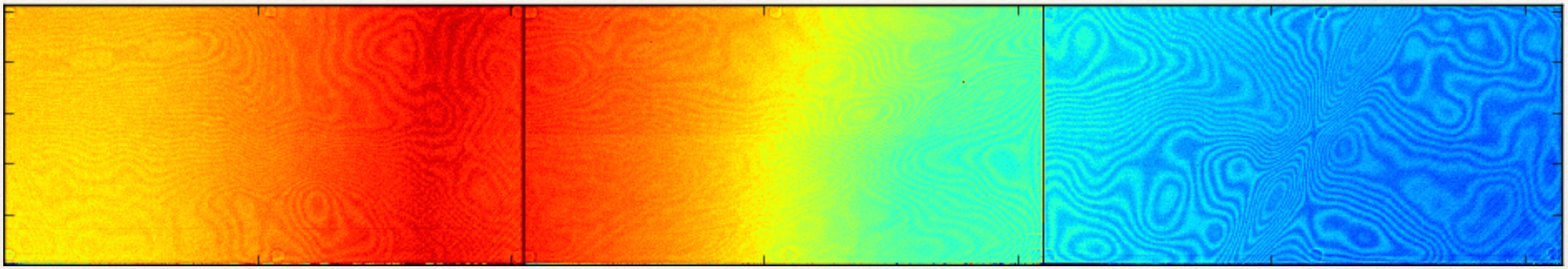
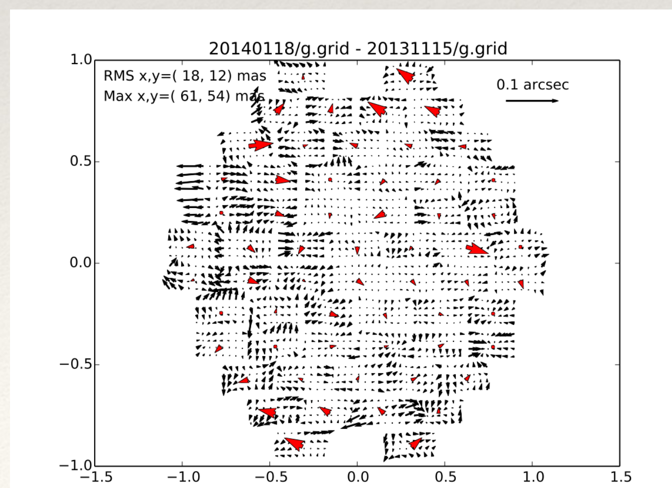


The quirks and qualities of DECam data

Gary Bernstein
(University of Pennsylvania)
and the DES Collaboration

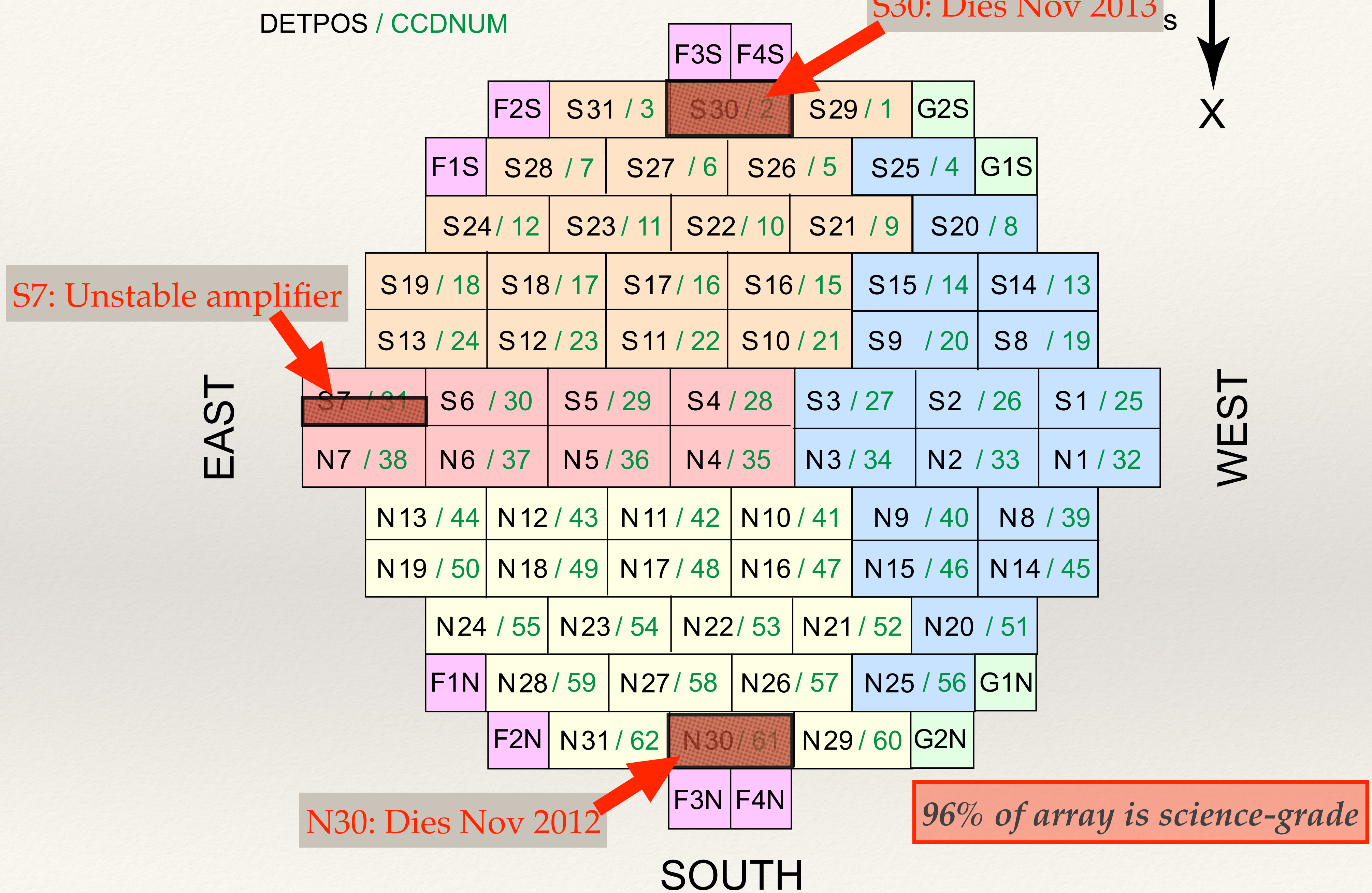
11 March 2015



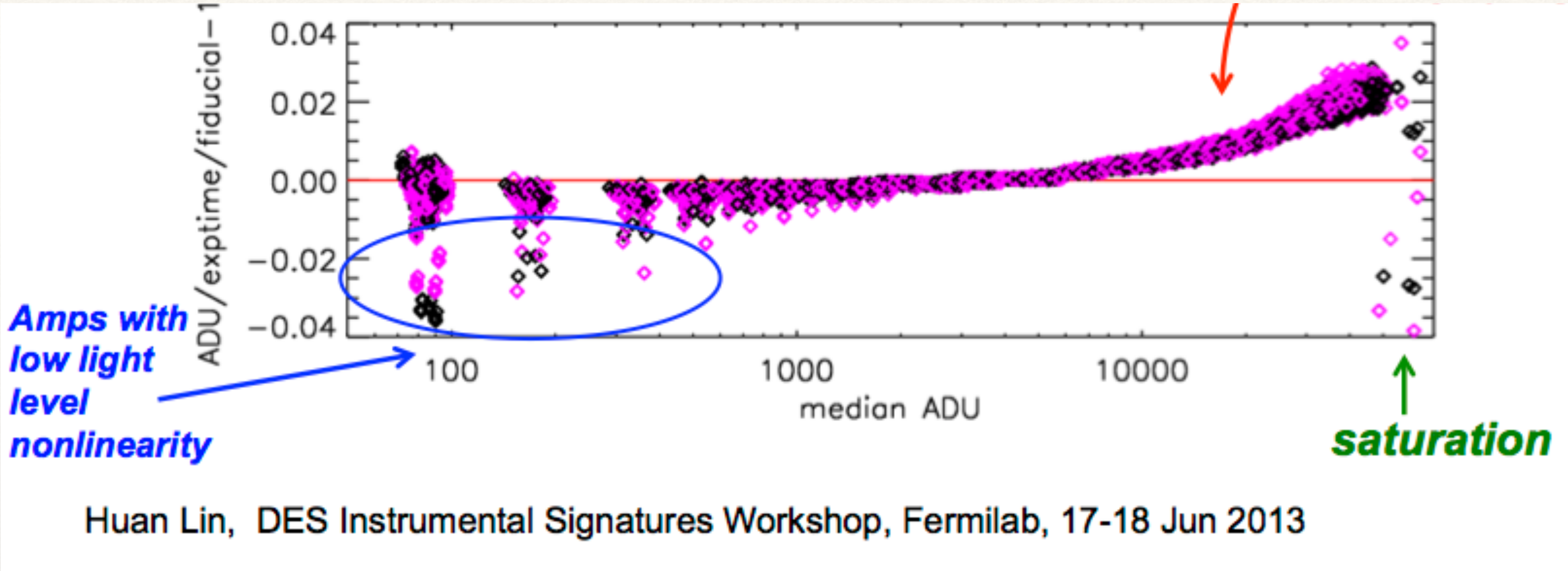
Overview

- Nonlinear processes:
  - Single-pixel nonlinearities
  - Crosstalk
  - The brighter/fatter effect
  - Edges & other oddities
- Linear processes:
  - Photometry and flats
  - Astrometric solutions
  - Sky subtraction

Sky Orientation of DECam

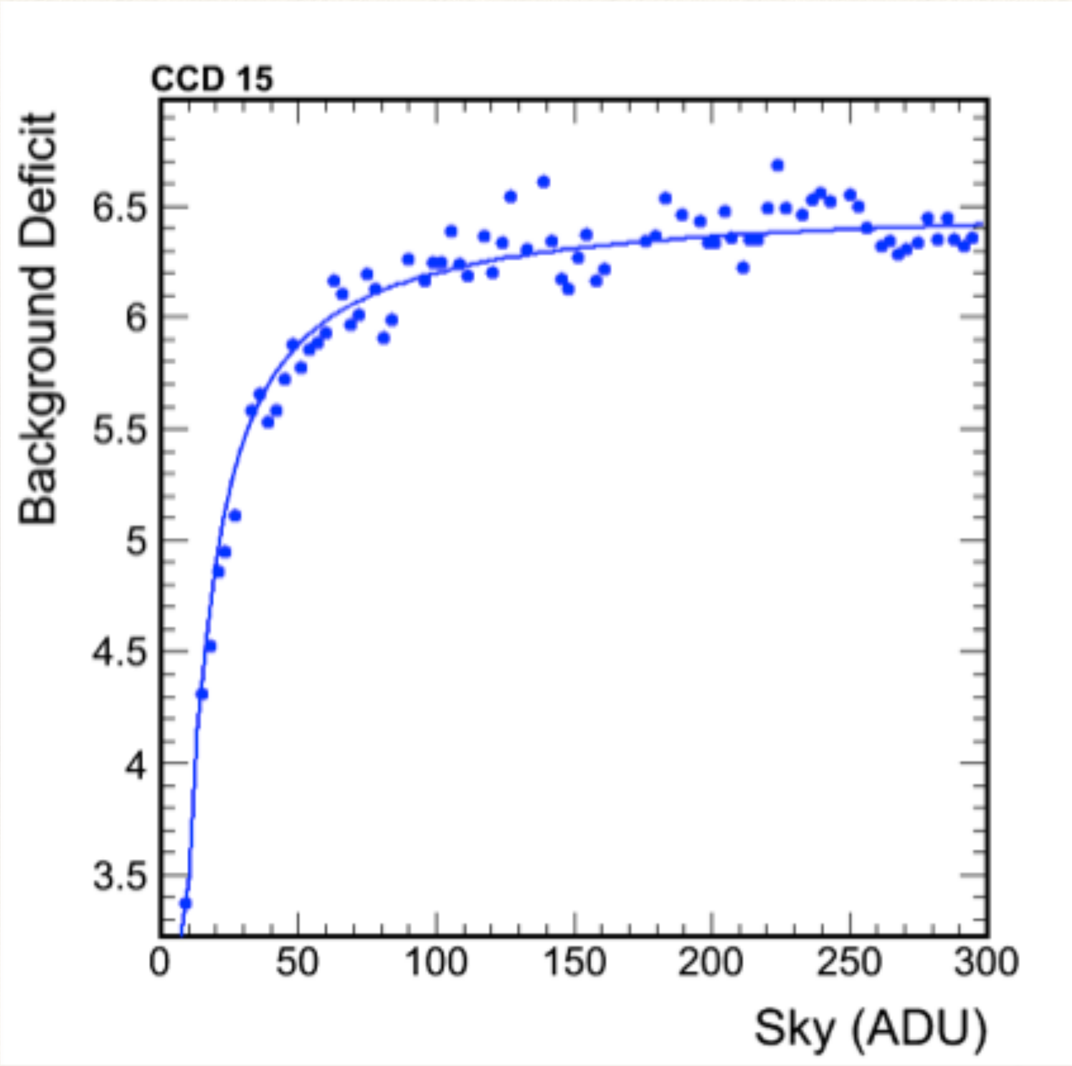


“Classical” nonlinearity



- Tests from dome flats of varying exposure time, analysis by Huan Lin
- All amps have high-light-level nonlinearity consistent with quadratic response term
- No evidence of change from continued monitoring
- Easily fixed by remapping ADU’s after bias subtraction.

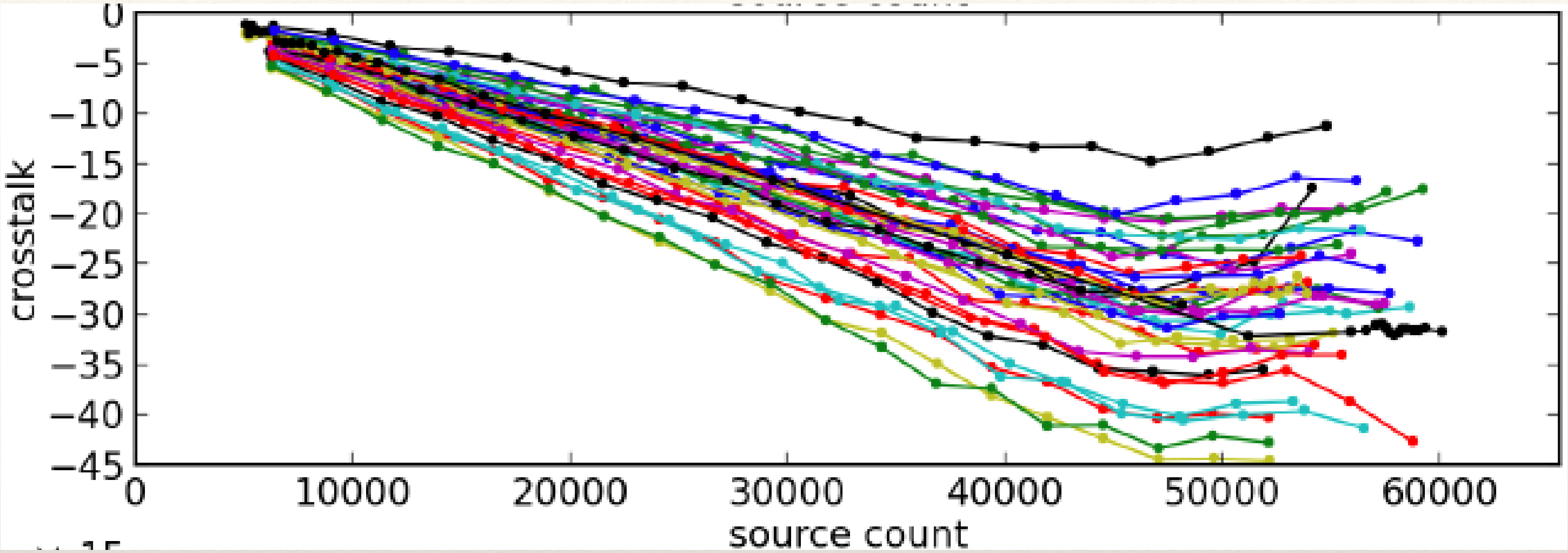
Low-light-level nonlinearity



- A few ADU get "lost" between 0 and ~100 ADU exposure.
- Worst amp shown here
- ~10 amps affected above ~2 ADU, 10e.
- Fixed in linearity correction.
- No sign of change in 2 yrs.

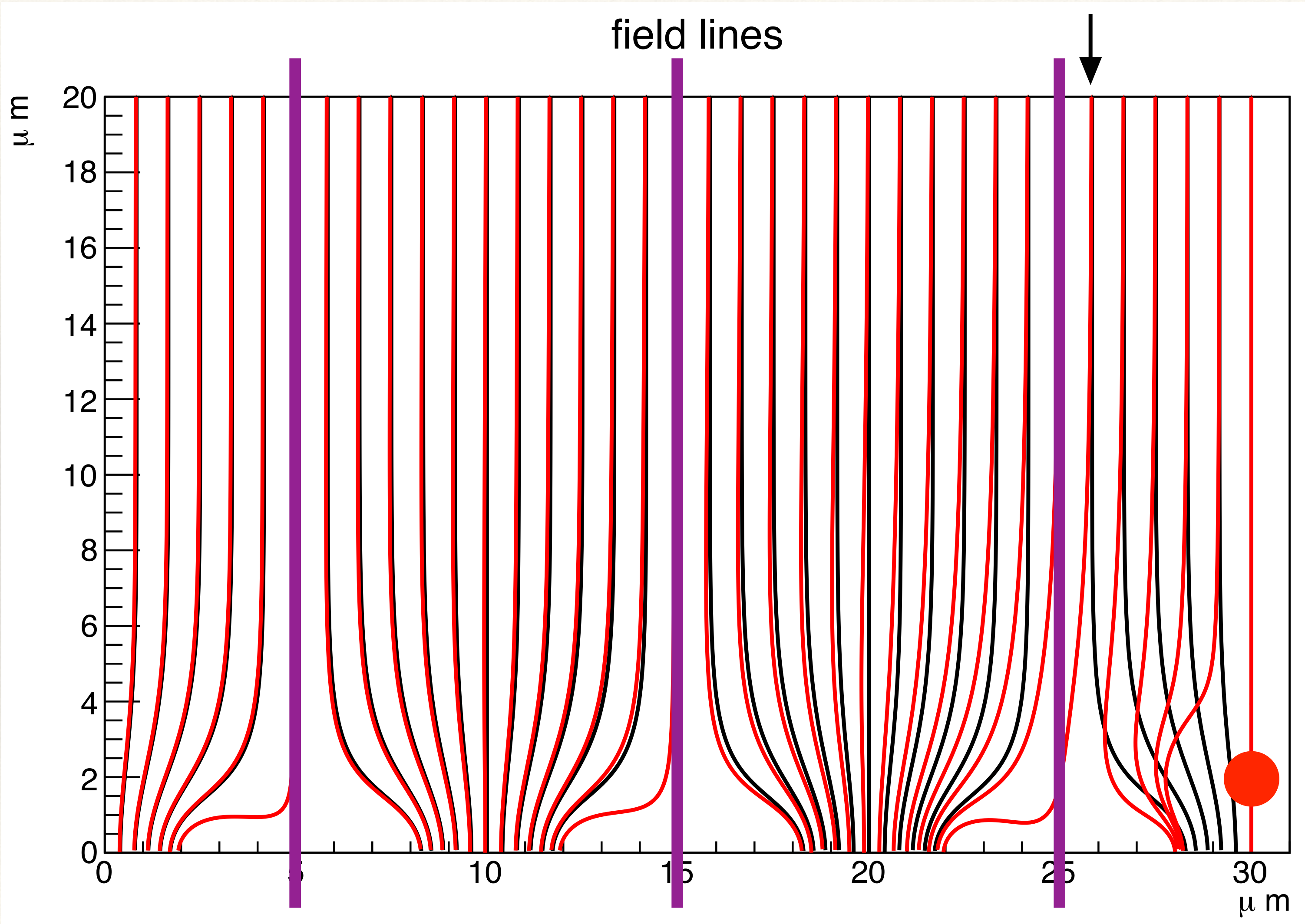
Normal DES operations do not exercise the low-light regime and this effect is not well understood or characterized.
If your data have <100 ADU of sky, you should be checking photometry carefully.

Crosstalk



- Characterized by Kerstin Paech from SV exposures
- Significant between all A & B amps on same CCD
- Only a few inter-chip pairs are significant
- Victim effect is nonlinear function at high source flux
- Easily fixed
- No evidence of change

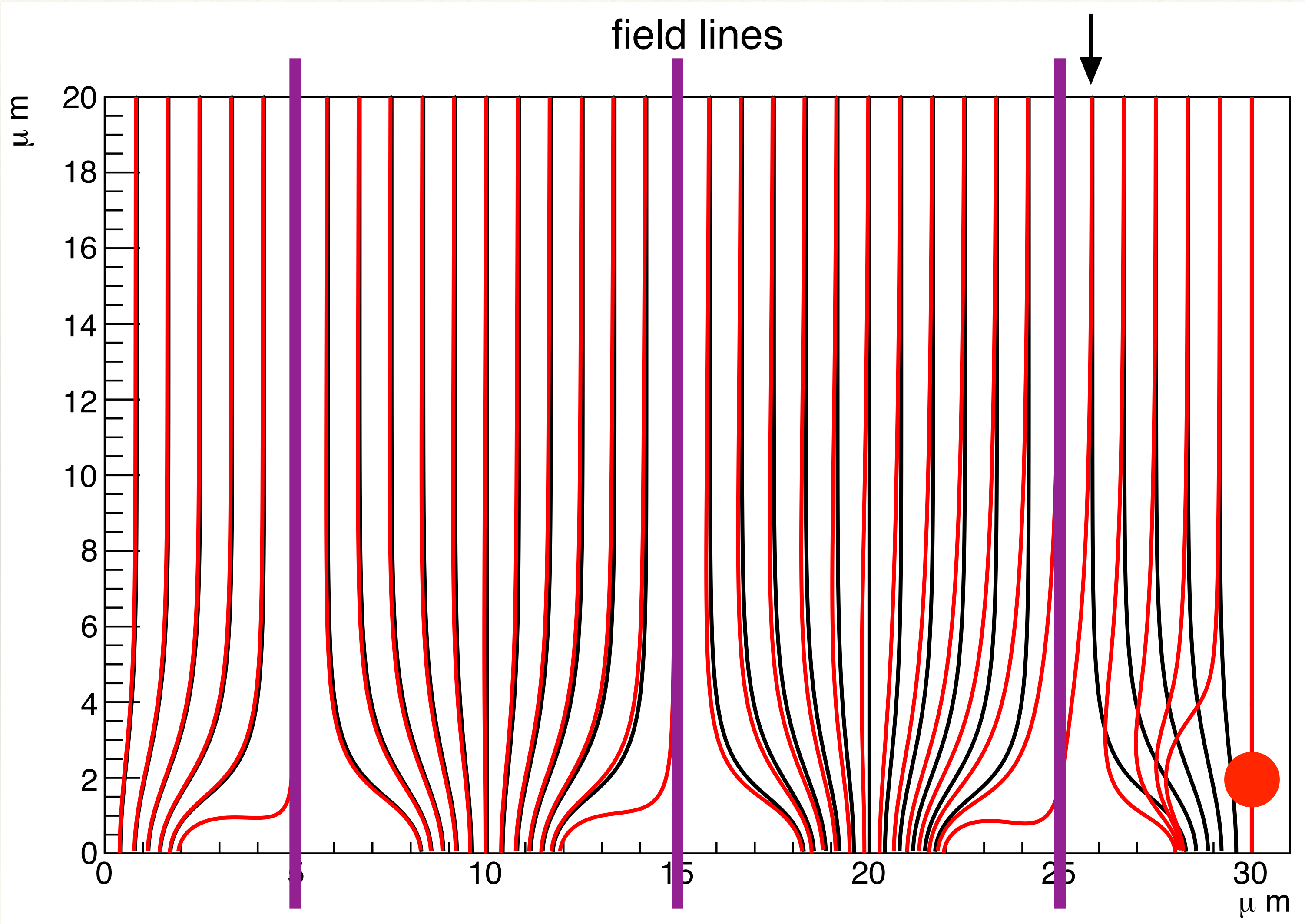
Brighter-fatter effect



Charge collected in this pixel…

Figure from Antilogus *et al*, arXiv 1402.0725

Brighter-fatter effect

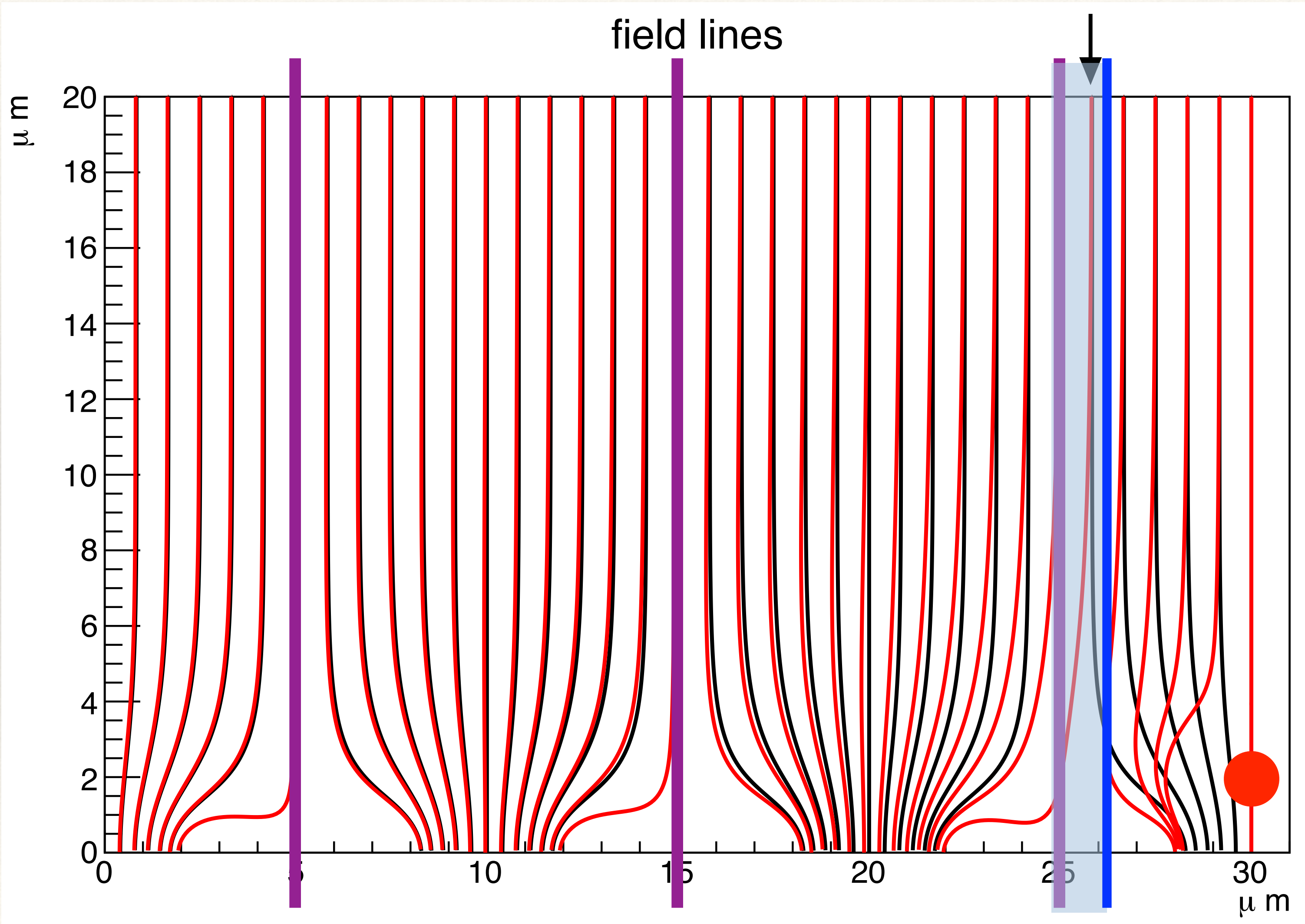


Repels further charge…

Charge collected in this pixel…

Figure from Antilogus *et al*, arXiv 1402.0725

Brighter-fatter effect



Shifts pixel boundary.

Repels further charge…

Charge collected in this pixel…

Figure from Antilogus *et al*, arXiv 1402.0725

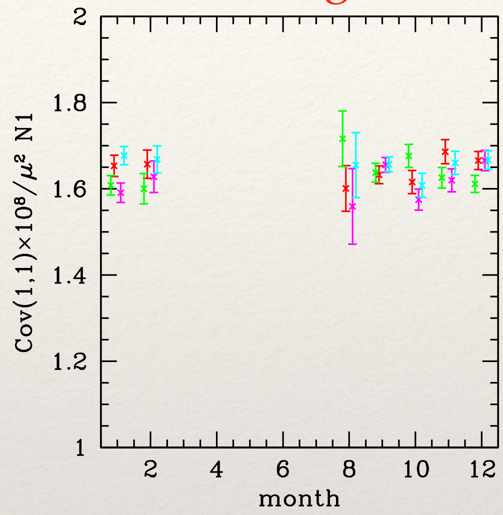
B/F behavior

- Object sizes (and shapes) depend on flux
- Image is quadratic function of illumination: charge shifts are the image convolved with some kernel.
- Pixel-size changes are manifested as noise covariances in flat fields, which can be measured to constrain the kernel (but still need to make some guesses to solve).
- Caused standard gain estimates to be wrong by ~10%!
- If you know the kernel, you can revert the effect on the image to good accuracy.
- Likely to be present on all CCD cameras, other integrating detectors too?

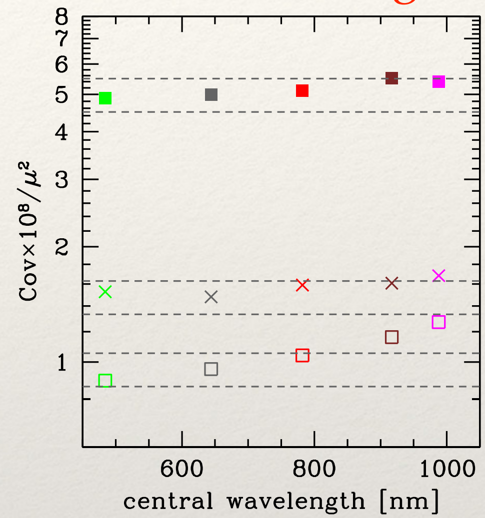
DECam's B/F

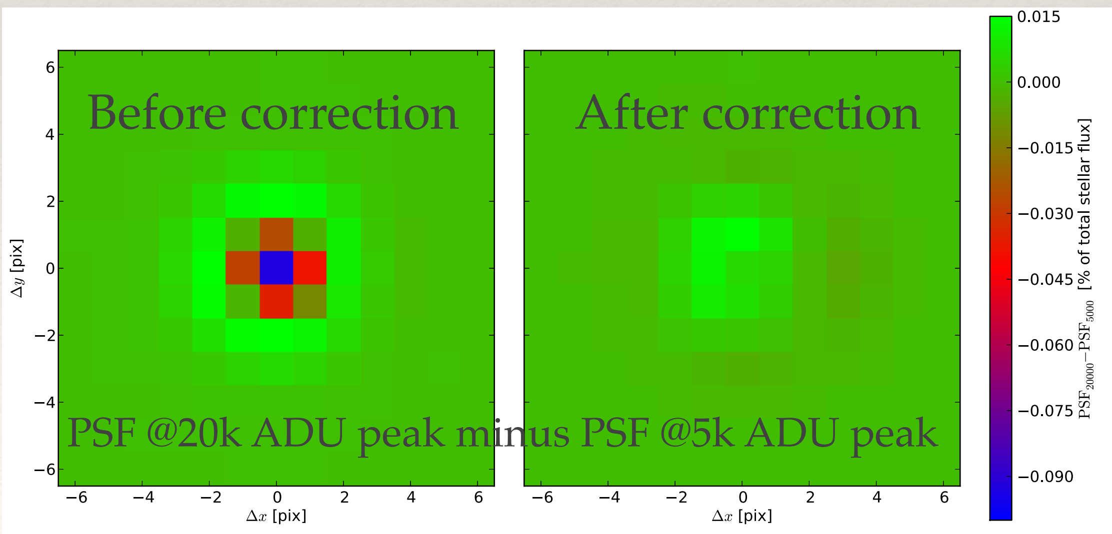
- Characterized by Daniel Gruen *et al.* (arXiv 1501.02802)
- Stars near saturation lose 2% of their signal in central pixel.
- Nearly independent of wavelength
- Same effect on both amps, amplitude varies between CCDs
- No sign of change with time
- Correction reduces effect on stars by ~10x

N1 B/F strength vs time



…vs wavelength



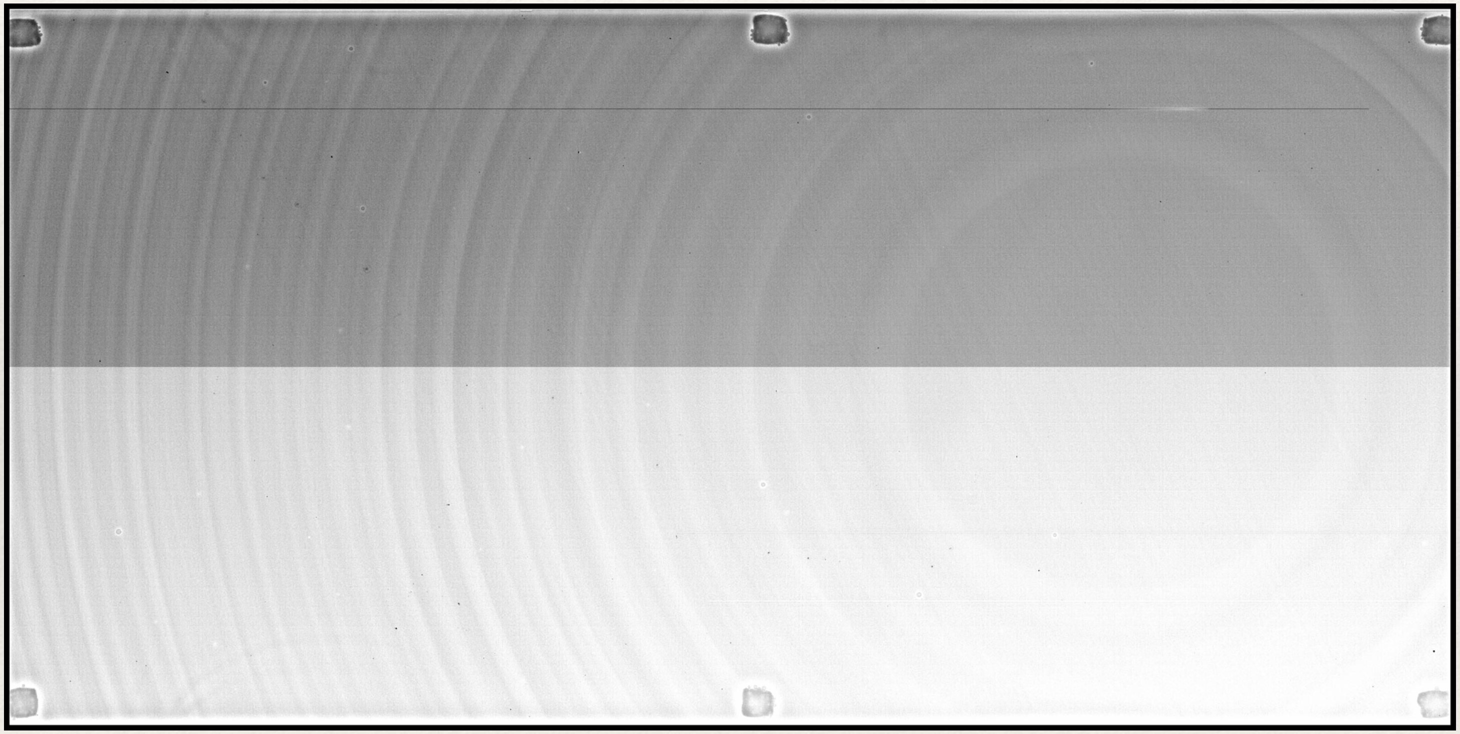


Key thoughts for detrending DECam data*

- ~10% of the photons detected *did not follow the design optical path*, i.e. they arrive after unwanted reflections.
- The camera signal from a smooth sky or dome is *not* the same as the response to focussed starlight.
- There are *variations in pixel solid angle and position up to 1% on many angular scales*, so there is a difference between calibrating *flux* and calibrating *surface brightness* in the pixels.
- The night-sky background needs to be *subtracted*, the source signal needs to be *divided* for calibration.

*or any other astronomical data, really!

Most of the visible structure in domes is pixel size variation!



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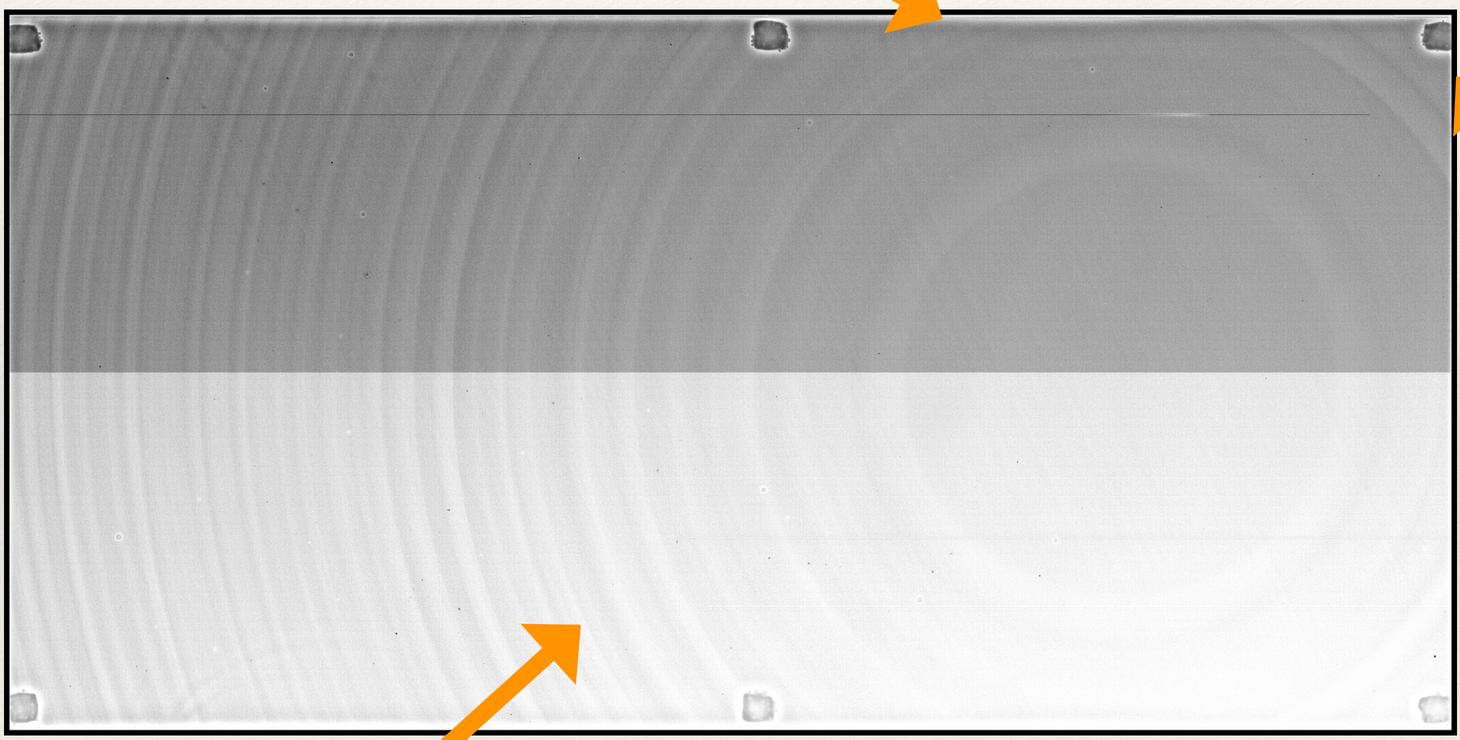

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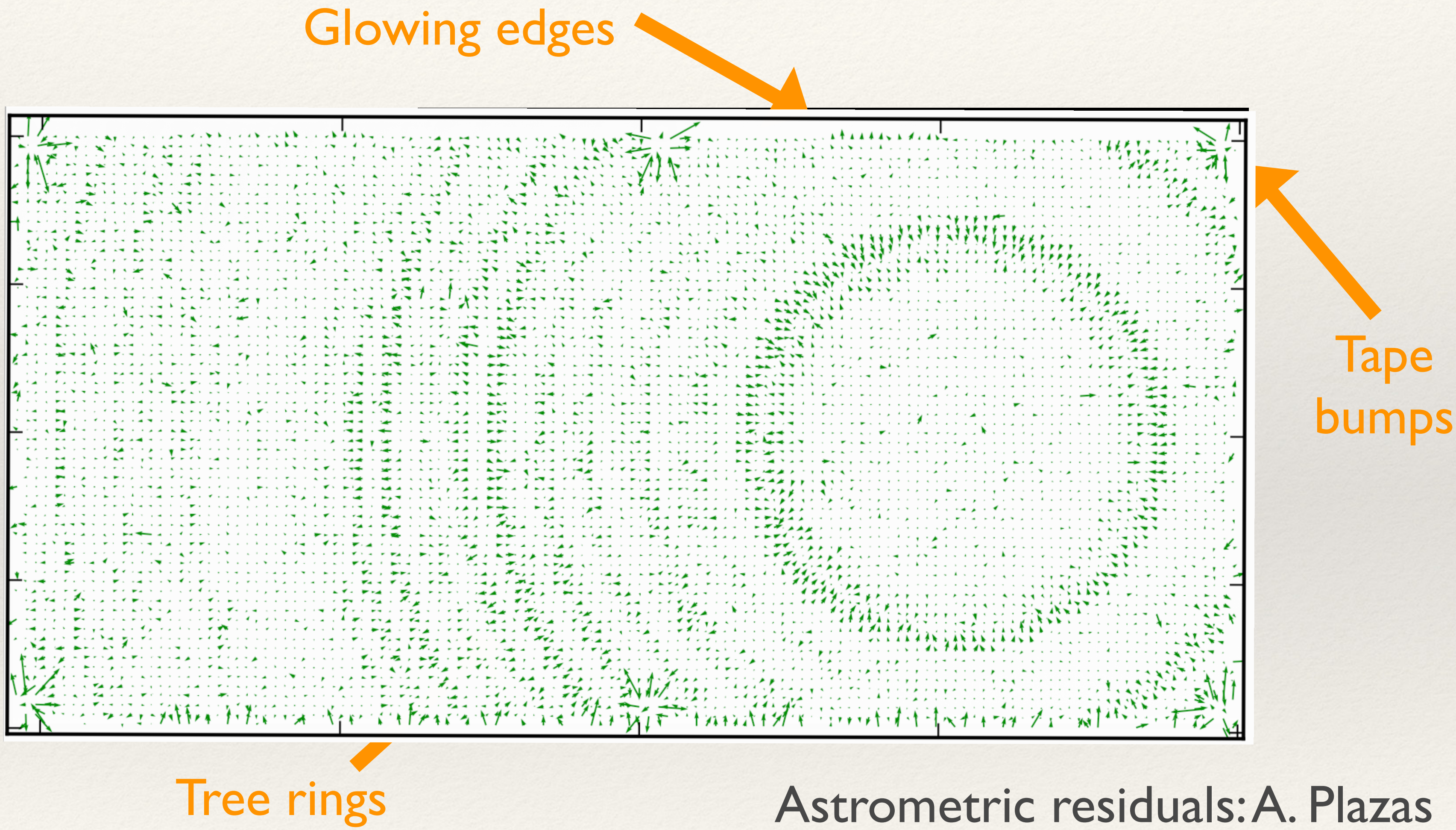
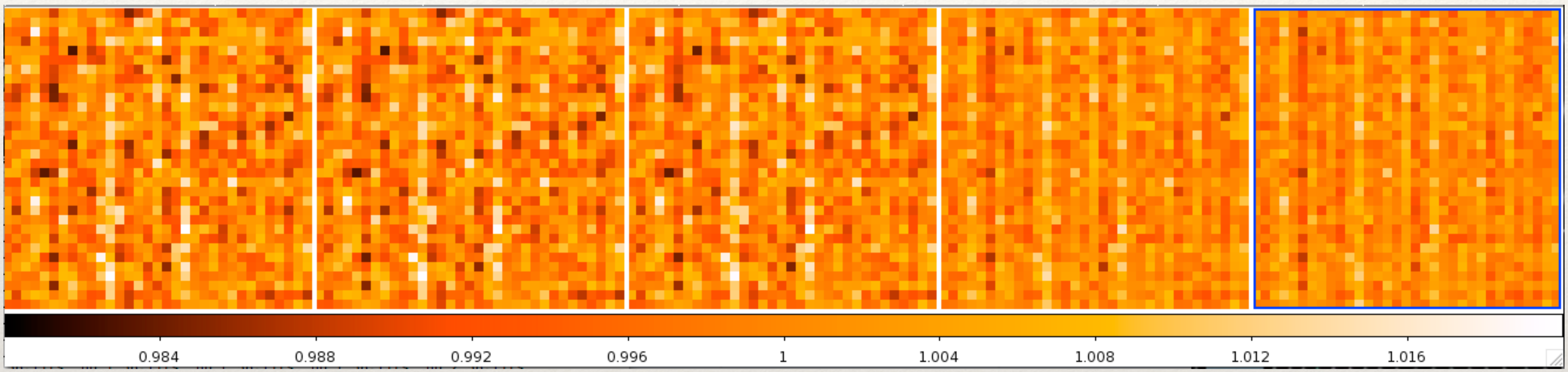


Astrometric residuals: A. Plazas

Small-scale structure in flats is also mostly pixel-size variation



g: 0.63% RMS r: 0.62% RMS i: 0.60% RMS z: 0.47% RMS Y: 0.43% RMS

- Patterns repeat across filters and are clearly not noise
- Some, but not all, of the variation has coherence on rows/columns
- Amplitude weakens near silicon red edge when some photons reach the gates
- Consistent with most but not all of small-scale structure being variation in the shape of gates/channel stops, 0.003 pixel @45 nm RMS, fields extend substantially into depletion region.

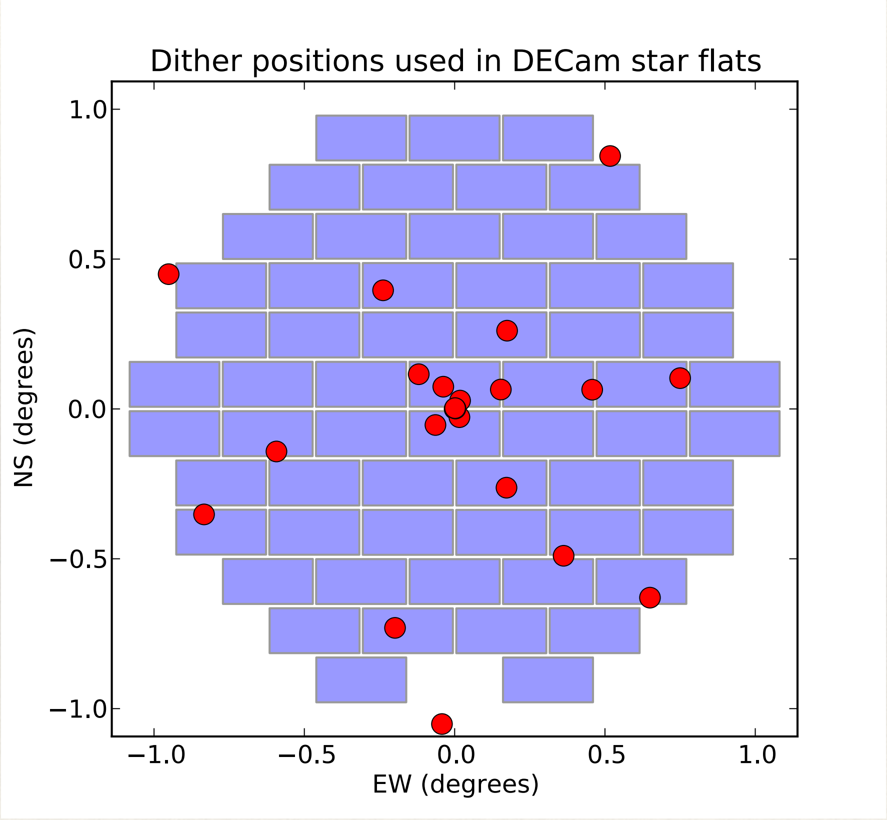
To dome or not to dome?

- Good things about dome flats:
  - They have very high S/N on all scales every night
  - They illuminate the focal plane without airglow spectral lines (no fringes)
  - Will fix any nightly changes in response - but are there any??
- Bad things about dome flats:
  - They are not the same spectrum as sources or sky
  - They are (at best) response to Lambertian source (including scattered light), not to focussed starlight
  - They can't distinguish QE variation from pixel-size variation.
  - The dome illumination is not the same every night! Varies by mmags

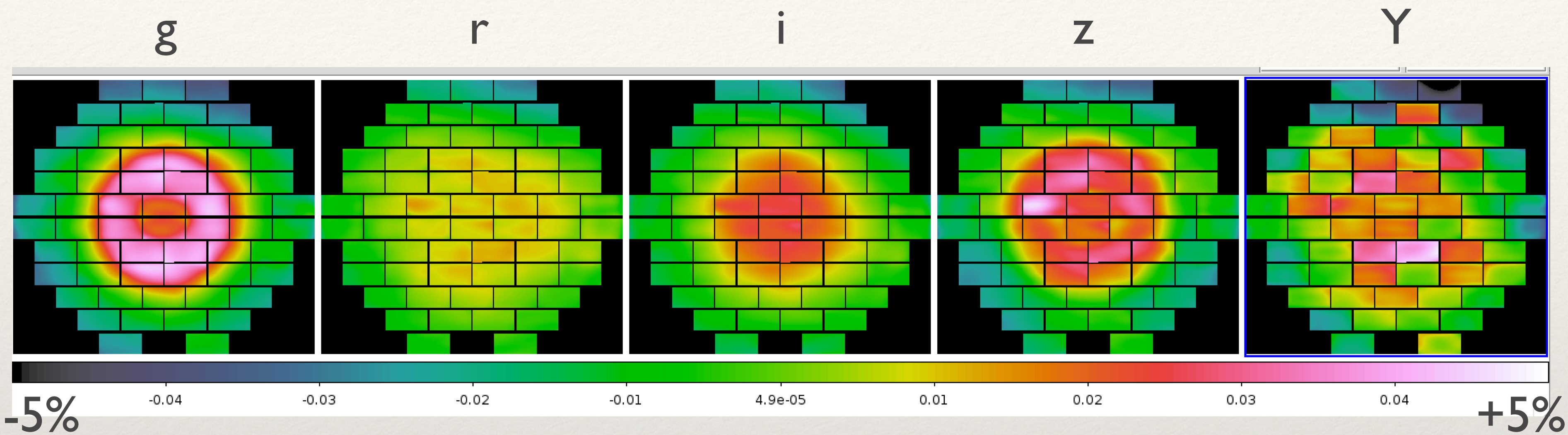
The right way to calibrate camera’s response to focussed starlight

…is to measure the signals from focussed stars!

- **Star Flats** are maps of stellar response constructed by forcing signals from each star to agree for exposures on many parts of the focal plane.
- Easy to obtain >10,000 high-S/N stellar mags per DECam exposure.
- Standard DECam sequence of ~20 exposures dithered by up to FOV taken every 2-3 months in each filter and solved for camera’s stellar response *after* normalization by a dome flat.

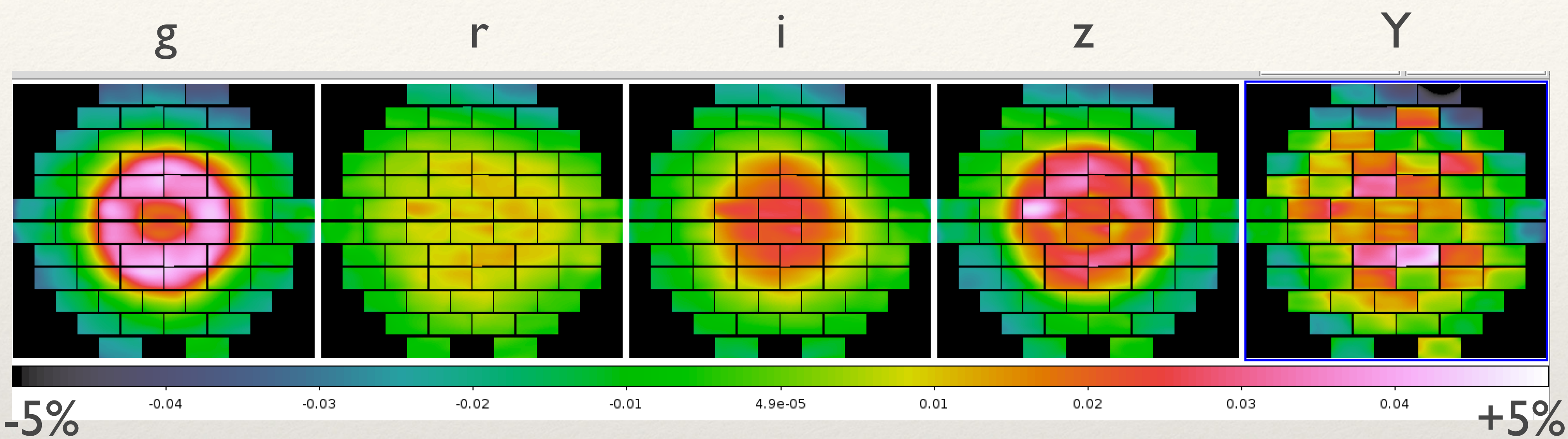


Star flats: large scale

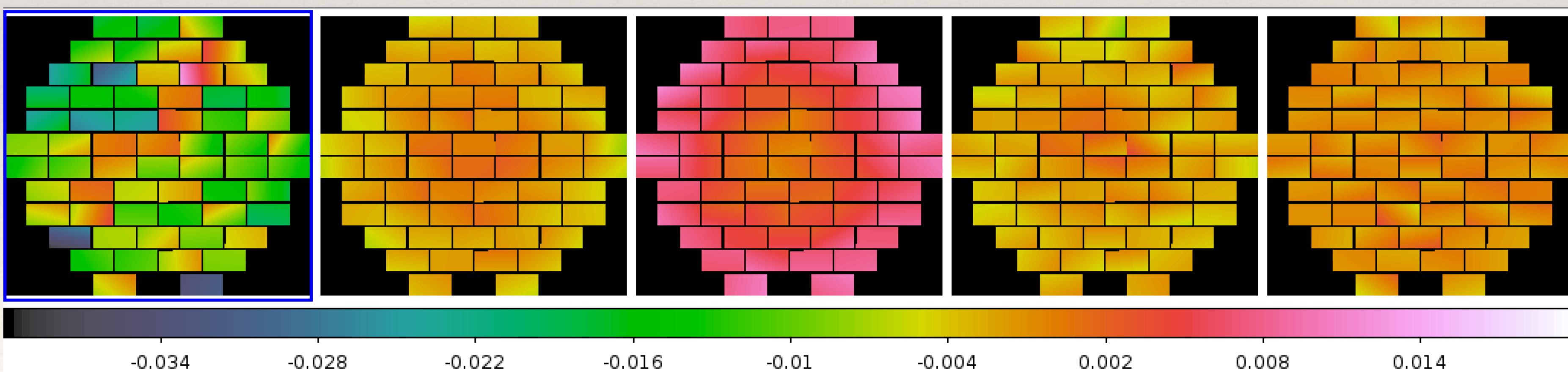


- Stray light is up to 10% of photons in a pixel from diffuse (dome) source.
- Agreement on pattern from 4 codes (Bauer, Bernstein, Regnault, Kent)
- Roughly as expected from Steve Kent optical models, but strongest at filter edges.
- Star flat data easily measures color term variation across array as well.

Star flats: large scale

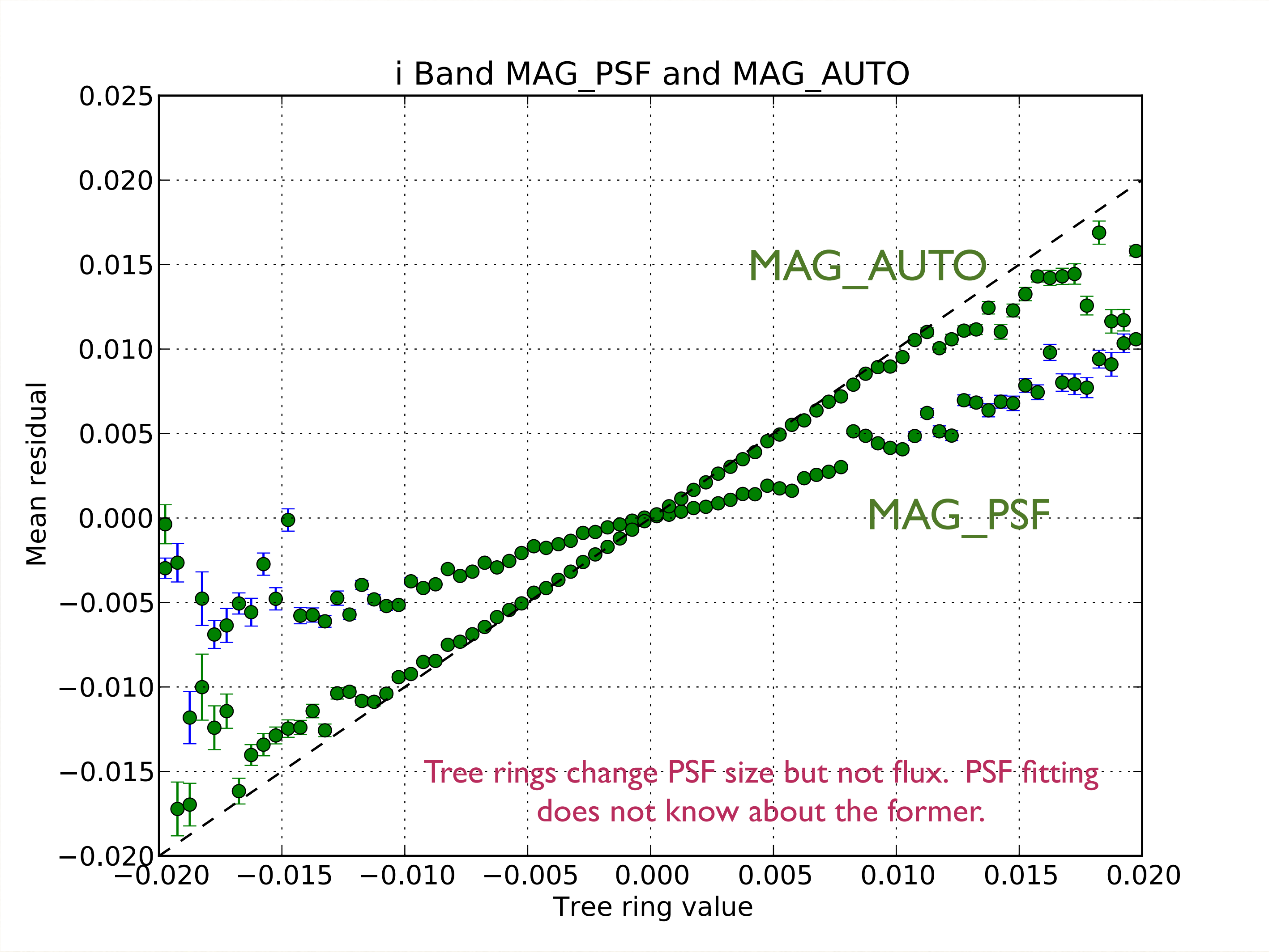


Color terms:



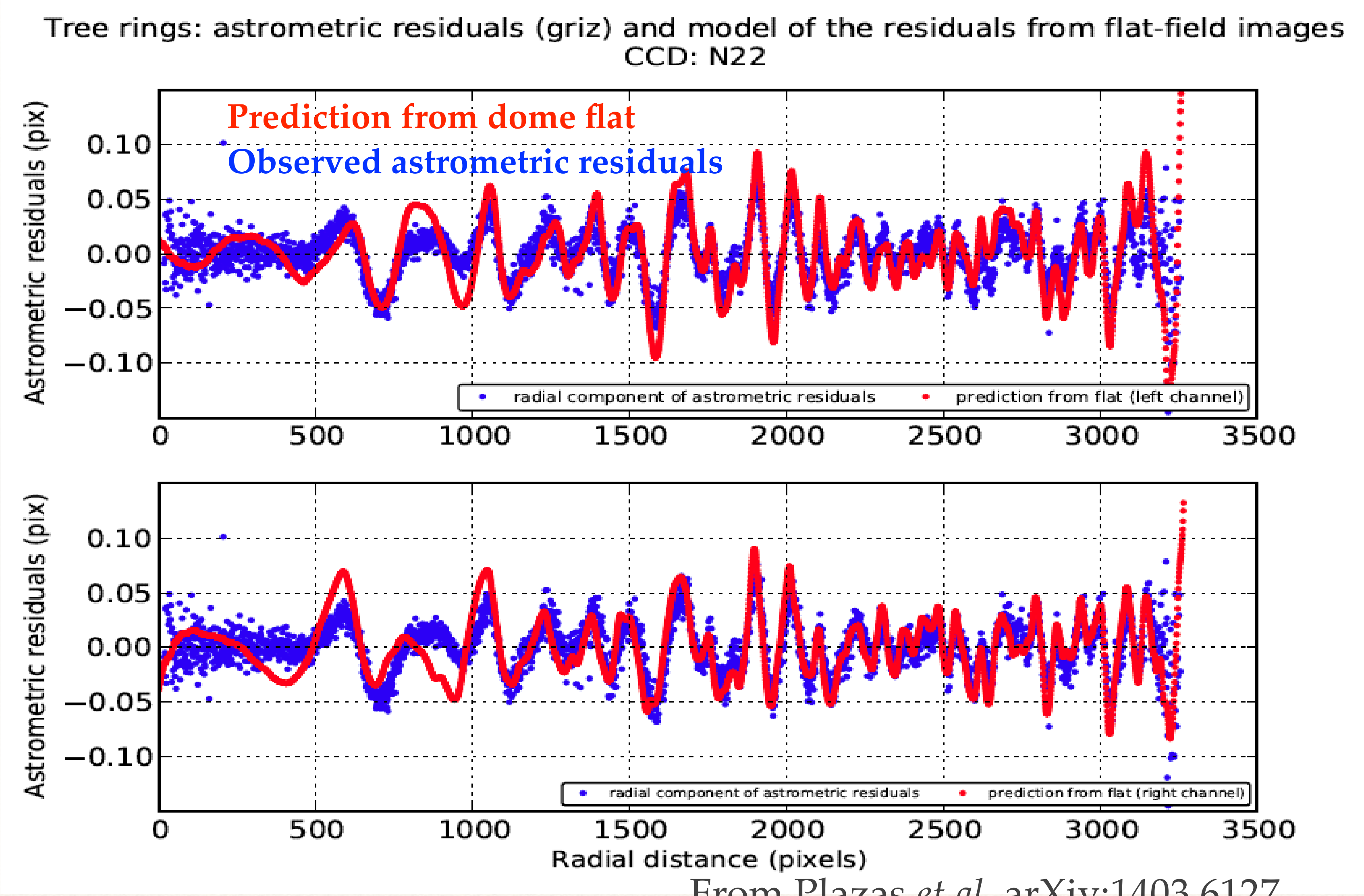
s.

Star flats: tree rings are pixel-area, not QE variation



Dividing images by dome flat makes aperture photometry *worse* for pixel-size variations

Rings in dome flats nearly perfectly predict annular astrometric displacements

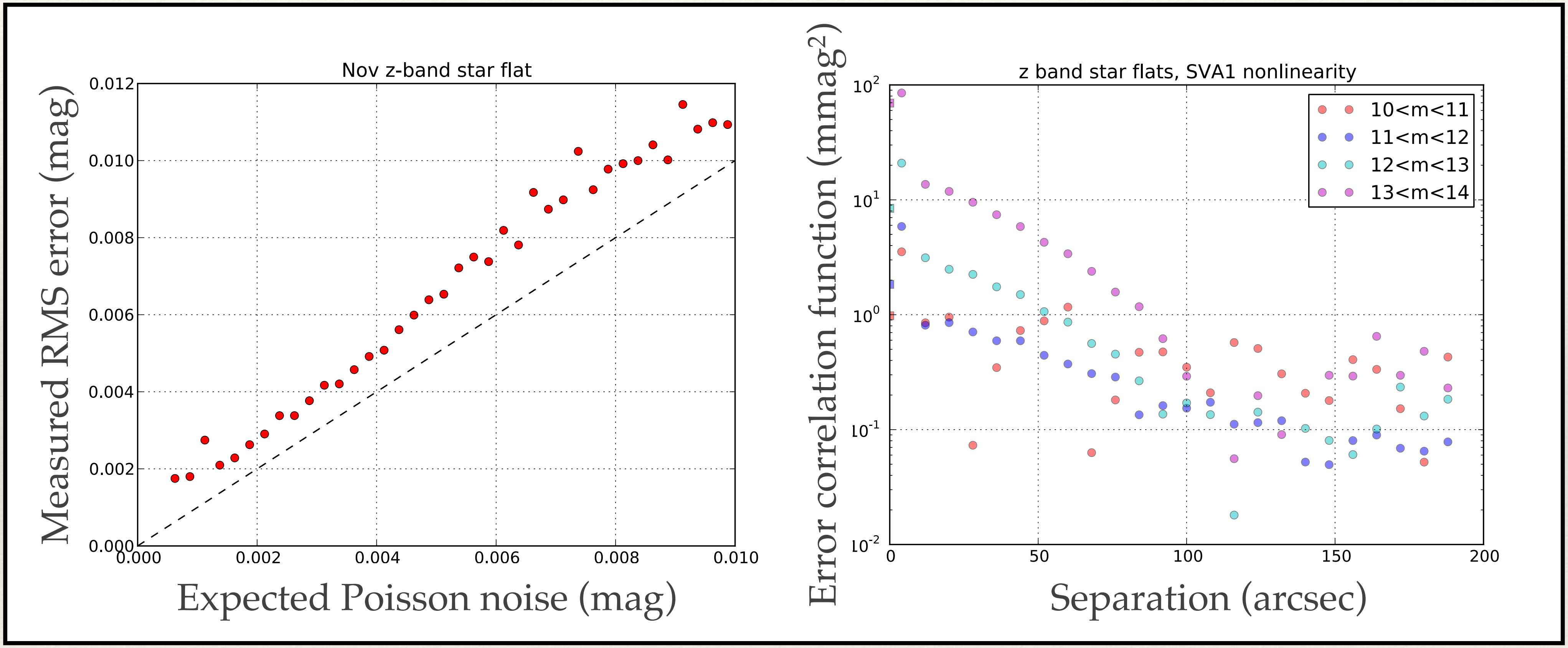


From Plazas *et al.* arXiv:1403.6127

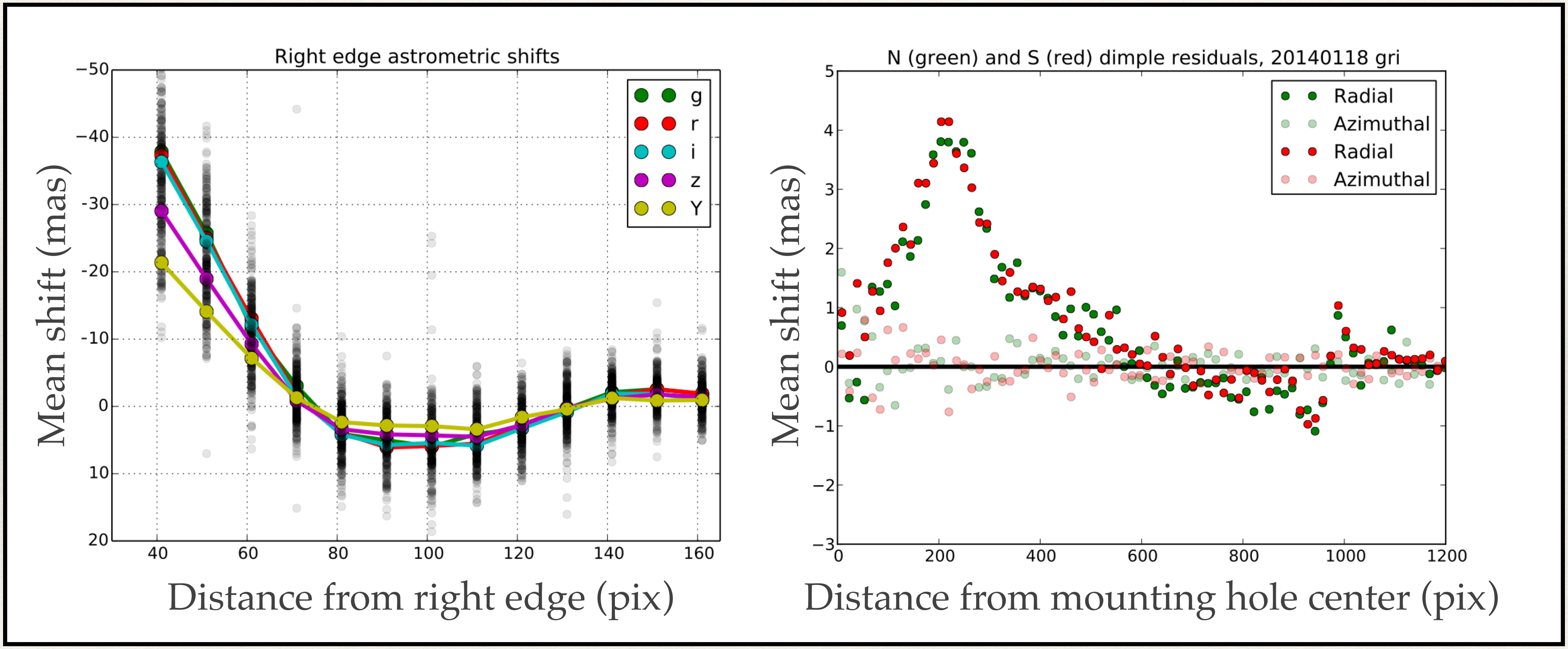
Astrometric / photometric models

1. Polynomial per CCD (plus polynomial color term), fixed for all exposures
2. Additional low-order polynomial across full array per exposure
3. Tree-ring template derived from dome flats, with free rescaling parameter per filter
4. Piecewise linear function of x (or y) near detector edges
5. Small-scale photometric response variations taken from dome flats, by necessity.

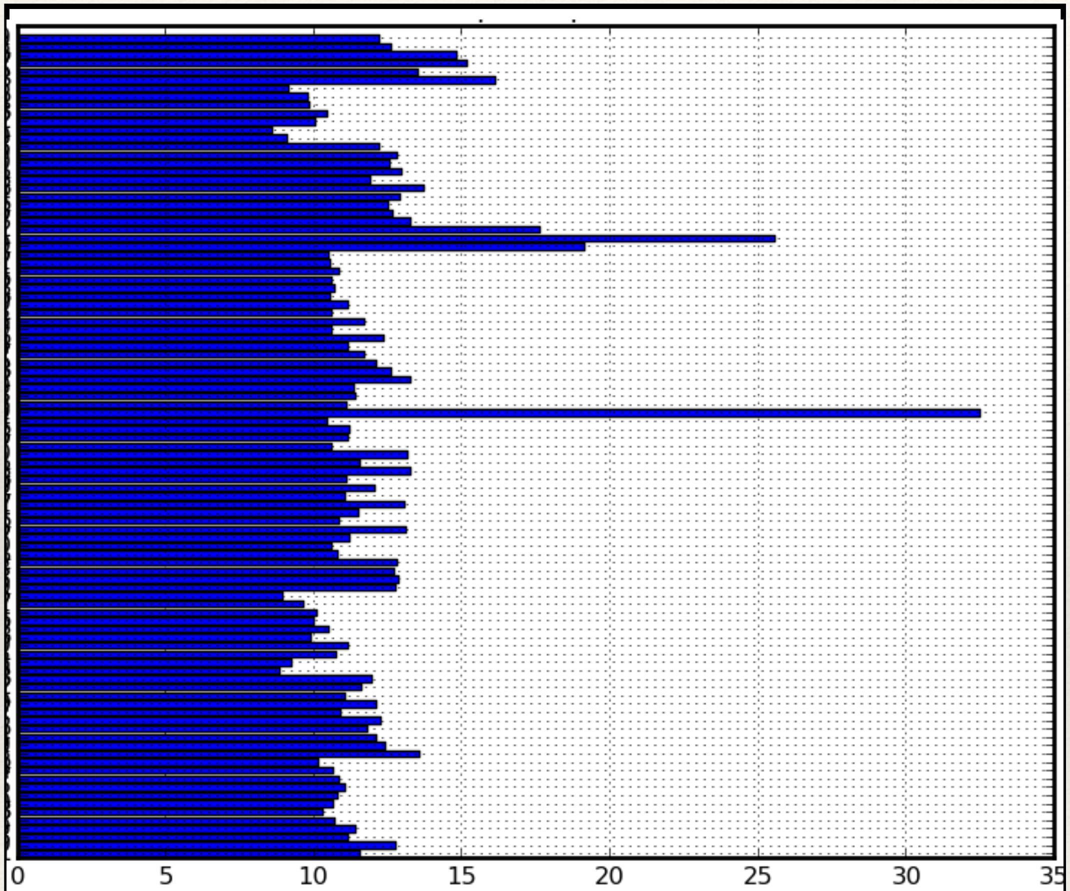
Photometric precision



Astrometric personality



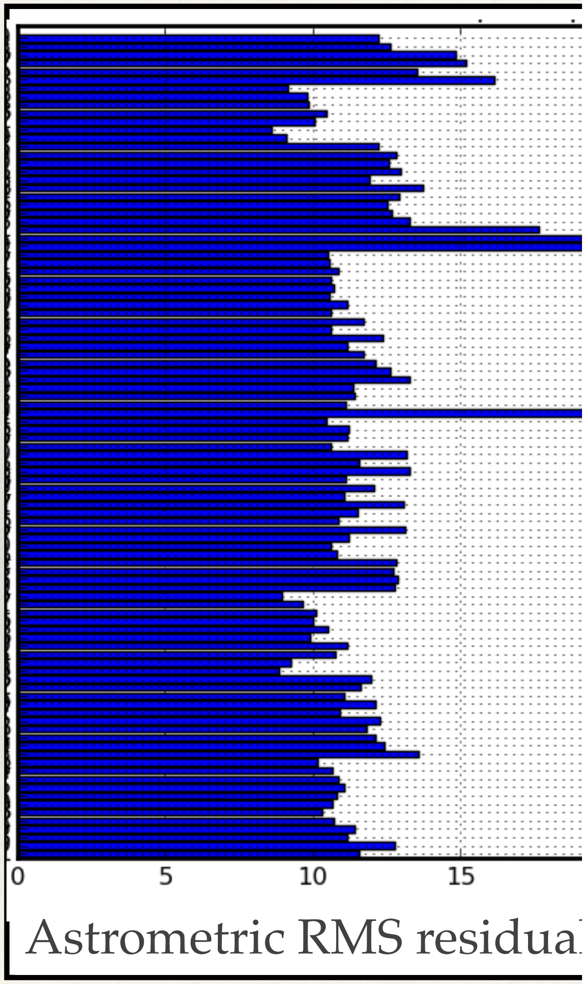
Astrometric precision

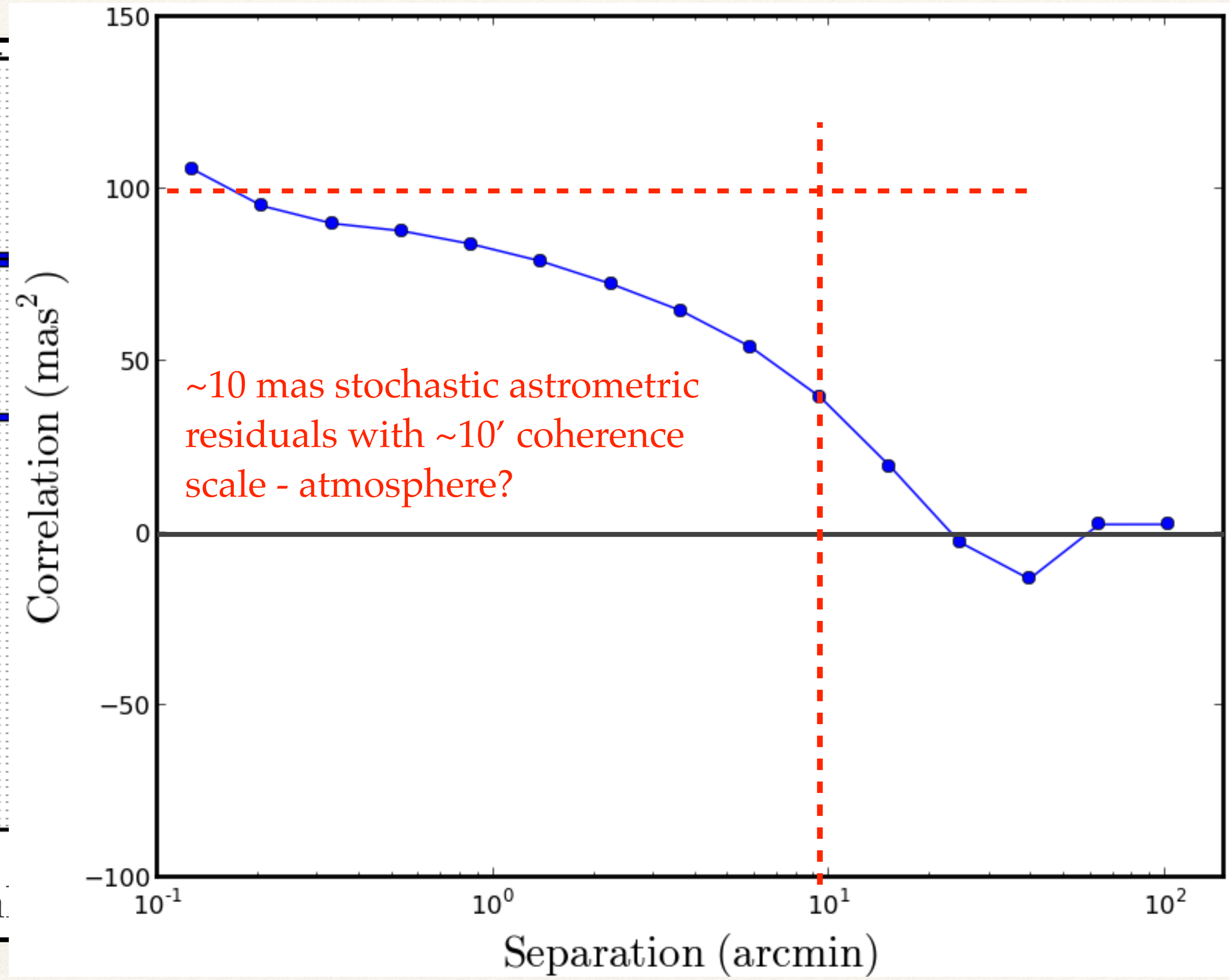


Astrometric RMS residuals (mas) per exposure

(from Bob Armstrong)

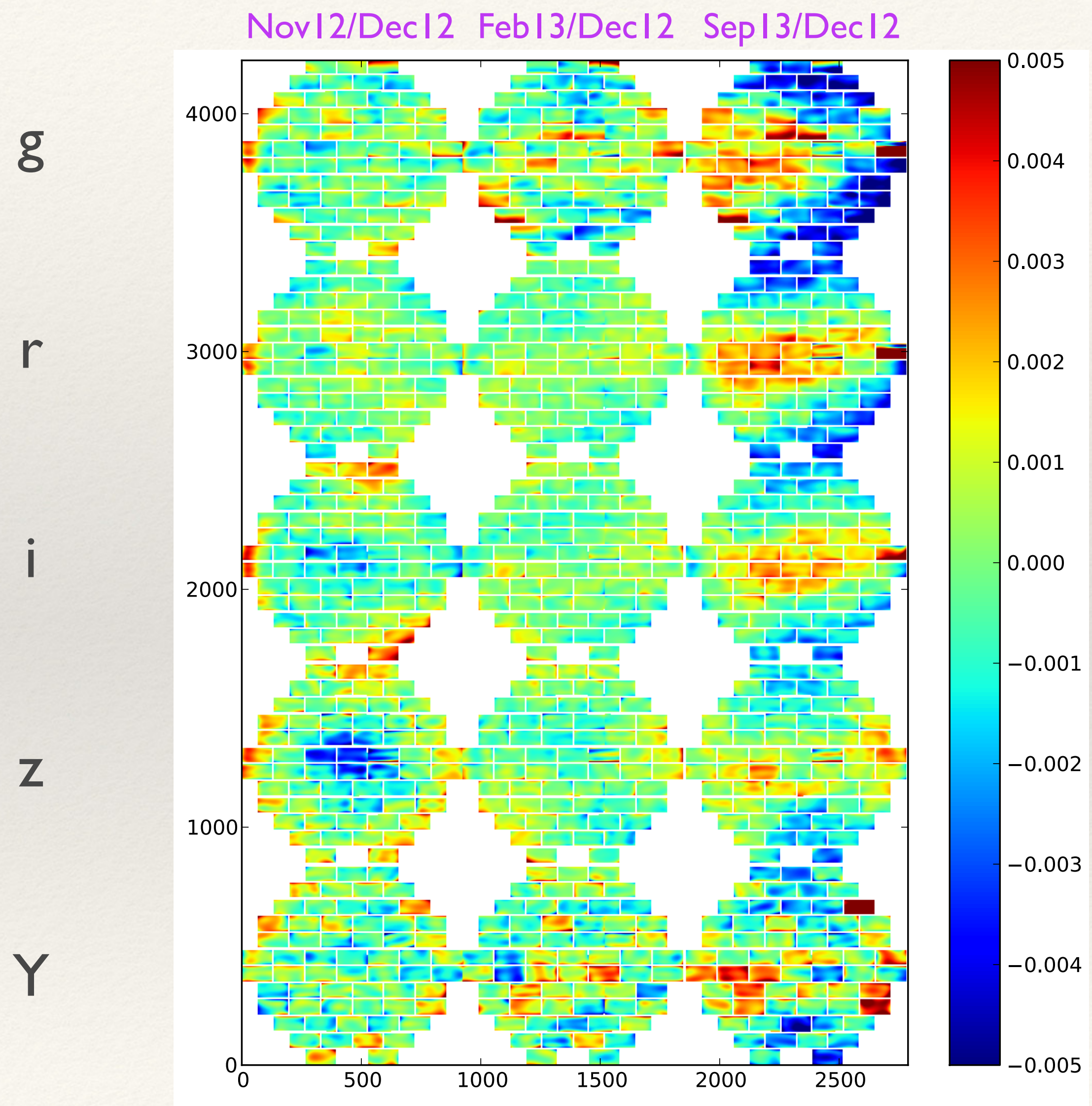
Astrometric precision





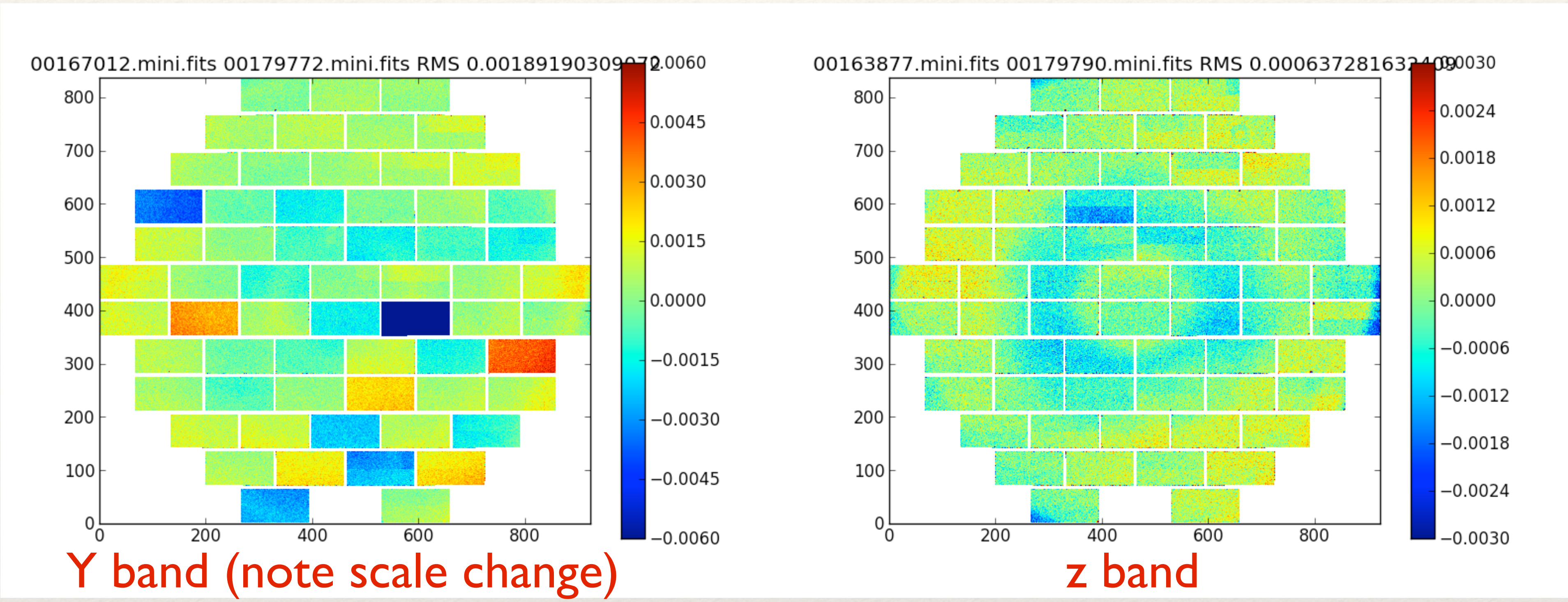
(from Bob Armstrong)

Photometric response changes few mmag over months



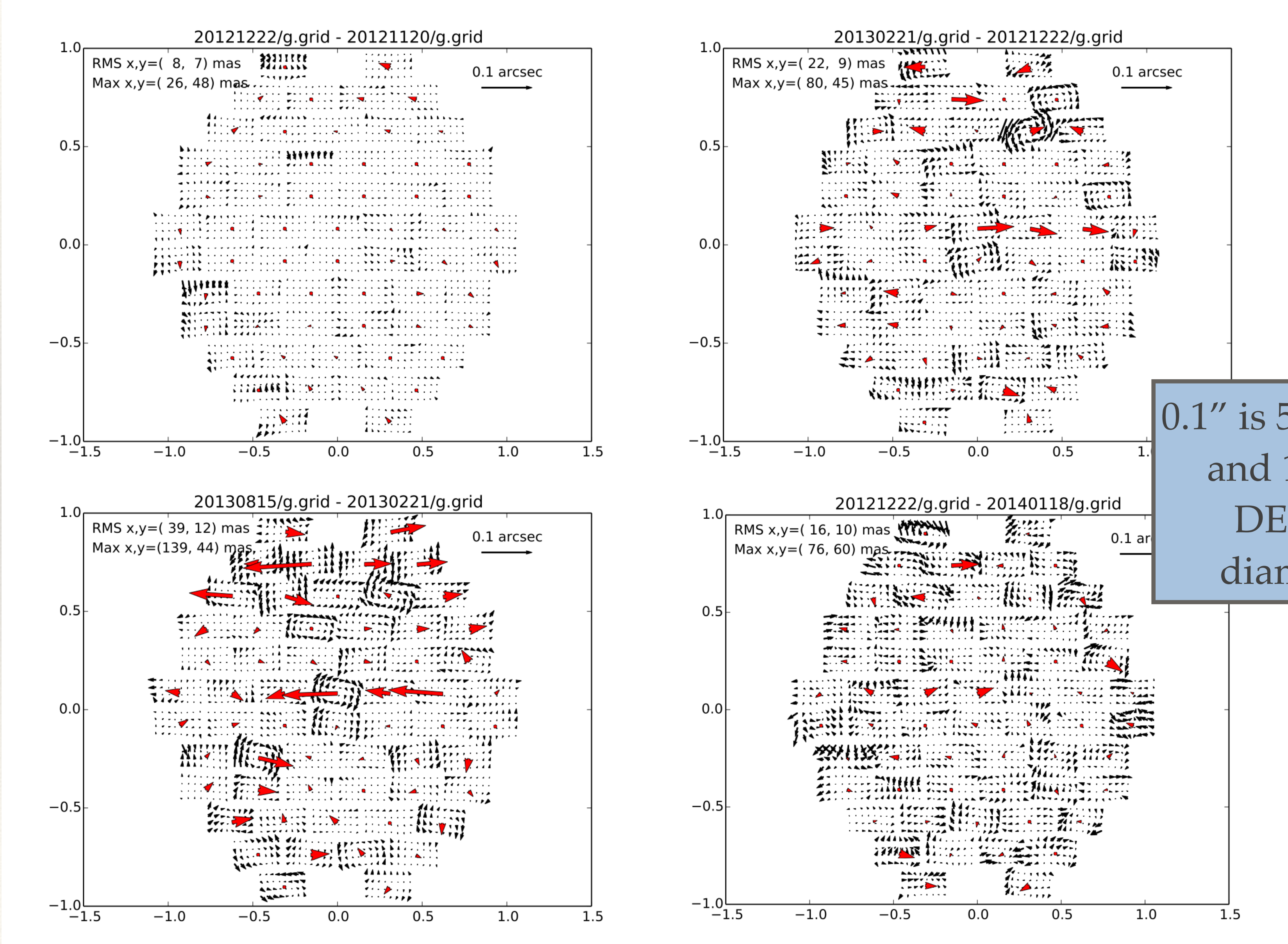
Dome x Star Flat relative to Dec 2012

Photometric changes in Y band after temperature fluctuations



Few-mmag change in response is consistent with a small change in silicon red edge response at a new equilibrium device temperature. Stellar response change is different from dome flat change. Detectable for focal plane temperature excursions as small as 5K.

Astrometric stability

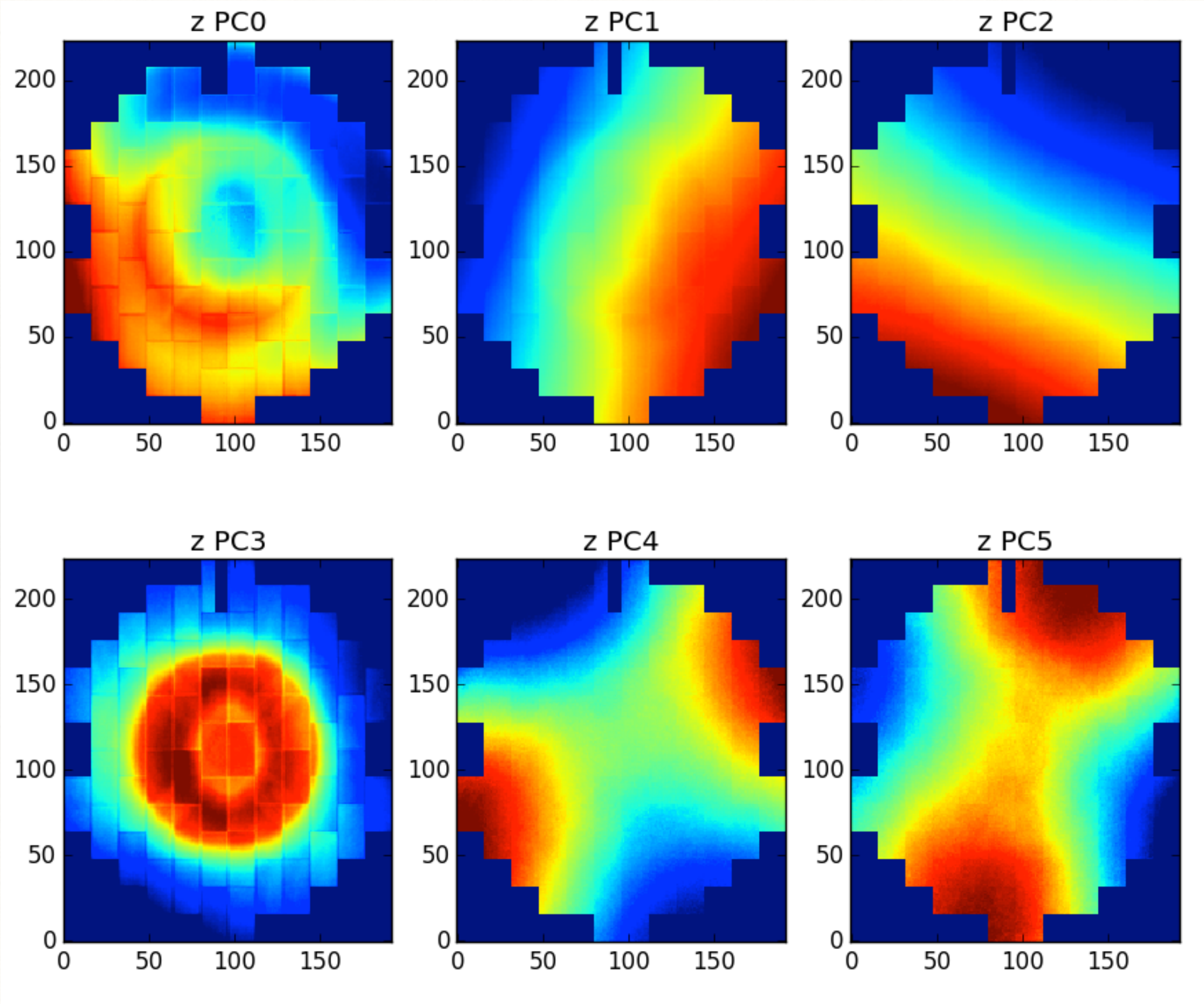


0.1″ is 5 microns and 10-5 of DECam diameter!

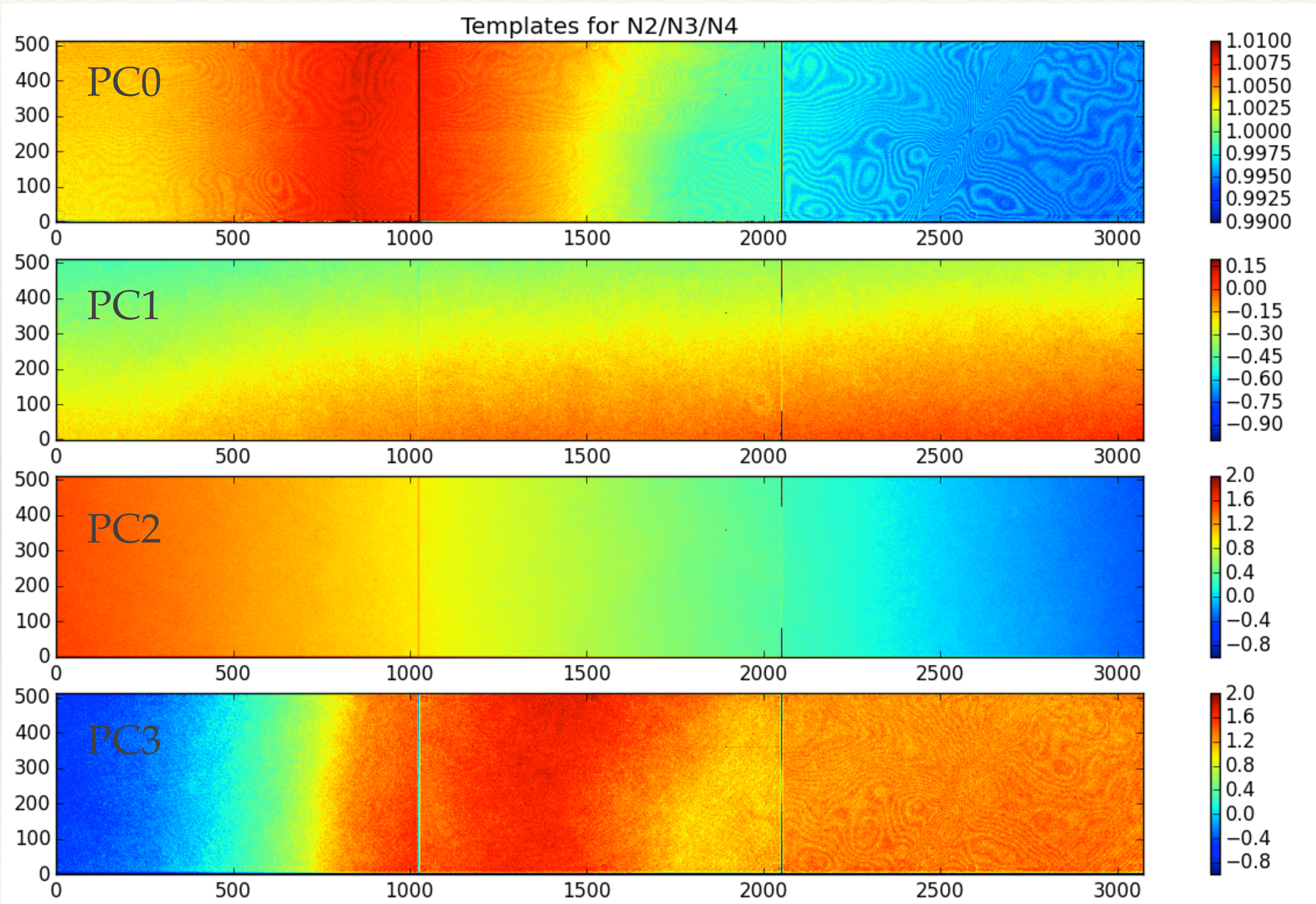
Sky subtraction

- "Sky"=signal from nearly uniform background; not ghosts or halos of individual celestial objects
- Expect this to depend on a small number of parameters:
  - Brightness and gradient of zodi
  - Brightness and gradient of scattered moonlight
  - Strength, spectrum of airglow
- Do *not* expect scattered-light pattern of sky to be the same as that of dome flat.
- Perform robust principal-components analysis on ~1000 DECam images per filter.

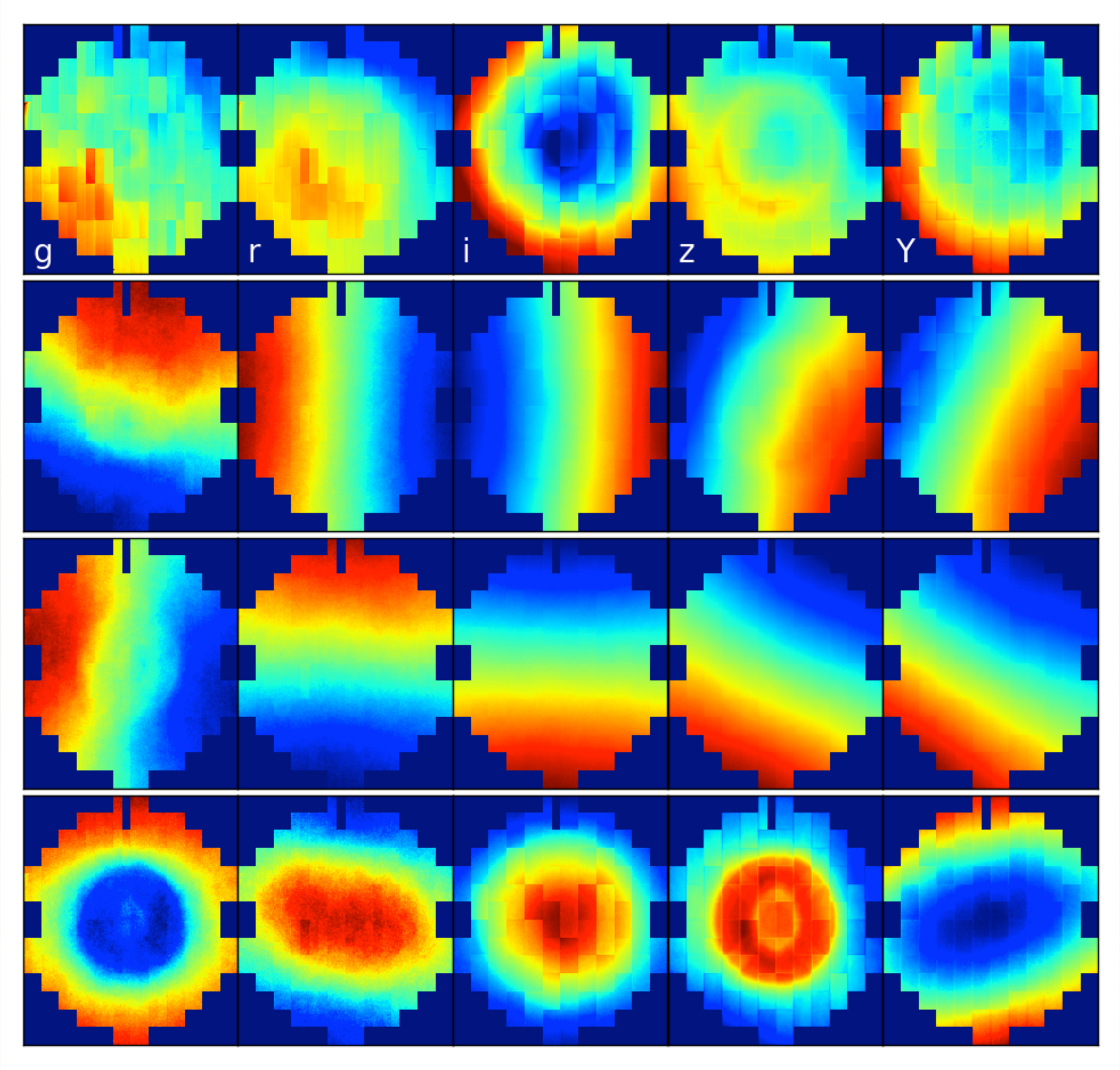
Large-scale view of z-band sky components



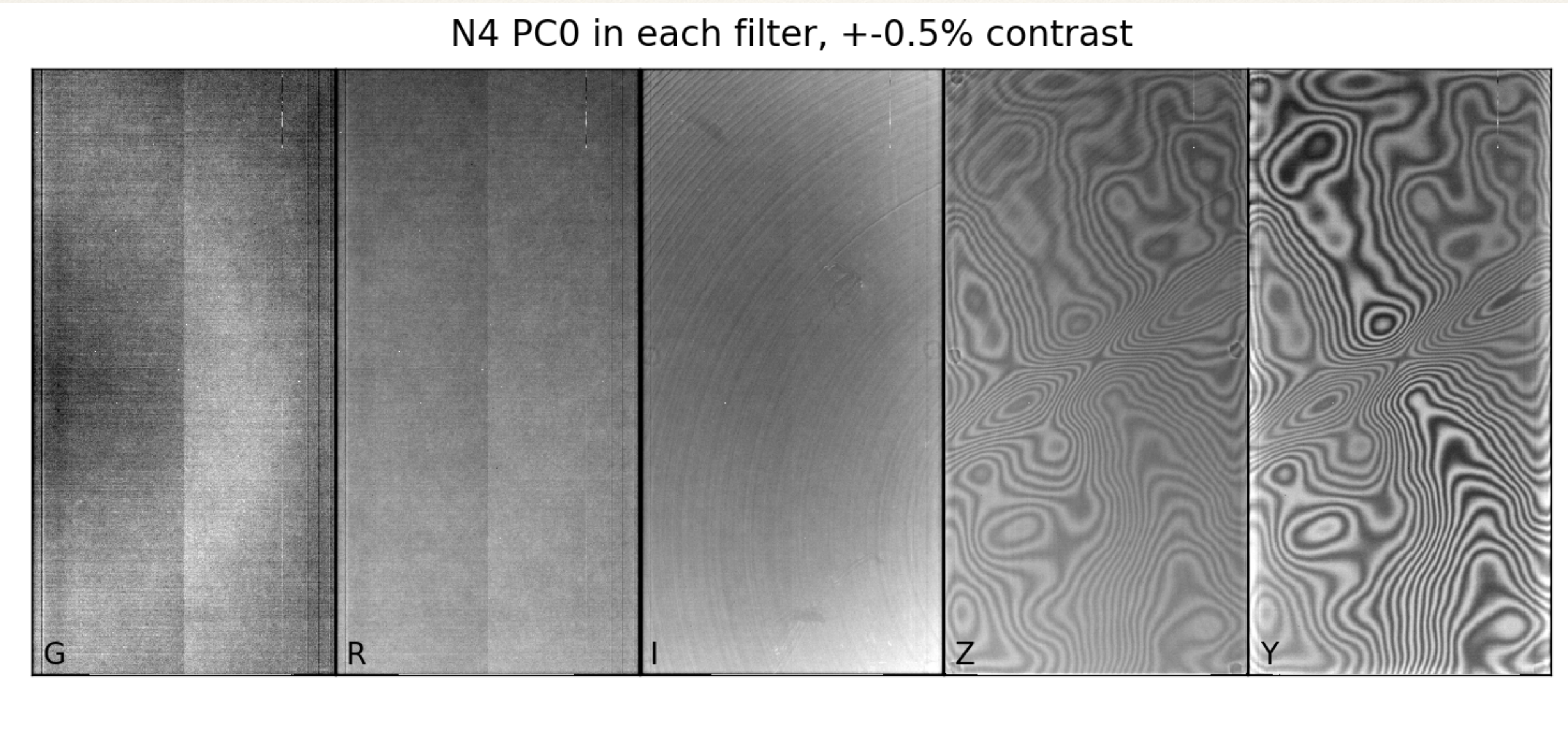
Small-scale behavior of z-band sky components



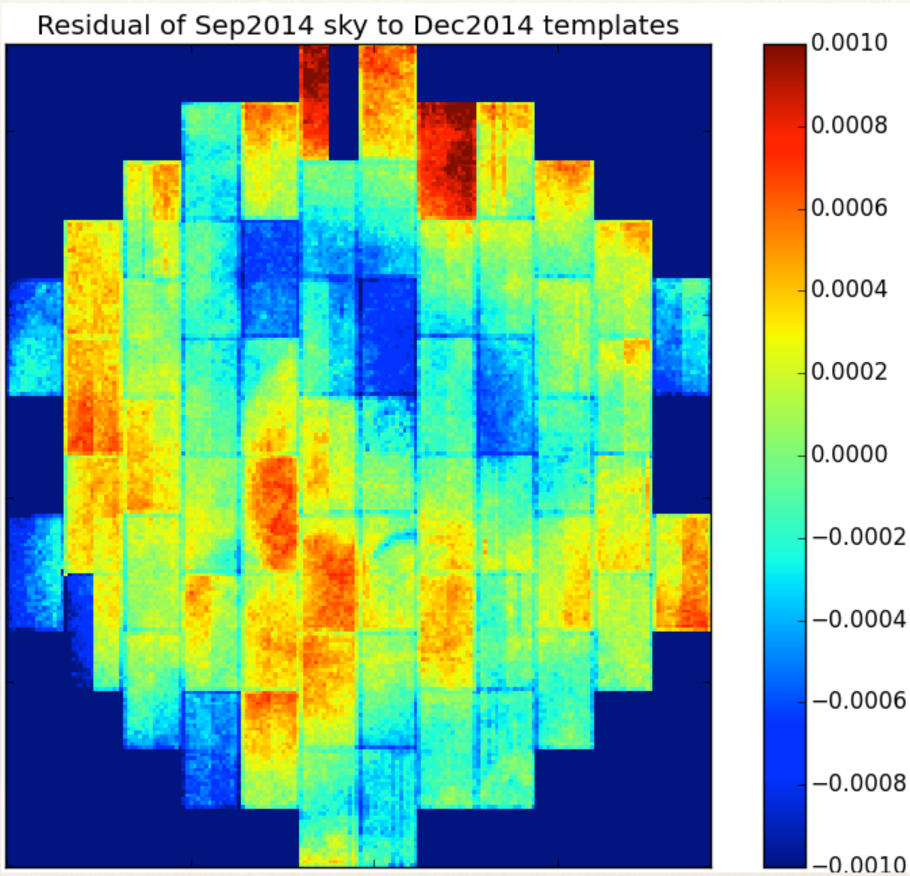
Top 4 sky components *grizY*

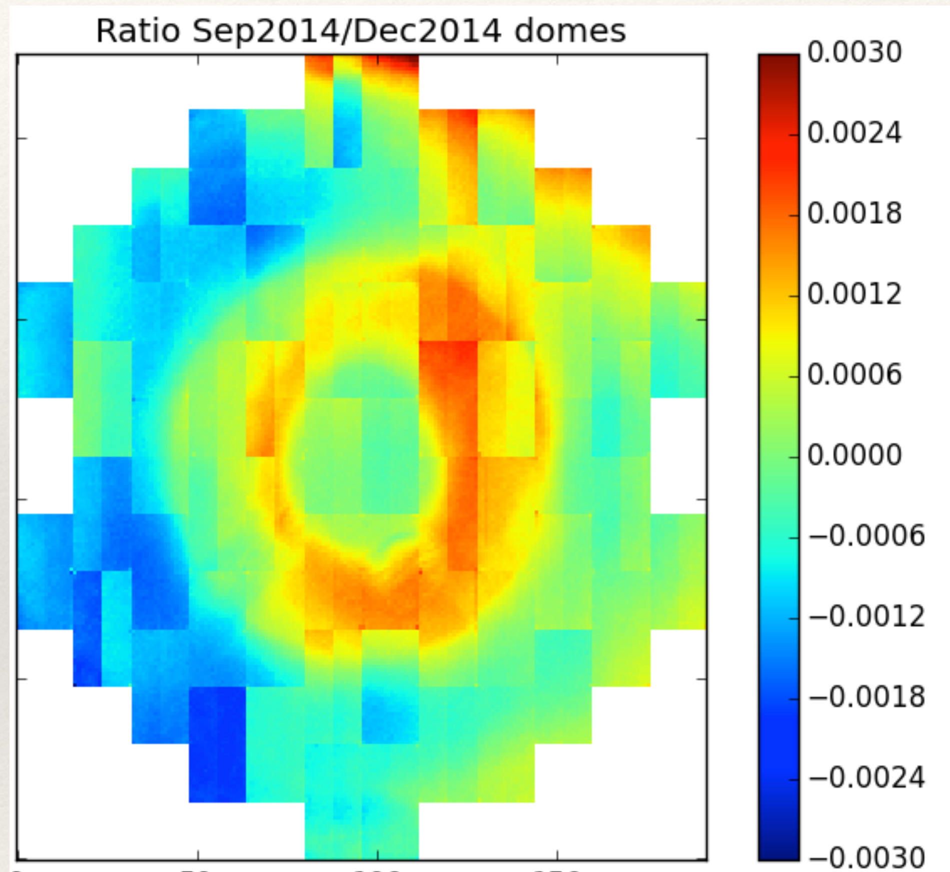


PC0 for CCD N4 in *grizY*



Sky signal stability in DES Y2

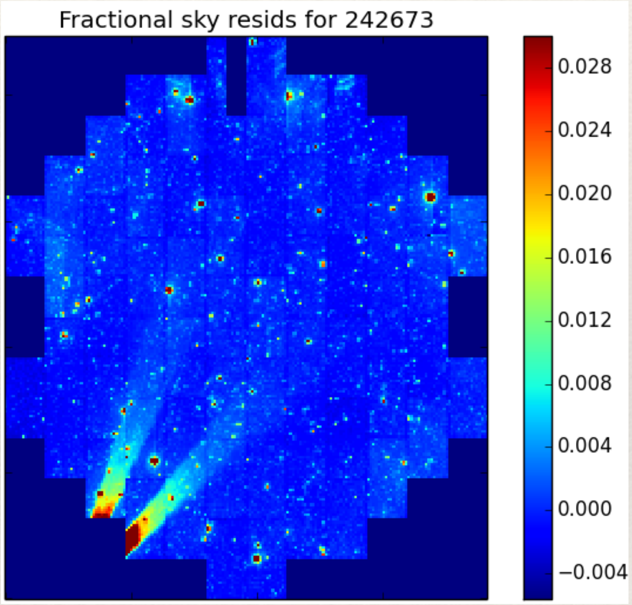




The sky pattern is stable to <0.1%… while the dome pattern changes +-0.3%!

Residuals sky after fitting and subtracting 4 templates

- Many "rays" like this are seen - gone after 2014 March painting of shiny filter-box surface identified by Steve Kent.
- Look at 49 worst *r*-band residuals.
- Fringes gone too, but possibly some very weak phase changes of fringe pattern.
- Typical exposures has RMS sky residuals below 0.005 of sky amplitude.
- Still need some local sky determination for most science.



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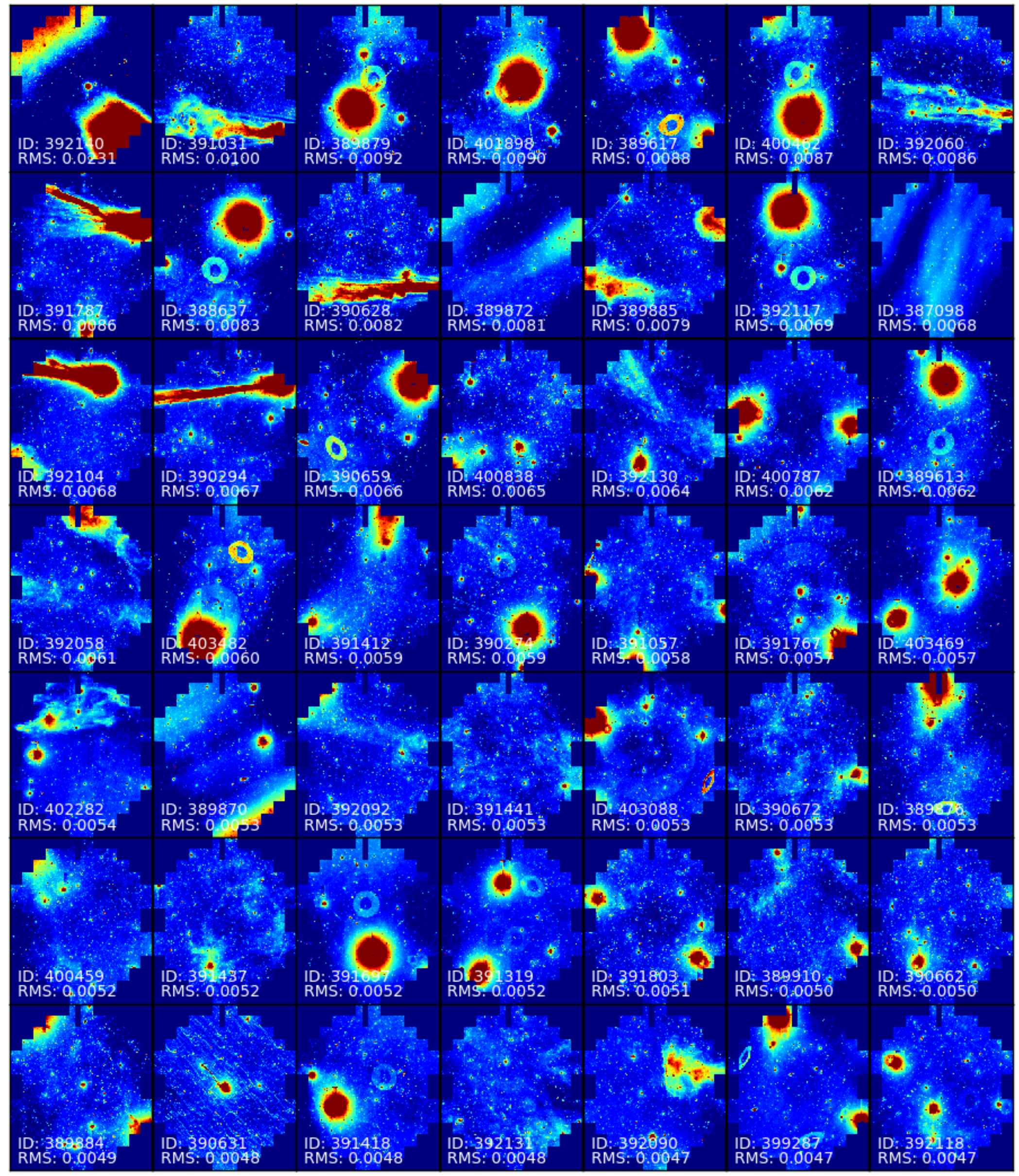
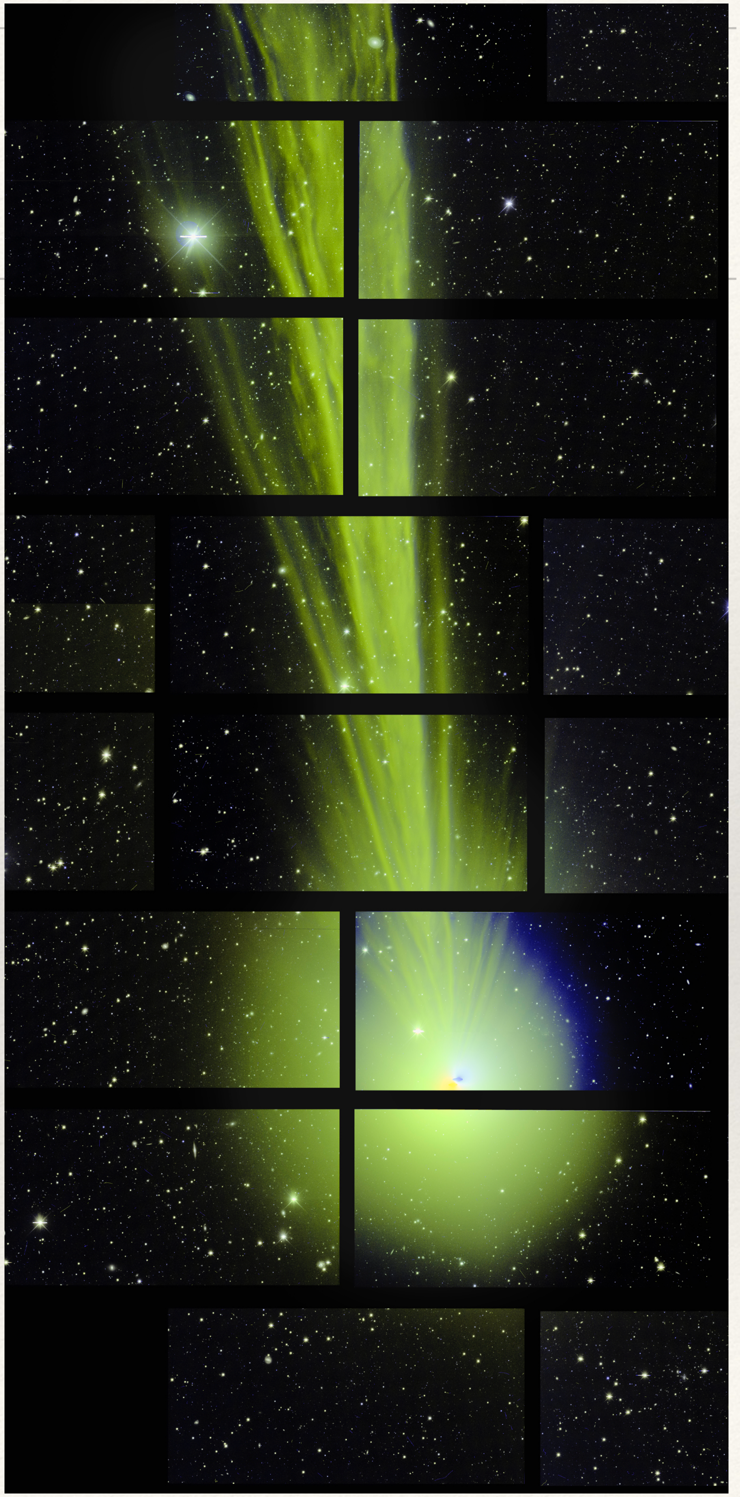


Summary: DECam

- DECam is *very* well behaved and stable.
- Aside from LLLNL, all of the subtleties we have found are likely to have been present in all CCD cameras at some level.
- DECam photometric response can be calibrated across array to <2 mmag for single night's data. Global calibration accuracy TBD.
- Astrometric residuals of ~10 mas appear dominated by stochastic atmospheric effect.
- Calibrations appear stable at ~3 mmag, <10 mas level on seasonal basis (excepting warmups). More stable than the dome flats.
- Sky PCA is successful at removing fringing, "pupil ghost," and identifying large diffuse sources in the field



Summary: pipelines

- Precision photometry, astrometry, or shape measurement must incorporate these steps:
  - Star flat corrections for focussed vs diffuse illumination
  - Mid-scale astrometric (and pixel-area) corrections from tree rings, edges, + ???
  - Brighter/fatter correction, including re-calculating gains
  - …and you already know that atmospheric refraction and extinction, and clouds, are not constant across DECam FOV!
- Above effects are being incorporated into DESDM Y2A1 processing, along with
  - PC-based sky subtraction
  - Calibration "epochs," full-array normalization.
- Migration of above into CP is TBD
- YMMV: low-background linearity, Y-band calibration at mmag level