Photometric Calibration of LSST Data

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ESO Instrumental Calibration Workshop
Garching
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LSST Calibration Working Group

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Material and Content
from

Sloan Digitial Sky Survey
PanSTARRS
Canada French Hawaii Telescope

Topics

Mission and Photometric Specifications

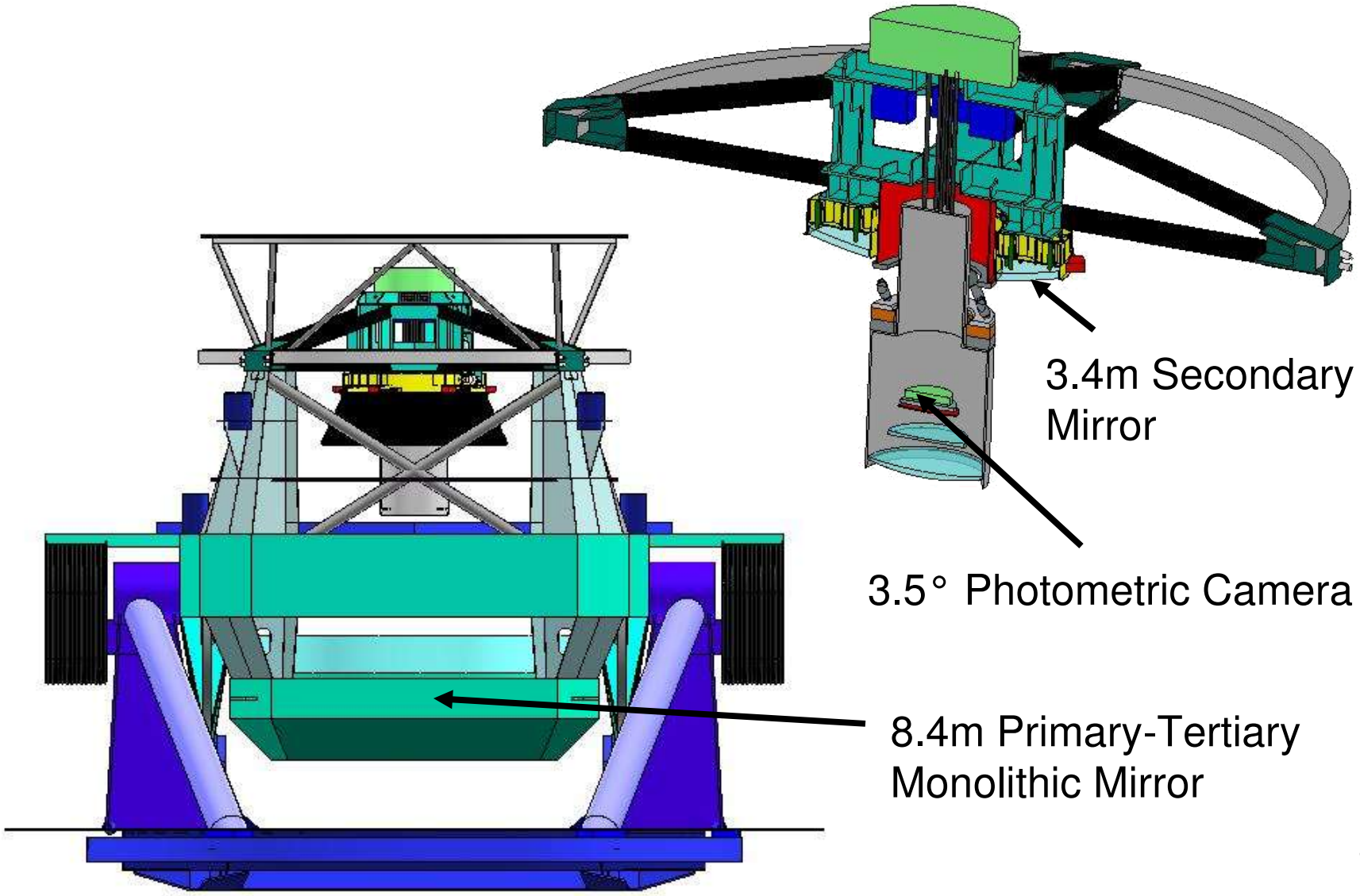
Calibration Strategy and Process

Calibration with Celestial Sources

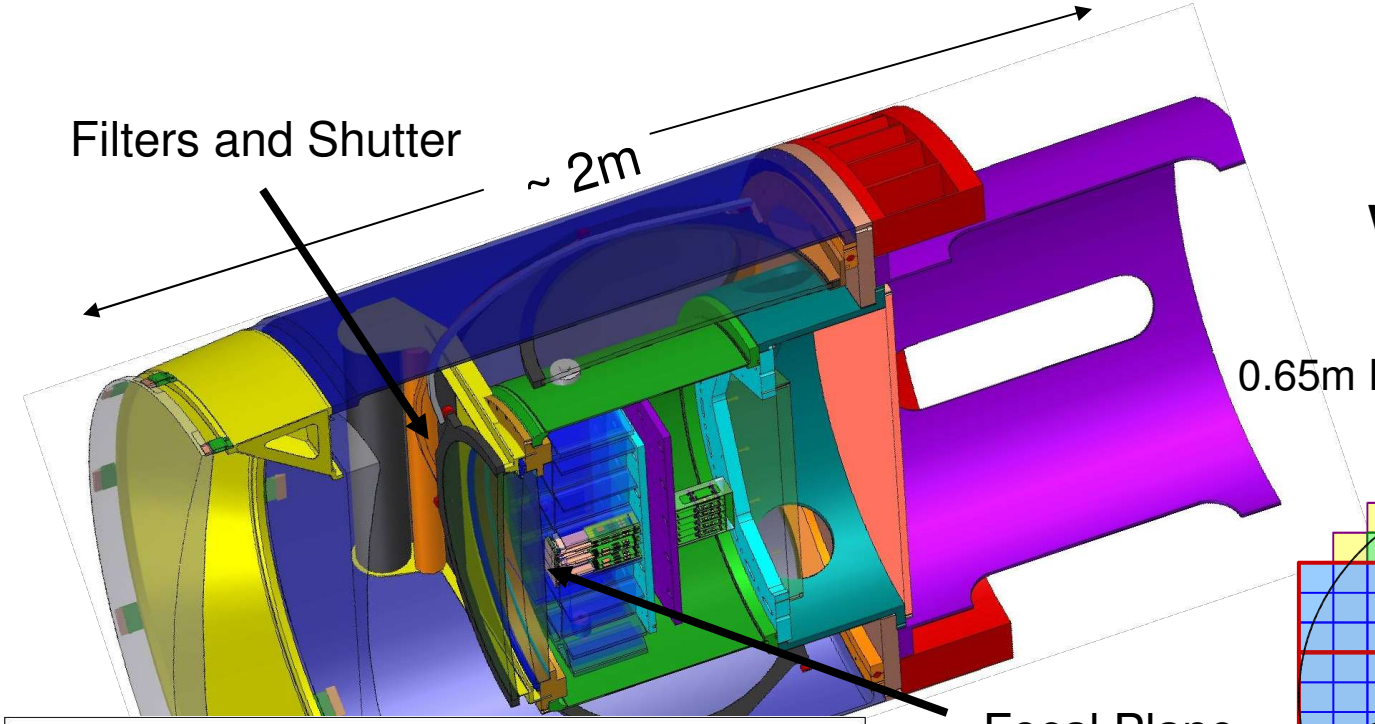
Atmospheric Measurement and Modeling

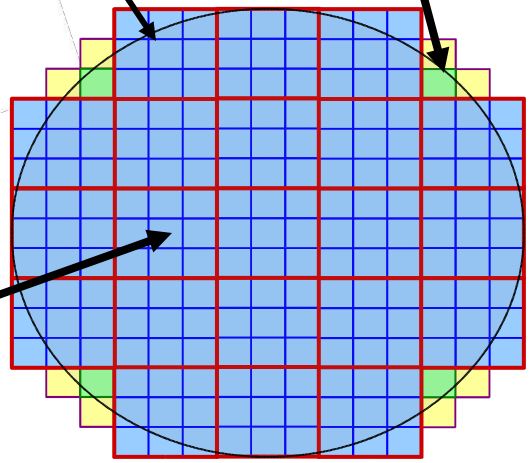
Instrumental Calibration

Large Synoptic Survey Telescope

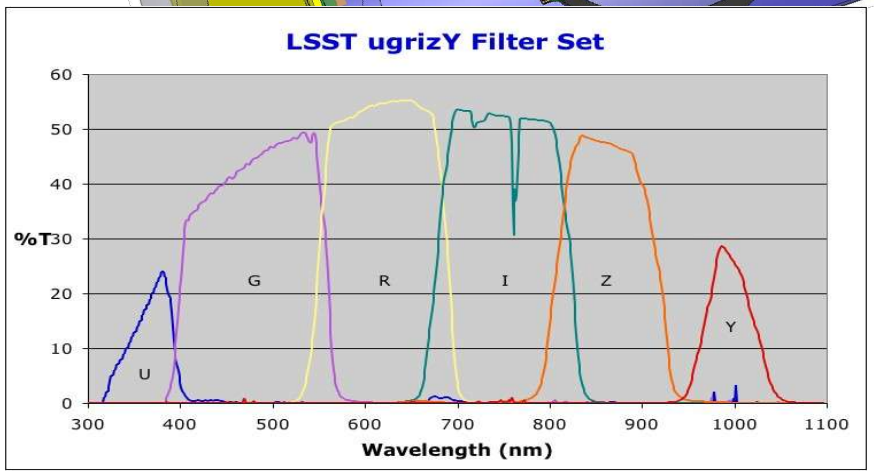


Camera and Focal Plane Array





191 4kx4k CCDs
3.2 giga pixels



The Mission

Photometric survey of half the sky (≅ 20,000 square degrees).

Multi-epoch data set with return to each point on the sky approximately every 4 nights for a decade.

→ One pointing every 40 seconds – two 15 sec exposures with 2 sec read-out and 5 sec slew.

Deliverables

Archive 3 billion galaxies with photometric redshifts to z = 3.

Detect 250,000 Type 1a supernovae per year (with photo-z < 0.8).

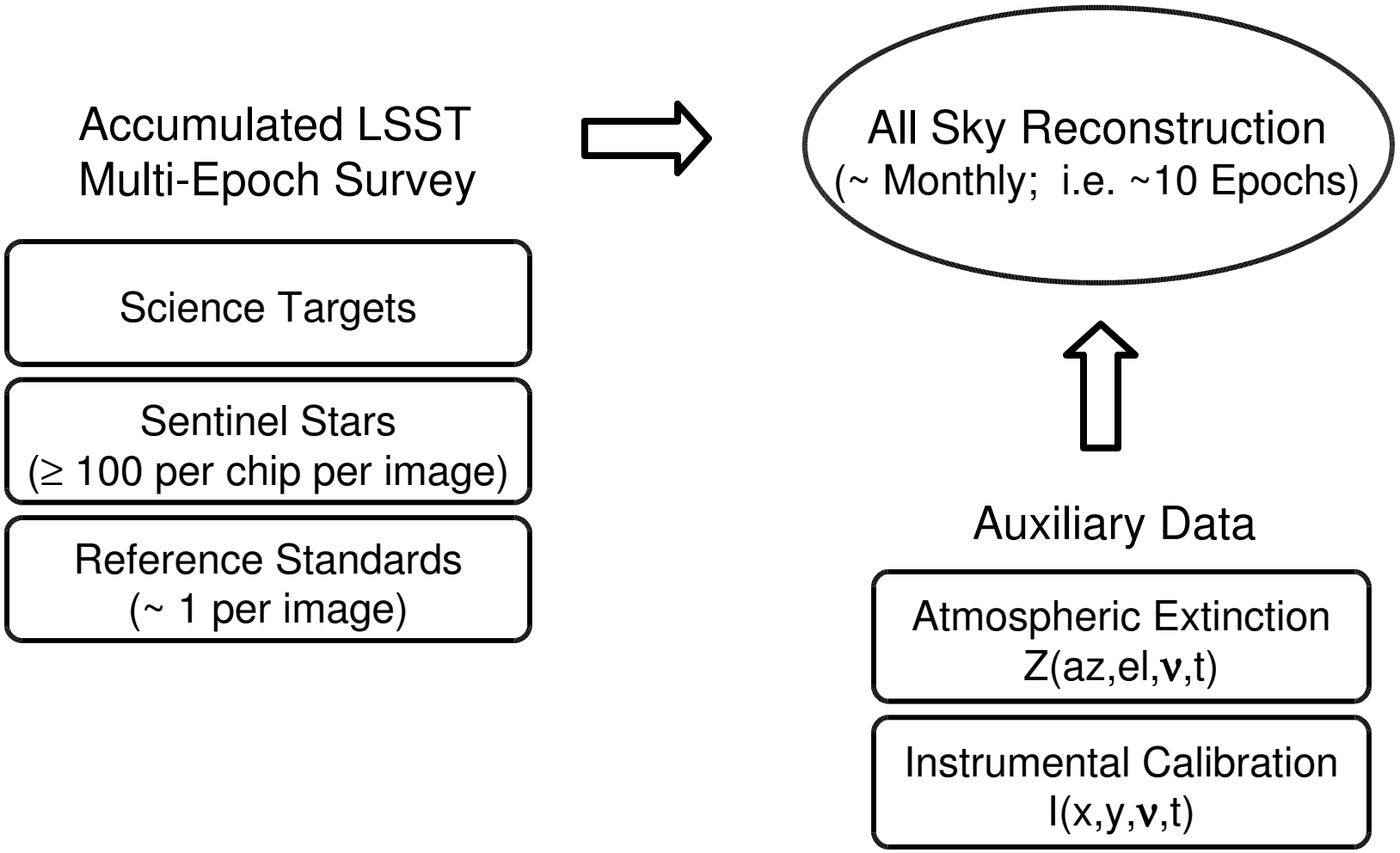
Photometric Design Specifications

Except as noted, specifications are given for isolated bright stars ($17 < r < 20$).

- Repeatability of measured flux over epochs of 0.005 mag (rms).
- Internal zero-point uniformity for all stars across the sky 0.010 mag (rms) in *g,r,i* ; 0.020 in other bands.
- Transformations between internal photometric bands known to 0.005 mag (rms) in *g,r,i*; 0.010 to other bands.

  (This is a specification on the absolute accuracy of measured colors.)
- Transformation to a physical scale with accuracy of 0.020 mag.

Calibration Elements



Photometric Calibration Philosophy

- Reduce accumulated all-sky multi-epoch survey to a single arbitrary scale for each filter band.
  - Sentinel stars: ~ 10^8 main-sequence stars (10^5 per image).
- Determine six filter-band zero-points.
  - Reference standards: ~ 2000 hydrogen white dwarf stars.
- Physical scale
  - Conventional (Landolt, Stetson) standard stars.
  - HST 1% photometry – DA WDs.
  - NIST laboratory calibrated detectors?

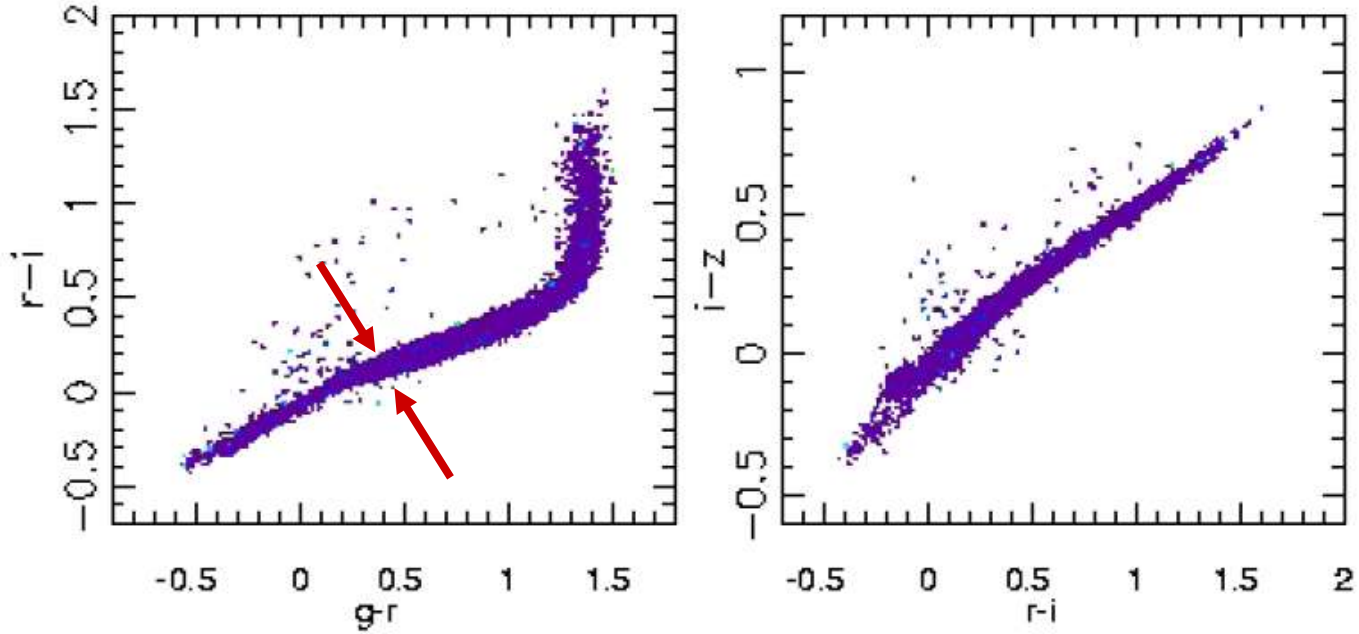
Sloan SDSS "Über-cal"

Southern Survey (Stripe 82)

300 deg^2 along celestial equator.
Multiple (30-40) epochs.

Main sequence stellar color locus is quite narrow.

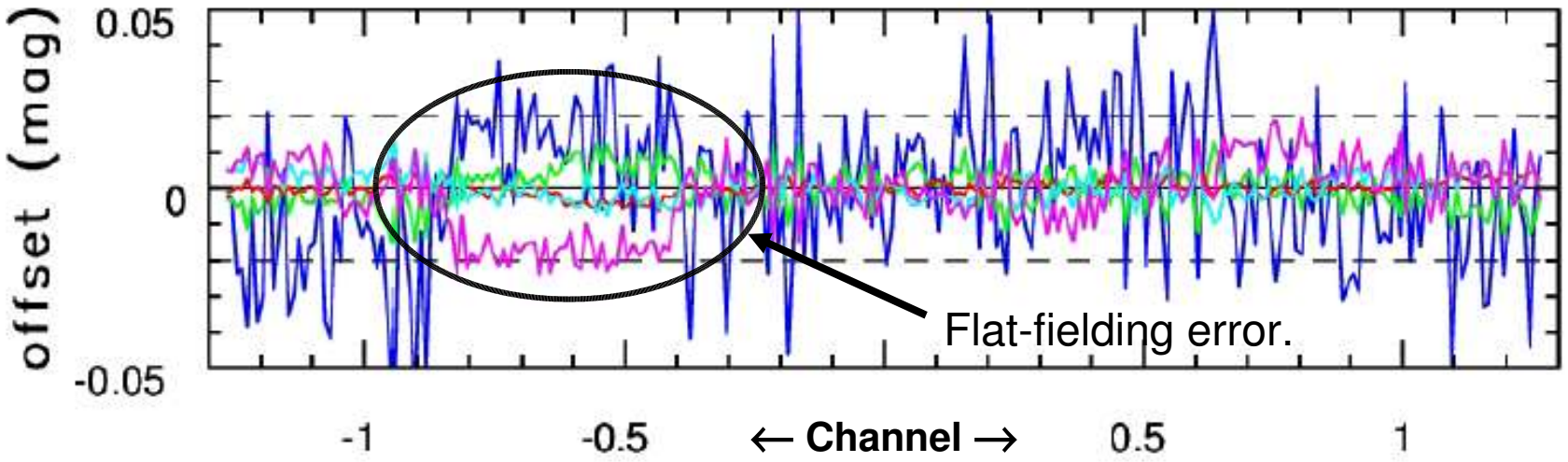
Averages of stars with r < 20 define photometric zero-points.



Projections of main sequence locus in *gri* and *riz*.

Sloan SDSS "Über-Cal"

Channel-by-channel averages of ~ 10^6 stars.

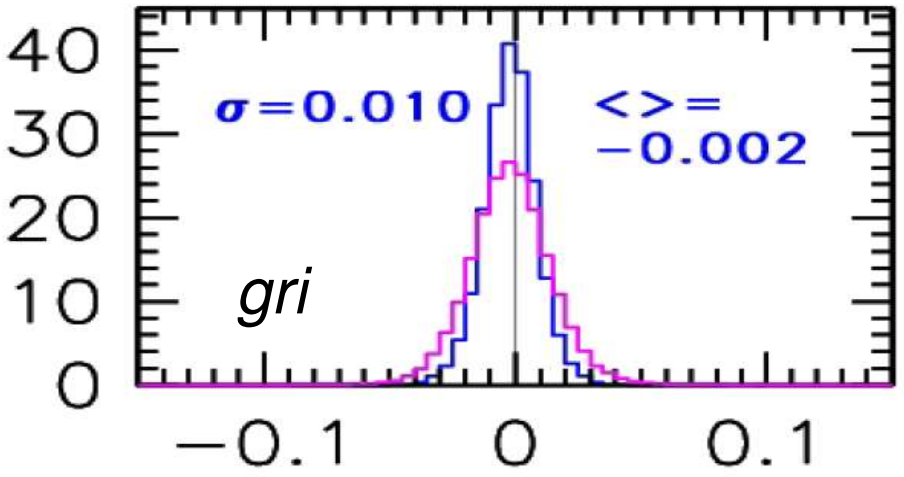


Uniformity of internal zero points in photometric conditions:

gri ≤ 5 milli-mags

uz ≤ 10 milli-mags.

→ Meets LSST goals.



Catalogs and Standards

Sentinel Catalog

Main-sequence stars 17< r < 21 (photon statistics below 0.5%).

SDSS fields observable from Pachon – useful overlap.

Standards

SDSS ~ 4000 spectroscopically confirmed DA WDs (17 < g < 19) in the southern sky.

HST has spectrophotometry for a number observable from Pachon.

Extend across southern sky.

SkyMapper, precursor campaigns, and LSST commissioning.

Auxiliary Data

1. Measure atmospheric extinction.

   → Z(az,el,**ν**,t)

   → Photons at the top of the atmosphere to the telescope pupil.

   SDSS analysis indicates that spatial, temporal, and/or spectral variations in atmospheric conditions that are unobserved and un-modeled dominate residual calibration errors.

2. Calibrate telescope and camera instrumentation.

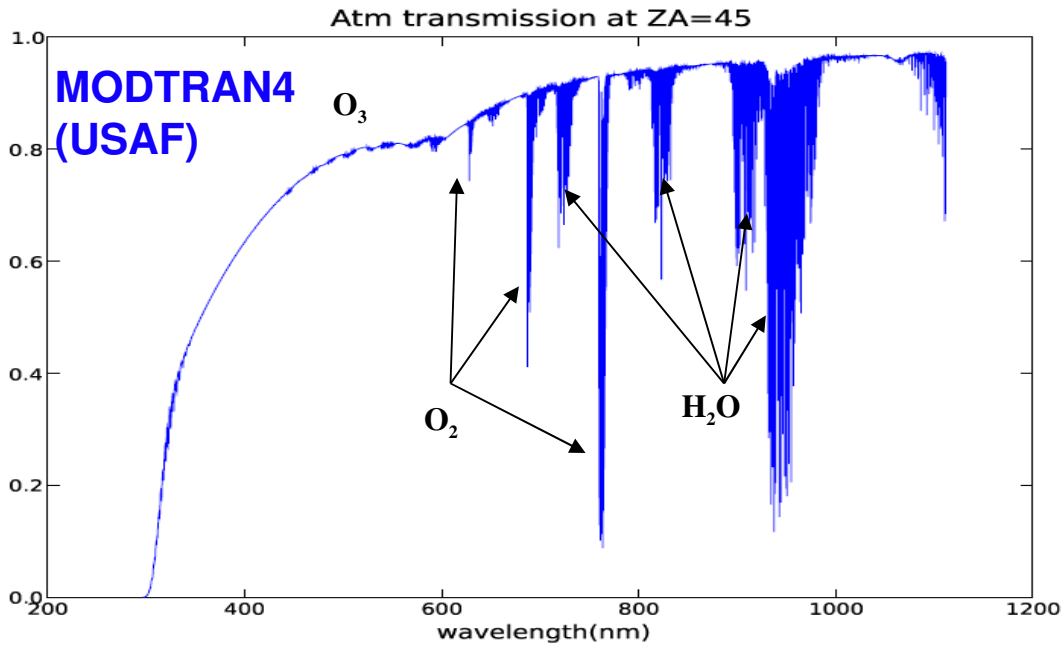
   → I(x,y,**ν**,t)

   → Reconstruction of photons in the telescope pupil.

Atmospheric Composition and Optical Extinction

U.S. Standard Atmosphere (1976)

Permanent Constituents		Variable Constituents	
Constituent	**% by volume**	**Constituent**	**% by volume**
Nitrogen (N_2)	78.084	Water vapour (H_2O)	0-0.04
Oxygen (O_2)	20.948	Ozone (O_3)	0-12x10^{-4}
Argon (Ar)	0.934	Sulphur dioxide (SO_2)1	0.001x10^{-4}
Carbon dioxide (CO_2)	0.033	Nitrogen dioxide (NO_2)1	0.001x10^{-4}
Neon (Ne)	18.18x10^{-4}	Ammonia (NH_3)1	0.004x10^{-4}
Helium (He)	5.24x10^{-4}	Nitric oxide (NO)1	0.0005x10^{-4}
Krypton (Kr)	1.14x10^{-4}	Hydrogen sulphide (H_2S)	10.00005x10^{-4}
Xenon (Xe)	0.089x10^{-4}	Nitric acid vapour (HNO_3)	Trace
Hydrogen (H_2)	0.5x10^{-4}		
Methane (CH_4)	1.5x10^{-4}		
Nitrous oxide (N_2O)1	0.27x10^{-4}		
Carbon monoxide (CO)1	0.19x10^{-4}		



Rayleigh and aerosol scattering extinction coefficients

$$k_{scat}(\lambda) = a \cdot \lambda^{-4.05} + b \cdot \lambda^{-\alpha}$$

Aerosol spectral index α depends on particulate size and shape and varies between 0.5 – 1.5.

Telluric absorption varies nonlinearly with airmass - saturated.

Auxiliary Telescope (AT) and Thermal IR Camera

Auxiliary 1.4-meter telescope to determine atmospheric components and measure extinction.

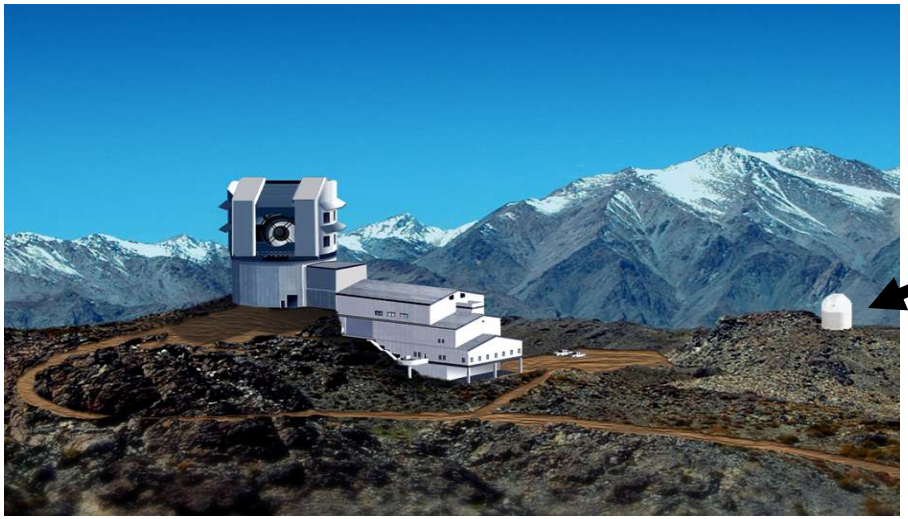
→ Contemporaneous narrow-band spectra of probe stars in (or near) LSST FOV.

→ Photometric extinction of standards over wide ZA.

Thermal IR (≅ 10-micron) camera bore-sighted with LSST to monitor thermal emission from clouds.

→ Resolve profiles of thin clouds ($\tau \leq 0.01$) with arc-min resolution.

Cerro Pachón
Northern Chile



Auxiliary Telescope

Auxiliary Telescope

Measure (changes in) atmospheric transmission with sufficient resolution in wavelength to accurately compute spectral extinction across all wavelengths, e.g. with MODTRAN4.

- Spectroscopy ($R = \lambda/d\lambda \sim 100$) of bright stars $r < 15$ near LSST fields (~ 50% duty factor).
  - Modeled $Z(az,el,\nu,t)$ relative to standard atmosphere.

- Photometry on DA WDs over wide airmass (from 1 to 2) throughout the night (~ 50% duty factor).
  - Measured Z(al,el,band,t).
  - Filter bands optimized for computing atmospheric properties.

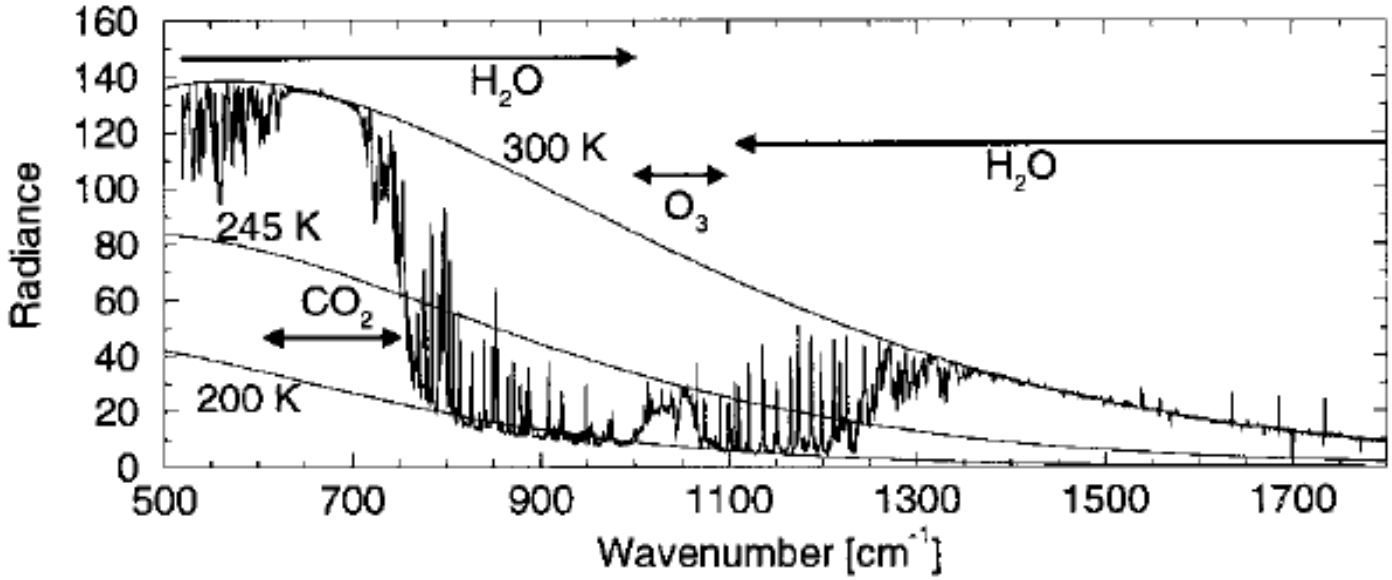
Thermal Camera and Sky Radiance

Raytheon / Thermal-Eye

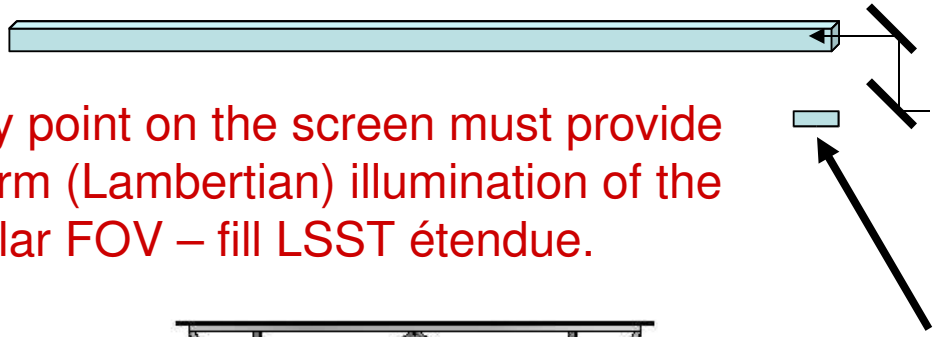
- 160x120 pixels.
- 7-14 micron.
- <50 mK sensitivity.

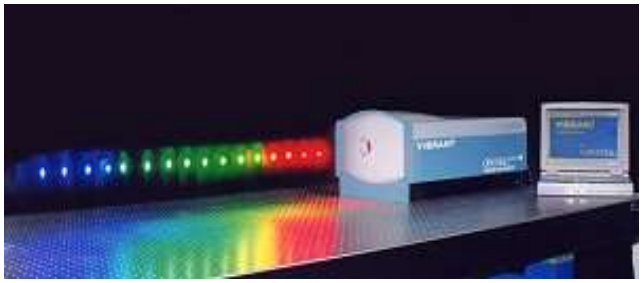
FLIR Systems

- Near, mid and long IR models.
- 640x512 array format.
- < 35 mK sensitivity.
- Standard frame rate.



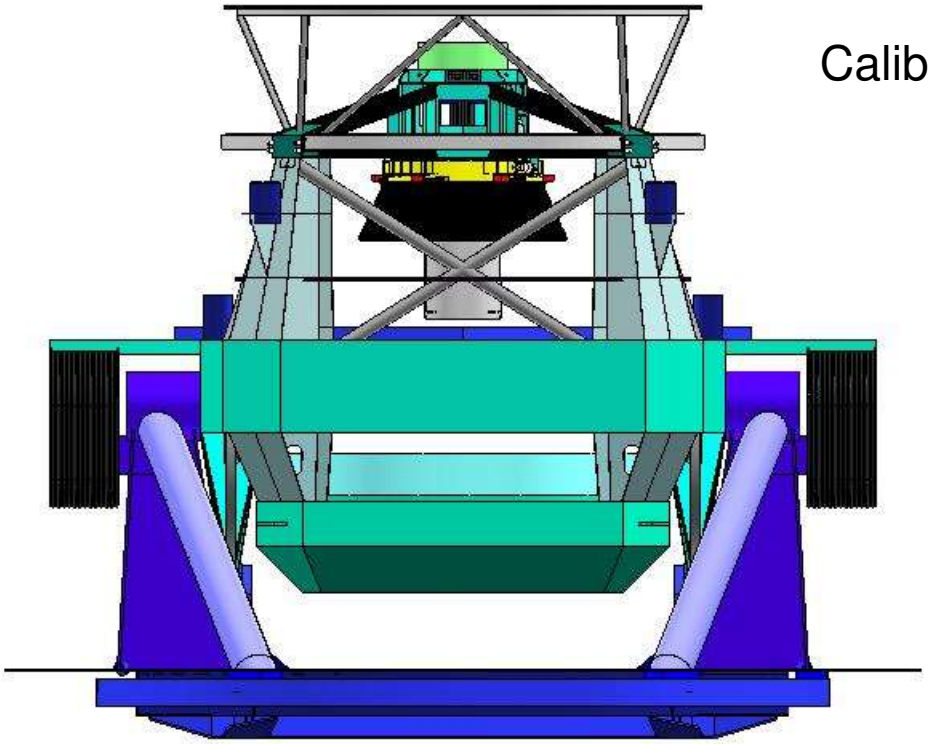
Instrumental Optical Calibration





Tunable Laser

Every point on the screen must provide uniform (Lambertian) illumination of the angular FOV – fill LSST étendue.

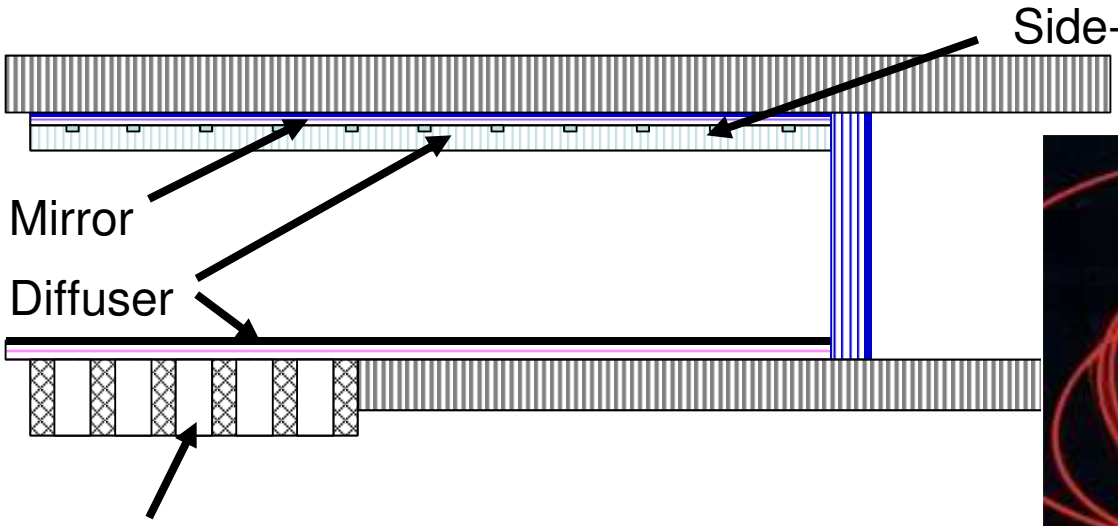


Calibrate at NIST across wavelength (*griz*) to part in ~ 10^{-3}.

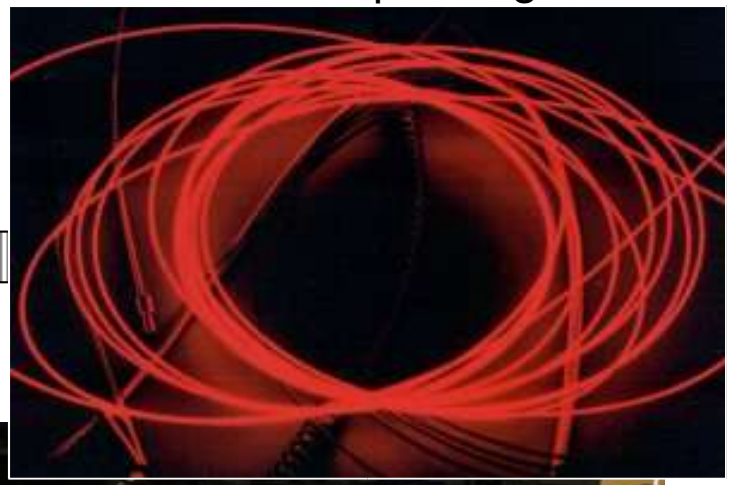
Collaboration with PanSTARRS. (J. Tonry, et al.)

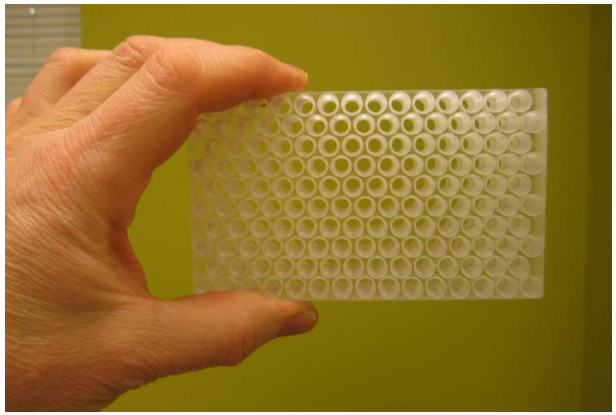
Back-Lit Diffuse Dome Screen

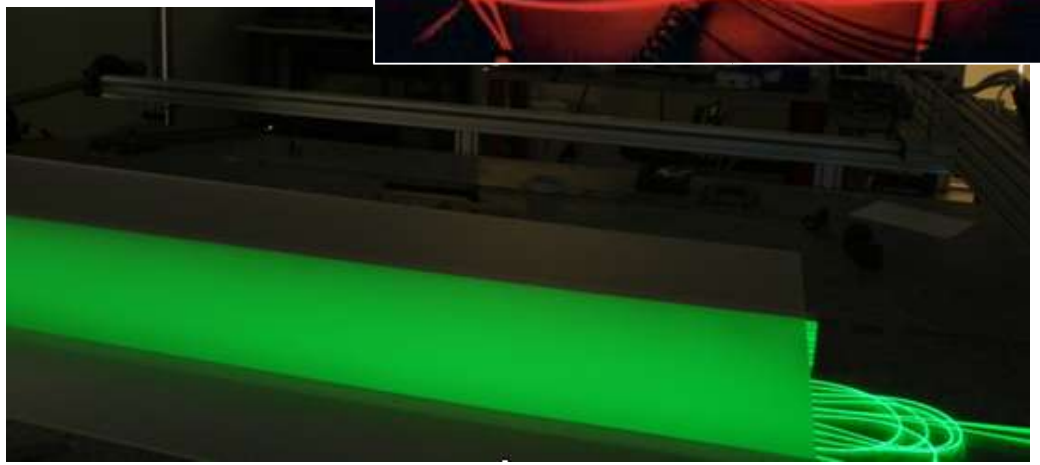
Concept Sketch and Prototype



Somta Corp of Riga, Latvia



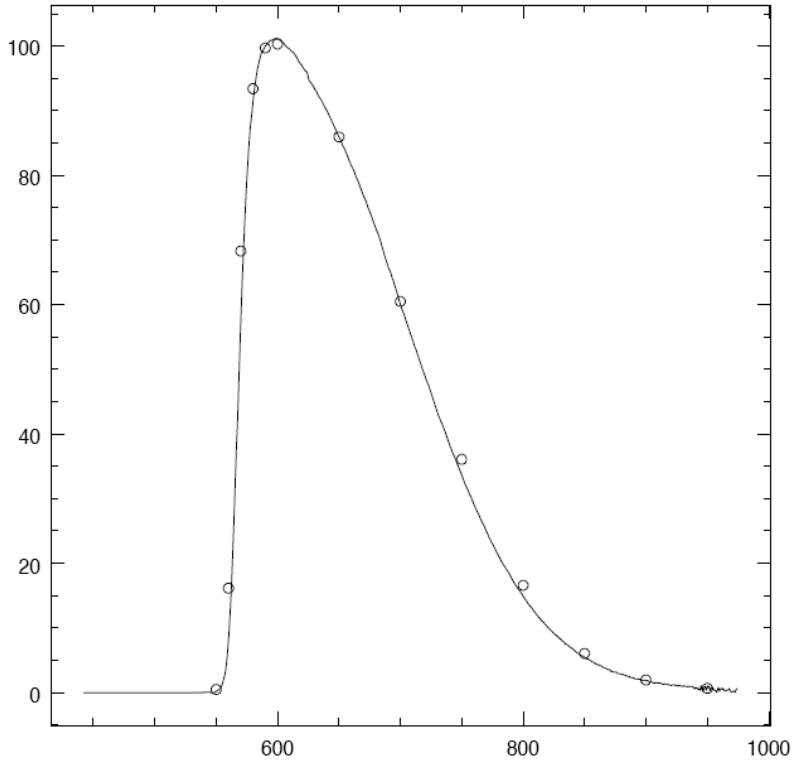




Performance and Issues

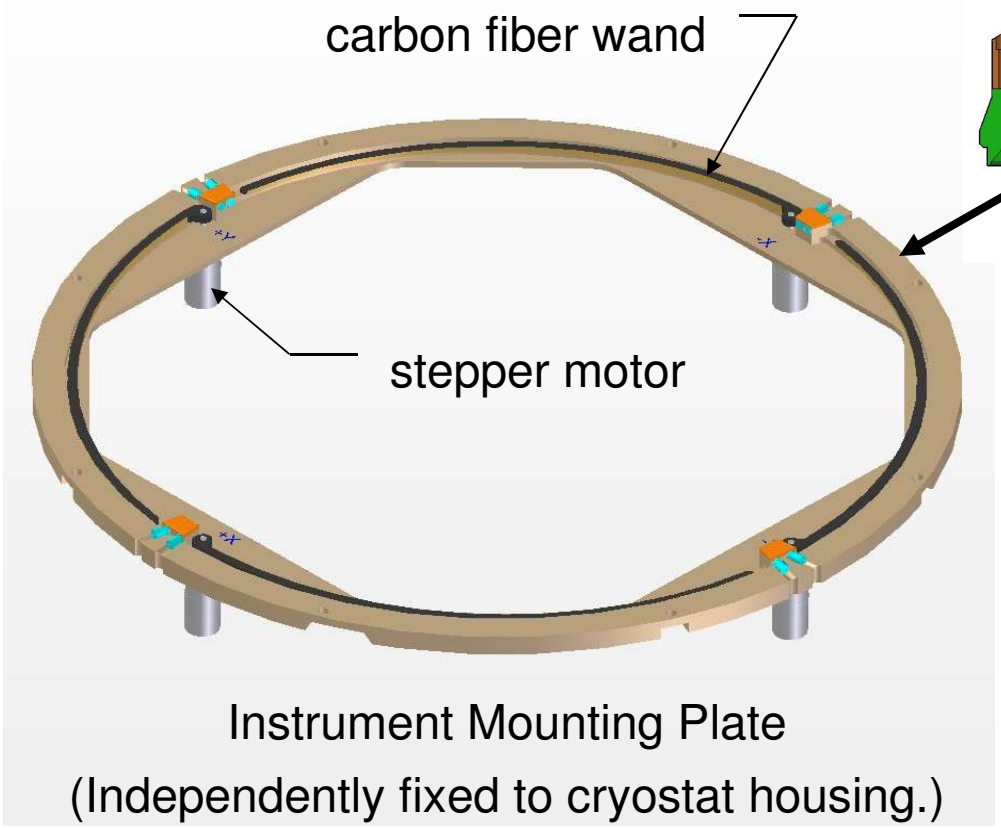
- **Illumination uniformity.**
- **Stray and scattered light.**
- **Mechanical construction.**

Test on CTIO Blanco.

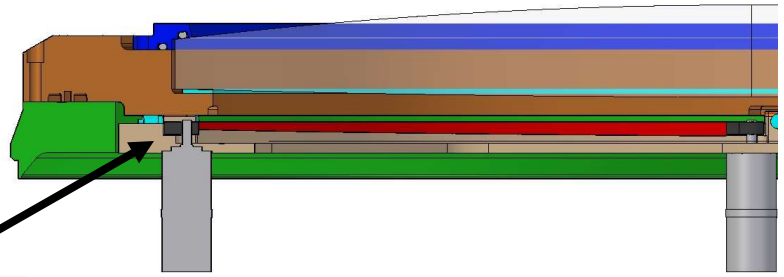


Comparison of Blanco r-filter facility reference bandpass and dome illumination measurements.

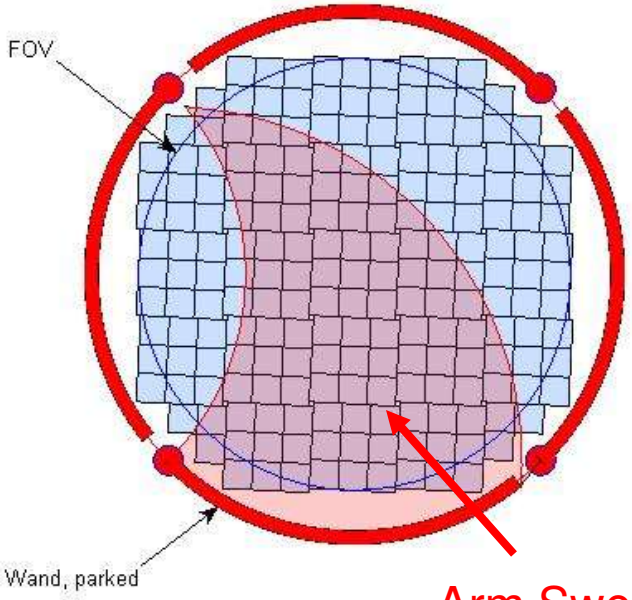
FPA In-Situ X-Ray System



Instrument Mounting Plate
(Independently fixed to cryostat housing.)



Clearance between the tapered arm and FPA is 5.7mm (ref).



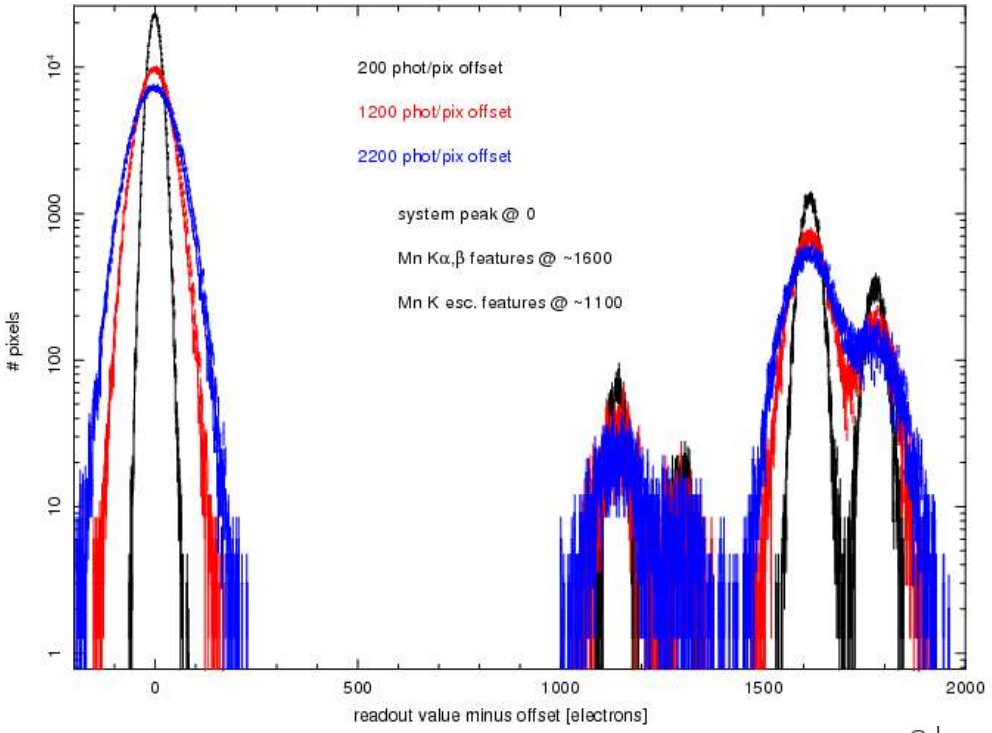
X-Ray Measurements

- Measure wavelength-independent response of sensor electrical circuits and front-end electronics.
  - Charge transfer efficiency (CTE)
  - Absolute gain in e^-/ADU.
  - Offset and linearity.
  - Cosmetics

→ Combine with monochromatic screen calibration to obtain complete (and over-constrained) characterization of the system response of the telescope and camera.

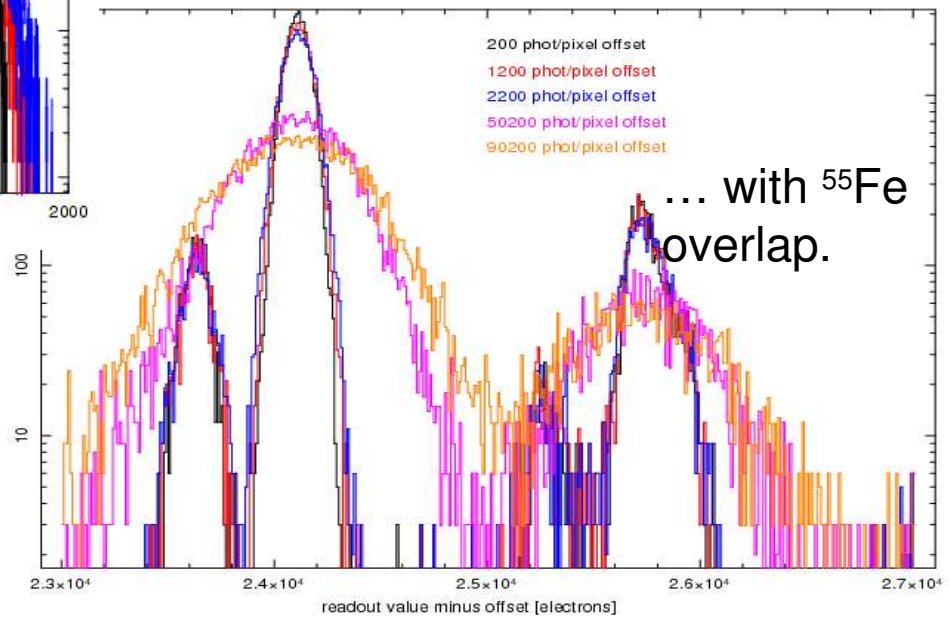
- Simultaneous x-ray and optical dome screen exposures?
  - Measure response up to pixel full-well potential.

Simulations



^{55}Fe X-rays (~ 6 keV)

^{109}Cd X-rays (~ 88 keV)



… with ^{55}Fe overlap.

Simultaneous optical bias up to pixel full-well (shown at 10% occupancy and bias subtracted).

Project Milestones and Schedule

1	Site Selection Construction Proposals (NSF and DOE).
2007-2009	Complete Engineering and Design Long-Lead Procurements
2010-2013	Construction
2013	First Light and Commissioning