Reference Image Reanalysis

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Motivation

- There was a push early in the survey to generate reference images for as much of the sky as possible in order to commence alert generation.
- Reference image usage:
  - Image subtraction → alert production, asteroid detection.
  - Accompanying source catalogs provide "seed positions" for generating lightcurves.

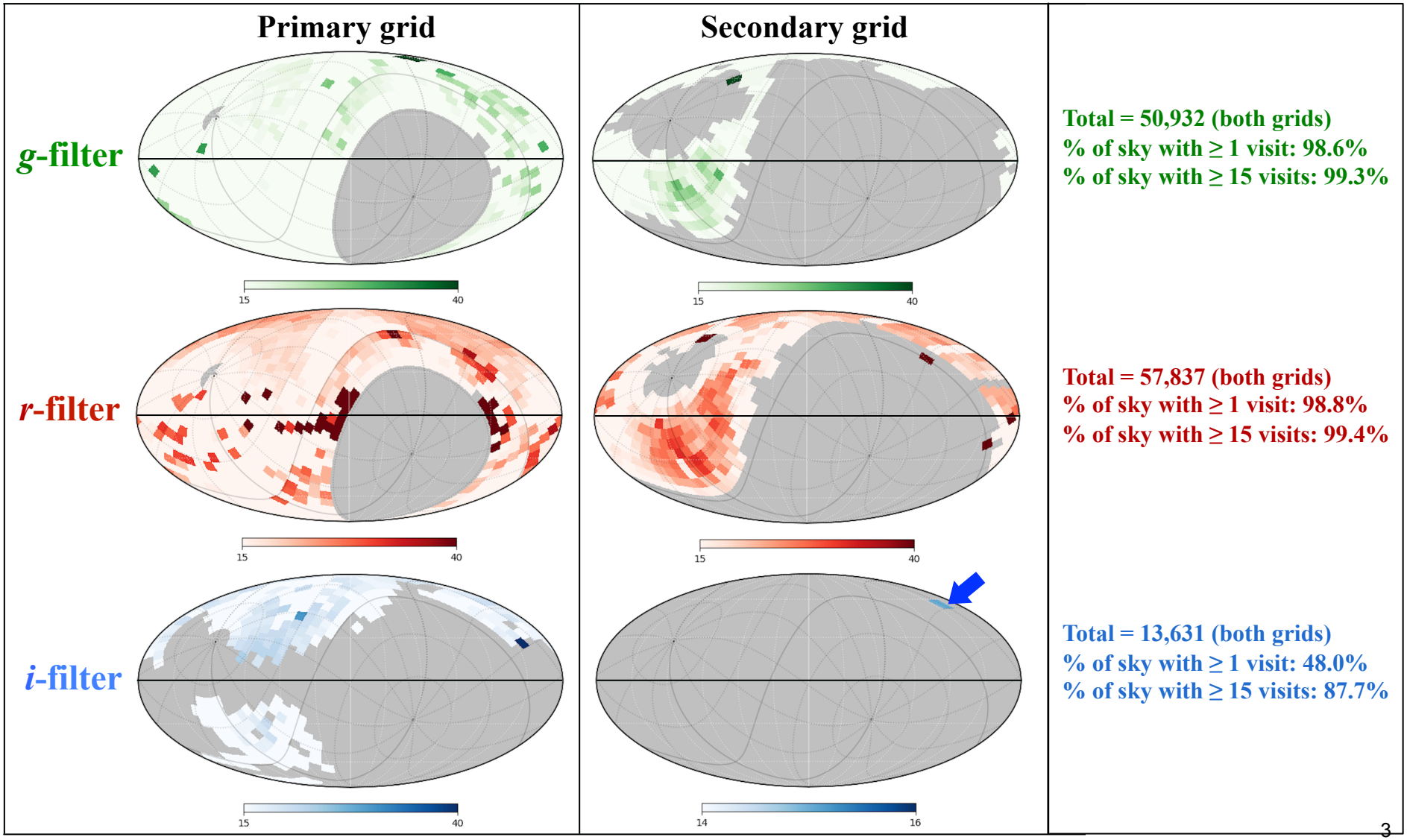
- Procedure to this day:
  - Execute reference image "checker" pipeline every morning.
  - Checks which fields / CCD-quadrants / filters are missing references.
  - As soon as N ≥ 15 science images satisfy quality criteria, generate a reference image.
  - Archive and lock-down the reference image; never revisit. Max cutoff is 40 input images.

- Now that we have a lot more epochal data, it's worth revisiting whether we can improve reference image quality by being more restrictive on the input image selection criteria.

- Reference image quality impacts all science programs.

Reference Image Coverage: Aug 23, 2019

galactic projection (l, b = 0, 0 centered)

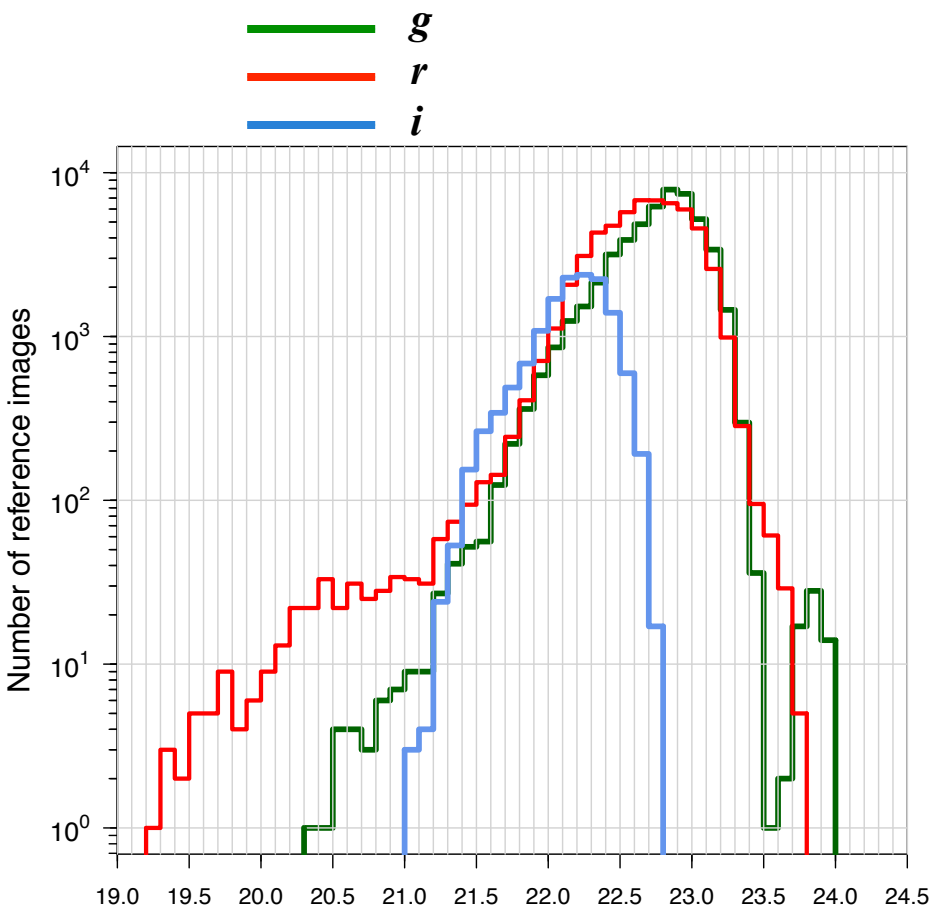


Total = 50,932 (both grids)
% of sky with ≥ 1 visit: 98.6%
% of sky with ≥ 15 visits: 99.3%

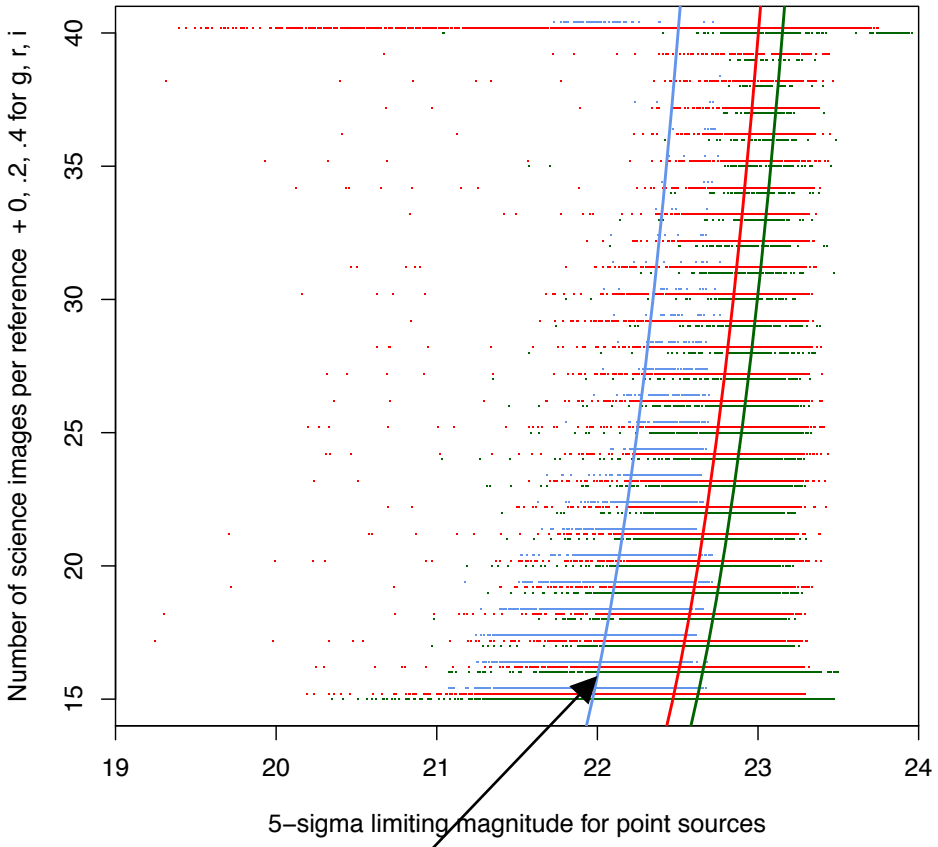
Total = 57,837 (both grids)
% of sky with ≥ 1 visit: 98.8%
% of sky with ≥ 15 visits: 99.4%

Total = 13,631 (both grids)
% of sky with ≥ 1 visit: 48.0%
% of sky with ≥ 15 visits: 87.7%

Current reference image depths



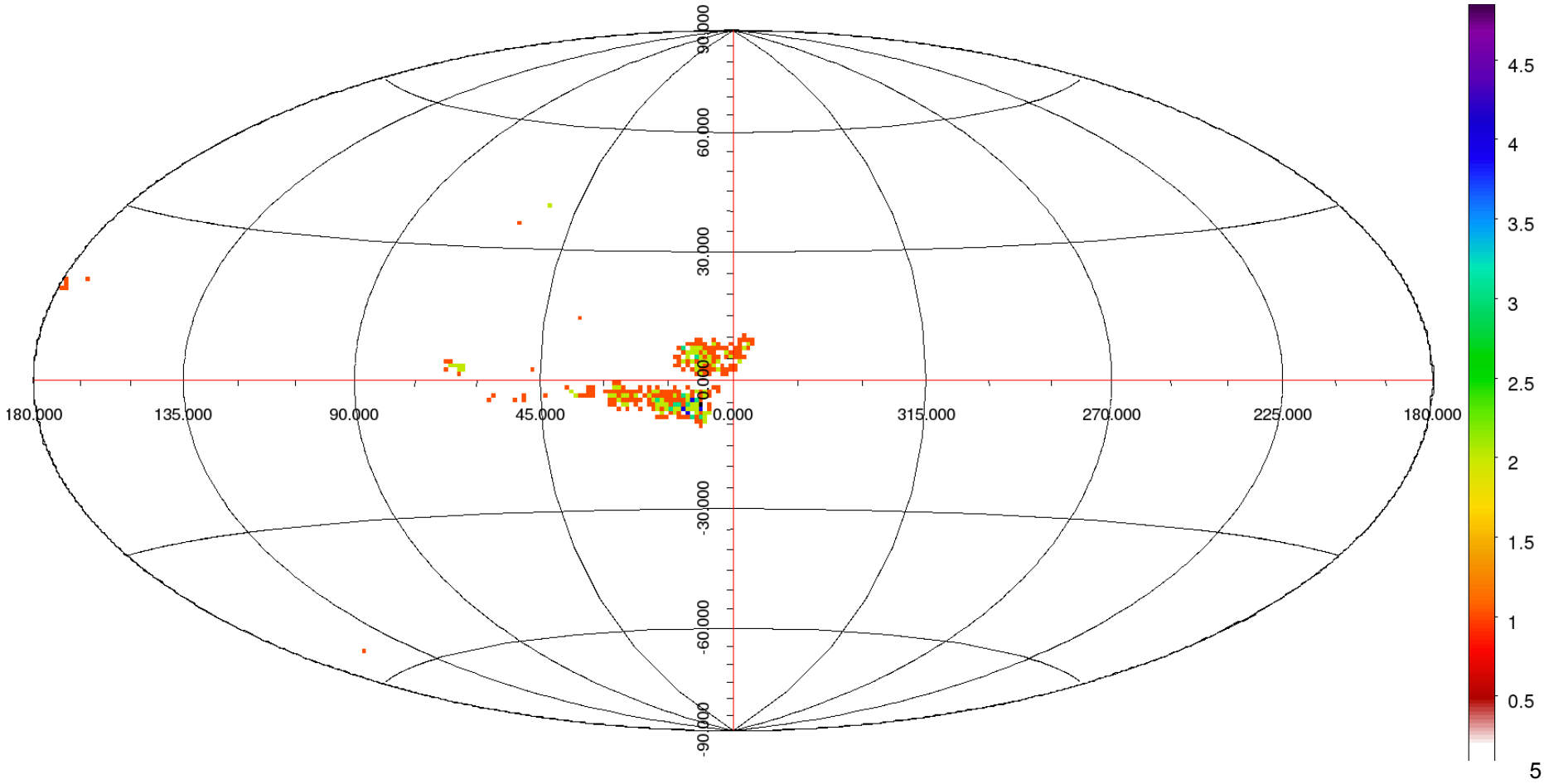
Fields with ultra-high source confusion (PTO): noise & mag-limit estimators break down



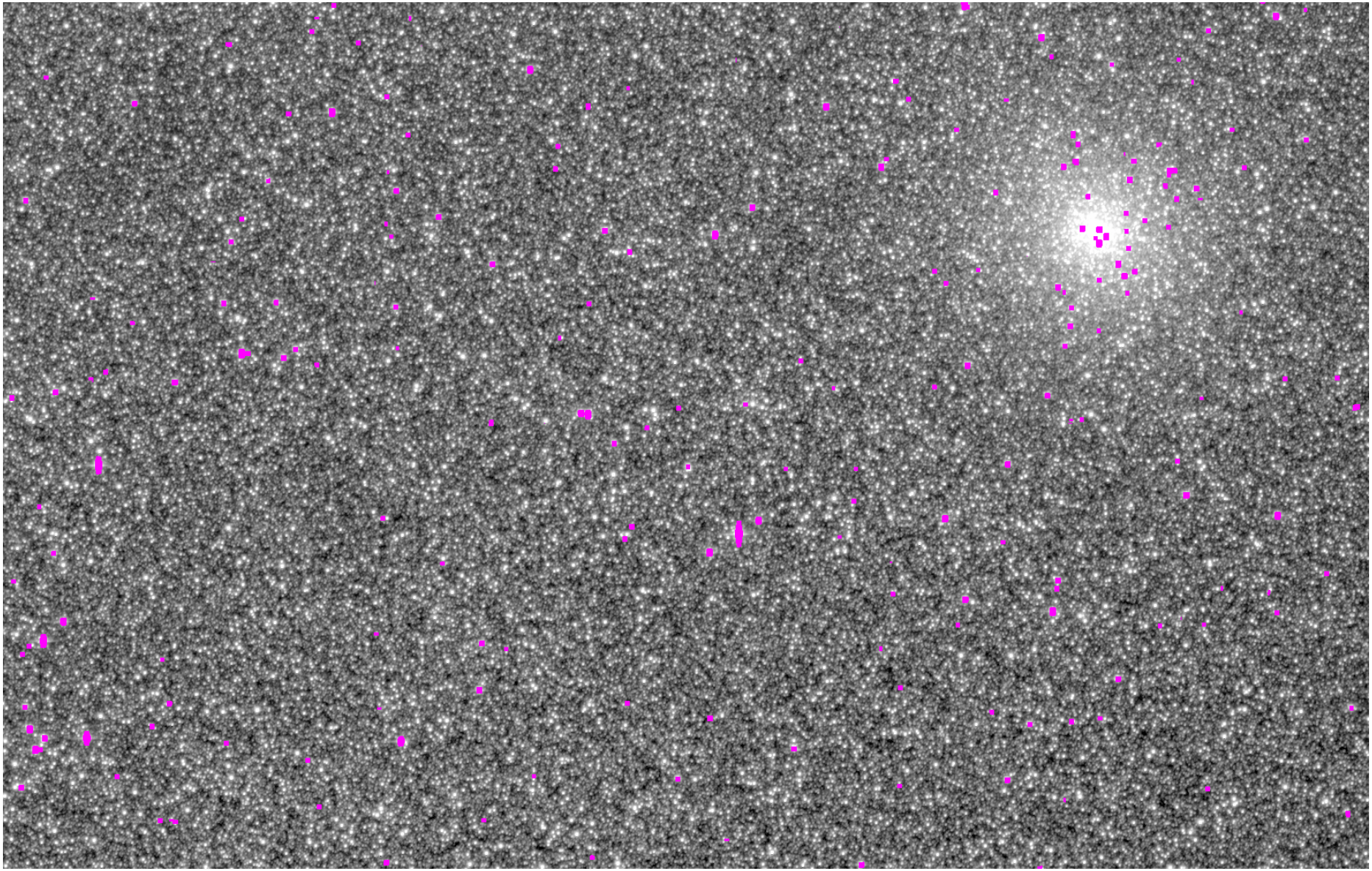
Prediction: $m_{limref} \sim m_{limsci} + 1.25 \log_{10} N$

Where are those "low-depth" reference images located?

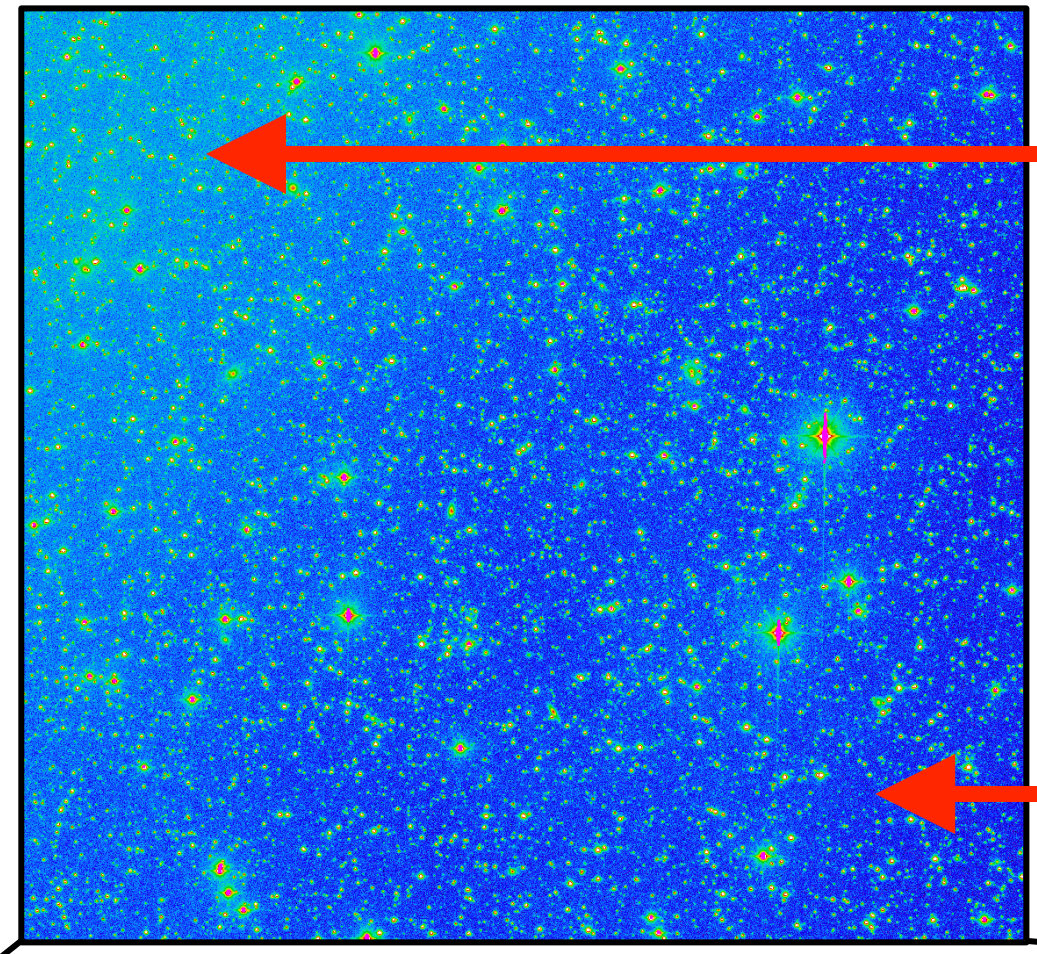
- Shown are CCD-quadrant "footprints" mapped into galactic coordinate system.
- Only those with limiting magnitudes < 21.2 mag are shown (388 references).
- Colors refer to overlaps which include effects from resampling onto a coarser grid.



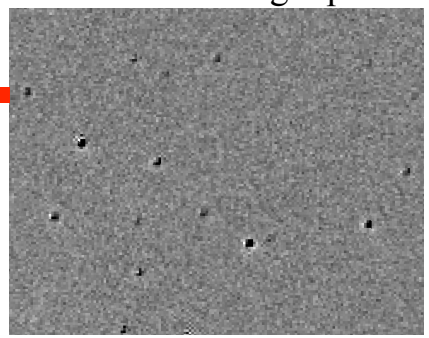
Example of a reference image near galactic center (this is a zoom!)



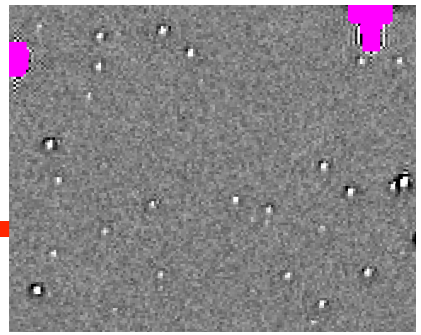
Example of a bad quality reference and its impact



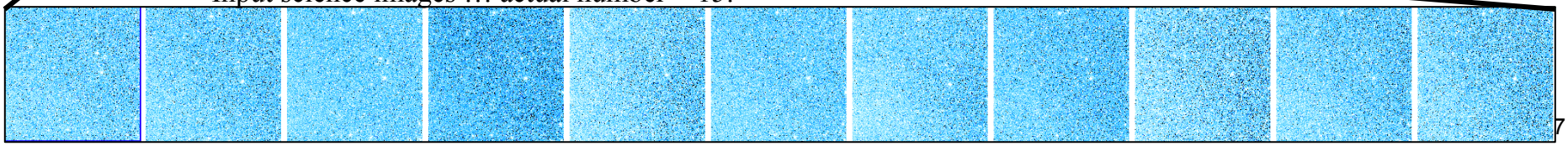
Subtraction using top left



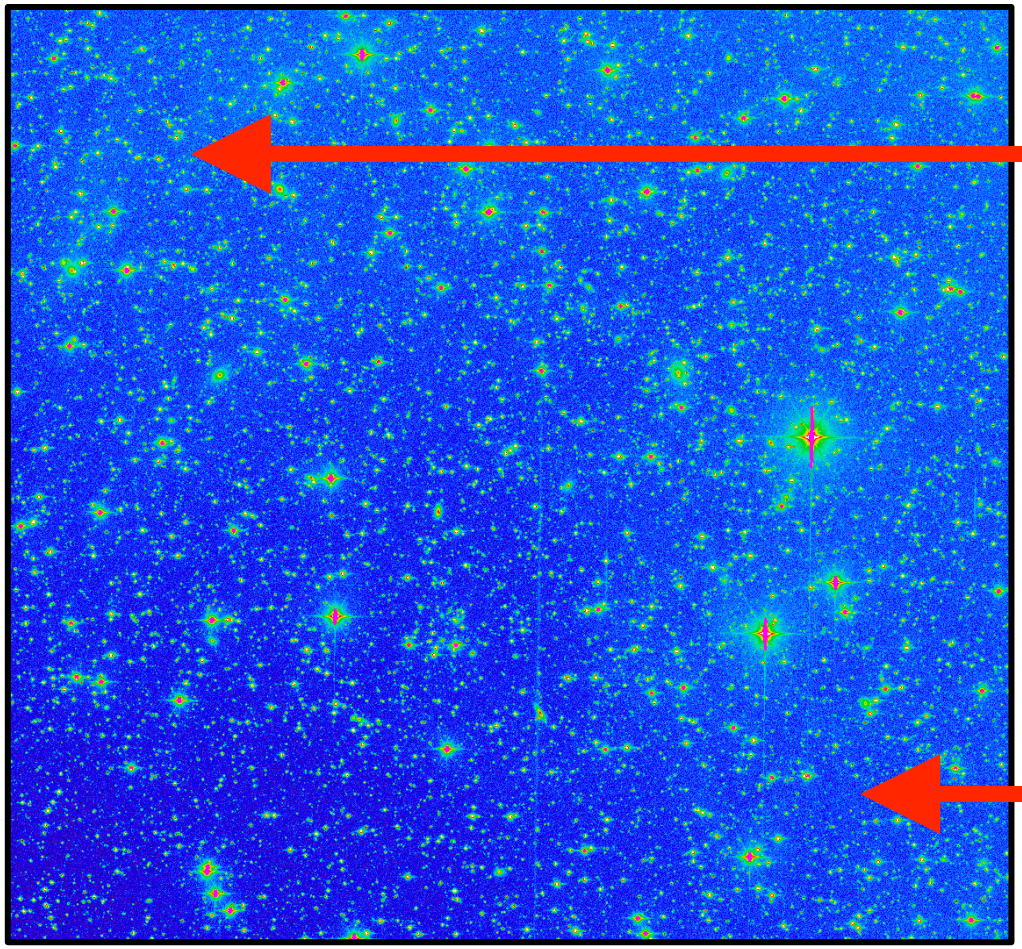
Subtraction using bottom right



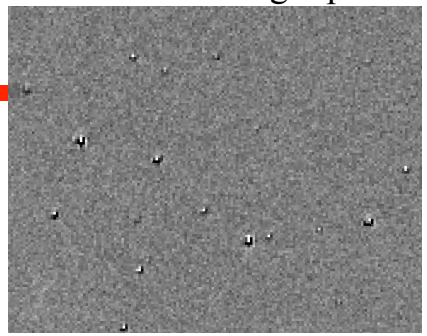
Input science images … actual number = 15:



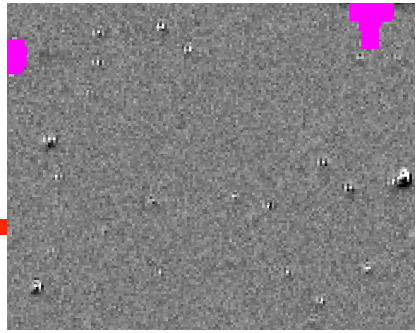
Same reference image using cleaner (*flatter*) input science images



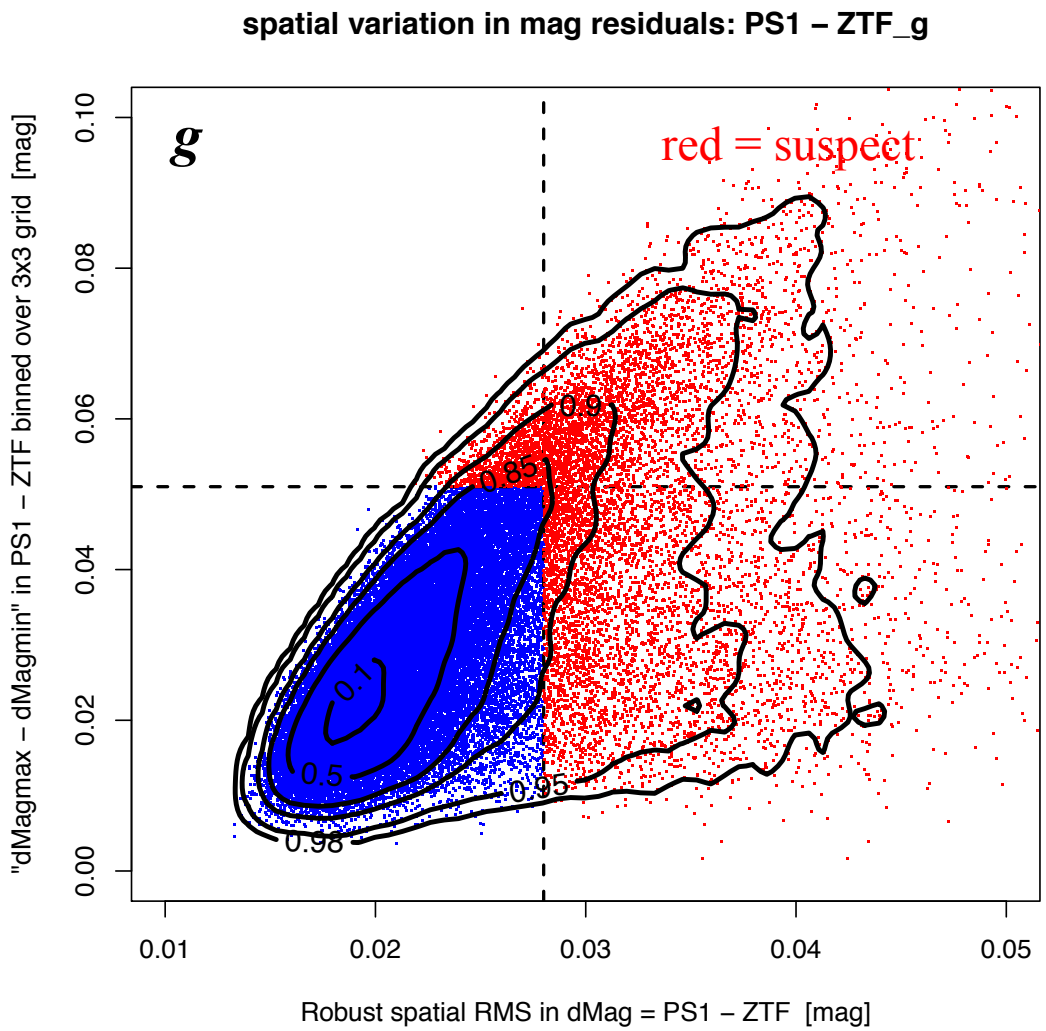
Subtraction using top left



Subtraction using bottom right



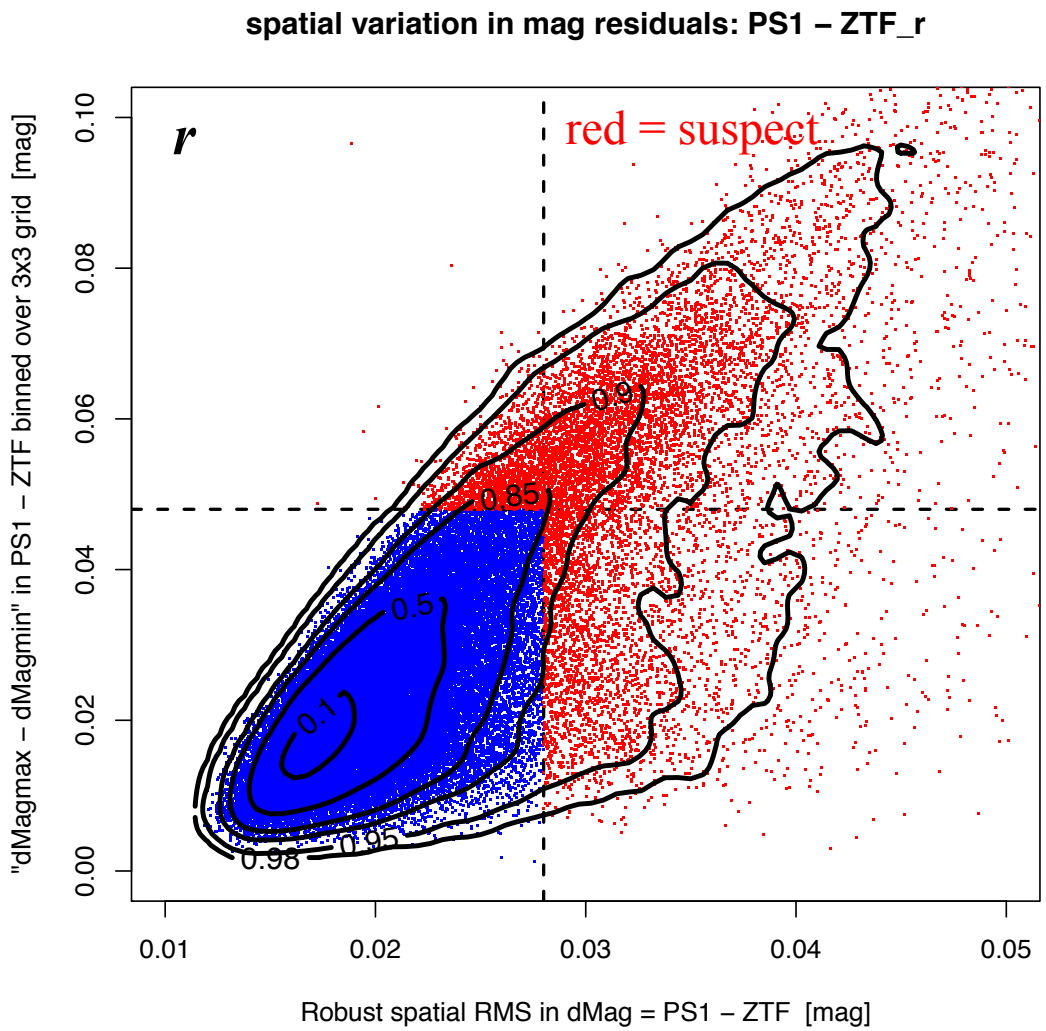
Suspect reference images in *g*



For each ref image, computed:
$\Delta = max\{\text{dMag}\} - min\{\text{dMag}\}$ where $\{\text{dMag}\} = median(\text{PS1} - \text{ZTF}_{\text{mag}})$ in 3×3 spatial bins over each image
and
Robust global *RMS* in dMag for all sources with $13.5 \leq mag \leq 18.5$.

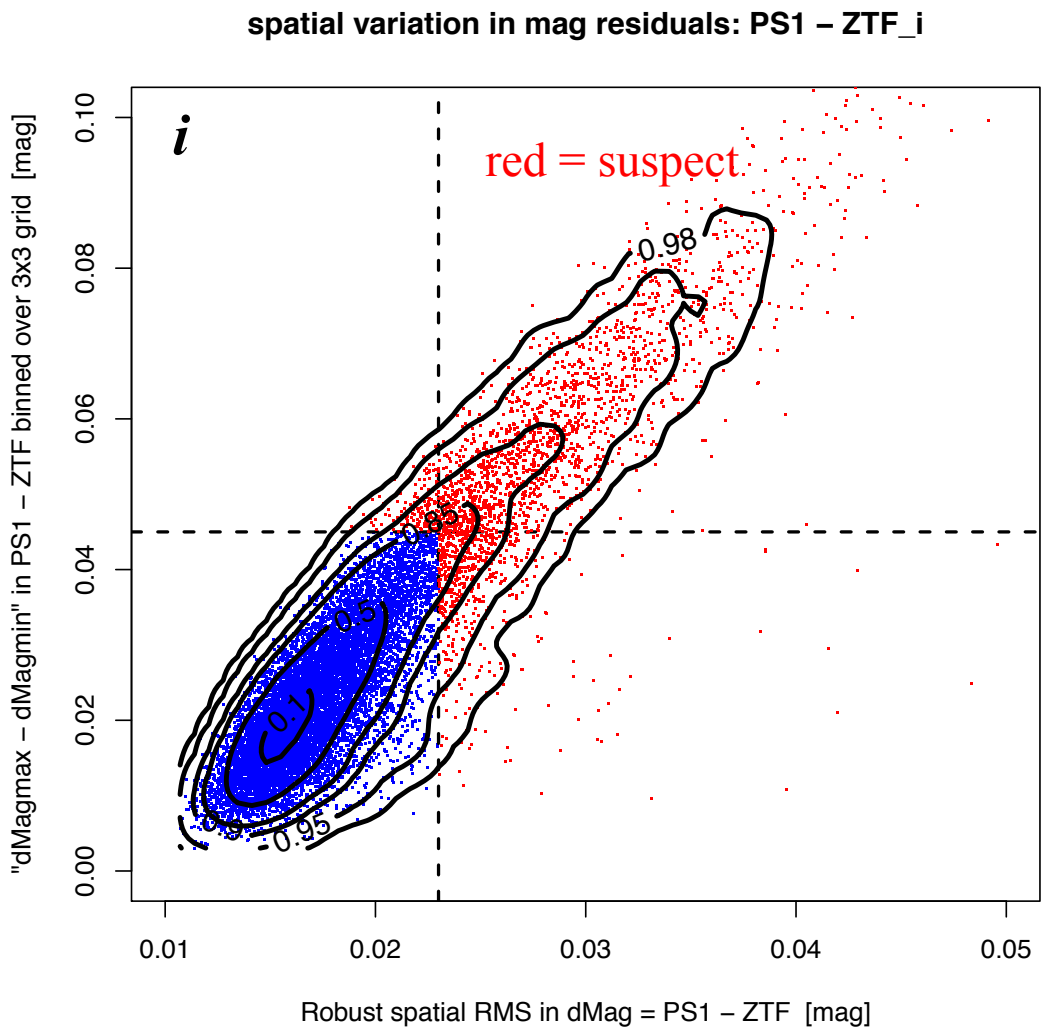
- Total number in *g* : 50,932
- Number suspect : 6,574
- Percentage suspect : ~ 12.9%
- Could be lower since metrics are dependent on confusion level and effective mag range used.

Suspect reference images in *r*



- Total number in *r* : 57,837
- Number suspect : 7,621
- Percentage suspect : ~ 13.2%
- Could be lower since metrics are dependent on confusion level and effective mag range used.

Suspect reference images in *i*



- Total number in *i* : 13,631
- Number suspect : 1,734
- Percentage suspect : ~ 12.7%
- Could be lower since metrics are dependent on confusion level and effective mag range used.

Plan: extend selection criteria for science image inputs

Current criteria, from: **https://zwicky.tf/ykv** (Section 6.7):

(i) Image quality falling in range $1.7 \leq \mathrm{FWHM} \leq 5.0$ arcsec for the *g* and *R* filters, and $1.7 \leq \mathrm{FWHM} \leq 4.5$ arcsec for *i* filter.
(ii) Overall quality *status* = 1 where the criteria used to set *status* = 1 (or equivalently, none of the bad `INFOBITS`) are defined in Section 10.4.
(iii) $25.3 \leq \mathrm{MAGZP}(g) \leq 26.5$ or $25.3 \leq \mathrm{MAGZP}(R) \leq 26.5$ or $25.25 \leq \mathrm{MAGZP}(i) \leq 25.85$ for filters *g, R, i* respectively.
(iv) $-0.20 \leq \mathrm{CLRCOEFF}(g) \leq 0.15$ or $-0.05 \leq \mathrm{CLRCOEFF}(R) \leq 0.22$ or $0.05 \leq \mathrm{CLRCOEFF}(i) \leq 0.30$ for filters *g, R, i* respectively.
(v) $\mathrm{MAGLIM}(g) \geq 19.0$ or $\mathrm{MAGLIM}(R) \geq 19.0$ or $\mathrm{MAGLIM}(i) \geq 18.0$ for filters *g, R, i* respectively.
(vi) Global pixel median: $gmedian(g) \leq 1900$ DN or $gmedian(R) \leq 1600$ DN or $gmedian(i) \leq 1200$ DN for filters *g, R, i* respectively.
(vii) Global robust pixel RMS: $gpctdif(g) \leq 100$ DN or $gpctdif(R) \leq 100$ DN or $gpctdif(i) \leq 80$ DN for filters *g, R, i* respectively.
(viii) All science exposures acquired on or after UT night-date February 5, 2018. This is when the camera was reinstalled on the telescope.
(ix) A minimum of 15 overlapping science images satisfying (i) to (viii).
(x) Following criteria **(i)** to **(ix)**, the resulting science image list is sorted in order of *increasing* FWHM after which the first N_{max} images are retained. N_{max} therefore defines the desired depth. Currently, $N_{max} = 40$.

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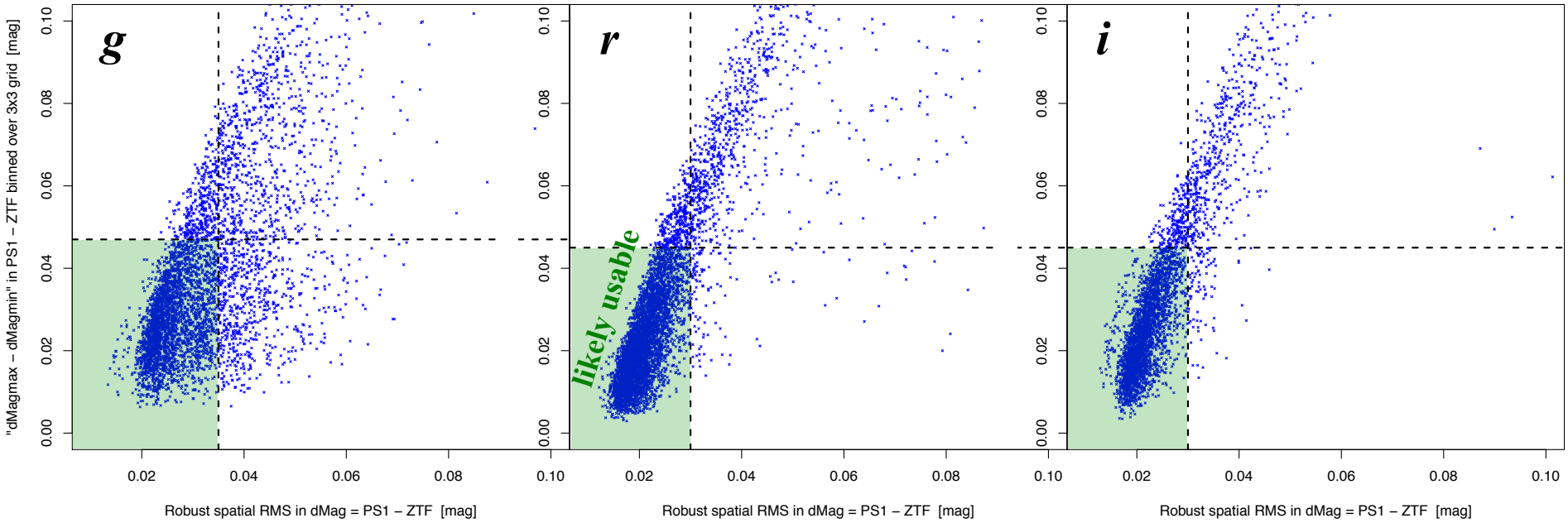
Flatness Criterion

Spatial distribution in photometric throughput in a science image using residuals w.r.t. PS1 catalog over a grid is < some threshold.

This will also filter images with significant spatial variations from varying atmospheric transparency.

Setting "throughput-flatness" thresholds
for science images

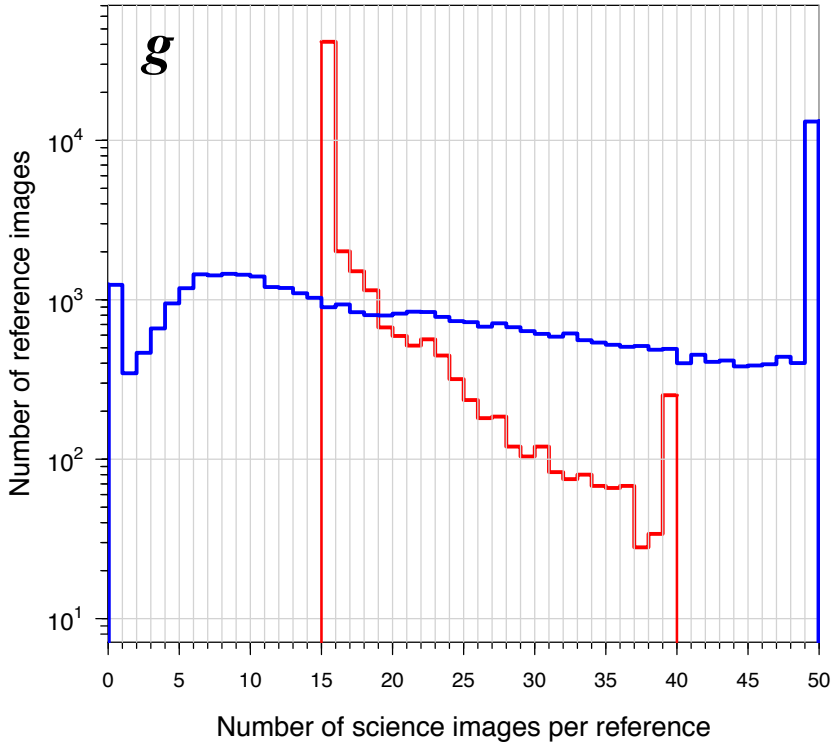
- Used same metrics as before (slide 9: Δ versus *rms*) but this time compute for a random sample of science images.
- **Goal:** explore impact on reference image statistics if impose a flatness criterion when selecting input images.



- Provisional (experimental) thresholds to select usable science images for reference image generation:
  g : $rms \leq 0.035$; $\Delta_{minmax} \leq 0.047$
  r : $rms \leq 0.030$; $\Delta_{minmax} \leq 0.045$
  i : $rms \leq 0.030$; $\Delta_{minmax} \leq 0.045$
- In reality, I expect these thresholds to be field dependent (e.g., high source confusion will impact metrics).

Reference image statistics in *g* using new criterion

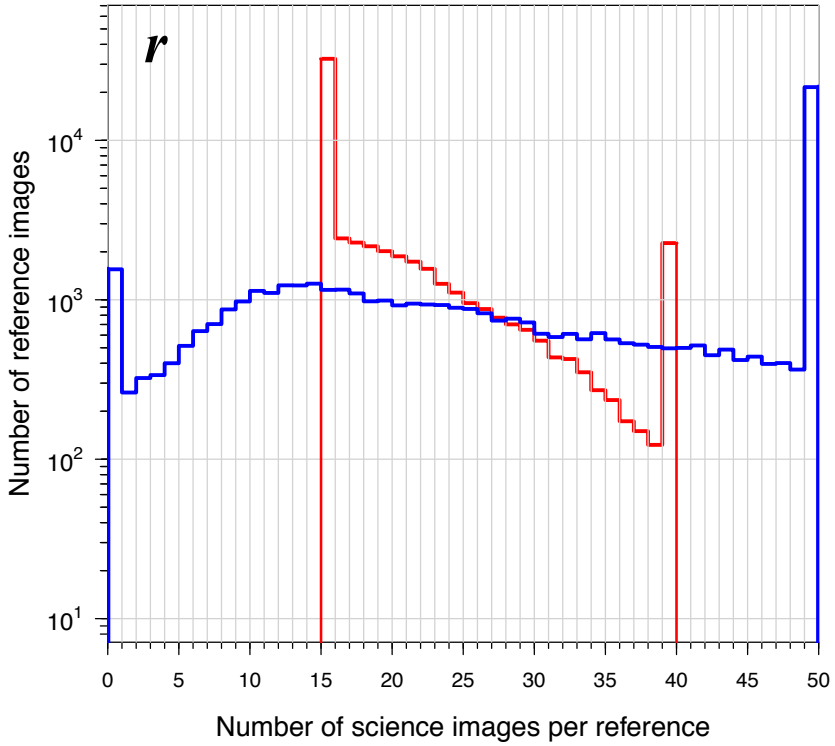
- **Red histogram:** what we have now in archive
- **Blue histogram:** what we'll get if all references were to be regenerated with *flatness* criterion included



***g*-filter:**
Nrefsnow (Nmin=15; Nmax=40) : 50,932
Nrefsnew (Nmin=15; Nmax=50) : 35,297; %lost ~ 30.7%
Nrefsnew (Nmin=10; Nmax=50) : 41,680; %lost ~ 18.2%

Reference image statistics in *r* using new criterion

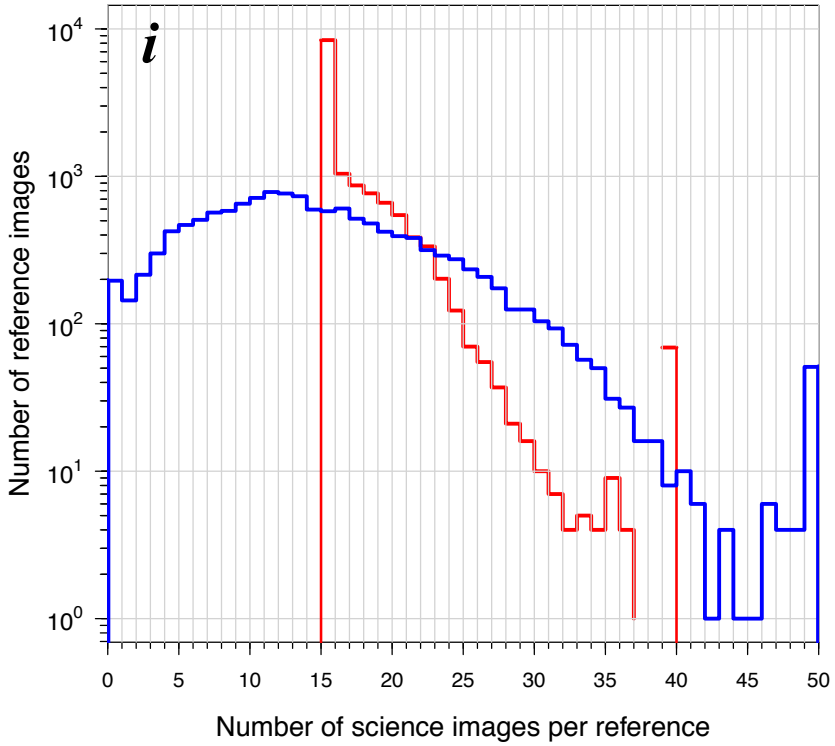
- **Red histogram:** what we have now in archive
- **Blue histogram:** what we'll get if all references were to be regenerated with *flatness* criterion included



***r*-filter:**
Nrefsnow (Nmin=15; Nmax=40) : 57,837
Nrefsnew (Nmin=15; Nmax=50) : 46,516; %lost ~ 19.6%
Nrefsnew (Nmin=10; Nmax=50) : 52,217; %lost ~ 9.7%

Reference image statistics in *i* using new criterion

- **Red histogram:** what we have now in archive
- **Blue histogram:** what we'll get if all references were to be regenerated with *flatness* criterion included



***i*-filter:**
Nrefsnow (Nmin=15; Nmax=40) : 13,631
Nrefsnew (Nmin=15; Nmax=50) : 6,420; %lost ~ 52.9%
Nrefsnew (Nmin=10; Nmax=50) : 10,149; %lost ~ 25.5%

Consequences of regenerating (ones I know about)

- There will be losses in reference-image sky coverage if *flatness* criterion is included.
  - can retune/relax other input filters to minimize losses.

- Lightcurves derived from differential photometry in alert packets will change depending on input timespans and level of contamination from inadvertent inclusion of real transient signal in ref image.
  - lost/irrecoverable alerts, particularly near thresholds.
  - changes in the positions of already published alerts, not only photometry.

- Source positions in reference image catalogs will change – used to seed source-matching across epochs for generating lightcurves (*source matchfile* products, **not** subtraction image photometry).
  - breaks the "appending model" when updating lightcurves at Cahill. Need to re-match (do once) and re-assign new objectIDs in databases.
  - lost sources in reference image by virtue of *"transient behavior"* over time (not reoccurring variables) => lost lightcurves.

- Changes in reference image quality => retraining of machine-learned classifiers for point-source transients and streaks (asteroids) detected in subtraction images. Difficult to quantify.

Moving Forward

Goal: maximize reference image quality but also minimize loss in sky coverage.

Possible direction:

1. Retune input science image selection criteria (explore field dependencies / source confusion).
2. Identify & regenerate suspect references (<~ 13% per filter): *Nmin* = 15, *Nmax* = 50 images deep.
   - ➢ if have $N < 15$ images, flag existing reference in archive as "potentially updatable" : check these daily as survey proceeds and regenerate as soon as $N \geq 15$.
3. Regenerate non-suspect references only if new selection criteria yield deeper references.

Special case:

- *i*-filter – makes sense to deploy fringe corrector; reprocess all science images and re-archive; then regenerate all reference images using new criteria.
  - ➢ we can indeed support reprocessing of all *i*-filter image data at this time.

- "Re-baselining" the survey to a new reference image library makes sense in the long term due to intermittent updates to the observing system and calibrations:
  - ➢ camera/cryostat cleansing; new CCD waveforms; new electronic gains/linearity curves; focal-plane leveling; DIQ refinements from flexure correction model updates, …