Calibration of LSST Instrument and Data

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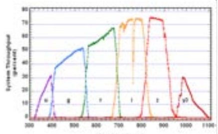
Science studies with the Large Synoptic Survey Telescope will push experimental systematics to unprecedentedly low levels, demanding high-precision astrometric and photometric calibration. Our photometric requirements of 1.0% on repeatability and uniformity of measurements of magnitudes of stars, and 0.5% on the accuracy of measured colors, under varying observing conditions, pose a particular challenge. We are therefore developing innovative methods combining telescope-camera system throughput calibration with a tunable laser, real-time spectroscopic monitoring of atmospheric extinction and the high redundancy of our observing program. To optimize and validate the calibration scheme, we are pursuing studies on existing telescopes and putting in place a large simulation of instrumental and atmospheric effects.

Introduction :

The LSST will observe in six photometric bands *b=u,g,r,i,z,y* similar to the SDSS bands (Fukugita et al. 1996). The instrumental bandpasses computed for this system with the LSST design (accounting for the transmission through a typical atmosphere at Cerro Pachon, the reflectivity of the reflective optics, the transmissivity of the refractive optics, and the quantum efficiency of the sensors) are shown below (LSST SB, 2009).

The survey photometric calibration procedure distinguishes two aspects :
- Calibration of the instrument response.
- Calibration of atmospheric effects, which is the focus of this poster.



Calibration requirements :

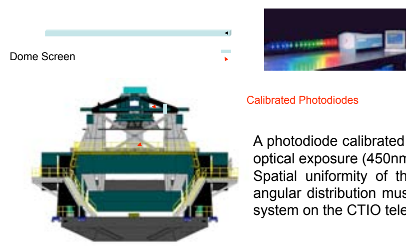
The science goals of the LSST pose stringent requirements on the stability and uniformity of photometric measurements. The specifications are defined for bright isolated stars that will not be affected by the photon statistics for a single exposure (e.g r < 21) and are summarized in the table below. (Ivezic et al 2007)

Absolute	Repeatability gri/uzy	Spatial uniformity	Color accuracy
0.010 mag rms	0.005/0.008 mag rms	0.010 mag rms	0.005 mag rms

Such photometric precision has been approached with SDSS and the CFHT, but in general errors are typically a factor of two larger. Furthermore, the aggressive LSST observing schedule demands observations under diverse, less than ideal conditions. One of the key factors in achieving our calibration goals is the control and monitoring of atmospheric effects.

Instrumental response :

A tunable laser can be used to calibrate the response function of the instrument and camera. (Stubbs & Tonry 2006). It produces a "flat-cube" of combined optical efficiency and electronic response at coordinates (**i, j,** λ).



A photodiode calibrated to 0.1% relative accuracy monitors the integrated optical exposure (450nm < λ < 950 nm).

Spatial uniformity of the dome screen within 10% is sufficient, but its angular distribution must be uniform on the 3.5º LSST FOV. Tests of this system on the CTIO telescope have been reported (Stubbs 2007b).

Monitoring atmospheric variations with the auxiliary telescope : CALYPSO

CALYPSO, a 1.2m auxiliary telescope equipped with spectrometer will be installed next to the LSST to monitor the spectral transmission using stars with known SEDs to determine atmospheric extinction at the same time as LSST observations.

Monitoring of stars
↓
Parametrize SED & fit observations to analyse atmospheric effects
↓
Temporally dependent extinction maps of the atmospheric color terms (~min).

Calibration strategy :

Self-calibration : Calibrating with LSST observational data

Reference stars : 100 main sequence stars 16<r<21 per chip per image **get δ_m**

Color standards: Hydrogen white dwarfs (Butner et al. 2009) **get Δ_m-Δ_n**

Calibration for data release

$$m_{cat} = m_{true} + \sigma + \delta_m(x, y, \phi, \alpha, \delta, SED, t) + \Delta_m$$

Determine m_{true} on top of the atmosphere magnitudes

Auxiliary data

Atmospheric transmittance **get T^{atm}**

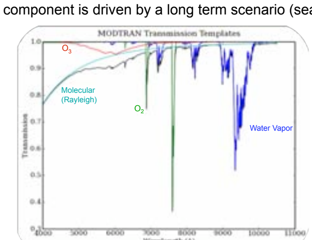
Instrumental response **get T^{instr}**

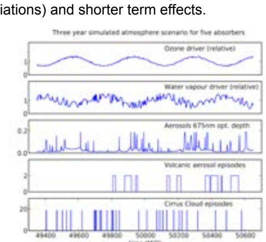
➡System response function **T**

$$T = T^{atm} \times T^{instr}$$

Simulating the atmospheric transmittance :

The MODTRAN (MODTRAN4) atmospheric model code is used to simulate the spectral extinction by various atmospheric components at the time and in the direction of each LSST pointing. The behaviour of each component is driven by a long term scenario (seasonal variations) and shorter term effects.

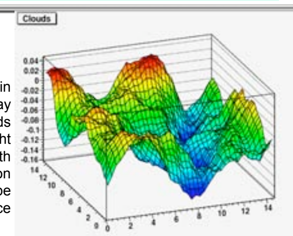




Our approach, in course of validation, is to fit MODTRAN atmospheric models to observed reference star SEDs in order to determine the contribution of each atmospheric component. We can then evaluate the effective color dependent extinction for any desired spectral band.

Simulating and calibrating small scale variations : the grey extinction challenge

Under non ideal observing conditions, the presence of thin clouds can affect the photometry. A first simulation of gray extinction has been produced using gaussian random fields based on measured clouds structure functions (see right panel). This part of the simulation is combined with atmospheric transmittance studies to produce a full simulation of the atmospheric effects. Variations in gray extinction can be measured by adopting a given observation as the reference and comparing all other observations to it.



To determine relative zero point errors on small scales (δ_m) over 10 years multi epoch all sky survey, observational data will be used for autocalibration. The procedure will be based for LSST on the SDSS Übercal (Padmanabhan,2007, Ivezic 2007). For each patch *p* on each image *j*, the relative error $\delta_m(p,j)$ is found by minimizing :

$$\chi^2 = \sum_{(i,j)} \frac{m^{meas}(i,j) - (m^{true}(i) + \delta_m(p,j))^2}{(\delta_m(i,j))^2}$$

This procedure will be validated for LSST, via the development of a precise simulation of the atmospheric transmittance including gray and non-gray components of the extinction.

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