DARK ENERGY SURVEY

DES Photometric Calibration Strategy

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Filter and Calibrations Strategy Workshop
4 April 2008

Basic Observing Strategy

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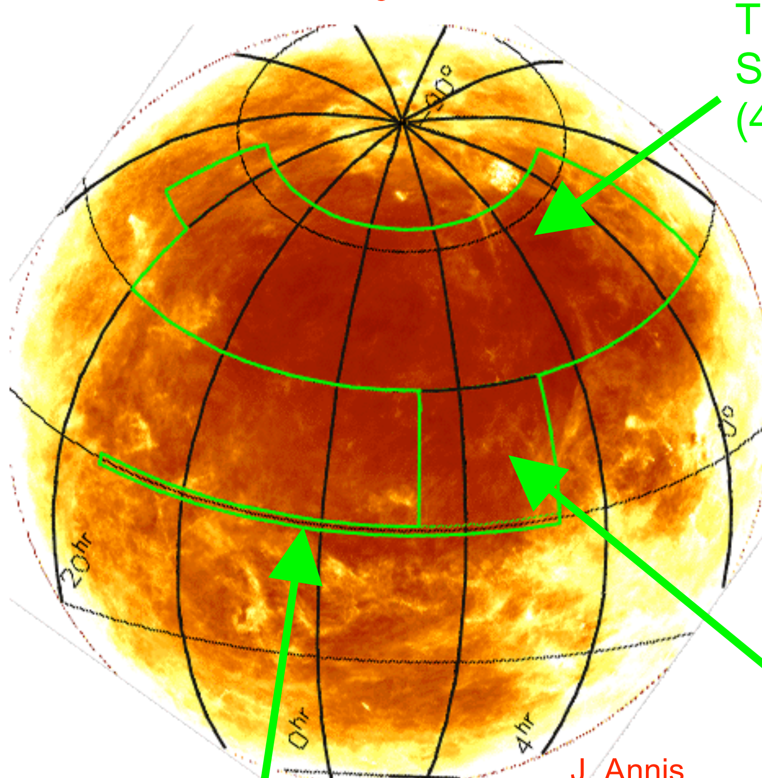
Observing Strategy

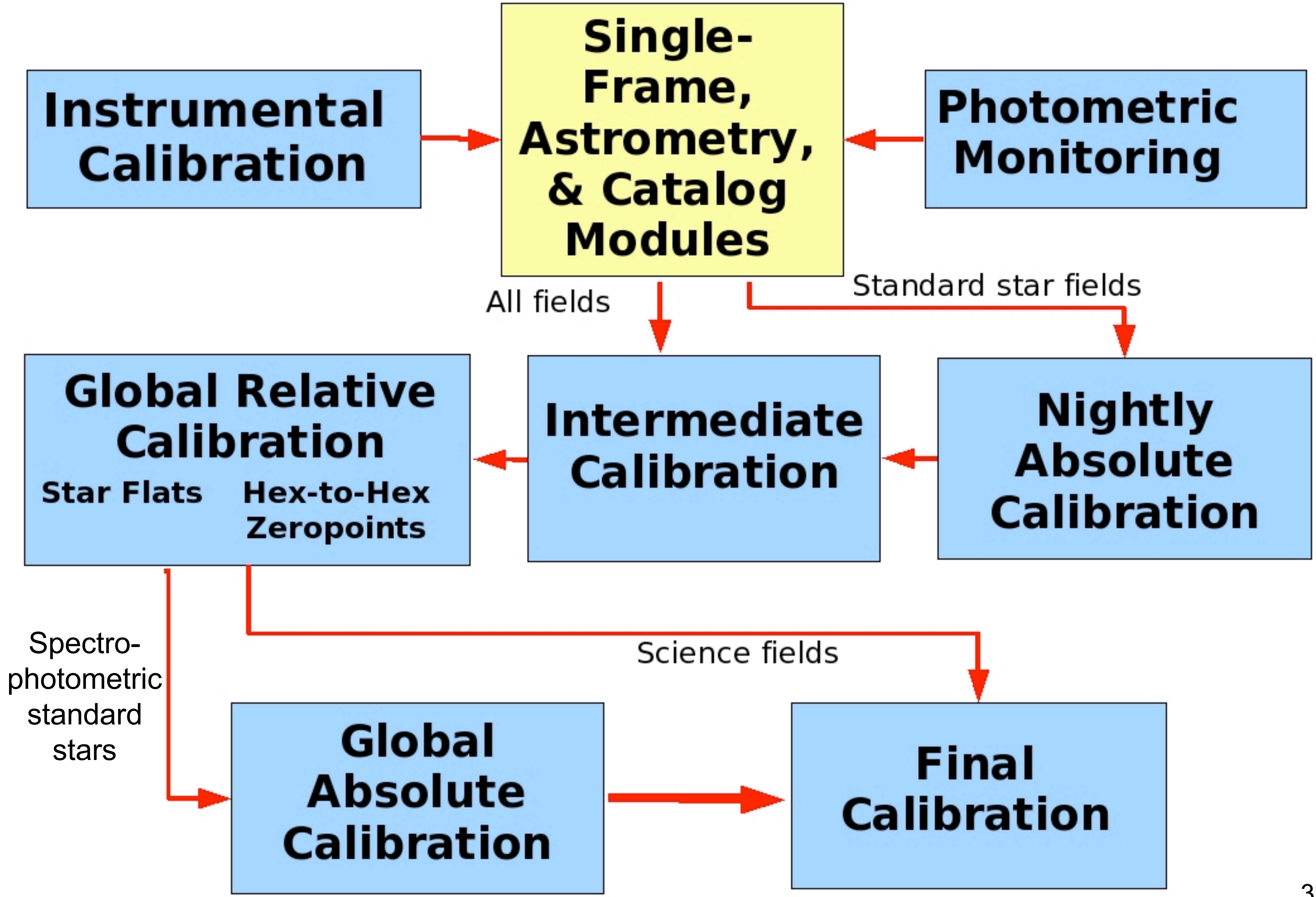
- 100 sec exposures
- 2 filters per pointing (typically)
  - *gr* in dark time
  - *iZ* in bright time
  - Y filter
- Multiple tilings/overlaps to optimize photometric calibrations
- 2 survey tilings/filter/year
- All-sky photometric accuracy
  - Requirement: 2%
  - Goal: 1%

Survey Area



Total Area: 5000 sq deg

DES Calibrations Flow Diagram (v2)



Nightly Absolute Calibration: Standard Star Observing Strategy

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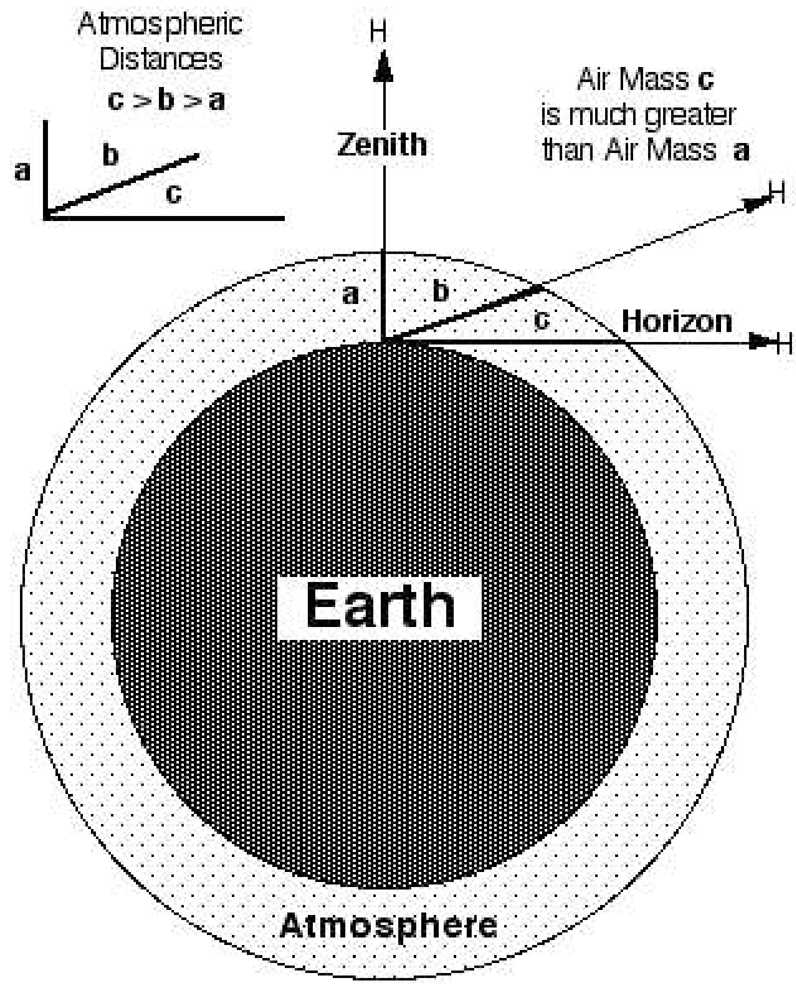
- Observe 3 standard star fields, each at a different airmass (*X*=1-2), between nautical (12°) and astronomical (18°) twilight (evening and morning).
- Observe up to 3 more standard fields (at various airmasses) throughout the night
- Also can observe standard star fields when sky is photometric but seeing is too poor for science imaging (seeing > 1.1 arcsec)
- Use fields with multiple standard stars (to cover focal plane and to cover a wide range of colors)
- Keep an eye on the photometricity monitors



Airmass $X \approx \sec Z$

X=1 overhead, X=2 at Z=60°

Nightly Absolute Calibration: The Photometric Equation I

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- We want to fit the observed magnitudes of a set of standard stars to their "true" magnitudes via a simple model (photometric equation); e.g.:

  $m_{inst} - m_{std} = a_n + kX$

  - 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 (output)
  - X is the airmass (input)

- This assumes:
  - There are no color terms needed to place the magnitudes on the standard star photometric system (i.e., the standard stars on on the "natural" system of the telescope+detector+filter)
  - The shape of the system response curve of the telescope+detector+filter does not vary substantially over the focal plane of the camera
    - Define the "natural" system using the average system response over the focal plane?
    - Define the "natural" system using a single CCD near the center of the focal plane?
    - In either case, there will be CCD-to-CCD color terms

Nightly Absolute Calibration: The Photometric Equation II

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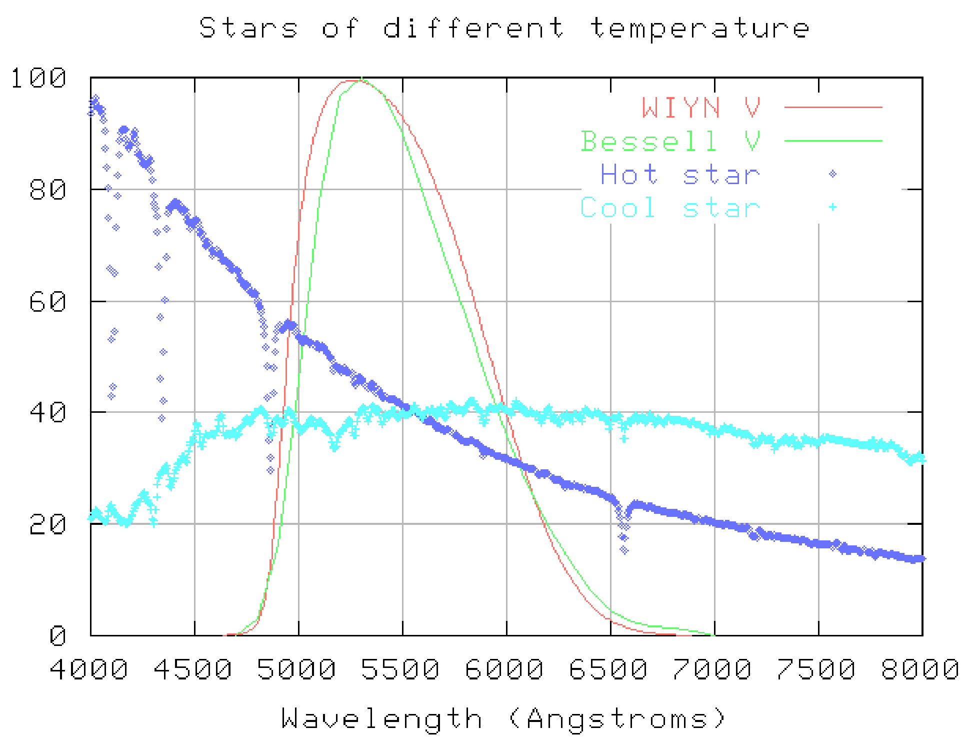
- A refinement: add an instrumental color term for each CCD to account for small differences between the standard star system and the natural system of that CCD:

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

  - b_n is the instrumental color term coefficient for CCD n (n = 1-62) (output)
  - *stdColor* is a color index, e.g., *(g-r)* (input)
  - $stdColor_0$ is a constant (a fixed reference value for that passband) (input)



Need a set of standard stars that covers a wide range of colors

Credit: Michael W. Richmond

Blanco Cosmology Survey, Fixing *b*'s to 0 (rms=0.041 mag, χ^2/ν=4.24)

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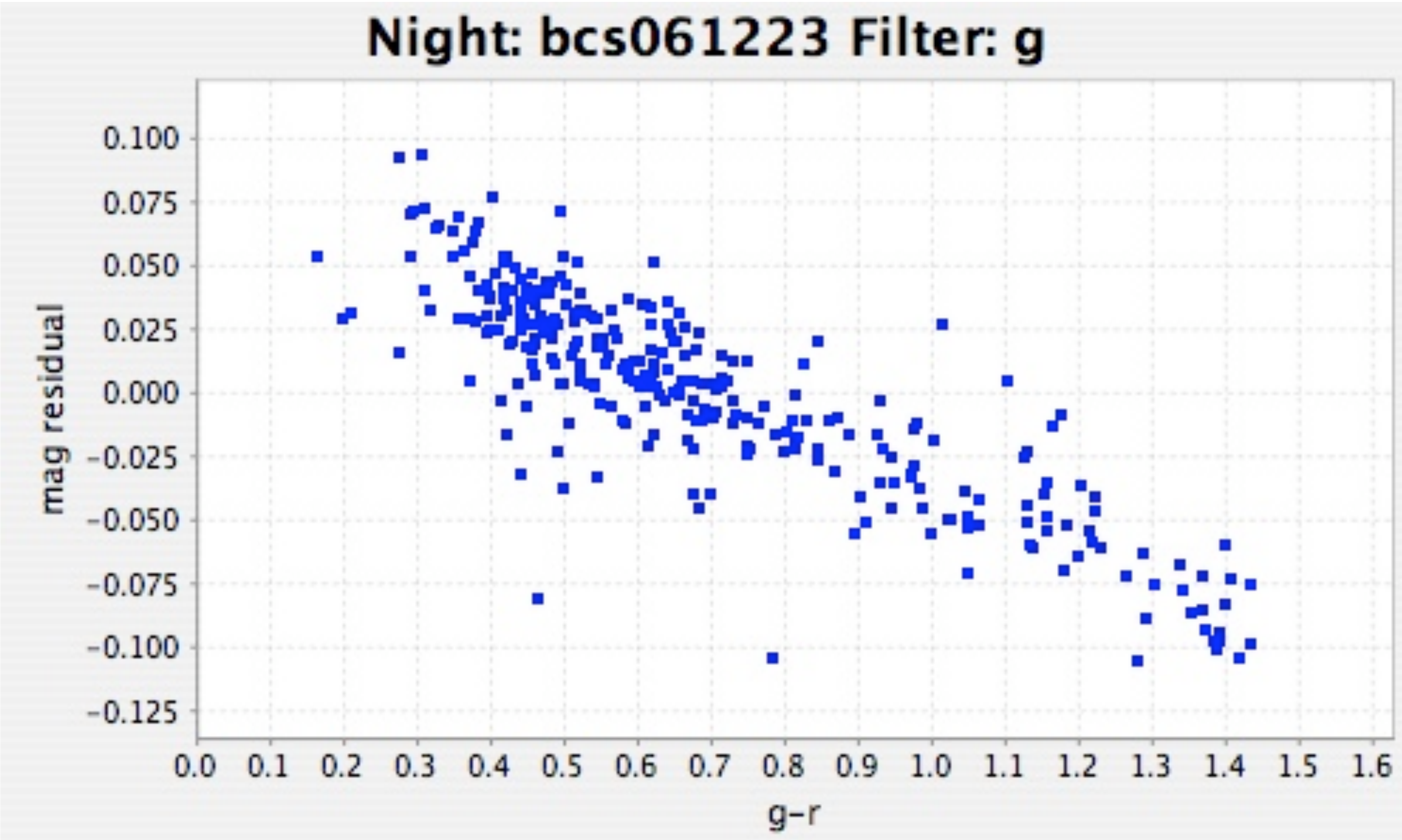

Blanco Cosmology Survey, Solving for *b*'s (rms=0.017 mag, χ^2/ν=0.74)

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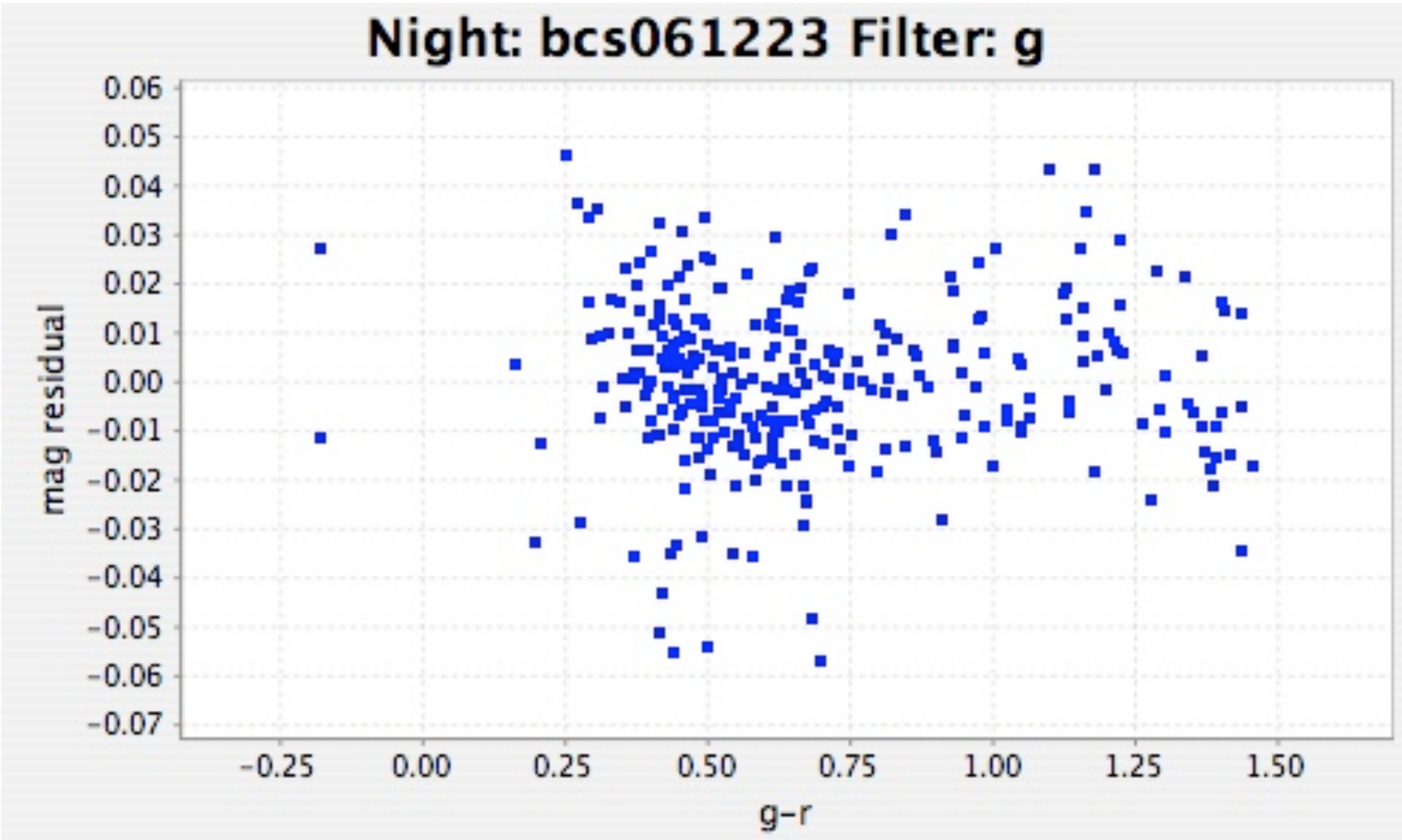

Global Calibration:
The Need and the Strategy

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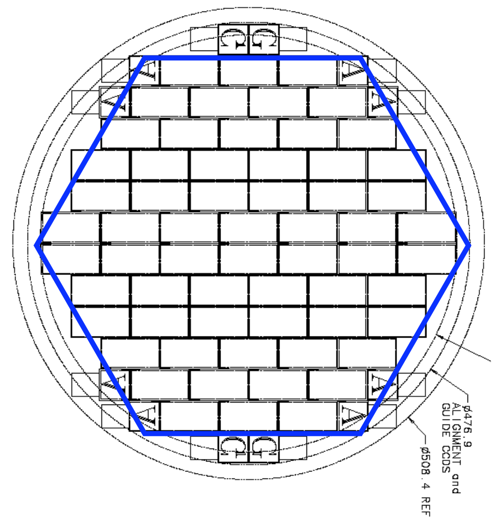
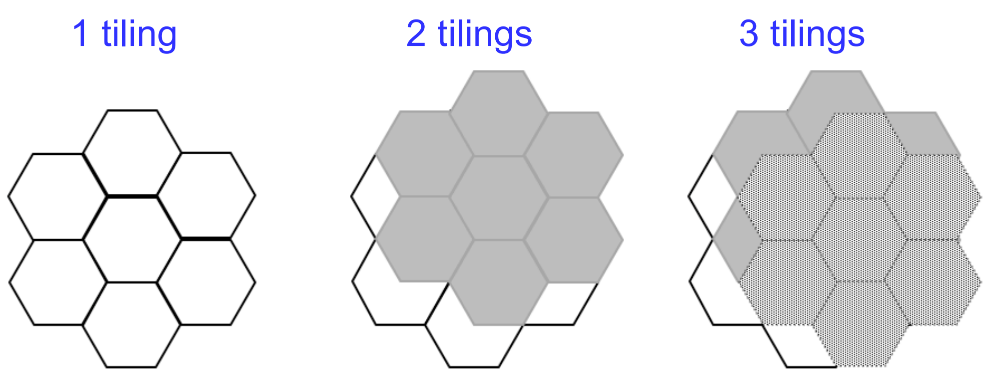
DES will not always observe under truly photometric conditions…

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



DECam Focal Plane:
"The Hex"

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



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.

Global Calibration Module : Global Relative Calibrations

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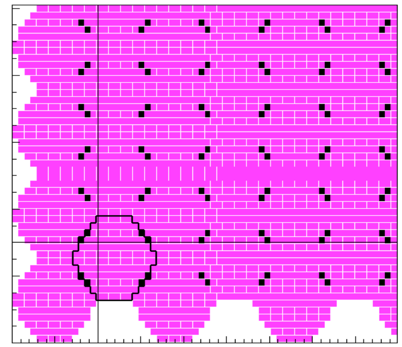
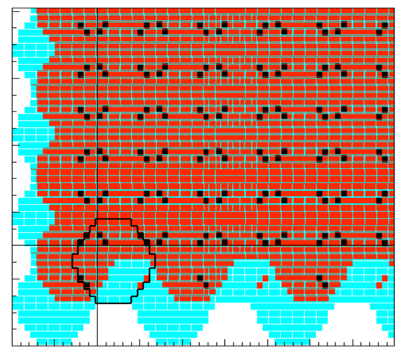
GCM Zeropoint Solver Code

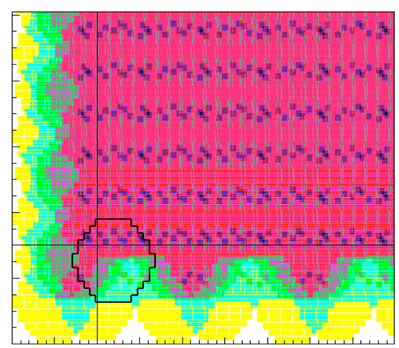
- Uses matrix inversion algorithm developed by Glazebrook et al. (1994) and used by MacDonald et al (2004).
- NxN matrix inversion, where N=# of hexes (or number of tiles or 62 x # of hexes…)
- Written in Java
- Uses cern.colt.matrix
- **Input:** An ASCII table of all unique star matches in the overlap regions
- **Output:** The ZP offsets to be applied to each field, the rms of the solution, and QA plots



1 tiling



2 tilings



3 tilings

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

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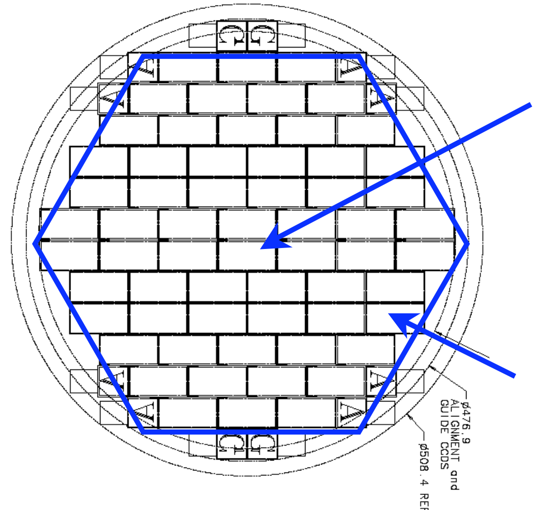
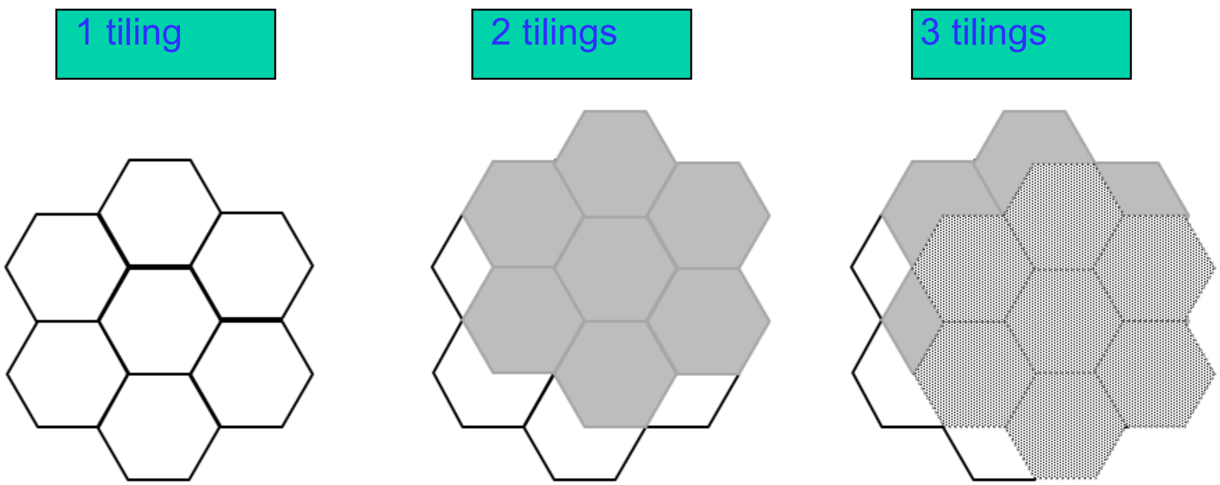
What if there are non-negligible differences in the shape of the response curves for different parts of the focal plane?



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



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

- Variations of the system response will hopefully be quite small (1-2%) across the focal plane (and over time)
- Fit for color terms during nightly calibration (PSM) and track b_n:

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

- 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

(At least one iteration is necessary due to non-photometric data)

Global Absolute Calibration and Final Calibration

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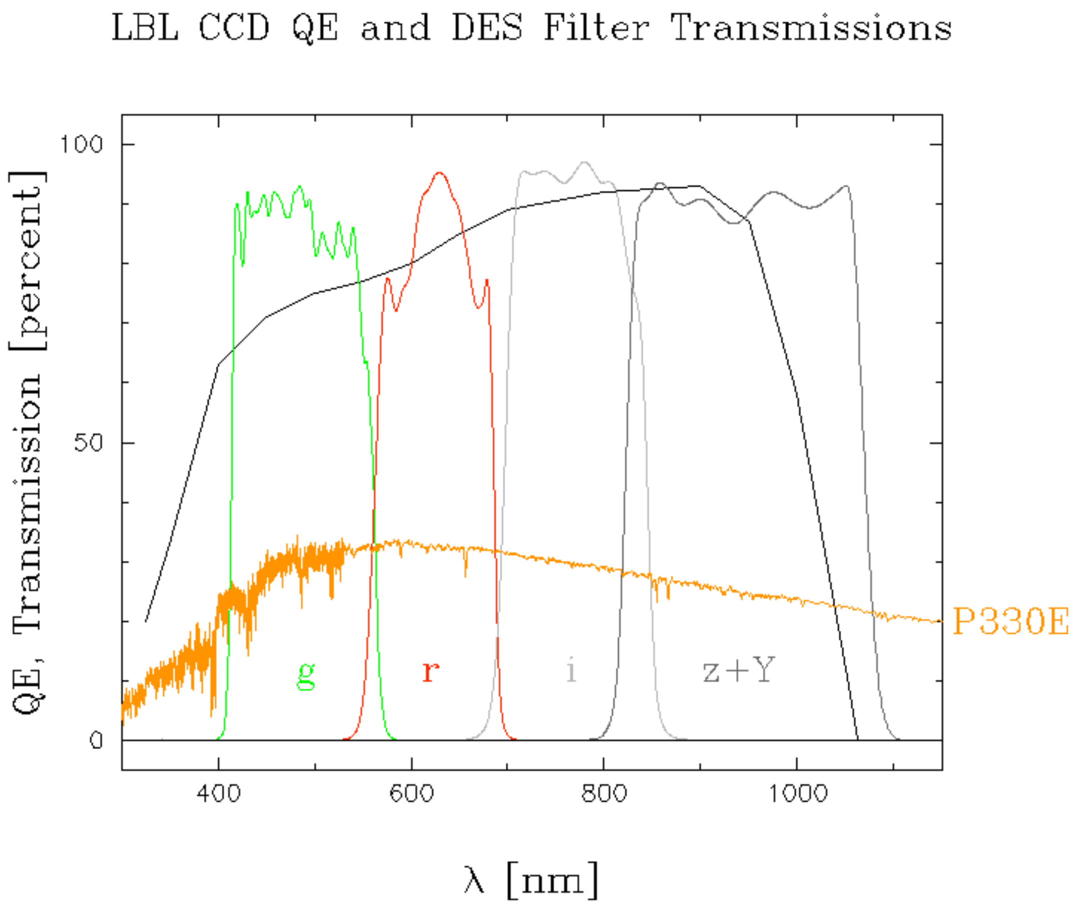
Global Absolute Calibration

- 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.

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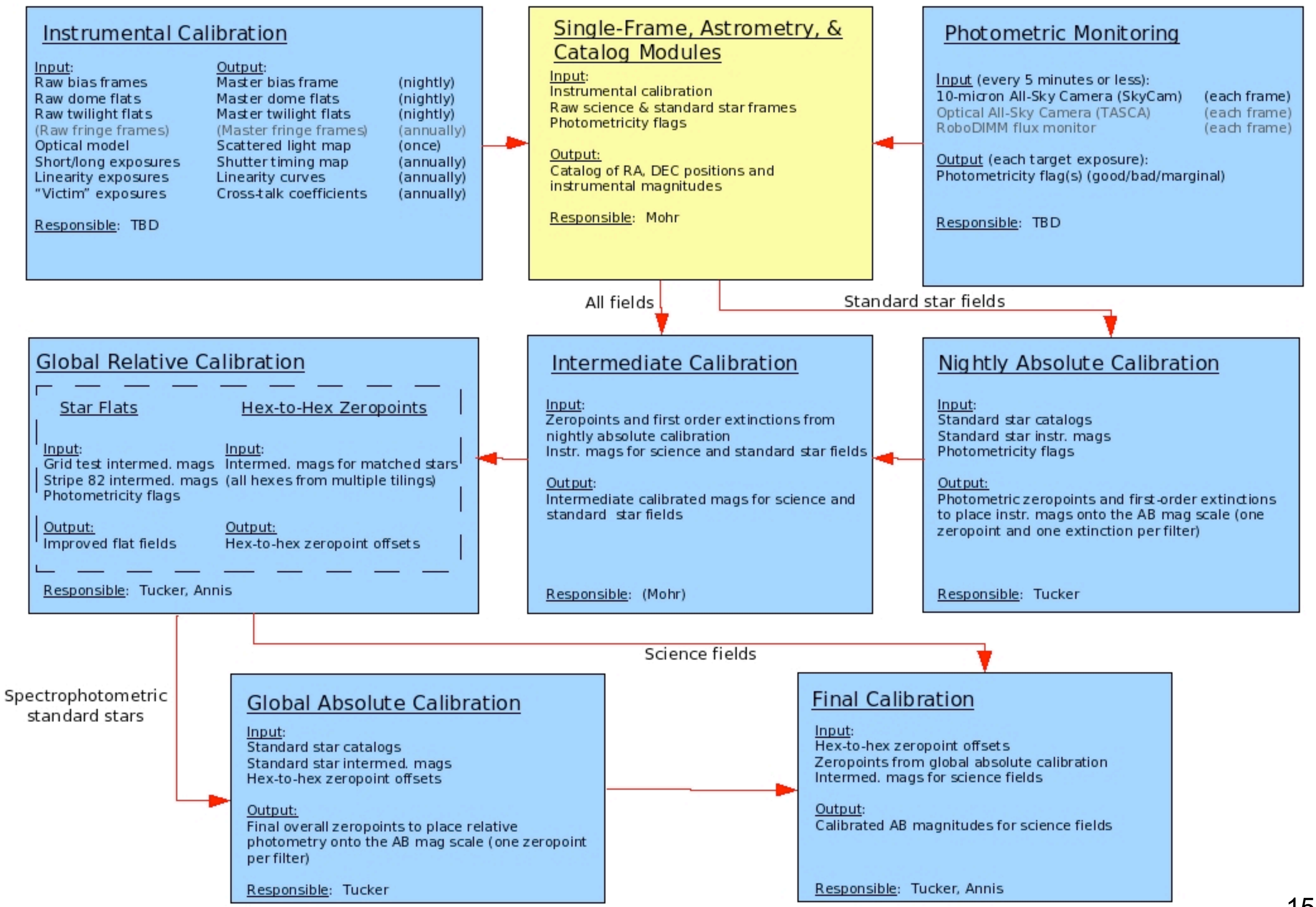
Extra Slides

DES Photometric Calibrations Flow Diagram (v2.2)



Blanco Cosmology Survey, Fixing *b*'s to 0 (rms=0.041 mag, χ^2/ν=4.24)

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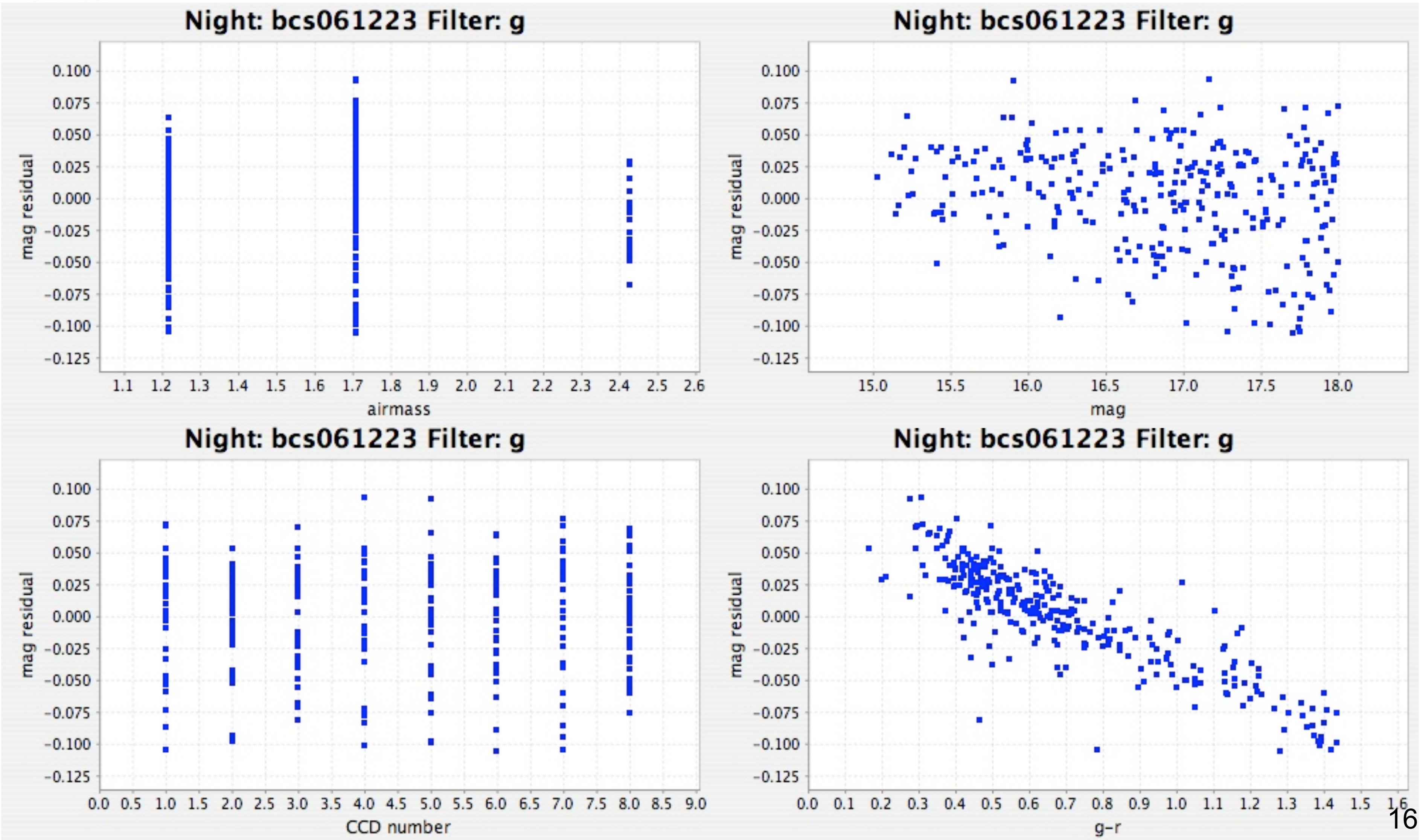

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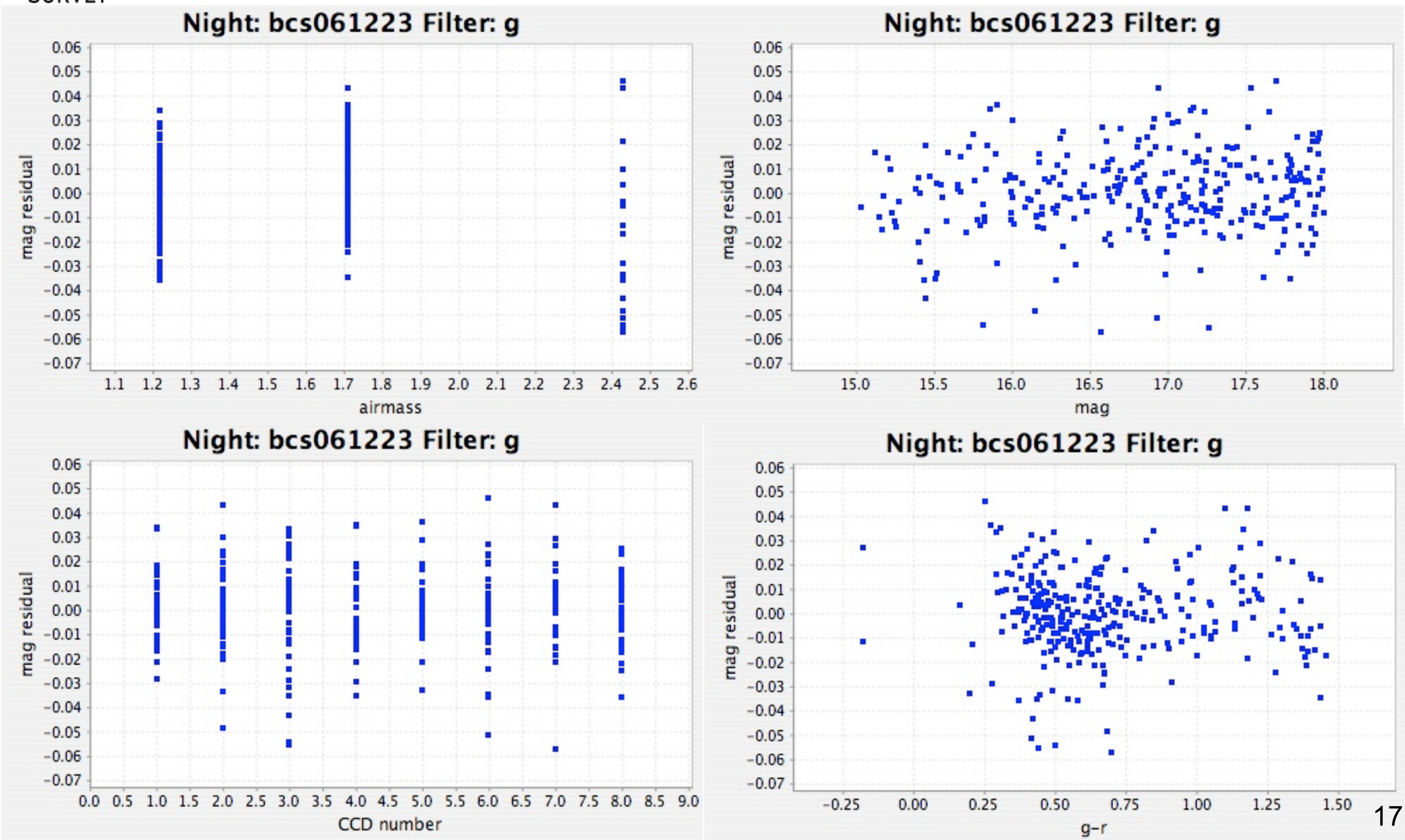
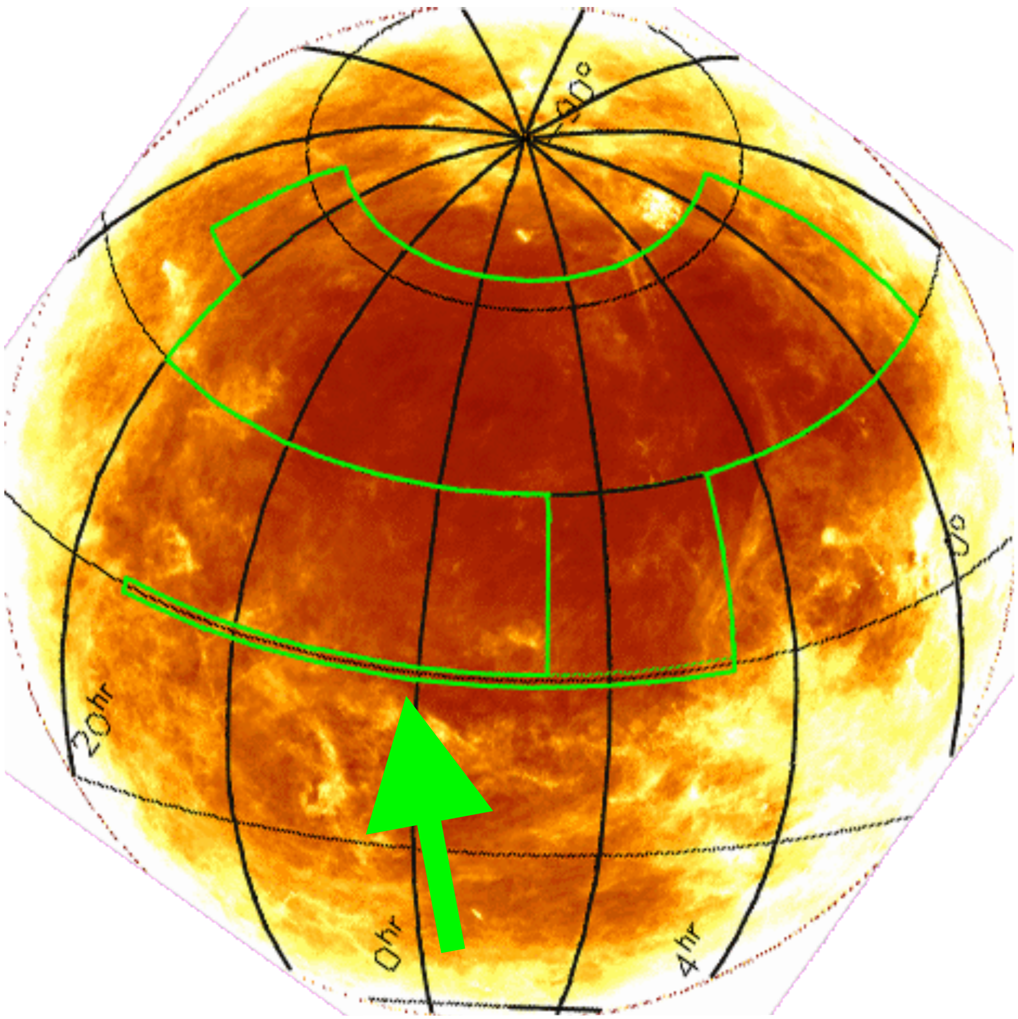
Blanco Cosmology Survey, Solving for *b*'s (rms=0.017 mag, χ^2/ν=0.74)



Nightly Absolute Calibration: SDSS Stripe 82 *ugriz* Standards



Already part of the DES survey strategy.

Readily observable at a range of airmasses throughout most nights during the DES program.

2.5° wide (compares favorably with DECam's FOV (≈2.2°).

Value-added catalogue of tertiary standards is being made

- Area of Stripe 82 has been observed by SDSS > 10x under photometric conditions
- ~ 1 million tertiary SDSS *ugriz* standards (r = 14.5 - 21)!
- ~ 4000 per sq deg (on average)
- See Ivezić et al. (2007)

Nightly Absolute Calibration: Southern *u'g'r'i'z'* Standards

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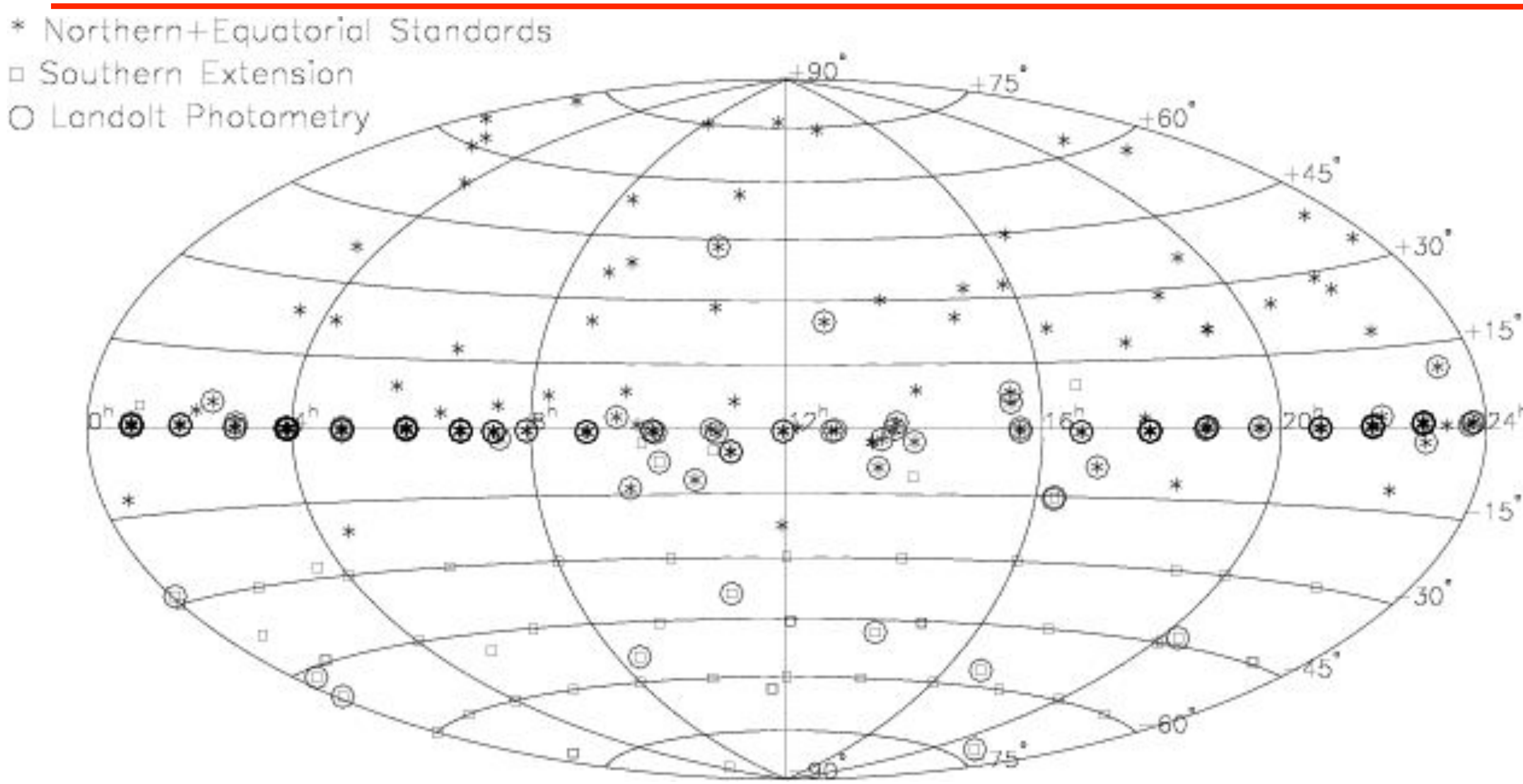

- Smith, Allam, Tucker, Stute, Rodgers, Stoughton
- 13.5' x 13.5' fields, typically tens of stds. per field
- *r* = 9 - 18, ~60 fields, ~16,000 standards
- stars as bright as r≈13 can likely be observed by DECam with 5+ second exposures under conditions of poor seeing or with de-focusing (FWHM=1.5").
- http://www-star.fnal.gov/Southern_ugriz/

(Others: SkyMapper standards? VST OmegaCam standards? Stars from PanSTARRS-1 3π survey?)

Global Absolute Calibration: Spectrophotomeric Standards

- ~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")

Hex-to-Hex Zeropoints
The Algorithm (I)

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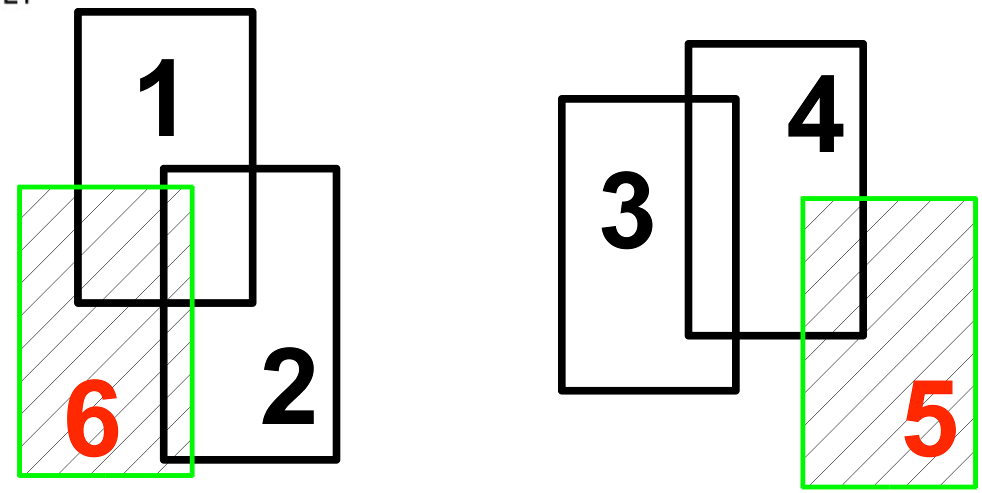

A Generic Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.

- 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 $S = \Sigma\Sigma\, \theta_{ij} (\Delta_{ij} + ZP_i - ZP_j)^2$

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

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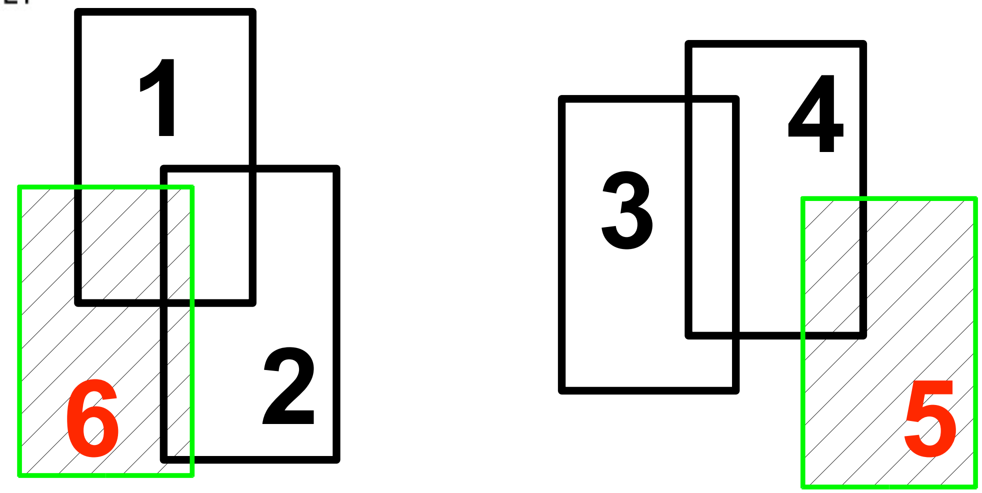

Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.
(From Glazebrook et al. 1994)

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