Final Technical Report on DOE Office of Science Grant DE-FG02-08ER41569:
"Attaining the Photometric Precision Required by Future Dark Energy Projects"

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This report outlines our progress towards achieving the high-precision astronomical measurements needed to derive improved constraints on the nature of the Dark Energy. This science goal is a top priority for the DOE, as emphasized by P5 and other national science prioritization panels.

Our approach to obtaining higher precision flux measurements has two basic components: 1) determination of the optical transmission of the atmosphere, and 2) mapping out the instrumental photon sensitivity function vs. wavelength, calibrated by referencing the measurements to the known sensitivity curve of a high precision silicon photodiode, and 3) using the self-consistency of the spectrum of stars to achieve precise color calibrations.

We have made substantial progress on all three fronts, as evidenced by both our refereed publications and technical progress. Specific accomplishments made under this award include:

- The development and application of the Stellar Locus Regression (SLR) calibration method, which uses the uniformity of the stellar locus in color-color space to provide precise color calibrations (all that is really needed to extract high-quality photometric redshift estimates) for any images in the griz passbands. This method was described in High et al, *Stellar Locus Regression: Accurate Color Calibration and the Real-time Determination of Galaxy Cluster Photometric Redshifts*, AJ, 138, 110 (2009). This is now a standard technique and is being used by both the Dark Energy Survey (DES) and LSST for calibration of the photometry of multiband sky surveys.

- This methodology was applied to the determination of galaxy photometric redshifts in *Optical Redshift and Richness Estimates for Galaxy Clusters Selected with the Sunyaev-Zel'dovich Effect from 2008 South Pole Telescope Observations, High et al, ApJ 723, 1736 (2010).* This clearly demonstrated the utility and viability of this approach, which as mentioned above has now been much more broadly applied.

- Will High completed his PhD work under this grant, and went on to a postdoc with the SPT cluster cosmology team at the University of Chicago.

- We refined our methods for the in-situ determination of instrumental sensitivity functions, and produced a conceptual design for what we will implement for the in-dome apparatus for LSST. This is described in internal LSST technical memos.

- Our methods for measuring the variable aspects of the optical transmission of the atmosphere were also further developed during this performance period.

- We developed methods for achieving percent-level repeatability in photometric measurements over periods exceeding five years. This level of stability is essential in order for LSST to meet its design goals. This is indicated by the data in Figure 1, from G. Narayan's thesis, showing the repeatability of photometric calibrations of type Ia supernova photometry.

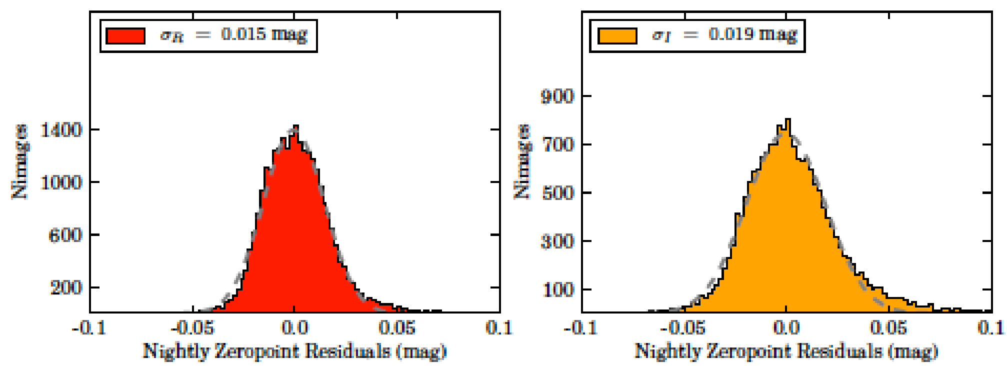

Figure 3.8: Histograms of the residuals of R (Left) and I (Right) zero points to the average nightly zero point, adjusted for differences in exposure time, airmass and the aperture correction. The scatter is $< 2\%$ in both passbands, and very comparable to the values found in M07, illustrating that zero points are very consistent from field to field. The dashed grey lines are Gaussian fits to the data.

Figure 1 (reproduced from G. Narayan PhD thesis). This figure shows the 2% stability in photometric calibration achieved over 5 years in the analysis of the ESSENCE supernova data.

- On the atmospheric transmission measurement aspect, we developed and installed a water band monitor in Hawaii. This project was led by Isaac Shivvers, an undergrad who has since gone on to graduate study at Berkeley.