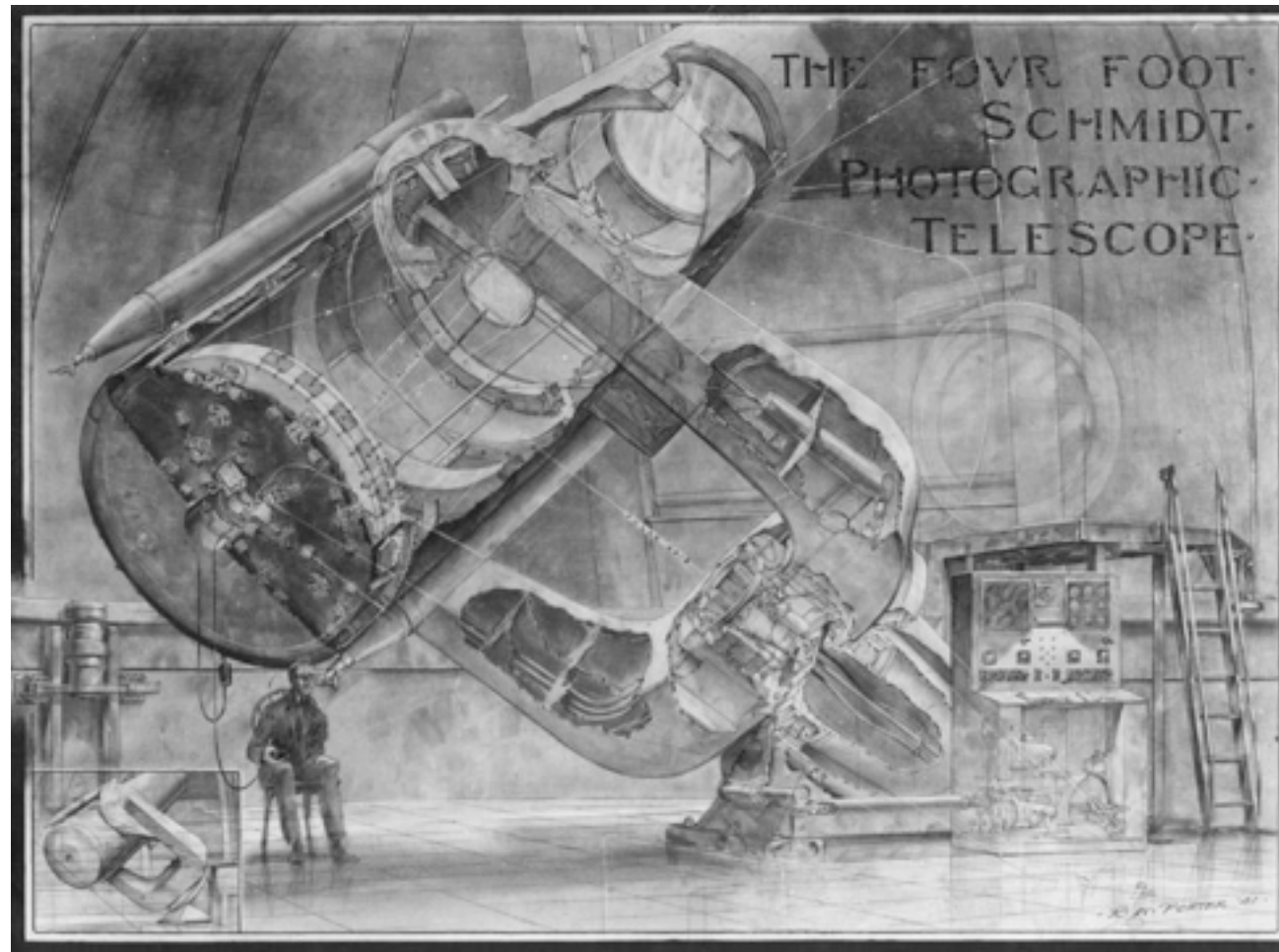


Data Mining the Optically Variable Sky since 1950



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ApJS, 209, 33 (2013)

[arXiv:1309.6322](https://arxiv.org/abs/1309.6322)

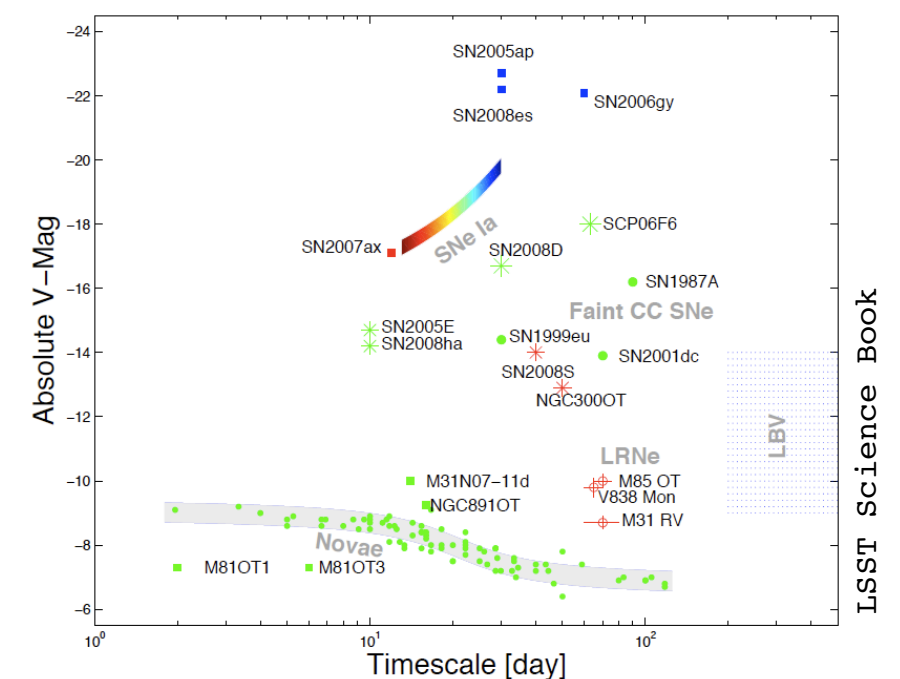


Motivation

- Current and next generation transient surveys limited to a few year time-scales
- Harness the long temporal & huge sky coverage of historical optical survey data
- Statistical analysis of large classes of variables
 - AGN/QSOs: structure of central engine
 - RR Lyr: structure of Galactic halo
 - Period changes in Miras, eclipsing binaries
- Discovery & understanding of outbursts from rare objects
 - dwarf novae, FU Ori, R Cor Bor, LBVs
- Explore new parameters in luminosity-duration space
- Improve historical photometry; legacy value



48" Schmidt at Palomar



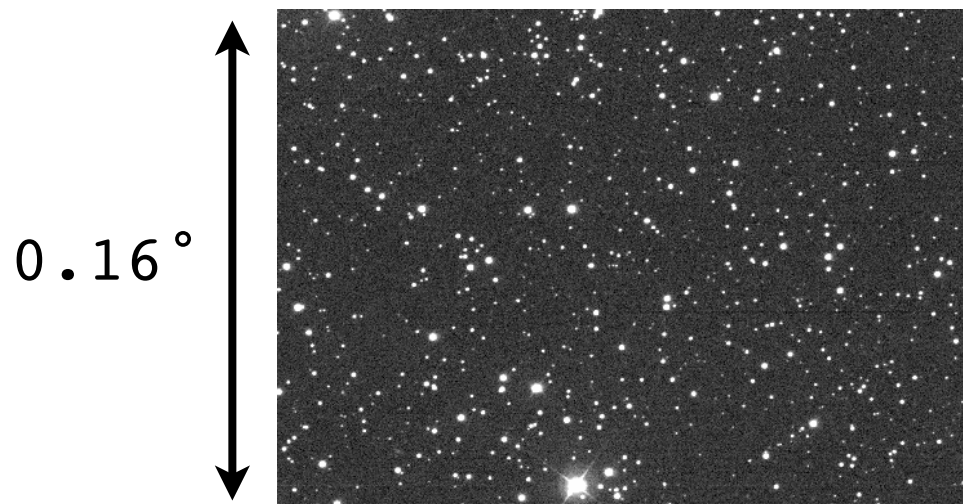
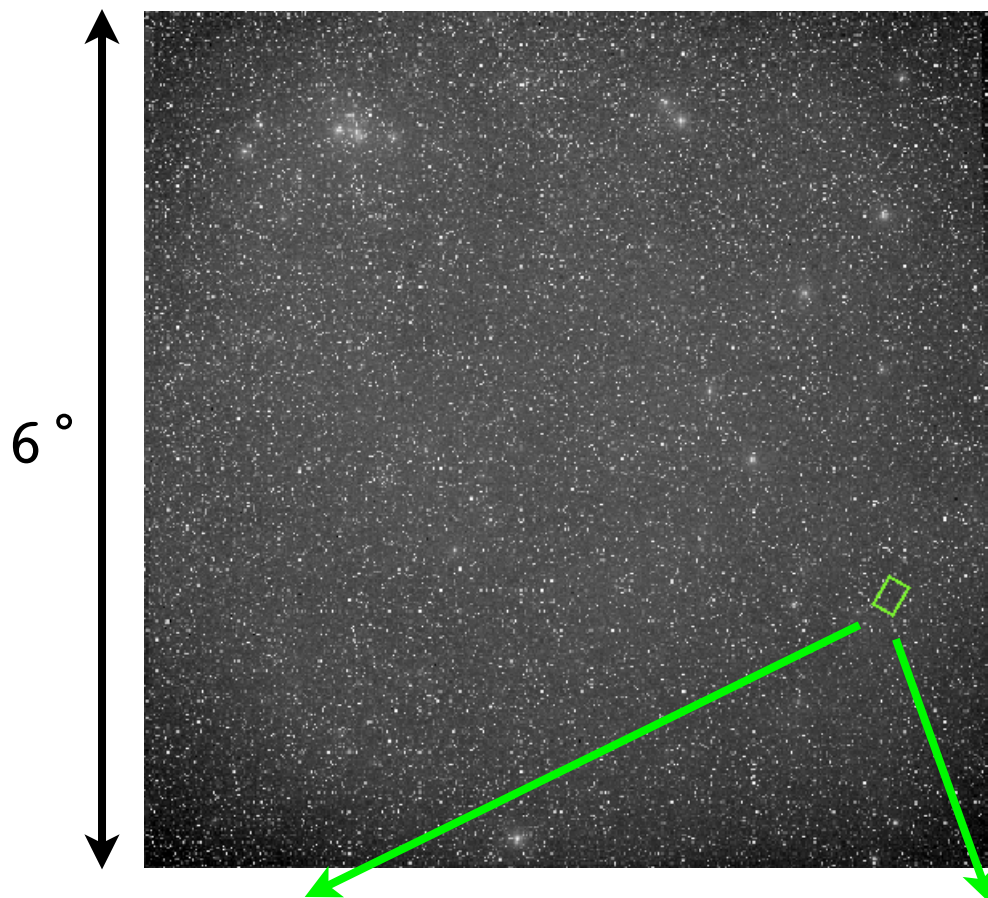
Approach: Use Existing Catalogs

- Photographic plate surveys go back ~100 years; digitised to create modern catalogs (e.g. USNO-B, GSC, SuperCosmos, DASCH)
- Plates very good for astrometry, OK for photometry
- USNO-B:
three-band, five-epoch photometry of a billion objects
- Sloan Digital Sky Survey (SDSS) Data Release 9:
accurate, five-band photometry of 260M *point sources*
- Compare SDSS & USNO-B catalogs to conduct blind search for variability
sensitivity ($\approx 20^{\text{th}} - 21^{\text{st}}$ mag)
areal coverage ($\approx 30\%$ of sky),
temporal coverage (~ 60 years)

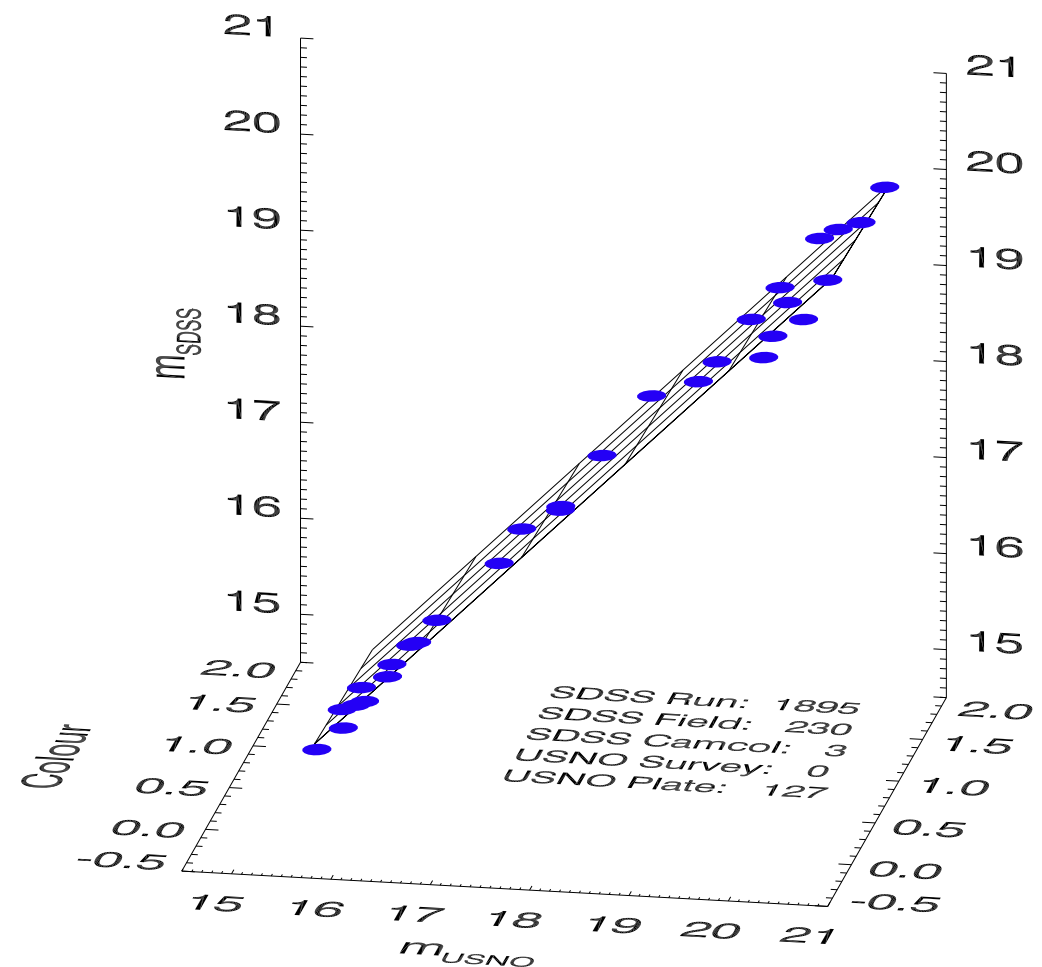


Recalibration: Stage 1

POSS-II Blue Plate



SDSS Field



- Identify calibration objects
- Calculate coefficients:

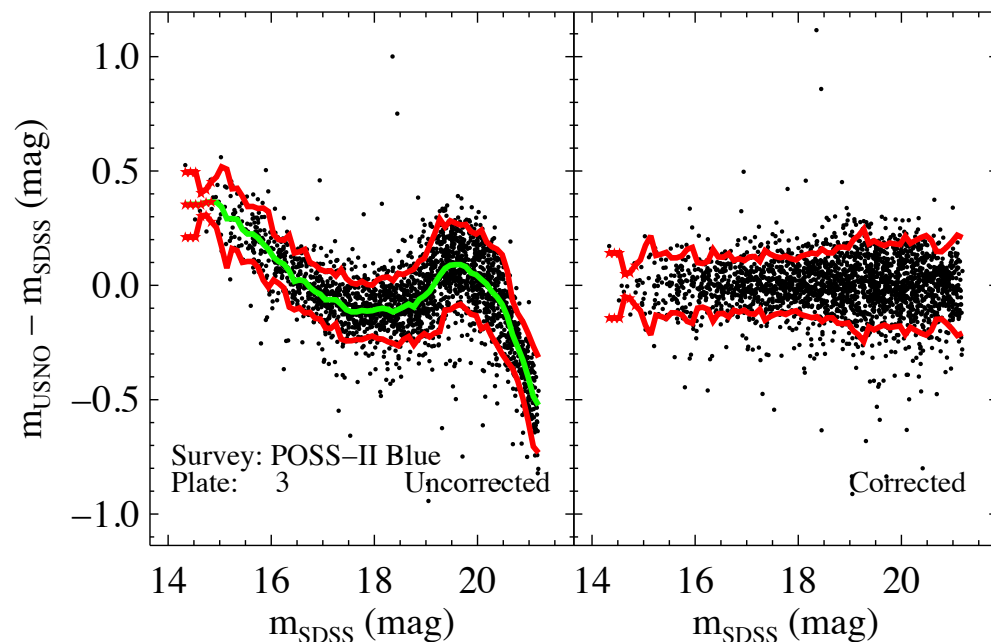
$$A * m_{USNO} + B * (\text{colour}) + C$$

that minimise $m_{SDSS} - m_{USNO}$

- Adjust USNO magnitudes

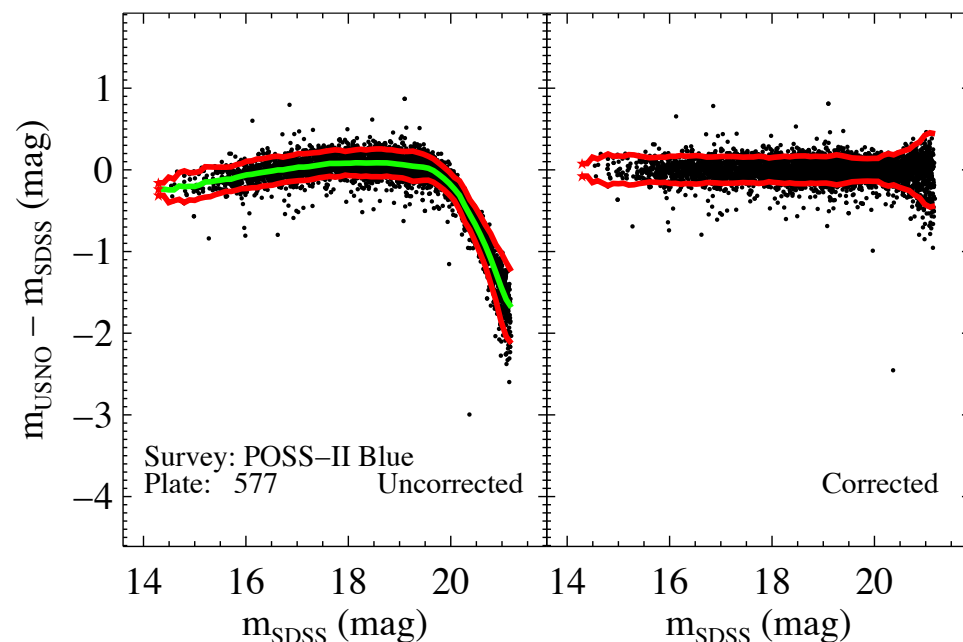
Recalibration: Stage 2

POSS-II Blue Plate: 3



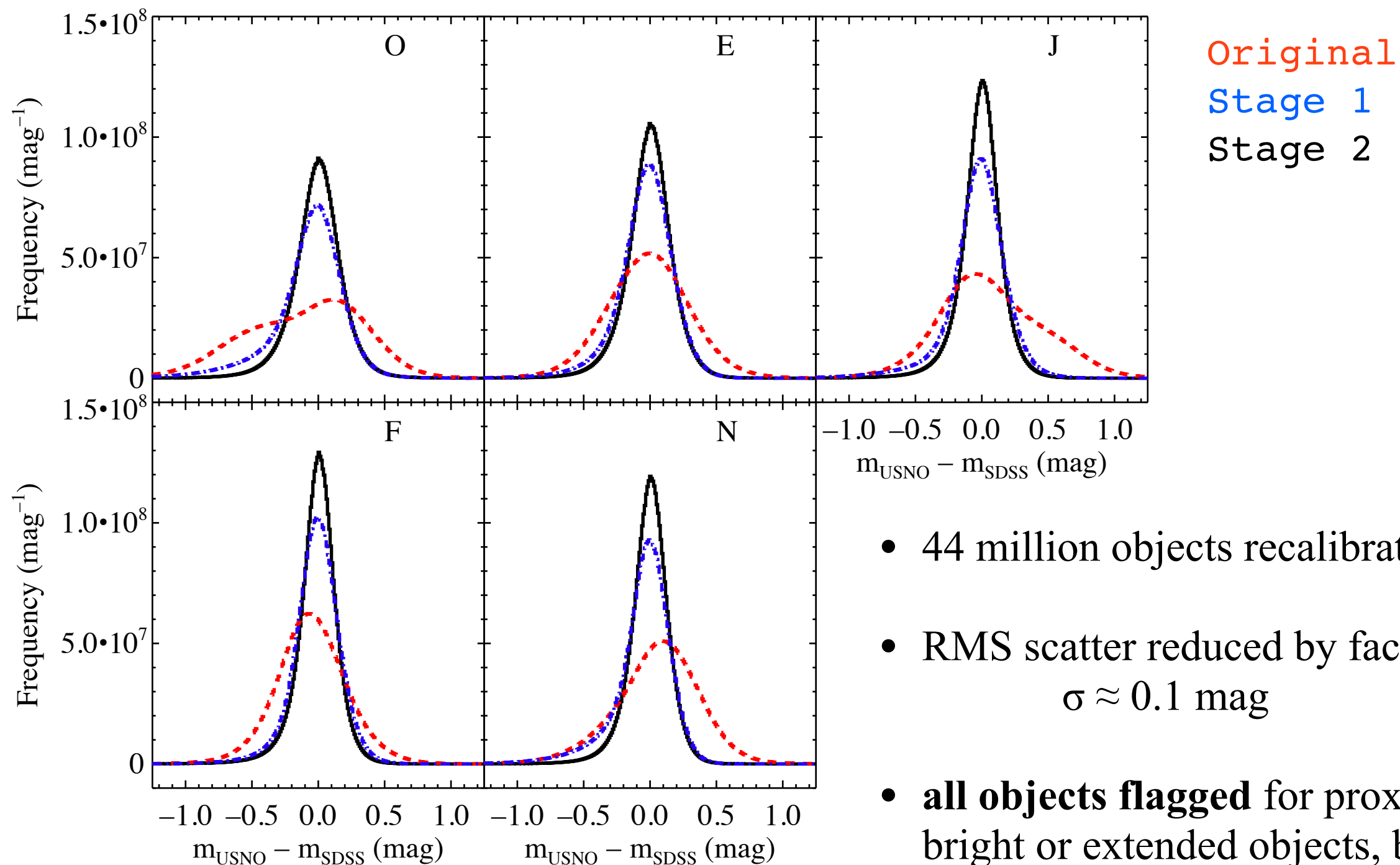
- Plate-wide (large angular scale) calibration problems remain
- Common pattern in residual magnitude vs. magnitude

POSS-II Blue Plate: 577



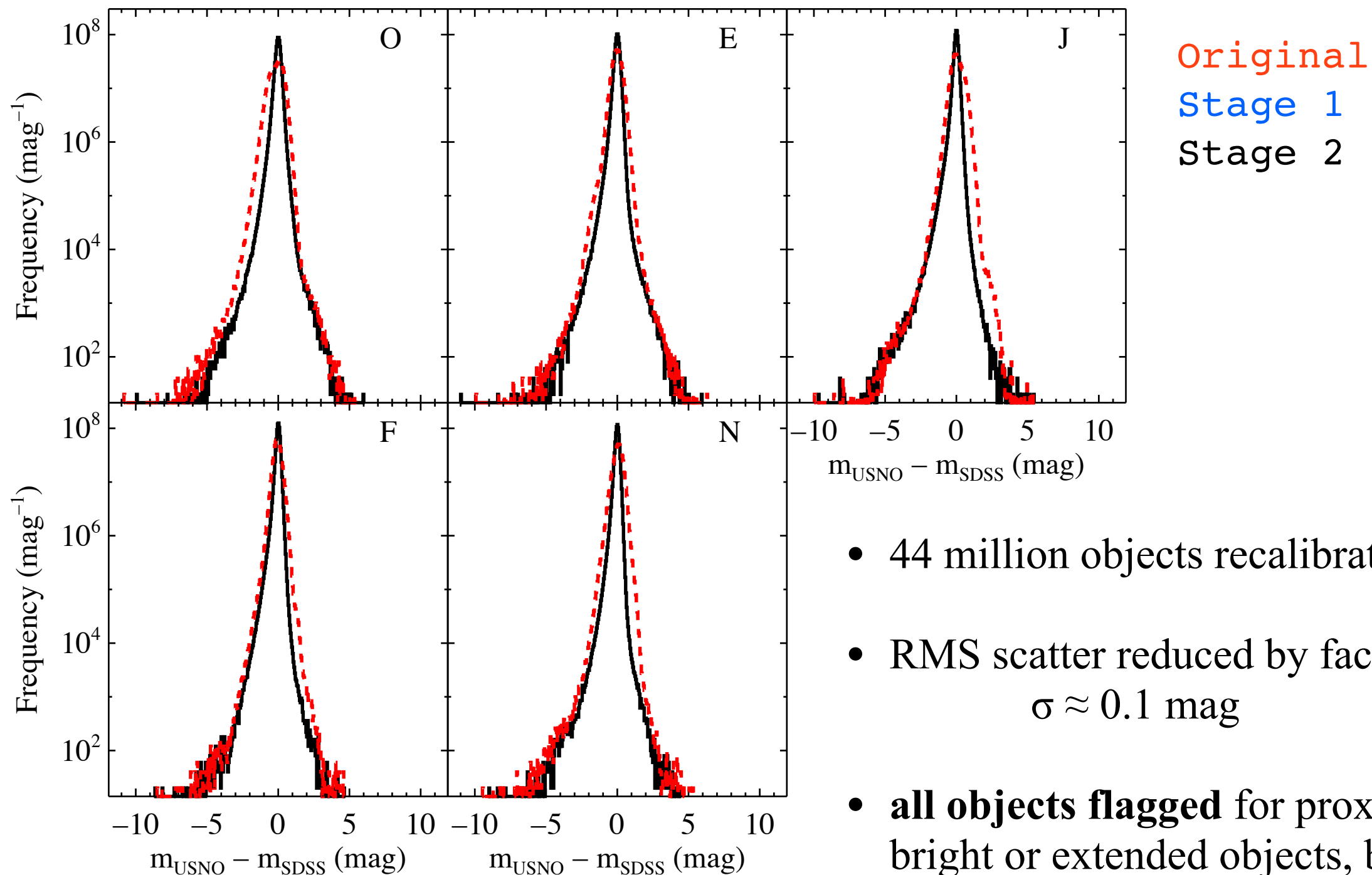
- USNO magnitude adjusted to remove pattern
- Residual scatter used as proxy for photometric accuracy

Recalibration: Results



- 44 million objects recalibrated
- RMS scatter reduced by factor of ≈ 4
 $\sigma \approx 0.1$ mag
- **all objects flagged** for proximity to bright or extended objects, blended sources, consistent magnitudes

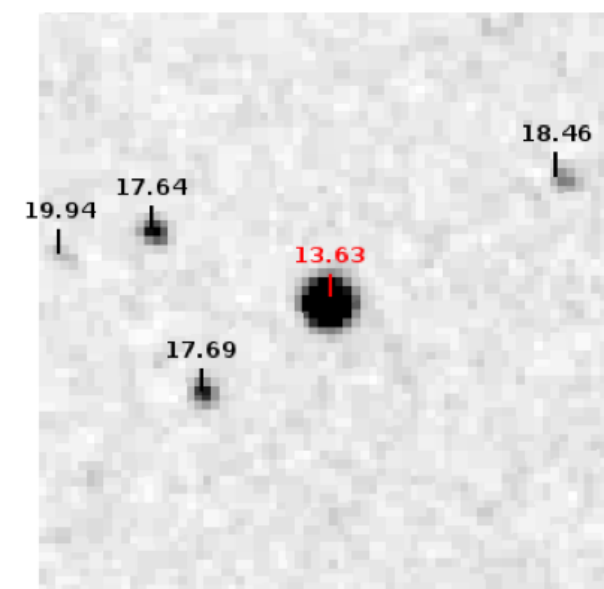
Recalibration: Results



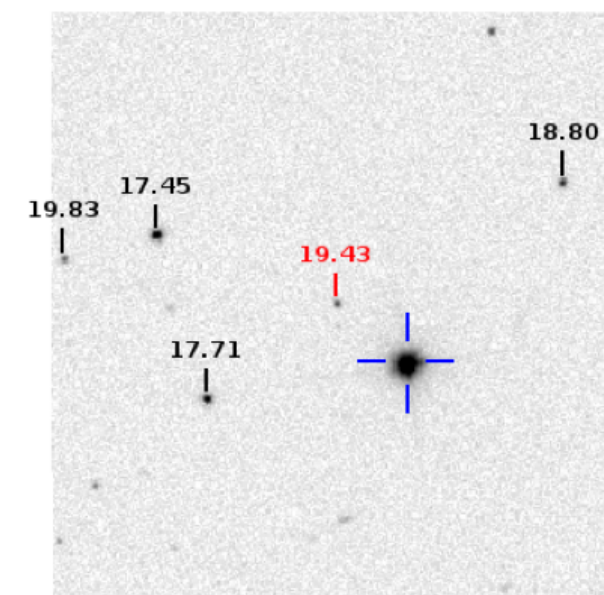
- 44 million objects recalibrated
- RMS scatter reduced by factor of ≈ 4
 $\sigma \approx 0.1$ mag
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Lessons & Limitations

- Careful, self-consistent treatment of proper motions and cross-matching (10% move by $> 1''$)
- Robust, automatic identification of objects blended with stars, galaxies, & artefacts (affects $\approx 15\%$)
- Check consistency of USNO, GSC, and SuperCosmos magnitudes of the *same* objects ($\approx 5\%$ are inconsistent)
- Visual inspection of large samples used to assess catalog reliability
- Remaining issues
 - blends with unusual artefacts
 - ‘pathological’ proper motions
 - inaccurate Sloan magnitudes (!)
 - object is not point source



E''_{USNO}

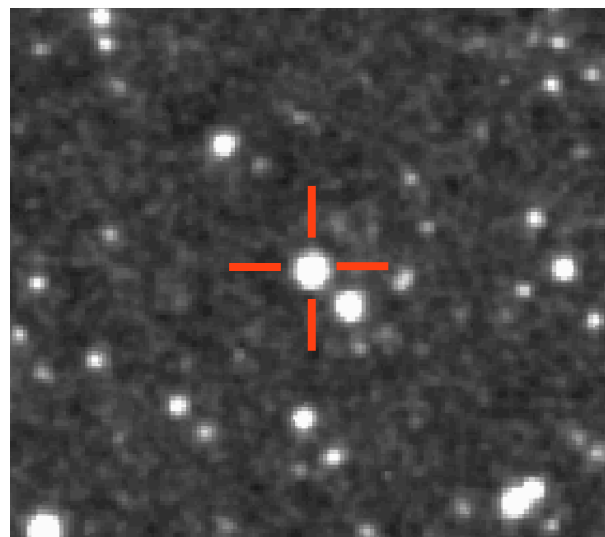


E_{SDSS}

Large Amplitude Variables

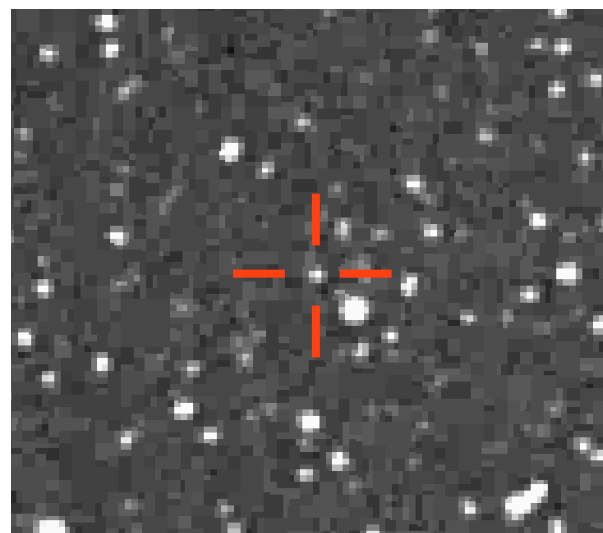
- $\approx 1.5\text{M}$ objects exhibit $\Delta m > 1.0$ mag
 - *98% are spurious*; removed by flagging
- $\approx 250,000$ candidate large amplitude (4σ) variables
 - visual inspection suggests $\approx 70\%$ are real
 - only 4% appear in major variable catalogues (VSX, CRTS)

New Mira?



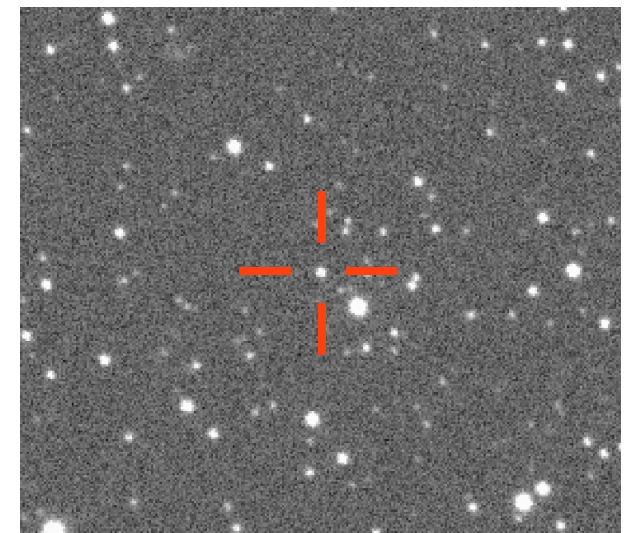
O-band mag: 16.0 ± 0.2

Date: 1954.48



20.0 ± 0.2

1988.46

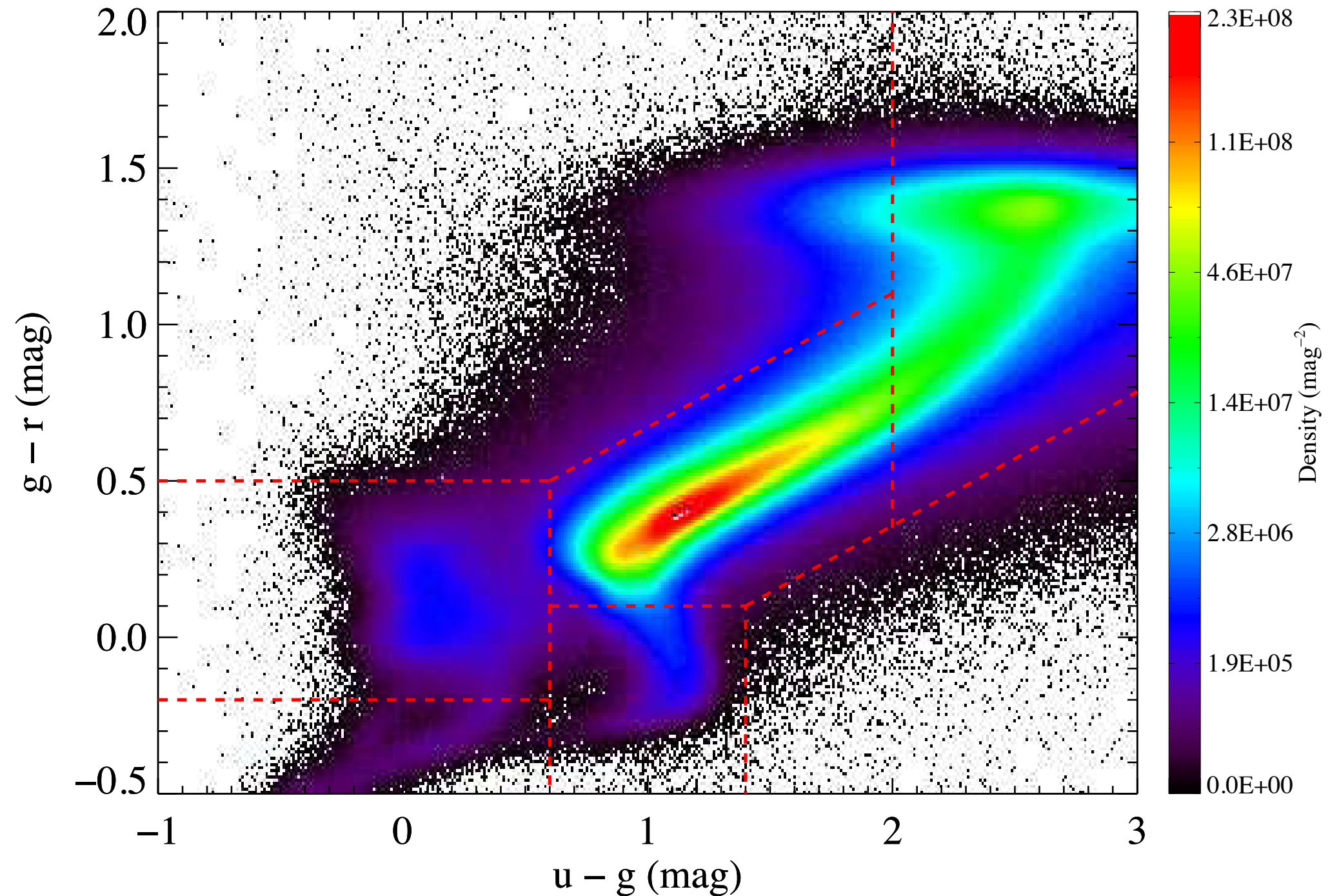


20.5 ± 0.02

2005.43

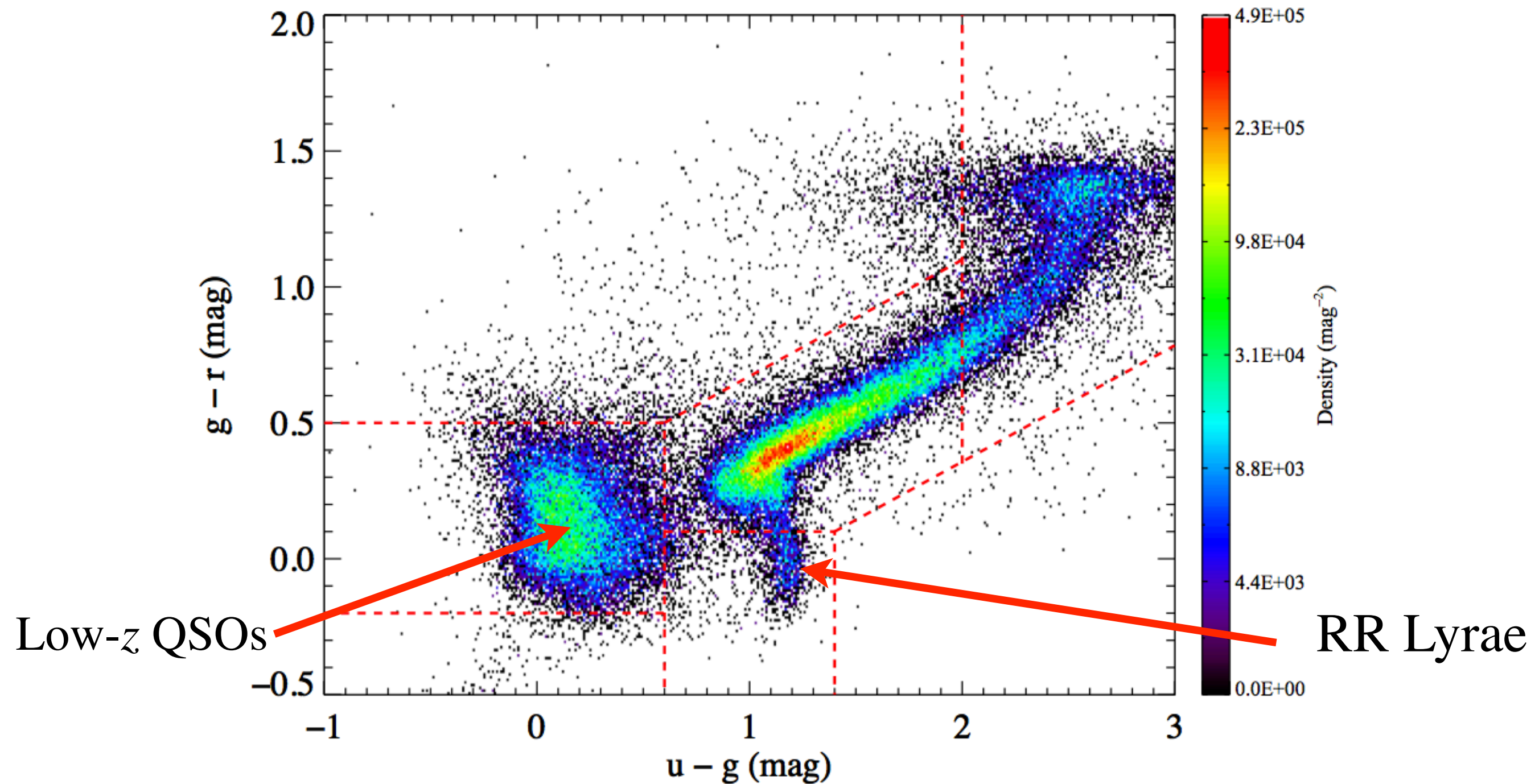
Classifying Variables

All cross-matched SDSS point sources



Classifying Variables

4σ variables (J -band; 75k objects)



Summary

- Improved historical photometric catalogue
 - six-epoch photometry of ≈ 44 M stars & quasars (1950-2010)
 - 95% complete to $g \approx 20.0$ mag; accurate to ≈ 0.1 mag
 - very low contamination rate
 - $> 250,000$ large amplitude variable candidates; mostly uncataloged
 - legacy value for future surveys (e.g., LSST)
- Future work
 - ingest ongoing wide-field optical surveys to extend sky coverage; extend cross-matching to UV, IR, radio...
 - identify “transients”

Transients Teaser?