Photometric Calibration

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LPNHE - IN2P3 - CNRS - University Paris 6 and Paris 7

SNLS Collaboration Meeting

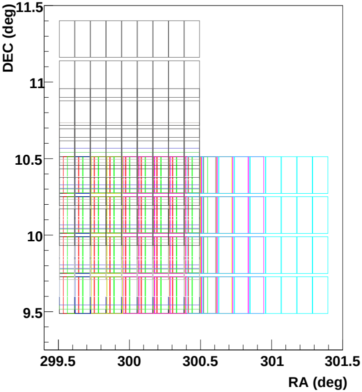
Outline

Outline

Internal Calibration

- Uniformity
- Linearity
- Repeatability

The Photometric Grid



- Modeling the non-uniformities of the photometric response
  - Plate scale variations
  - scattered light
- Dense stellar fields (RA=20:00:00, DEC=10:00:00)
- 13 dithered exposures variable steps: $\sim$ 100 pixels $\longrightarrow$ half a camera
- Reobserved after each significant modification of the optics
- No control observations

- grid corrections applied to the pixels by the `Elixir` pipeline (*scatter flats* or *photometric flats*)

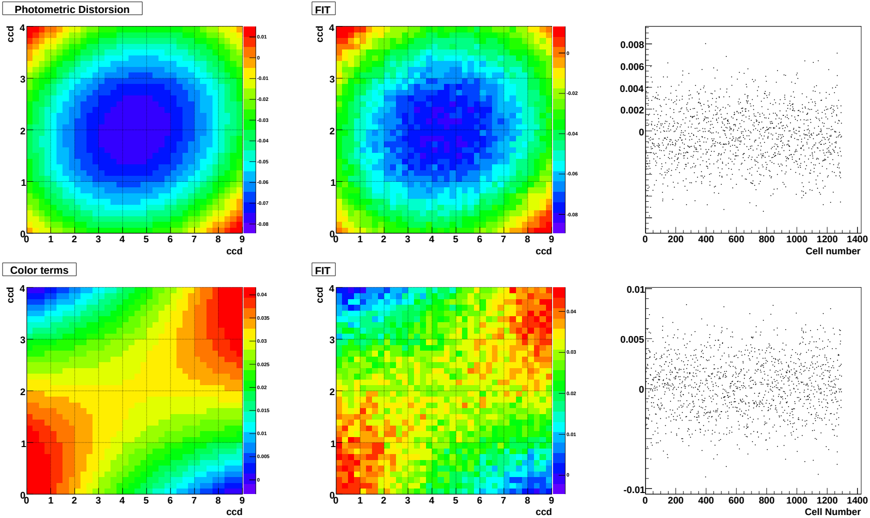
Analysis of the Photometric Grid

- Each CCD is divided into 4×9 cells (δzp) / 2×3 cells (δk)
- $\sim 50,000 - 100,000$, isolated, well measured stars, each observed on $\sim$6 (3 – 12) cells
- We use the star flux measurements to measure:
  - an intercalibration coefficient w.r.t. the reference cell, δzp_{cell}
  - a possible color term drift w.r.t the reference cell, δk_{cell}
- Model

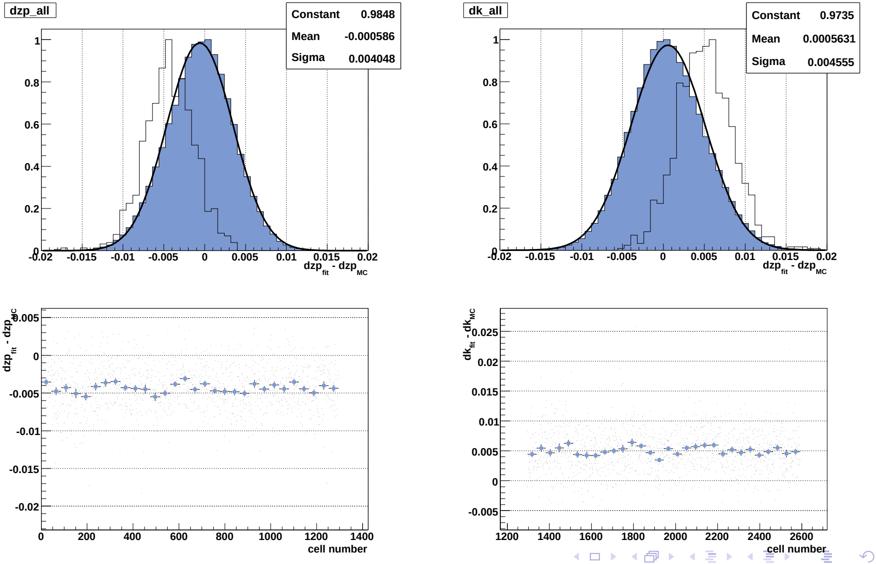
$$m(\mathrm{star}, \mathrm{cell}) = m(\mathrm{star}) + \delta zp(\mathrm{cell}) \quad [+\delta k(\mathrm{cell}) \times col(\mathrm{star})]$$

- Large fit !
  - $1295\ (\delta zp) + 215\ (\delta k) = 1510\ (\delta zp + \delta k)$ calibration parameters
  - $\sim 100,000$ star fluxes (known only on the reference cell)

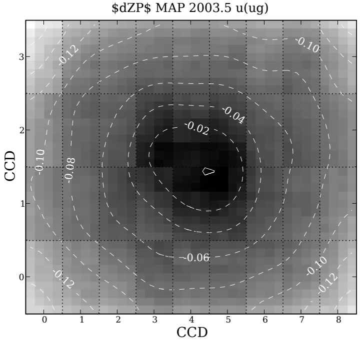
Simulation

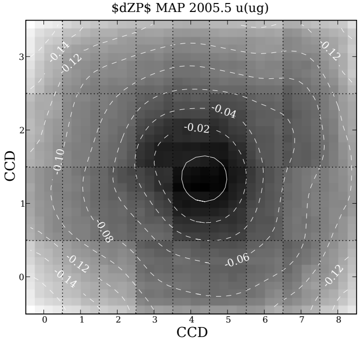

Photometric Distorsion
FIT
Color terms
FIT
ccd
Cell number
Cell Number

Simulation

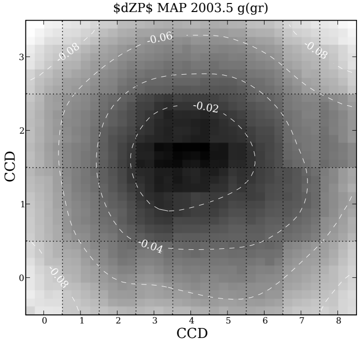

dzp_all
Constant 0.9848
Mean -0.000586
Sigma 0.004048
$dzp_{fit} - dzp_{MC}$
dk_all
Constant 0.9735
Mean 0.0005631
Sigma 0.004555
$dzp_{fit} - dzp_{MC}$
$dzp_{fit} - dzp_{MC}$
cell number
$dk_{fit} - dk_{MC}$
cell number

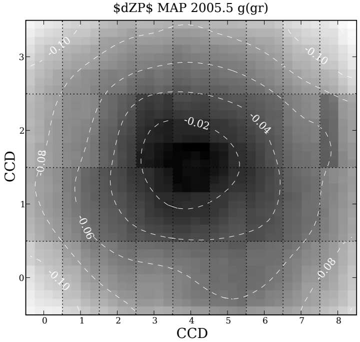
δzp, u-band



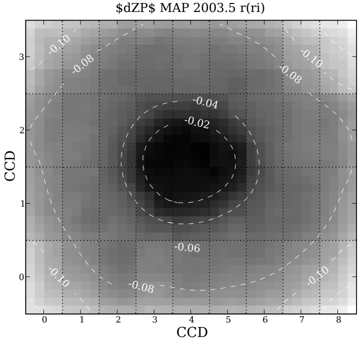


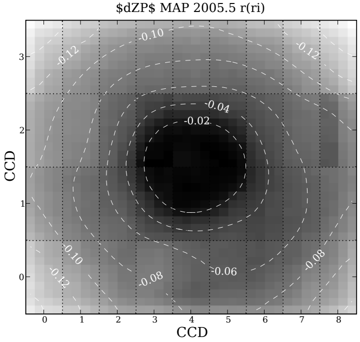
δzp, g-band



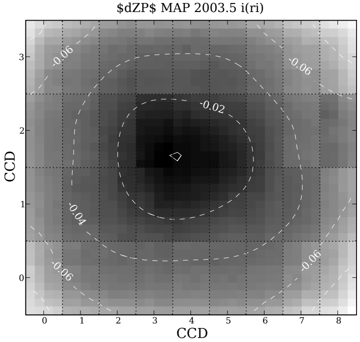


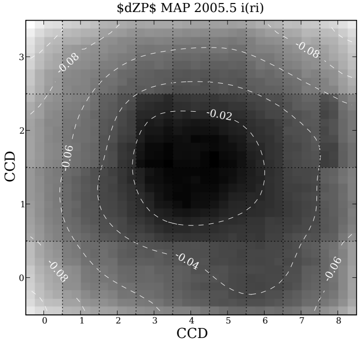
δzp, r-band



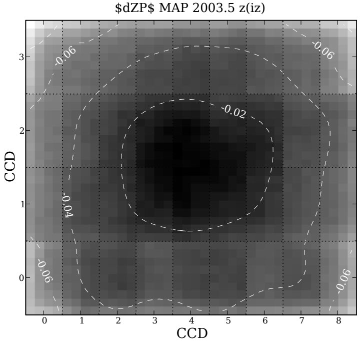


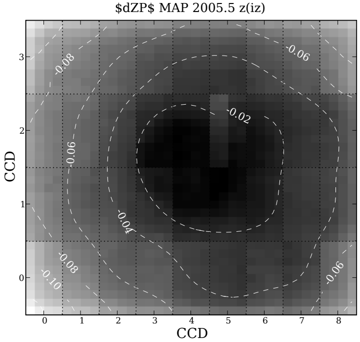
δzp, i-band



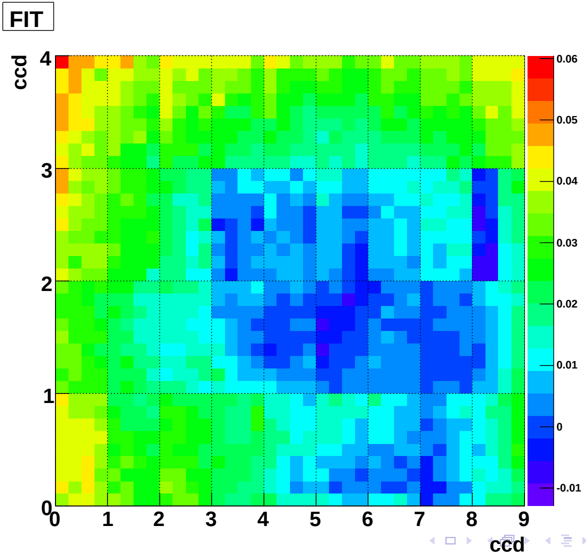


δzp, z-band





Elixir Residuals

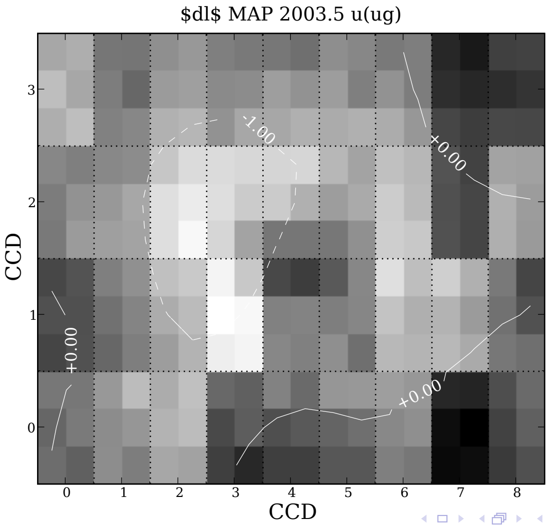


How do we convert $\delta k's \longrightarrow \delta\lambda's$?

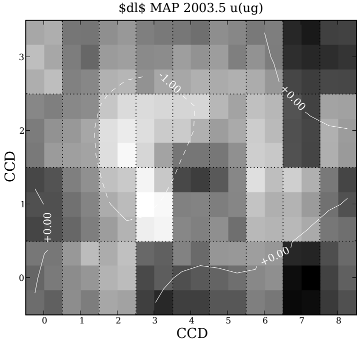
- More complicated than just: $\delta k = \delta\lambda/(\lambda_1 - \lambda_2)$
- We use the (Pickles, 1992) library, a model of the SNLS passbands, and we simulate the $\delta k(\delta\lambda)$ function.
- We find ($\delta\lambda$ in nanometers):

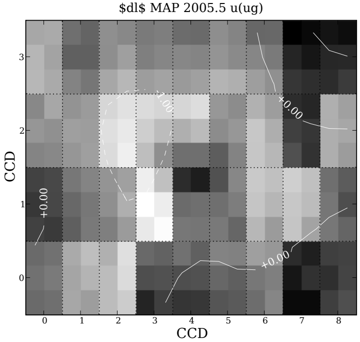
$$
\begin{aligned}
\delta\lambda_u &= 91.1 \times \delta k(u, ug) \\
\delta\lambda_g &= 97.8 \times \delta k(g, gr) \\
\delta\lambda_r &= 100.7 \times \delta k(r, ri) \\
\delta\lambda_i &= 170.7 \times \delta k(i, ri) \\
\delta\lambda_z &= 157.7 \times \delta k(z, iz)
\end{aligned}
$$

$\delta\lambda$, u-band

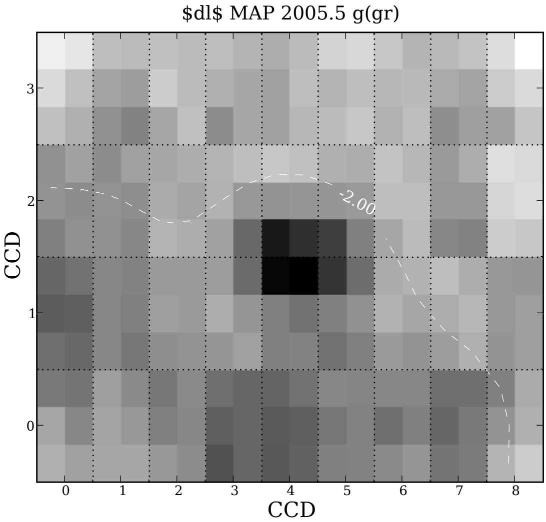


$\delta\lambda$, *u*-band

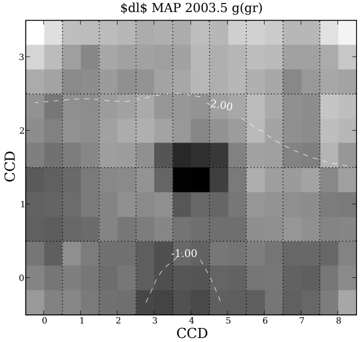


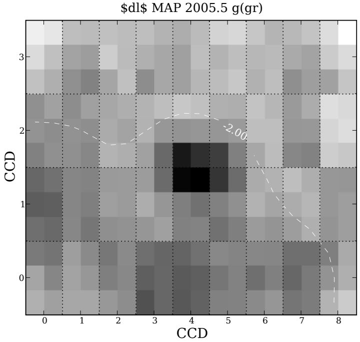


$\delta\lambda$, g-band

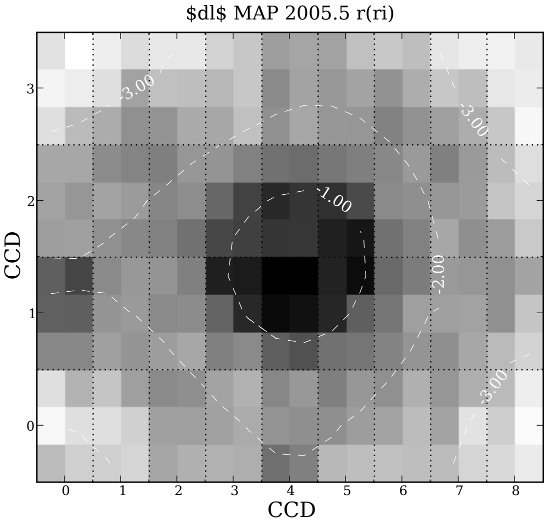


$\delta\lambda$, g-band

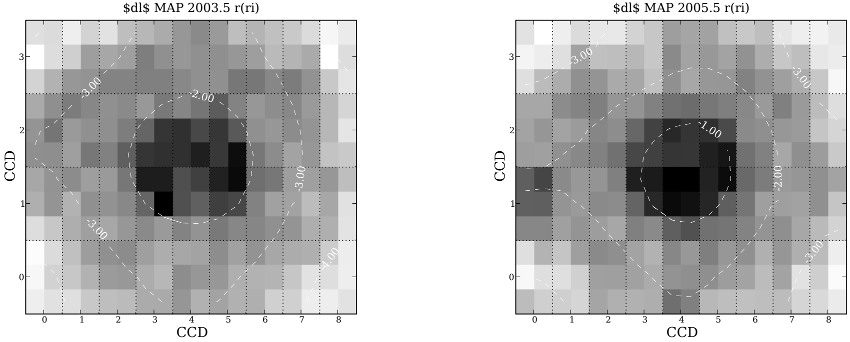




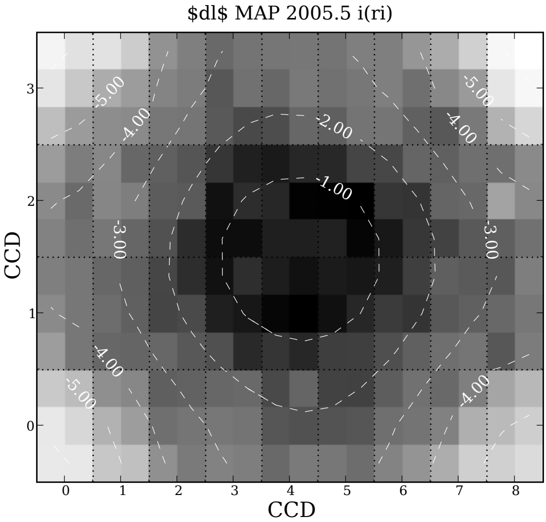
$\delta\lambda$, r-band



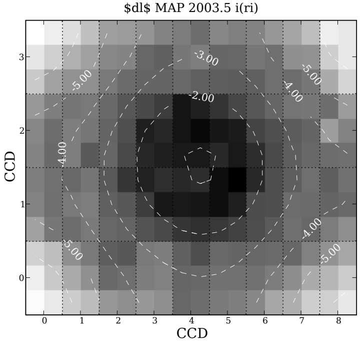
$\delta\lambda$, r-band

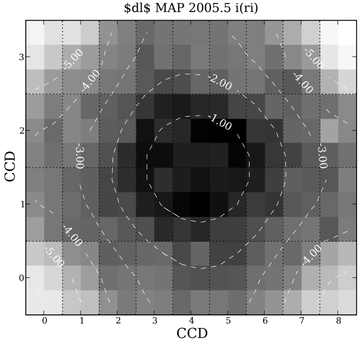


$\delta\lambda$, *i*-band

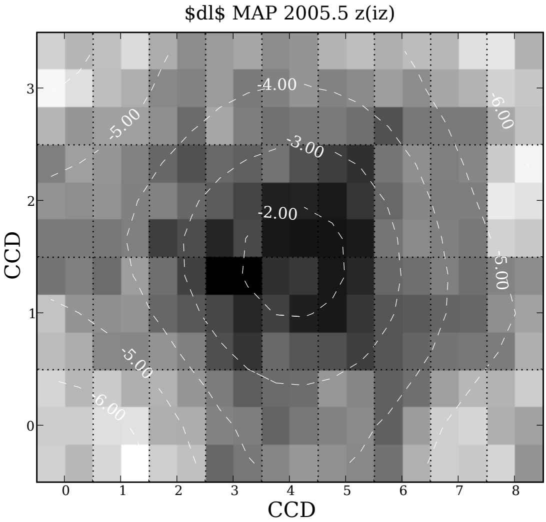


$\delta\lambda$, *i*-band

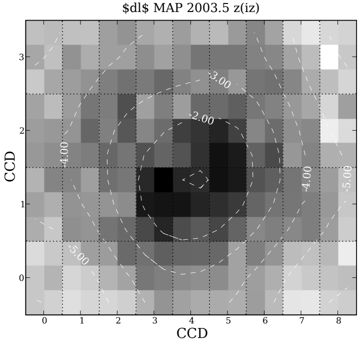


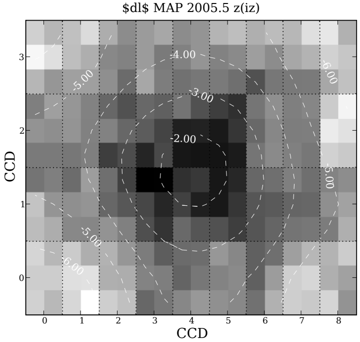


$\delta\lambda$, z-band

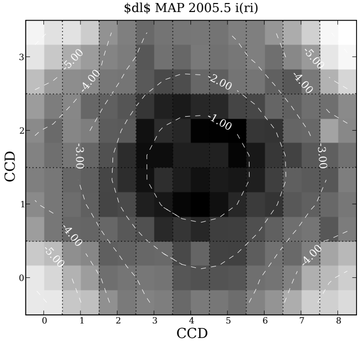


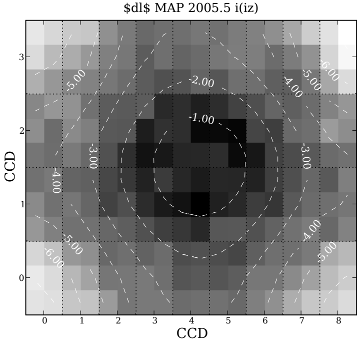
$\delta\lambda$, *z*-band



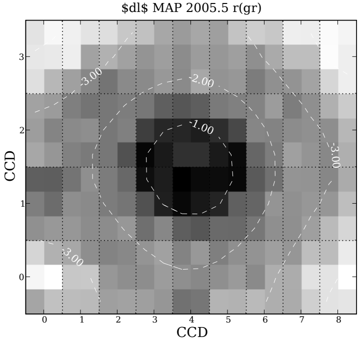


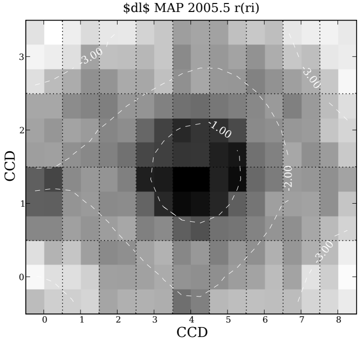
Consistency Checks



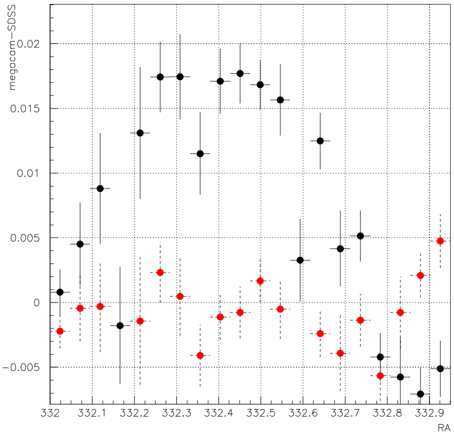


Consistency Checks

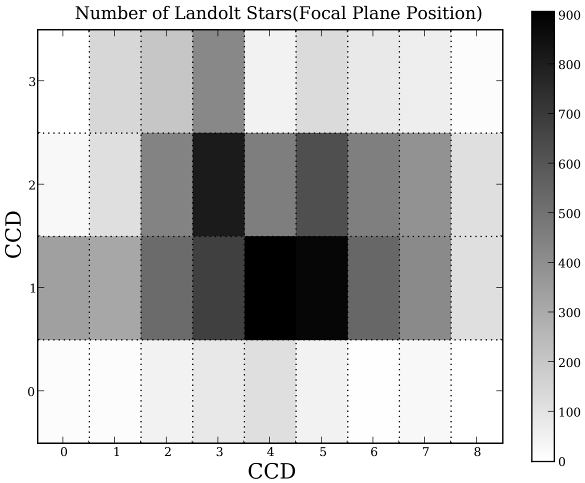




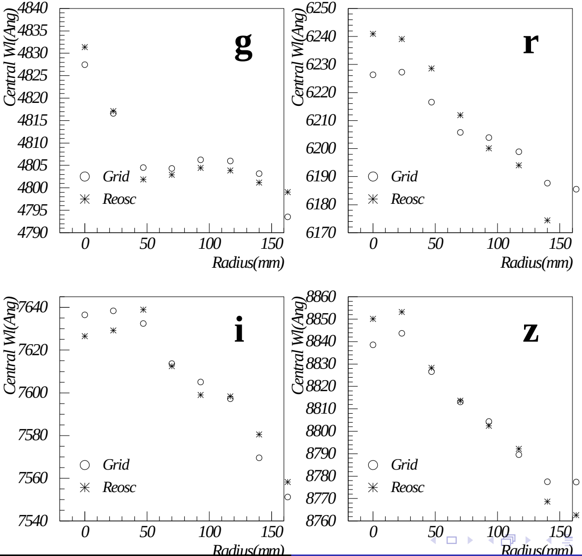
SDSS Southern Strip



Why Does Uniformity Matter ?



REOSC (2003) Scans versus Grid



What's next ?

- We (SNLS) correct for the residual non-uniformities at the flux (/color) level
- We have implemented a model of the radially variable passbands (from the REOSC filter scans)
- It would be great to have the new δzp grids applied directly to the pixels $\Rightarrow$ flat photometry for objects of a reference color (which color should we choose ?)
- How do we go about it ?
  - independant analysis of the grid dataset by another group ?
  - checks on a smaller dataset (one DEEP field, a few wide fields, MAPC dithers) ?

Outline

Magnitude System

- Natural Magnitudes

$$m(\mathbf{x}) = -2.5 \ \log_{10} \left(\frac{\int \phi(\lambda) T(\lambda; \mathbf{x}) \ d\lambda}{\int \phi_{\mathrm{ref}}(\lambda) \ T(\lambda; \mathbf{x}) \ d\lambda} \right)$$

- Calibration Model

$$\tilde{m}(\mathbf{x}_3, t) = m_3(\mathbf{x}_3) + \delta\mathrm{k}(\mathbf{x}_3) \times (\mathrm{col}_{\mathrm{ref}} - \mathrm{col}_g) + \mathrm{ZP}(t)$$

$$\tilde{m}(\mathbf{x}_2, t) = m_2 + \mathcal{C}(\mathrm{col}_2) + \delta\mathrm{k}(\mathbf{x}_2) \times (\mathrm{col}_2 - \mathrm{col}_g) + \mathrm{ZP}(t)$$

The Landolt Flux Scale

- How do we convert Landolt magnitudes to flux ?
(Landolt colors to flux ratio)

$$\Phi_L = 10^{-0.4 m_L} \times 10^{+0.4 m_{ref}} \times \int S_{ref}(\lambda) B(\lambda) d\lambda \qquad (1)$$

- We need a model of the Landolt passbands.
- We need to know the magnitudes of the fundamental flux standard in the Landolt system.

Landolt System Passbands

- Not known with precision
- *UBV* close to (Johnson, 1953)
  - Johnson *UBV* not well defined either
- *RI* close to Cousins $R_c I_c$
  - But there are differences.

$\Rightarrow$ We start with the (Bessel, 1990) recommendantions. We allow each filter to shift by an unknown quantity $\delta\lambda_{filter}$

$$B(\lambda) \quad \longrightarrow \quad B(\lambda - \delta\lambda)$$

Landolt (Johnson-Cousins) Fundamental SED

- Vega usually chosen as the fundamental flux standard
- But we could choose any other star or set of stars with known spectra and known Landolt magnitudes.
- The CALSPEC library provides one with spectra taken with HST (STIS/NICMOS) (supplemented with ground based spectroscopy).
- We start with the latest HST Vega SED determination (Bohlin, 2006) from CALSPEC as a fundamental standard

Magnitudes of Vega in the Landolt System

The Traditional way

- Historical color indexes (Johnson et al, 195X;196X)
- Color transformations (Landolt, 1973;1983;1992;2007)

	V	$B-V$	$U-B$	$V-R$	$R-I$
hist	0.030	0.000	-0.010	0.000	0.006
L83	0.024	-0.002	-0.007	-0.0002	0.0049

- Determination of the $V-R$ color problematic (connection between the Johnson and Cousins systems). No measurements of $V-R$ available
- Several measurements of R do not agree. (Ask Alex for details)
- Long transformation chain. Drifts ?

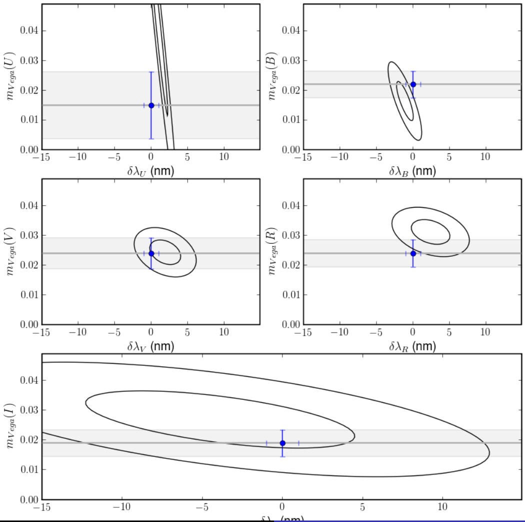
Magnitudes of Vega in the Landolt System

The CALSPEC way

- (Landolt & Uomoto, 2007) report magnitudes of 31 HST spectrophotometric standards. Among them, 5 standards with HST-only SEDs. (+1 (Landolt, 1992) standard with an HST SED).
- Same spectroscopy source as the one we took the Vega SED from.
- Determination of $\delta\lambda$ and m_{ref} by minimizing:

$$\chi^2 = \sum_{s=1}^{N_{stars}} \sum_{b=1}^{N_{bands}} w_{sb} \; \left(m_{obs}(s,b) - m_{synth}(s,b;\delta\lambda, m_{ref})\right)^2$$

The CALSPEC analysis



CALSPEC Internal Dispersion

- Dispersion of $\sim 1\%$ within the CALSPEC / (Landolt & Uomoto, 2007) data
- Not described by the uncertainties reported by (Landolt & Uomoto, 2007) and CALSPEC/Bohlin.
- Set the scales of the uncertainties
- How do we account for it ?

$\longrightarrow$ in release 2008-06-06, we attributed all this uncertainty to the Landolt measurements (without correlations)

CALSPEC Internal dispersion

	$U-V$	$B-V$	$V-R$	$V-I$	$B-R$
CAN	0.0124	0.0069	0.0069	0.0069	–
CALSPEC +ZP	0.0263	0.0072	0.0051	0.0081	0.0070
CALSPEC +ZP (new)	0.0132	0.0057	0.0041	0.0043	0.0056

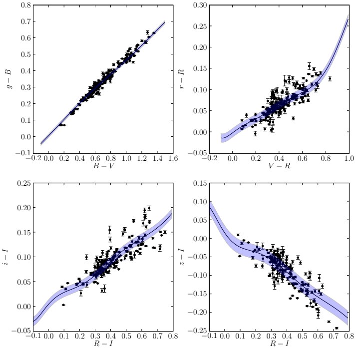
Conclusion on the CALSPEC analysis

- The CALSPEC analysis is now stable
- Magnitudes of Vega compatible w/ historical magnitudes (except in R)

Outline

The Megacam Zero-Points – Tertiary Standards

- model the color transformations using piecewise-linear functions
- use synthetic photometry to model these transformations
  - physical model
  - $\delta\lambda$ and m_V fitted along with the ZP (w/ CALPSEC constraints)
  - full covariance matrix of calibration parameters



Calibration Fit

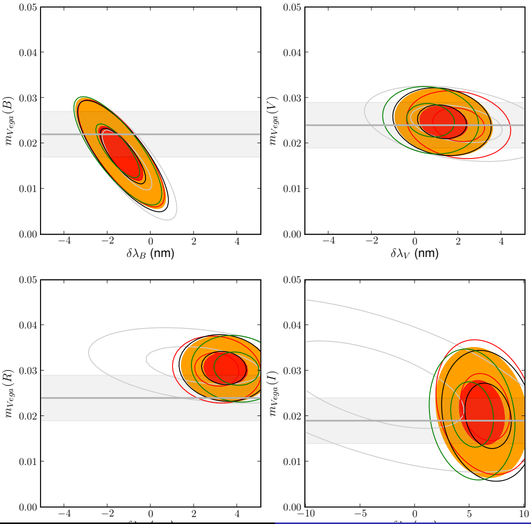
- We want to propagate the uncertainties (including the correlations) of the (Landolt & Uomoto, 2007) based determinations of $\delta\lambda$, m_V.
- Incorporate them into the fit as a prior.

$$\chi^2 = \sum_i w_i \left(\mathbf{C}_i^T \mathbf{p} + \mathbf{D}^T \mathbf{z} + m_{2_i} + \delta\mathrm{k}(\mathbf{x}_i)\ \delta\mathrm{col}_{2_i} - \tilde{m}_i\right)^2 + (\mathbf{p} - \mathbf{p}_0)^T \mathbf{W}_p (\mathbf{p} - \mathbf{p}_0)$$

with $\mathbf{p} = (\delta\lambda, m_V)$

- Multiband fit. Fit all zero points at once.

Megacam Zero Points



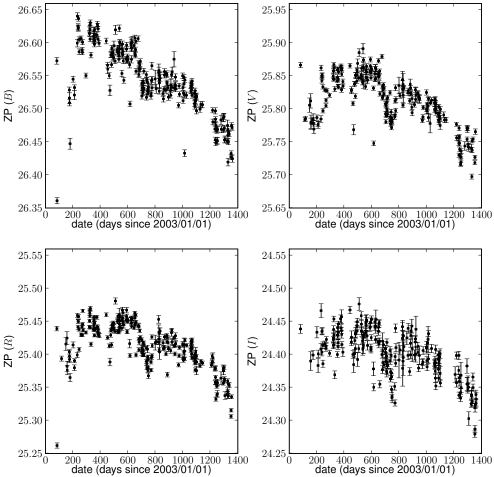
The Megacam Zero-Points – Tertiary Standards

- As of today

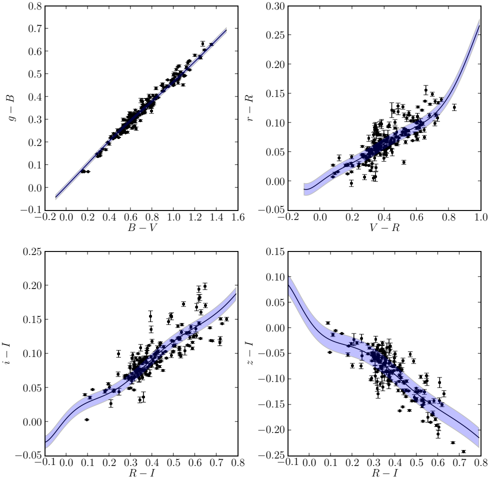
	U	B	V	R	I
$\delta\lambda$	$+10.57$	-12.89	$+12.48$	$+33.85$	$+67.01$
	$U-V$	$B-V$	—	$R-V$	$I-V$
Δm_V	$+0.0242$	-0.0050	—	$+0.0054$	$+0.0002$

- 1% differences in the *riz* zero points (Fr calibration may still change on this aspect).

Calibration Fit



Calibration Fit



Full uncertainty matrix