DES Photometric Calibrations

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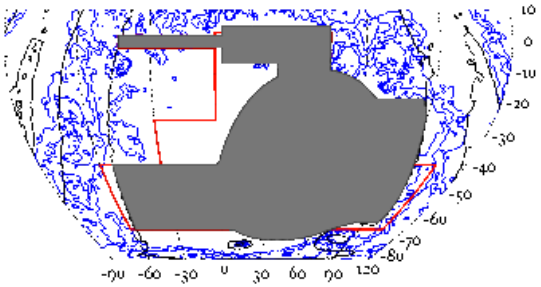
DES Photometric Calibration Requirements (5-year, coadded)

DARK ENERGY SURVEY

1. **Internal:** 2% rms on scales of 0.05° - 4°.

   Goals: 1% rms and/or over 160° in RA, 30° in DEC.

   (We will focus mostly on this req. in this talk.)



2. **Absolute Color:** 0.5% (*g-r, r-i, i-z*); 1% (*z-Y*).

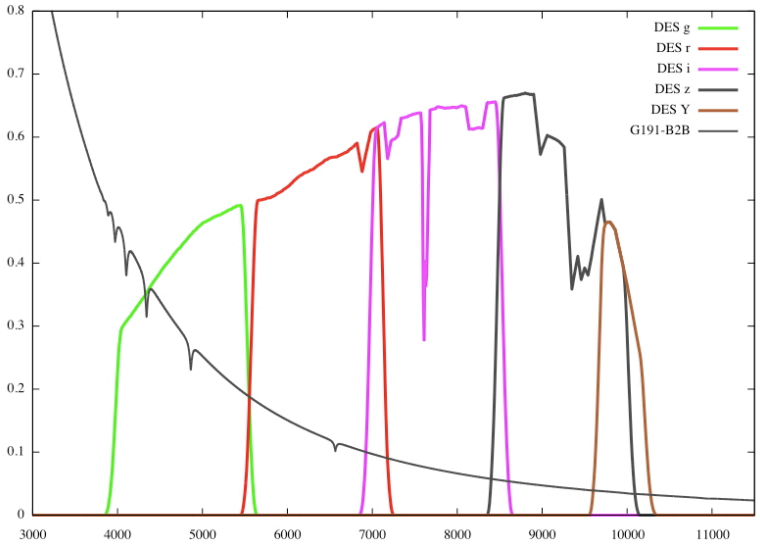
   Averaged over 100 objects scattered over the focal plane.

   "Between-filters" calibration.

3. **Absolute Flux:** 0.5% in *i*-band.

   Relative to standard star BD+17 4708.

   Zeropointing the overall filter system.



Yearly Science Goals: Photom. Calibrations

(see Robert Gruendl and Brian Yanny's Talk)

DARK ENERGY SURVEY

- Year 1 (Y1A1): <4% relative photometry
- Year 2 (Y2A1): <3% photometry
- Year 3 (Y3A1): 2% photometry
- Year 4 (Y4A1): <2% photometry across large areas
- Year 5 (Y5A1): attempt 1% (stretch goal) photometry

We will likely meet all these goals early.

Global Calibration Steps for Y1P1/Y1A1 (using GCM)

DARK ENERGY SURVEY

1. **Pre-Calibrate:** create a set of local DES tertiary standards in each isolated area (Stripe 82 equatorial area, SPT areas, SN areas) to tie the zeropoints to the DES AB system as well as to anchor the relative calibrations against gradients.

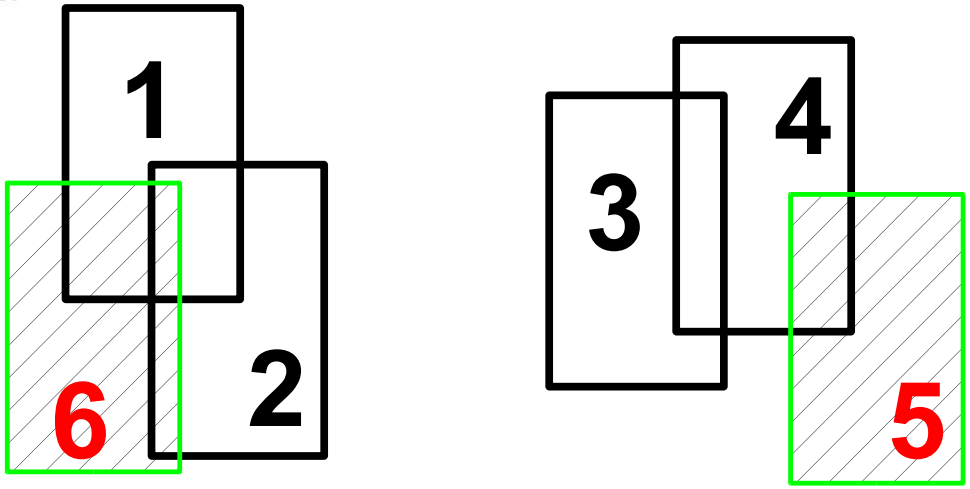
2. **StarMatch:** find all unique matches for star detections in the image-to-image overlaps and between star detections and the local tertiary standards.

3. **GCM-zeropoint:** solve for the photometric zeropoints for all the images observed in a given isolated Y1P1 area.

4. **NCSA Handoff:** hand off list of ccd image zeropoints to NCSA for uploading into database.

Global Calibration Module (GCM): Field-to-Field Zeropoints

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

DARK ENERGY SURVEY

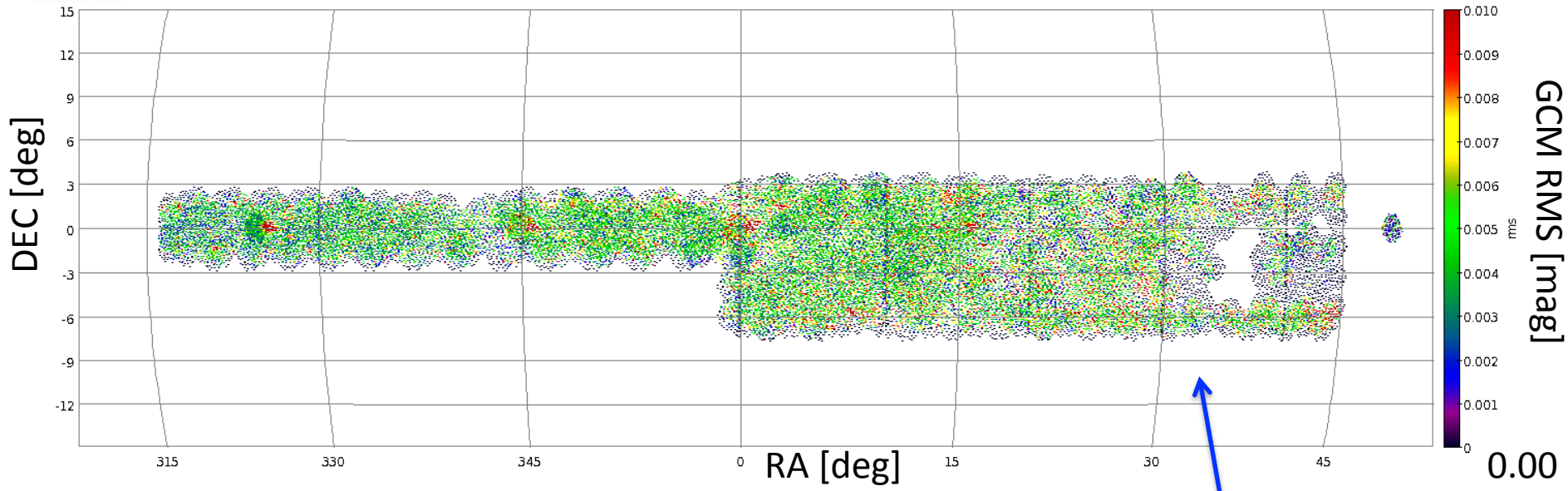
Stripe 82 Equatorial Area

- ***Essentially complete overlap with SDSS DR10.***
- → "Punt" and just use SDSS DR10 (transformed into the DES AB mag system) as local tertiary standards.
- Perform a single-pass GCM solution, solving for photometric zeropoints on a CCD image by CCD image basis.

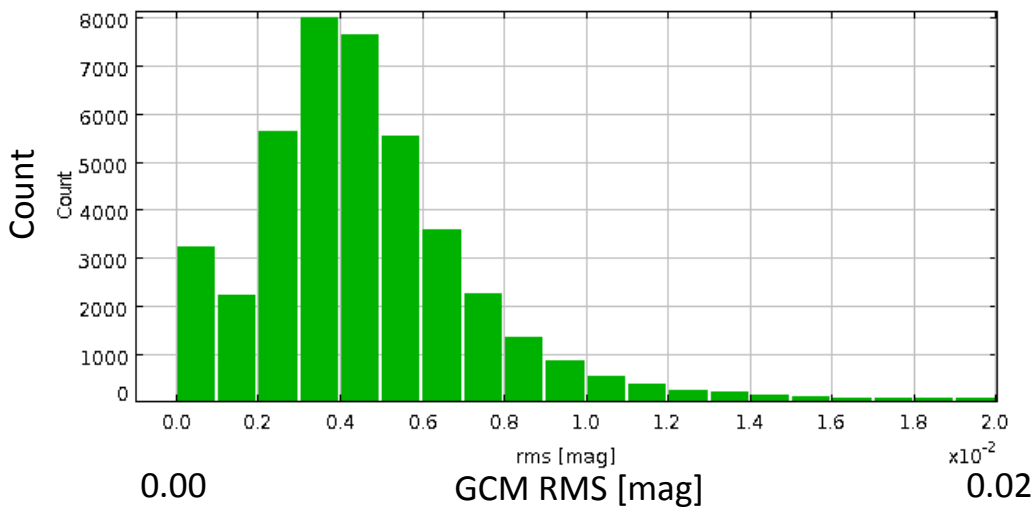
(Thanks to Keith Bechtol & Bob Armstrong for testing the Y1P1 coadded photometry with their SLR codes!)

Y1P1 Equatorial Area: g-band GCM RMS's (internal errors)

DARK ENERGY SURVEY



Each "point" is an Individual CCD image

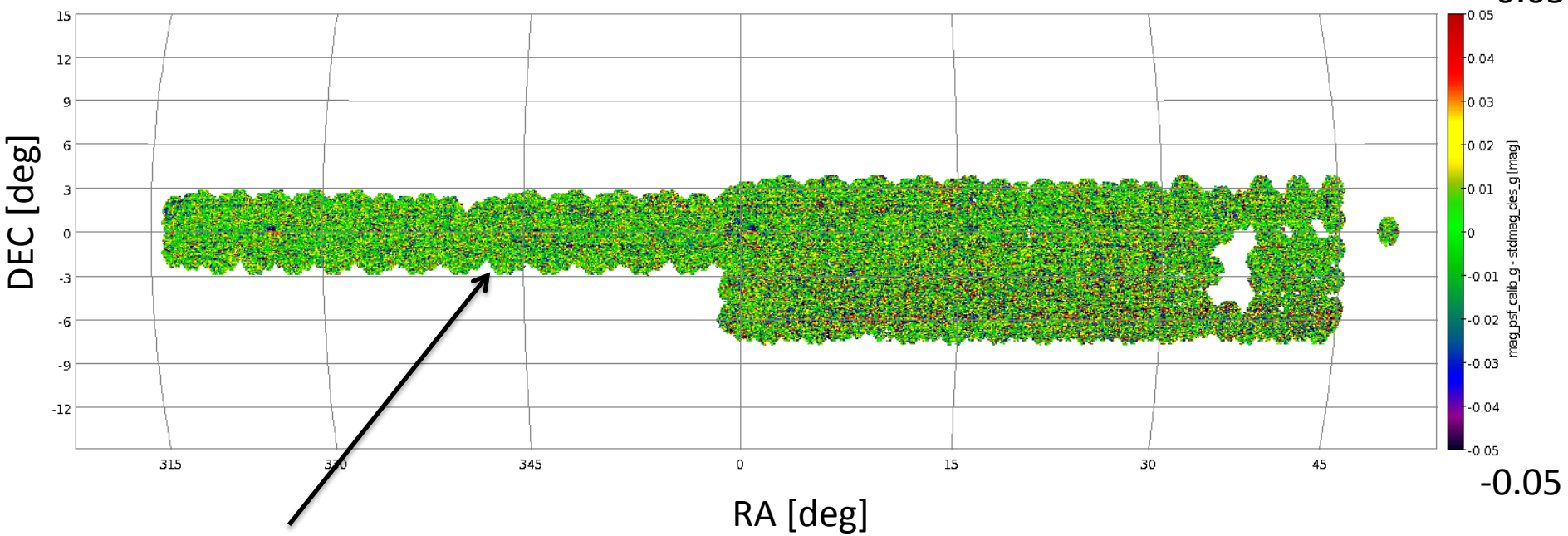


(Note that the x-axis is in units of 0.01 mag)

Y1P1 Equatorial Area: Cross-Check for Systematic Errors

DARK ENERGY SURVEY

GCM-calibrated mag_psf minus stdmag* vs. (RA,DEC): g-band



Each point is an individual star

*stdmag = SDSS DR10 mag transformed to DES AB mag

(Additional gory details in DES-doc#7642.)

DARK ENERGY SURVEY

SPT Areas

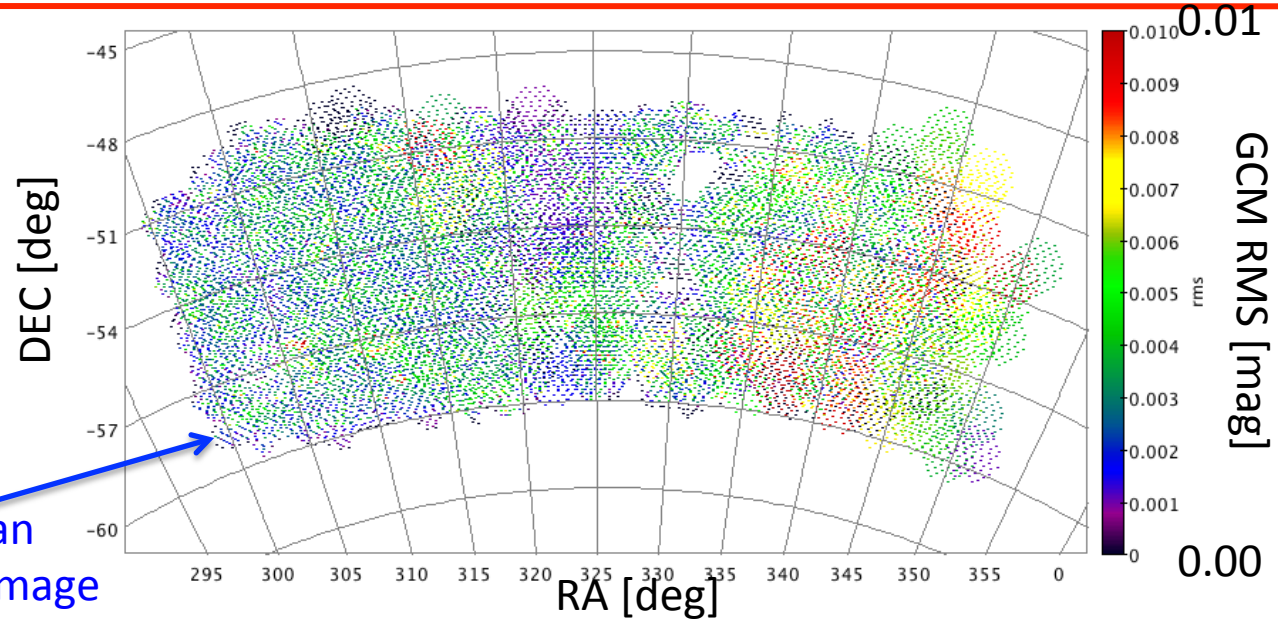
- Not much overlap with previously calibrated grizY standards stars
- Need to create local tertiary standards* from PSM solutions or from other sources.
- Calibrate SPTE in two steps:

1. Calibrated photometric exposures on an exposure-by-exposure basis, tossing out dome occluded/non-photometric exposures iteratively, and tying to the local tertiary standards.
2. Calibrate non-photometric/dome-occluded exposures on a CCD image by CCD image basis by tying to calibrated data from Step 1 (“quaternary standards”?).

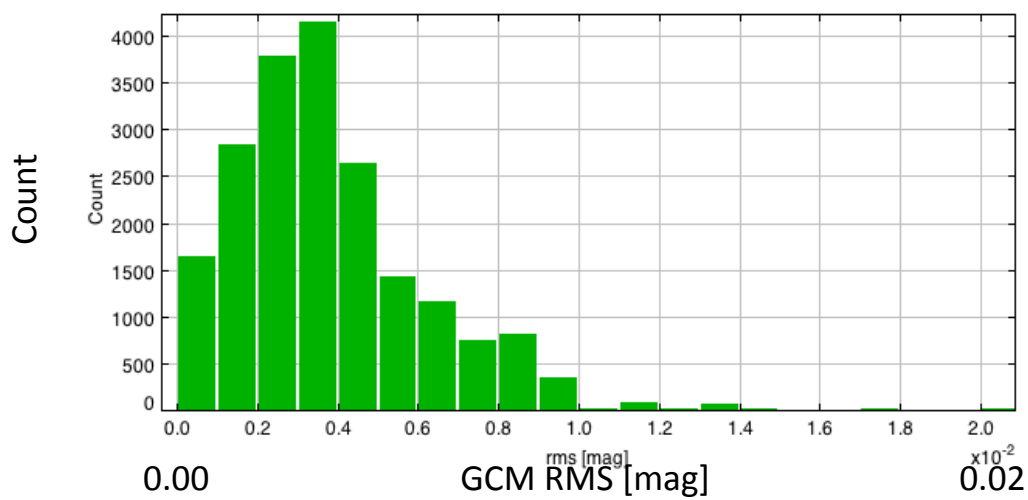
(*Thanks to Sam Wyatt for creating these tertiaries!
Thanks to Bob Armstrong for testing the initial set of tertiaries via his SLR code!)

Y1P1 SPT Area: g-band GCM RMS's (internal errors)

DARK ENERGY SURVEY



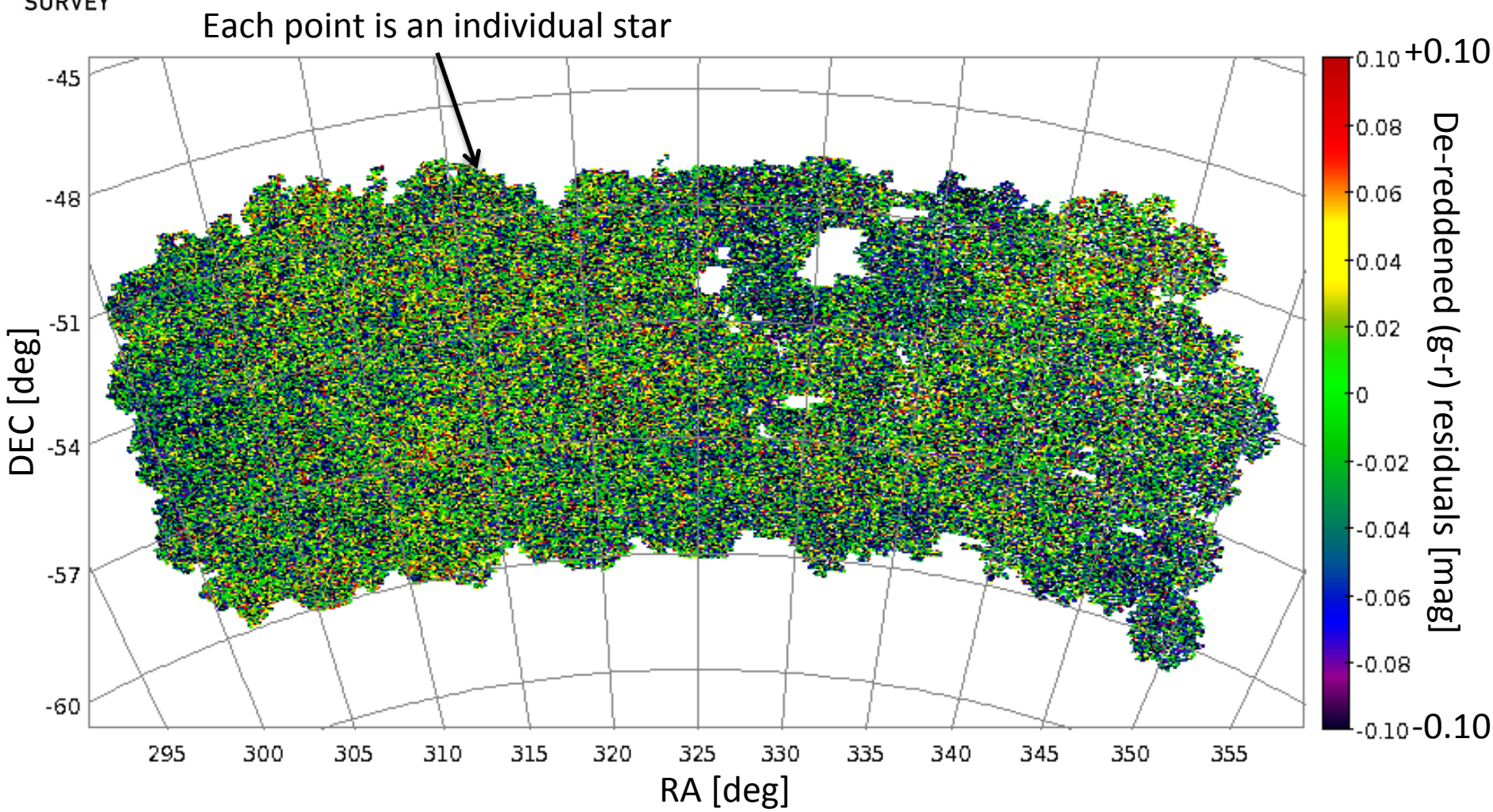
Each "point" is an individual CCD image



(Note that the x-axis is in units of 0.01 mag)

Y1P1 SPT Area: (g-r) Cross-Check using "Poor Man's SLR"

DARK ENERGY SURVEY



(i, z, and Y zeropoints for the Y1P1 SPT area were "tweaked" by using a "Poor Man's SLR" before delivery to NCSA.)

DARK ENERGY SURVEY

SN Areas

- Lots of overlap with previously calibrated DES grizY tertiary standards.
- Update previously calibrated DES grizY tertiary standards* using new data from Year 1.
- Perform a single-pass GCM solution, solving for photometric zeropoints on a CCD image by CCD image basis.
- Not included in Y1P1 (ran out of time for the calibrations).
- Will be included in Y1A1.

(*Thanks to Sam Wyatt for creating these tertiaries!)

Plans for Y1A1

1. The basic plan is to follow the Y1P1 plan:
   a. Update tertiaries as time allows.
   b. Run starmatch routines.
   c. Run GCM zeropoint-solver routines.
   d. Submit to NCSA.

2. Note that other global calibration codes will be tested in Y1A1:
   a. Anne Bauer's Übercal/Nebencal (DES-doc#7687)*
   b. Jim Annis's YaCal (DES-doc#7690)
   c. Gary Bernstein's PhotoFit (DES-doc#7689)
   d. David Burkes Forward Global Calibration (DES-doc#7688)

*Übercal/Nebencal is sufficiently advanced that it could even replace the current GCM for Y1A1.

Caveats and Conclusions

DARK ENERGY SURVEY

Caveats

- The previous Y1P1 QA plots were for the ***single-epoch*** mag_psf photometry for stars. Y1P1 ***coadd*** mag_psf photometry was affected by problems in the single-epoch astrometry (so stellar images from overlapping images did not overlap so well). This issue for the astrometry has been fixed in preparation for Y1A1 processing (via Robert Gruendl's astrometric refinement module).
- The SDSS->DES transformation equations are not yet perfect, so there are still some small residual color terms in the "DES natural system" photometry.

Conclusions

- For the Y1P1 global relative calibrations of the single-epoch photometry:
  - Internal errors are typically ~0.5% (~5mmag) rms.
  - External/systematic errors appear to be < 2-3% rms.
- We expect the same or better for Y1A1.

Extra Slides

From the Scientific Requirements Document

(DES-doc#20-v32: sciReq-9.86, 10 June 2010)

DARK ENERGY SURVEY

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.

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.

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

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.

For 5-year Survey

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.

Enhanced goals

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Overall DES Calibrations Plan in 5 Points

DARK ENERGY SURVEY

1. Instrumental Calibration (Nightly & Periodic): Create biases, dome flats, linearity curves, cross-talk coefficients, system response maps.

2. Photometric Monitoring: Monitor sky conditions with 10μm All-Sky Cloud Camera and the GPS and atmCam atmospheric transmission monitors.

3. 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.

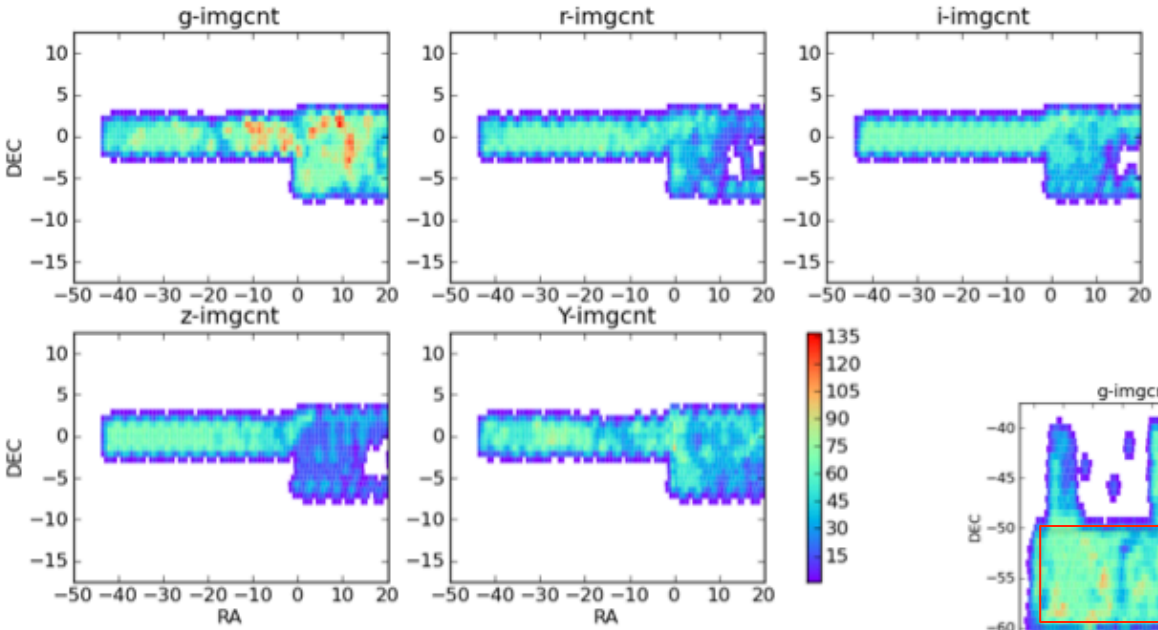
4. Global Relative Calibrations: Use the extensive overlaps between exposures over multiple tilings to tie together the DES photometry onto an internally consistent system across the entire DES footprint.

5. 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.

The Y1P1 Region

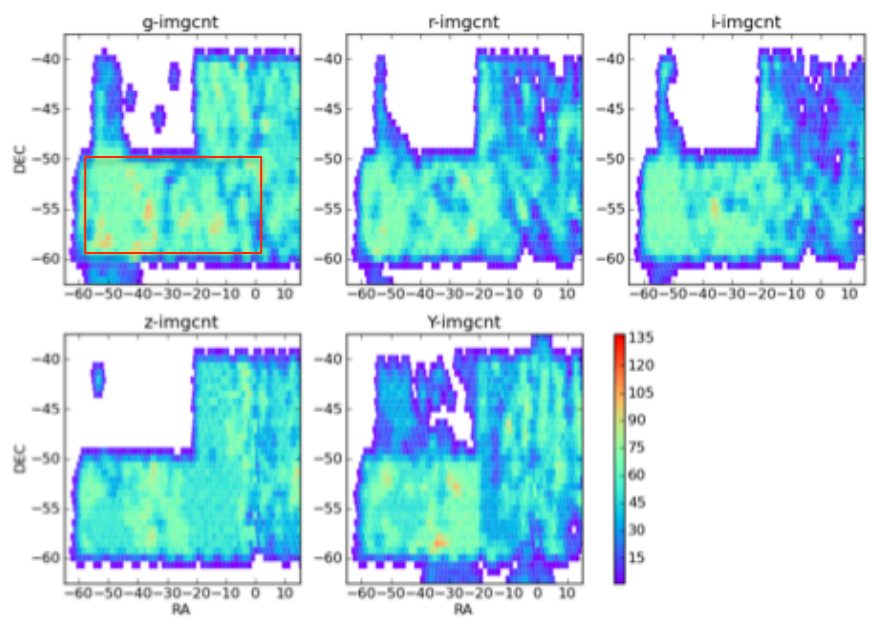
(credit: R. Gruendl)

DARK ENERGY SURVEY



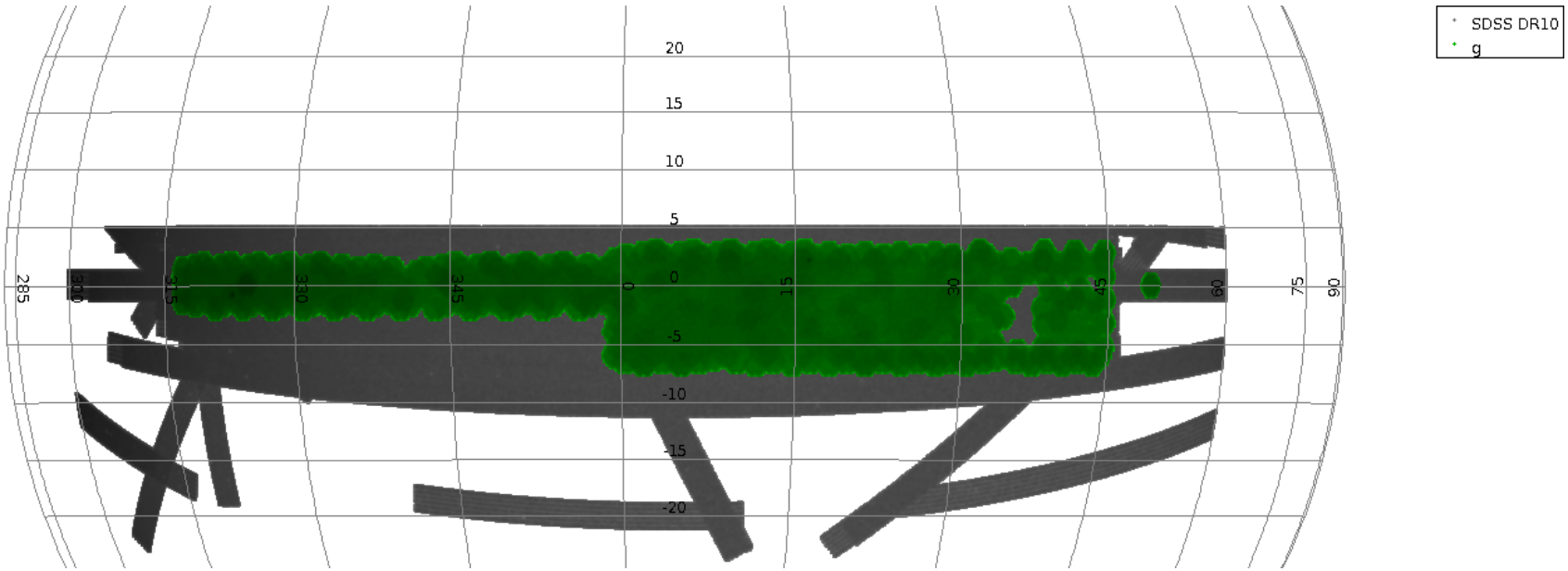
Stripe 82

SPT (western end)



(SN fields: if there is time.)

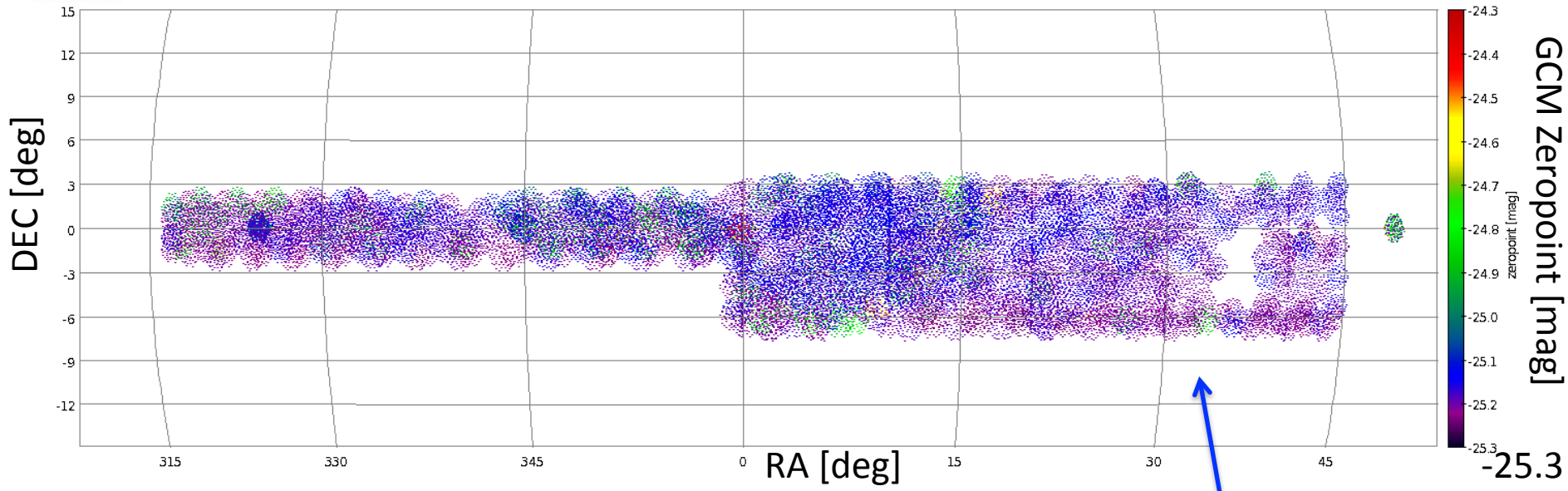
Y1P1 Equatorial Area vs. SDSS DR10: g-band

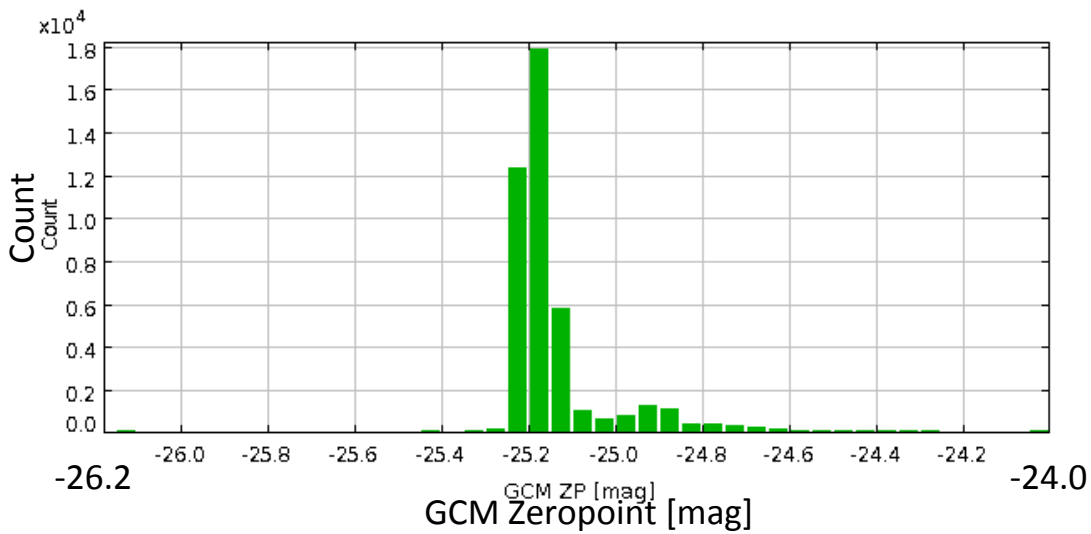


- Tie directly to DES-transformed SDSS DR10
- Calibrate CCD image by CCD image

Y1P1 Equatorial Area: g-band GCM Zeropoints

DARK ENERGY SURVEY

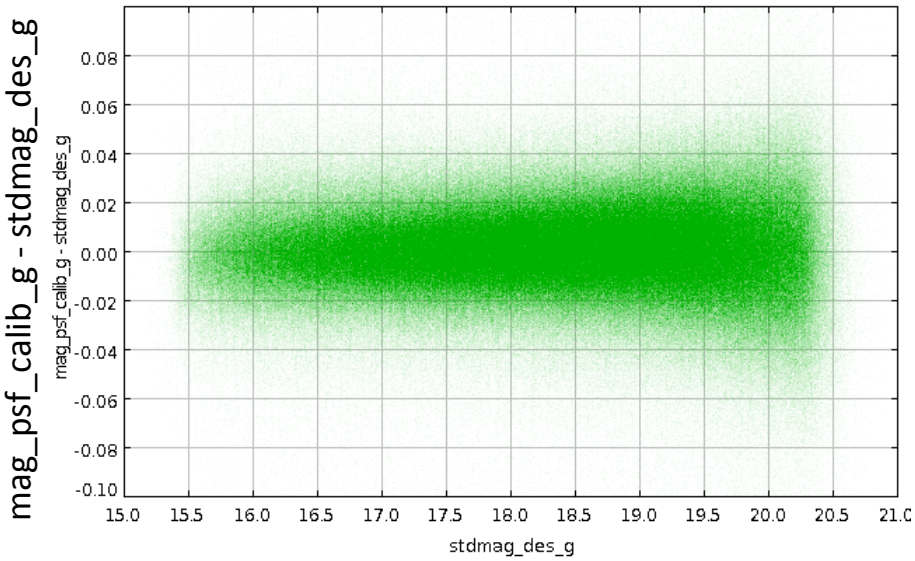


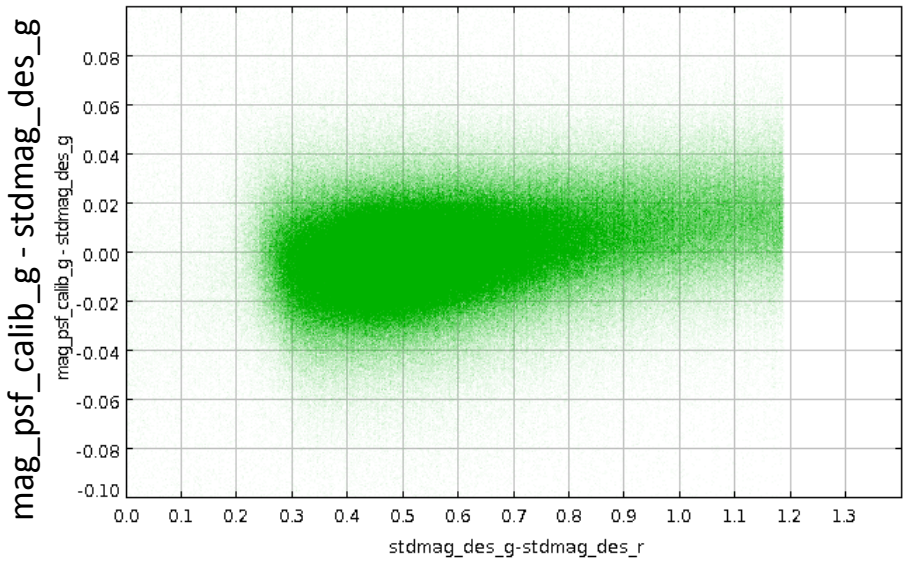


Each "point" is an Individual CCD image

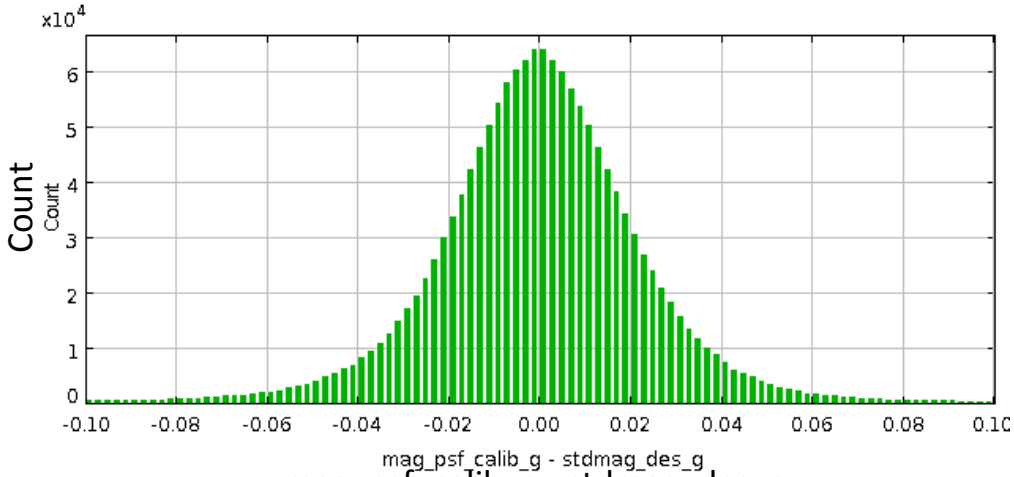
Y1P1 Equatorial Area: Cross-Check for Systematic Errors

DARK ENERGY SURVEY





stdmag_des_g – stdmag_des_r



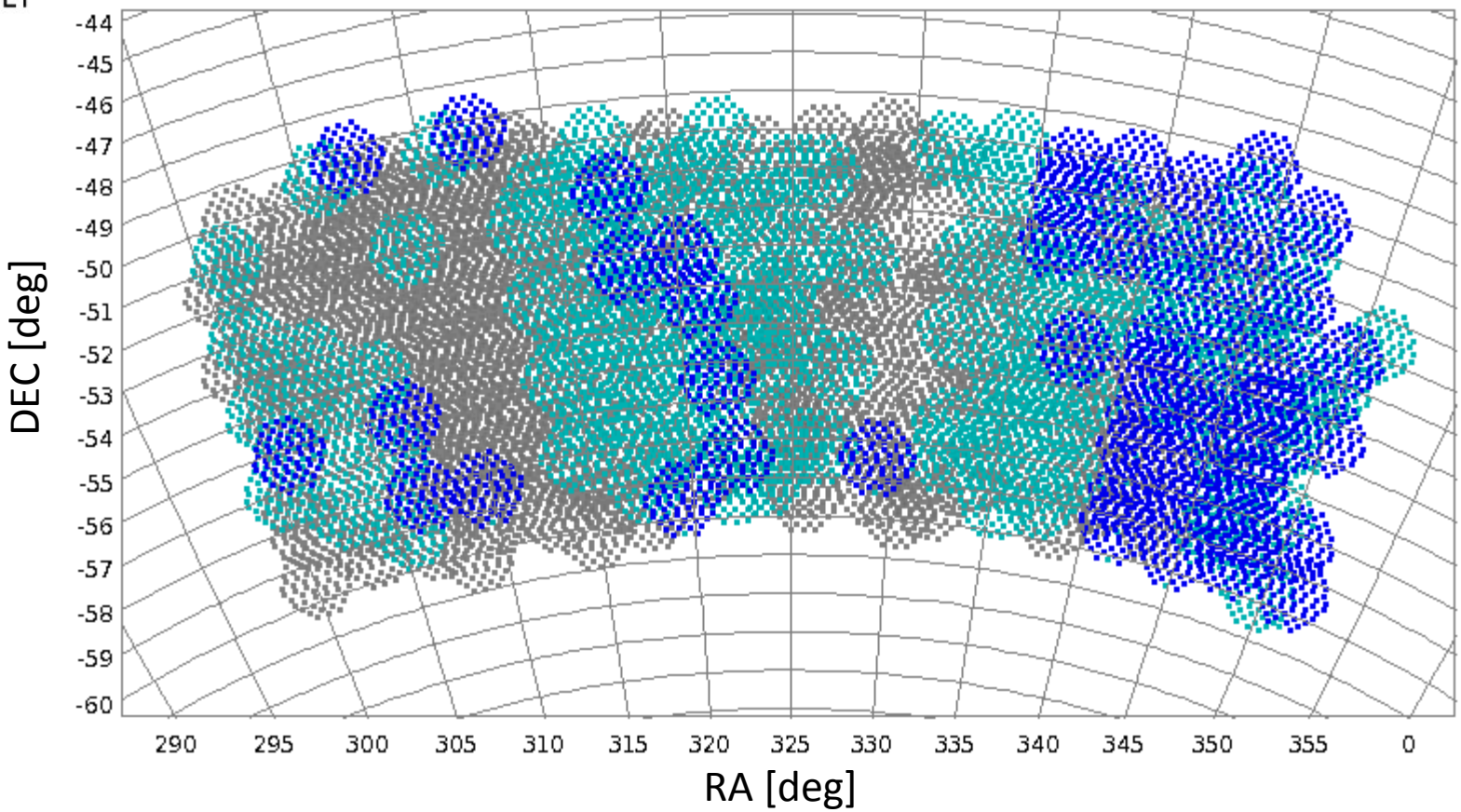
mag_psf_calib_g - stdmag_des_g

Note residual color term

(stdmag = SDSS DR10 mag transformed to DES AB mag)

Y1P1 SPT Area: g-band

DARK ENERGY SURVEY



Gray: Non-photometric conditions*

Cyan: Photometric conditions*

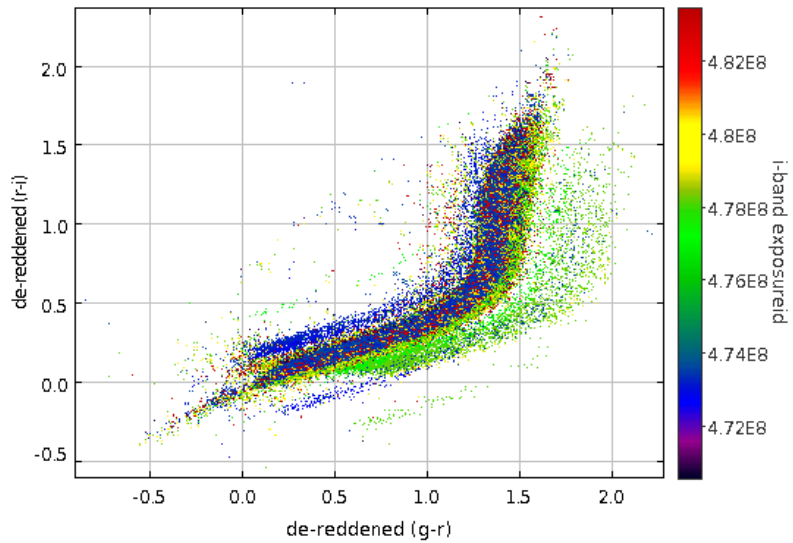
Blue: Photometric conditions* ***AND*** good std star ("PSM") solution for night

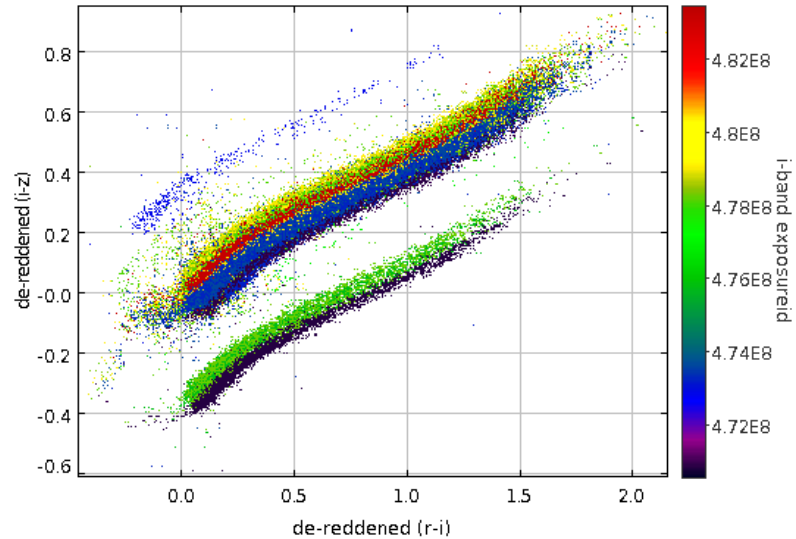
*According to RASICAM

After Culling Non-Photometric* Exposures and Exposures w/o a Good PSM Solution

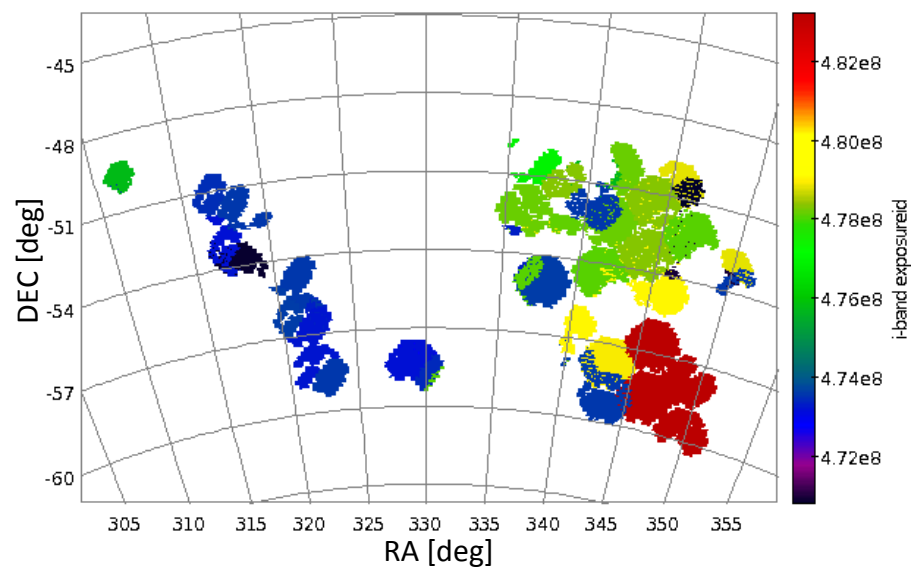
*As determined by RASICAM

DARK ENERGY SURVEY



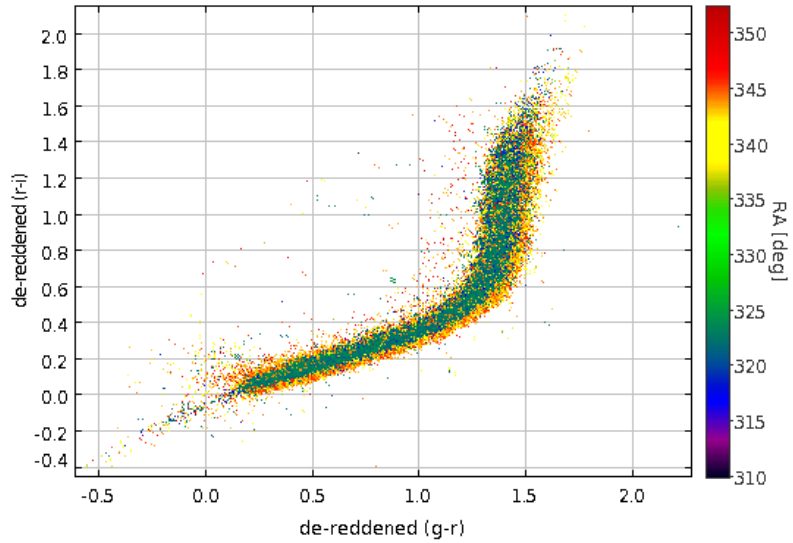


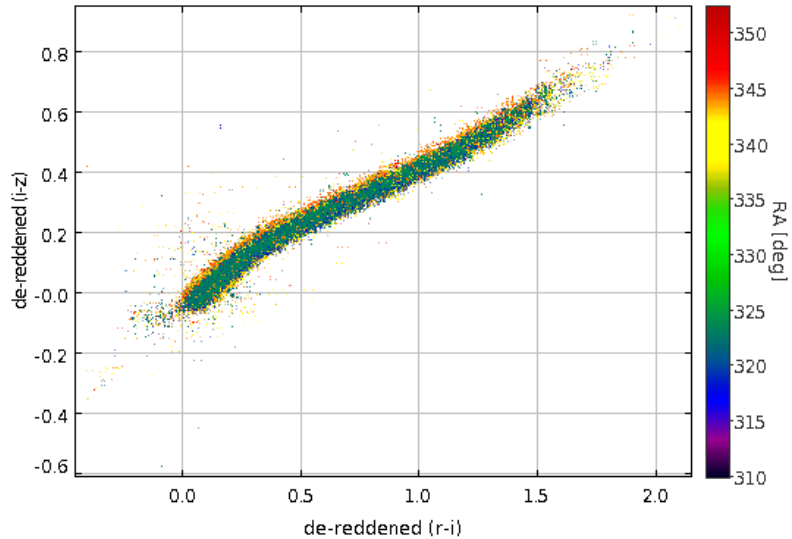
Symbols color-coded by i-band exposure id



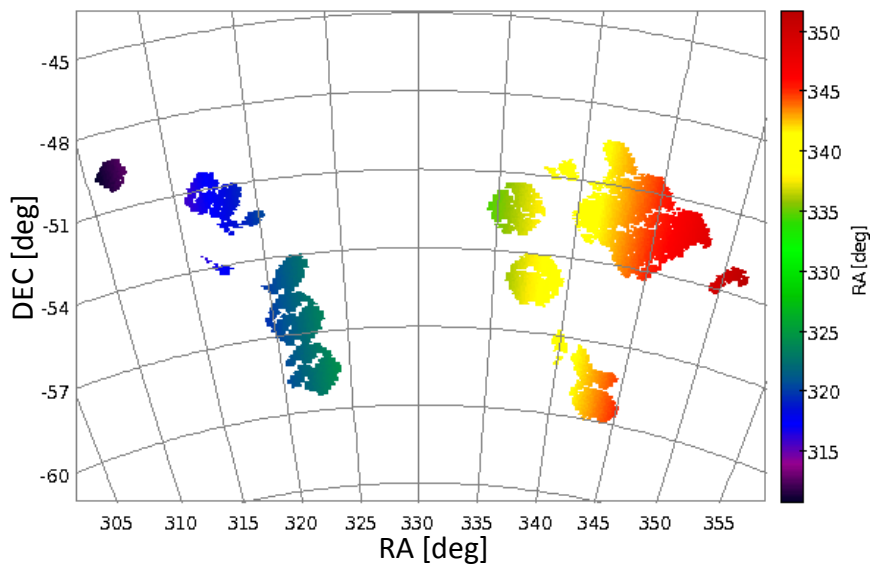
After Additional Culling…
(Any remaining trends vs. RA?)

DARK ENERGY SURVEY



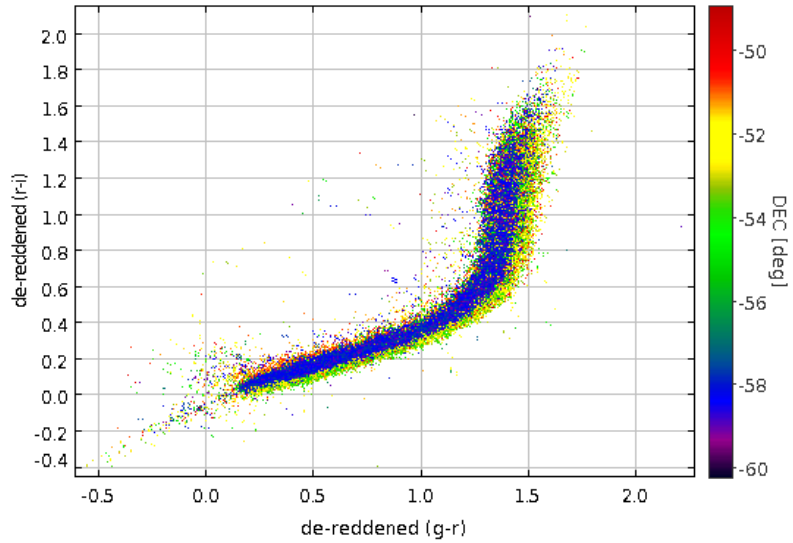


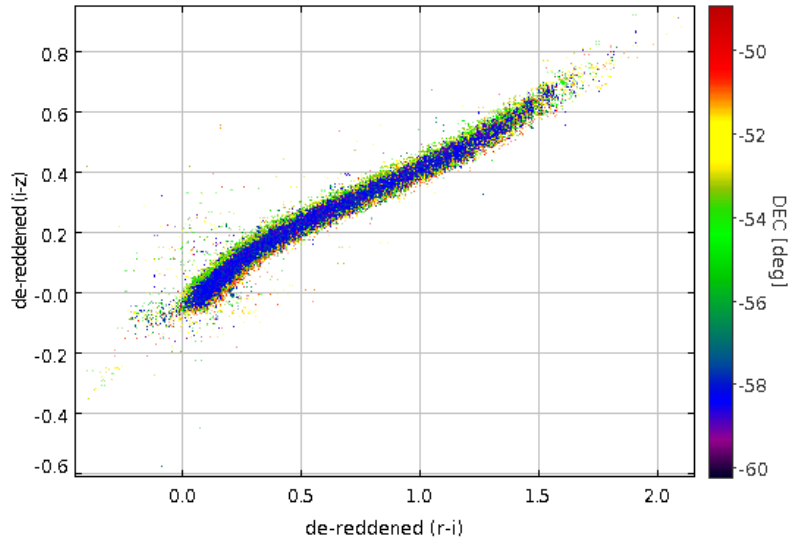
Symbols color-coded by RA



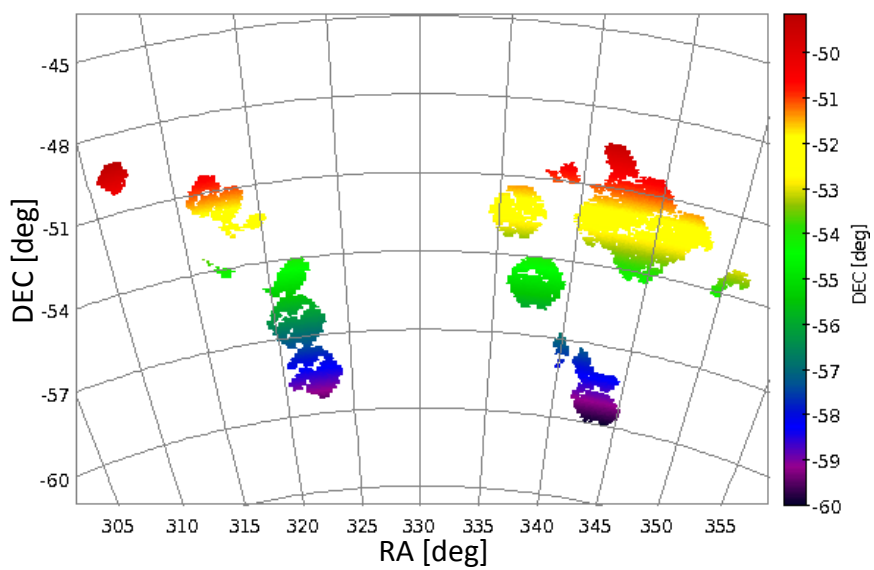
After Additional Culling…
(Any remaining trends vs. DEC?)

DARK ENERGY SURVEY





Symbols color-coded by DEC



SN Areas Status and Summary

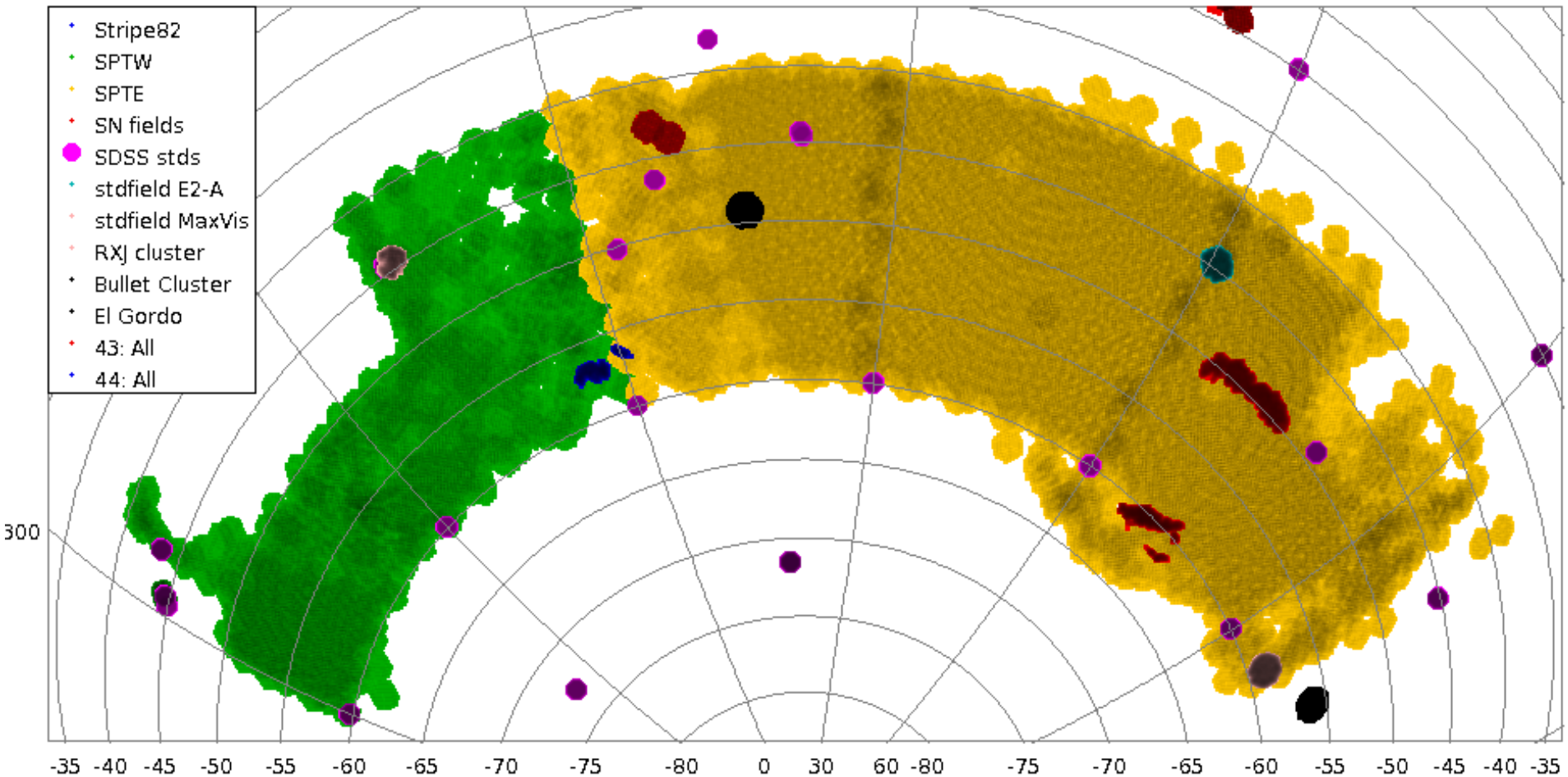
DARK ENERGY SURVEY

1. After SPTW.

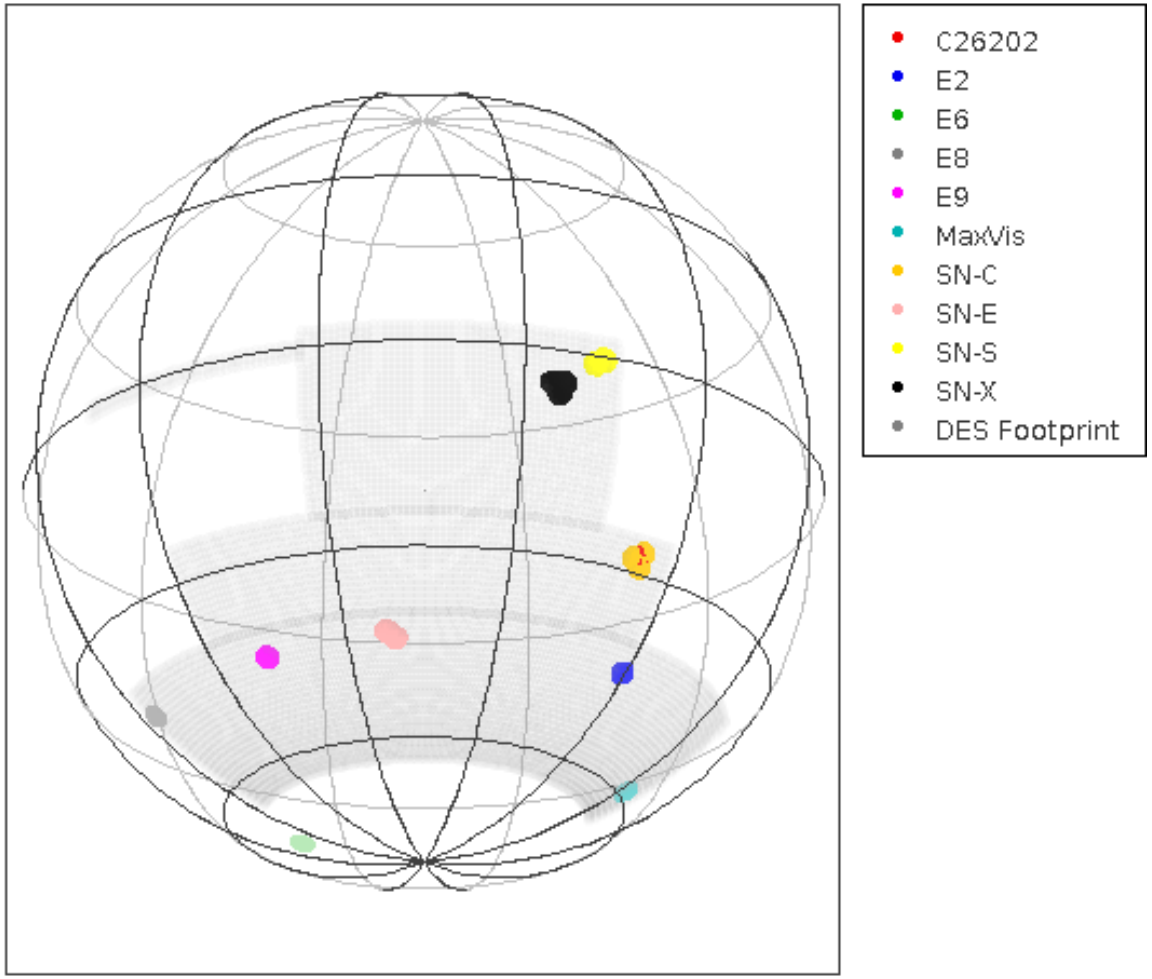
2. Calibrate all SN exposures, or just those that make the DM cut? (DESDM wants just the smaller sample, for coadds; SNWG wants all, for single-epoch calibrations).
   - Also u-band and Y-band requested by SNWG – a request left over from SVA1.

Y1A1 SPT Area: Tertiary Fields I

DARK ENERGY SURVEY



Y1A1 SPT Area: Tertiary Fields II



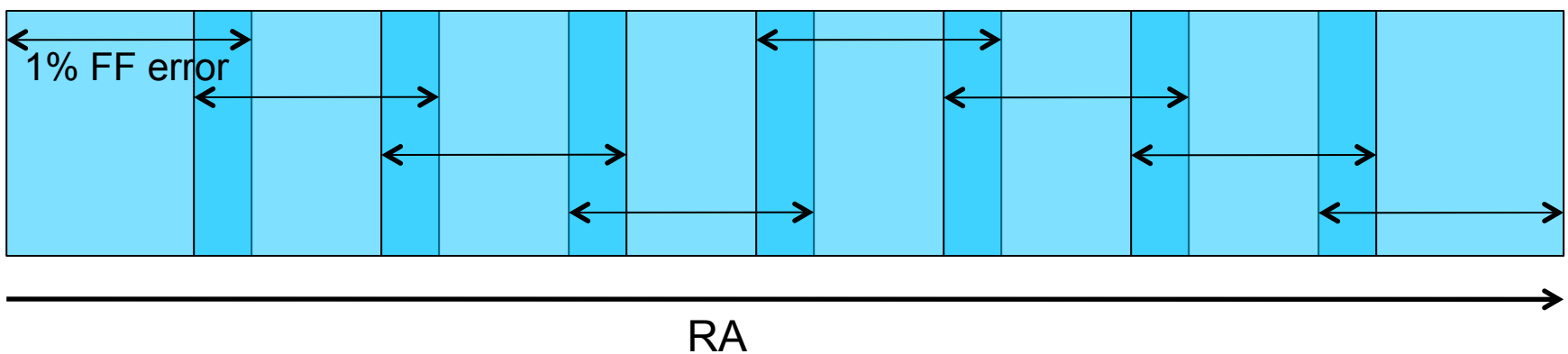
Credit: Sam Wyatt

Statistical vs. Systematic Errors

DARK ENERGY SURVEY

- It is possible to get a statistically good solution from a relative calibrations solver (like GCM) but still have large systematic errors.

- Consider the a long, thin strip in RA, with a 1% flat fielding error (edge-to-edge) from West to East:



- One could still get a statistically tight offset between fields from the overlaps, but still end up with large systematic errors.