The Photometric Calibration of Pan-STARRS1 (and the SDSS)

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Photometric Calibration

Simple picture

- Telescope CCD records counts from an object in the sky
- We want to know the flux of the object in a band
- Photometric calibration relates counts to flux in a band

Photometric Calibration

- This simple description includes a lot:
  - overall throughput of the telescope (area, efficiency)
  - dependence on object spectrum
  - dependence on pipeline behavior
- We perform only a limited *relative* photometric calibration
  - Ignore actual relationship between counts and flux
  - Ensure only that the relationship is fixed
  - Single overall throughput per image (neglect filter shape variation and non-linearity)

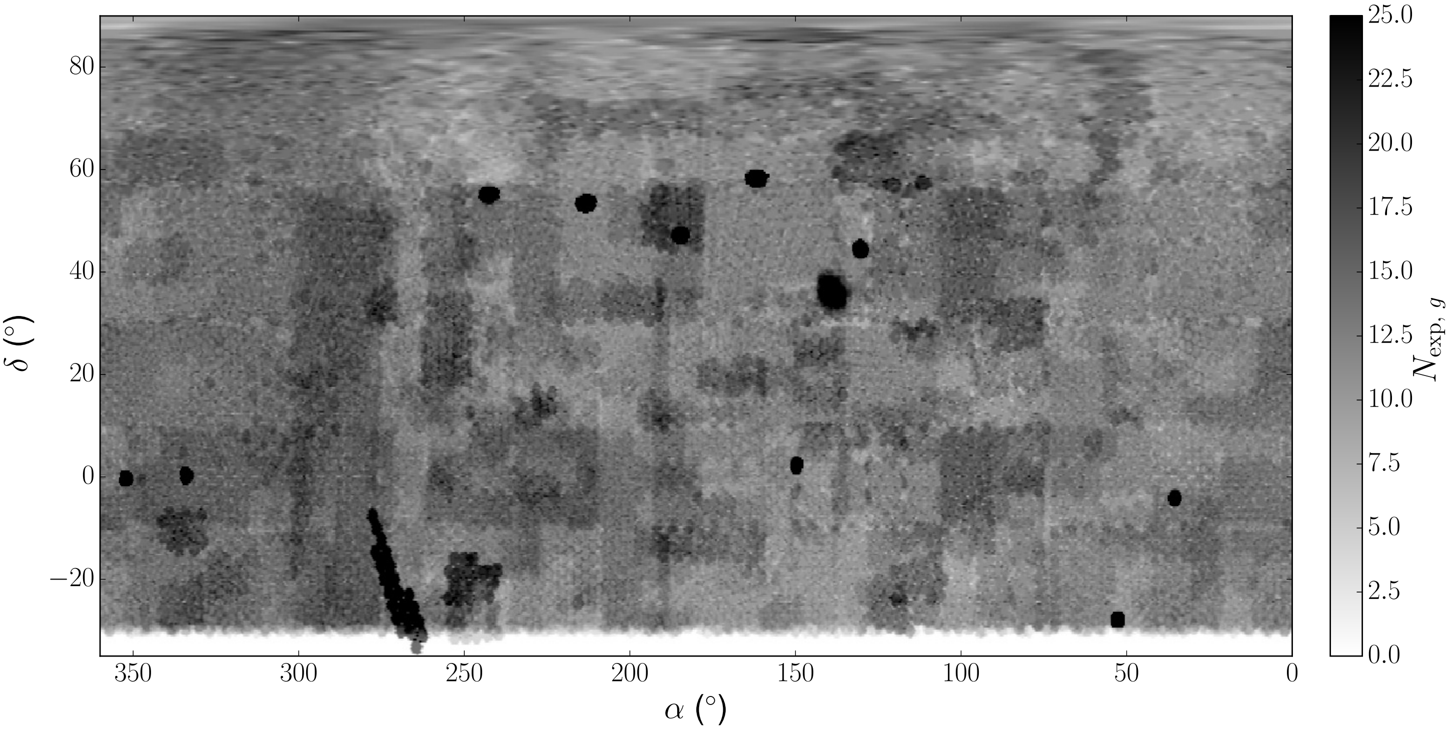
Photometric Calibration

- The remaining problem is still hard
- The count to flux ratio can change because of
  - airmass
  - atmospheric transparency
  - detector efficiency
  - image quality
  - ...
- We model & remove these effects

PS1

- 7 square degree field of view
- Billion pixel camera
- 5 band, *grizy*, 400 nm – 1000 nm
- > 12 epoch
- $\delta > -30^\circ$
- 10 "medium deep" fields with thousands of exposures

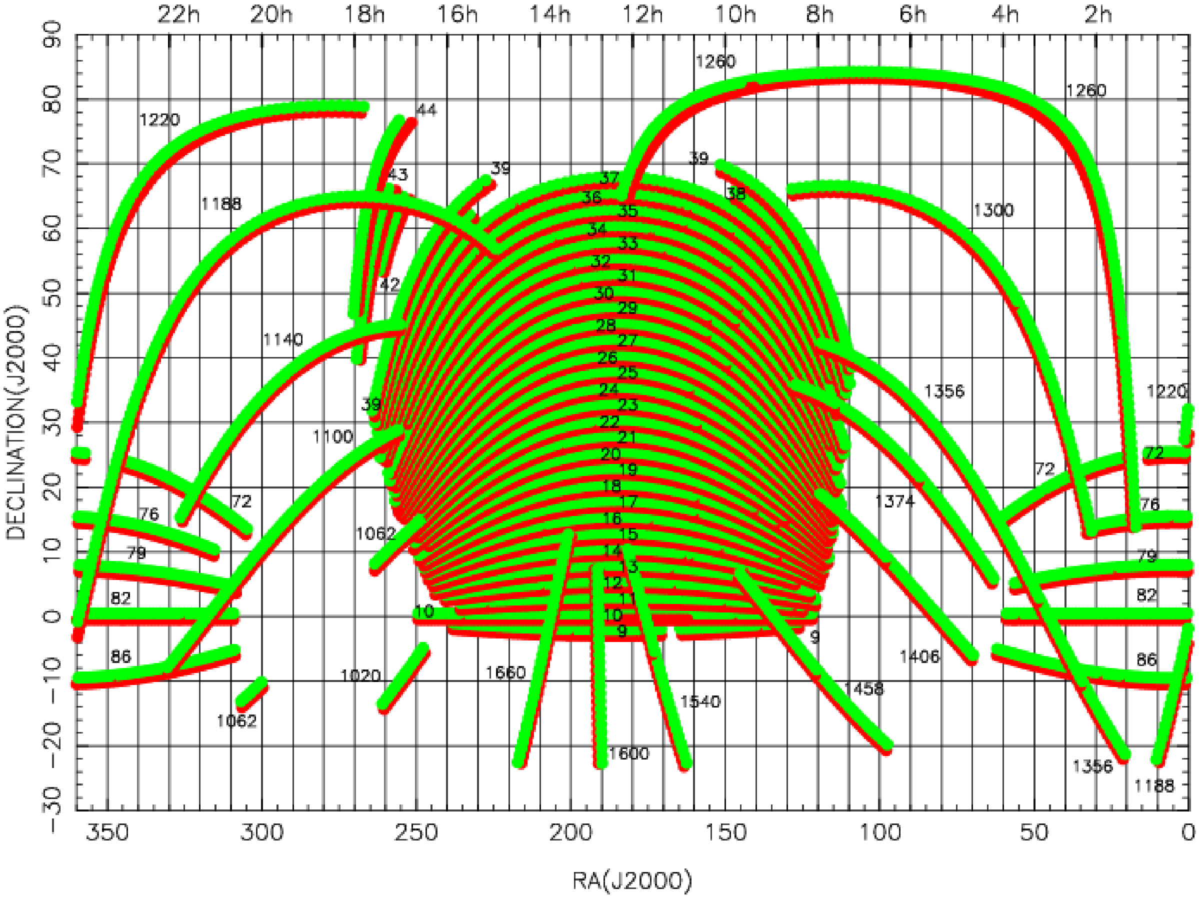
PS1 Coverage



SDSS

- 7 square degree field of view
- 130 million pixel camera
- 5 band, *ugriz*, 300 nm – 1000 nm
- ~ 1 epoch
- $\delta > -10^\circ$, extragalactic
- ~ 60 epoch Stripe 82 observations

SDSS Coverage



Method

General technique:

- We have multiple images of many stars.
- These images are taken in different conditions, at different
  - airmasses
  - times
  - image qualities
  - locations in the focal plane
- We can then use them to determine how the system throughput changes.
- Same technique adopted in the SDSS

Method

- We calibrate PS1 instrumental magnitudes m_{inst} by finding zero points Z, that give objects consistent magnitudes m.
- $m = m_{\mathrm{inst}} + Z$
- We adopt a simple model for Z

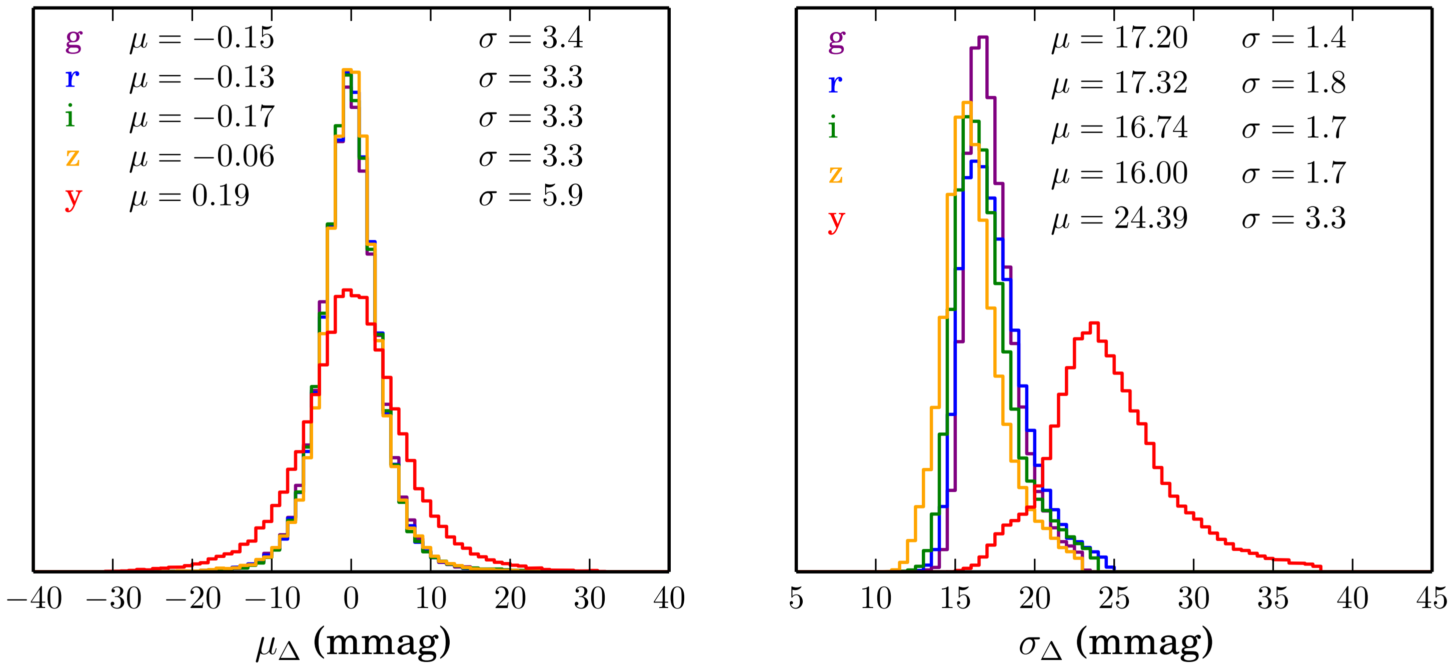
$$Z = a_n - k_n x + f + w(F)$$

where
  - a: system zeropoint (one parameter per night)
  - k: atmospheric opacity (one parameter per night)
  - x: airmass of observation
  - f: flat field (1024+ parameters)
  - w: image quality correction function
- We then solve for the parameters of this model for Z, to minimize

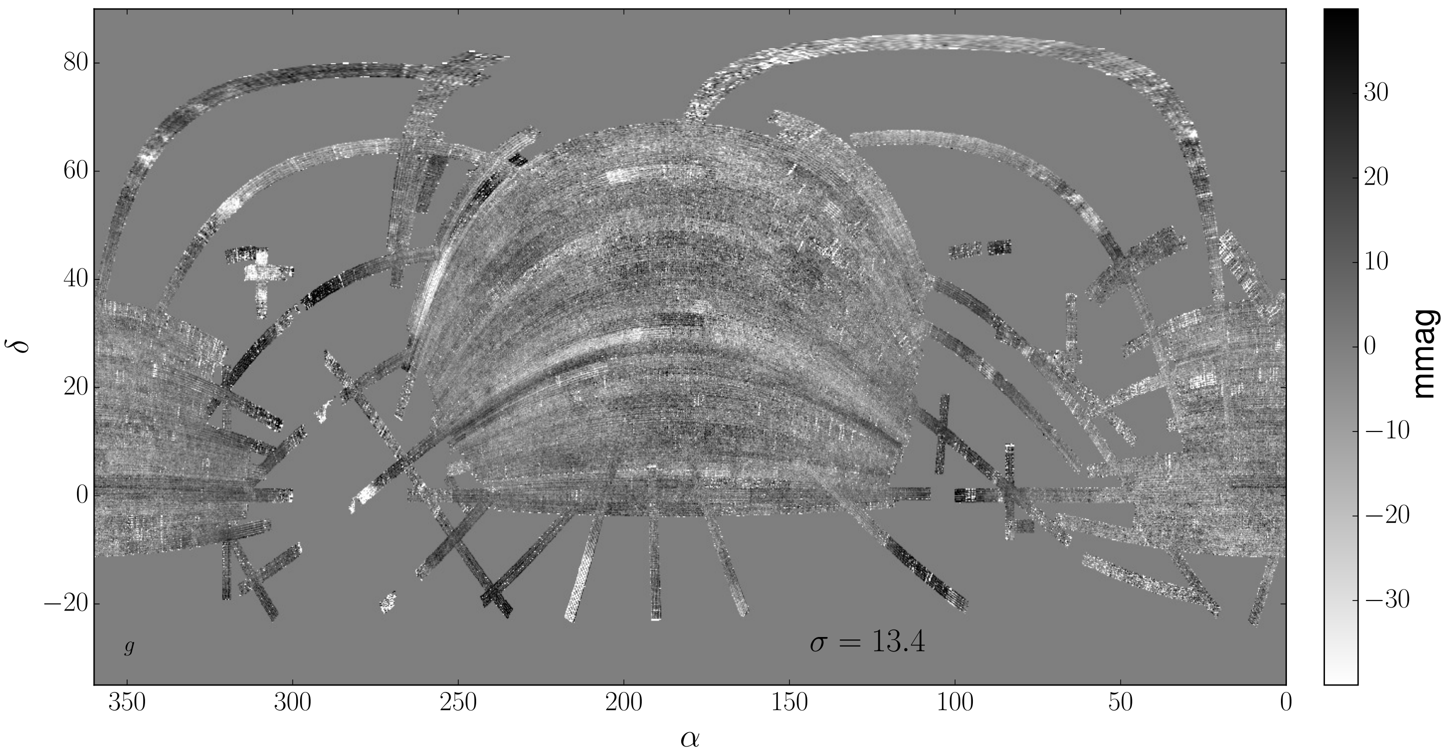
$$\chi^2 = \sum_o \sum_i \frac{(m_{o,i} - \overline{m_o})^2}{\sigma_{o,i}^2}$$

- Large (few thousand parameter) underdetermined linear least-squares problem; solve using standard SVD techniques.

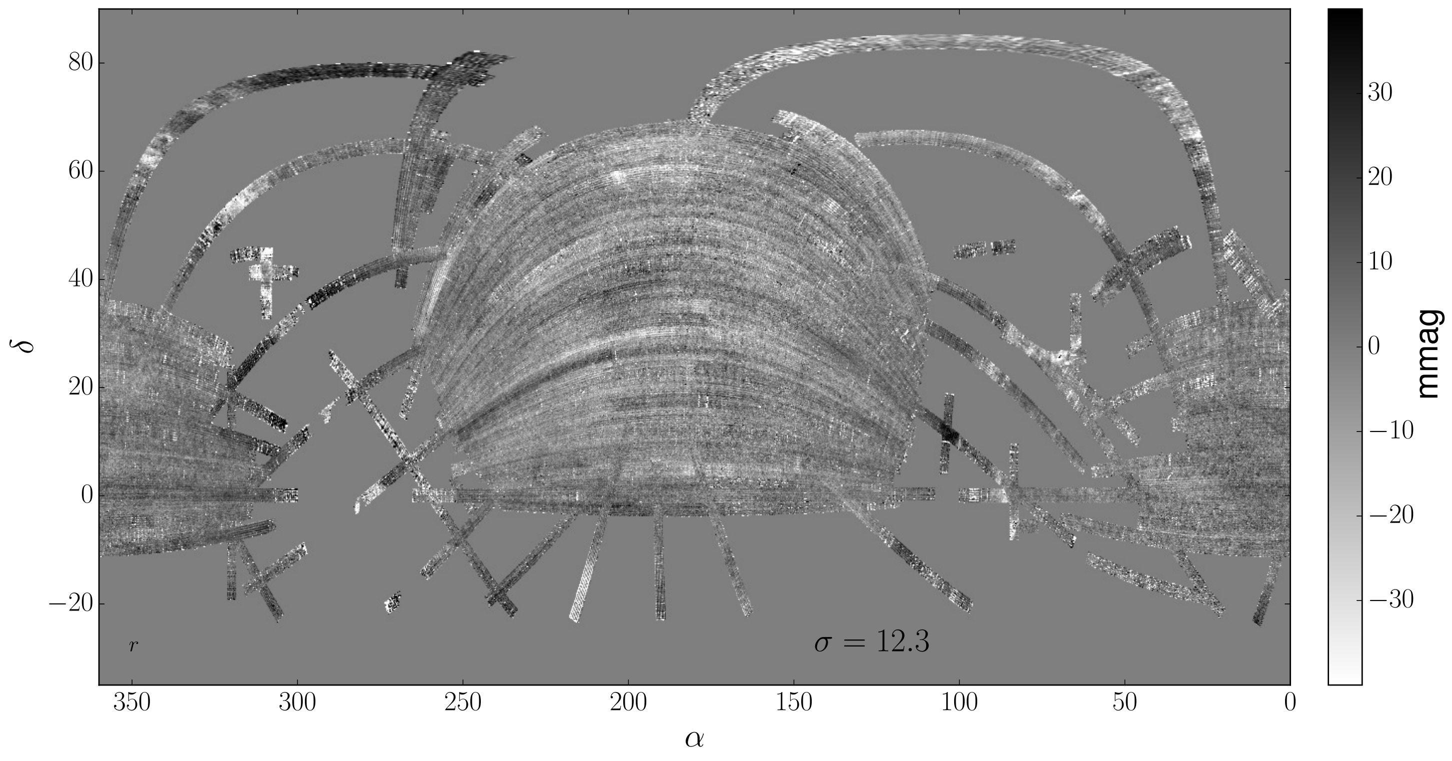
Internal Consistency



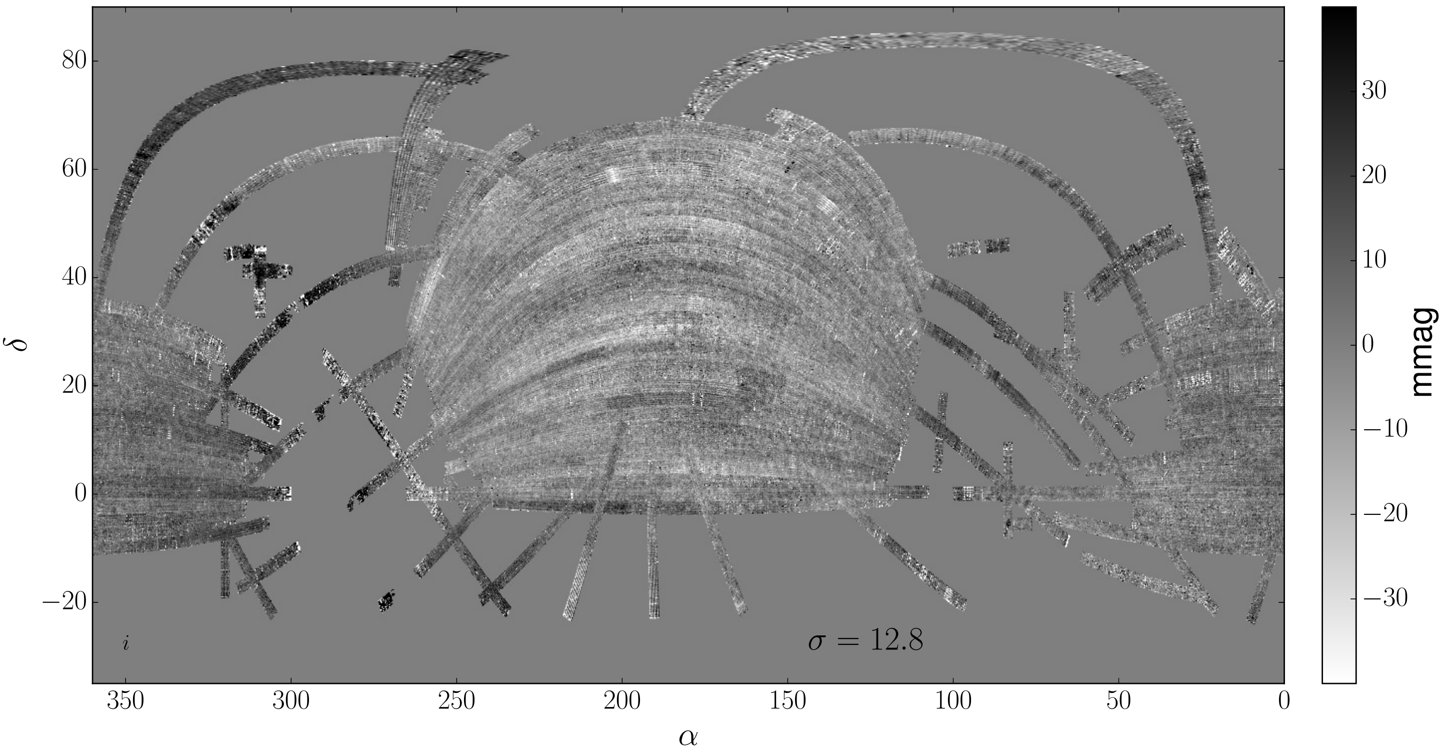
Comparison with the SDSS



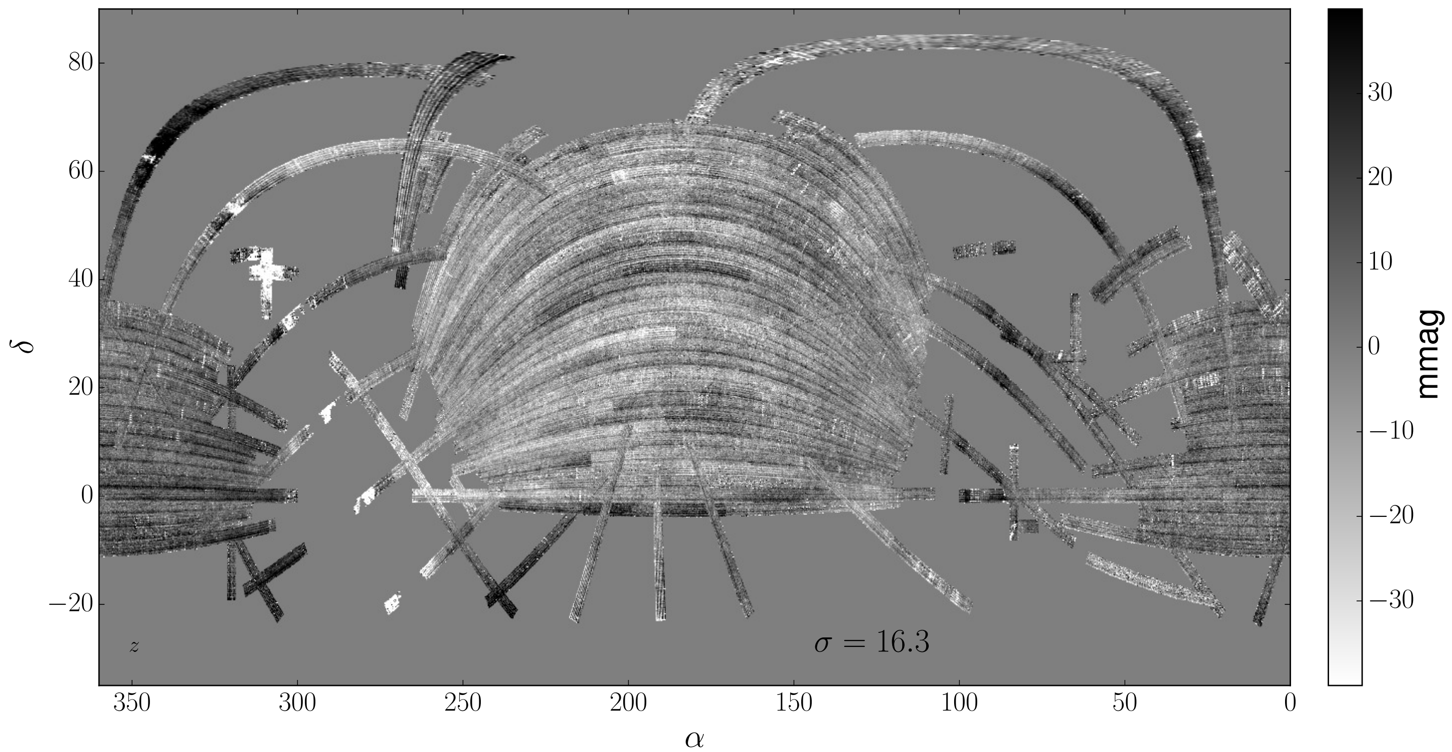
Comparison with the SDSS



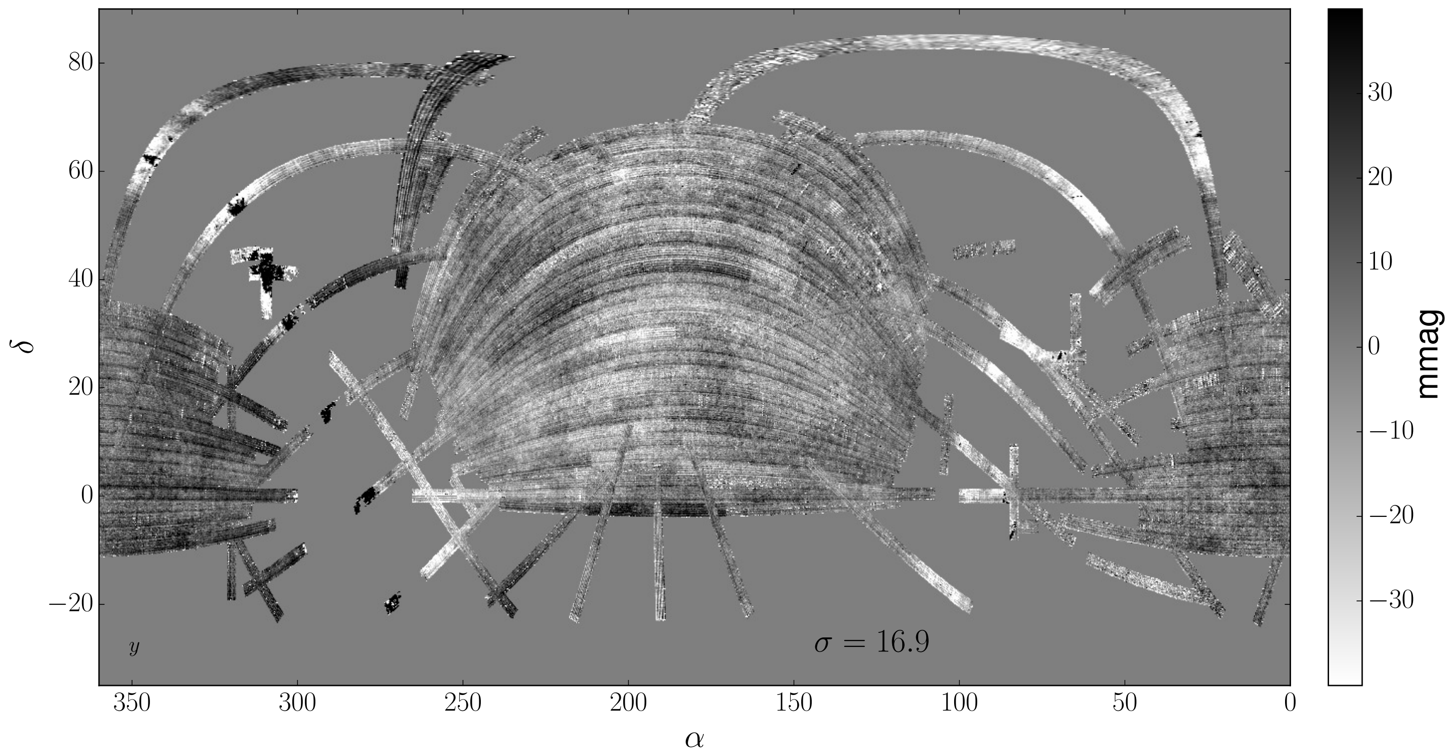
Comparison with the SDSS



Comparison with the SDSS

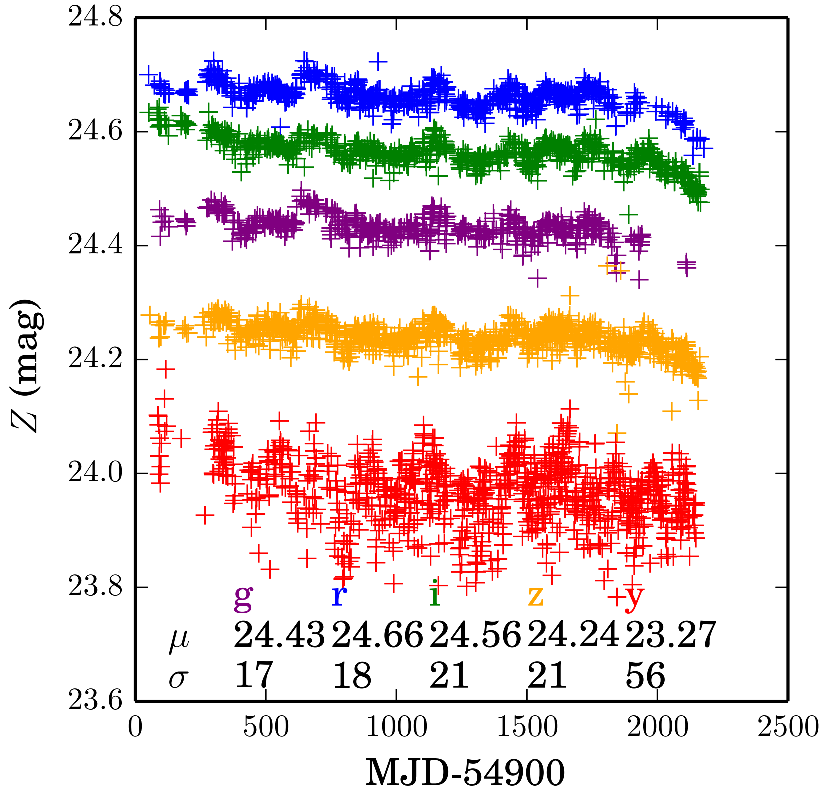


Comparison with the SDSS



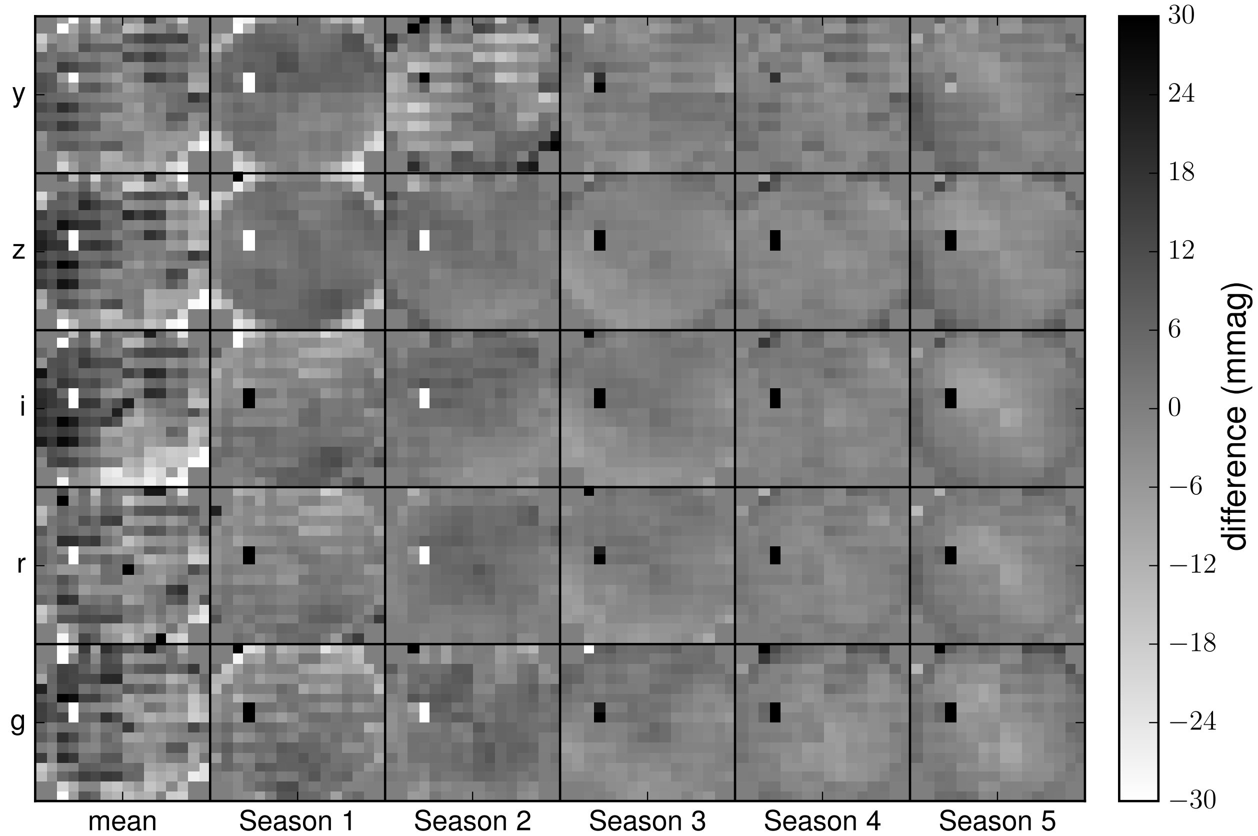
System Stability

∼ 20 mmag stability in overall throughput at 1.2 airmasses.



Detector Stability

The detector flat field is virtually unchanged over the course of the survey.



Conclusion

- Precision better than 10 mmag in all bands
- Enables wide variety of PS1 science
- Applicable to any multi-epoch survey