Large Synoptic Survey Telescope

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Calibration of LSST Instrument and Data

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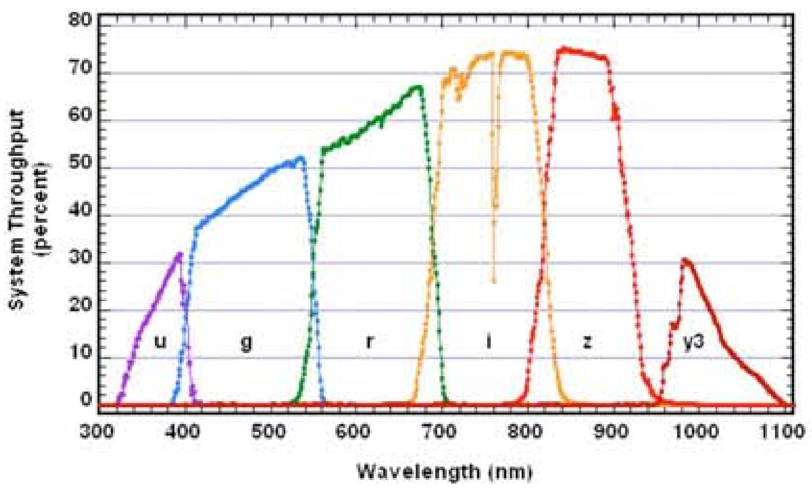
Science studies made by the Large Synoptic Survey Telescope will reach record systematic limits in nearly all cases. Requirements for precision of measured colors to 0.5% and magnitudes relative to some physical process to 1% or better are particularly challenging. Advantage will be taken of the rapid multi-epoch cadence of the LSST survey to use stars to calibrate stability and uniformity of astrometric and photometric data. A new technique using a tunable laser is being developed to calibrate the wavelength dependence of the total telescope and camera system throughput and response. Spectroscopic measurements of atmospheric extinction and emission will be made continuously to allow the broad-band optical flux observed in the instrument to be corrected to flux at the top of the atmosphere. Repeated observations of standard stars in the accumulated survey will be combined with instrumental and atmospheric throughput measurements to calibrate data releases. Observational studies with existing telescopes and simulations are underway to validate and optimize this strategy.

Introduction

The LSST optical photometric bands (*u,g,r,i,z,y*) are similar to those used in the Sloan Digital Sky Survey (SDSS) (Fukugita et al. 1996). The combined efficiencies of the optics and filters, sensor quantum efficiency, and typical atmospheric extinction are shown in the figure.



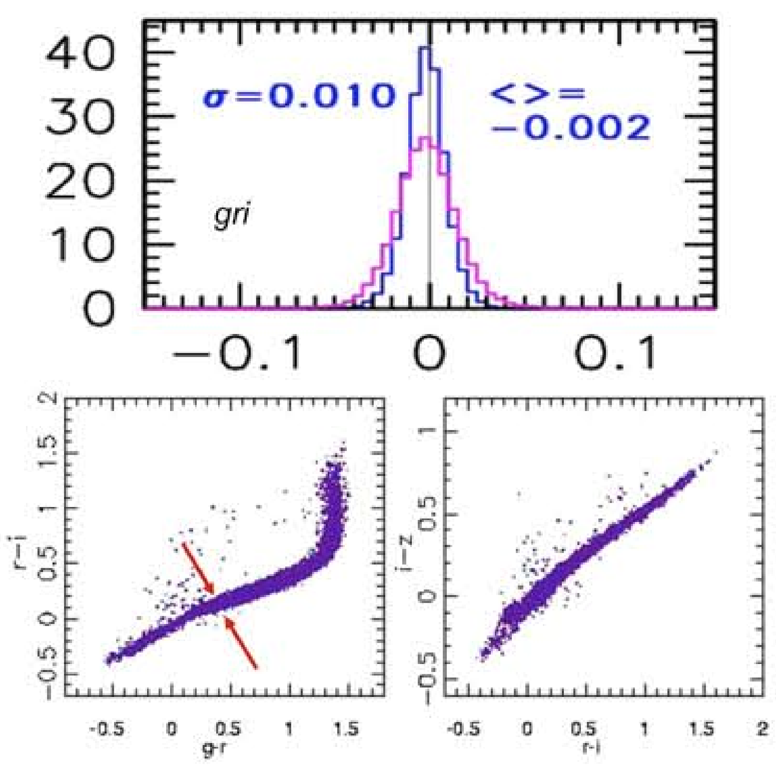
Design specifications for LSST stellar photometry are given below. The first three specifications are relative quantities defined within the native LSST photometric system in AB magnitudes. These are for bright stars not limited by photon statistics in a single exposure (e.g. r < 21).

LSST Design Specifications for Stellar Photometry

Repeatability	Spatial Uniformity	Color Uniformity	Absolute
(mag rms)	(mag rms)	(mag rms)	(mag rms)
0.005	0.010	0.005	0.010

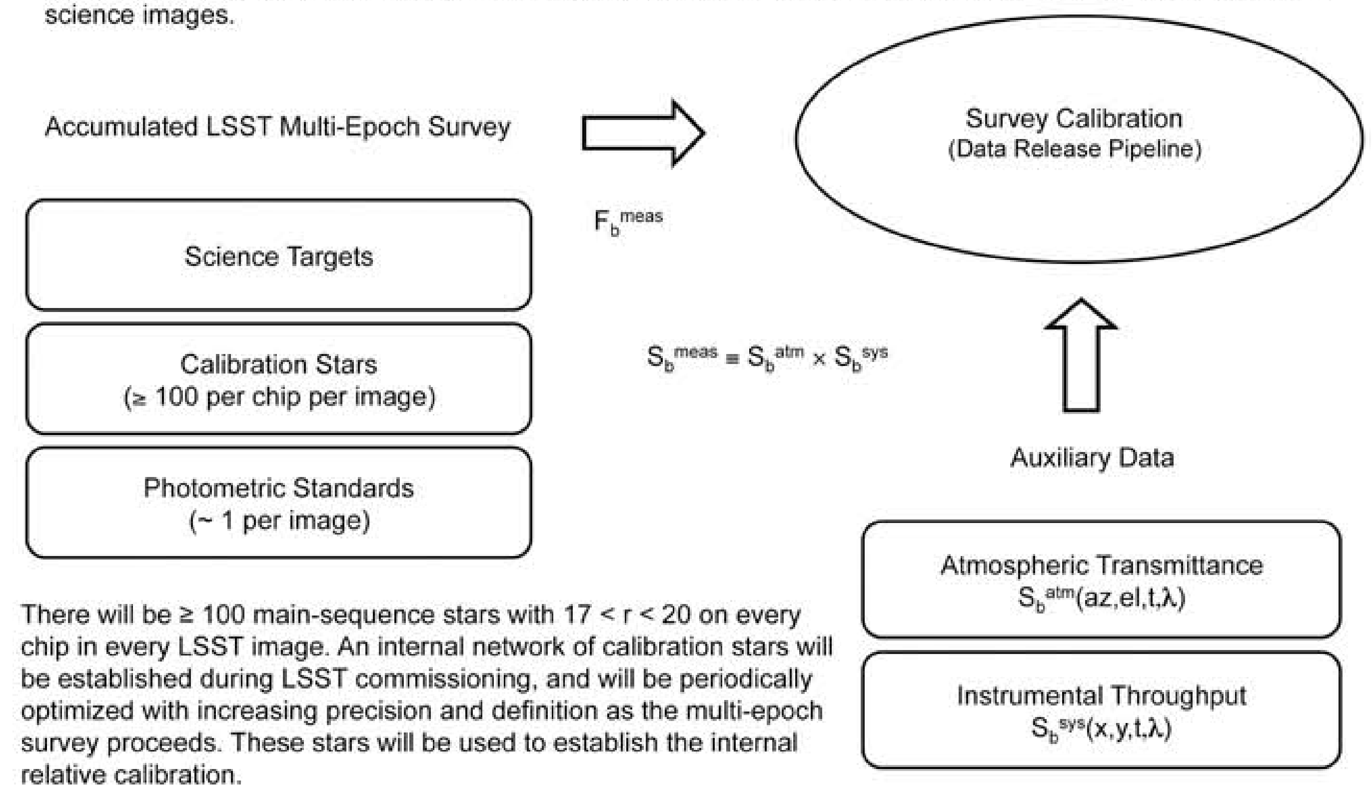
Precision of photometric measurements by existing large surveys, such as SDSS and CFHT, have approached the specifications for LSST (Stoughton 2002; Ivezic 2004; Magnier 2004). But measurements with ground-based telescopes typically produce errors a factor of two or so larger.

Global all-sky multi-epoch ("über-cal") analysis of data taken in good photometric conditions have reached LSST specifications (Ivezic 2007; Padmanabahn 2007). But LSST must achieve these performance characteristics in even non-photometric conditions to optimize survey operations and efficiency.



LSST Data Release Calibration

The LSST process decouples establishment of an internal relative calibration from assigning absolute optical flux to celestial objects. The latter task requires determination of a single zero point for each filter band for the accumulated multi-epoch data set. Celestial sources will be used to define the internal photometric system. Standardization of photometric scales will be done through observation of stars with well-understood SEDs in science images.



There will be ≥ 100 main-sequence stars with 17 < r < 20 on every chip in every LSST image. An internal network of calibration stars will be established during LSST commissioning, and will be periodically optimized with increasing precision and definition as the multi-epoch survey proceeds. These stars will be used to establish the internal relative calibration.

Well understood DA white dwarf stars (WDs) (Bohlin 2001) will be reference standards for LSST colors. The density of DA WDs with magnitudes 17 < *g* < 20 is great enough (Eisenstein 2006) that, even at high galactic latitudes, one will be in a large fraction of LSST science images.

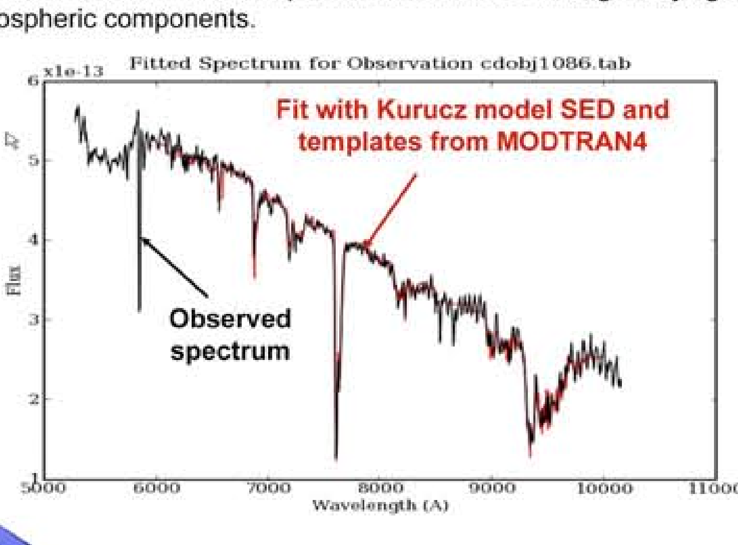
Measurement of Atmospheric Composition and Transmittance S_b^{atm}

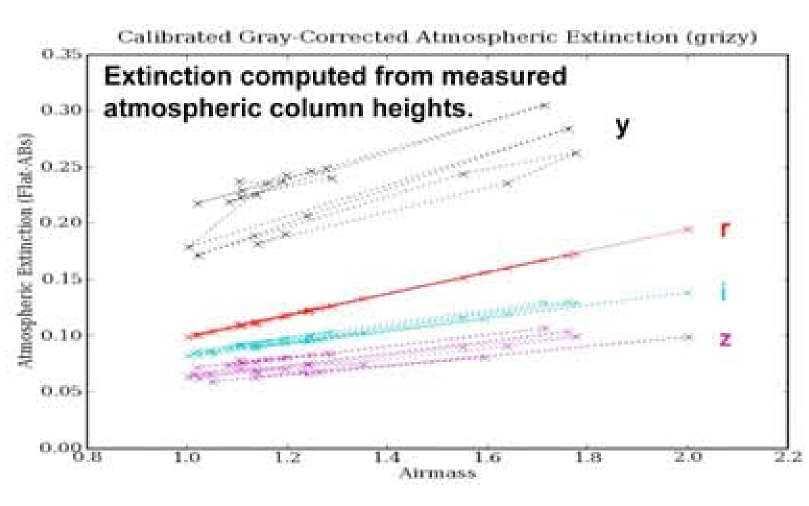
Modern atmospheric transport codes (MODTRAN4) can be used to compute accurate templates for scattering and absorption of light by atmospheric components (Stubbs 2007a). The LSST will use an Auxiliary Telescope (AT) to acquire spectra of stars to be used in conjunction with computed templates to extract measurements of atmospheric transmittance $S_b^{atm}(az,el,t,\lambda)$ in real time for each of the LSST filter bands.

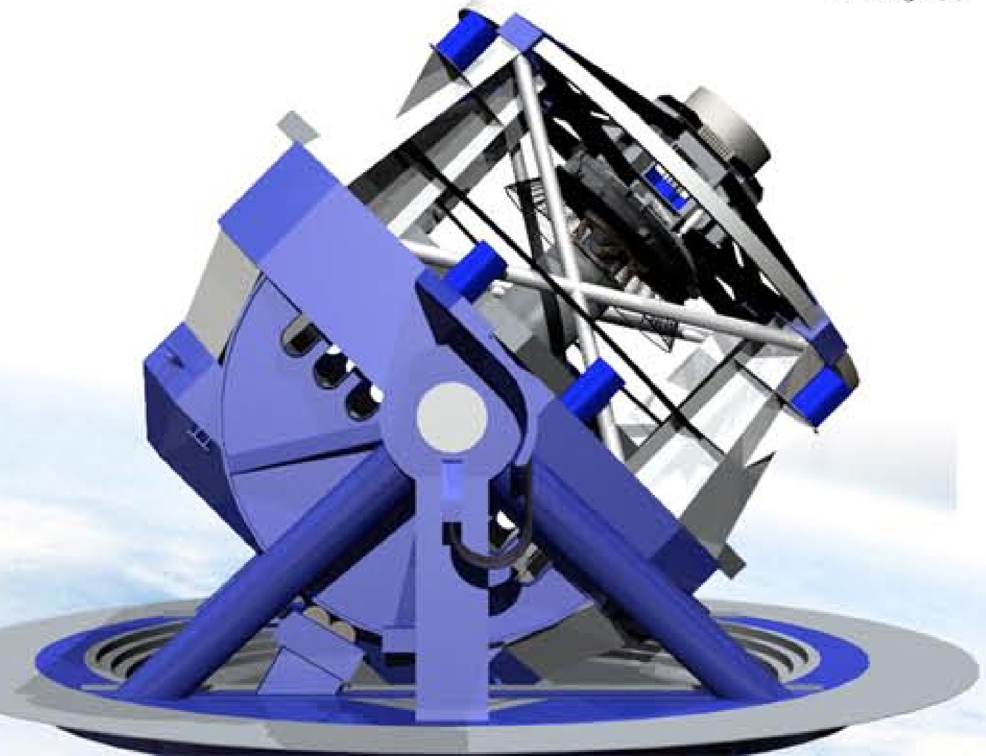
The functional requirement of the AT is to acquire relative spectro-photometry of stars with magnitude r < 15 AB with resolution R ≥ 400 and S/N > 200 across the LSST bandwidth. The AT must slew and acquire a spectrum every 10 minutes. The magnitude is chosen to guarantee sufficient density of target stars, the resolution and sensitivity chosen to guarantee sufficient definition of atmospheric components responsible for scattering or absorption, and the speed is required to be fully sensitive to changing atmospheric conditions – particular water vapor. These lead to a baseline specification of a 1m-class telescope.

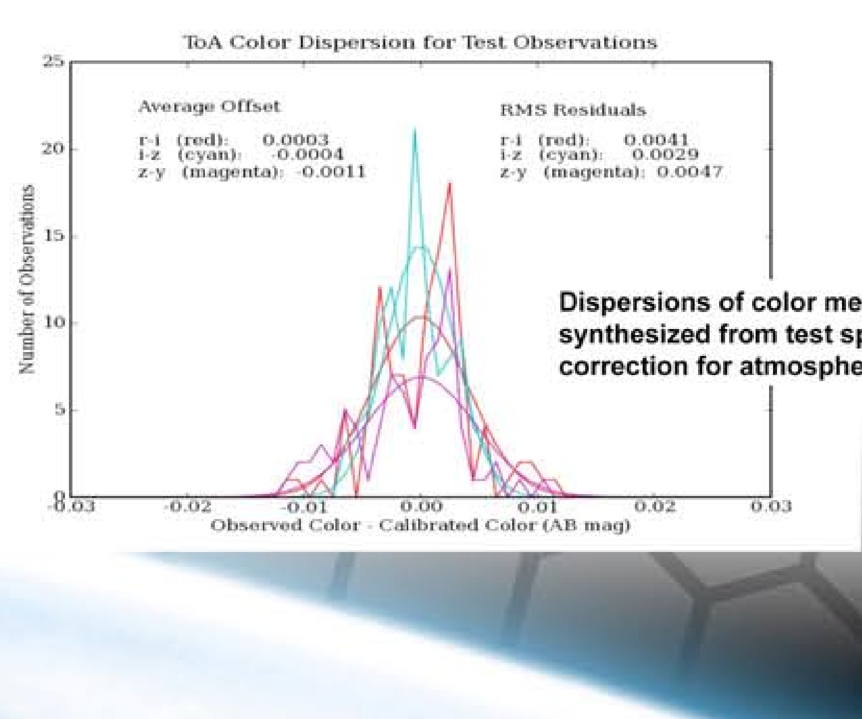
Studies of these techniques are underway with existing telescopes. Below is a spectrum of an F0 star taken through 1.25 airmass with the 1.5m SMARTS telescope on Cerro Tololo at CTIO. A fit of a model spectrum, Rayleigh scattering, and absorption by ozone, O2, water vapor, and other trace elements is quite good. The fit includes an overall "gray" coefficient to account for cloud cover. Repeated measurements of a pattern of such stars through varying airmass as they move across the sky allows determination of the relative column heights of each of the non-gray atmospheric components.

Shown here are values of atmospheric extinction computed (*rizy* for a flat SED) from column heights measured over three nights of observing in November 2007. The points are connected in temporal sequence; extinction is found to vary considerably from a constant linear fit with airmass. Application of these calibrated extinction to additional test observations taken on the same night demonstrate reproducibility well within LSST specifications for measurements of colors.



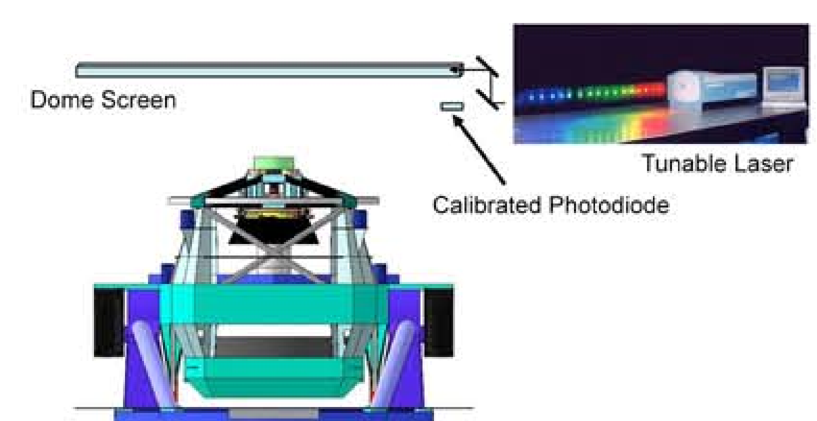






Measurement of Instrument Response S_b^{sys}

A system to use a tunable laser to calibrate the combined telescope and camera response function I(x,y,v,t) is being developed. (Stubbs and Tonry 2006).



A photodiode calibrated to ~ 0.1% relative accuracy (NIST98) from 450nm to 950nm monitors the integrated optical exposure. Spatial uniformity of light from the screen need only be ~ 10%, but the angular distribution must be uniform (Lambertian) over the 3.5° LSST FOV. First tests of a similar system on the CTIO Blanco telescope have been reported (Stubbs 2007b).

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