DARK ENERGY SURVEY

# Global Calibrations Module:
## A Viewpoint from the PreCam Catalog Simulations

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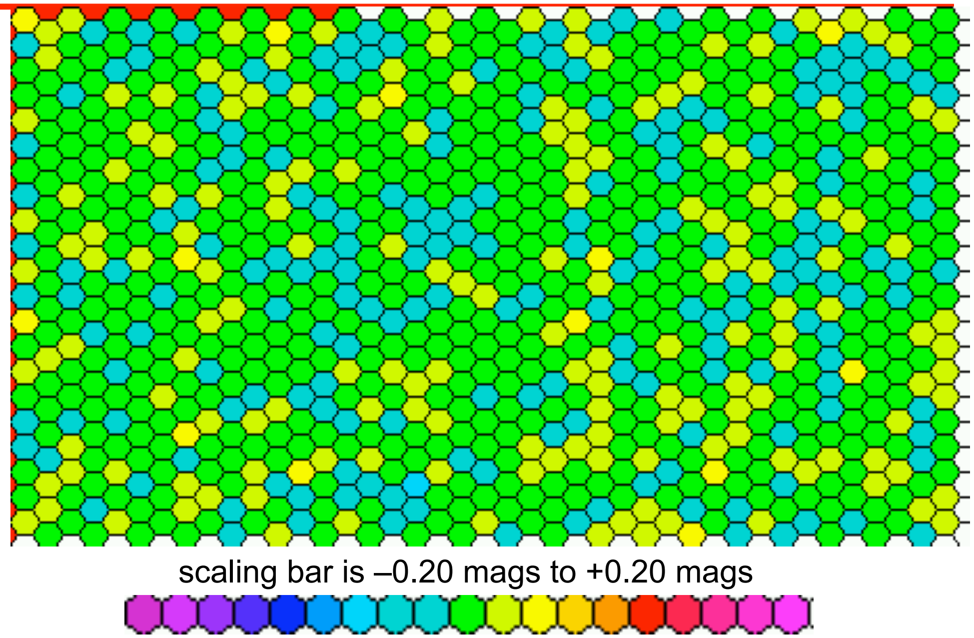
Munich Algorithms Meeting
10 May 2010

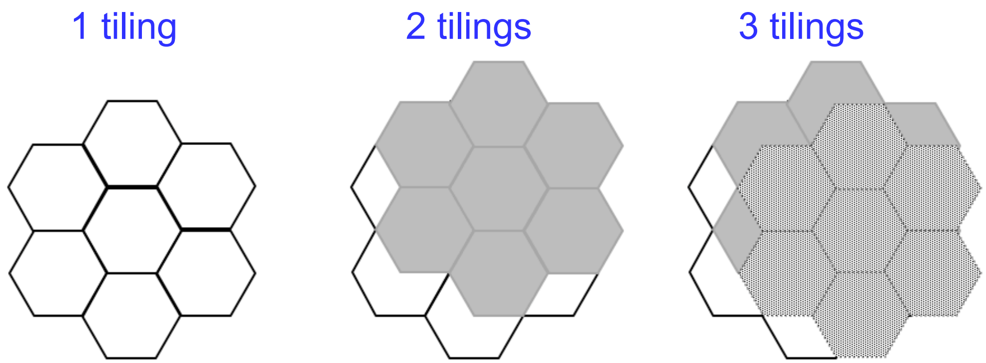
# Field-to-Field Zeropoints: The Need and The Strategy

DES will not always observe under truly photometric conditions…

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

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




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

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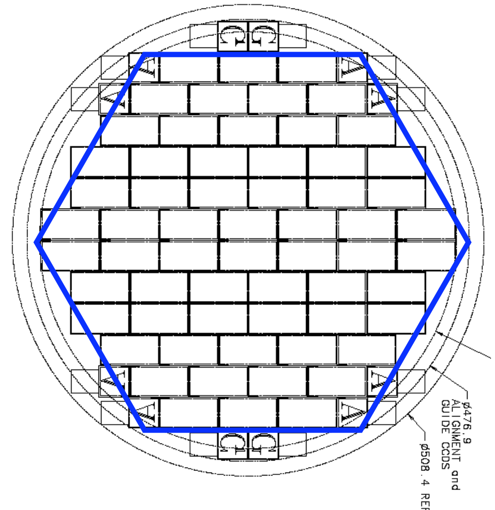
# Global Relative Calibrations: Field-to-Field Zeropoint Offsets

- DES covers the sky twice per year per filter. This is called tiling.
- It takes ~1700 hexes to tile the whole survey area.

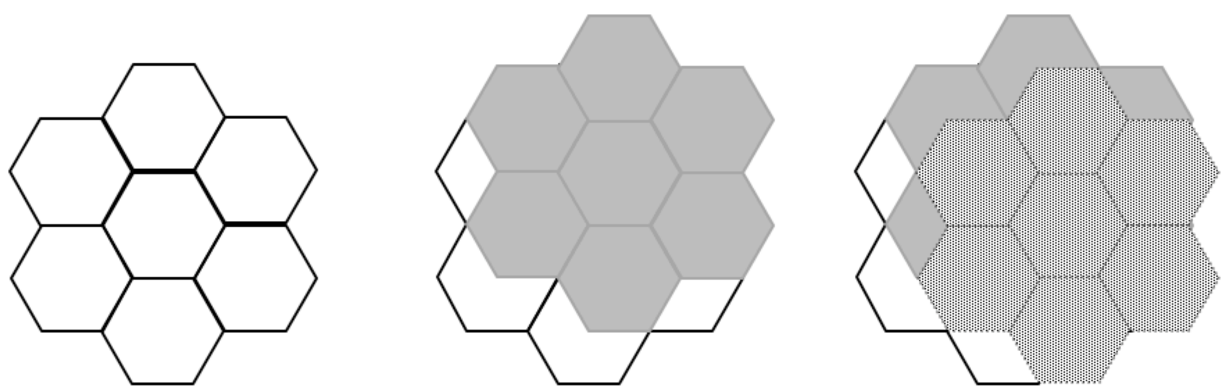


DECam Focal Plane: “The Hex”

Recipe:

- Tile the plane
- Then, tile the plane with hex offset half hex over and up
- This gives 30% overlap with three hexagons
- Repeat, with different offsets
- Large overlaps provide very robust hex-to-hex relative calibrations
- Similar to PanStarrs strategy

1 tiling | 2 tilings | 3 tilings



# Field-to-Field Zeropoints
# The Algorithm (I)

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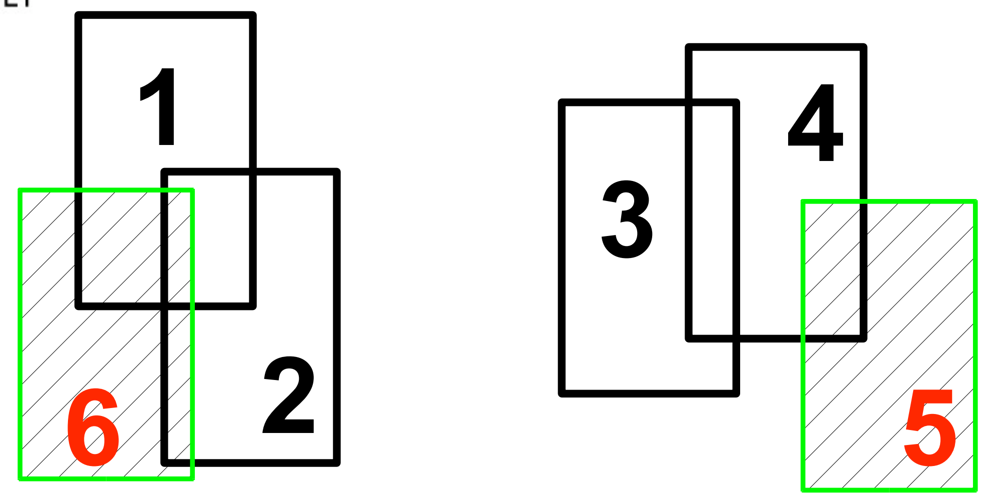


A Generic Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.

- 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 $\Delta_{ij} = -\Delta_{ji}$). (Note: GCM currently uses *median*)
- 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 $S = \Sigma\Sigma\, \theta_{ij} (\Delta_{ij} + ZP_i - ZP_j)^2$

# Field-to-Field Zeropoints: The Algorithm (II)

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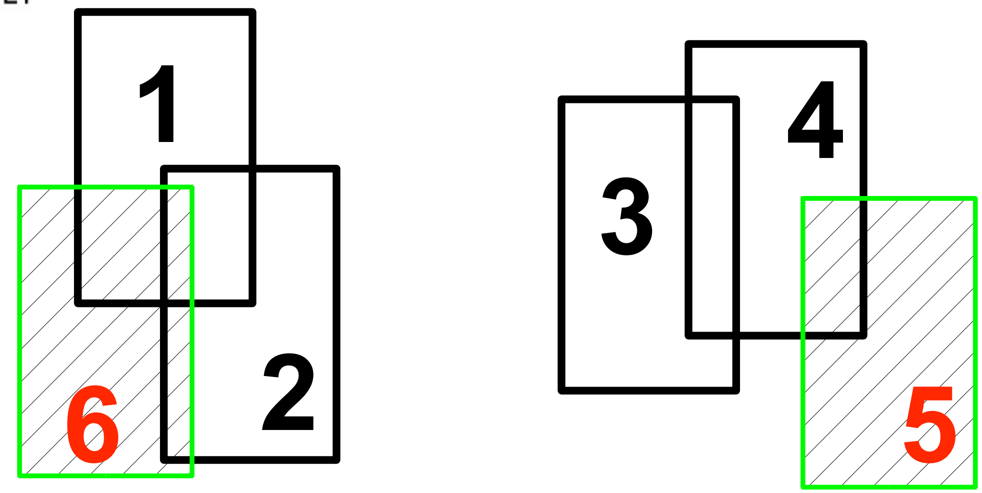
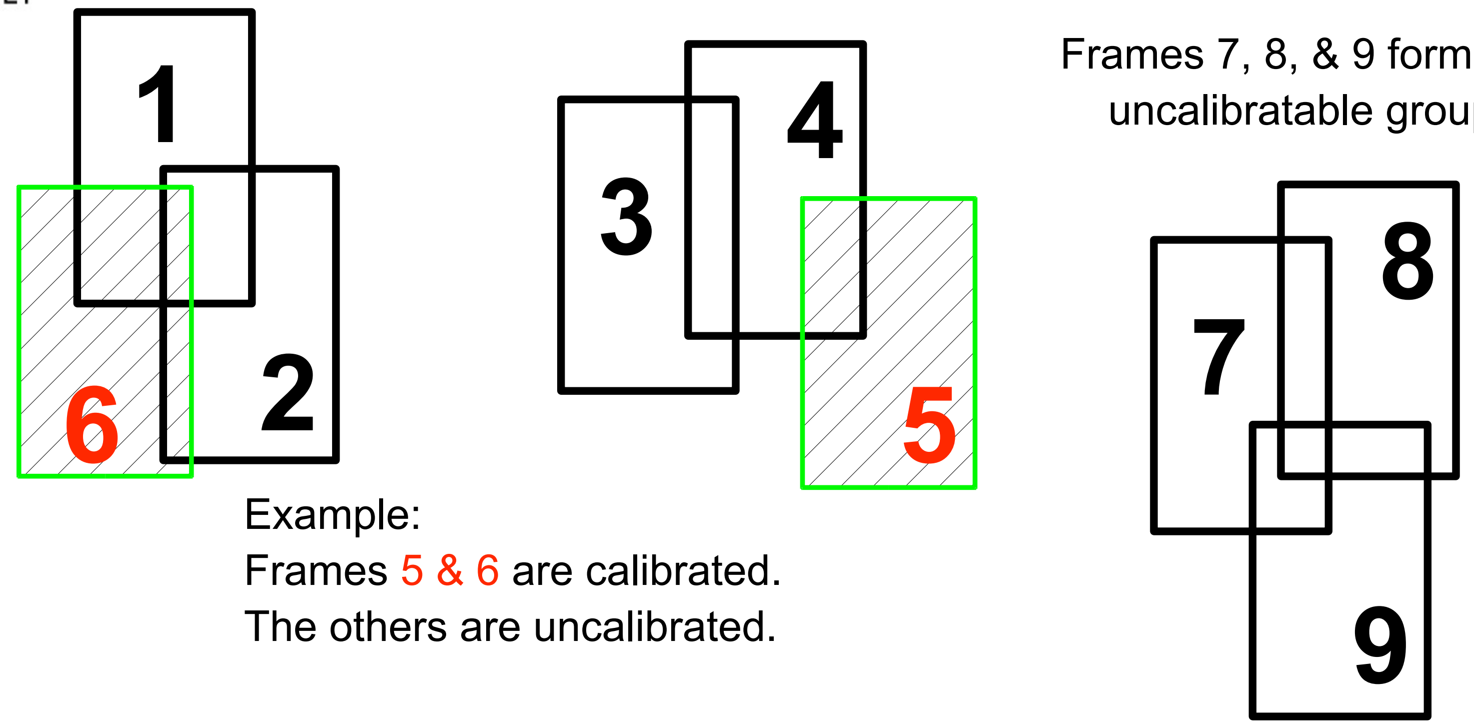



Example:
Frames 5 & 6 are calibrated.
The others are uncalibrated.
(From Glazebrook et al. 1994)

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

# Field-to-Field Zeropoints: An Issue with "Islands"




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

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

Issue: uncalibratable islands results in un-invertable matrices

# Field-to-Field Zeropoints: A Solution for "Islands"

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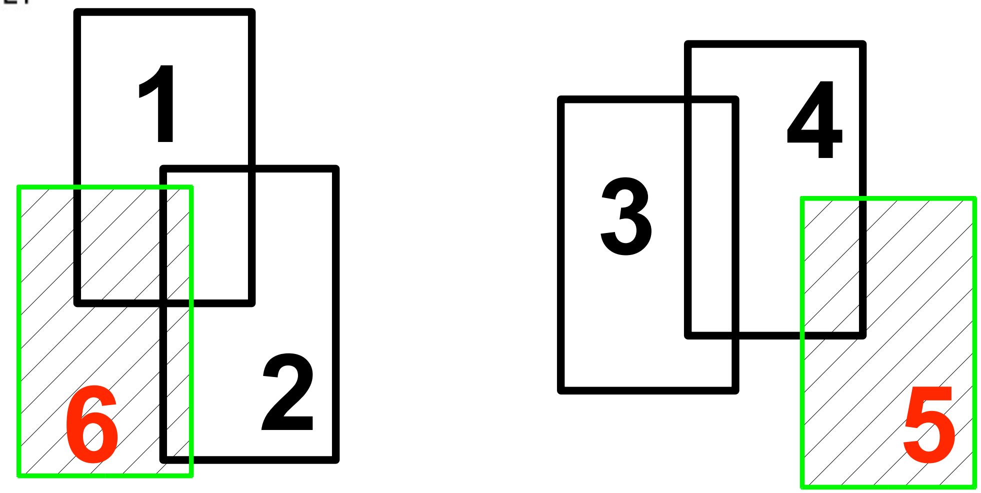
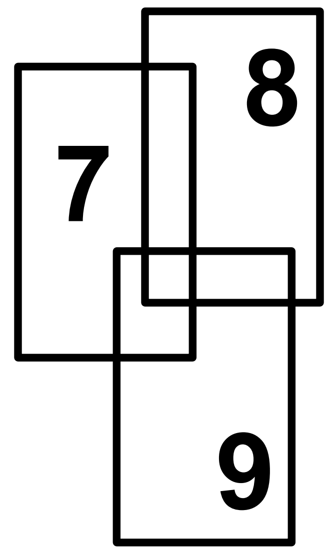



Frames 7, 8, & 9 form an uncalibratable group or "island"




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

# Global Relative Calibrations: The Global Calibrations Module (GCM)

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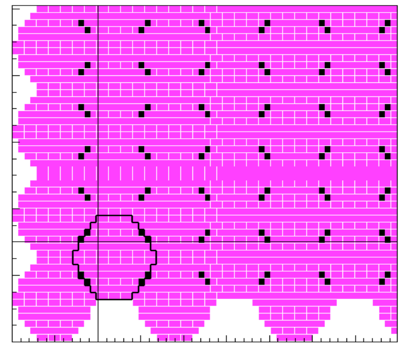
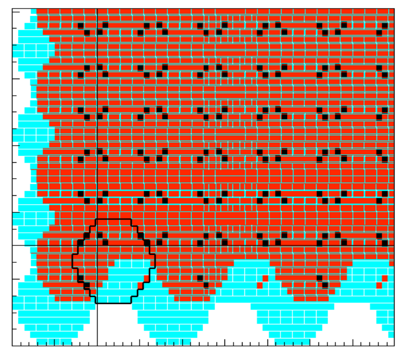
## GCM Zeropoint Solver Code

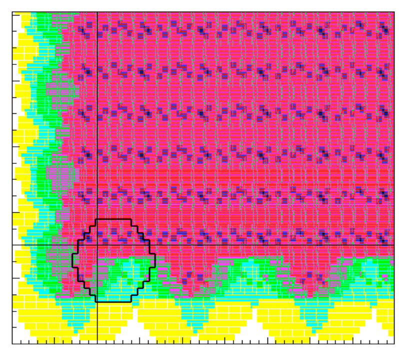
- NxN matrix inversion, where N=# of hexes (or number of tiles or 62 x # of hexes…)
- Written in Java
- Uses cern.colt.matrix
- **Input:** An ASCII table of all unique star matches in the overlap regions
- **Output:** The ZP offsets to be applied to each field and the rms of the solution.
- **Issue:** Switchng from hex-by-hex zeropoints (where N~5000) to CCD-by-CCD zeropoints (where N~300,000) is proving to be difficult. (Jim Annis is conversing with Mike Jarvis regarding this issue.)



1 tiling



2 tilings



3 tilings

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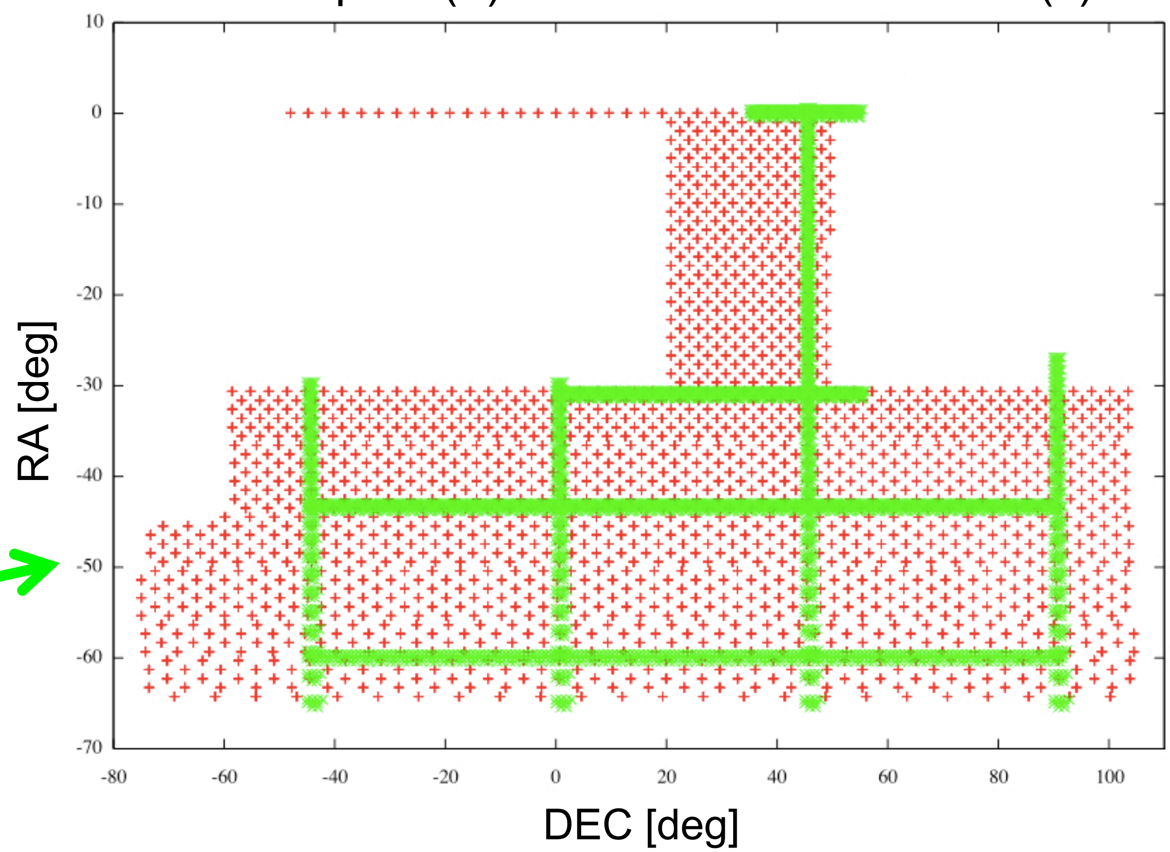
# Global Relative Calibrations: DES + PreCam data

- Can include both DES and PreCam survey fields when running the Global Calibration Module.
- The PreCam Full Footprint Strategy would provide an additional tiling of the DES footprint.
- The PreCam Rib & Keel Strategy would provide a rigid framework upon which to tie the calibrations of the DES.

DES Footprint (+) and PreCam Rib & Keel (x)



# Global Relative Calibrations: Residual Star Flats

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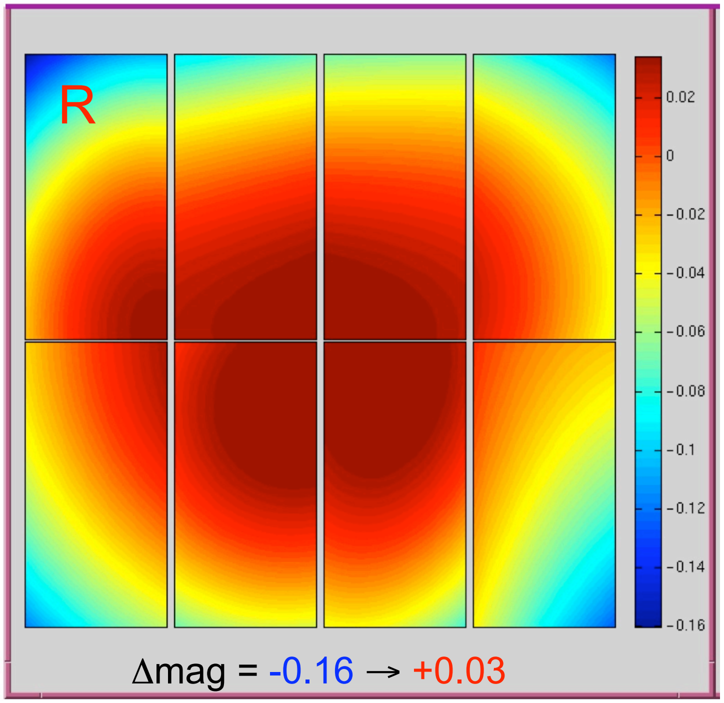
- Due to vignetting and stray light, a detector's response function differs for point sources and extended sources
- Standard flat fields (domes, twilights, skies) may flatten an image sky background well, but not the stellar photometry
- The solution: star flats (Manfroid 1995)
  - offset a field (like 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)

- The worst effects should be modeled by PSM-StarFlat (see earlier slide).
- The many field-to-field overlaps inherent in the DES Survey Strategy can be used to refine the star flats created by the PSM-StarFlat module.
- *Not yet implemented in Global Calibrations Module.*

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# Surveys to Simulate
## (Catalog-level Simulations)

1. DES g-band (Year 1 and Year 1+2)
   a. Fewest tilings
   b. Hardest relative calibrations

2. PreCam "Full Footprint"

3. PreCam "Rib & Keel"

# Types of Simulations

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1. "Perfect" Data (DES, PreCam)
    a. No Poisson noise in stellar mags
    b. No flat-fielding errors
    c. Only deviations from perfection are the pointing-to-pointing zeropoint offsets provided by Jim Annis from his Survey Strategy software.

2. "Realistic" Data (PreCam)
    a. All stars used have Gaussian random errors ($\sigma$ = 0.01mag)
    b. Residual flat-fielding errors of 1% across the focal plane
        1) Linear flat-fielding error across focal plane
        2) Direction of flat-fielding error is random (0°-360°)

3. "Pessimal" Data (DES)
    a. Same as "2" above, but the 1% flat-fielding error is always in the same direction, from West to East

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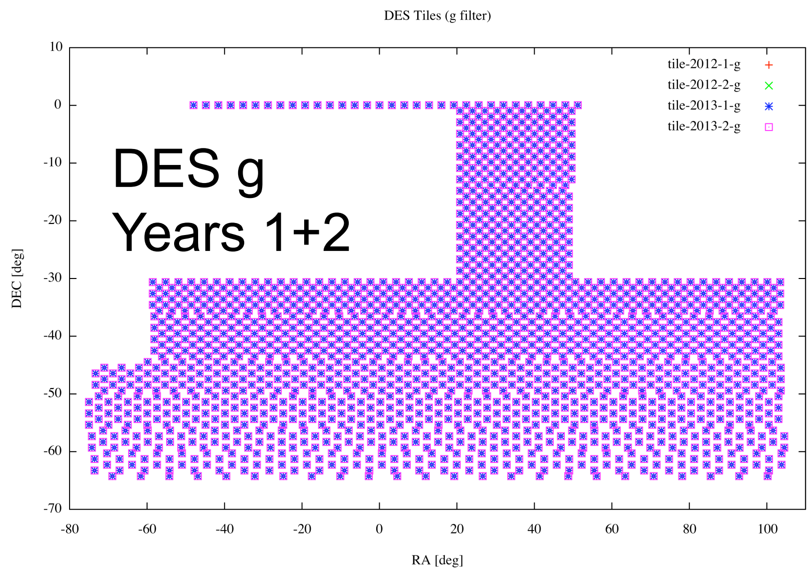
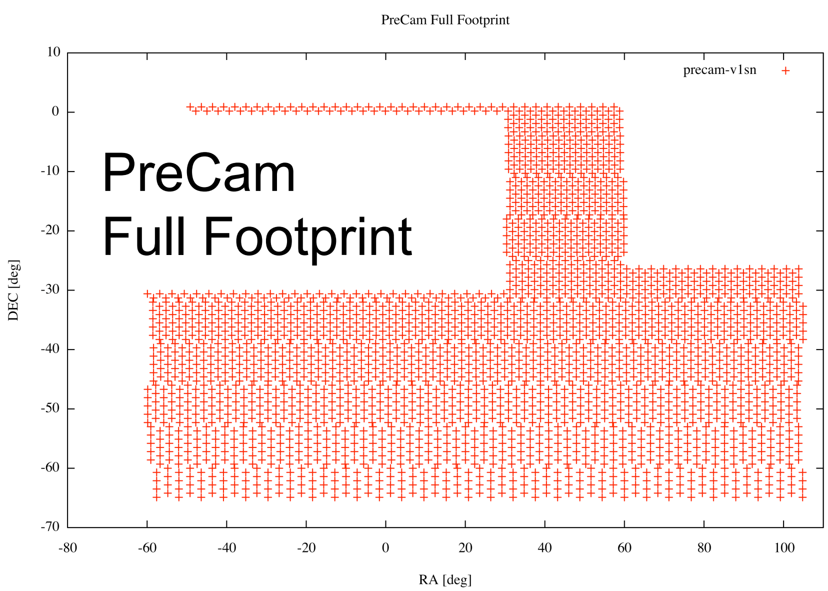
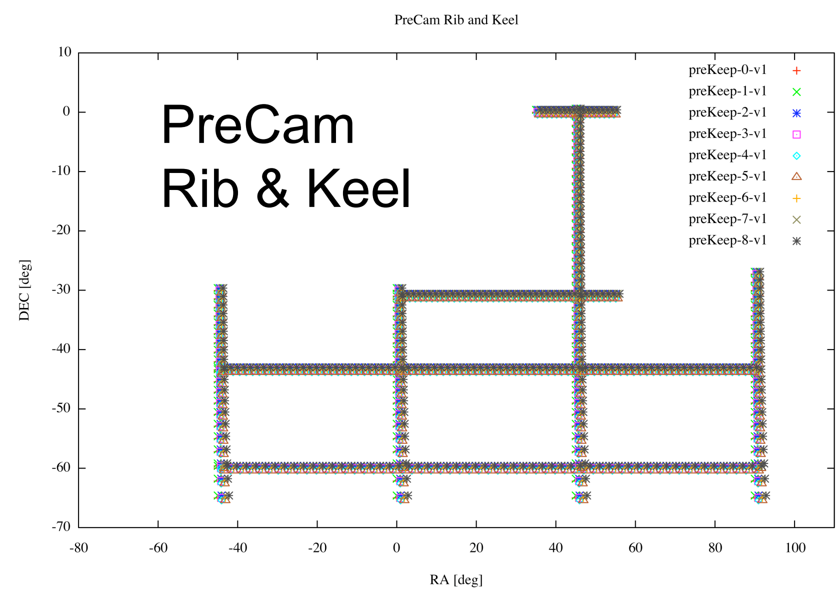
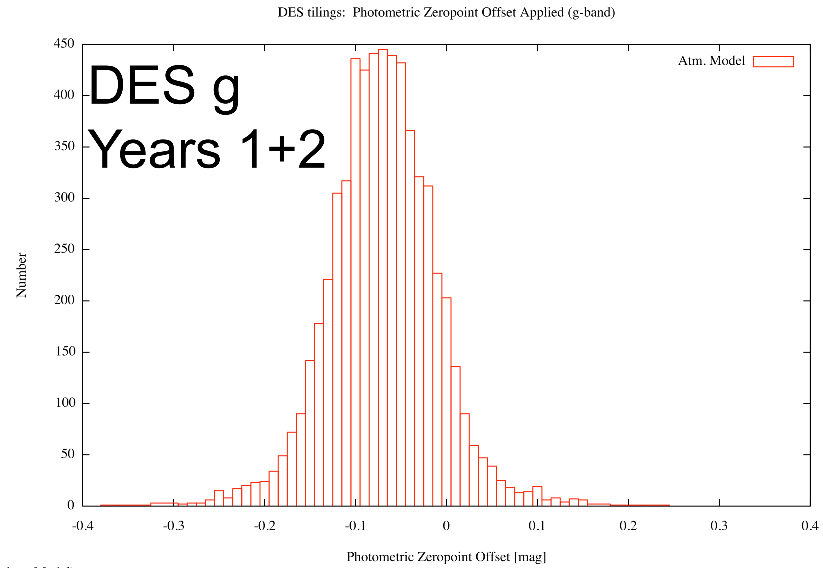
# RA, DEC Plots of 3 Surveys

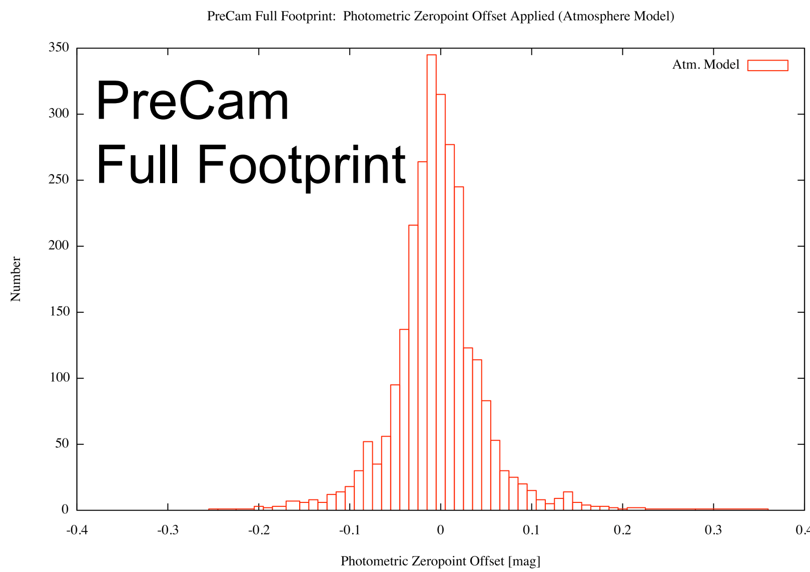


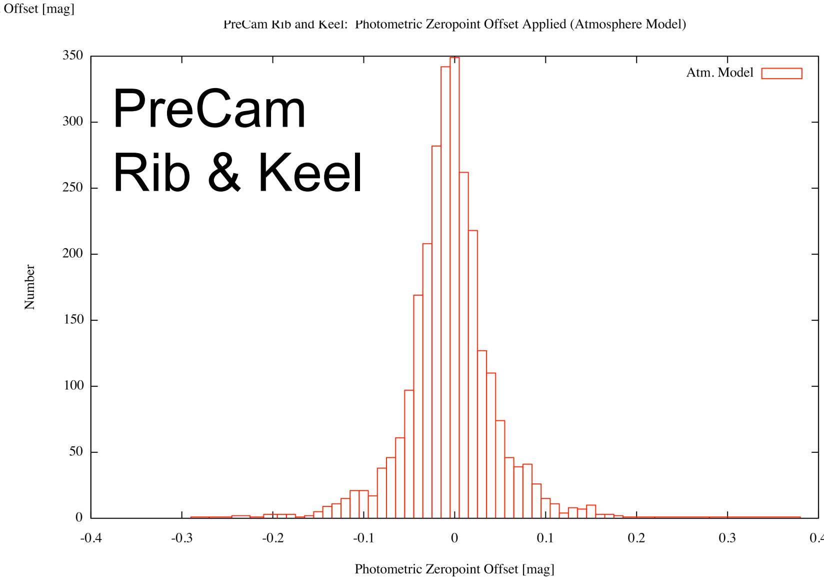



# Photometric Zeropoint Offsets from Survey Strategy



# Simulated Stars on the Focal Plane

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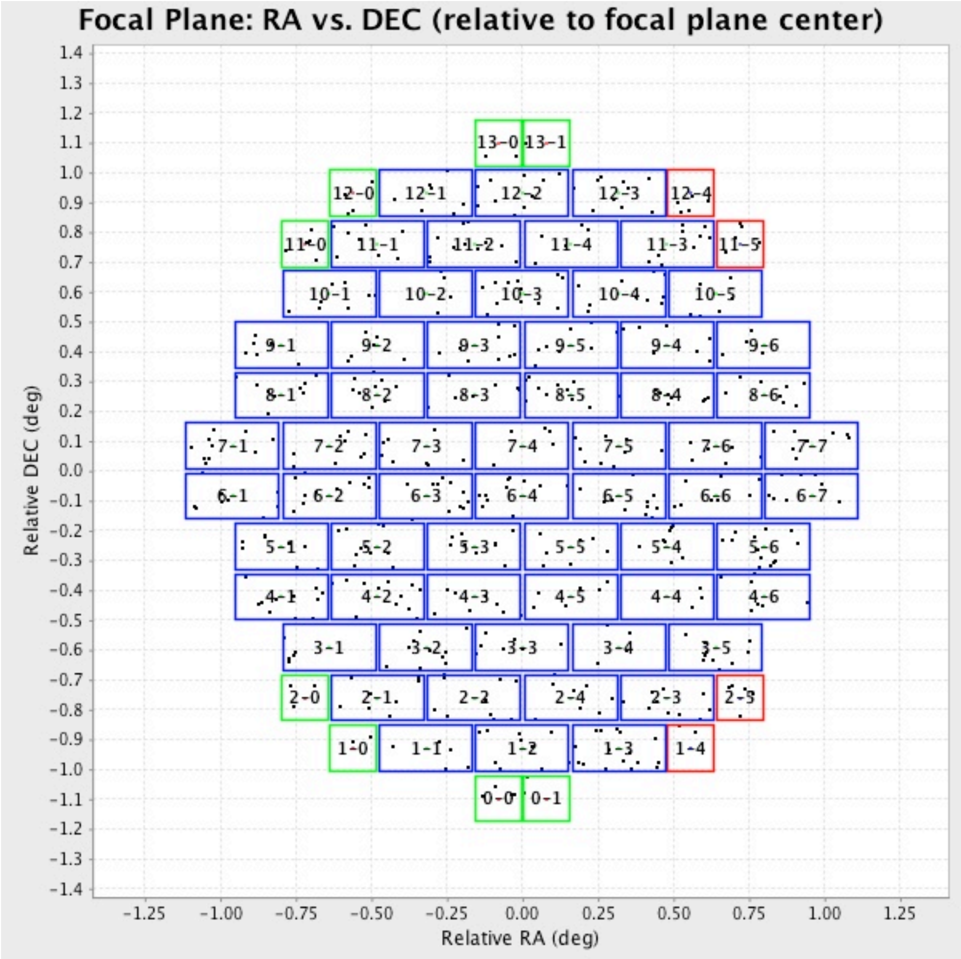
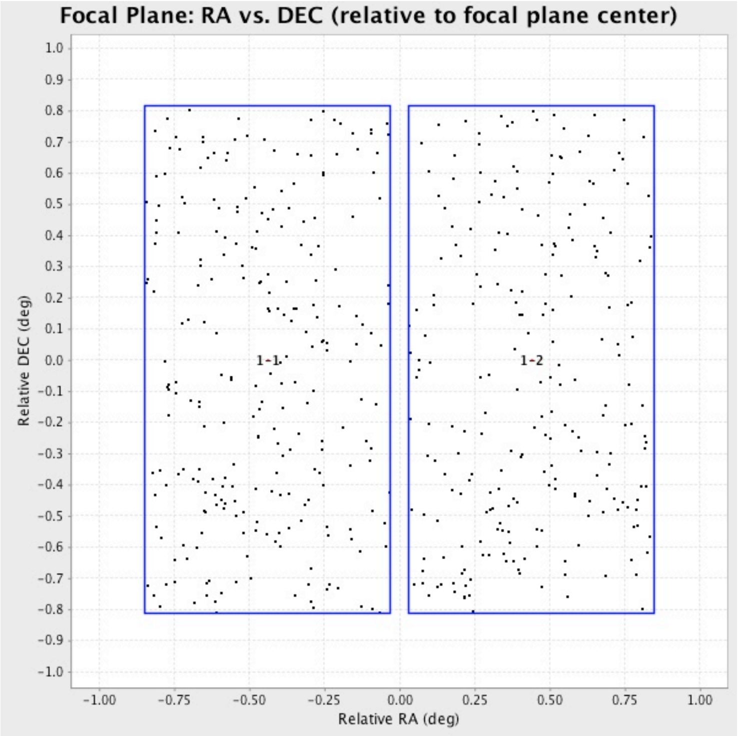
DECam




PreCam




(Not the same fields.)

# Global (Relative) Calibrations Module (GCM)

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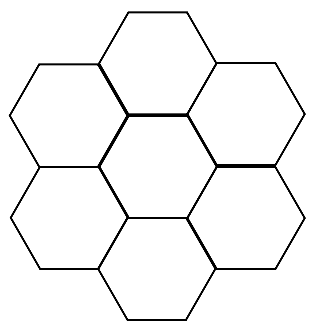
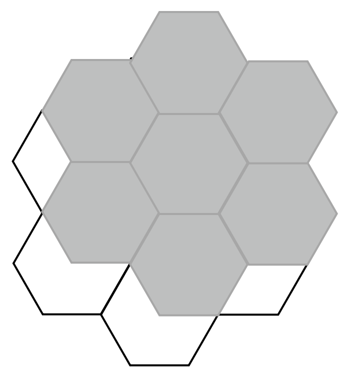
- Use overlapping images to measure relative photometric offsets.
- Big matrix inversion problem (uses algorithm of Glazebrook et al. 1994).
- For the current simulations, do focal plane-by-focal plane solutions (not CCD-by-CCD solutions), to cover full DES footprint without memory problems.

Example of PreCam Full Footprint Strategy + First Year of DES

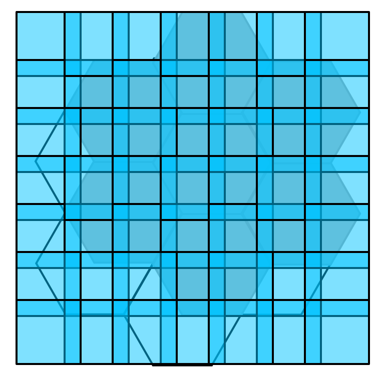
1 tiling



2 tilings



2 tilings + PreCam



From DES-doc #3610

# Statistical vs. Systematic Errors

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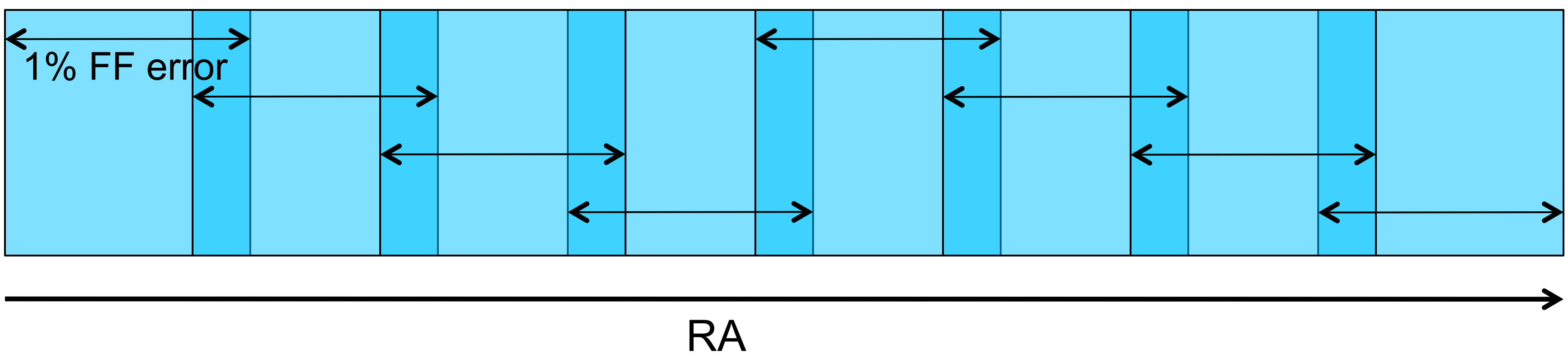
- It is possible to get a statistically good solution from GCM but still have large systematic errors.

- 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.

# Baseline Test of GCM: Solving ZPs for the “Perfect” Simulations

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- “Perfect” simulations tested:
  - DES g Years 1+2
  - PreCam Full Footprint
  - PreCam Rib & Keel

- RMS of the GCM solutions is << 0.00001 mag (below the round-off)
  - This is a measure of the statistical error.

- RMS of (GCM ZP – True ZP) << 0.00001 mag (below the round-off)
  - This is a measure of the systematic error.

# Results

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| Simulated Data Set | RMS of GCM Solutions (measure of statistical error) | RMS of "GCM ZP-True ZP" (measure of systematic error) |
|---|---|---|
| "Realistic" PreCam Full Footprint | 0.00431 mag | 0.00759 mag ✔ |
| "Realistic" PreCam Rib & Keel | 0.00398 mag | 0.01183 mag ✔ |
| "Pessimal" DES g-band | 0.00358 mag | 0.13089 mag ✗ |
| "Pessimal" DES g-band + "Realistic" PreCam Full Footprint | 0.00437 mag | 0.10304 mag ✗ |
| "Pessimal DES g-band + "Realistic" PreCam Rib & Keel | TBD | TBD |
| "Pessimal" DES g-band + *Median* "Realistic" PreCam Rib & Keel | 0.00568 mag | 0.02274 mag ✔ |

(For "Pessimal" DES g-band, both Years 1 and 2 were used.)

# "Pessimal" DES g-band Years 1&2 Alone

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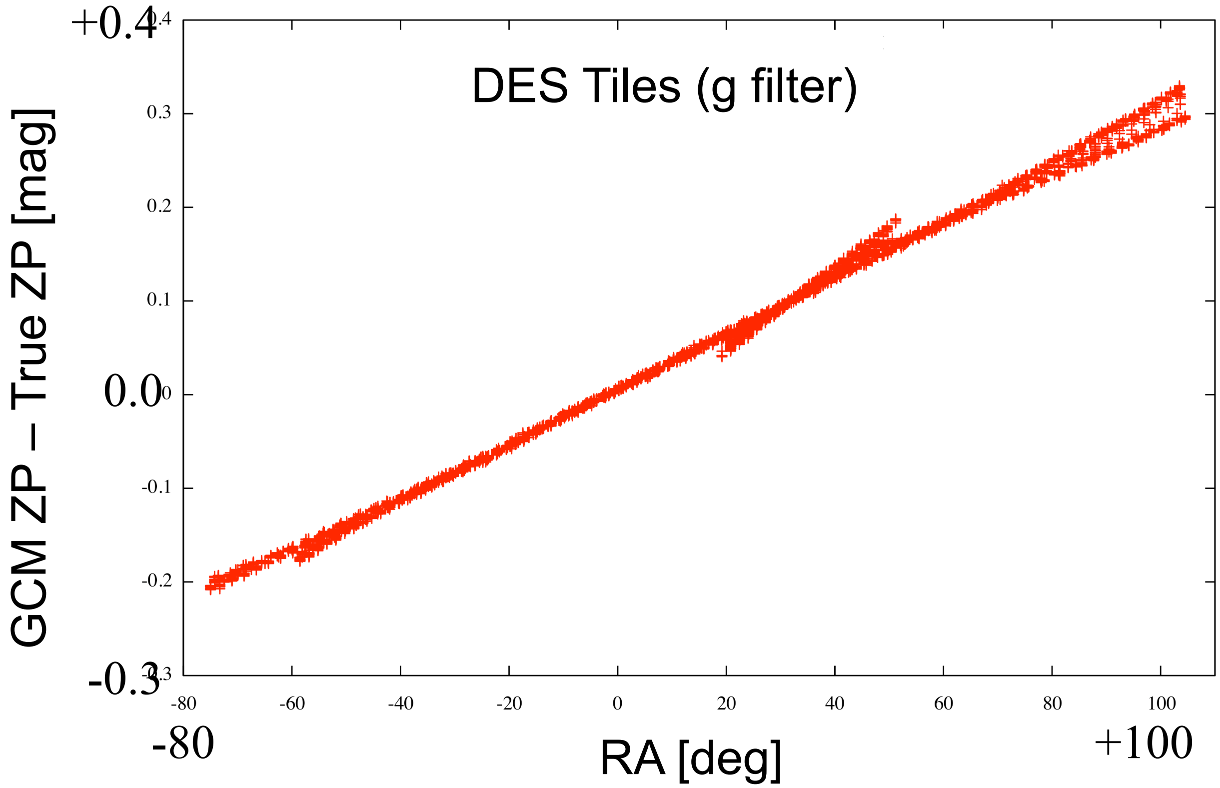
- RMS of the GCM solutions = 0.00358 mag
- RMS of (GCM ZP – True ZP) = 0.13089 mag ✗



# "Pessimal" DES g-band Years 1&2 + Median PreCam Rib & Keel

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- Here, we created a standard star catalog of all Rib & Keel stars observed at least 5 times, taking the median value for each star as its calibrated magnitude. We then used all these calibrated Rib & Keel stars as members of a single (albeit, strangely shaped) fiducial field, feeding this new fiducial field into the GCM with all the DES g-band stars.

- RMS of the GCM solutions = 0.00568 mag

- RMS of (GCM ZP – True ZP) = 0.02274 mag ✔

# Extra Slides

# “PreCamSim”

The DES/PreCam Calibration software is called “PreCamSim”.

1. Modular: StarCat, ImageCat, CCDImageCat

2. Written in Java
   a. In principal can be run on Linux, MacOSX, and Windows
   b. Currently only tested on Linux and MacOSX.
   c. Hard-wired UNIX-based directory separators (e.g., “/”) might be a problem for Windows.

3. Available:
   a. On des06.fnal.gov in /data/des06.a/data/dtucker/PreCamSim
   b. Also as a tar file: http://home.fnal.gov/~dtucker/DES/PreCamSim.tar.gz
   c. See README in the PreCamSim/doc subdirectory.

# StarCat

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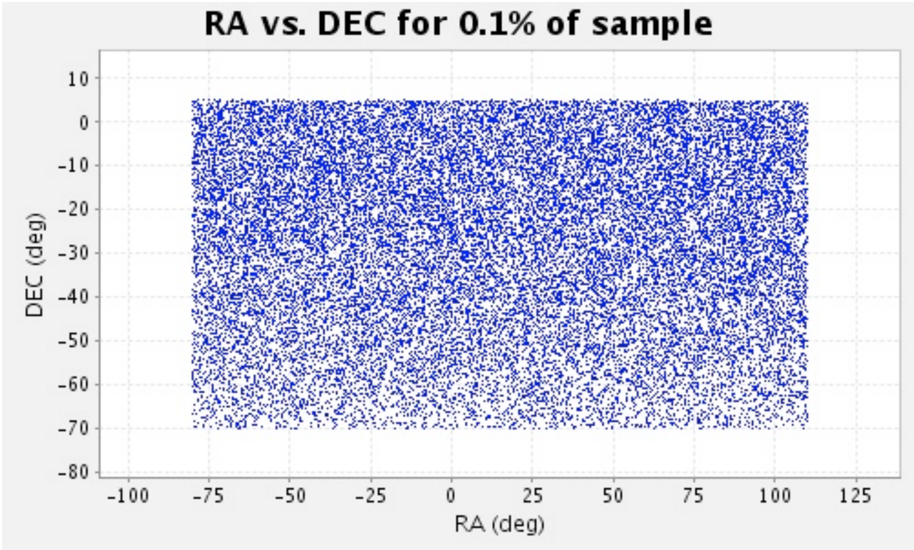
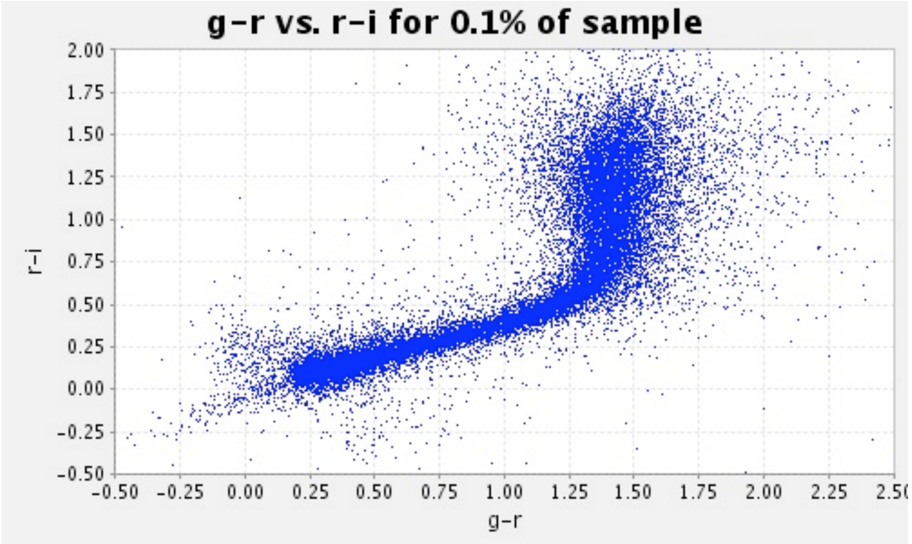
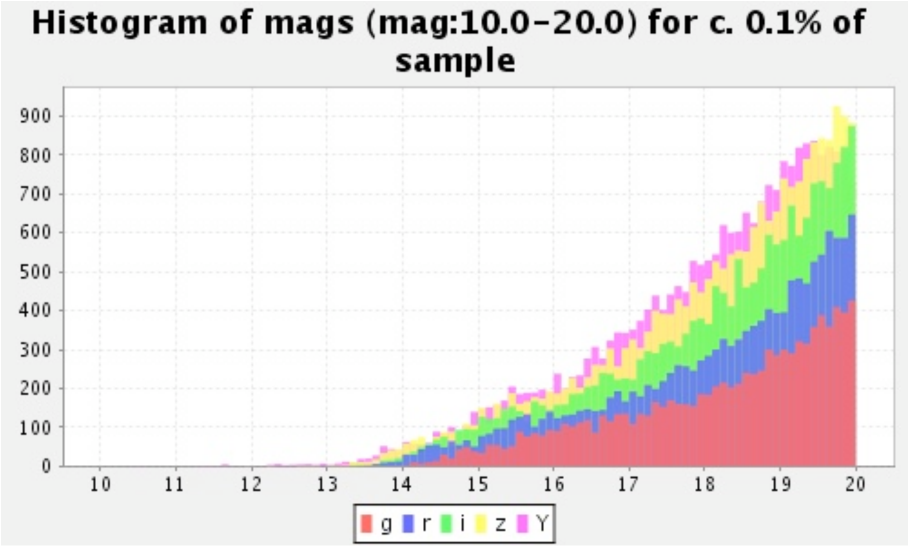
- **StarCat** – creates a random catalog ("truth table") of stars over the full survey region using *griz* data from the North Galactic Pole region in the SDSS (y-band mags are calculated using i-z colors).



# ImageCat

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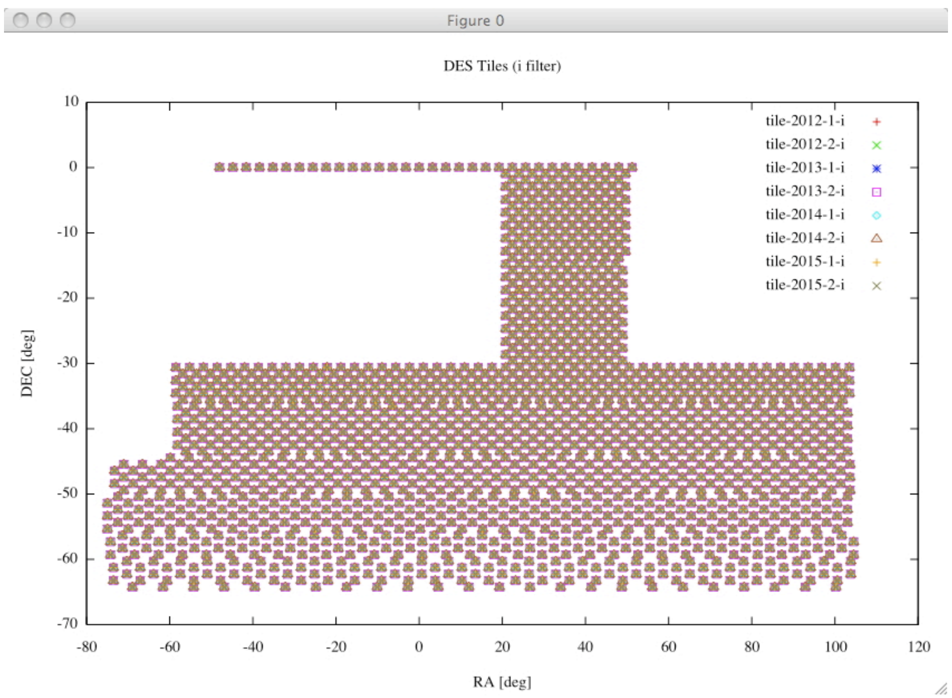
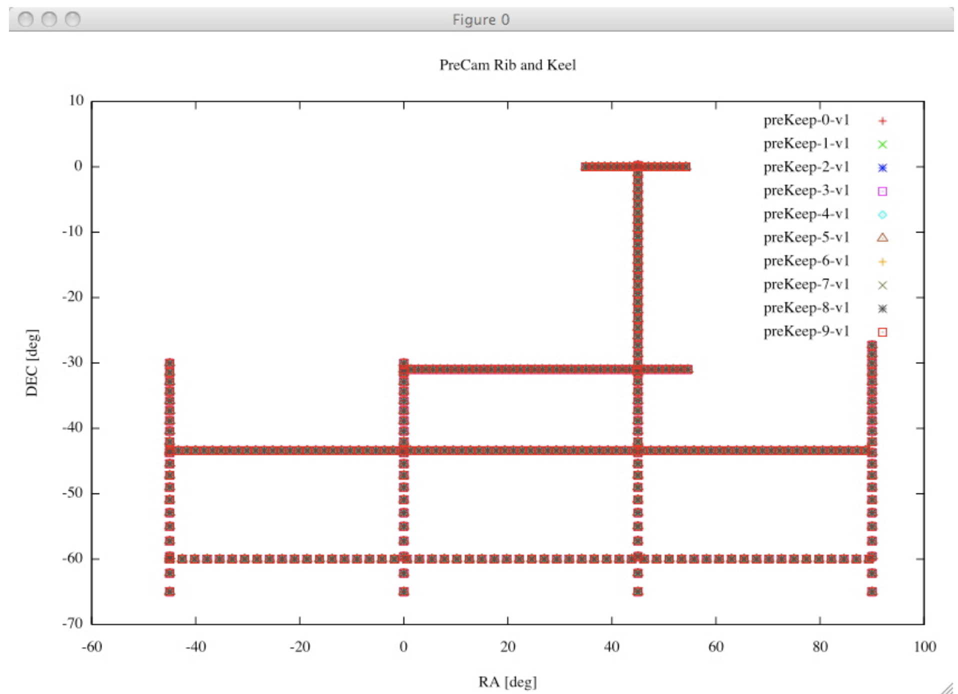
- **ImageCat** – takes a list of image centers and photometric zeropoint offsets (from Jim Annis) to create catalogs in a given pointing (DECam or PreCam)

DES i-band

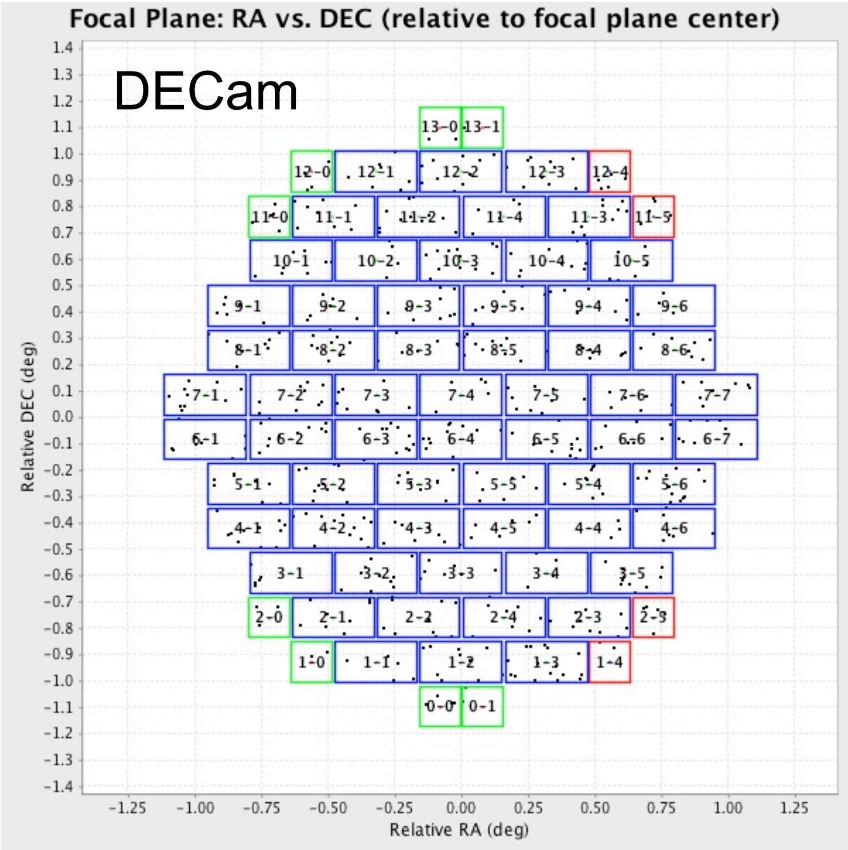


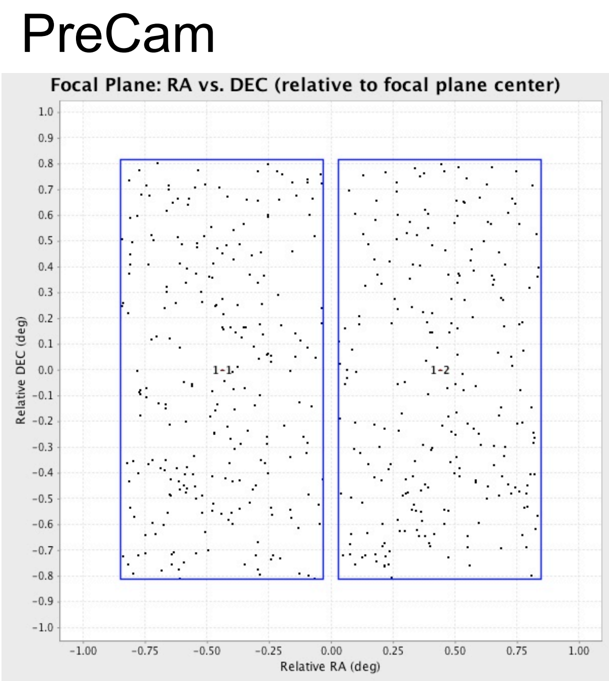

PreCam Rib & Keel



# CCDImageCat

- CCDImageCat – takes the image catalogs from the ImageCat step and identifies on which CCD each star is located on in the camera focal plane; additionally, can apply global (focal-plane-based) and local (ccd-based) flat-fielding errors to the simulated data.



# Functional Forms to the Flat-Field Errors

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- Global (focal-plane-based):

  dmag = fp0 + fp1*R + fp2*R**2 + fp3*R**3

  … where R is the fractional radial distance from the center of the focal plane (R=0 → center; R=1 → edge)

- Local (ccd-based):

  dmag = ccd0 + ccdx*Xccd + ccdy*Yccd + ccdxx*Xccd**2 + ccdyy*Yccd**2 + ccdxy*Xccd*Yccd

  … where Xccd,Yccd are the fractional x,y distances from the center of the CCD (Xccd, Yccd=0 → center; Xccd,Yccd=1 → edge)

# Output of CCDImageCat

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- Updated image catalogs for each pointing; e.g.:

```
# mag = old_mag + (-0.2 + 0.02*R + -0.02*R^2 + 0.01*R^3) + (0.1 + 0.04*x + -0.17*y + -0.13*x^2 + 0.06*y^2 + 0.08*x*y),
#    where R is the normalized radial distance from the center of the focal plane (R=0->center, R=1->edge),
#    x is the normalized distance in the x-direction from the center of the given CCD (x=0->center, x=1->edge), and
#    y is the normalized distance in the y-direction from the center of the given CCD (y=0->center, y=1->edge).
#
#expName    = PRECAM-20001349
#expFullID = 20001349
#expFilter = g
#expNight  = 1349
#expID     = 1349
#expRaDeg  = -2.5371
#expDecDeg = -41.8
#expZPOffset  = -0.0050
#
```

| #starID | starRaDeg | starDecDeg | mag_g | old_mag_g | relStarRaDeg | relStarDecDeg | ccdname | ccd_x(pix) | ccd_y(pix) | FP_x(mm) | FP_y(mm) | R | x | y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95500 | -1.60220 | -42.24803 | 16.4013 | 16.4336 | 0.69206 | -0.45179 | 1-2 | 1660.577 | 910.618 | 26.134 | -17.061 | 0.719 | 0.622 | -0.555 |
| 112495 | -3.18013 | -42.10784 | 17.4703 | 17.4927 | -0.47706 | -0.30962 | 1-1 | 928.689 | 1268.526 | -18.015 | -11.692 | 0.495 | -0.093 | -0.381 |
| 122676 | -1.97870 | -41.19363 | 16.7615 | 16.9524 | 0.42021 | 0.60501 | 1-2 | 976.201 | 3571.090 | 15.868 | 22.846 | 0.641 | -0.047 | 0.744 |
| 172309 | -2.35838 | -41.03429 | 16.4463 | 16.8047 | 0.13482 | 0.76557 | 1-2 | 257.746 | 3975.309 | 5.091 | 28.910 | 0.676 | -0.748 | 0.941 |
| 179610 | -1.44748 | -41.19388 | 16.6836 | 16.8886 | 0.81995 | 0.60092 | 1-2 | 1982.531 | 3560.814 | 30.963 | 22.692 | 0.884 | 0.936 | 0.739 |
| 187786 | -2.87875 | -42.88973 | 16.6923 | 16.8826 | -0.25036 | -1.09023 | none | -1000.000 | -1000.000 | -9.454 | -41.169 | 0.973 | -1000.000 | -1000.000 |
| 264708 | -2.36626 | -40.96934 | 17.5193 | 17.7115 | 0.12901 | 0.83053 | none | -1000.000 | -1000.000 | 4.872 | 31.363 | 0.731 | -1000.000 | -1000.000 |
| 316335 | -2.79021 | -41.04672 | 16.4066 | 16.5839 | -0.19091 | 0.75300 | 1-1 | 1649.069 | 3943.662 | -7.209 | 28.435 | 0.675 | 0.610 | 0.926 |
| 335877 | -2.96453 | -41.10155 | 16.1650 | 16.3388 | -0.32211 | 0.69765 | 1-1 | 1318.762 | 3804.320 | -12.164 | 26.345 | 0.668 | 0.288 | 0.858 |
| 338675 | -1.61714 | -41.18635 | 16.9387 | 17.1122 | 0.69236 | 0.60995 | 1-2 | 1661.340 | 3583.526 | 26.145 | 23.033 | 0.802 | 0.622 | 0.750 |
| 358235 | -1.89311 | -42.01268 | 17.3856 | 17.4301 | 0.47848 | -0.21447 | 1-2 | 1122.898 | 1508.070 | 18.069 | -8.099 | 0.456 | 0.097 | -0.264 |
| 409398 | -2.12718 | -41.68651 | 16.2644 | 16.4131 | 0.30613 | 0.11276 | 1-2 | 688.996 | 2331.872 | 11.560 | 4.258 | 0.284 | -0.327 | 0.139 |
| 519417 | -1.90940 | -41.90926 | 17.1741 | 17.2428 | 0.46713 | -0.11097 | 1-2 | 1094.330 | 1768.646 | 17.640 | -4.190 | 0.418 | 0.069 | -0.136 |
| 526494 | -2.60264 | -41.37446 | 17.4986 | 17.7070 | -0.04918 | 0.42552 | 1-1 | 2005.853 | 3119.242 | -1.857 | 16.069 | 0.372 | 0.959 | 0.523 |
| 535560 | -3.49624 | -41.52978 | 16.6108 | 16.8591 | -0.71802 | 0.26621 | 1-1 | 322.077 | 2718.190 | -27.114 | 10.053 | 0.666 | -0.685 | 0.327 |
| 566996 | -2.21849 | -42.22059 | 17.1134 | 17.1355 | 0.23596 | -0.42103 | 1-2 | 512.347 | 988.071 | 8.910 | -15.899 | 0.420 | -0.500 | -0.518 |
| 618472 | -3.13821 | -40.79909 | 16.2777 | 16.4681 | -0.45511 | 0.99932 | none | -1000.000 | -1000.000 | -17.186 | 37.737 | 0.955 | -1000.000 | -1000.000 |
| 653885 | -2.20941 | -41.40199 | 17.3029 | 17.5331 | 0.24580 | 0.39754 | 1-2 | 537.132 | 3048.804 | 9.282 | 15.012 | 0.406 | -0.475 | 0.489 |
| 658796 | -2.67703 | -41.59895 | 17.2006 | 17.3745 | -0.10464 | 0.20096 | 1-1 | 1866.236 | 2553.925 | -3.952 | 7.589 | 0.197 | 0.822 | 0.247 |
| 661739 | -2.03172 | -42.76002 | 16.8287 | 17.0196 | 0.37110 | -0.96111 | none | -1000.000 | -1000.000 | 14.014 | -36.294 | 0.896 | -1000.000 | -1000.000 |
| 701834 | -2.33729 | -40.98068 | 17.5857 | 17.7779 | 0.15086 | 0.81914 | none | -1000.000 | -1000.000 | 5.697 | 30.933 | 0.724 | -1000.000 | -1000.000 |
| 723265 | -1.28644 | -41.87625 | 16.5828 | 16.7744 | 0.93119 | -0.08302 | none | -1000.000 | -1000.000 | 35.164 | -3.135 | 0.813 | -1000.000 | -1000.000 |
| 744358 | -2.04140 | -42.37679 | 17.4752 | 17.4184 | 0.36620 | -0.57785 | 1-2 | 840.243 | 593.283 | 13.829 | -21.821 | 0.595 | -0.179 | -0.710 |
| 764686 | -3.78177 | -41.69002 | 16.7726 | 16.9642 | -0.92943 | 0.10325 | none | -1000.000 | -1000.000 | -35.097 | 3.899 | 0.813 | -1000.000 | -1000.000 |
| 783605 | -1.97237 | -41.52049 | 17.4201 | 17.5683 | 0.42283 | 0.27812 | 1-2 | 982.787 | 2748.165 | 15.967 | 10.502 | 0.440 | -0.040 | 0.342 |
| 799070 | -2.05887 | -42.42245 | 17.8436 | 17.7723 | 0.35304 | -0.62343 | 1-2 | 807.113 | 478.521 | 13.332 | -23.542 | 0.623 | -0.212 | -0.766 |
| 809486 | -1.90944 | -41.12814 | 17.3850 | 17.5687 | 0.47281 | 0.67013 | 1-2 | 1108.614 | 3735.050 | 17.854 | 25.306 | 0.713 | 0.083 | 0.824 |