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

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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: \(\sim 10,000 \text{ deg}^2\): 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 $\chi^2$ 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
• Variable point sources in the UV corner
• 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

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