Image Differencing for LSST

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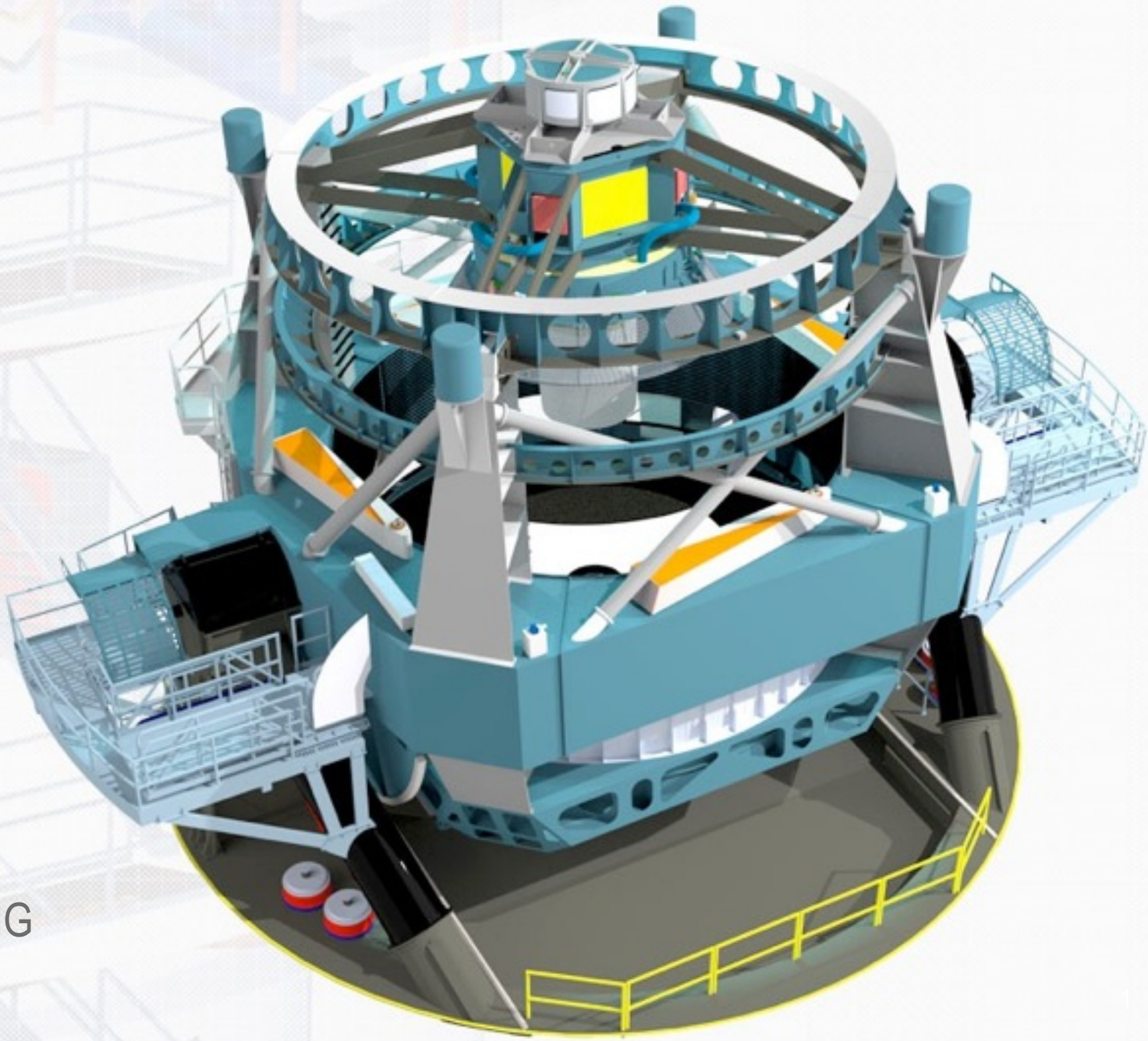

ZTF - LSST JOINT MEETING
November 12, 2014

Overview of Image Subtraction

- Two Snaps of a Visit are combined into an Exposure **I**
- A previous deep Template image **T** is retrieved

Overview of Image Subtraction

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Classical Method

- The PSFs of **I** and **T** are matched via matching kernel **K**
  - $I \approx T \otimes K$
- Subtract the images pixel-by-pixel
  - $D = I - T \otimes K$
- Filter for detection
  - $D' = D \otimes PSF_I$
  - Positive and negative detections
- **Measure on D**

Prefiltering Method

NOTE: $D' = I \otimes PSF_I - T \otimes K \otimes PSF_I$

- Filter **I** with PSF_I
  - $I' = I \otimes PSF_I$ (likelihood image)
  - FWHM $I' = \sqrt{2}$ FWHM **I**
- The PSFs of I' and **T** are matched via matching kernel K'
  - $I' \approx T \otimes K'$
- Subtract the images pixel-by-pixel
  - $D' = I' - T \otimes K'$
- Detect on D'
- **Measure on D'**

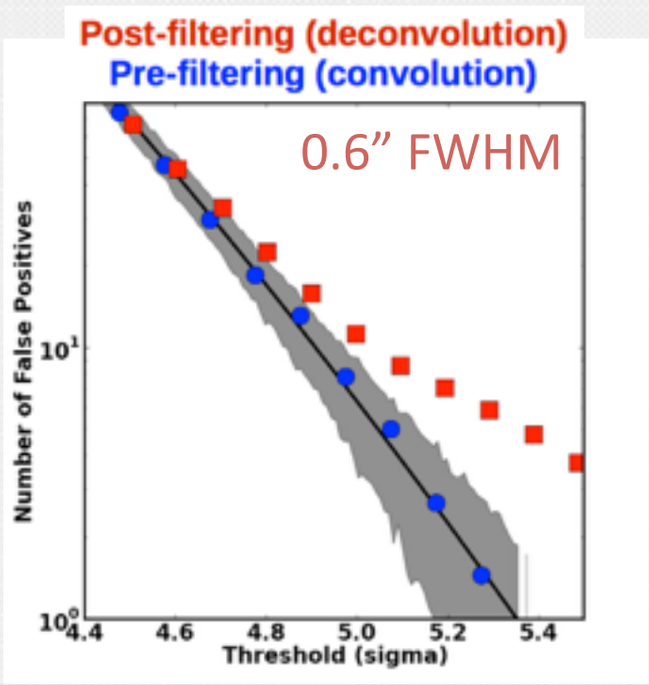
Overview of Image Subtraction

- **K** is modeled using a linear combination of bases $\mathbf{B_i}$
  - $\mathbf{K} = \Sigma_i \mathbf{a_i B_i}$
  - Coefficients $\mathbf{a_{i,j}}$ are determined using two sub-images of same object at position x_j, y_j
    - Reflects intrinsic match of basis set to underlying kernel shape
  - A spatial model is built by modeling $\mathbf{a_i}(x,y)$
    - The best fit Chebyshev polynomial for each coefficient is evaluated at each pixel
- Detection algorithm run on resulting difference image
  - Positive and negative polarity
  - Detections are measured

Image subtraction is sensitive to everything upstream, especially masking/correcting

Irreducible Sources of Noise

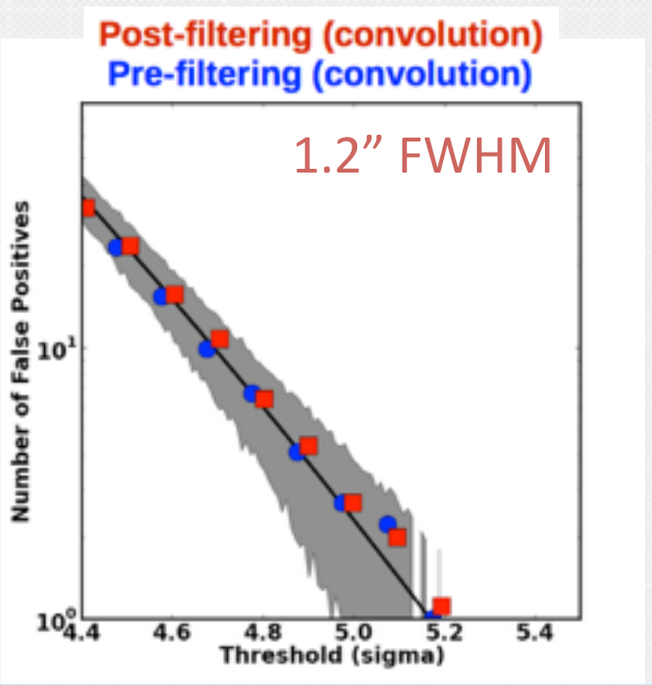
- Fluctuations in random Gaussian fields lead to false positives/negatives
  - Kaiser 2004 (PSDC-002-010)
  - Function of seeing
    - Better seeing, more fluctuations at that scale
  - Function of detection threshold
    - More fluctuations at lower sigma
- In 4k x 4k LSST images:
  - At 5-sigma and 1.2” seeing, 3 per CCD
  - At 5-sigma and 0.6” seeing, 12 per CCD
  - Steep function that drops to < 1 CCD^{-1} at 5.5-sigma in 0.6” seeing



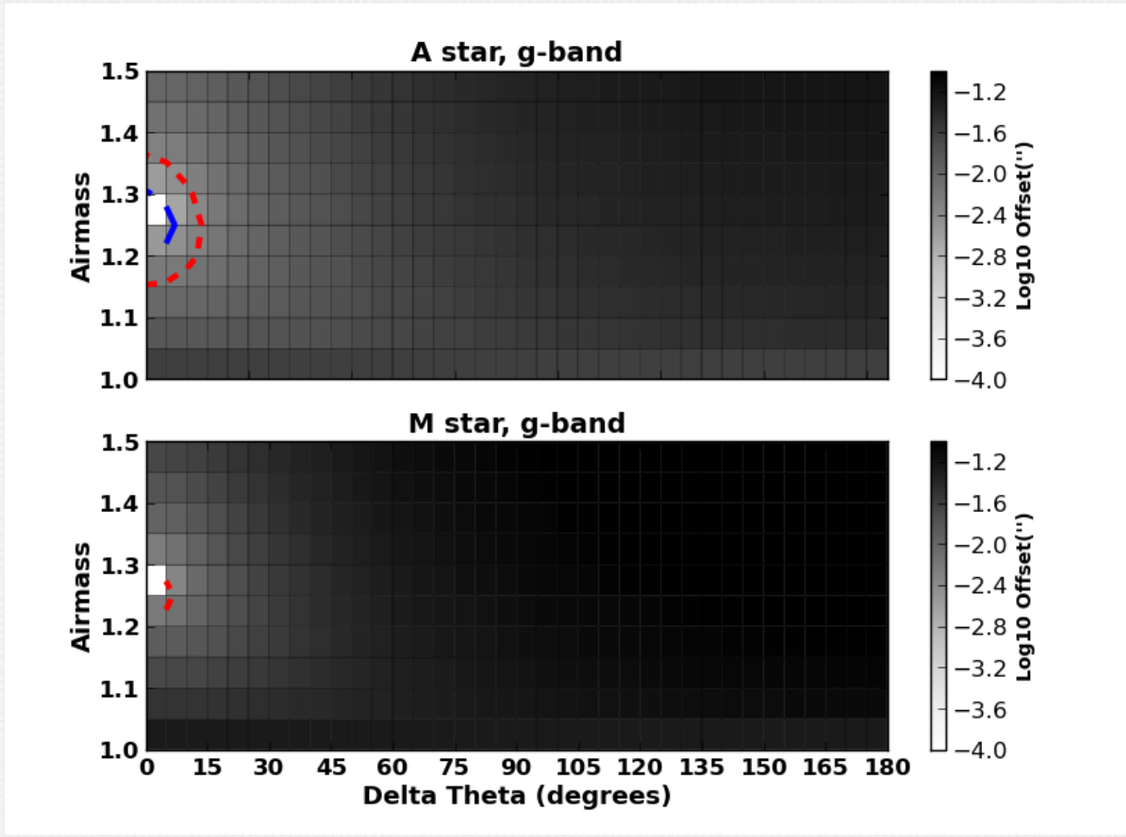
Expected number of false positives vs threshold

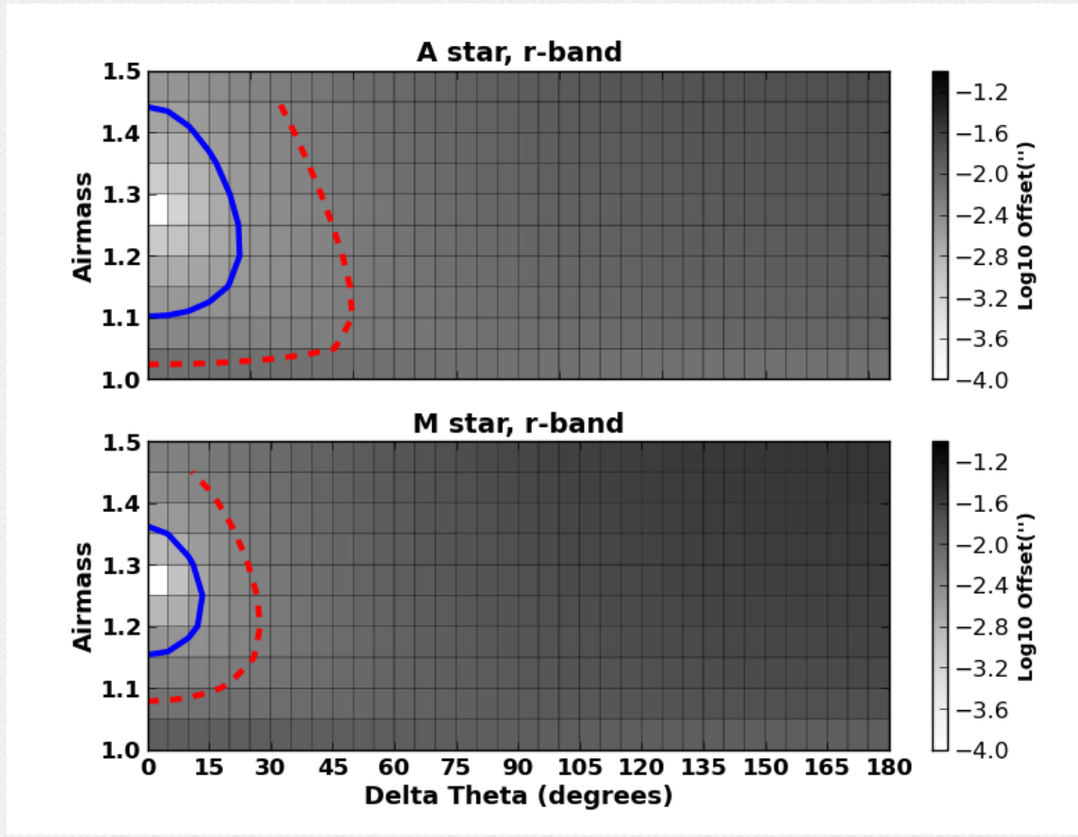
Variance from Monte Carlo Simulations

Data have 1-2% correction In variance



The impact of DCR



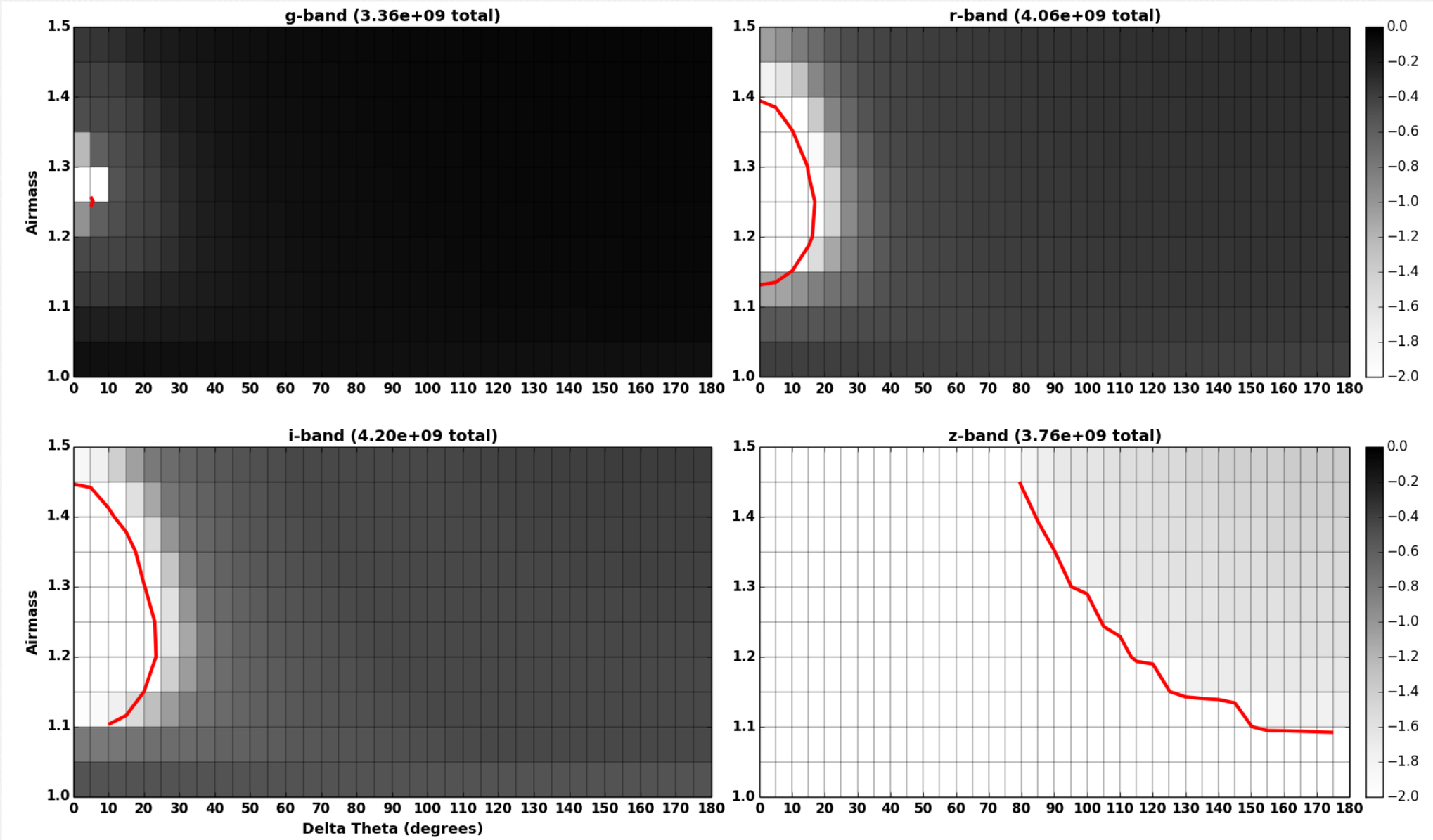


Offset due to DCR from a G0V star at an airmass of 1.25.

Difference in parallactic angle is on the x-axis and airmass is on the y-axis.

Contours are at 3mas (blue) and 6mas (red). At 6mas, there is ~1% chance of measuring a dipole.

The impact of DCR



Given realistic (CatSim) distribution of SEDs, the fraction of stars with 5mas or more from DCR.

Red contour is at 1%.

Brighter-Fatter Effect

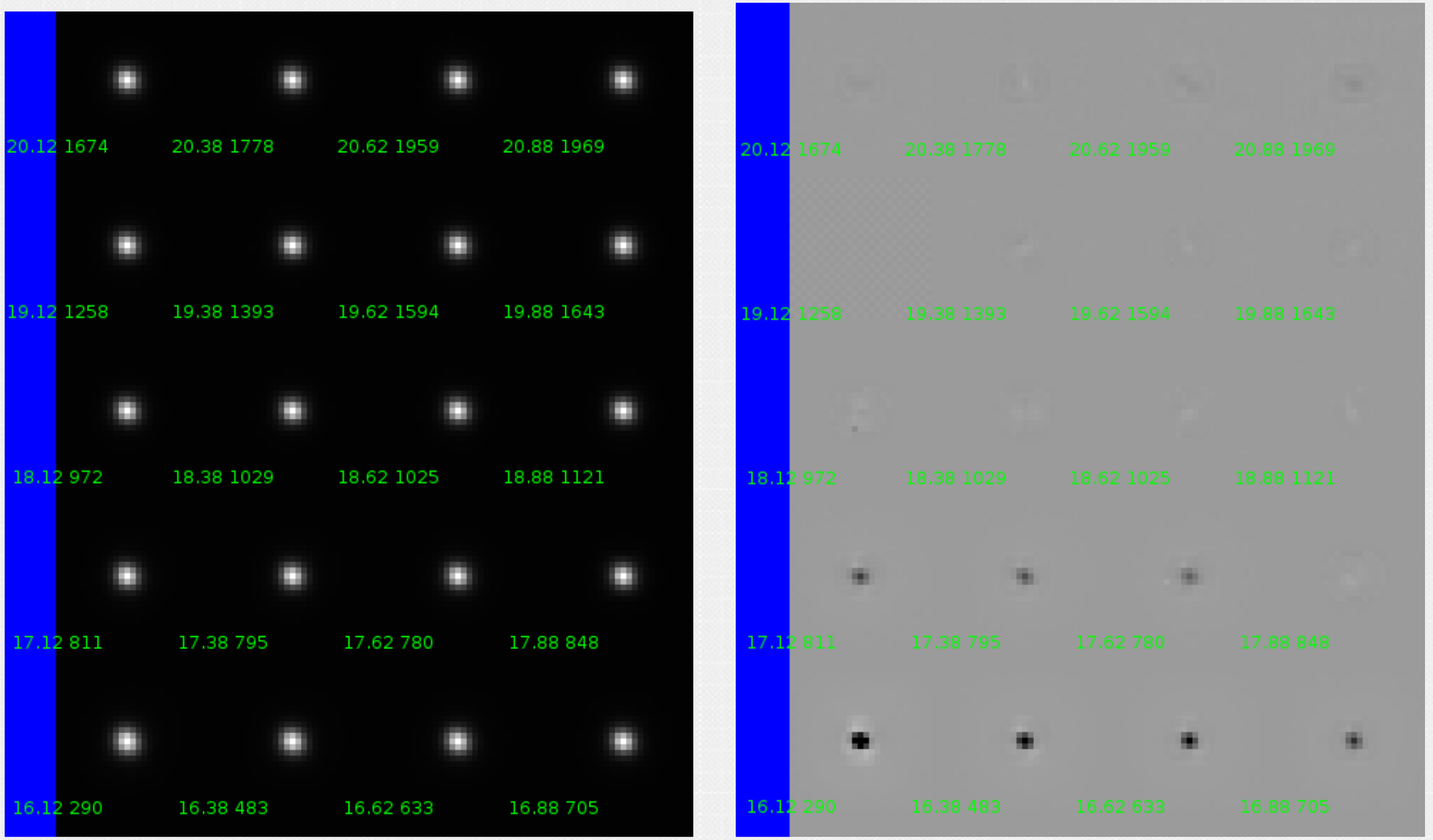


Figure 19: (left) Average star images in 0.25 mag wide bins (16–16.25 mag in bottom left), scaled to peak 1.0 (right) The residuals resulting from subtracting the average star in the 19–19.25 mag bin from all the average stars in the previous mosaic (scaled to equal flux). The core of the bottom left star corresponds to $\sigma \sim 0.75$ pixels.

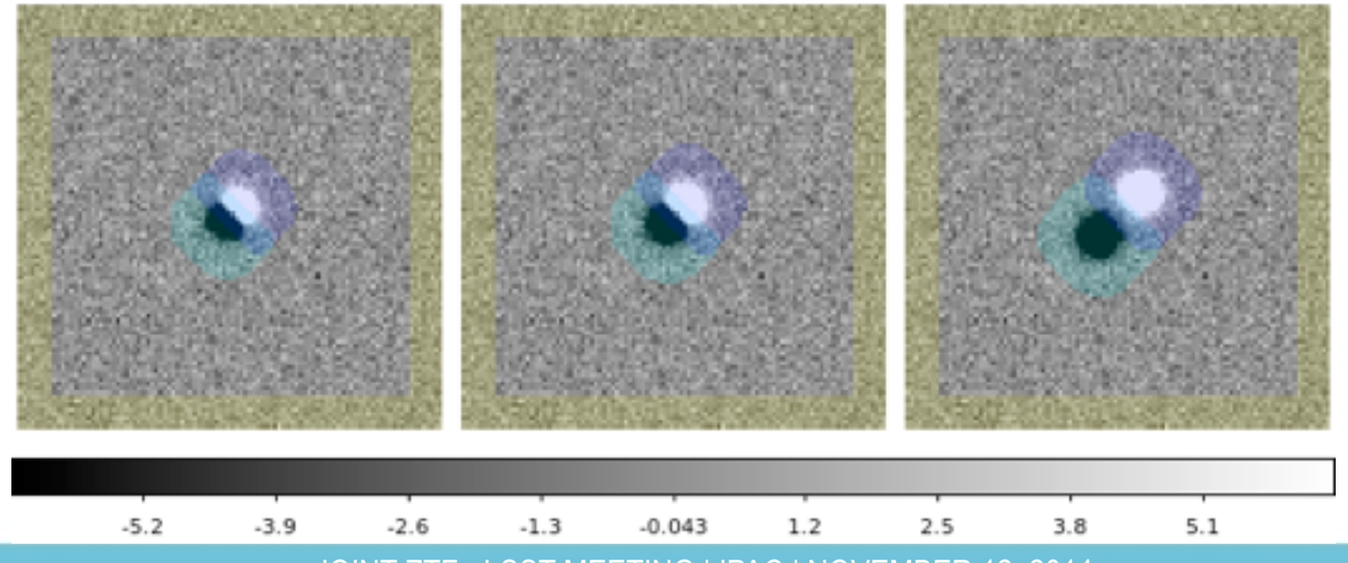
Measurement Suite

- After detection, positive and negative sources are measured
  - Measurement suite:
    - Aperture photometry (multiple elliptical apertures)
    - PSF photometry (PSF of science image)
    - Dipole measurement suite (e.g. PSF photometry of lobes)
    - Adaptive shape measurement (Second moments)
    - Trailed source measurements (Detected using point source filter, measured as trailed)
    - Different for pre- vs. post-filtered difference images
- After measurement, DIASources filtered by Alert Generation Pipeline

Detection and Measurement Prototypes

	Post-filtering	Pre-filtering
Detection	Prototyped and QA*	Prototyped and QA
Centroiding	Prototyped and QA	Prototyped and QA
Aperture/PSF photometry	Prototyped and QA	Prototyped and QA
Dipole Characterization	Prototype implementation	Prototype implementation
Adaptive Shape Measurement	Prototyped and QA	Prototype under development
Trailed Source	On roadmap (FY17)	On roadmap (FY17)

Forced PSF Photometry	Prototyped and QA (on Exposures, seeded from Coadds)



[*] http://ls.st/me7

Sources of False Detections

- Systematic
  - Extant time-domain surveys
    - PS1
    - Palomar Transient Factory

- Statistical
  - Fluctuations of random Gaussian fields
  - False detections as a function of
    - Seeing
    - Detection threshold

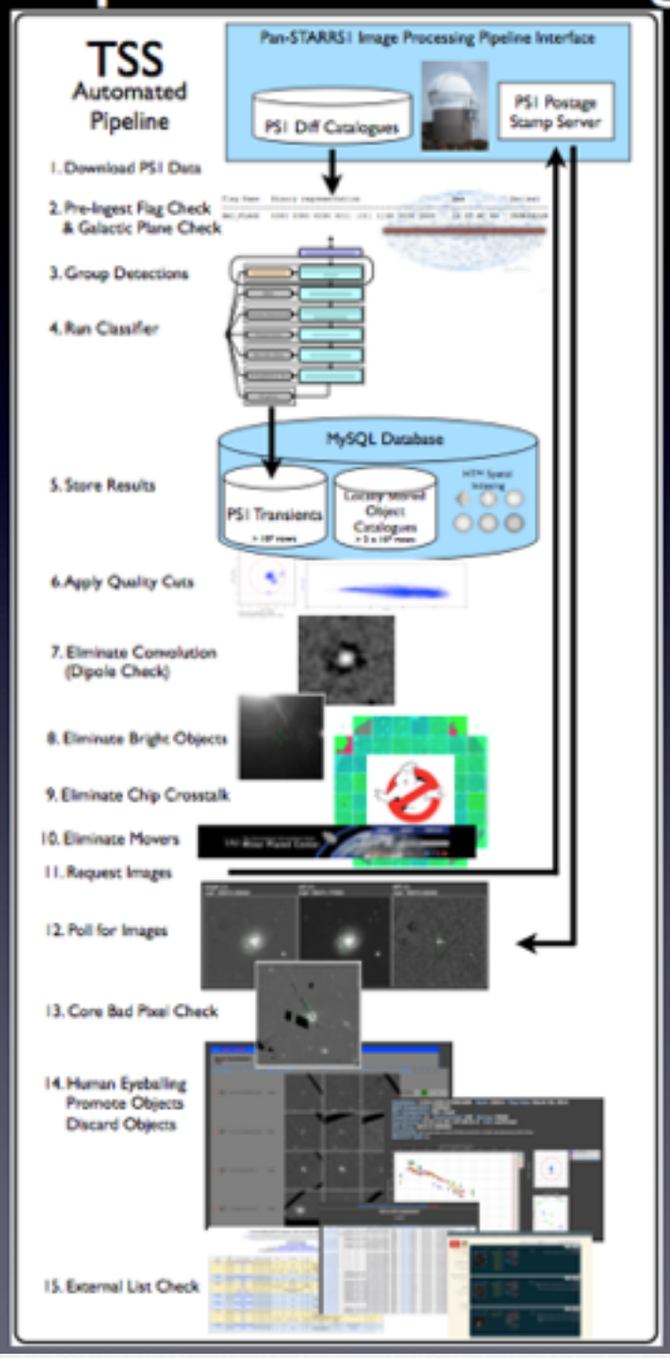
PS1

Example Stats for 1 Night

Medium Deep

3rd September 2013
7 MD Nightly Stacks (avg = 4.5 stacks / nt)

Stage	Number of Remaining Detections
1. Raw Data	366267
2. Flag & GP Check	-
3. Detection Grouping	118412
6. Post Ingest Cuts	6068
7. Convolution Check	2242
8. Bright Object Check	1019
9. Chip Crosstalk Elimination	-
10. Movers	1019
13. NaN Checker	266
14. Eyeballing	97



3π

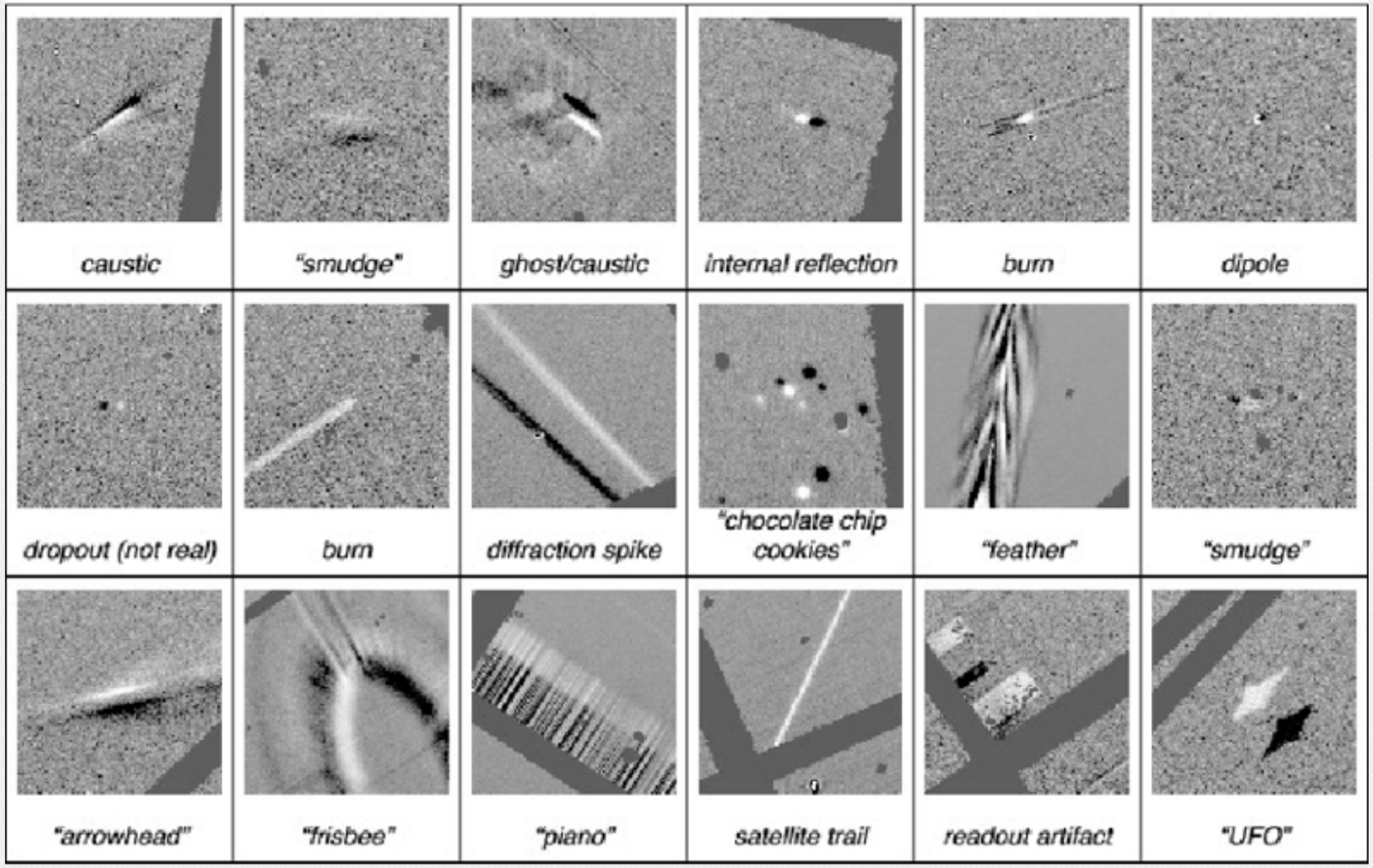
1st September 2013
162 Exposures (avg = 222 exps / nt)

Stage	Number of Remaining Detections
1. Raw Data	3036226
2. Flag & GP Check	1364961
3. Detection Grouping	1135166
6. Post Ingest Cuts	2389
7. Convolution Check	1891
8. Bright Object Check	1699
9. Chip Crosstalk Elimination	1168
10. Movers	1163
13. NaN Checker	-
14. Eyeballing	184

- Multi-stage automated pipeline (TSS)
  - Det at 3/4.5-sigma
  - Only positive dets
- Suite of cuts reduces false positives by 10^3 - 10^4
  - Pair coincidences
  - 5-sigma
- Medium Deep
  - ~40% purity
- 3 pi
  - ~20% purity

Ken Smith, private communication

Pan-STARRS1 Systematic False Detection Gallery



Denneau et al. (2013PASP..125..357D)

Sources of False Detections

1. Saturated / near-saturated stars and cores of galaxies
2. Imperfect reference images
3. Radically different seeing (including deconvolution)
4. Optical ghosts
5. Electronics noise, crosstalk, and detector artifacts

- LSST plans to reduce false detection rates through both hardware and software design

6. Understanding of saturated stars is tractable
7. Multi-epoch observations will enable high quality reference images
8. Pre-filtering technique may obviate the need for deconvolution
4. Ghost image : precision on sky brightness due to ghosting < 1%
5. Crosstalk : < 0.2% intra-raft before correction
   - Correctable to 2.5e-5 for alert production

- Requirements:
  - Report *all* transients at 5 sigma
  - At 5 sigma: 99% completeness and 50% purity
    - Moving object pipeline
  - At 6 sigma: 90% completeness and 95% purity

Tuning the method

- Basis set
- Number of basis functions
- Regularization of basis functions
- Order of spatial model
- Detection and measurement tuning

Testbed for Algorithm QA

- Imsim-based testbed
- Metered increase of simulation complexity

Sources

- SEDs
- Star/Galaxy/Asteroids
- Brightness distribution
- Stellar density
- Variability
- Motion

Atmosphere

- Airglow
- Clouds
- Seeing

Observations

- Passband
- Altitude
- Tracking
- Blooming
- Diffraction

Testbed for Algorithm QA

- Imsim-based testbed
- Metered increase of simulation complexity

Sources

- Single SED
- All stars
- 19 < r < 20
- 1000/CCD
- No variability
- Not moving

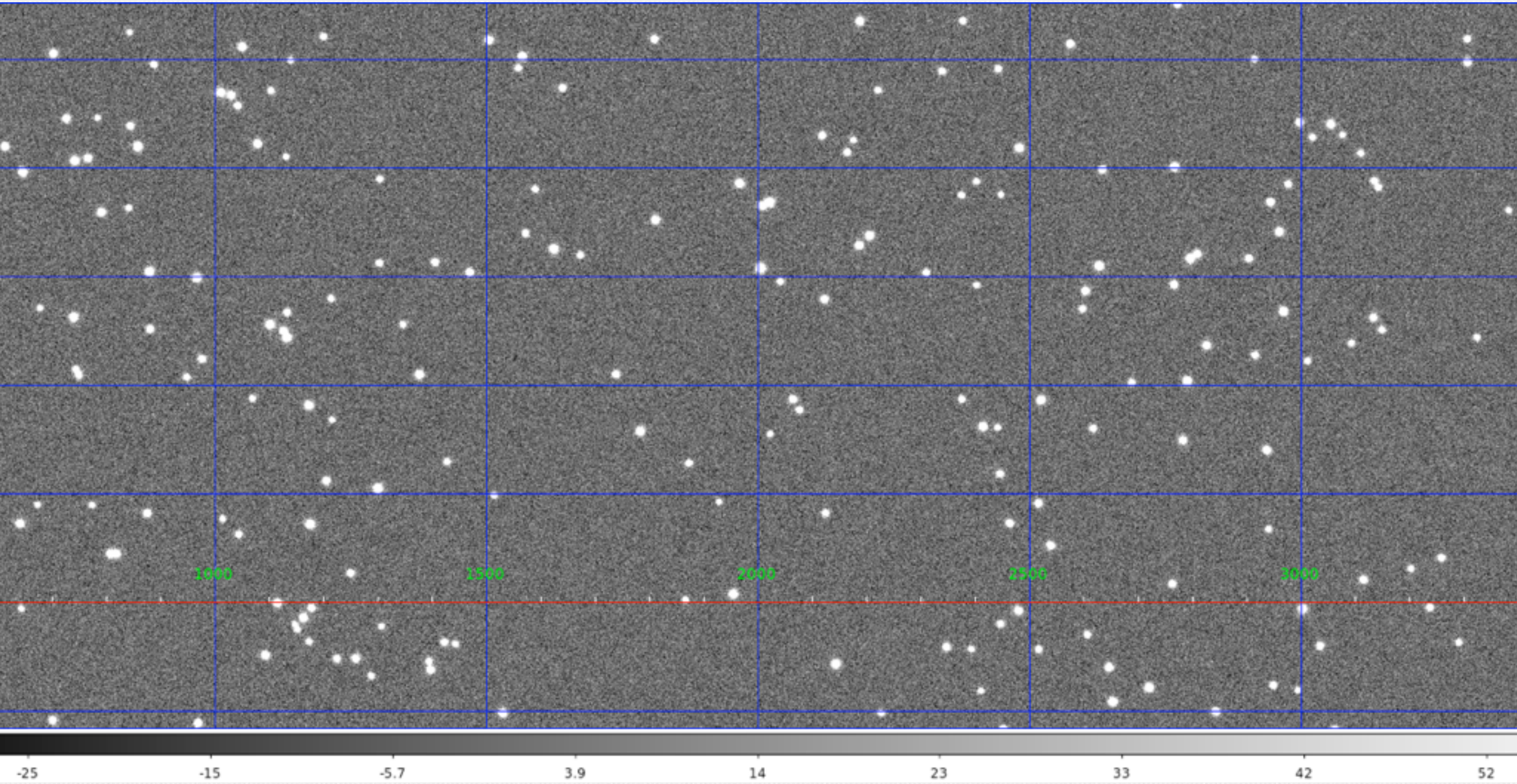
Atmosphere

- No airglow
- No clouds
- Seeing 0.6”, 0.88”, 1.2”
  - Template 0.88”

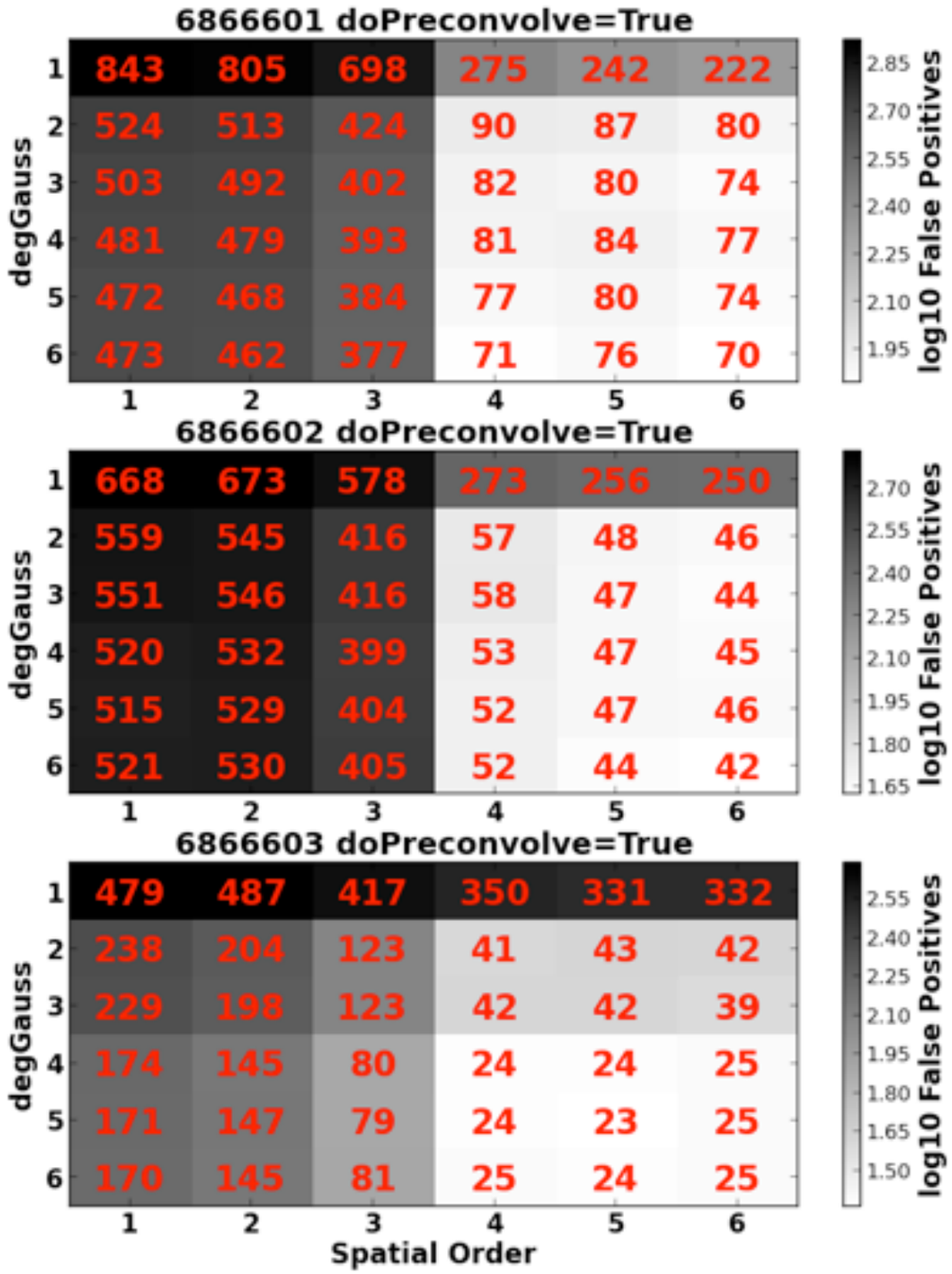
Observations

- *i*-band
- At zenith
- No tracking errors
- No blooming
- No diffraction

Example semi-idealized test image



QA Infrastructure:
Number of false detections vs pipeline configuration



Performance of Prototype Pipeline

- At 5-sigma detection threshold, the theoretical number of false detections / CCD:
  - 0.6” seeing: 12
  - 1.2” seeing: 3
- This drops to ~1/CCD in 0.6” seeing at 5.5 sigma
- Pre-filtering significantly outperforms a post-filtering deconvolution
- Underestimate of noise by 1-2% leads to factor 1.5-2 more false detections at 5 sigma
  - Pre-filtering variance plane underestimates by 1-2%
  - Post-filtering variance plane underestimates by 3-4%
    - Double convolution of template
- Background misestimation changes ratio of +/- false detections

Trailed Source Measurement

- Trailed source measurement on DIASources
  - PSF convolved with a line
    - Forward modeling
    - Due to 2 snaps, expect a dip in the middle
    - Will measure: flux, length, angle, covariance, goodness of fit
  - Enable identification as moving object
    - Satellites, meteors, or asteroids
    - On the roadmap (FY17) before MOPS development cycle (FY18)
- Released in alert stream (<60 seconds)
  - Trailed source metrics enable recognition as fast moving object

Questions?