Global Photometric Calibrations

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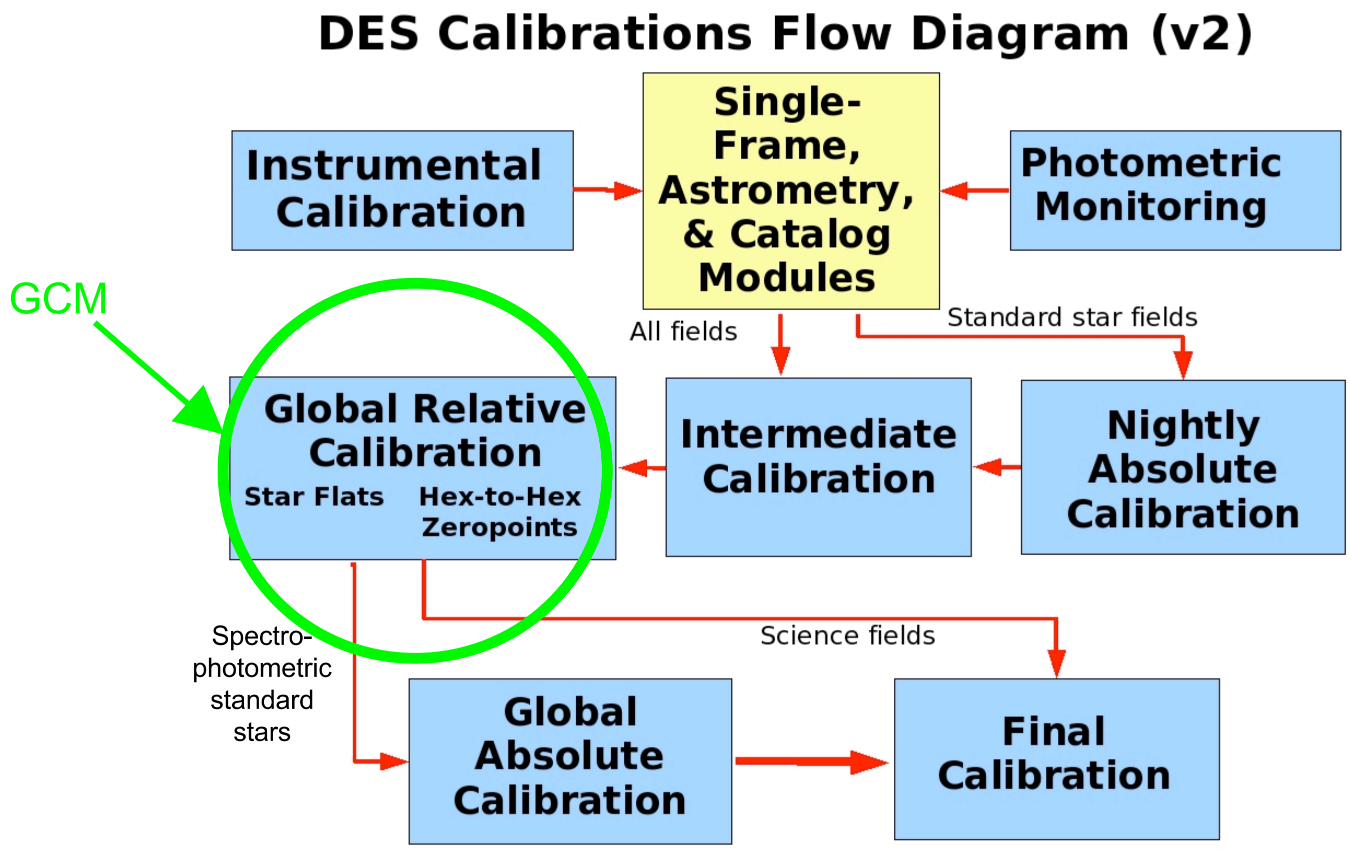
29-31 January 2008

Global Photometric Calibrations

DARK ENERGY SURVEY

The Global Calibrations Module (GCM) is part of the overall calibration plan



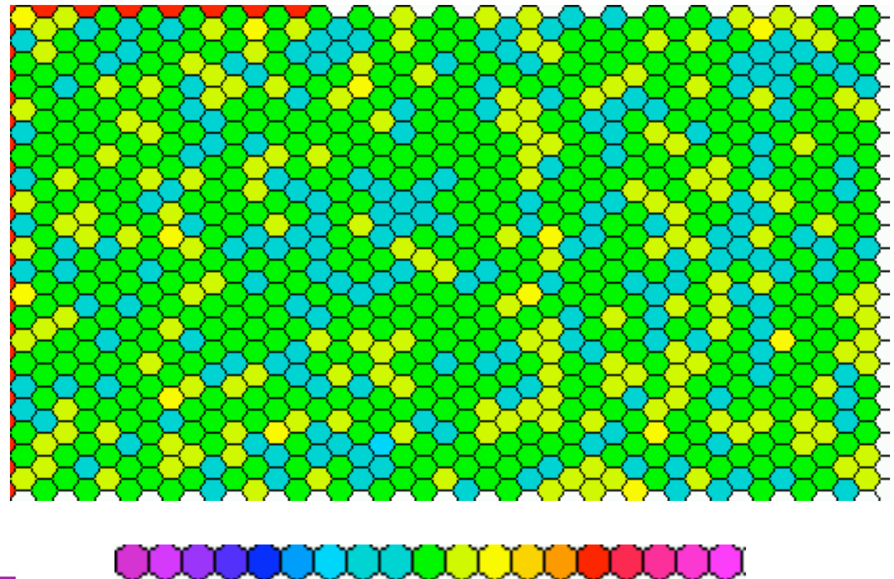
Global Calibration Module: Two Main Functions

DARK ENERGY SURVEY

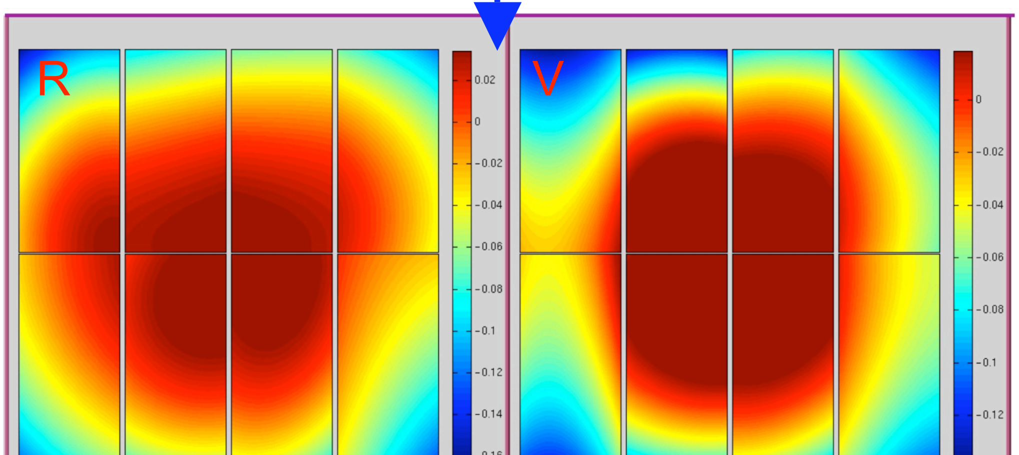
The GCM has two main functions:

1. Remove hex-to-hex zeropoint offsets to achieve a uniformly “flat” all-sky relative calibration of the full DES survey.

2. Calculate “star flats” to remove any lingering effects of vignetting and stray light in the object photometry.



scaling bar is –0.20 mags to +0.20 mags



Koch et al. 2004, ESO WFI star flats based on SDSS Stripe 82

Currently, these two functions are split into two separate sub-modules, although they could be combined in the future.

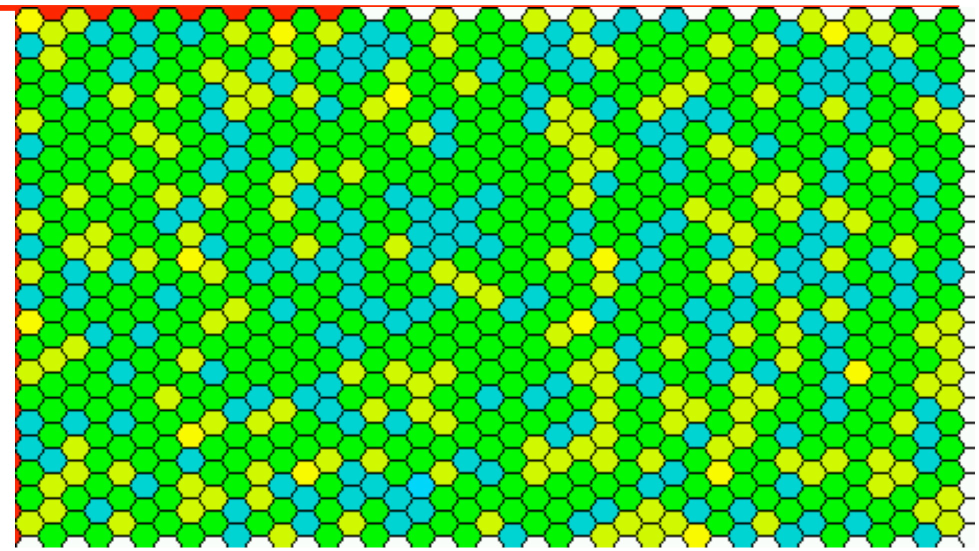
Hex-to-Hex Zeropoints: The Need and The Strategy

DARK ENERGY SURVEY

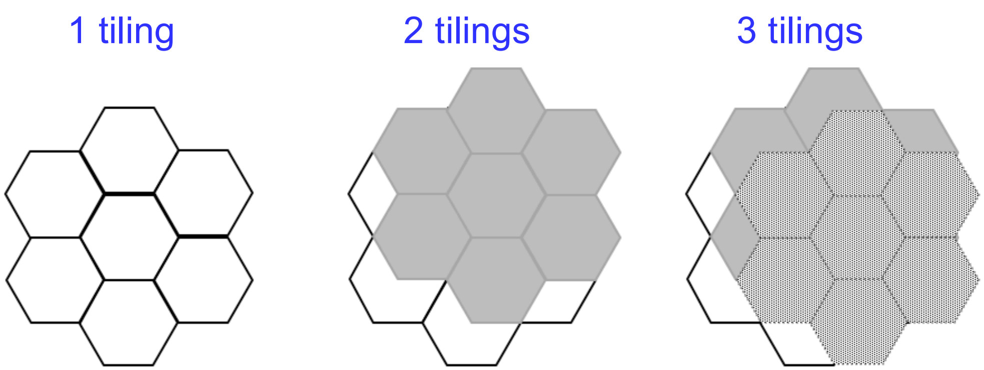
DES will not always observe under truly photometric conditions…

…and, even under photometric conditions, zeropoints can vary by 1-2% rms hex-to-hex.

Jim Annis
DES Collaboration Meeting,
May 5-7, 2005



scaling bar is –0.20 mags to +0.20 mags

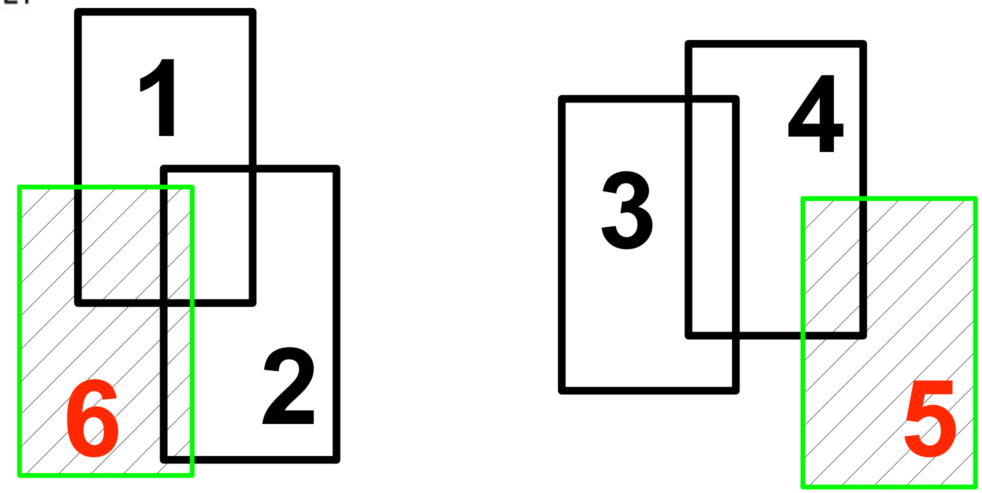


The solution: multiple tilings of the survey area, with large offsets between tilings.

We cover the sky twice per year per filter. It takes ~ 1700 hexes to tile the whole survey area.

Hex-to-Hex Zeropoints
The Algorithm (I)

DARK ENERGY SURVEY



A Generic Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.

- Method used by Oxford-Dartmouth Thirty Degree Survey (MacDonald et al. 2004)
- Developed by Glazebrook et al. (1994) for an imaging K-band survey

- Consider n frames, of which (1, …, m) are calibrated and (m+1,…,n) are uncalibrated.
- Let $\Delta_{ij} = \langle mag_i - mag_j \rangle_{pairs}$ (note $\Delta_{ij} = -\Delta_{ji}$).
- Let ZP_i be the floating zero-point of frame i, but fixing $ZP_i = 0$ if $i > m$.
- Let $\theta_{ij} = 1$ if frames i and j overlap or if i = j; otherwise let $\theta_{ij} = 0$.
- Minimize $S = \Sigma\Sigma\, \theta_{ij}\, (\Delta_{ij} + ZP_i - ZP_j)^2$

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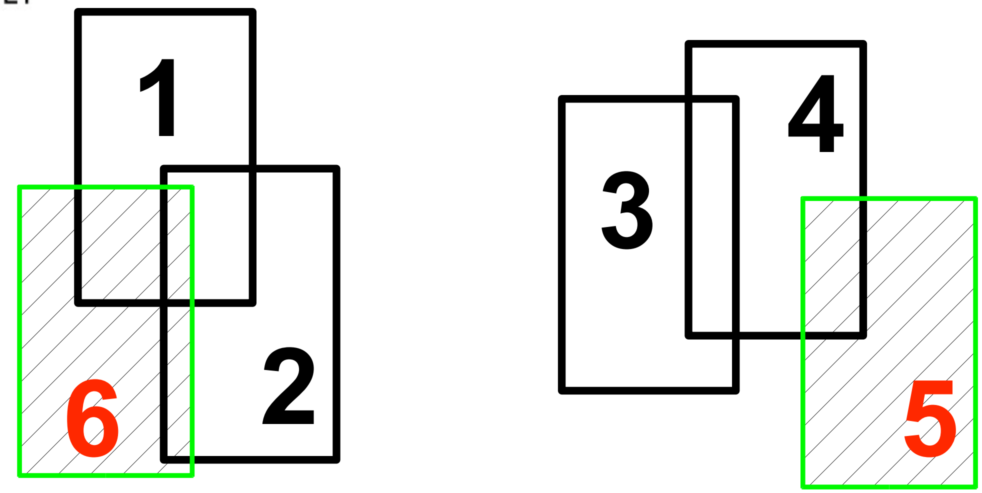
Hex-to-Hex Zeropoints: The Algorithm (II)

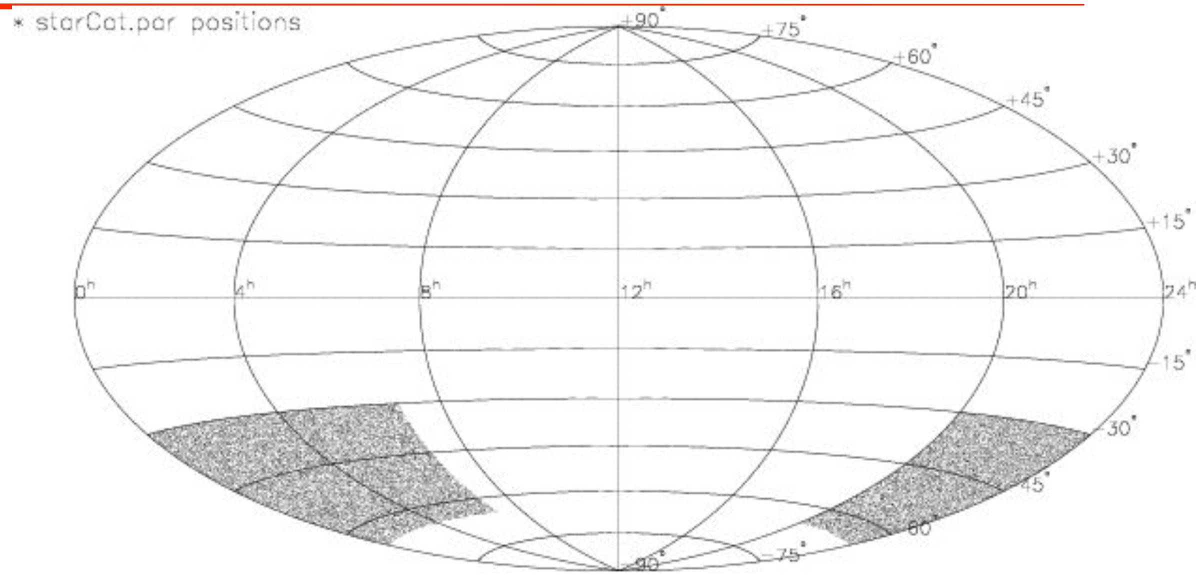


Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.
(From Glazebrook et al. 1994)

$$\begin{vmatrix} -2 & 1 & 0 & 0 & 0 & 1 \\ 1 & -2 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & -2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix} \times \begin{vmatrix} ZP1 \\ ZP2 \\ ZP3 \\ ZP4 \\ ZP5 \\ ZP6 \end{vmatrix} = \begin{vmatrix} \Delta_{12} + \Delta_{16} \\ \Delta_{21} + \Delta_{26} \\ \Delta_{34} \\ \Delta_{43} + \Delta_{45} \\ 0 \\ 0 \end{vmatrix}$$

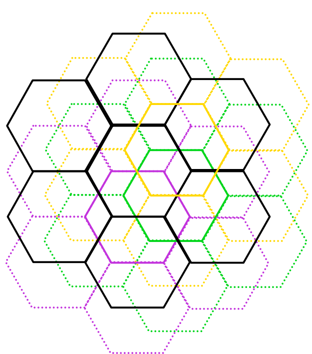
Hex-to-Hex Zeropoints:
The Code + A Simple Test Case

DARK ENERGY SURVEY



GCM Zeropoint Solver Code

- First real test against DES simulations in Data Challenge 3
- Written in Java
- Uses cern.colt.matrix
- **Input:** An ASCII table of all unique star matches in the overlap regions
- **Output:** The ZP offsets to be applied to each field, the rms of the solution, and QA plots

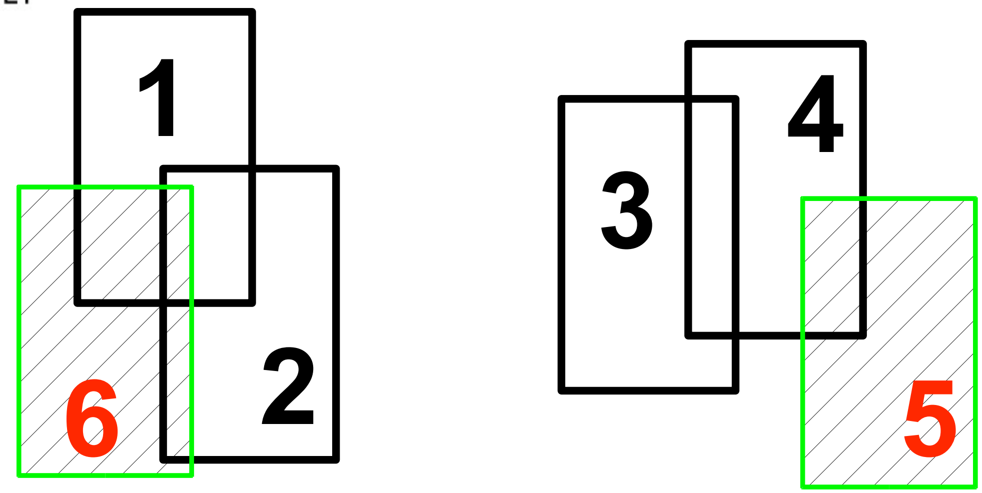


Simple Test Case:

- 38,000 stars over 3800 sq deg
- 4500 overlapping 2.2°-diameter circular regions
  - 70% photometric (ZP = 0.00 +/- 0.02 mag (rms))
  - 30% non-photometric (ZP = 0.25 +/- 0.50 mag (rms))
- 300,000 unique star matches in the overlap regions
- About 5 minutes of CPU time on an Apple PowerBook G4
  - most of the CPU time is involved in the setup
  - inversion of 4500x4500 matrix takes about 90 seconds.

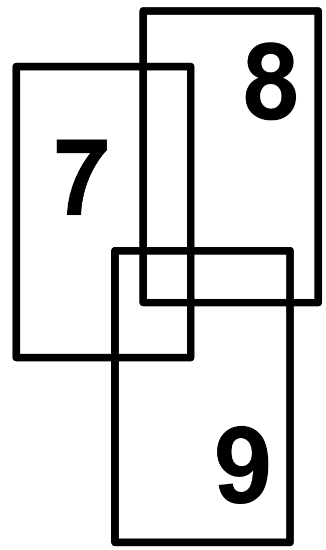
DARK ENERGY SURVEY

Hex-to-Hex Zeropoints: An Issue with "Islands"



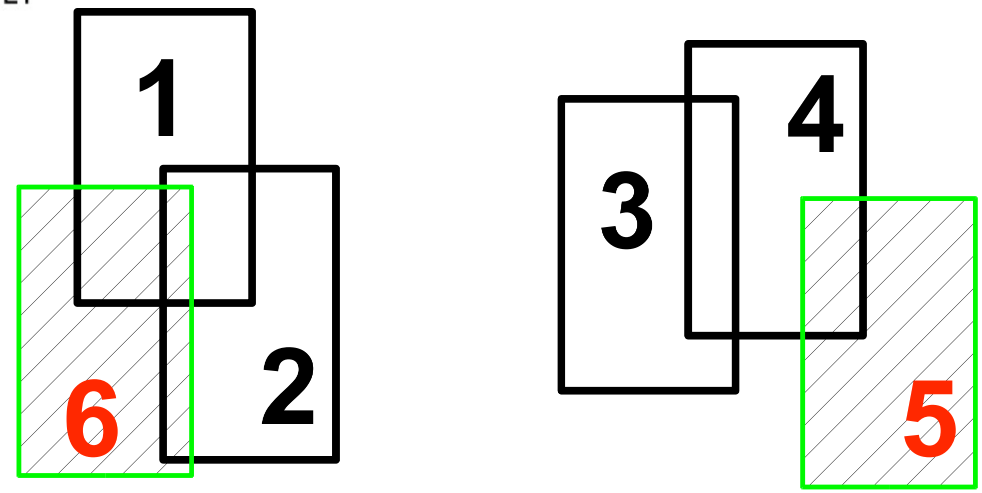
Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.

Frames 7, 8, & 9 form an uncalibratable group or "island"

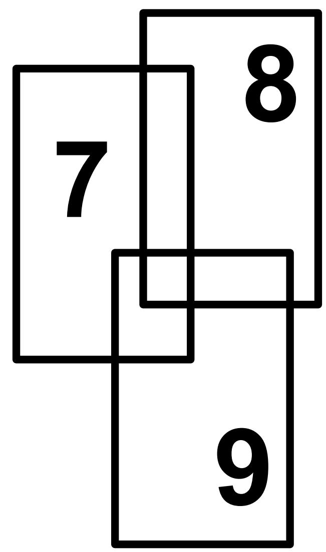


Issue: uncalibratable islands results in un-invertable matrices

Hex-to-Hex Zeropoints: A Solution for "Islands"



Frames 7, 8, & 9 form an uncalibratable group or "island"



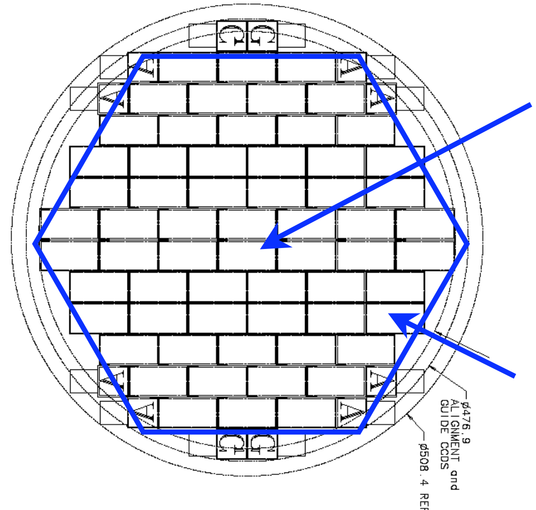
Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.

Solution: use Huchra & Geller (1982) Friends-of-Friends algorithm to identify and remove/adjust such uncalibratable islands

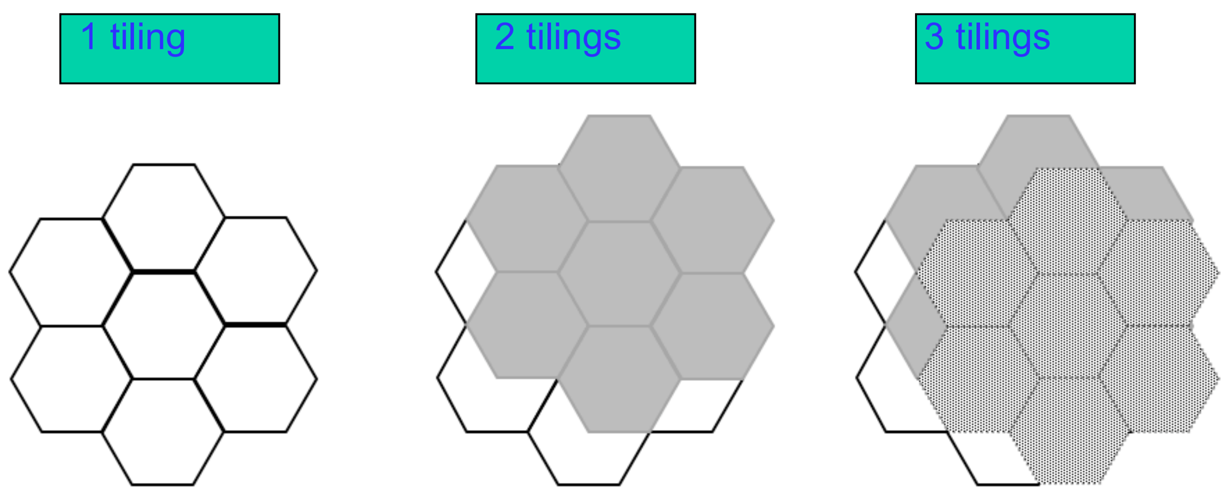
Hex-to-Hex Zeropoint Offsets: An Issue with Instrumental Color Terms

DARK ENERGY SURVEY

What if there are non-negligible differences in the shape of the response curves for different parts of the focal plane?



E.g., what if the system response varies from the center to the edge of the filters?



Hex-to-Hex Zeropoint Offsets: A Solution for Instrumental Color Terms

DARK ENERGY SURVEY

- Variations of the system response should be quite small (1-2%) across the focal plane (and over time)

- Fit for color terms during nightly calibration (PSM) and track

$$m_{inst} - m_{std} = a_n + b_n \times (color - \langle color \rangle) + kX$$

  - m_{inst} is the instrumental magnitude, $m_{inst} = -2.5\log(counts/sec)$ (input)
  - m_{std} is the standard ("true") magnitude of the standard star (input)
  - a_n is the photometric zeropoint for CCD n (n = 1-62) (output)
  - b_n is the instrumental color term coefficient for CCD n (n = 1-62) (input/output)
  - k is the first-order extinction (input/output)
  - *color* is a color index, e.g., *(g-r)* (input)
  - $\langle color \rangle$ is a constant (a fixed reference value for that passband) (input)
  - X is the airmass (input)

- Initially do not apply the color terms to fields (set $b_n=0$)
- Run GCM zeropoint solver and apply zeropoint offsets to fields
- Apply color terms to fields
- Iterate

Extra Slides

Nightly Absolute Calibration: The Photometric Standards Module

DARK ENERGY SURVEY

- The PSM is basically a big least squares solver, fitting the observed magnitudes of a set of standard stars to their "true" magnitudes via a simple model (photometric equation); e.g.:

$$m_{inst} - m_{std} = a_n + kX \qquad (1)$$

  - m_{inst} is the instrumental magnitude, $m_{inst} = -2.5 log(counts/sec)$ (input)
  - m_{std} is the standard ("true") magnitude of the standard star (input)
  - a_n is the photometric zeropoint for CCD n (n = 1-62) (output)
  - k is the first-order extinction (input/output)
  - X is the airmass (input)

- A refinement: add an instrumental color term for each CCD to account for small differences between the standard star system and the natural system of that CCD:

$$m_{inst} - m_{std} = a_n + b_n (stdColor - stdColor_0) + kX \qquad (2)$$

  - b_n is the instrumental color term coefficient for CCD n (n = 1-62) (input/output)
  - *stdColor* is a color index, e.g., *(g-r)* (input)
  - $stdColor_0$ is a constant (a fixed reference value for that passband) (input)
  - DES calibrations will be in the DECam natural system
    - Even if SDSS Stripe 82 *ugriz* and Smith et al. Southern *u'g'r'i'z'* standards are "pre-transformed" to the DES system, eq. 2 is still useful for track changes in DECam instrumental response across the focal plane and over time

Hex-to-Hex Zeropoints: A Simulation

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INSTRUMENT MODEL:

A multiplicative flat field gradient of amplitude 3% from east to west

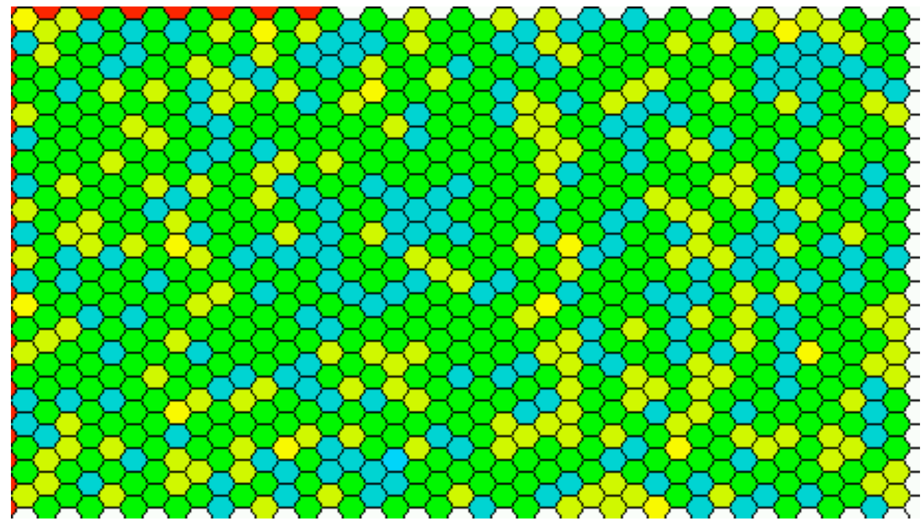
An additive scattered light pattern with a amplitude from the optical axis, 3% at the edge of the camera

An additive 3% rms scattered light per CCD

Solution:

- Simultaneous least squares solution to the underlying relative photometry given the observations

Jim Annis
DES Collaboration Meeting,
May 5-7, 2005



scaling bar is –0.20 mags to +0.20 mags

Relative Calibration	
Tiling	σ (rms of hex ZPs)
1	0.035
2	0.018
5	0.010

Star Flats:
The Need and The Strategy

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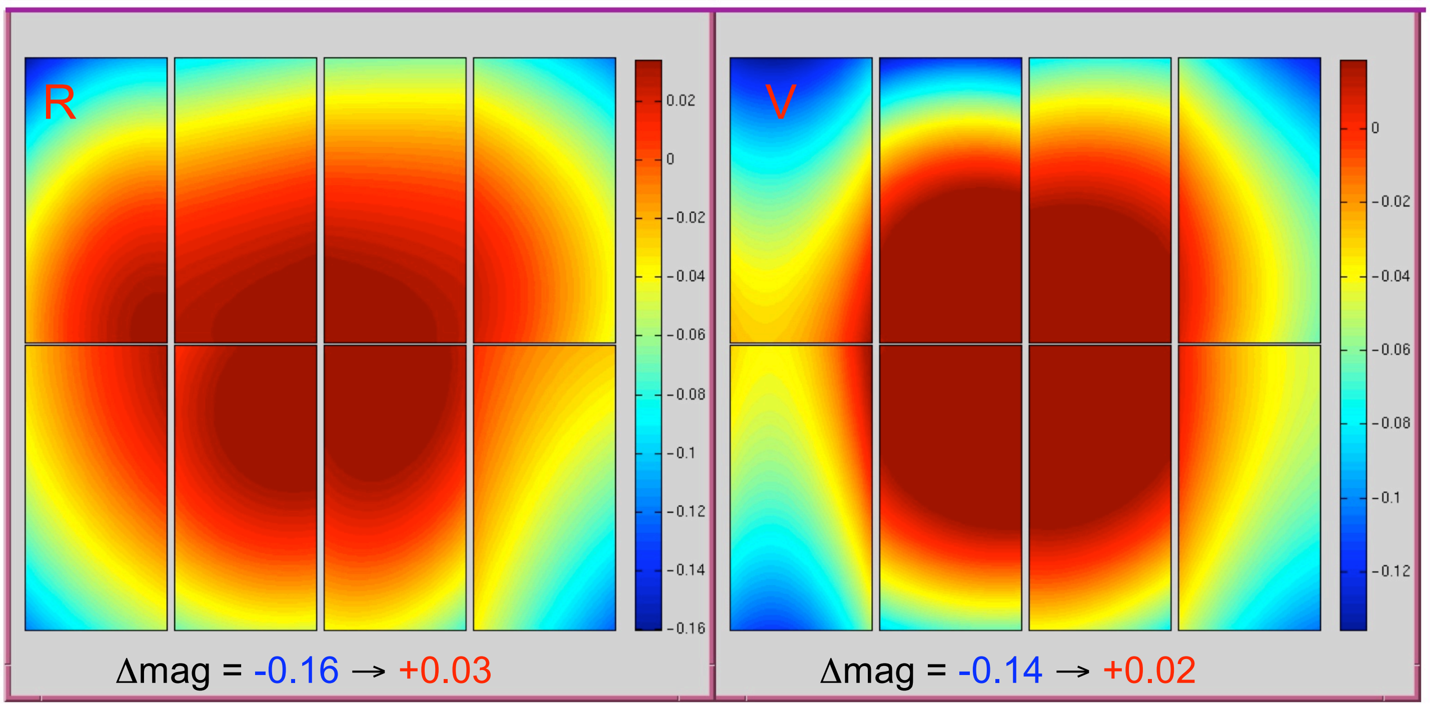
- Due to vignetting and stray light, a detector's response function differs for point sources and extended sources
- Standard flat fields (domes, twilights, skies) may flatten an image sky background well, but not the stellar photometry
- The solution: star flats (Manfroid 1995)
  - offset a field (like an open cluster) multiple times and fit a spatial function to the magnitude differences for matched stars from the different exposures
  - can also just observe a well-calibrated field once (Manfroid 1996)



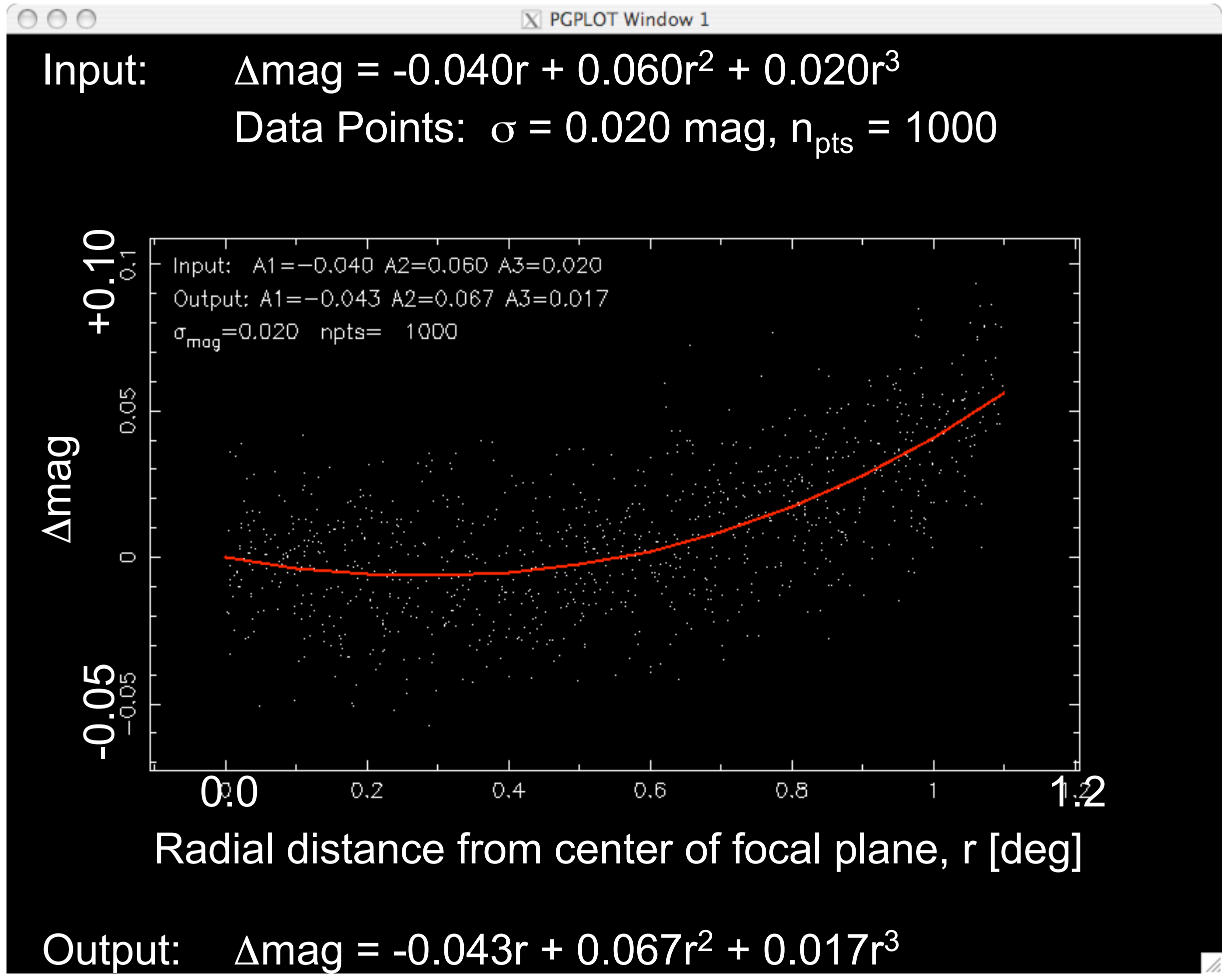
Koch et al. 2004, ESO WFI star flats based on SDSS Stripe 82 observations (2nd order polynomial fits)

Star Flats:
A Prototype Code

DARK ENERGY SURVEY

GCM Star Flat Code

- Basic prototype code developed in the SDSS software environment (Tcl/C)
- Future version in Java
- Currently assumes the star flat correction is a purely radial, 3rd order polynomial



Global Absolute Calibration and Final Calibration

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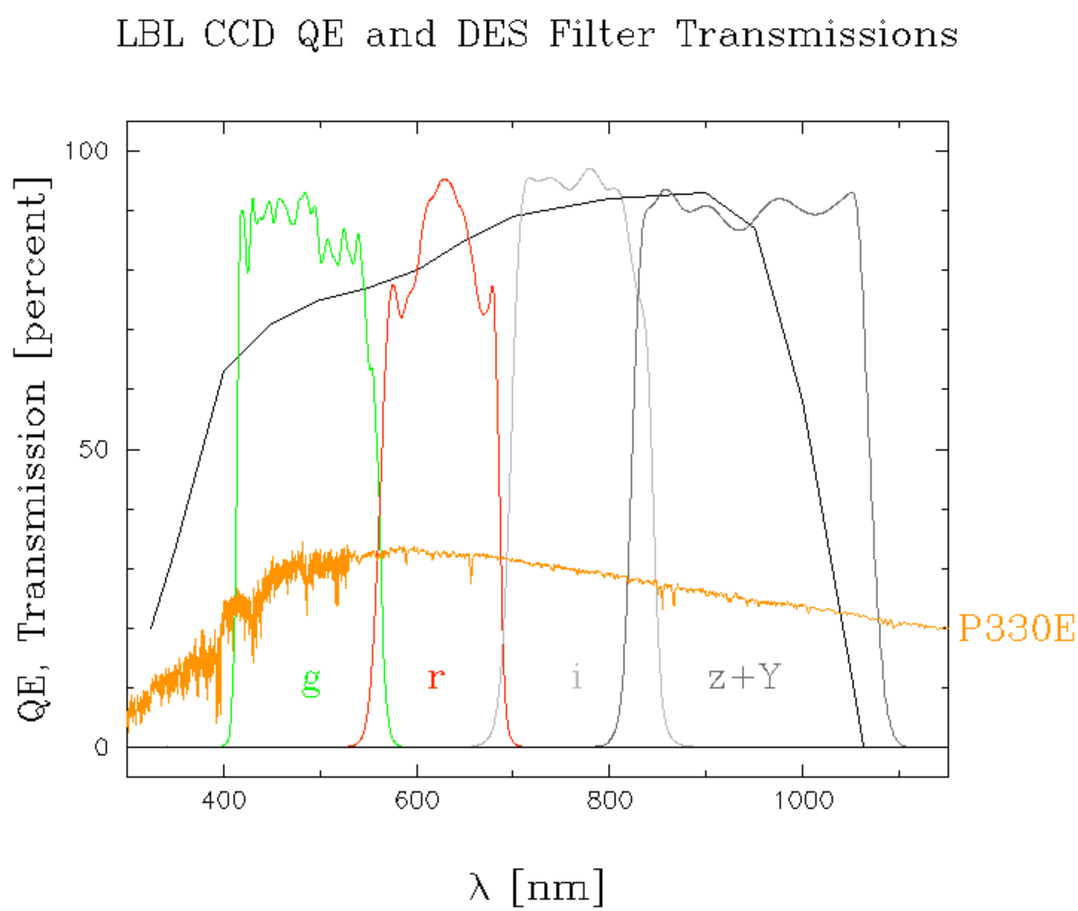
Global Absolute Calibration

- Compare the synthetic magnitudes to the measured magnitudes of one or more spectrophotometric standard stars observed by the DECam.
- The differences are the zeropoint offsets needed to tie the DES mags to an absolute flux in physical units (e.g., ergs s^{-1} cm^{-2} $Å^{-1}$).
- Absolute calibration requires accurately measured total system response for each filter passband as well as one or more well calibrated spectrophotometric standard stars.



Final Calibration

- Apply the magnitude zeropoint offsets to all the catalog data.

Global Absolute Calibration: Spectrophotomeric Standards

DARK ENERGY SURVEY

- ~100 Hot White Dwarfs (DA) in SDSS Stripe 82 (r=16-21)
  - Need to know temperature and log g for “true” SED (models)
  - Need high-resolution spectroscopy (ground-based) + modelling?
  - These set an absolute color scale
- LDS 749B (DES Fundamental Calibrator?)
  - In SDSS Stripe 82 (RA=21:32:16.24, DEC=+00:15:14.7; r=14.8)
  - In HST CalSpec database (STIS observations + model)
  - Sets the absolute flux scale relative to Vega (i.e., Vega taken as “truth”)
- Others
  - E.g, G158-100, GD50, GD 71, G162-66
  - All are HST WD spectrophotometric standards
  - All are visible from CTIO
  - All are V> 13.0 (won’t saturate DECam at an exposure time of 5 sec (FWHM ~ 1.5”)

Global Absolute Calibration: System Response

Full system response (excluding atmospheric transmission):
- filter transmission, CCD QE, and optical throughput for the Blanco+DECam

- Default Plan: tunable laser and NIST calibrated photo-diode
  - Pros: obtain system throughput in one fell swoop
  - Cons: relatively expensive, tunable laser can be finicky to deal with

- Backup Plan 1: LEDs and NIST-calibrated photo-diode (DePoy)
  - Pros: obtain system throughput in one fell swoop, less expensive and less finicky than a tunable laser system
  - Cons: under development

- Backup Plan 2: traditional method (monochromator the individual CCDs and the filters in the lab, take the manufacturers estimate of the transmission of the optical elements, and assume a reflectance of the mirrored surfaces)
  - Pros: well-tested
  - Cons: more layers of measurements where errors can creep in

Global Absolute Calibration: Atmospheric Transmission

The atmosphere is the final item in the train of the total system response.

- Default Plan: use a previously measured atmospheric transmission spectrum (e.g., Stone & Baldwin 1983, Baldwin & Stone 1984, Hamuy et al. 1992, 1994)
  - Pros: already available
  - Cons: does not account for temporal variations in the atmospheric transmission spectrum

- "Backup Plan": use one of the small telescopes at CTIO to monitor for variations in the atmospheric transmission spectrum during DECam operations
  - Pros: accounts for temporal variations
  - Cons: DES has not budgeted for such operations