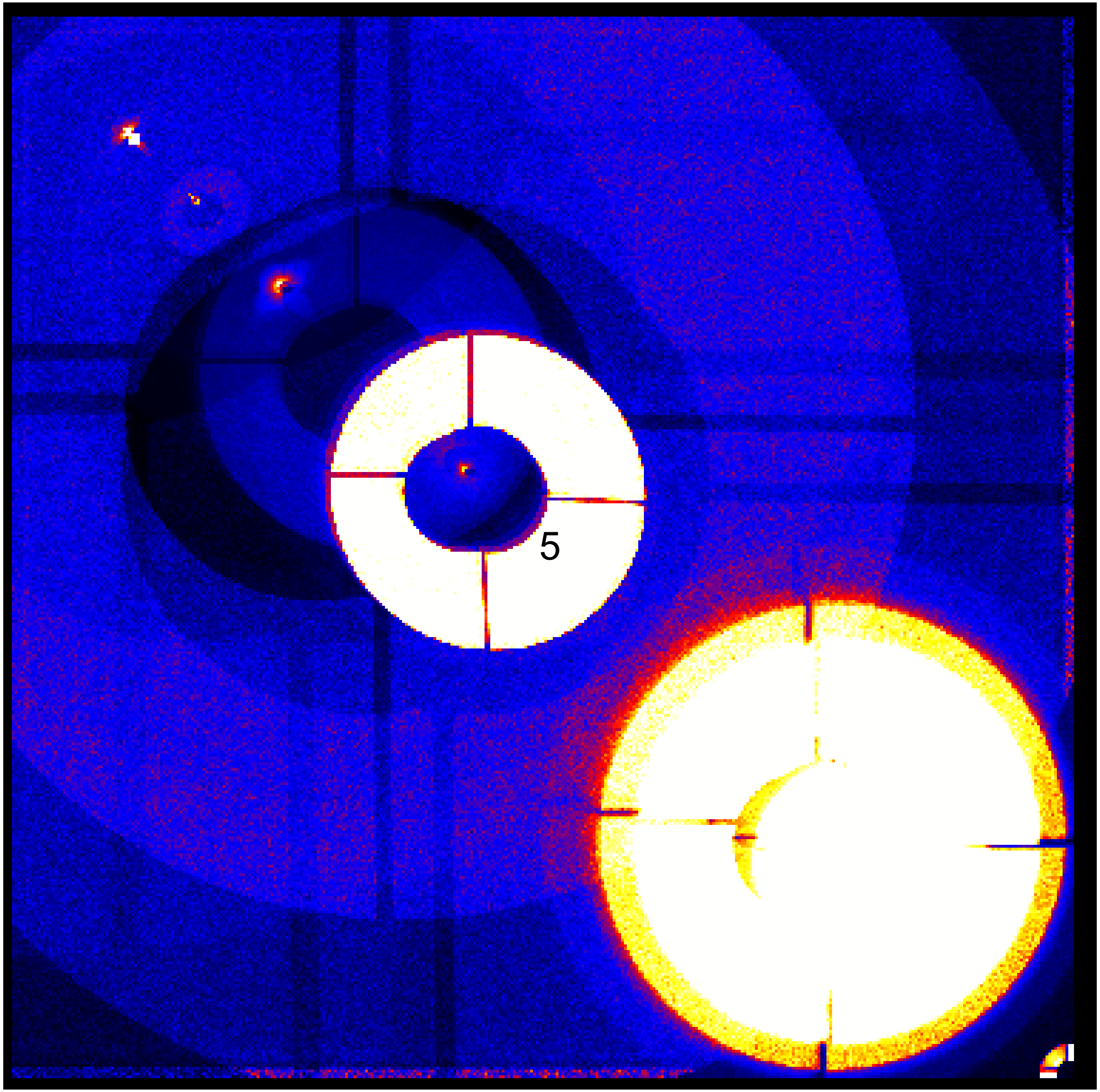
- Filter uniformity
  - MegaCam filters vary by ~ 5-nm center-to-corner.

(Magnier et al, '04)
(Regnault et al, '09)
(Betoule et al, '13)

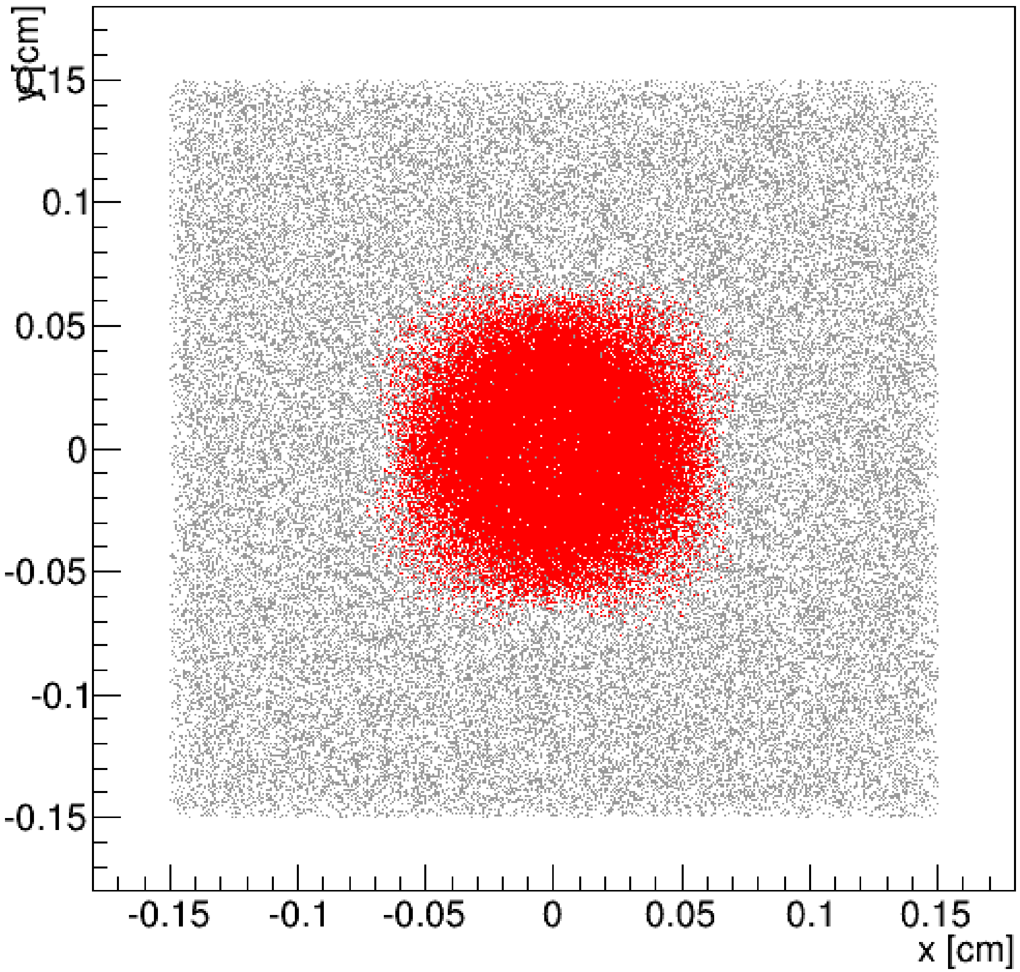
Ghosts

NGC3489 (MATLAS)
http://irfu.cea.fr/Projets/matlas/atlas3D/NGC3489.html

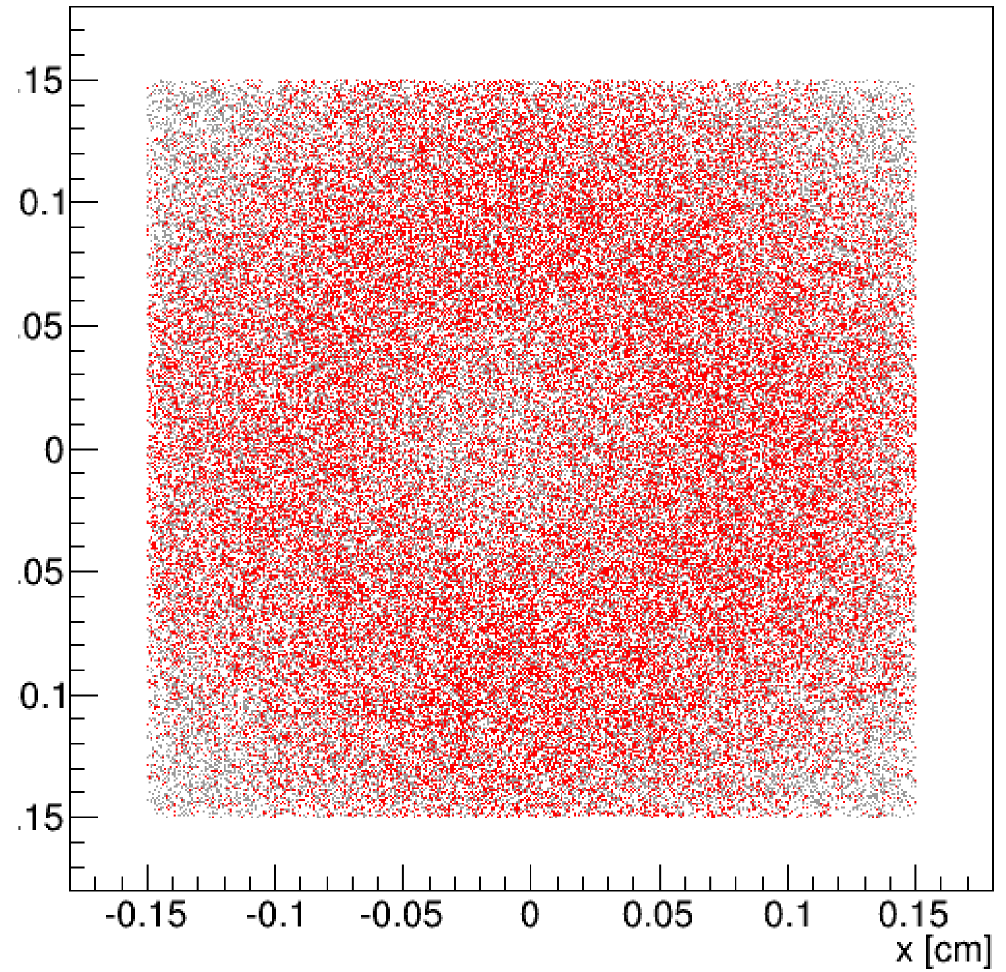

z (m)
13.6865
13.6345
13.6150
13.3579
13.2802
12.5773
12.2441
Zref
11.4762
0
mirror vertex
FP
W
25 mm
FILT
5 mm
ISU
10 mm
40 mm
L4
29.92 mm
L3
L2
29.72 mm
L1
44.68 mm
Primary mirror


5

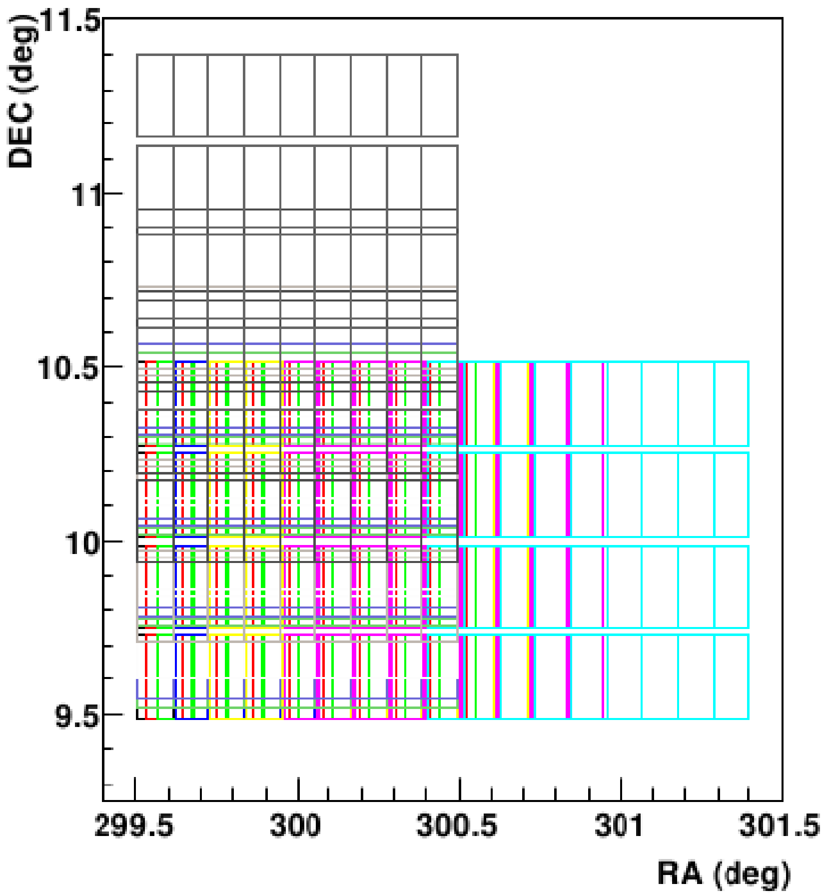
flat field [L4 ghost]



flat field [L3 ghost]



Mapping the instrument response



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

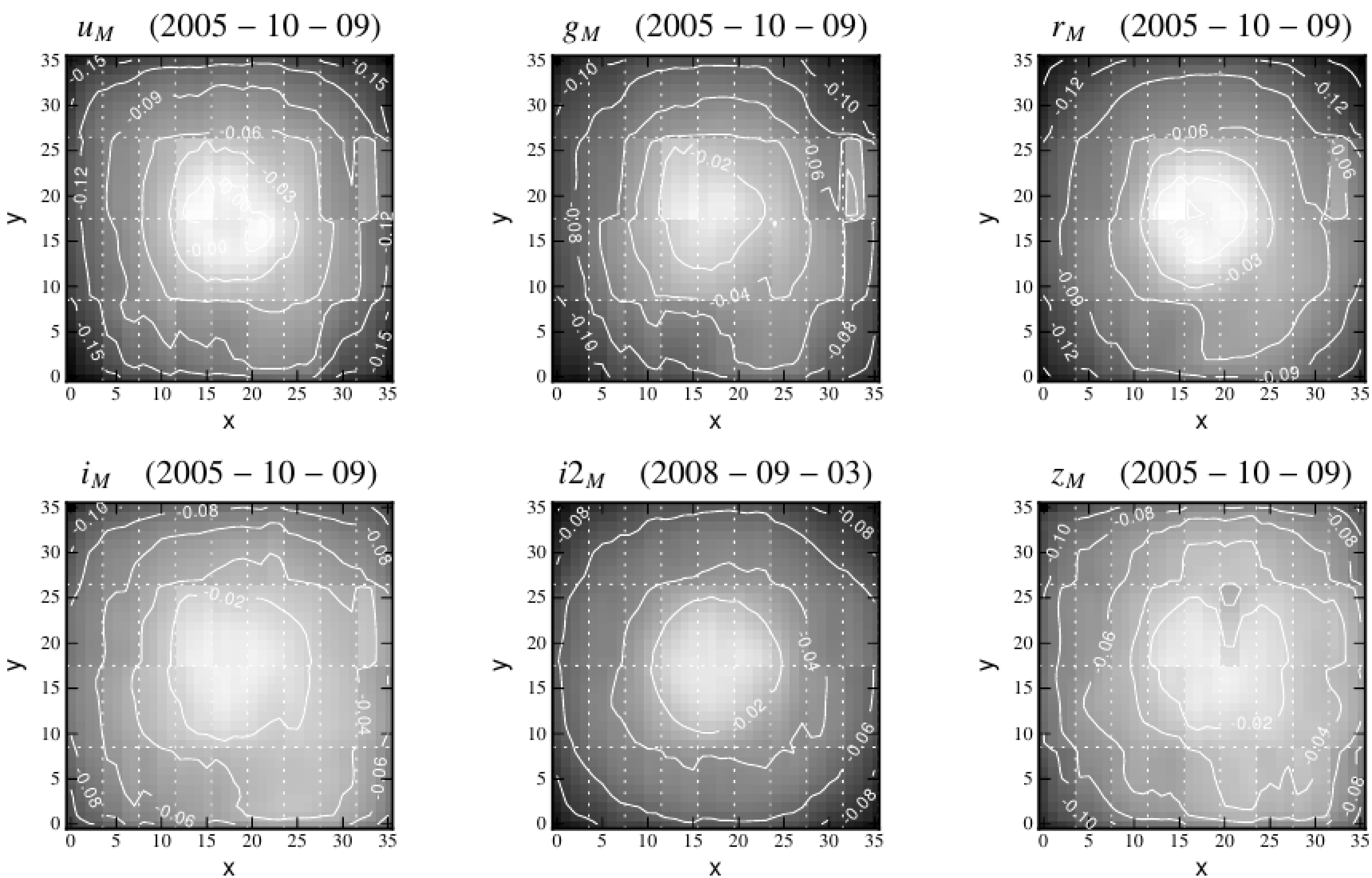
$$m(x) = m(x_0) + \delta zp(x) + \delta k(x) \times col$$

Star mags @ center
(~ 100,000 pars)

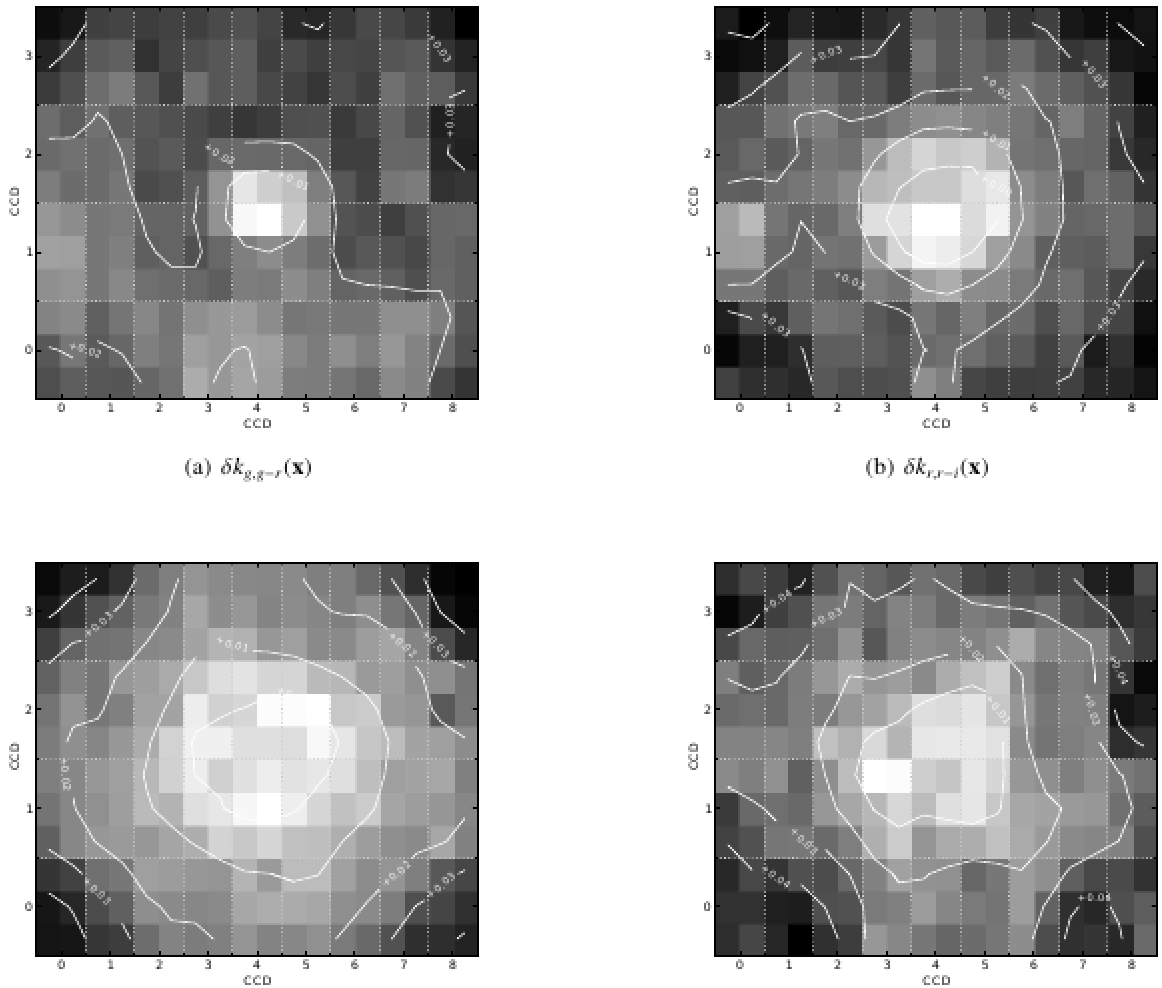
Maps
(~ 100 pars)

(Magnier & Cuillandre, 2004; Regnault et al, 2009)

Plate scale + ghosts



Filter variations (in λ)

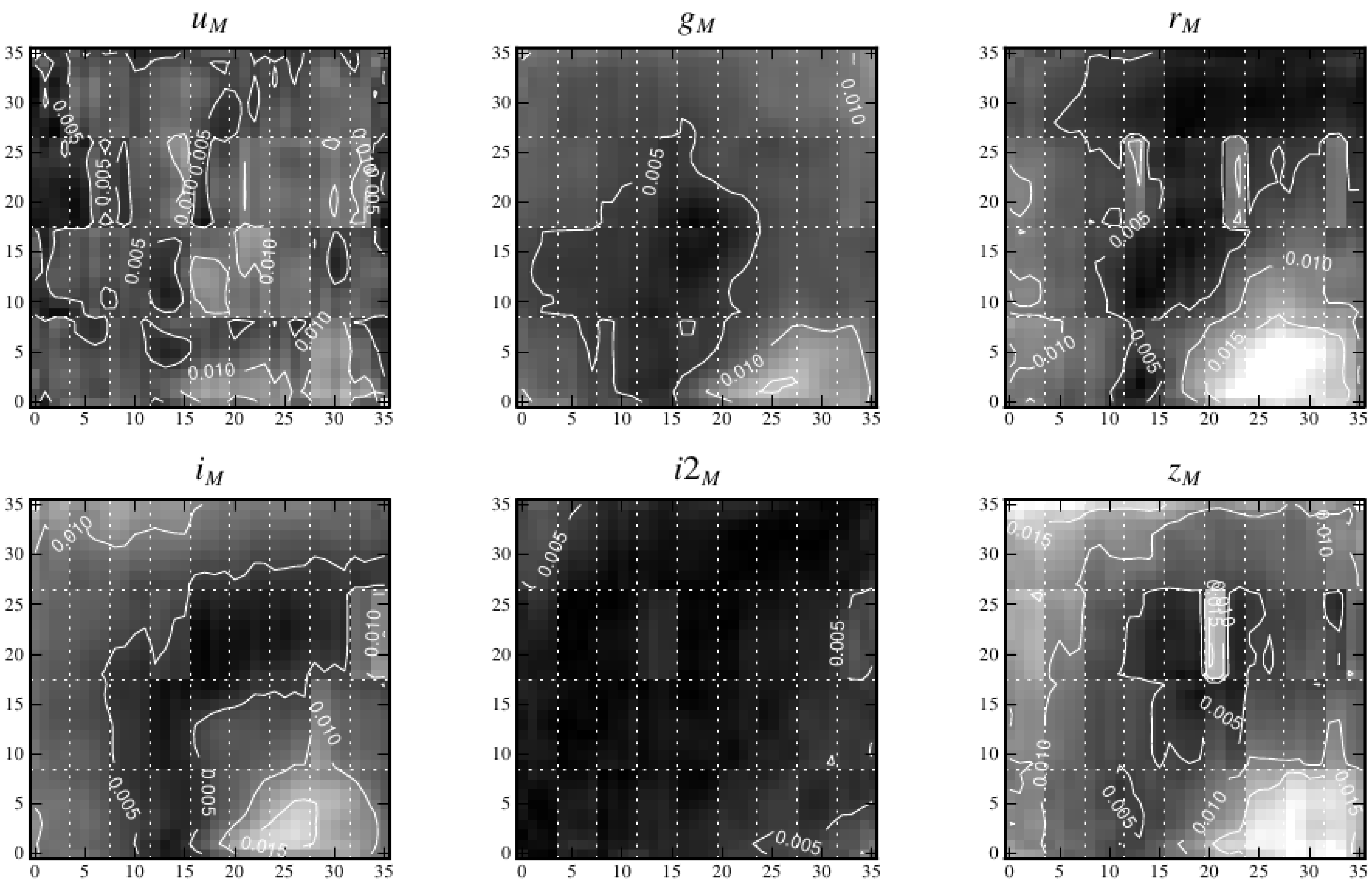


(a) $\delta k_{g,g-r}(\mathbf{x})$ (b) $\delta k_{r,r-i}(\mathbf{x})$

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

Preferable to measure the filters on a bench...)

Variability of the imager response



Uniformity

- Mapping techniques rely on sets of dithered observations which are
  - Costly in terms of observing time
    $\longrightarrow$ taken every ~ 6 months / 1 year
- BUT
  - ~ 1% variations observed, over ~ 6 months timescales
- Best solution would be a mix of
  - dithered observations
  - instrumental monitoring of the uniformity (every week)
- Why not instrumental monitoring only ?
  - because uniformity maps depend on flux estimator used...

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  - Fundamental flux standards
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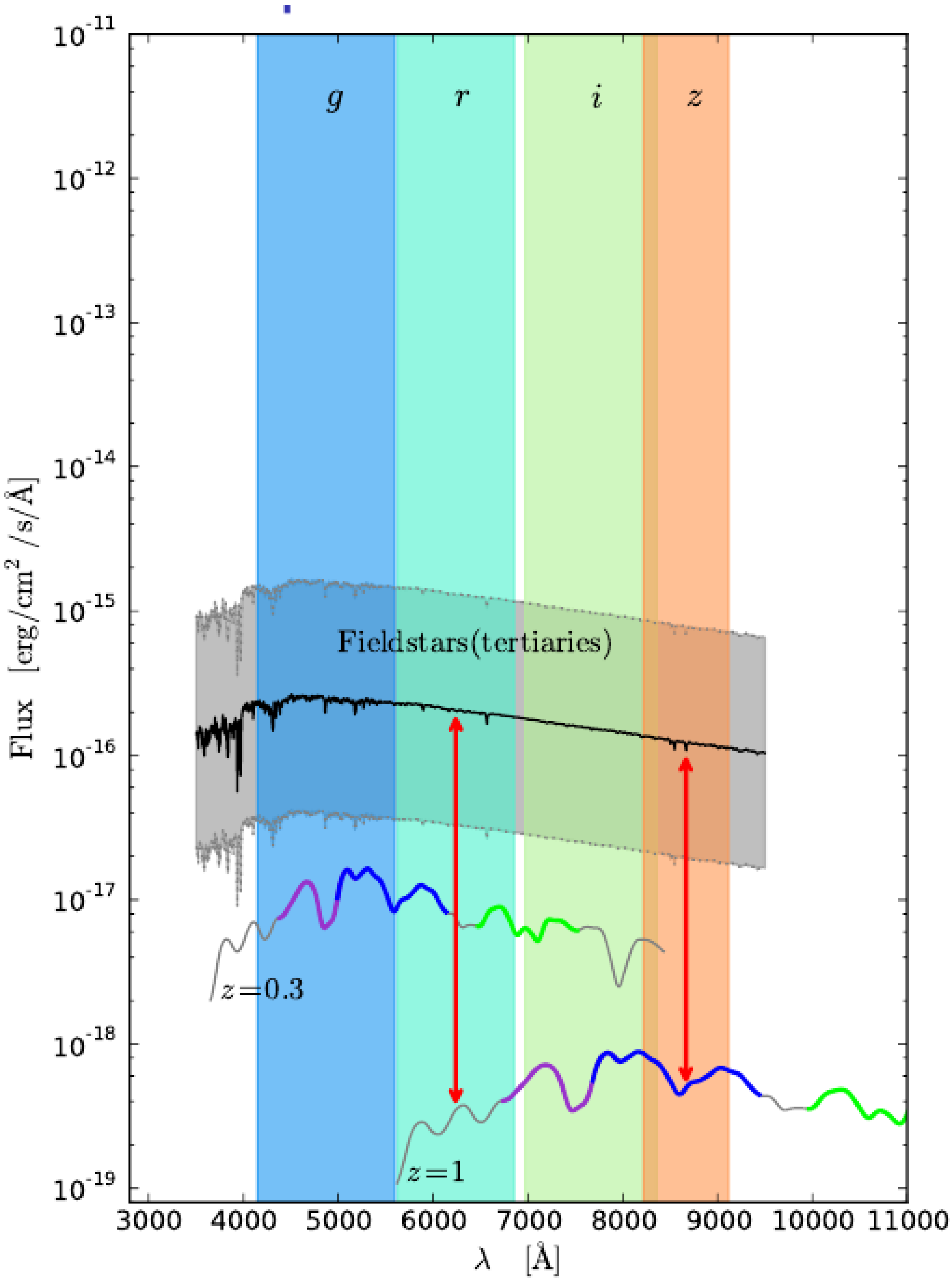
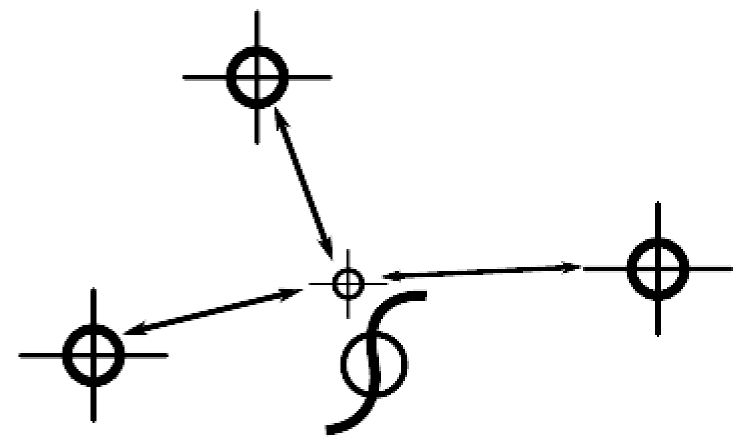
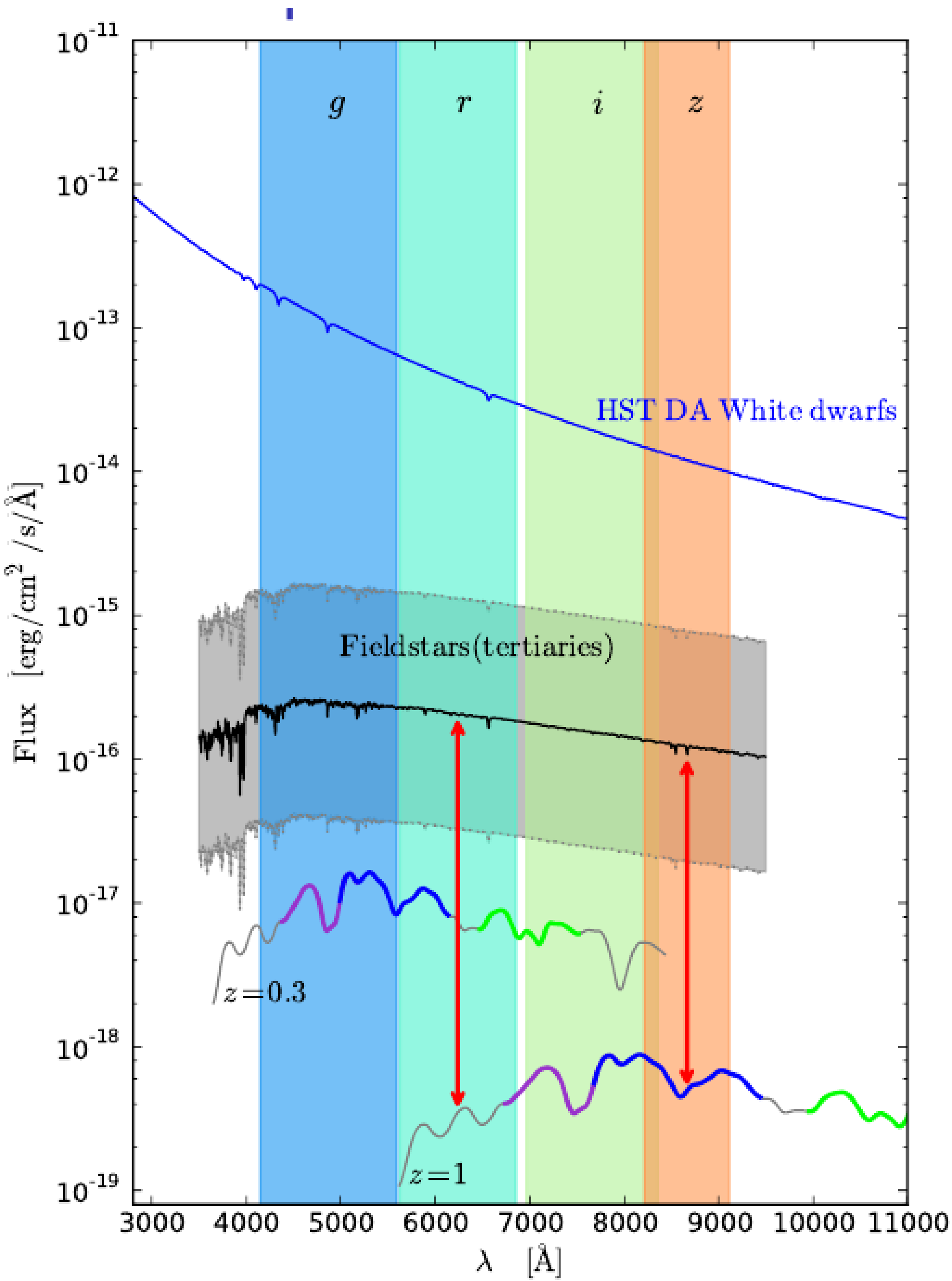
Flux metrology chain



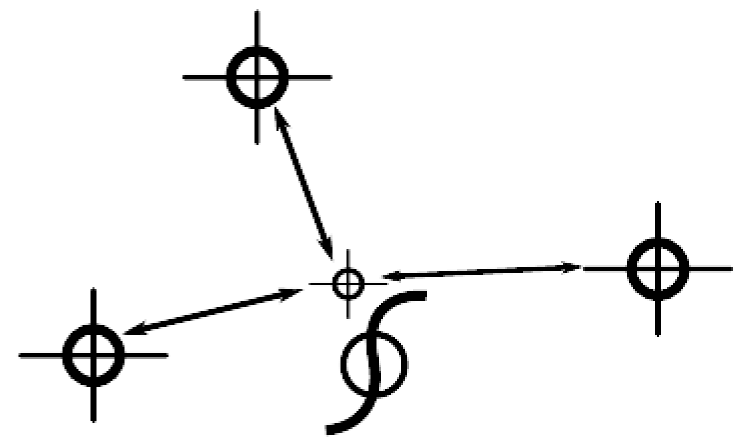
- Instrument response
  - Measure flux ratios in a single image



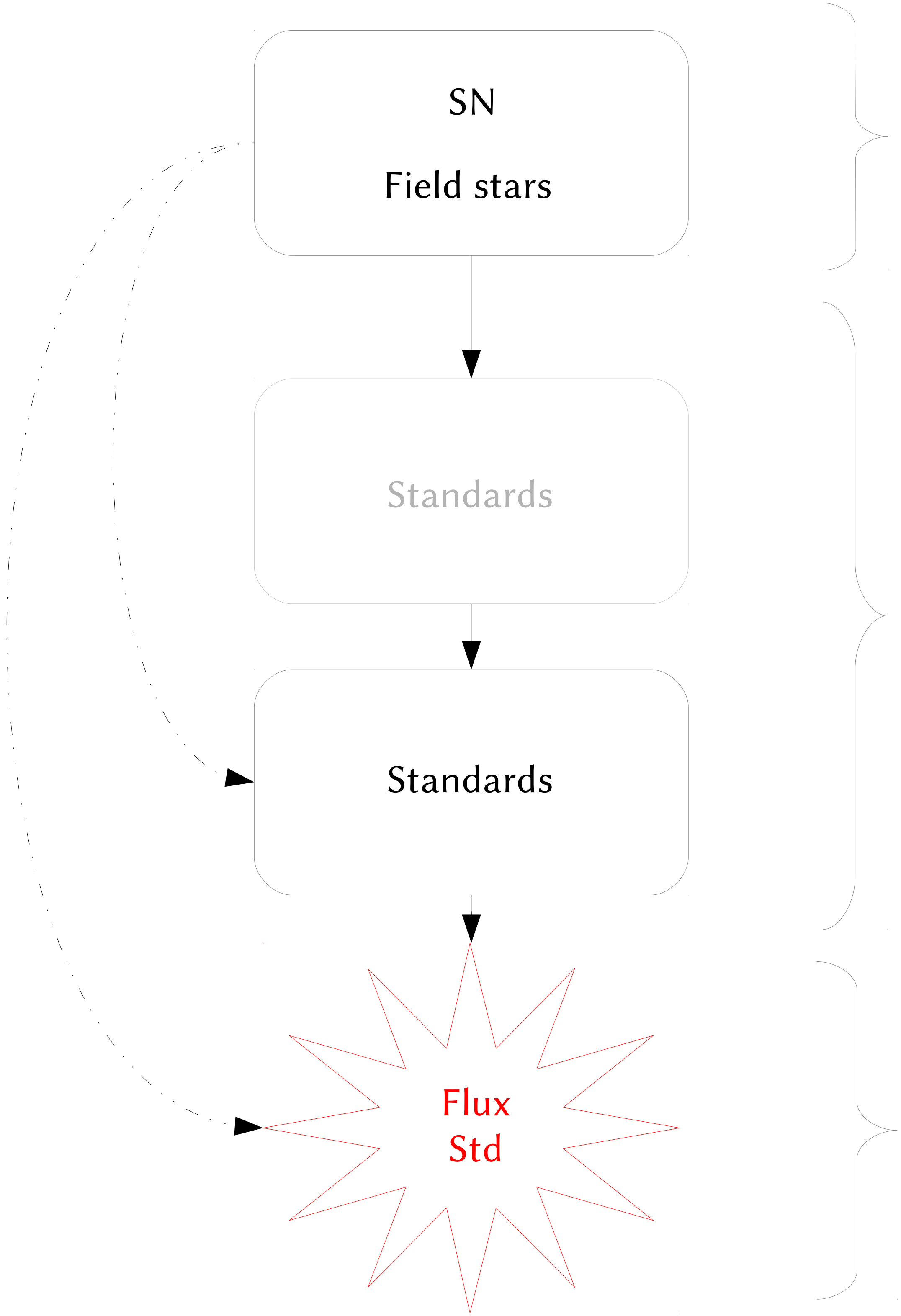
Flux metrology chain



- Instrument response
  - Measure flux ratios in a single image



- Calibration transfer
  - HST standards as primary flux calibrators



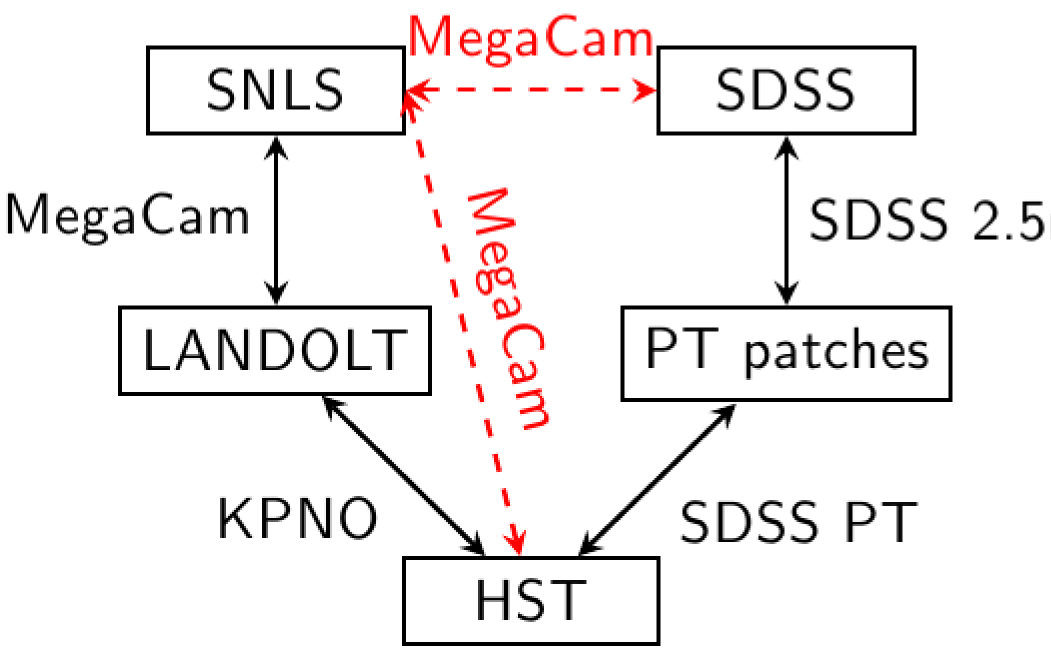
Field stars $\longrightarrow$ SN ~ a few 0.1%

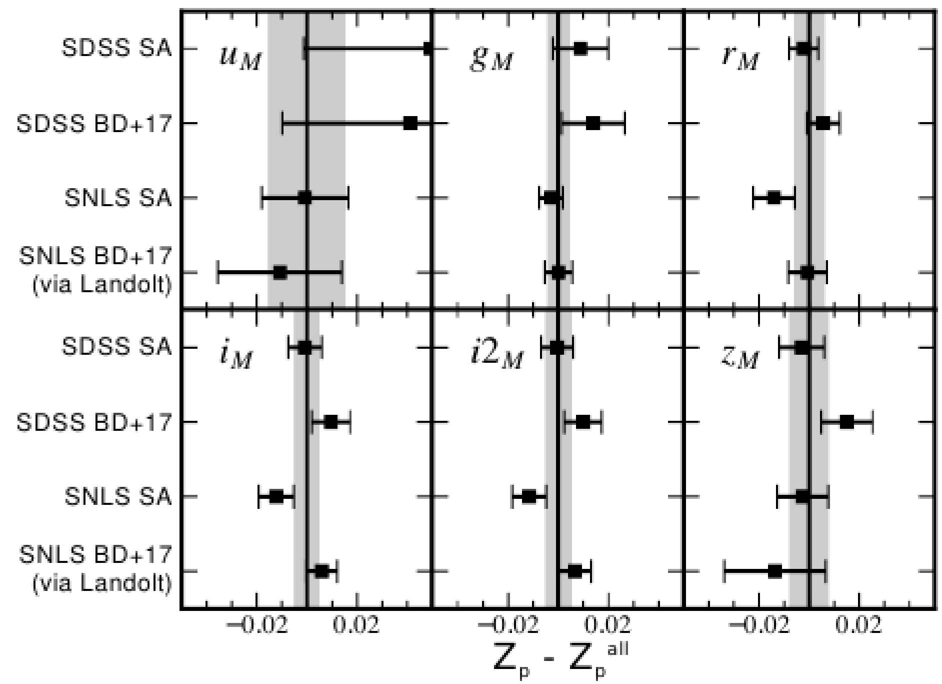
Goal < 0.3%
Typical repeatabilities ~2%
If careful < 1% per epoch

STIS repeatabiliy ~ 1%\

Model uncertainties ~ ?%

SNLS/SDSS (JLA) CALIBRATION PATHS





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

(Betoule et al, 2013)

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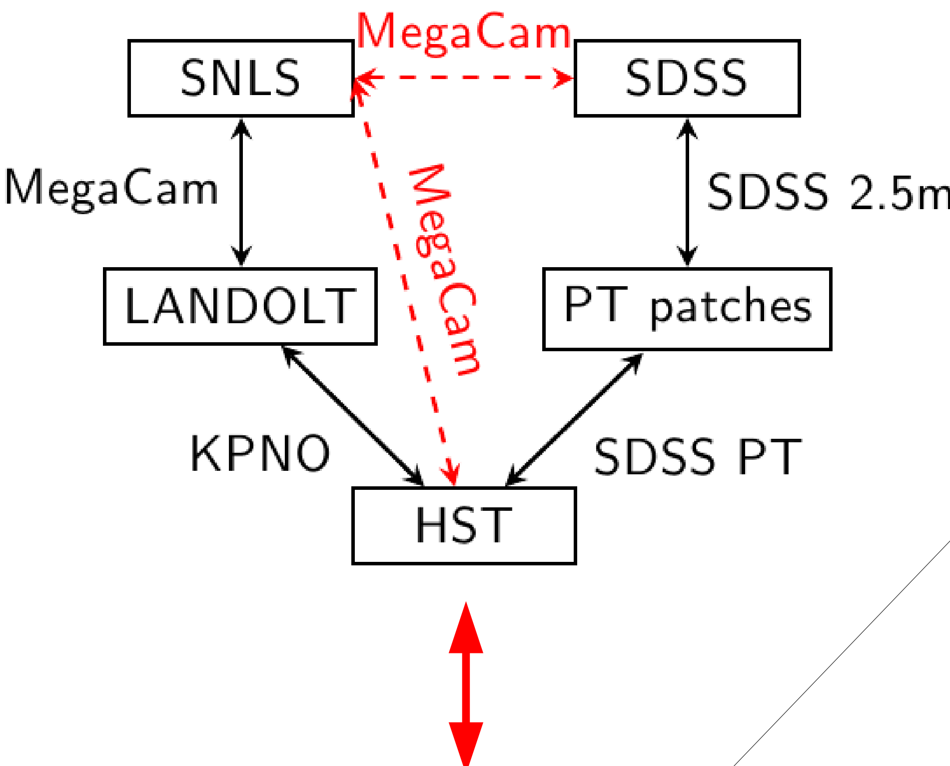
INSTRUMENTAL CALIBRATION



Hamamatsu S2281

- Stellar flux standards

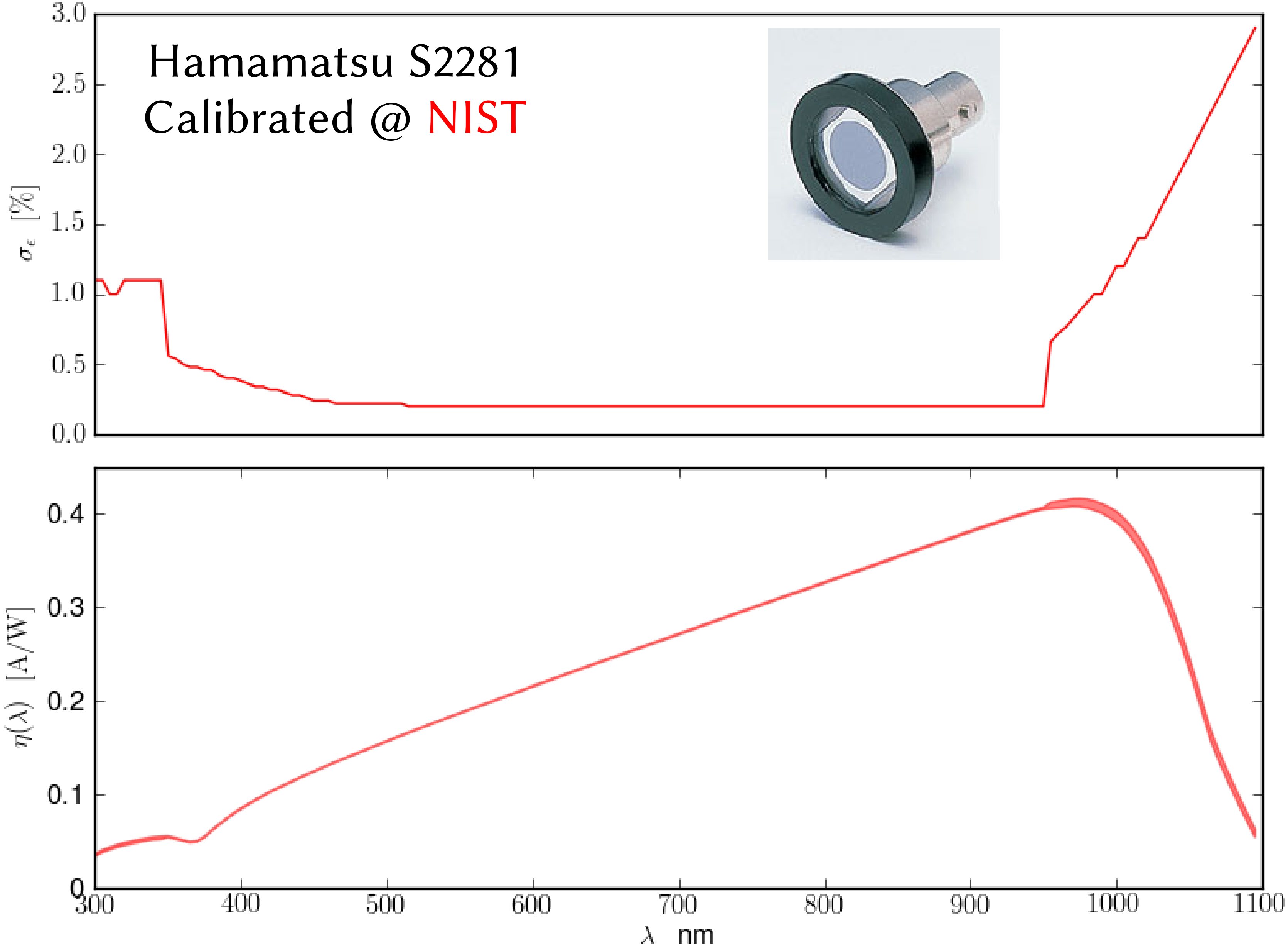
  vs

  Laboratory standards

- Precision monitoring of large focal planes

- 0.1% calibration accuracy

Switching to a Lab Standard



A NEW METROLOGY CHAIN

DETECTORS | SOURCES

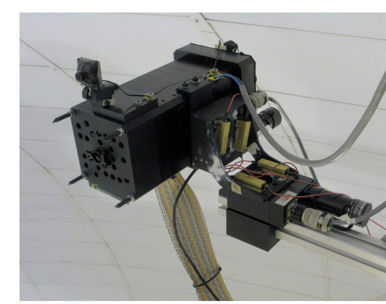
POWR (NIST)
(Houston & Rice 2006)

SIRCUS/SCF (NIST)
(Brown et al. 2006, 2000)
(Larason & Houston 2008)

Calibrated
Si photodiode

❶

Calibrated source
(in the telescope enclosure)



❷

Imager

Back to the stars...

A NEW METROLOGY CHAIN

DETECTORS | SOURCES

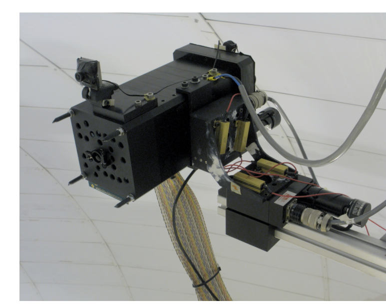
POWR (NIST)
(Houston & Rice 2006)

SIRCUS/SCF (NIST)
(Brown et al. 2006, 2000)
(Larason & Houston 2008)

Calibrated
Si photodiode

(Regnault et al, A&A)

Calibrated source
(in the telescope enclosure)

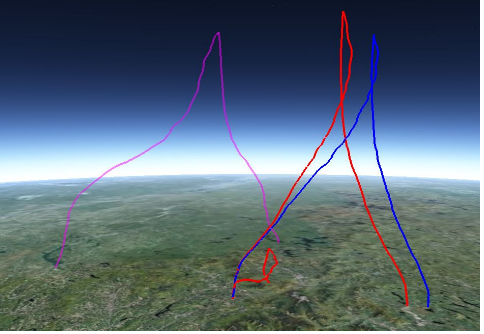


Imager

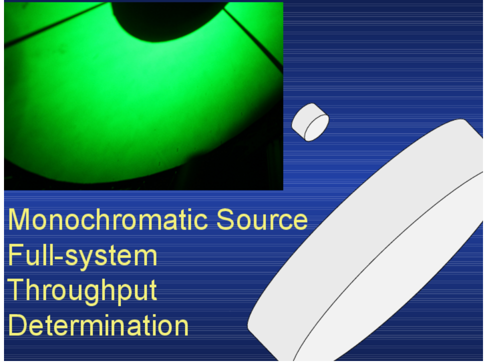
Current efforts
concentrate here

(S. Bongard's talk)

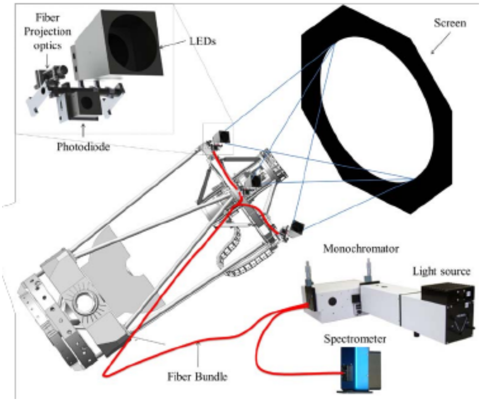
Back to the stars...

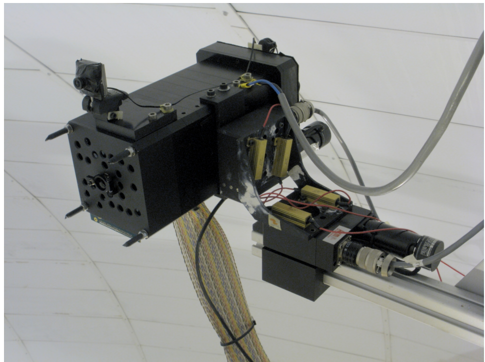


Calibration Projects

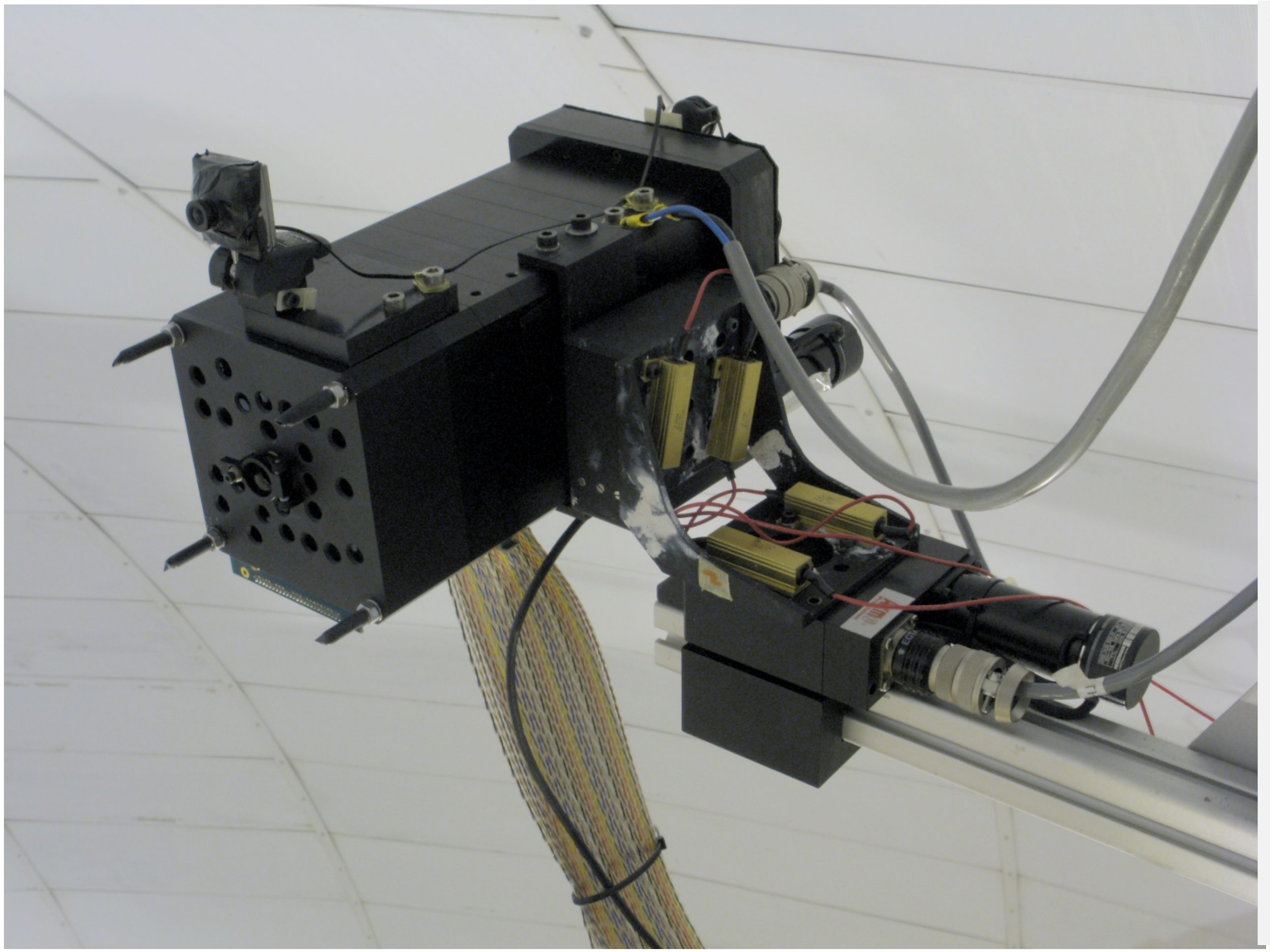


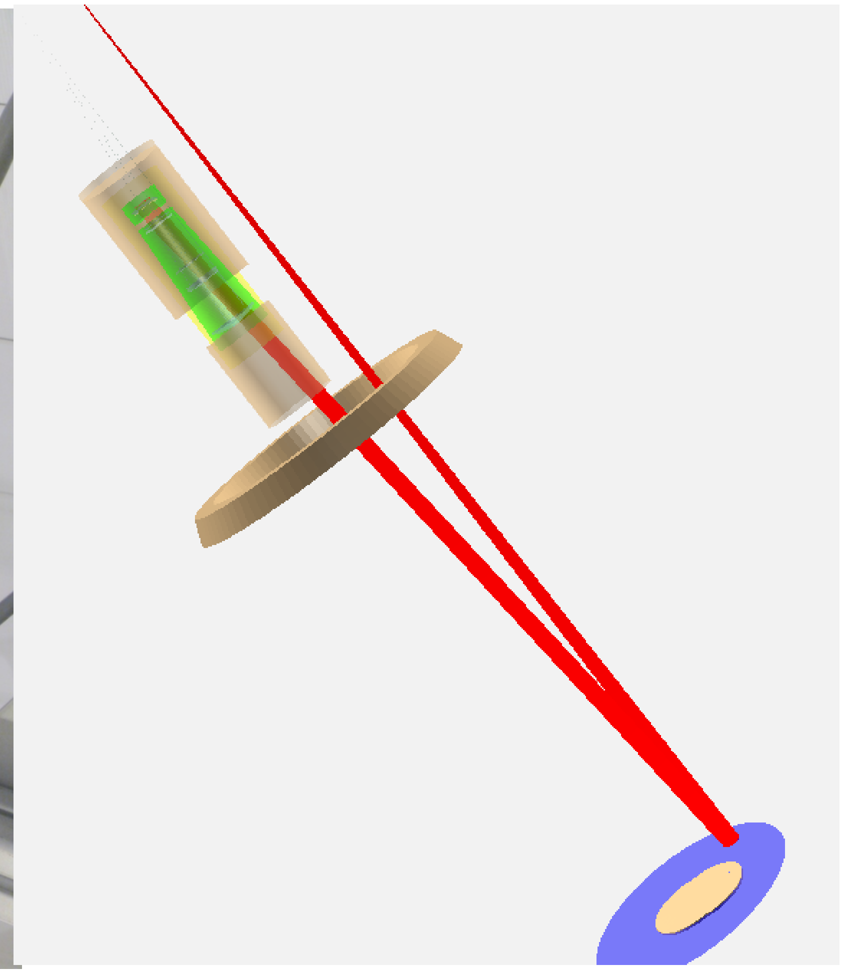
- Harvard (Stubbs et al)
  - ESSENCE
  - PanSTARRS
- Texas A&M (DePoy et al)
  - DES (Dark Energy Survey)
- NIST (Cramer et al)
  - Artificial star ⟶ recalibration of Vega
- ACCESS (Kaiser et al)
  - Small rocket-borne telescope (IR spectrophotometry)
- LPNHE
  - SnDICE (MegaCam)
  - SkyDICE (SkyMapper)



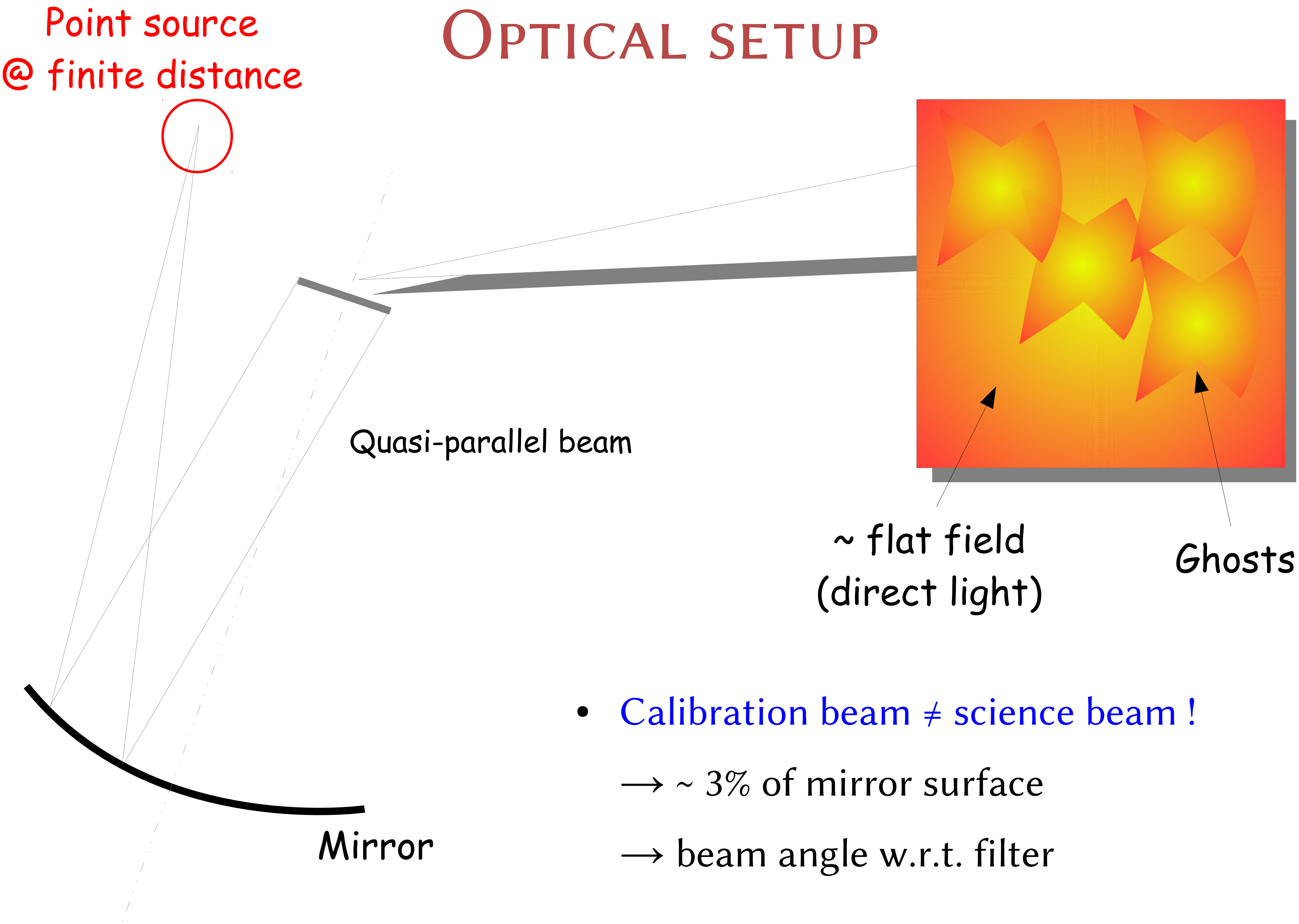


DICE : A STABLE LED SOURCE





Optical setup

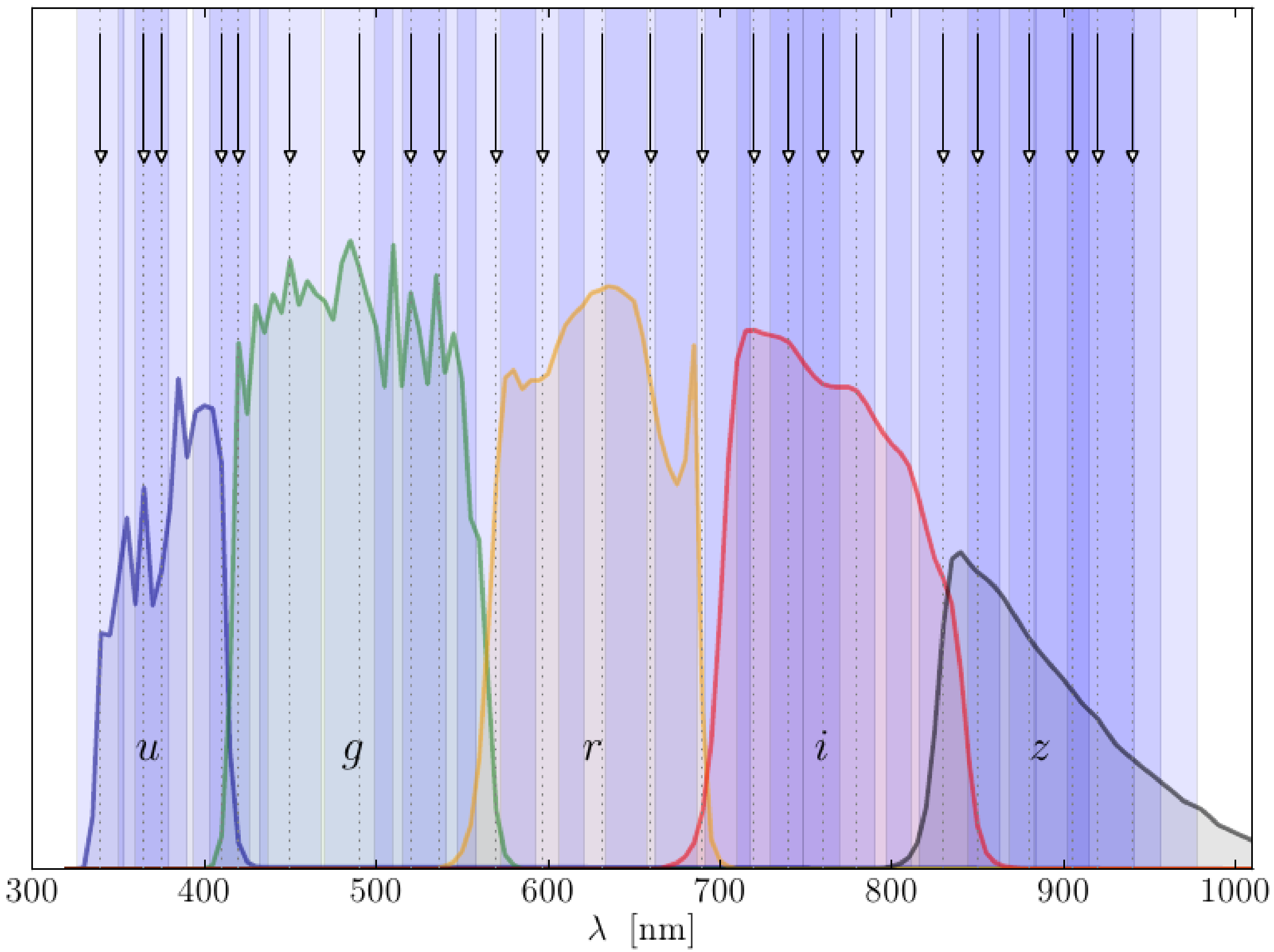


- Calibration beam ≠ science beam !

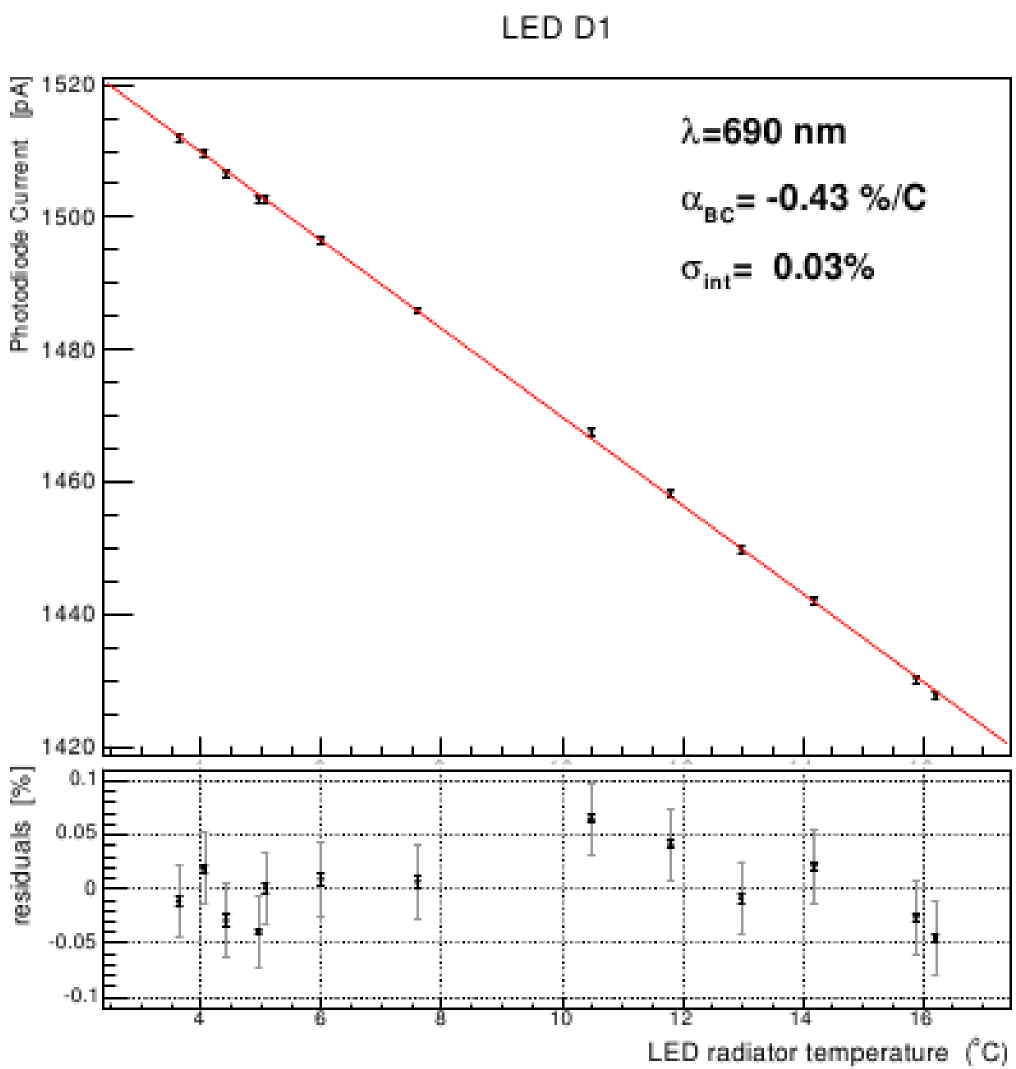
  → ~ 3% of mirror surface

  → beam angle w.r.t. filter

Typical LED coverage



The "Cooler-brighter effect"

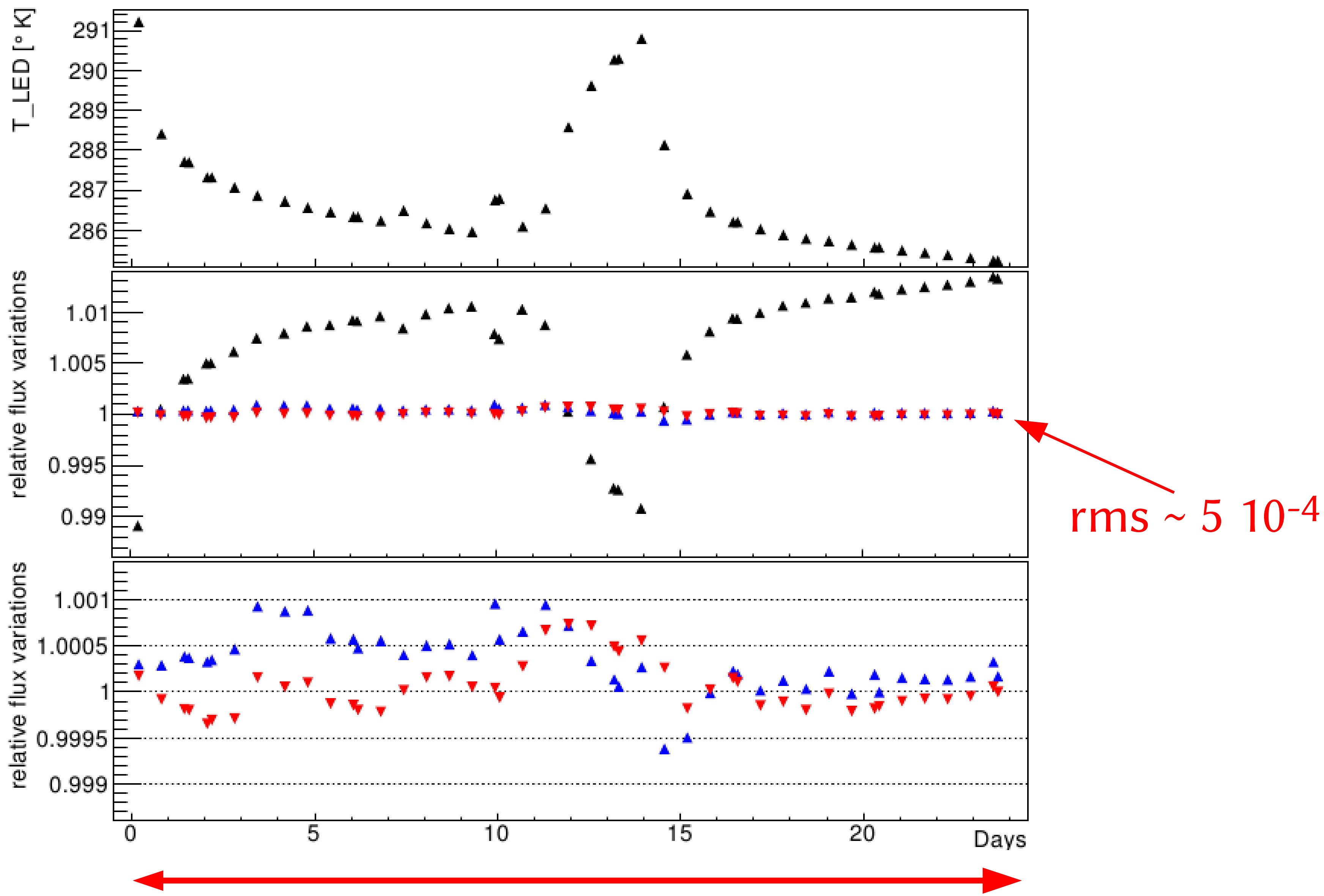


0.1%

(Regnault et al, submitted to A&A)

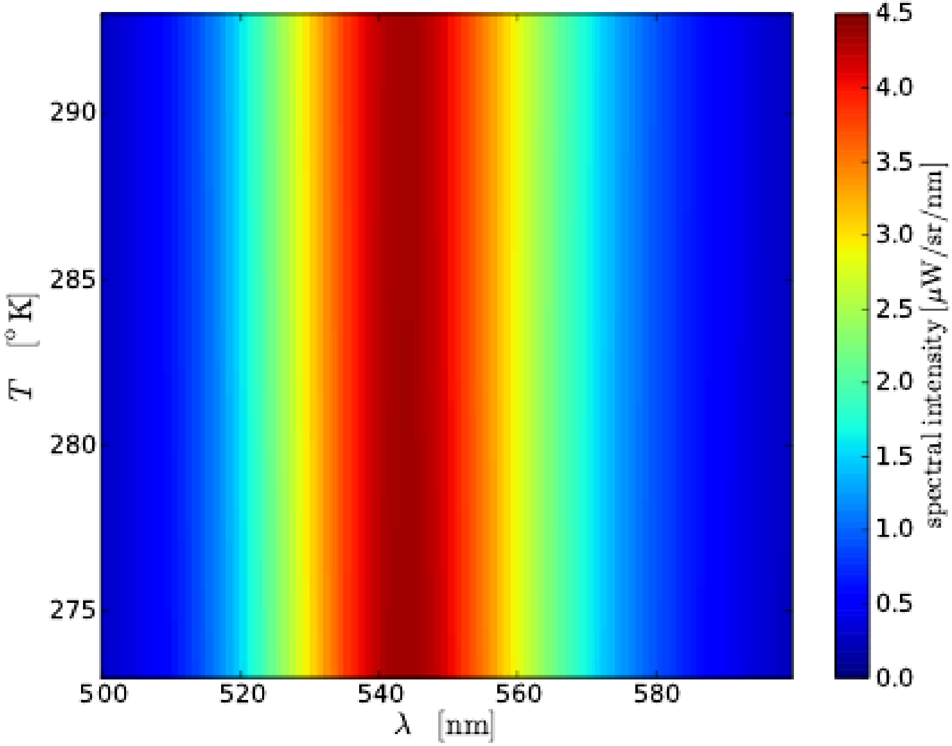
About 0.5% / °C for all LEDs

Long term stability studies

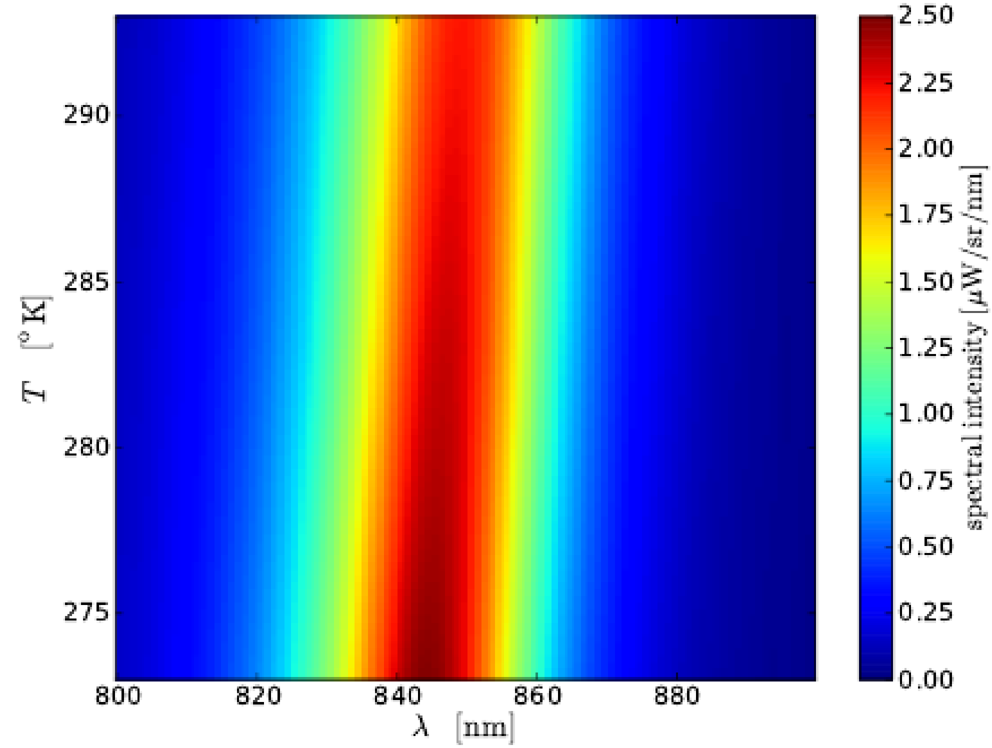


(Regnault et al, submitted to A&A)

A Spectrophotometric model for the LED source



(a) Golden Dragon® LT W5SM



(b) APG2C1-850 (Roithner LaserTechnik)

Predicts the LED spectral intensity (watts / sr / nm)
in a range of temperature ($0^oC < T < 25^oC$)

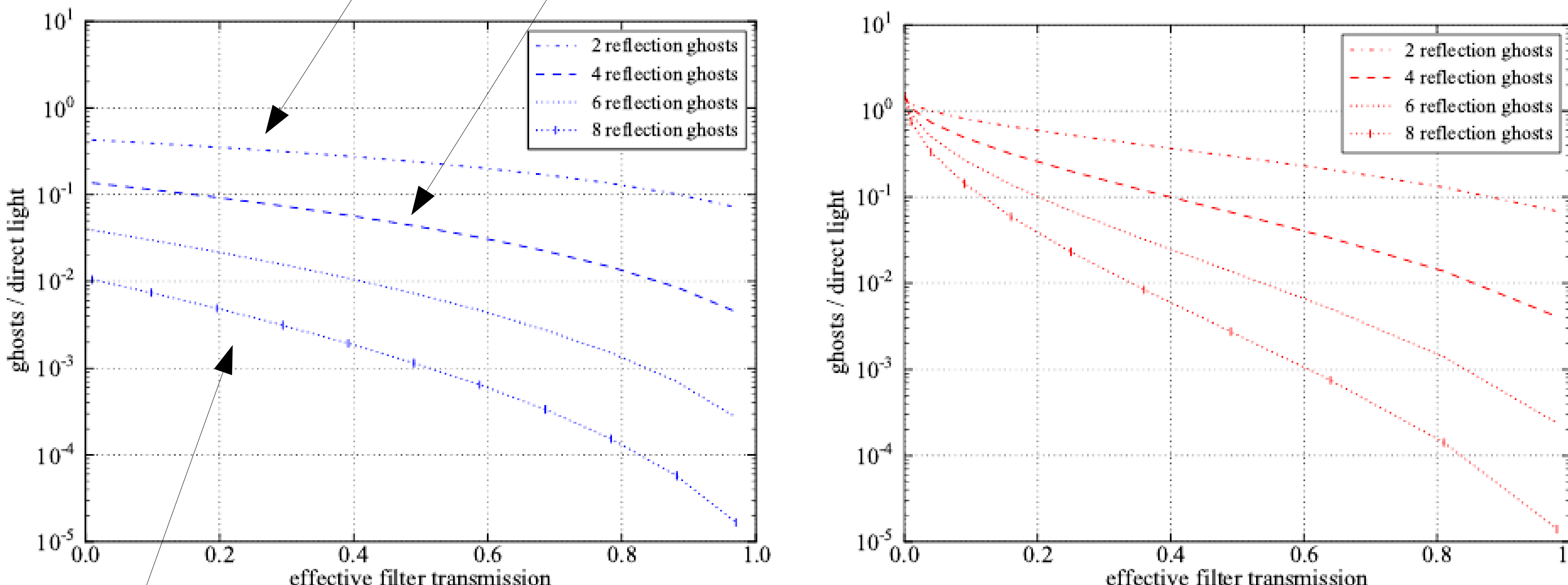
SnDICE LEDs ⟶ ~ microWatts / sr / nm ⟶ ~ O(1000 e- / s / pixel)

(Regnault et al, submitted to A&A)

Ghosts

105

7201



(a) Direct light & ghost intensities

(b) Ghost intensities (frac. of direct light)

67 221 727

Two different filter models

$$\phi_{\text{ghosts}} = \sum_r N_r \langle R \rangle^r$$

Conclusion

- Steady progress over the last decade

  ~ 10 years to increase accuracy by a factor ~ 10

- Each step requires
  - New techniques
  - more data

- We are ~ on-par with the precision of the fundamental (HST) flux calibrators

  $\longrightarrow$ Artificial sources under development