# Photometric Calibration Strategy of the Dark Energy Survey (DES)

Douglas L. Tucker
17 April 2012

Outline:
1. Basic Strategy
2. Evolving Strategy
3. Particular Problems for Year 1
4. A Call to Cooperate

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DARK ENERGY SURVEY

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# The Dark Energy Survey (DES)

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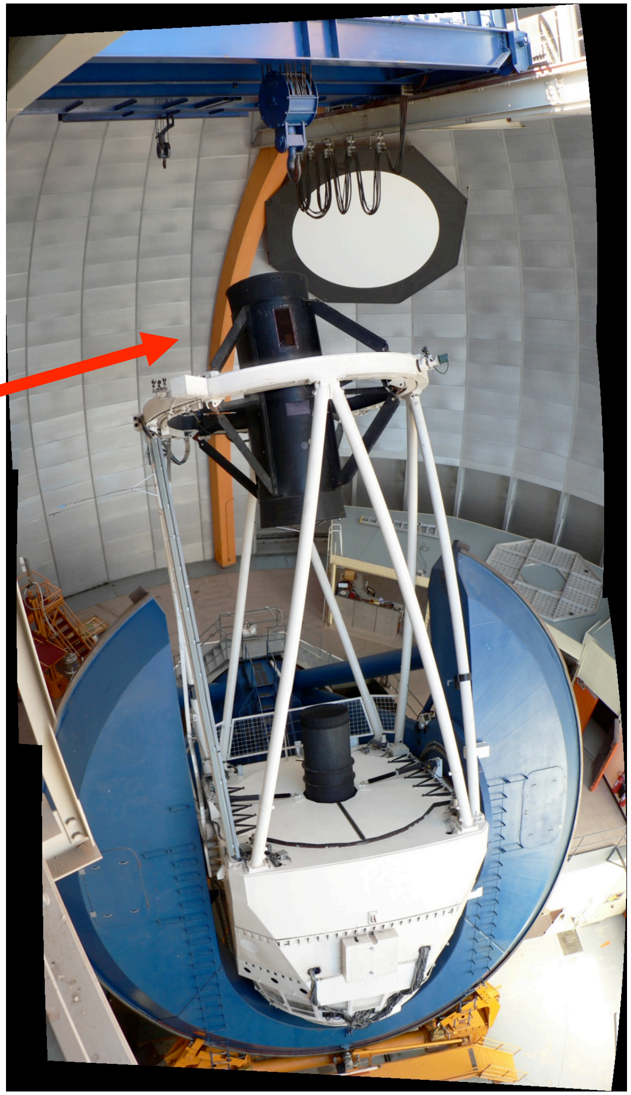
- Plan:
  - Perform a 5000 sq. deg. survey of the southern galactic cap in 5 optical and near-infrared filters (*g, r, i, z, Y*)
  - Measure dark energy with 4 complementary techniques
    - Cluster counts, weak lensing, baryonic acoustic oscillations, supernovae
- New Instrument (DECam):
  - Replace the prime-focus cage on the CTIO Blanco 4m telescope in Chile with a new 2.2° field-of-view, 570 Mega-pixel CCD camera + optics
- Survey:
  - 525 nights during 2012-2017 (September - February)
  - 30% of the telescope time



# Basic DES Observing Strategy

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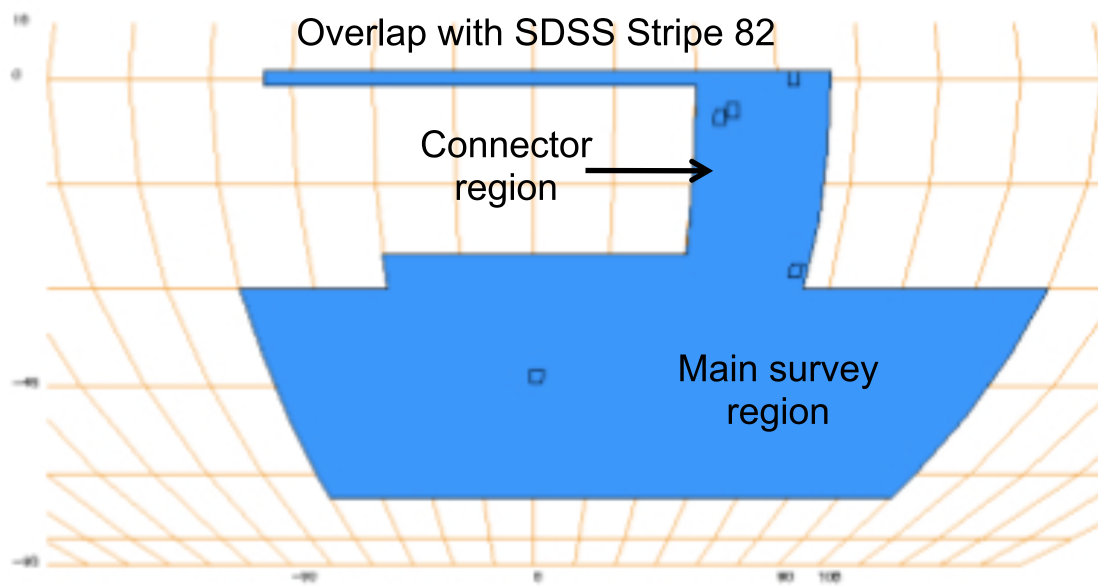
## Observing Strategy

- 100 sec exposures (nominally)
- 2 filters per pointing (typically)
  - *gr* in dark time
  - *izY* in bright time
- Multiple overlapping tilings (layers) to optimize photometric calibrations
- 2 survey tilings/filter/year
- Photometric Requirements (5-year)
  - All-sky internal: 2% rms (Goal: 1% rms)
  - Absolute Color: 0.5% (*g-r*, *r-i*, *i-z*); 1% (*z-Y*)
  - Absolute Flux: 0.5% in *i*-band (relative to BD+17 4708)
- 5-year depth (co-added): ~24th mag for galaxies in i-band

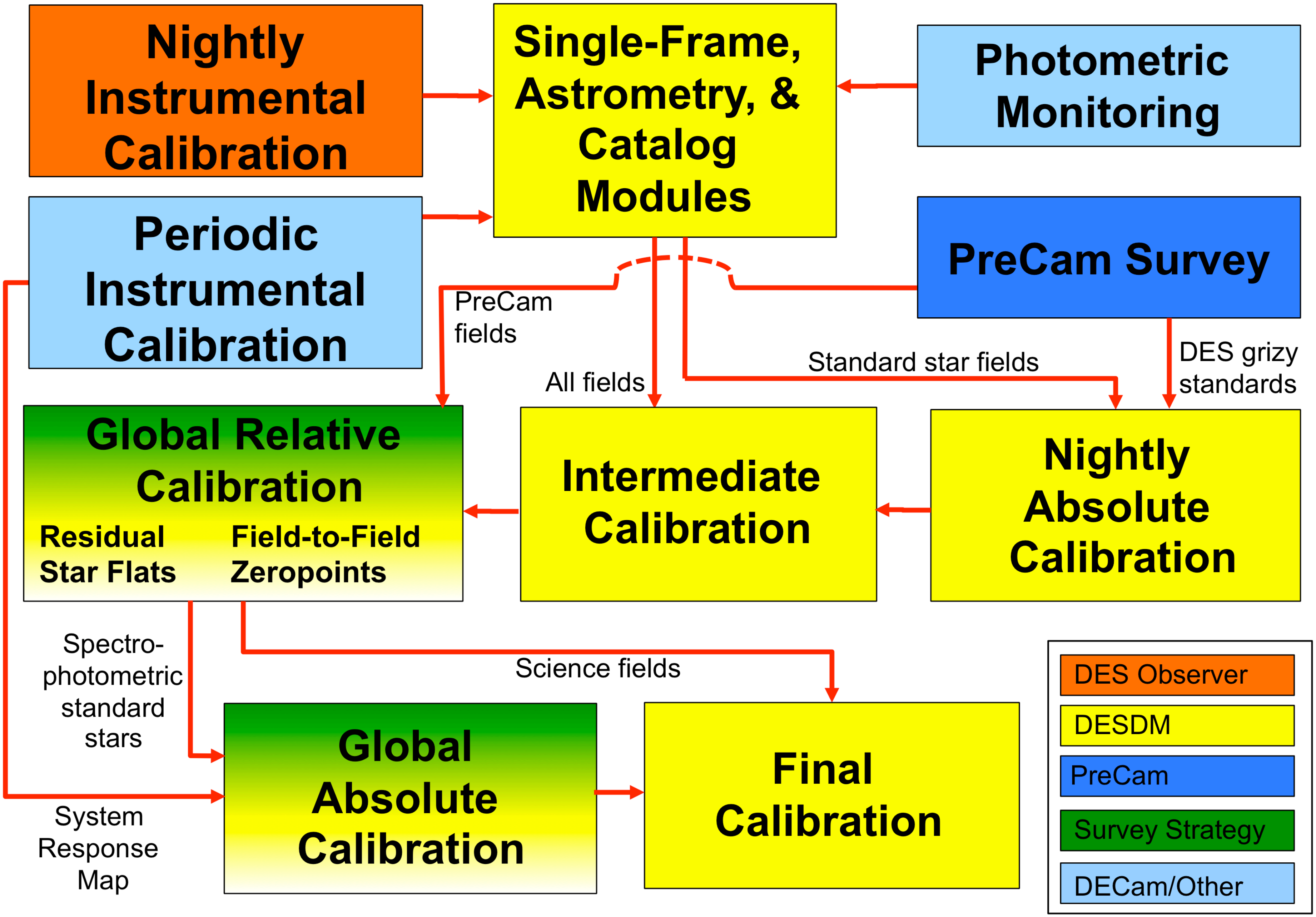
## Survey Area

Credit: J. Annis




Total Area: 5000 sq deg

# DES Photometric Calibrations Flow Diagram (v4.1)



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# DES Calibrations Plan in 6 Points

1. Instrumental Calibration (Nightly & Periodic): Create biases, dome flats, linearity curves, cross-talk coefficients, system response maps.
2. Photometric Monitoring: Monitor sky with 10μm All-Sky Cloud Camera.
3. PreCam Survey: Create a network of calibrated DES *grizy* standard stars for use in nightly calibrations and in DES Global Relative Calibrations.
4. Nightly and Intermediate Calibrations: Observe standard star fields with DECam during evening and morning twilight and at least once in the middle of the night; fit photometric equation; apply the results to the data.
5. Global Relative Calibrations: Use the extensive overlaps between exposures over multiple tilings to tie together the DES photometry onto an internally consistent system across the entire DES footprint.
6. Global Absolute Calibrations: Use DECam observations of spectro-photometric standards in combination with measurements of the full DECam system response map to tie the DES photometry onto an AB magnitude system.

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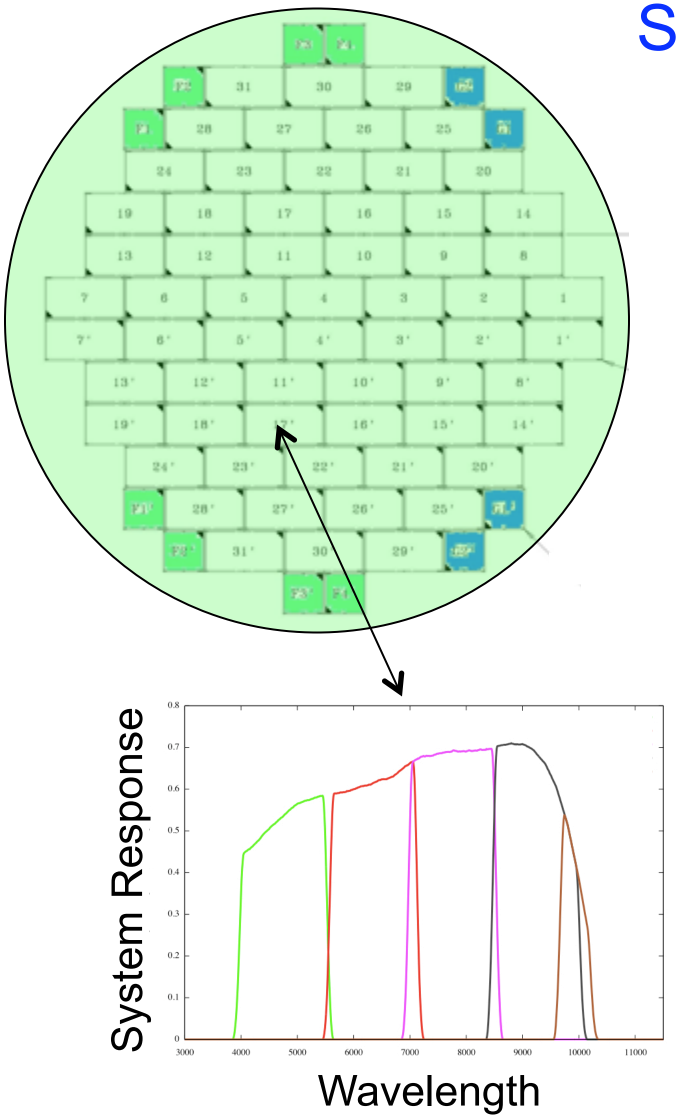
# 1. Instrumental Calibration:
# An Example of Periodic Instr. Calibration




## Spectrophotometric System Response Map

(See Jennifer Marshall's talk.)

- It is expected that the shape of the system response will be a function of position on the focal plane.
- Therefore, the system response map from the spectrophotometric calibration system will be important for Global Absolute Calibration, catalog and image co-adds, enhanced calibration of specific classes of astronomical objects, and system performance tracking over time.
- This would typically be a once-a-month calibration, taking several hours to measure all 5 DES filters.

# 2. Photometric Monitoring: The 10 micron All-Sky Camera

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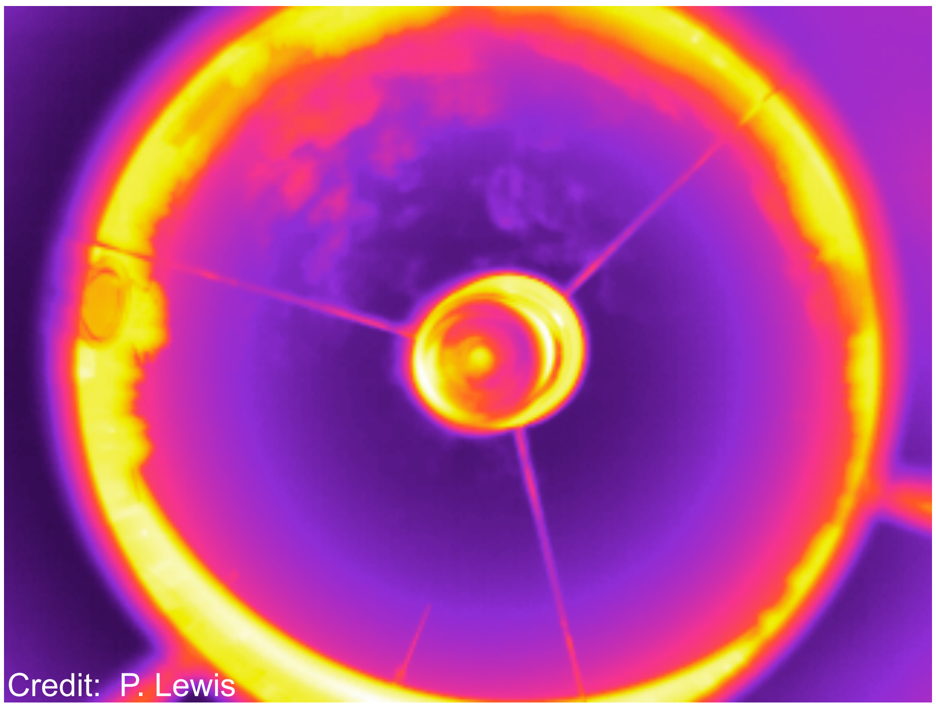
## 10 micron All-Sky Camera

- Provides real-time estimates of sky conditions for survey strategy
- Provides a measure of the photometric quality of an image for off-line processing
- Detects even light cirrus under a full range of moon phases (no moon to full moon)




RASICAM image: light cirrus

## The DES Camera: "RASICAM"

- "Radiometric All-Sky Infrared CAMera"
- Web interface for observers
- Photometricity flags passed to each exposures FITS header via SISPI for use by DESDM
  - Nightly calibrations
  - Global relative calibrations

# 3. The PreCam Survey: What is it?

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PreCam Survey: a quick, bright *grizy* survey in the DES footprint using a 4kx4k camera composed of DECam CCDs – the "PreCam" – mounted on the University of Michigan Dept. of Astronomy's Curtis-Schmidt Telescope at CTIO.

Observations took place in Aug/Sep 2010 and Nov 2010 - Jan 2011.

# 3. The PreCam Survey: Characteristics

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- 2 DECam 2k x 4k CCDs
  - FOV of 1.6º x 1.6º (2.56 sq deg) at a pixel scale of 1.4 arcsec/pixel
- 112 scheduled nights (which includes includes installation & commissioning)
- Goals: to act as a test-stand of DECam h/w and s/w and to obtain a sparse-but-rigid gridwork of stars in DES *grizy* photometrically calibrated to better than ~1%

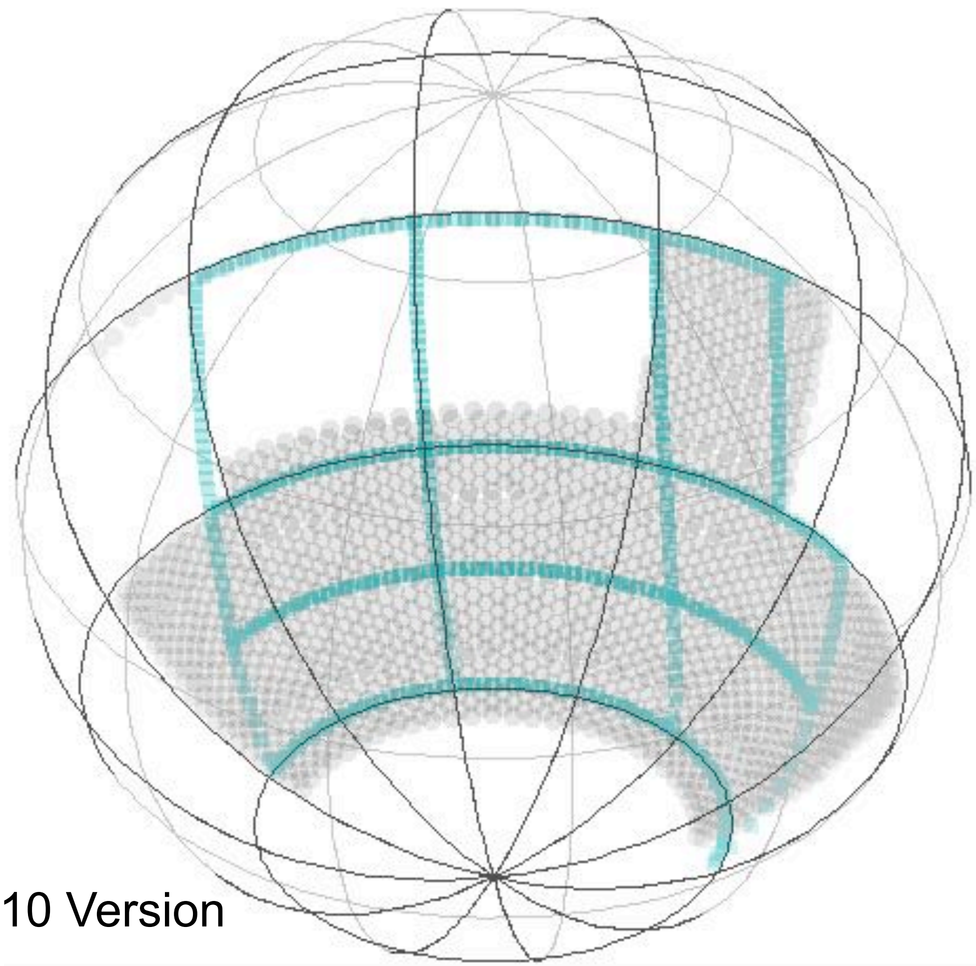
**Baseline PreCam Survey Point-Source Magnitude Limits (optimized to achieve S/N=50 at DES saturation + 1.5mag)**

| Band | Exposure time [seconds] | PreCam saturation limit | PreCam mag limit S/N=50 | Number of usable stars per sq deg (SGP) |
|---|---|---|---|---|
| g | 36 | 12.8 | 17.8 | 186 |
| r | 51 | 13.2 | 17.8 | 265 |
| i | 65 | 13.4 | 17.7 | 344 |
| z | 162 | 14.1 | 17.5 | 317 |
| y | 73 | 11.6 | 14.3 | 150 |

# 3. The PreCam Survey:
# The Survey Strategy as Planned

- ≈500 sq deg (10% DES area)
- ≈30° grid pattern
- Cover grid 10x in each filter (*g*, *r*, *i*, *z*, *y*)

For details and results, see talks by Kyler Kuehn and Sahar Allam.



Aug 2010 Version

# 4. Nightly/Intermediate Calibrations: Standard Stars for DES

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

<u>*SDSS Stripe 82*</u>

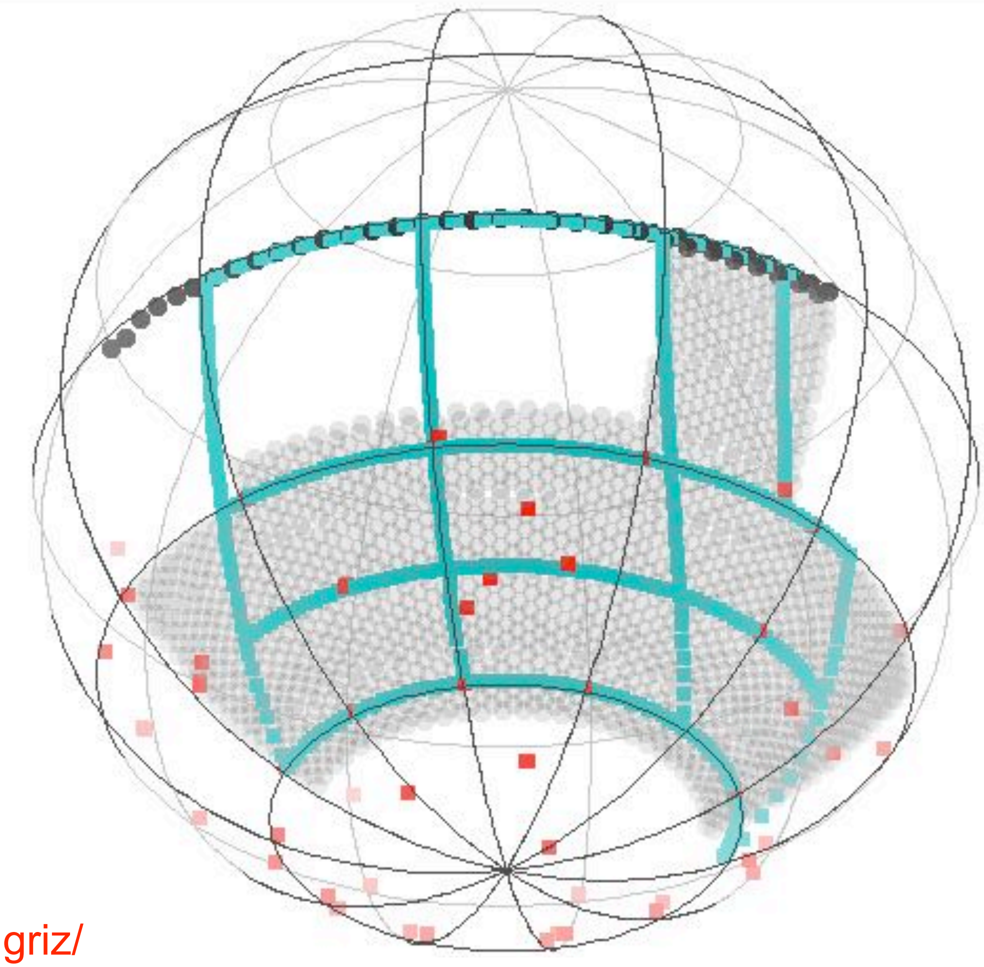
- ~$10^6$ tertiary *ugriz* standards
- *r* = 14.5-21
- ~4000 per sq deg
- 2.5° x 100° area
- See Ivezic et al. (2007)

<u>*PreCam*</u>

- DES *grizy*
- 500 sq deg
- ≈200 per sq deg

<u>*Southern u'g'r'i'z' Standards*</u>

- Sixty 13.5'x13.5' fields
- *r* = 9-18
- Typically tens per field
- See http://www-star.fnal.gov/Southern_ugriz/



# 5. Global Relative Calibrations: The Need and The Strategy

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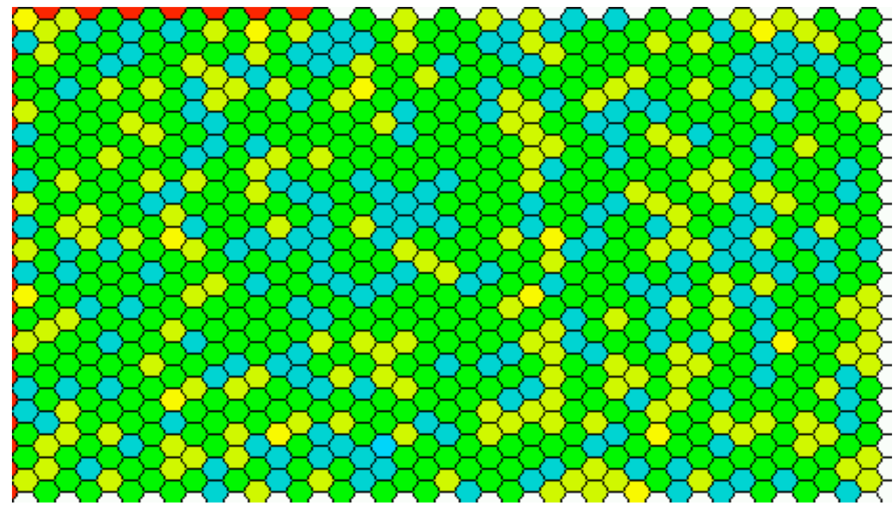
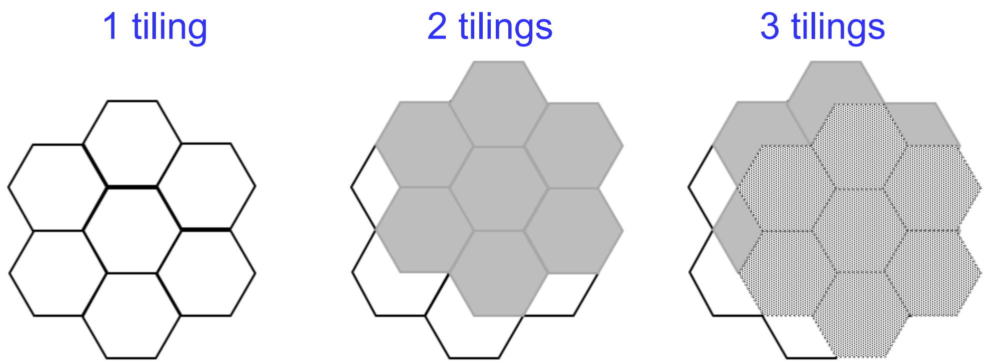
We want to remove field-to-field zeropoint offsets to achieve a uniformly “flat” all-sky relative calibration of the full DES survey, but…

DES will not always observe under truly photometric conditions…



scaling bar is –0.20 mags to +0.20 mags

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




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.

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

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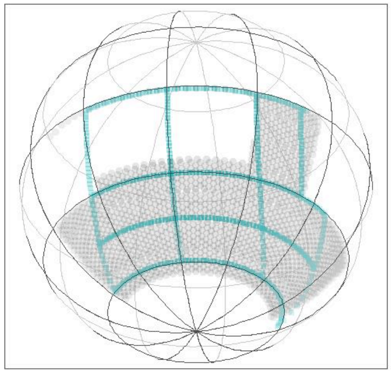
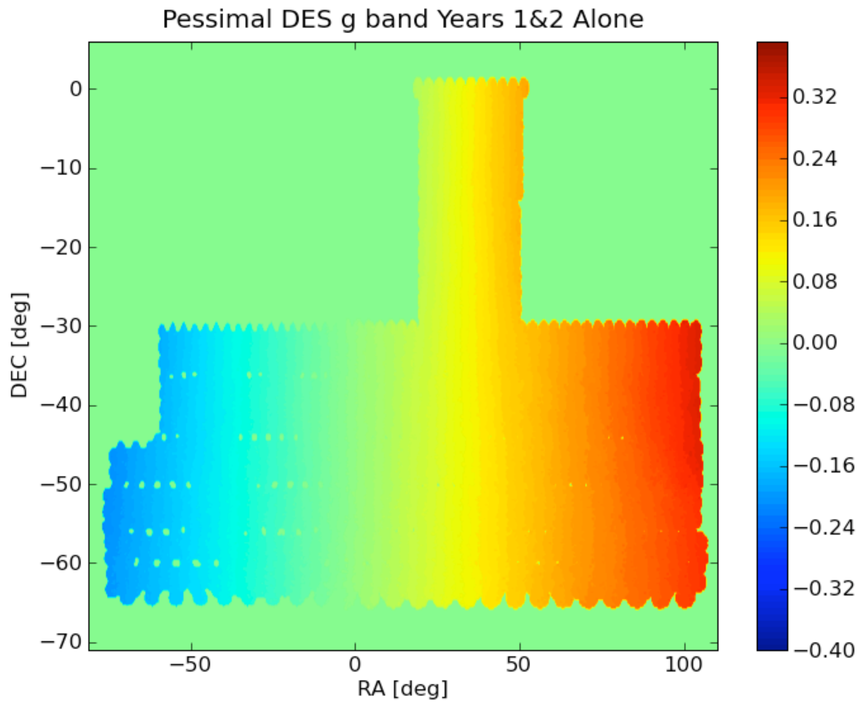
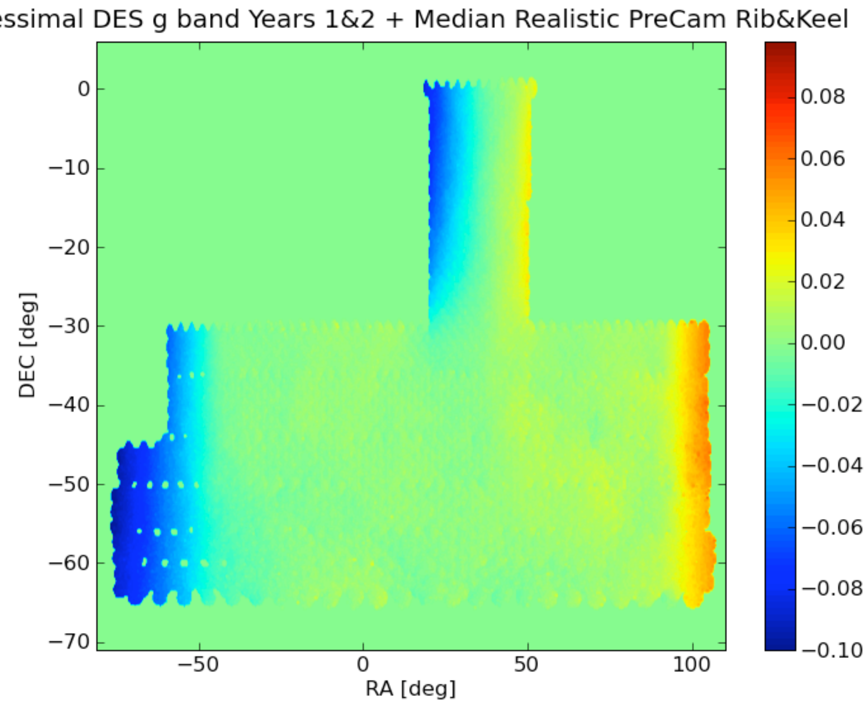
# 5. Global Relative Calibrations: The Role of PreCam Data

- A rigid framework onto which to tie the DES photometry
- PreCam helps DES achieve its global relative calibrations requirements sooner (and also helps protect against certain pathological calibration failures).

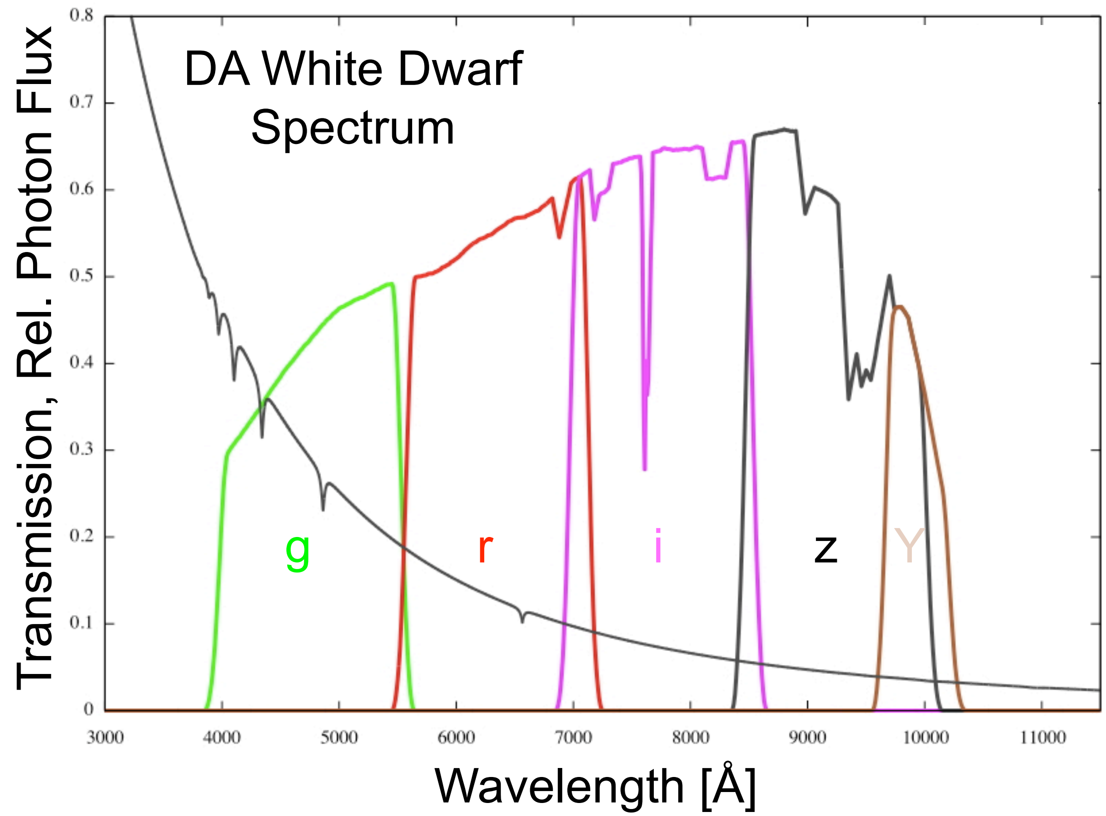




# 6. Global Absolute Calibrations: Basic Method

- 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.




- Plan: establish a “Golden Sample” of 30-100 well-calibrated DA white dwarfs within the DES footprint (J. Allyn Smith, William Wester).

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# Calibrating the Atmosphere: GPS (Rick Kessler)

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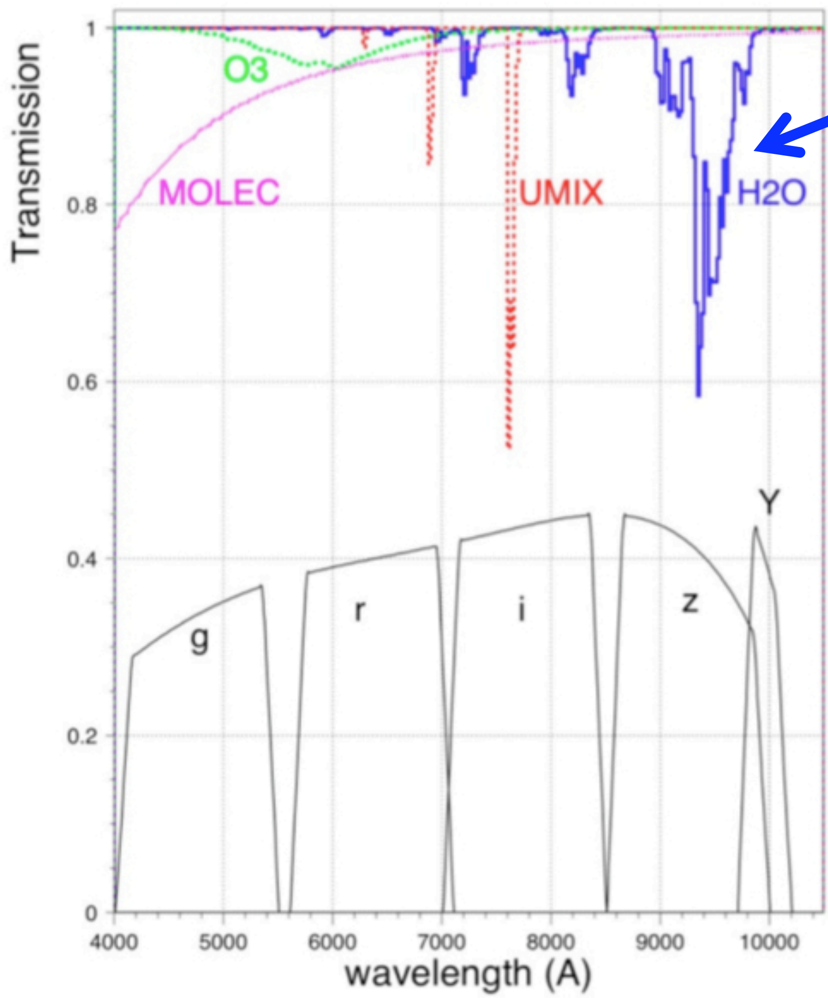


- **Why?** To correct the z-band calibration for changes in atm. absorption due to water vapor.

- **How?** The index of refraction of $H_20$ induces a time delay (n=1.3 for optical but n≈6 for radio). The $H_20$ delay is the actual time minus the calculated "dry" time. Estimated precision is 1mm of Precipitable Water Vapor (PWV).

- **Feasibility?** The correlation between z-band and PWV has recently been demonstrated, the "Suominet" GPS network already exists with 500 sites globally, and high-precision GPS is now commercially available. The system is also relatively inexpensive to install (e.g., less than US$10K).

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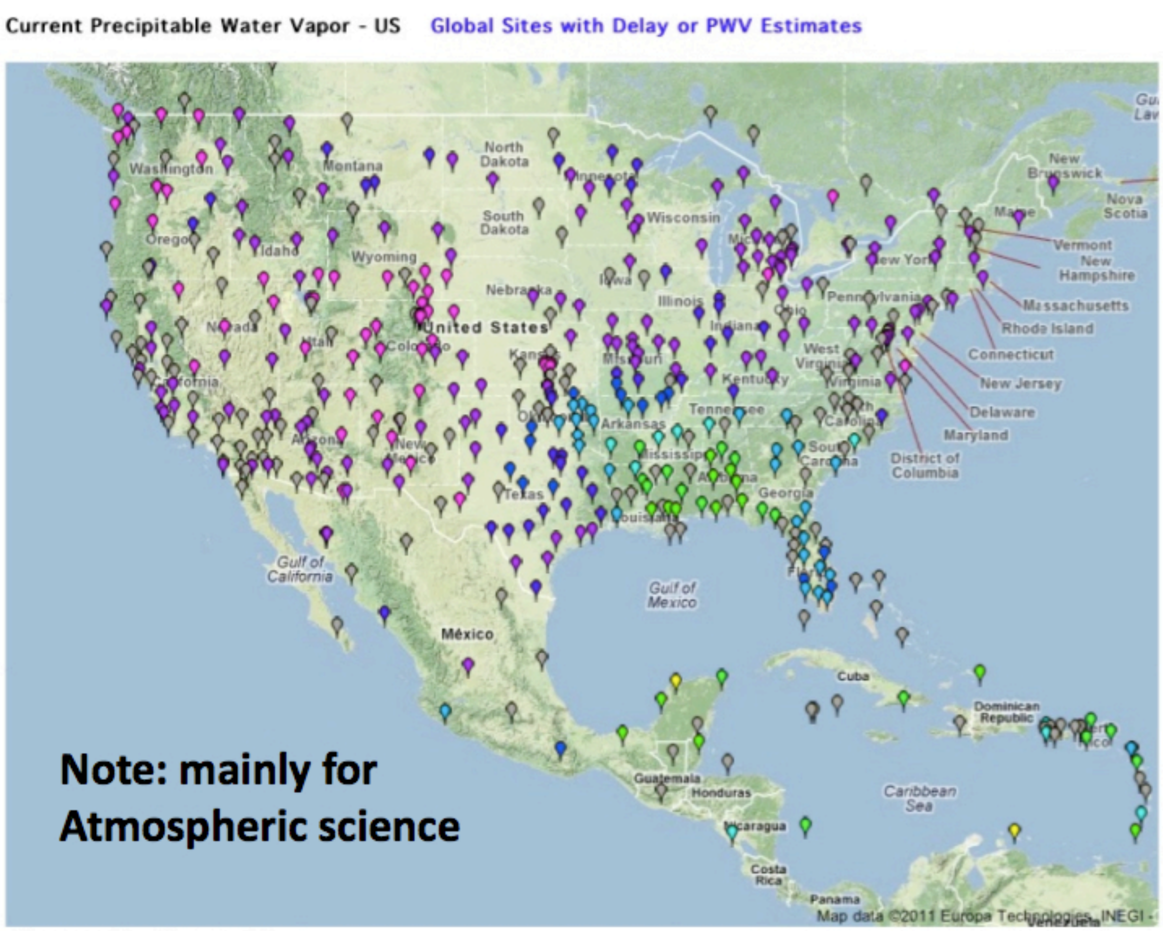
# Calibrating the Atmosphere: GPS (Rick Kessler)

**Suominet**

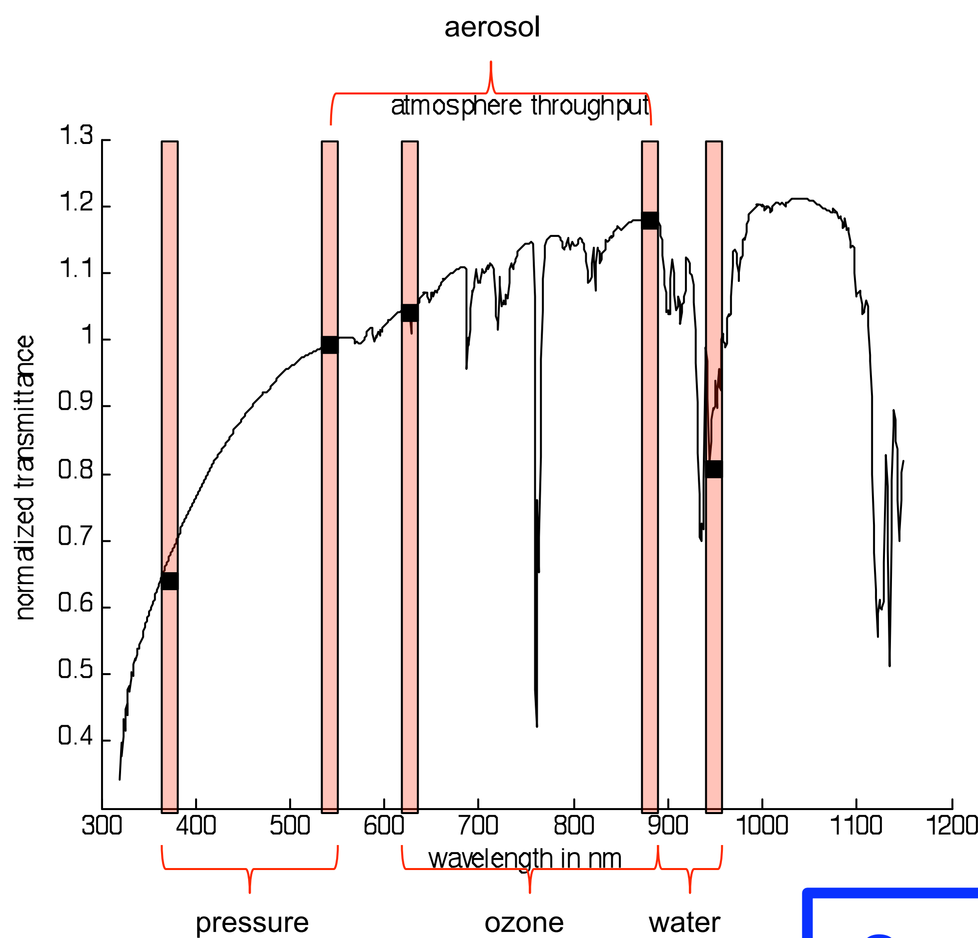
**http://www.suominet.ucar.edu**




- 400 US sites + 100 others.
- A GPS station has been ordered for CTIO.
- PWV results downloadable from Suominet webpage.

See also talk by Cullen Blake.

# Calibrating the Atmosphere: atmCam (D. DePoy, T. Li, J. Marshall)




TAMU Prototype

Giant 8-inch binoculars

See talk by Ting Li

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# DES Survey Strategy in Year 1

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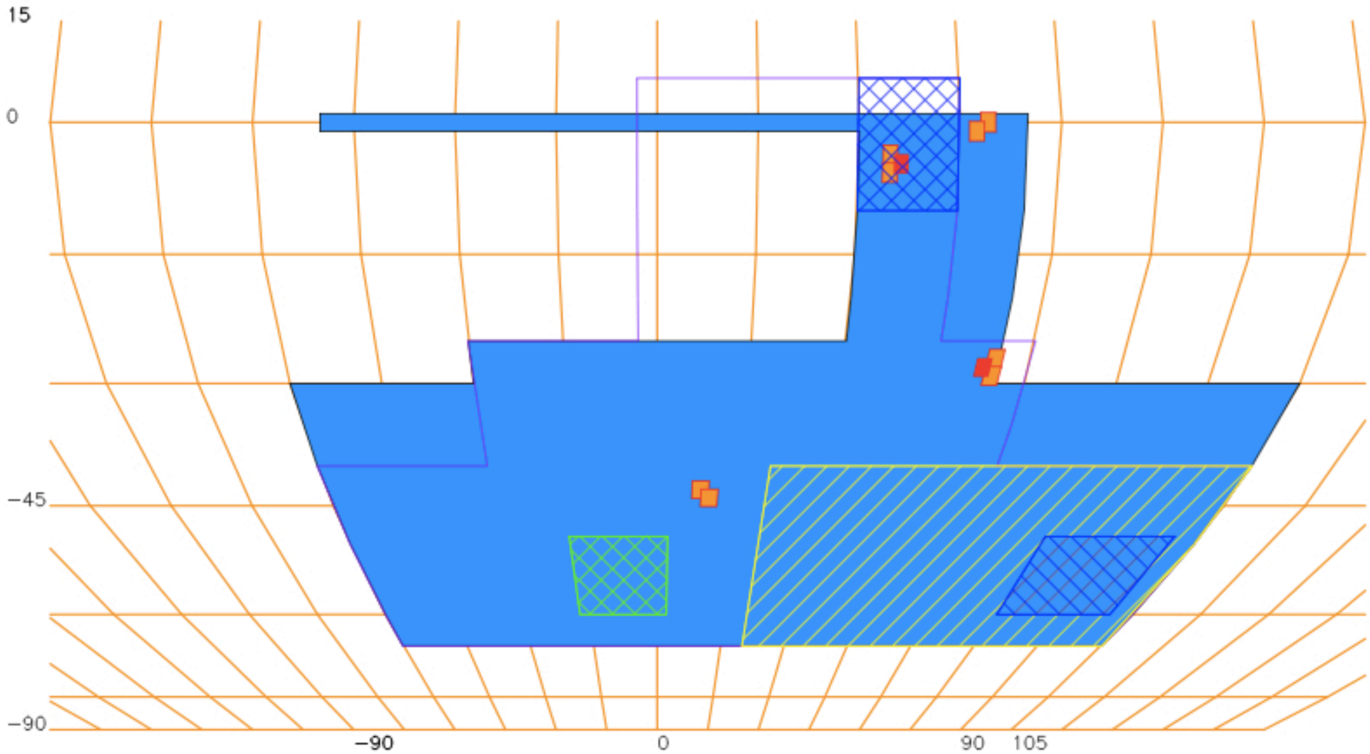


Figure 1: DES 5-year (blue) and first-season (hatched) footprints in a Putnins IV equal area projection. RA increases to the right. Cross-hatched regions show full 10-tiling depth areas of the "mini-survey"; single-hatched: 2-tiling area; red/orange squares: SN fields. The purple line outlines a modified 5-year footprint under consideration (the fiducial 5-year footprint will be finalized this April).

# Calibrating Early Data with the Stellar Locus Regression (SLR) Method

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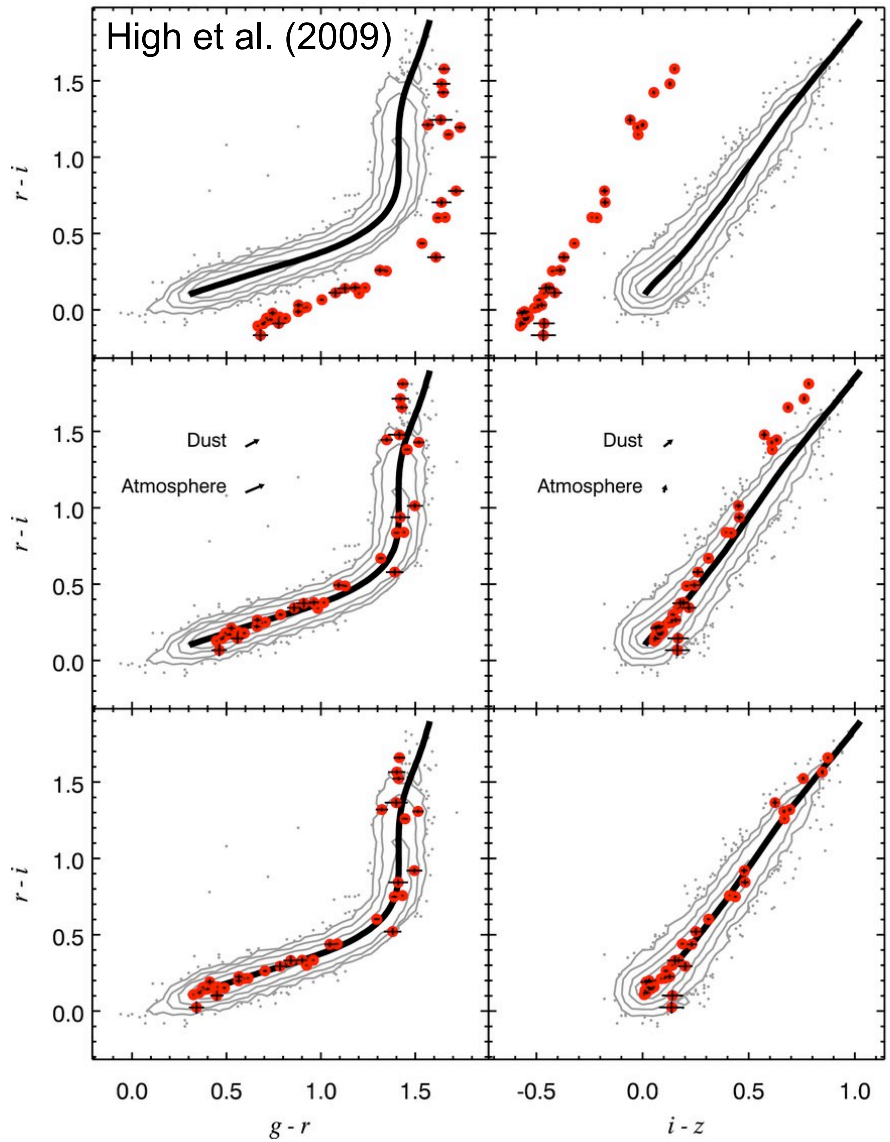
- In the DES, there is a strong philosophical legacy from SDSS to use the stellar locus primarily as a quality assurance check on the photometry (e.g., Ivezic et al. 2004).

- That said, especially in the first year or two, it will be hard to obtain good calibrations for DES.

- Therefore, we are looking into using the SLR method of High et al. (2009), as implemented by Bob Armstrong of the DESDM team, to help with calibrations in the early years.



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# A Call to Cooperate

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- There are several current or near-future optical/NIR surveys using similar (SDSS-like) filters, covering similar areas of sky (especially in the Southern Hemisphere), and having stringent calibration requirements. It would be good to cooperate, for the mutual benefit of all. Areas of possible cooperation include:

  1. Establishing a Golden Sample of DA white dwarfs or other spectrophotometric standards (e.g., solar analogs).
  2. Sharing code and techniques.
  3. Sharing (if possible) actual data (e.g., stars within a given magnitude range).
  4. Performing global calibrations across multiple surveys (cross-checks, identification of flat-fielding issues, etc.)

- How?

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# Extra Slides

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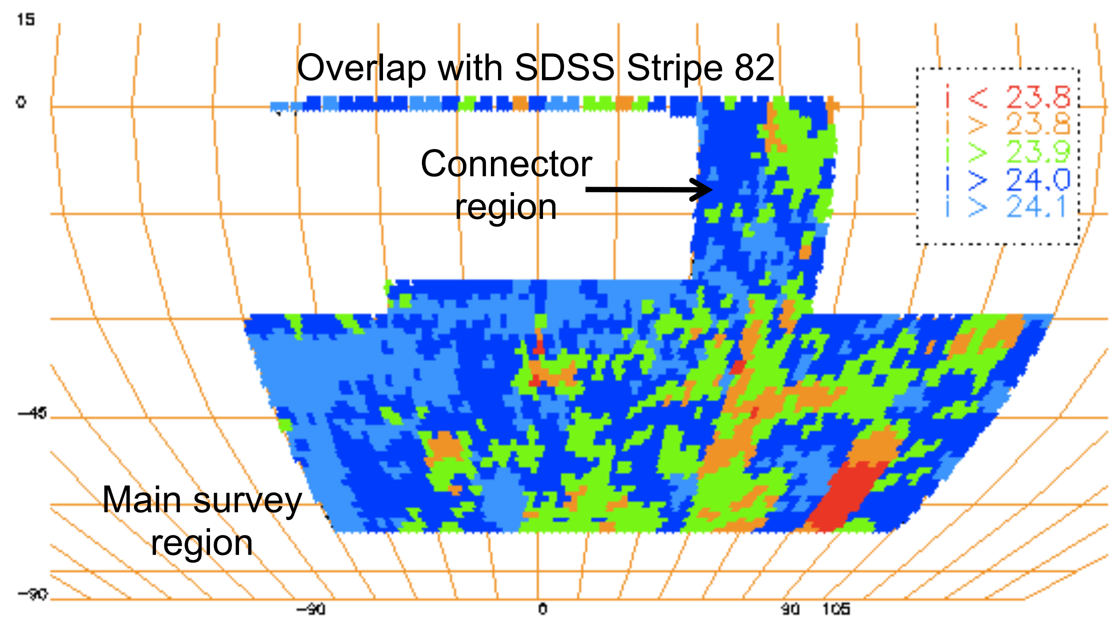
# Basic DES Observing Strategy

## Observing Strategy

- 100 sec exposures (nominally)
- 2 filters per pointing (typically)
  - *gr* in dark time
  - *izY* in bright time
- Multiple overlapping tilings (layers) to optimize photometric calibrations
- 2 survey tilings/filter/year
- Photometric Requirements (5-year)
  - All-sky internal: 2% rms (Goal: 1% rms)
  - Absolute Color: 0.5% (*g-r*, *r-i*, *i-z*); 1% (*z-Y*)
  - Absolute Flux: 0.5% in *i*-band (relative to BD+17 4708)

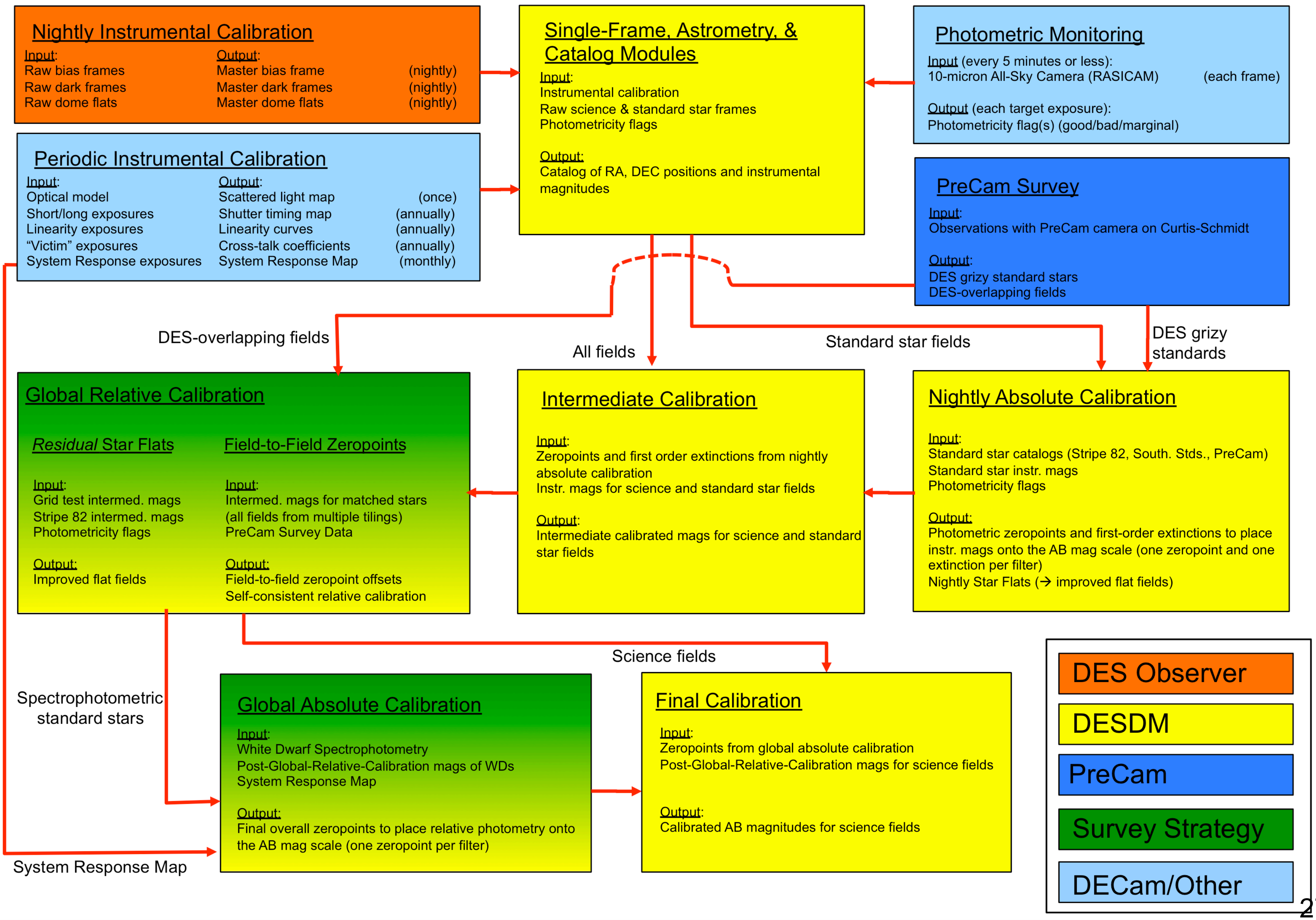
## Survey Area

Credit: J. Annis




Total Area: 5000 sq deg

# DES Photometric Calibrations Flow Diagram (v4.1)



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# 4. Nightly/Intermediate Calibrations: The Photometric Equation

- The Photometric Equation is a simple model that fits the observed magnitudes of a set of standard stars to their "true" magnitudes via a simple model; 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:

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

  - $b_n$ 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, but there may be variations from CCD to CCD within the DECam focal plane or over time.

# From the Scientific Requirements Document

## (sciReq-9.86, 10 June 2010)

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**R-10** For each of the *grizY* bandpasses of the wide-area survey, the fluctuations in the spatially varying systematic component of the magnitude error in the final co-added catalog must be smaller than 2% rms over scales from 0.05 to 4 degrees.

Internal (Relative) Calibration

$m_i = -2.5\log(f_{i1}/f_{i2}) + C$

**R-11** The color zeropoints between the survey fiducial bandpasses (*g-r, r-i, i-z*) must be known to 0.5% rms. The *z-Y* color zeropoint shall be known to 1% rms.

Absolute Color Calibration

$m_i - m_z = -2.5\log(f_i/f_z) + zp_{iz}$

**R-12** The i-band magnitude zeropoint relative to BD+17, and therefore the AB system, must be known to 0.5% rms.

Absolute Flux Calibration

$m_i = -2.5\log(f_i) + zp_i$

**R-13** The system response curves (CCD + filter + lenses + mirror + atmosphere at 1.2 airmasses) must be known with sufficient precision that the synthesized *grizY* magnitudes of any astronomical object with a calibrated spectrum agree with the measured magnitudes to within 2%. When averaged over 100 calibrating objects randomly distributed over the focal plane, the residuals in magnitudes due to uncertain system response curves should be < 0.5% rms.

System Response

**G-4** A goal of the survey is to achieve **R-10** at the enhanced level of 1% for the final co-added catalog.

**G-5** A goal of the survey is to achieve **R-10** over 160 degrees of Right Ascension and 30 degrees of Declination.