Large Synoptic Survey Telescope

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White Dwarf Stars as LSST Calibrators

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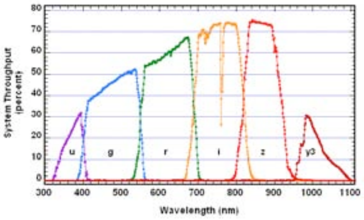
Hydrogen envelope white dwarf stars (DAs) have relatively simple spectra which can be analyzed to yield highly accurate values of T_{eff} and log-g. These spectra also yield colors for any synthesized filter band passes which fall within the observation range. These properties make DAs ideal candidates for calibration of color zero points for the LSST. Comparison of the DA spectra taken by the Auxiliary (monitoring) Telescope with the exo-atmospheric spectral energy distribution allows detailed understanding of the effect of the atmosphere on the observations. We present a strategy to develop DA white dwarfs as potential calibrators for the LSST. These stars will be used to establish and monitor the color zero points for the LSST photometric system and can be used to search for systematic errors in the color zero points over the area (ra, dec) of the survey. We include the observational strategy to have several hundred well characterized stars in place prior to the start of LSST operations and preliminary results from our early characterization observing efforts.

Introduction:

The LSST will observe the sky in six photometric bands *(u,g,r,i,z,Y)* similar to the SDSS system (Fukugita et al. 1996). The instrumental bandpasses computed for this system with the LSST design, taking into account the transmission through a typical Cerro Pachon atmosphere, the telescope and camera optics, and the quantum efficiency of the detectors, are shown below (LSST SB, 2009). To calibrate the LSST imaging data, we need to develop a series of calibration stars which may be used to monitor the Earth's atmosphere using synthetic photometry of DA white dwarf stars. These stars will also allow monitoring the color zeropoint stability across the survey area.



What makes a good calibration star?

- Need to be able to calculate a model atmosphere over a wide Temperature and gravity range which will accurately depict the continuum flux distribution and the detailed line profiles. DA white dwarfs have fully radiative, pure-hydrogen photospheres whose opacity sources can be calculated to high precision (at least for $T_{eff} > 14{,}000$K).
- Photometrically stable.
- Low levels of interstellar reddening.
- Spectral Energy Distributions useful from EUV to NIR.
- Wide range of T_{eff} and surface gravity to test synthetic photometry for stars different energy distributions and a wide range of colors. (Holberg & Bergeron 2006; Decin 2008).

Issues for Use of DAs:

- Unresolved low-mass companions.
- High levels of heavy-element abundance in some of the hotter DAs.
- Low levels of photometric variability at T_{eff} between 11,000 and 12,500 K (ZZ Ceti stars).
- Possible circumstellar material.
- Possible photospheric Helium enrichment in cool DAs ($T_{eff} < 10{,}000$ K).

How many are needed?

A few (20-30) bright WDs ($11 < g < 13$) will be needed across the survey area for use by the Auxiliary Telescope (AT) to characterize and monitor the atmosphere each night. Spectroscopic observations of these stars will be fast-paced to obtain information on the changes in the Earth's atmosphere. The pace is driven by the time scale of the atmospheric changes and the need to meet the LSST SRD (see poster by Bartlett *et al*.). The important point is that it is the spectrum of the WD as seen by the AT itself, over and over again that is critical, not the actually WD properties. We just use the WD as a convenient, uncomplicated source of backlight for the atmosphere.

A second group of WDs will be needed by the LSST itself. These will be in the ($17 < g < 20$) range and will be used to establish and monitor the uniformity of the color calibration across the sky. The number required is dependent upon the sampling density of the interstellar dust and how rapidly our calibration of color change varies across any region of the sky. In principle, this information will come from the 100,000 DA WDs and 10,000 DB WDs that will naturally occur in the LSST broad-band photometric sample. There are approximately 2000 LSST pointings across the sky. While one well-understood WD in each pointing would be ideal, this is not practical. However, some number of well-characterized DAs will be needed at the start of the survey to establish a baseline for the data.

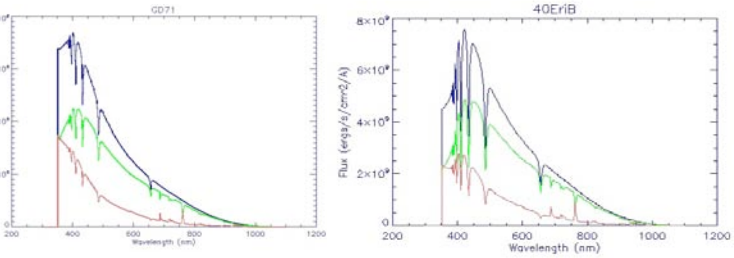
These WDs will be drawn from a variety of sources but chief among them will be the SkyMapper program (Keller et al. 2007) when it is completed about 2012.

Why white dwarfs?

White dwarfs (WDs) are the evolutionary end product for about 97% of all stars. They are generally carbon/oxygen objects supported by electron degenerate pressure with a thin non-degenerate envelope which is generally dominated by Hydrogen or Helium. Since fusion has stopped, the white dwarf loses energy from its vast thermal reservoir via radiation. The opacity of the non-degenerate atmosphere controls the loss rate. After an initial rapid cooling phase, the cooling slows, so most white dwarfs remain at nearly the same temperature (therefore color) for an extremely long time. Since WDs are small, they have low luminosities; therefore most of the known WDs are close to us, with little effect of interstellar reddening. The hydrogen atmosphere WDs (DA class) have relatively simple spectra which are "easy" to model. Observations can be fit to the models to determine the T_{eff} and surface gravity of the WD, and precisely determine its colors. These factors make WDs good, stable, nearby calibration sources.

Moderate resolution spectra of the WDs obtained through the Earth's atmosphere may be compared to the intrinsic WD spectra to determine the properties of the Earth's atmosphere at the time of observation. Obtaining several spectra per hour at various observation angles allows the LSST team to develop a temporal and spatial actualization of the atmosphere each night. These data may be used to remove the effects of the Earth's atmosphere from the LSST survey images. Changes in the atmosphere (clouds, seeing, absorption, scattering) as small as 0.5% (see Bartlett et al. 2010) may be detected via this technique.

We illustrate these effects with spectra of two white dwarfs (supplied by Jay Holberg): GD71 and 40 Eri B. Each of the plots shows the exo-atmospheric spectrum (navy), the spectrum after passing through the Earth's atmosphere (green; model supplied by Gurvan Bazin), and the change caused by the atmosphere (red). This change is what we seek to quantify across the LSST survey area each night. Use of the relatively simple DA Spectral Energy Distribution makes this a manageable task.



Spectra of the DA white dwarfs GD71 (Teff = 32,300K; log-g = 7.73) on the left and 40 Eri B (Teff = 16,900; log-g = 7.85) on the right. The Navy curve is the exo-atmospheric spectra from HST. The Green curve shows the spectra as viewed (simulated) from the Earth's surface. The effects of the atmosphere are shown in Red and are a combination of extinction, scattering, cloud.

The Calypso telescope (to be used as the AT) in action at Kitt Peak this past summer. On the left, Elaine Halbedel directs the FaST team in beginning operations for the evening. On the right, the telescope is at its ready position, waiting for sunset to begin operations for the night. Photo credit J. Allyn Smith

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