The SDSS Southern Survey Standards Catalog and its Implications for the LSST Calibration Requirements

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Outline

1. SDSS, photometric calibration, southern survey

2. The SDSS Southern Survey Standards Catalog

   - Motivation
   - Construction
   - Quality Tests

3. Applications of the Catalog

   - High-fidelity color-color diagrams
   - Calibration of non-photometric data

4. Implications for the LSST Calibration Requirements

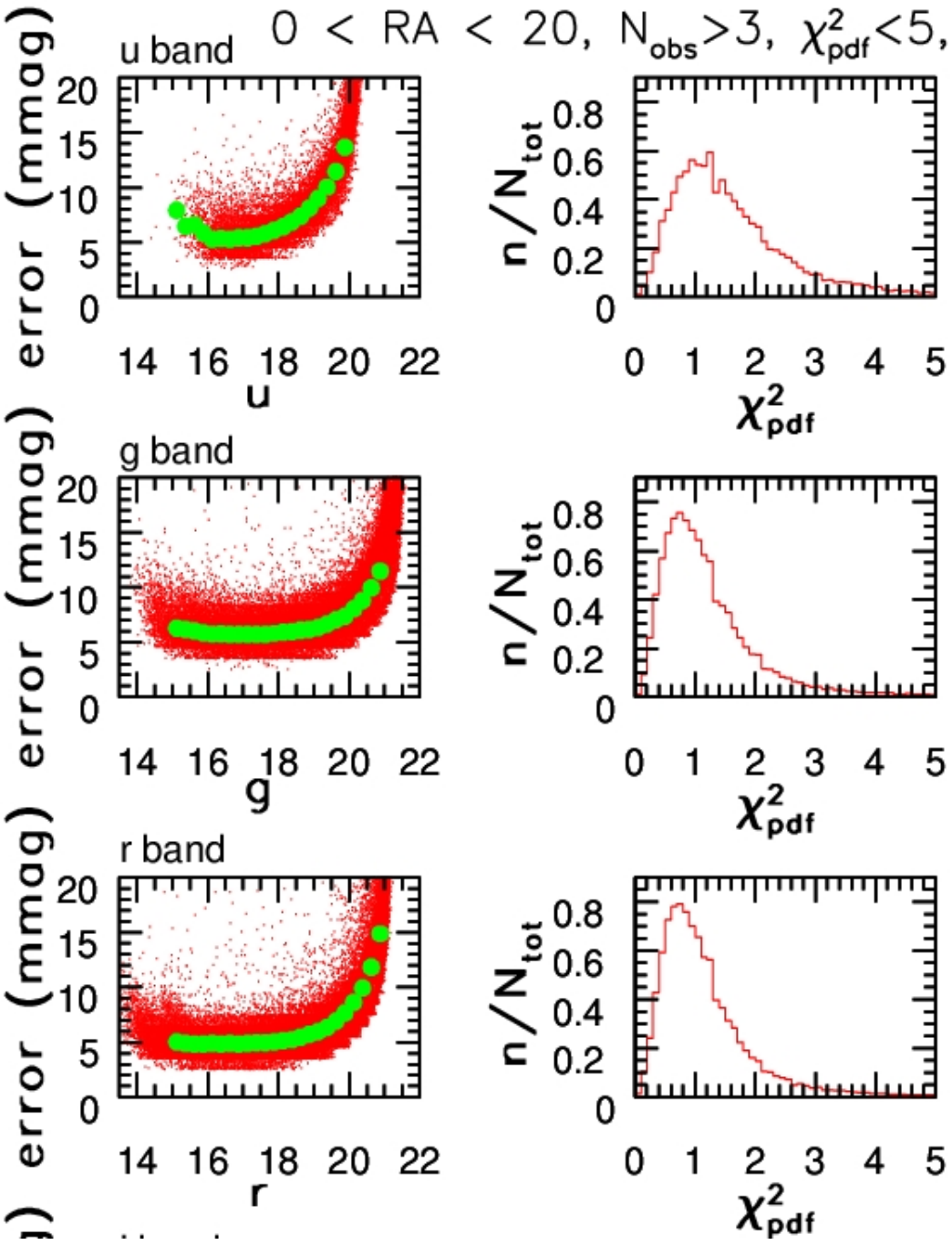
The Sloan Digital Sky Survey

- Imaging Survey
  - $\sim$10,000 deg^2, 5 bands (ugriz: UV-IR),
  - 0.02 mag photometric and $< 0.1''$ astrometric accuracy
  - Over 100,000,000, mostly main sequence, stars

- Spectroscopic Survey
  - Spectra for $>$200,000 stars (radial v to $\sim$10 km/s)
  - Spectra for 1 million galaxies
  - Spectra for 100,000 quasars

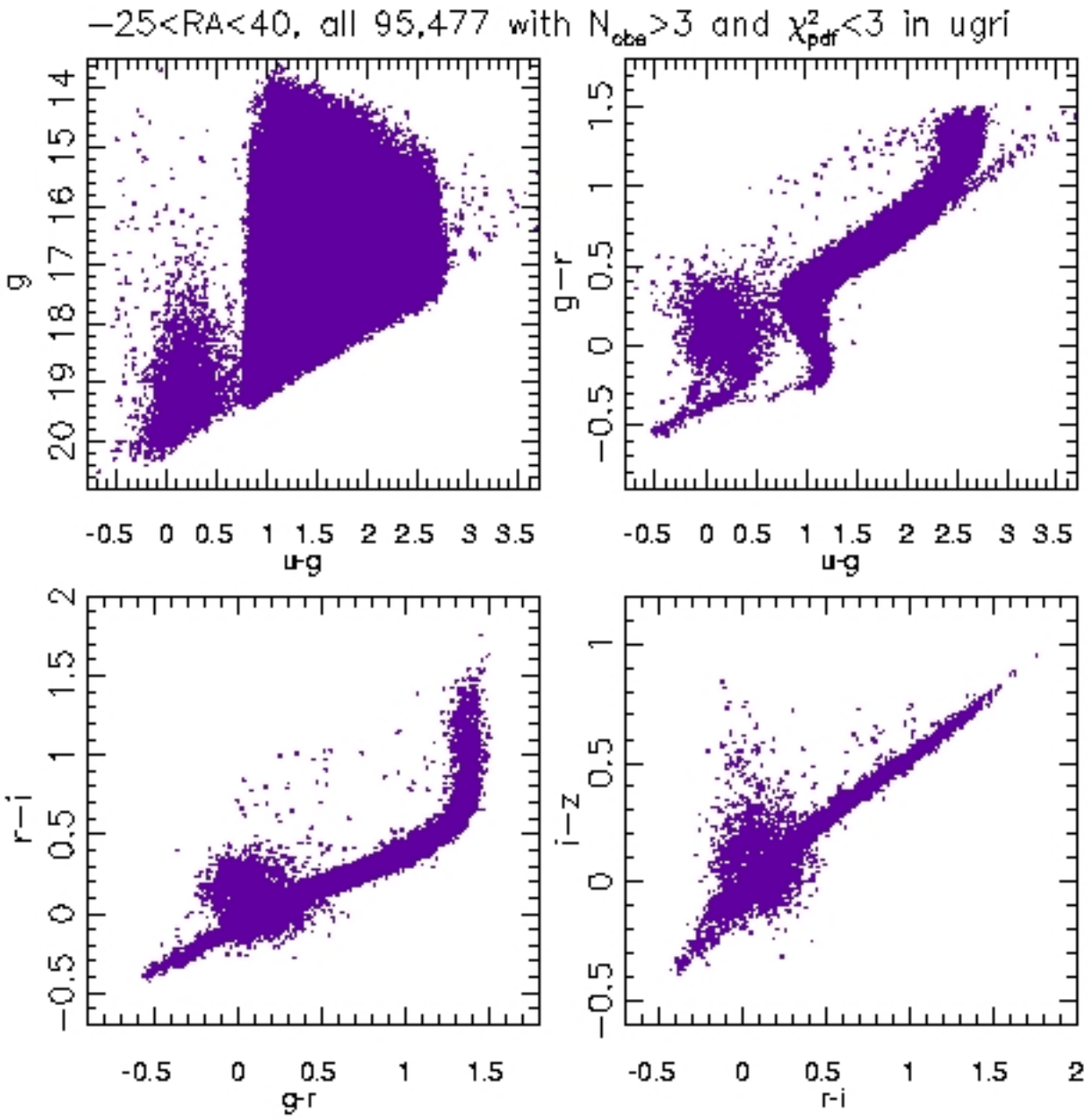
- Imaging Survey(s)
  - the Main Survey: $\sim$10,000 deg^2: 1 or 2 epochs
  - the Southern Survey: 300 deg^2 (along celestial equator with b$<$0) with many epochs (here 10, total close to 100)

- Photometric Calibration
  - The secondary standards are tied to the USNO primary standards (Smith et al. 2002)
  - The main (2.5m) survey is tied to secondary standards observed simultaneously in **sparse** patches – a patch every hour or so: can't resolve fast problems
  - Single 2.5m scans have calibration good to $\sim$1% in the gri and $\sim$2% in the u and z bands:
  - The averaging of single scans can improve photometry: $\sim$10 scans from the 300 deg^2 large SDSS Southern Survey

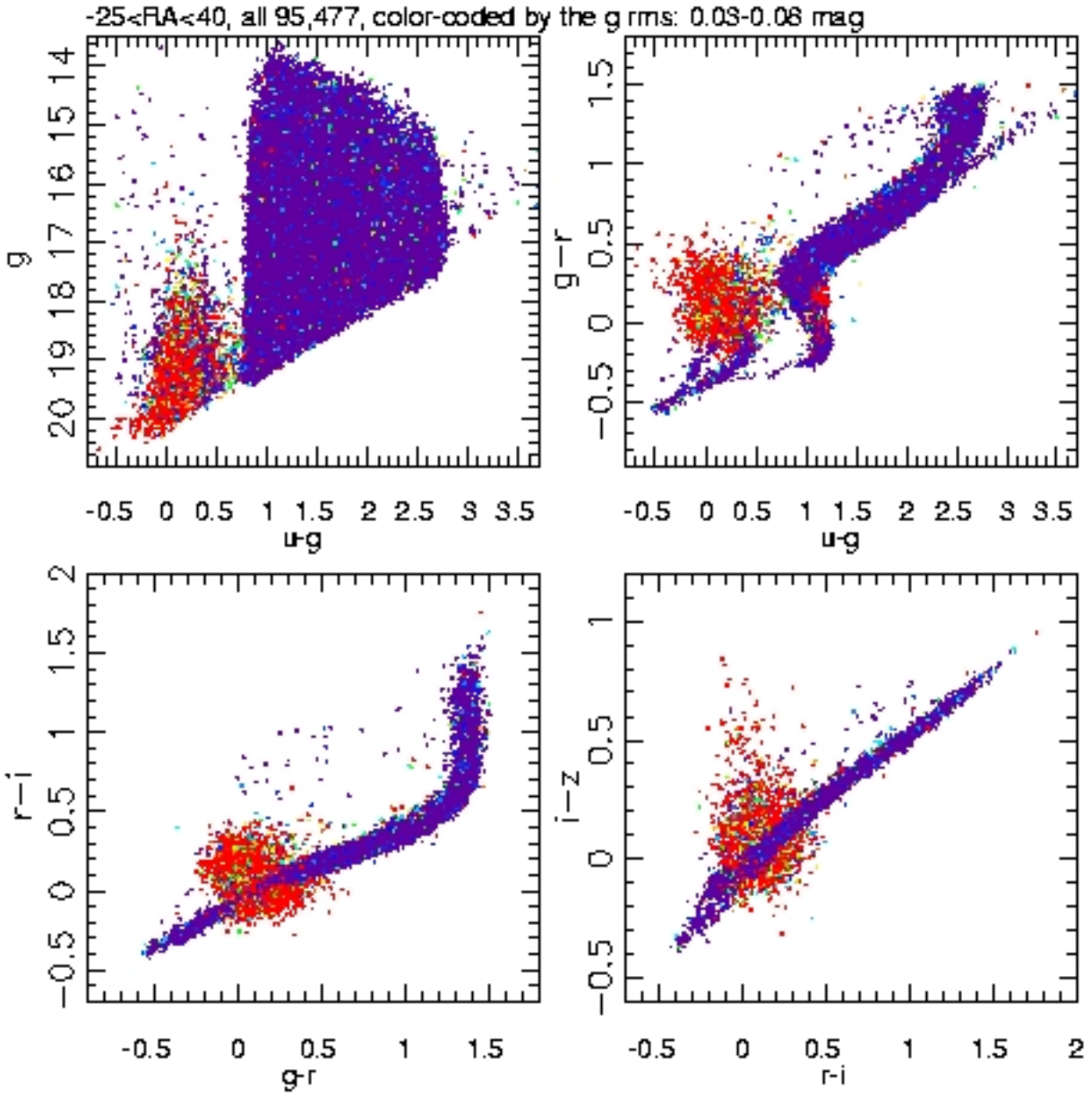


The Statistics of Repeated Measurements

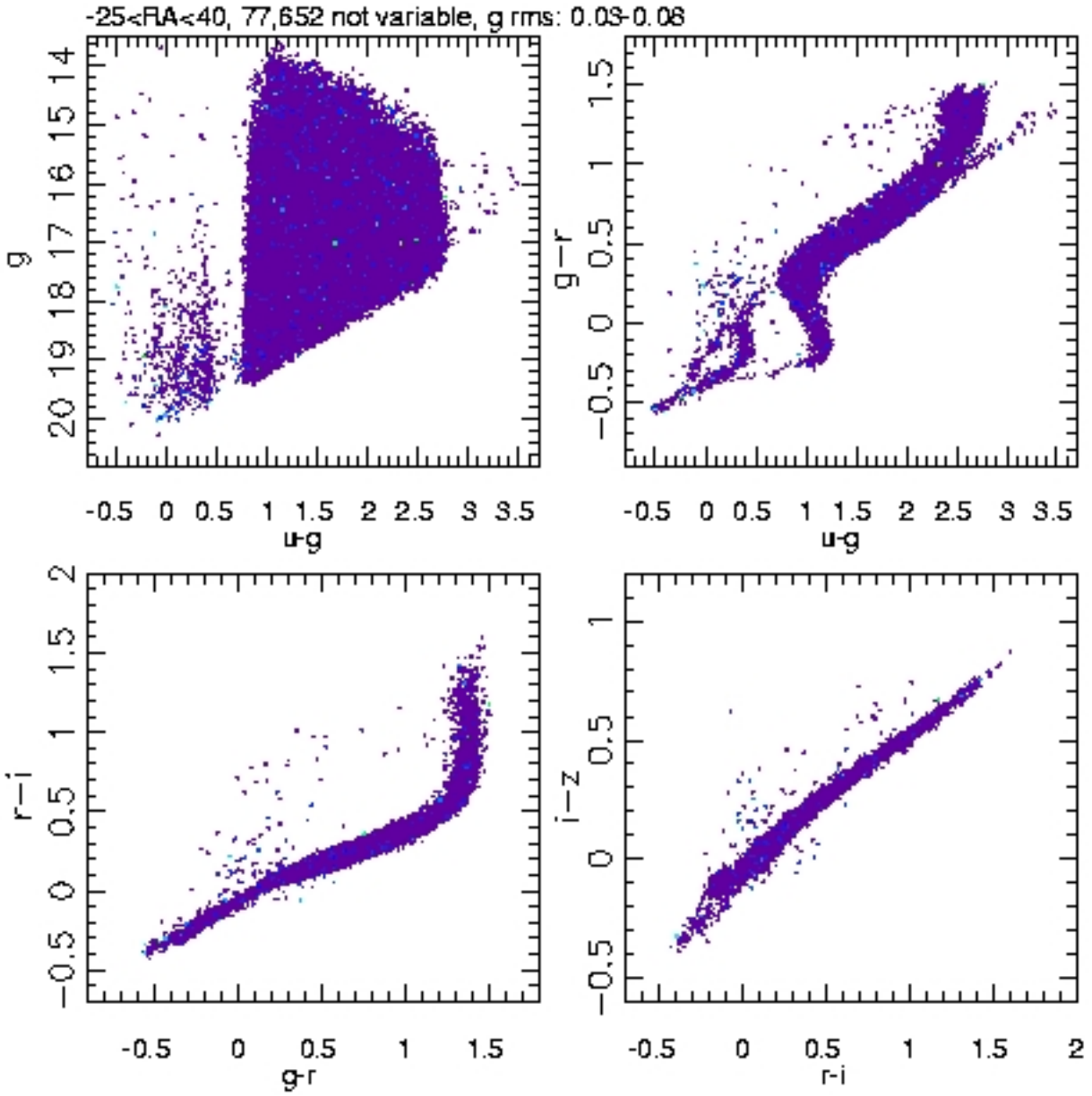
- The three rows: u, g and r bands (i and z are similar)
- The first column: (quoted) error for the mean: red dots are individual stars and green symbols are median errors as a function of magnitude. Random errors <0.01
- The second column: the χ^2 per degree of freedom distribution using quoted errors. Quoted (random) photometric errors are trustworthy.
- The sample includes 870,000 stars with the (random) r band magnitude errors $<1\%$ ($r<21$ over 300 deg^2).



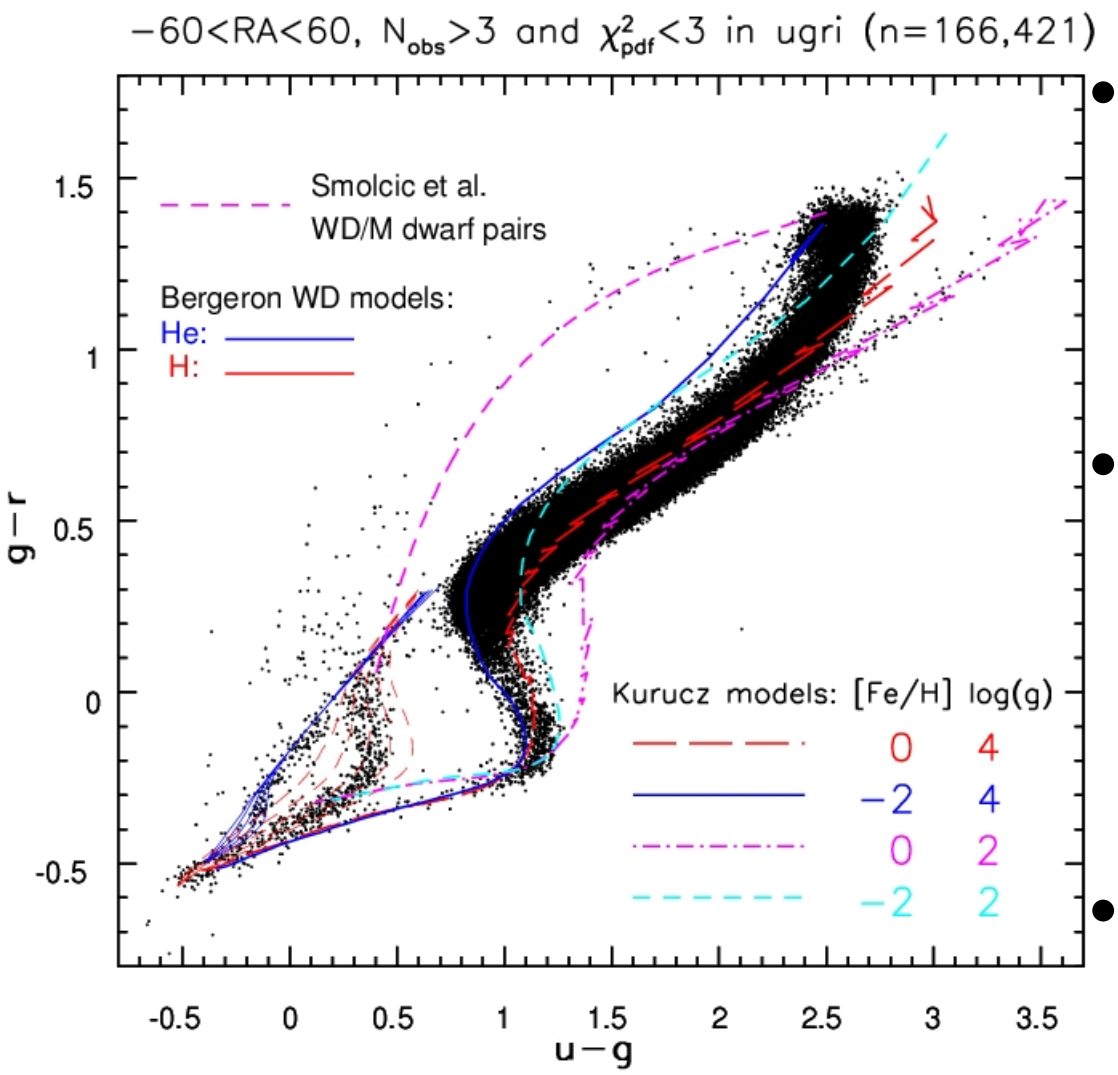
- All point sources with accurate multi-epoch photometry
- The variability information is readily available



- All point sources, color-coded by variability
- Quasars, RR Lyrae and other variables can be recognized and removed

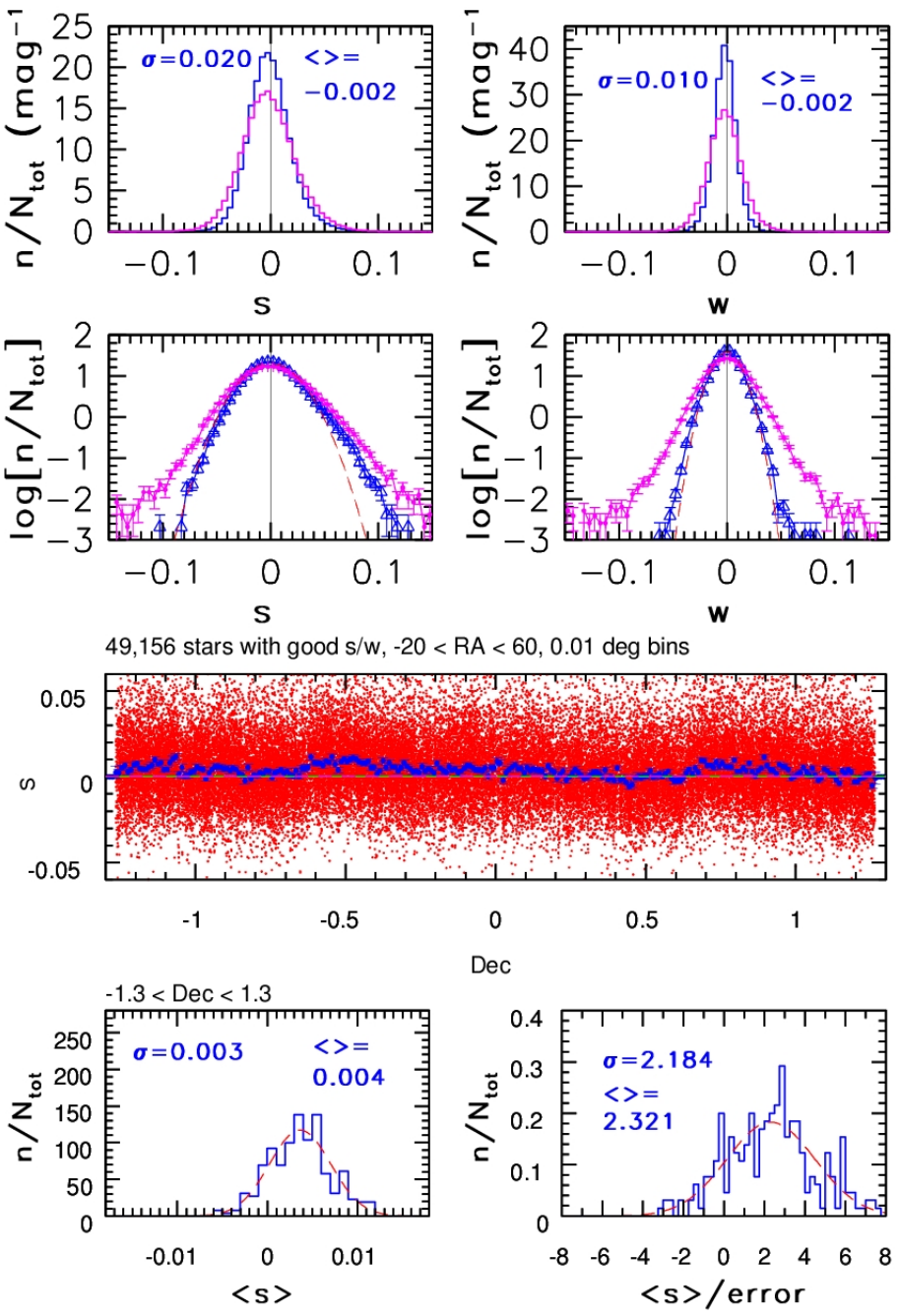


- Only non-variable sources are used for calibration



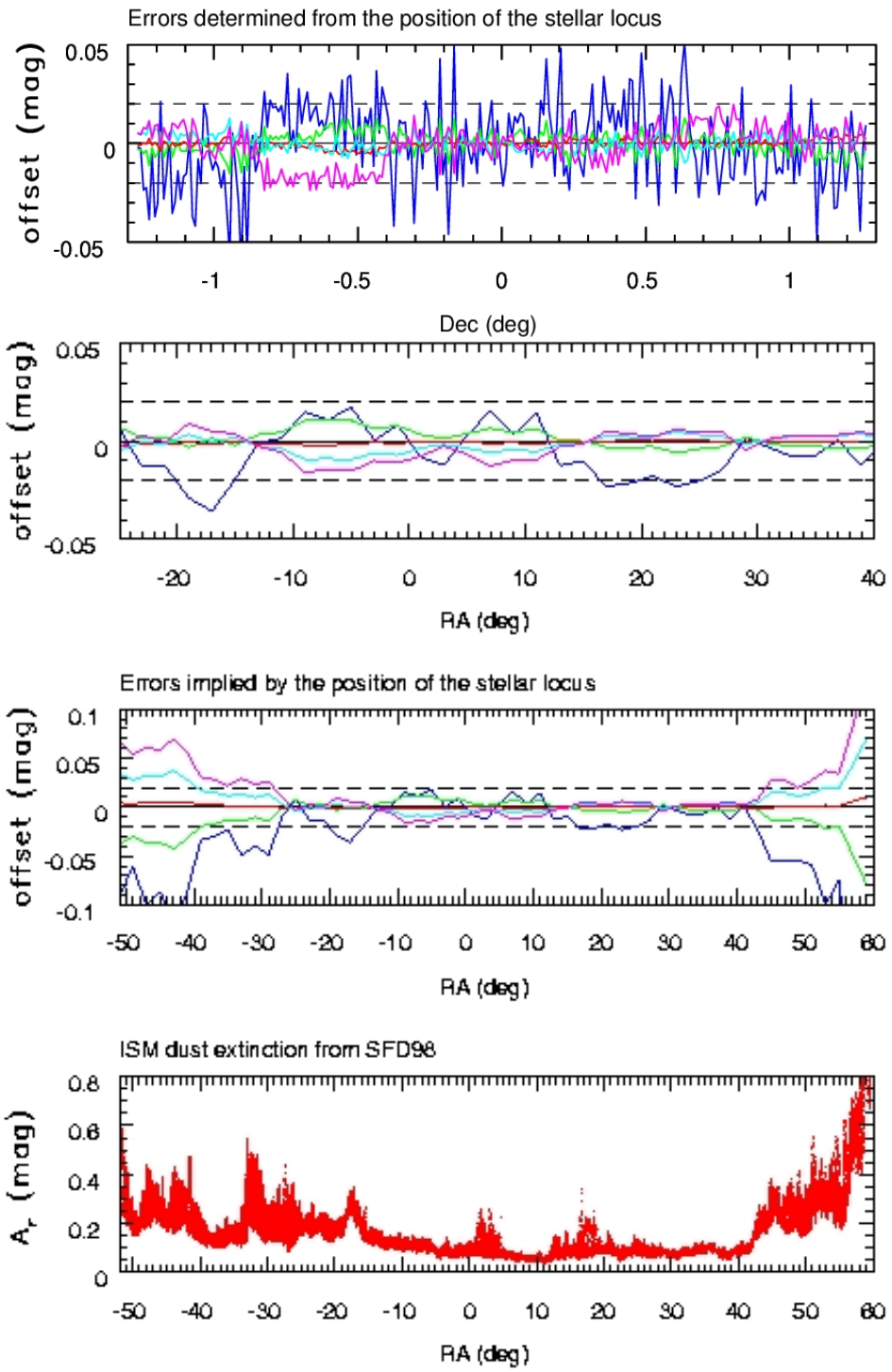
The Constraints on Systematic Errors

- The aperture magnitudes are repeatable to 0.005 mag between two "good" nights, and the **random** photometric errors are fairly accurate.
- What about systematic errors? Is the whole catalog on the same system? Are there variations of the zeropoints with position (including primary/secondary standards)?
- The position of the main sequence stellar locus is determined by astrophysics
- The full SDSS survey: the locus position in the multi-dimensional color space is reproduceable to 1-2% for $|b|$ >20



The Constraints on Systematic Errors

- The locus width is **very** small: it is possible to follow small shifts in the locus position using a small number of stars, leading to a high spatial resolution for discovering calibration problems
- Estimate/correct for systematics using stellar locus
- Used to correct flatfield and related problems at the 1-2% level
- The locus position constrains **only color shifts**. Closed the system by assuming that zero-point errors in the g, r, and i bands add to zero (similar to the determination of SDSS flatfield corrections to account for temporal dependence)



The Constraints on Systematic Errors

- Corrected for systematic effects in the Dec (narrow) direction: the rms for corrections is 20, 6, 2, 5 and 10 millimags in the ugriz bands
- For the high galactic latitude range ($-25 < RA < 40$): the rms for systematic errors implied by the stellar locus position (using 2×3 deg bins) is 13, 5, 1, 5, and 8 millimags in the ugriz bands
- Close to the galactic plane deviations increase: stellar populations change, incorrect dust extinction corrections, or systematic photometric errors?

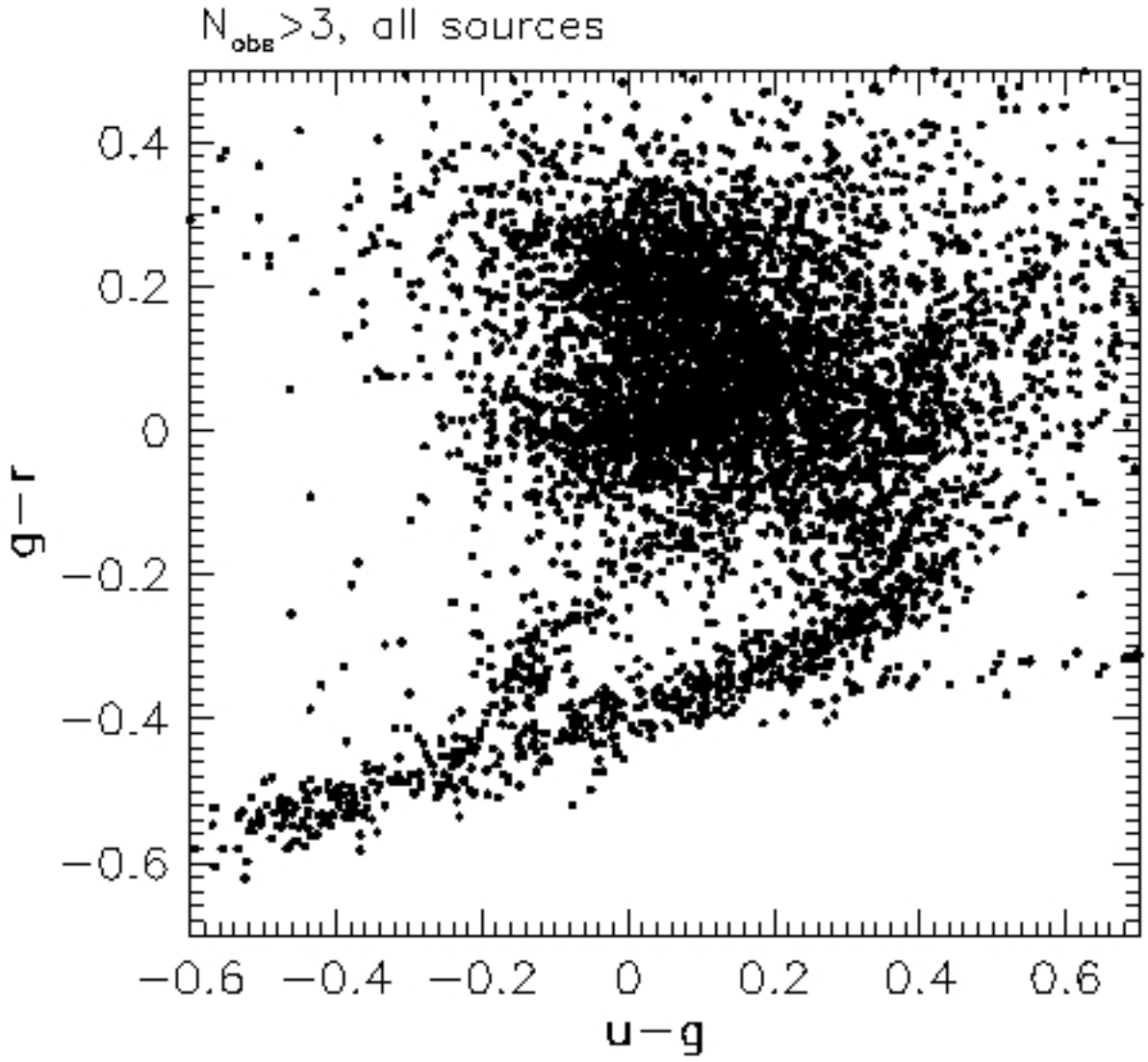
Applications of the Standard Star Catalog

1. High-fidelity color-color diagrams

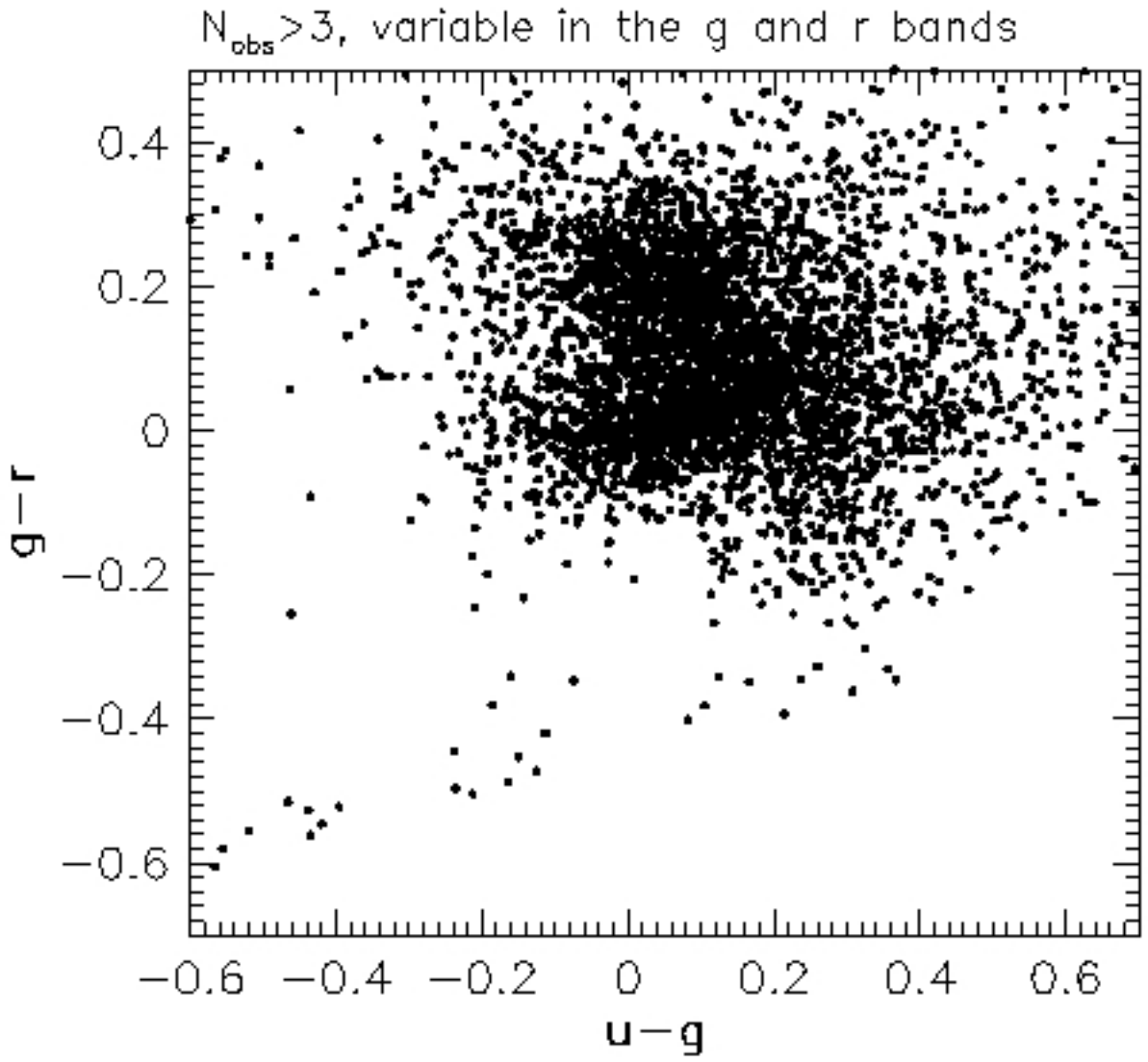
   - Separation of stellar populations using multi-epoch data due to variability informations and robust accurate photometry: white dwarfs (H vs He!), low-metallicity stars, spectral type to ± 1 subtype for main sequence stars

2. Calibration of non-photometric data

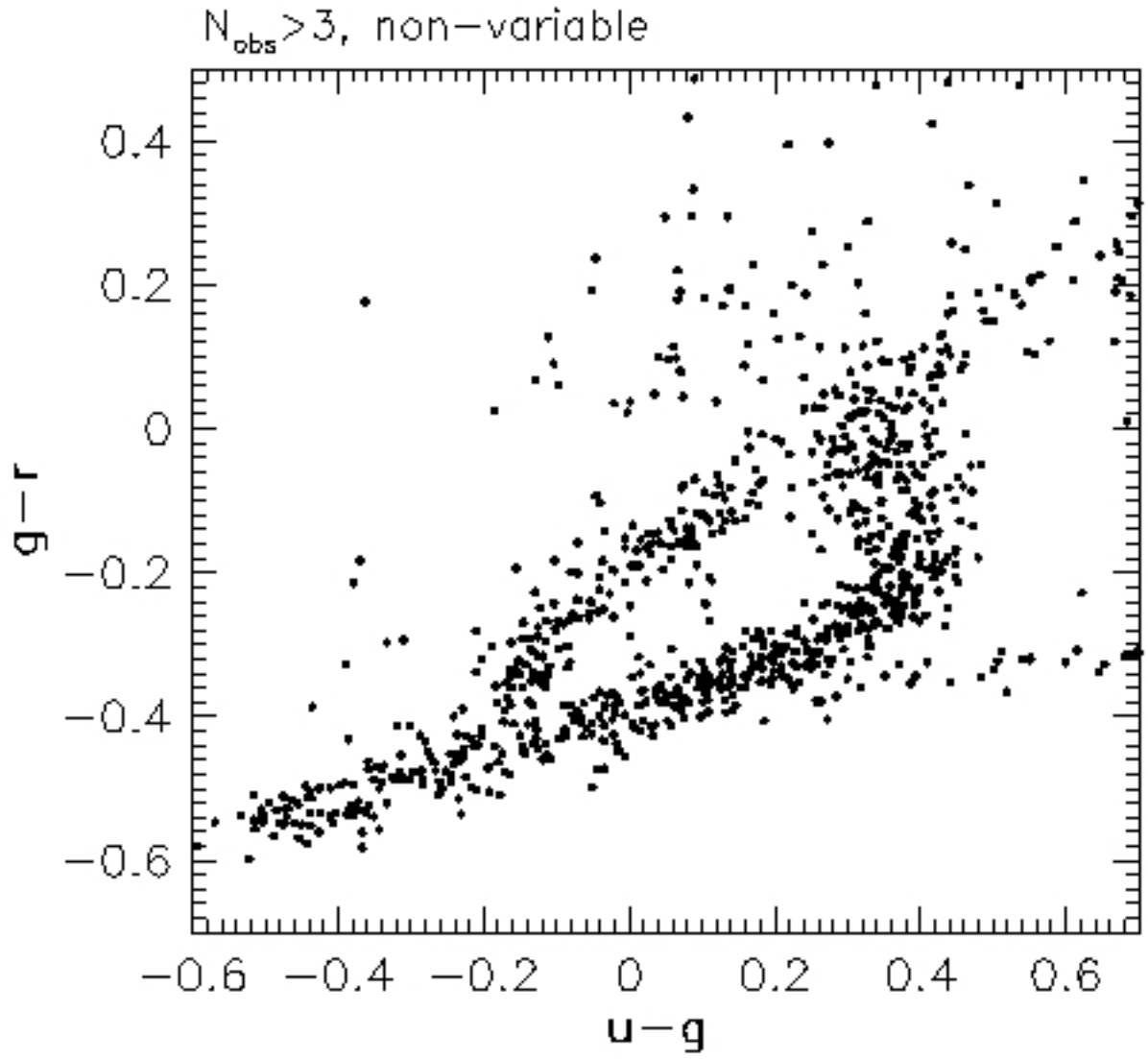
   - SDSS-II SNe scans (in the Southern Survey region) are sometimes obtained through several magnitudes of fast varying cloud extinction: to calibrate these data need numerous calibration stars



- All point sources in the UV corner



- Variable point sources in the UV corner



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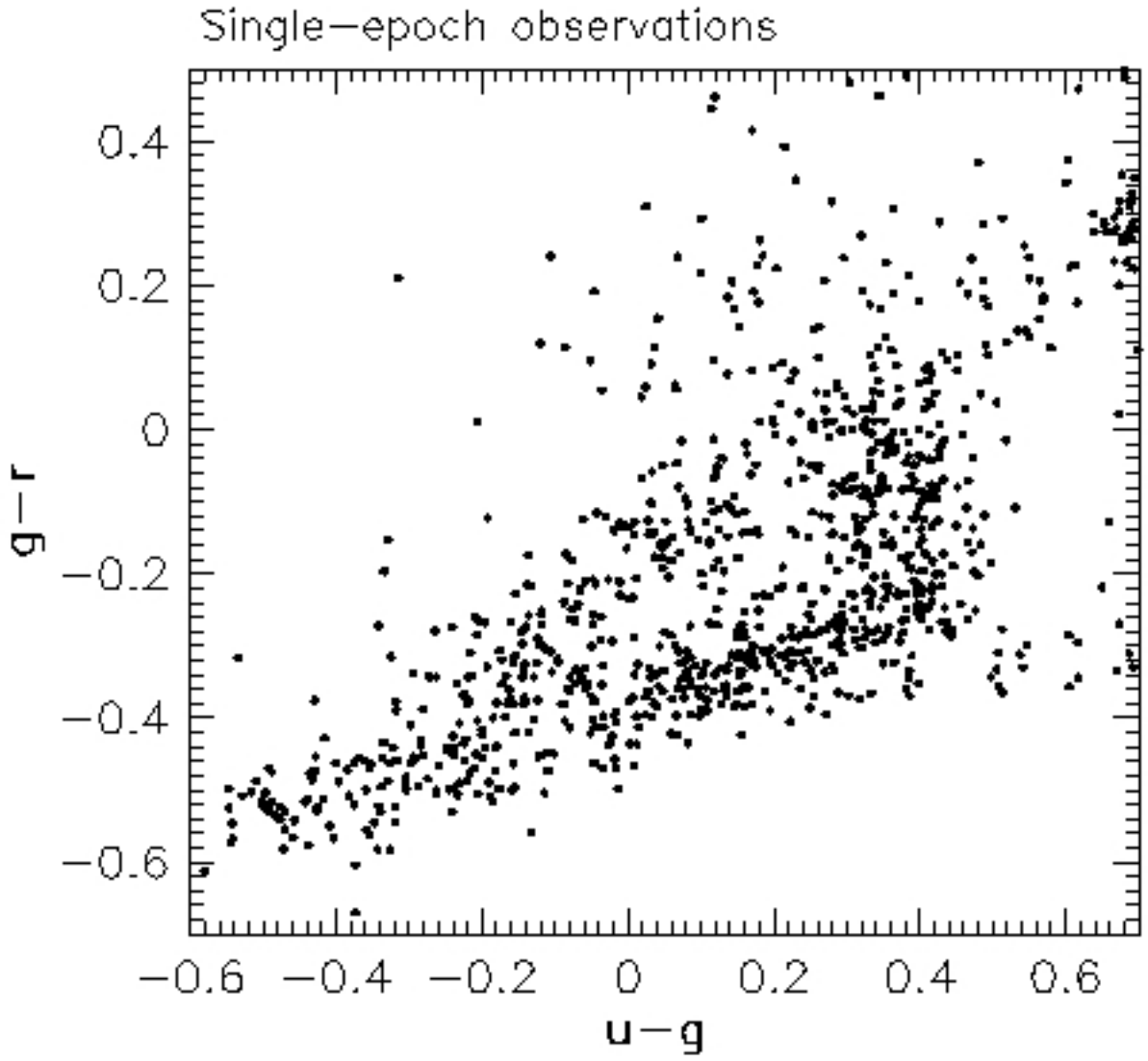
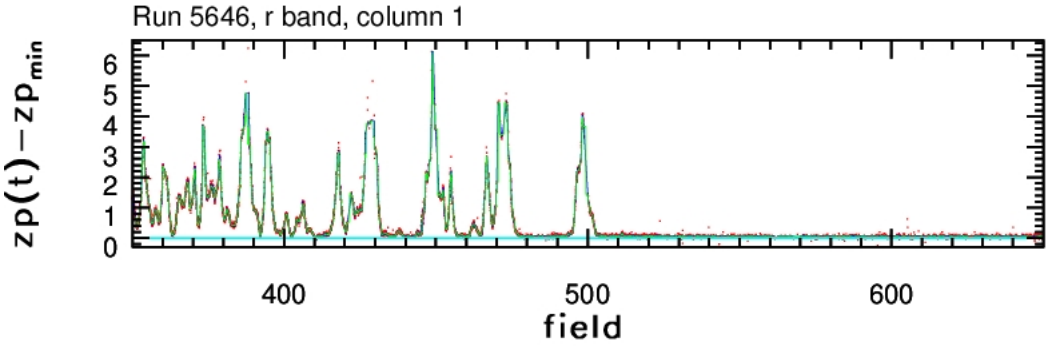
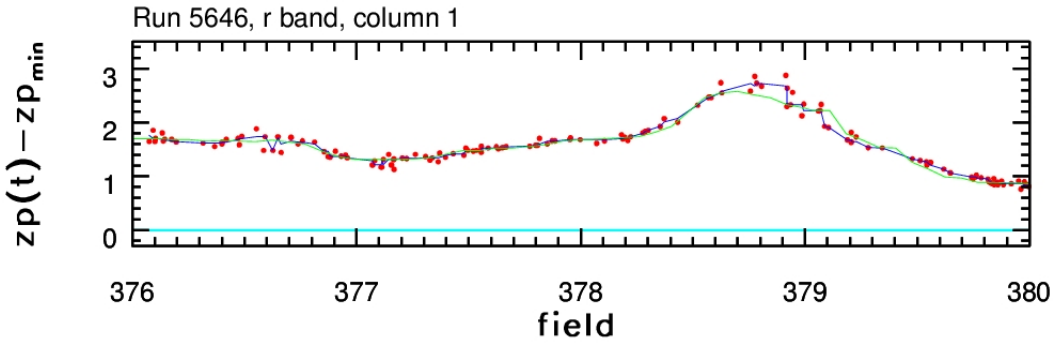
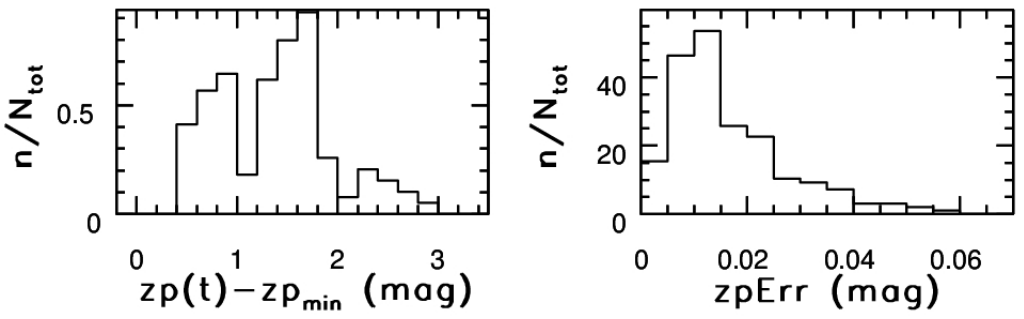


- Variable point sources in the UV corner single-epoch data

Observing through Clouds

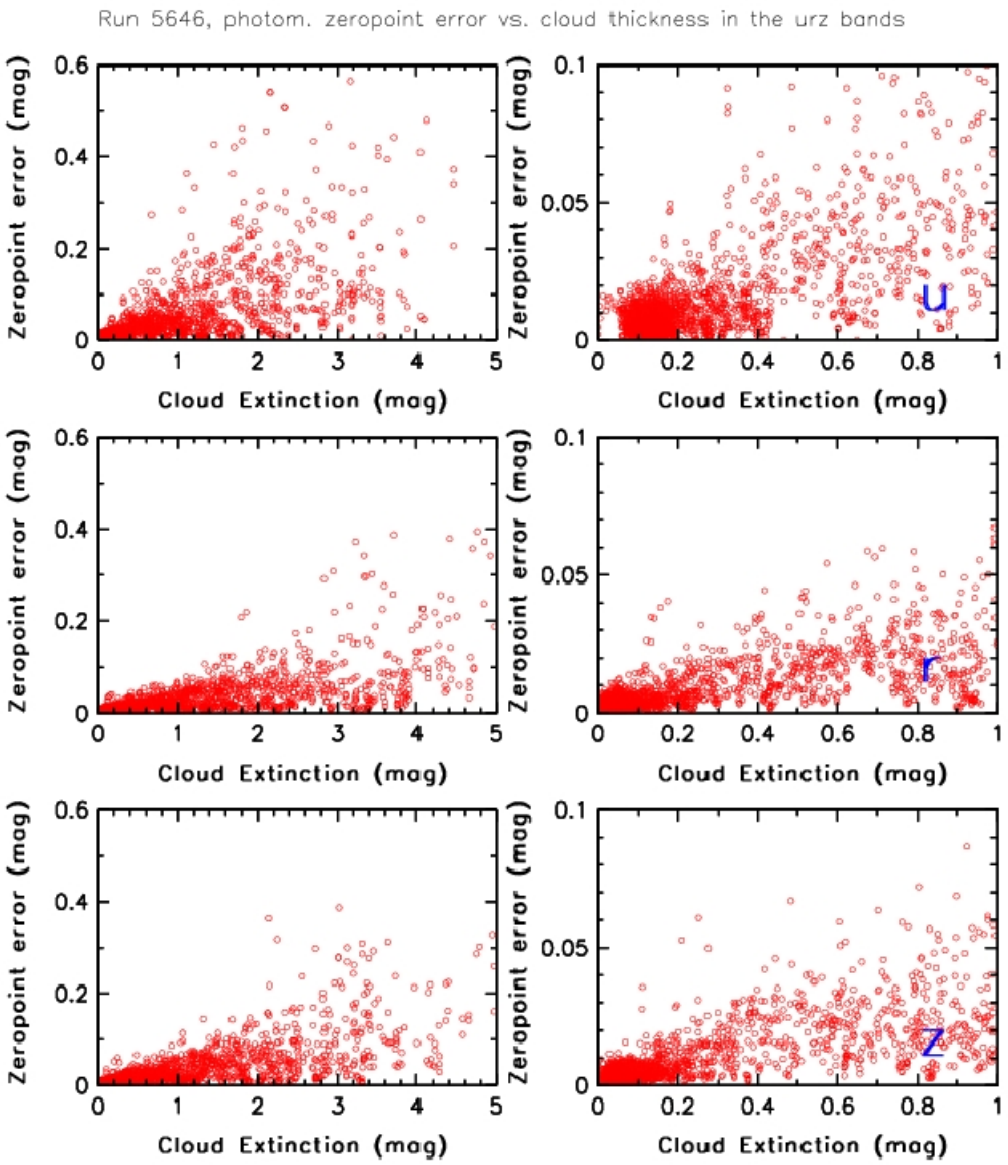






- Top panel: Cloud extinction vs. time; about 2 hours of scanning; an example of extremely bad night
- Middle panel: Zoomed-in stretch of 2 minutes worth of data with cloud extinction of several mag
- Bottom panels: Despite the cloud extinction of several mag, data are well calibrated (zero-point errors $<4\%$, with the median of 2%)
- The calibration accuracy depends on the clouds spatial structure and the sky density of calibration stars

Observing through Clouds



- Left panel: Zeropoint error as a function of cloud thickness in the urz bands (g and i bands are similar to r)
- For SDSS, the resulting point errors is in 95% of cases smaller than 5% of the cloud extinction. E.g. data can be calibrated with a median error of 2% through 1 mag thick clouds.
- LSST will gain from more stars and different observing mode: that LSST data should be (self)calibrateable with a 1% accuracy even through 3 mag thick clouds.

Implications for the LSST Calibration

1. Photometric Repeatability (random errors)
   - LSST: 0.005 mag SDSS: ok on good nights even with sparse patches
2. Internal Color Stability Across Sky (internal systematic color errors)
   - LSST: 0.005 (0.01) mag SDSS: ok
3. Internal Zeropoint Stability Across Sky (internal systematic gray error)
   - LSST: 0.01 mag SDSS: probably ok (in progress)
4. Transformation to AB system
   - Band-to-band: LSST: 0.005 (0.01) mag SDSS: ok (using hot white dwarfs: Eisenstein et al. 2006)
   - Overall (gray) physical scale: LSST: 0.02 mag ToDo

Conclusions

- The SDSS Southern Survey Standards Catalog includes close to a million $14 < V < 21$ stars with 1% ugriz photometry (including both random and internal systematic errors)

- Since this region is on celestial equator, it is a valuable resource, and effectively can be used as a definition of the SDSS photometric system

- Masive digital multi-epoch photometric surveys, such as LSST, should be able to deliver 1% photometry for billions of sources