Using a Fast Beam (f/1.2) to Characterize Thick CCD's

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Workshop on Precision Astronomy with Fully Depleted CCDs

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Motivation for LSST f/1.2 Beam Simulator

The LSST Weak Gravitational Lensing survey requires shape measurements for over a billion galaxies.

If systematic shape errors are left unmitigated, they will significantly bias the inferred cosmic shear correlation function (and thus the cosmological parameters under investigation), relative to the expected error budget.

LSST has facilities capable of characterizing the fundamental properties of candidate CCD sensors.

The f/1.2 LSST beam simulator at UC Davis (UCD) supplements these capabilities with a system that can perform end-to-end experimental validation of candidate sensors by emulating telescope observations in the lab. Data from such a system can be used to validate candidate sensor performance under realistic scenarios and to reveal deficiencies in how software simulations account for uncharacterized real-world performance of selected detectors.

LSST f/1.2 Beam Simulator

The LSST beam simulator is designed to simulate the f/1.2 beam of the LSST telescope, including the obscuration, and to provide a nearly diffraction limited image over a 60 mm diameter field covering an entire 4000x4000 ten micron pixel chip.

It is designed to over-illuminate a full CCD, including a sky with galaxies and stars with approximately black-body spectra superimposed on a spatially diffuse night sky emission with its complex spectral features.

The FWHM of star images is specified to be 5 microns over several wave-bands (rizy) that need to be imaged.

LSST Beam Simulator Specifications

- F/1.23 at image
- Image field size 60 mm in diameter
- Magnification = 1.06057
- Total length 665.7 mm
- Diameter 317.5 mm
- Bandwidths: 0.681-0.822; 0.811-0.921; 0.93-1.03; in three positions
- 100 mm diameter obscuration on beam-splitter window
- All spherical optics
- One mirror, three BK7 lenses, window

LSST f/1.2 Beam CCD Testing

Motivating Science

Precision Photometry: What is impact of CCD edge effects and PRNU?

Astrometry: What is impact of CCD edge effects and pixel area variation?

Shape measurement for WL: What shape measurement errors are due to CCD?

Deliverables

Baseline calibrations of CCDs used in other tests.

Map spatial distortion at various points and edges of CCD. Correlate:

- Astrometry
- Flat field structure (bigger pixels collect more light)
- PSF shape

Tests for flat fielding accuracy.

Assessment of shape measurement systematics and linearity.

Experiments

Baseline calibrations
flats vs. wavelength
dark current
noise
fixed patterns
Linearity

Astrometry
Measure spot separation (for a regular grid of small spots) as a function of displacement between image and CCD.

Repeat for several PSF sizes and wavelengths, with emphasis on oversampled PSFs.

Measure displacements of spots vs actual motion inferred from ensemble.

Map the variation over the field.

Check that reproducibility is consistent with S/N.

Analyze correlation with pixel alignment and dependence in PSF size.

PSF Shape Measurement

Select pupil stop and target apertures to match PSF size of LSST with seeing. Dither images and combine.

Measure PSF shape and map ellipticity across CCD. Repeat at several wavelengths.

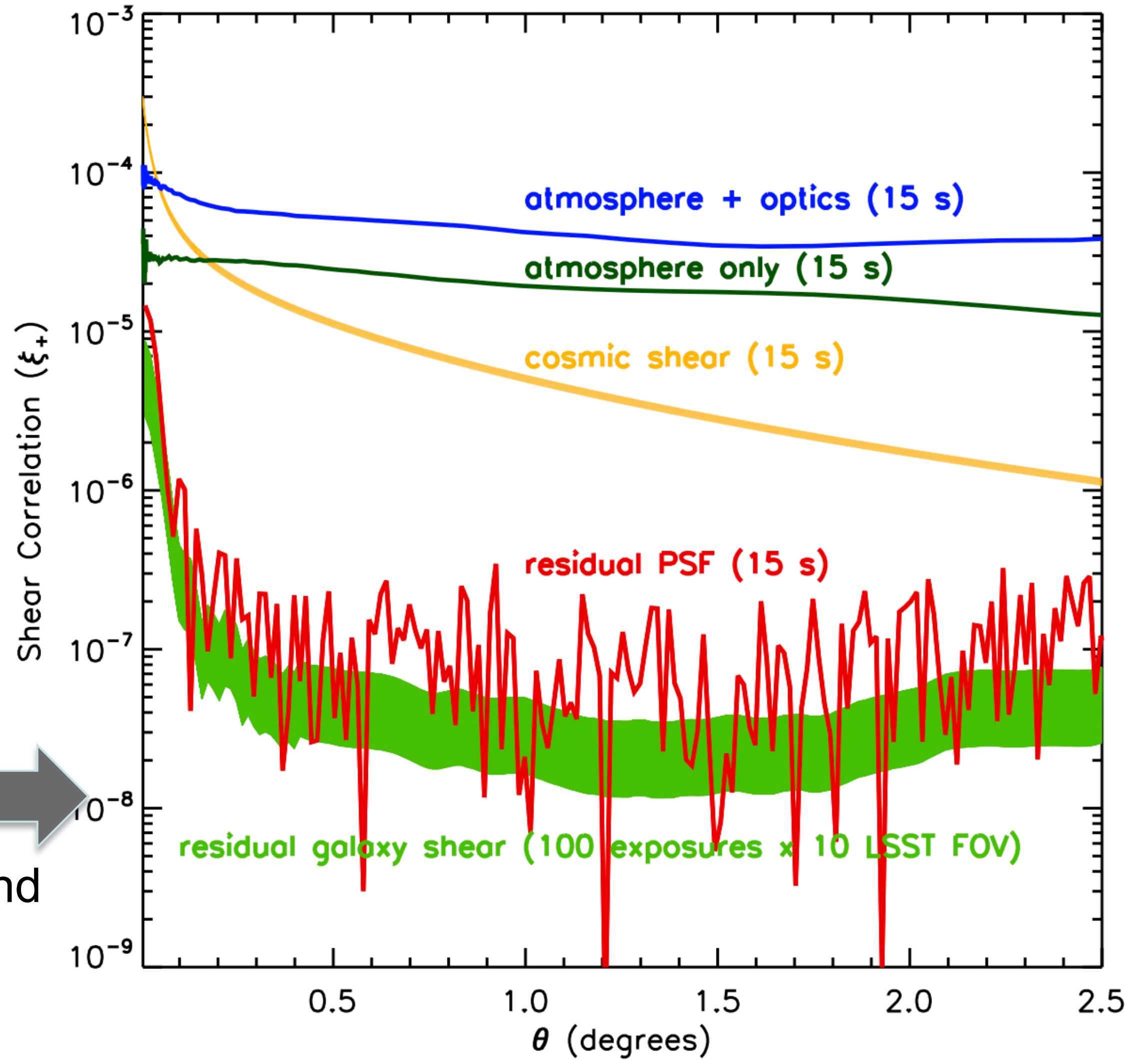
Measure PSF perturbations due to CCD (eg due to charge diffusion and CTE). Repeat the above test with pinholes, larger pupil stop and commensurately more dithers.

Make ellipticity, Strehl and FWHM maps.

Measure MTF versus location on CCD and compare to model.

Why worry about shapes of PSF?

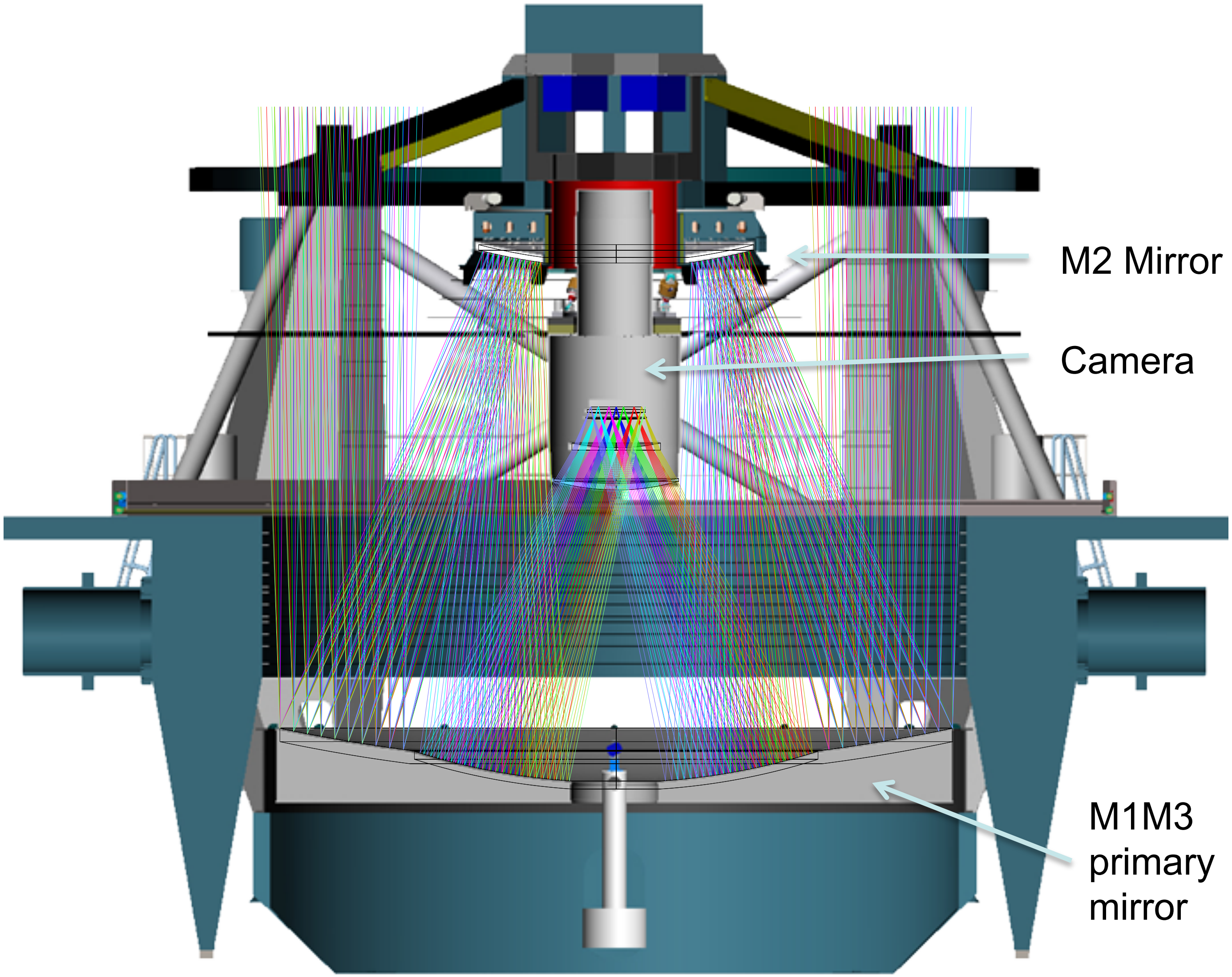
The shape of the PSF must be known (measureable and stable) to a part per ten thousand in each exposure at each position in the CCD. Software corrections to its effects on faint galaxies will be made: below are the shear-shear correlation residuals in a simulation of LSST observing.



CCD systematics must be controlled at this level

Combination of PSF systematics and Low surface brightness mapping systematics

The camera sits in the telescope beam just below the secondary and creates a 61% beam obscuration



Cross section through telescope and camera

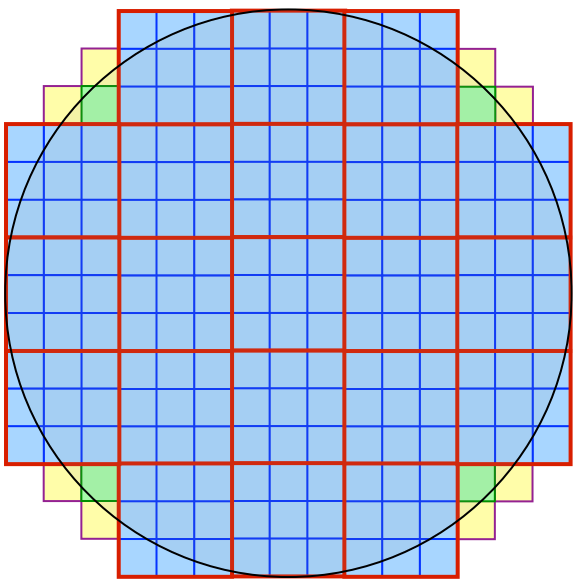
Focal Plane Throughput/PSF Performance

Focal Plane Throughput Parameters

QE + BBAR Coating

Contamination Effects

Condensation Effects



189 4kx4k science sensors

Focal Plane Image Quality Parameters

Sensor pkg flatness deviations

Sensor pkg bowing due to assembly forces

Sensor pkg motion due to variations in heating

CCD Charge diffusion

CCD Charge transfer efficiency

CCD Optical spreading

Detector Plane gravity-induced flexure and distortion

Grid gravity-induced flexure and distortion

Grid bow/twist due to changing gravity vector

Raft gravity-induced flexure and distortion Variation in K.C. pre-load due to changing gravity vector

Raft bowing due to changing gravity vector

FPA pistoning due to cryostat temp changes Grid tip/tilt due to flexure Temp

Grid piston due to flexure Temp

Grid distortion due to changing radiative heat loads

Raft distortion due to variable IR heat load

dz Image Degradation- FWHM & Flux for LSST

FWHM degradation	0	5	10	15	20	25	30
0.4"	0.40	0.40	0.41	0.43	0.46	0.50	0.54
0.5"	0.50	0.50	0.51	0.53	0.55	0.58	0.61
0.6"	0.60	0.60	0.61	0.62	0.64	0.66	0.69
0.7"	0.70	0.70	0.71	0.72	0.74	0.75	0.78
0.8"	0.80	0.80	0.80	0.81	0.83	0.84	0.86

Peak Flux Degradation	0	5	10	15	20	25	30
0.4"	1	0.98	0.93	0.85	0.75	0.65	0.56
0.5"	1	0.99	0.95	0.90	0.83	0.75	0.67
0.6"	1	0.99	0.97	0.93	0.88	0.82	0.75
0.7"	1	0.99	0.98	0.95	0.91	0.86	0.81
0.8"	1	0.99	0.98	0.96	0.93	0.89	0.85

From: Chris Stubbs

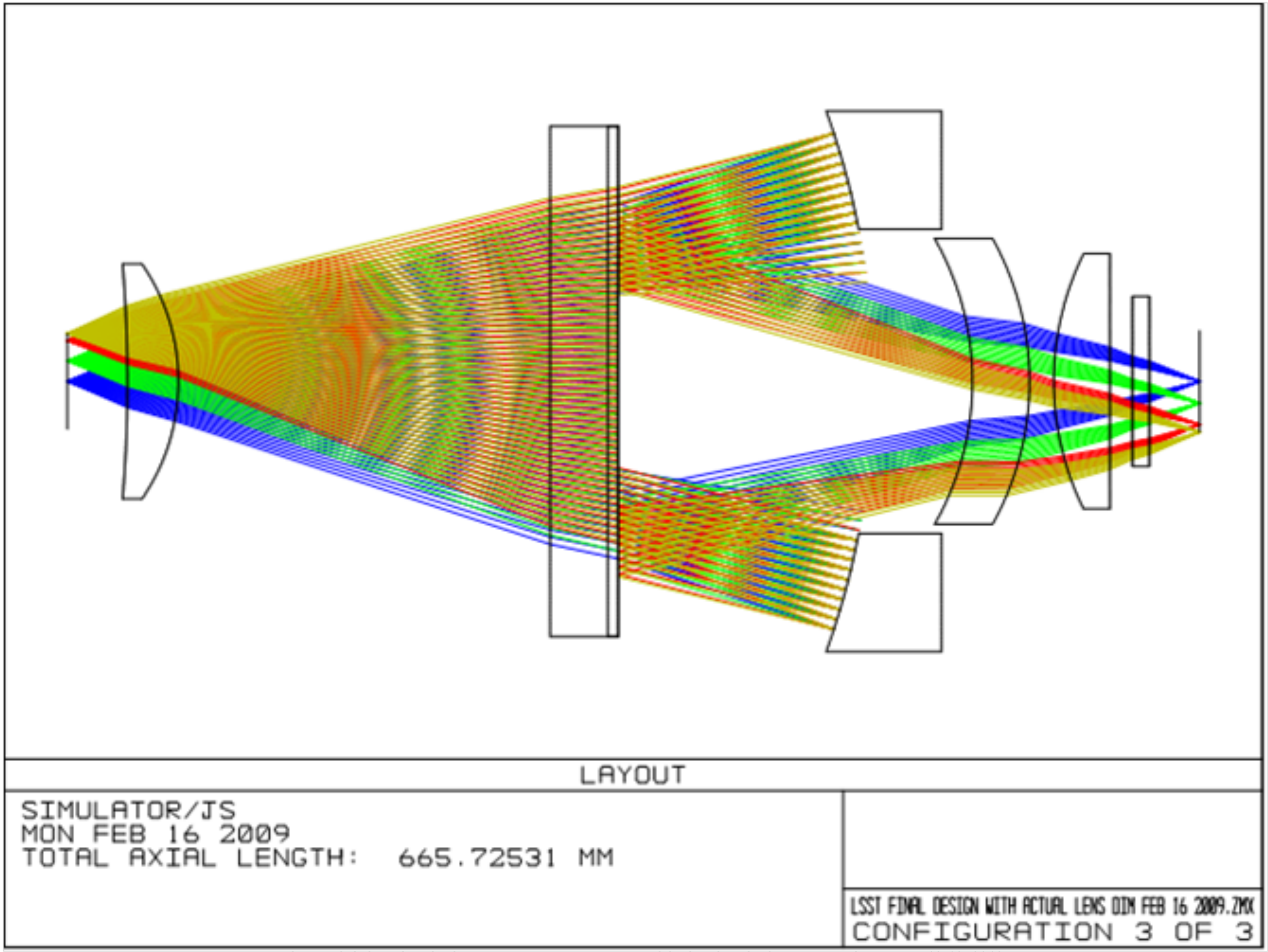
Geometrical RMS Spot radius - 100 Monte Carlo runs

- Nominal 5.257457μm
- Best 5.174935 μm
- Worst 8.473812 μm
- Mean 6.178084 μm
- Std Dev 0.808631 μm

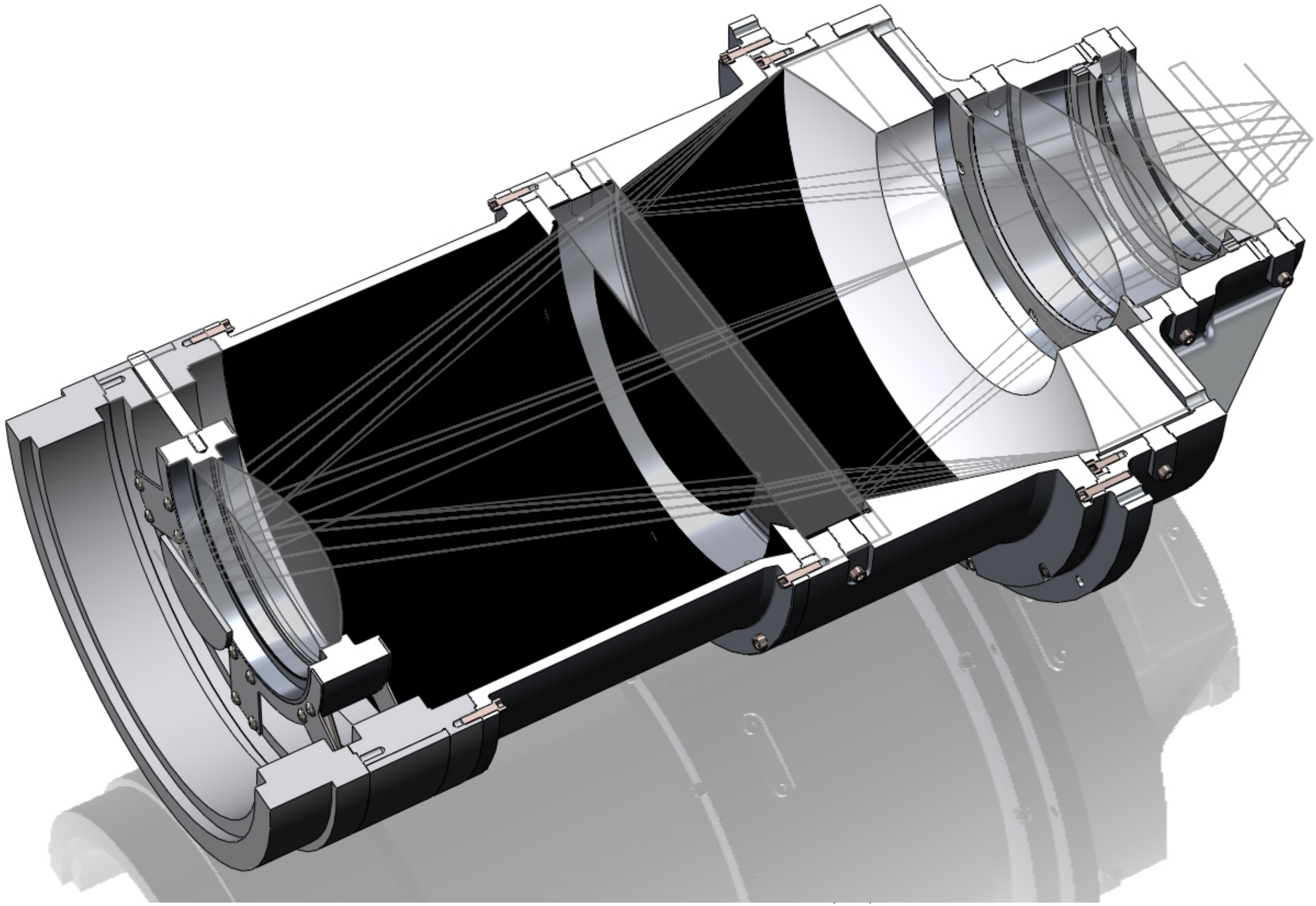
Tolerances

- 0.1 mm axial thickness
- 3 fringes power
- One arc minute surface tilts
- 0.5 fringe surface irregularity
- 0.0005 index
- 0.25 Abbe number (**material's dispersion in relation to the refractive index)**
- Focus compensation

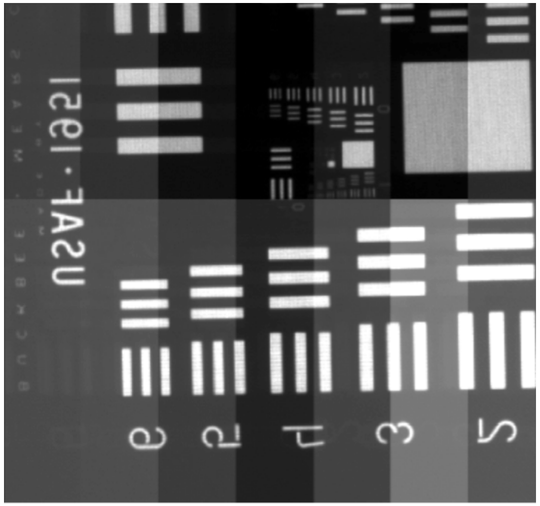
LSST Beam Simulator Ray Trace and Model

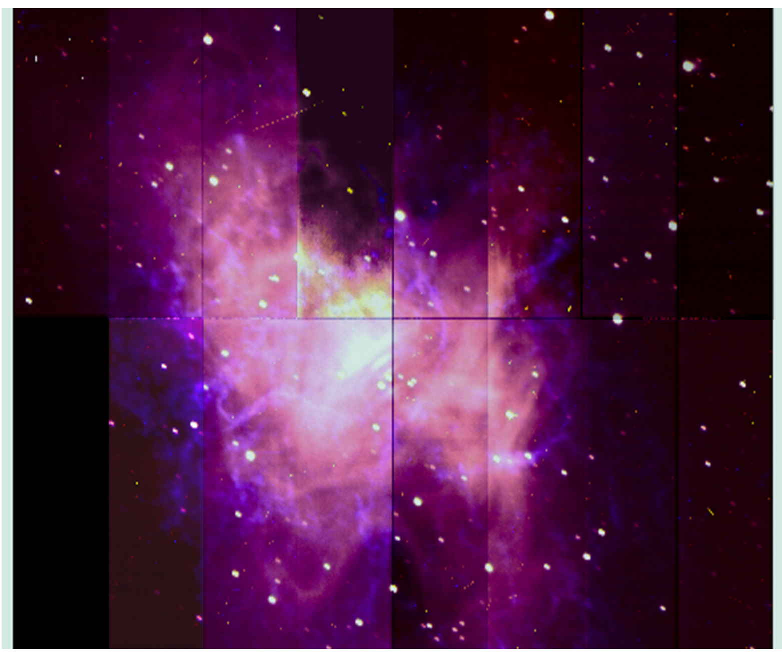


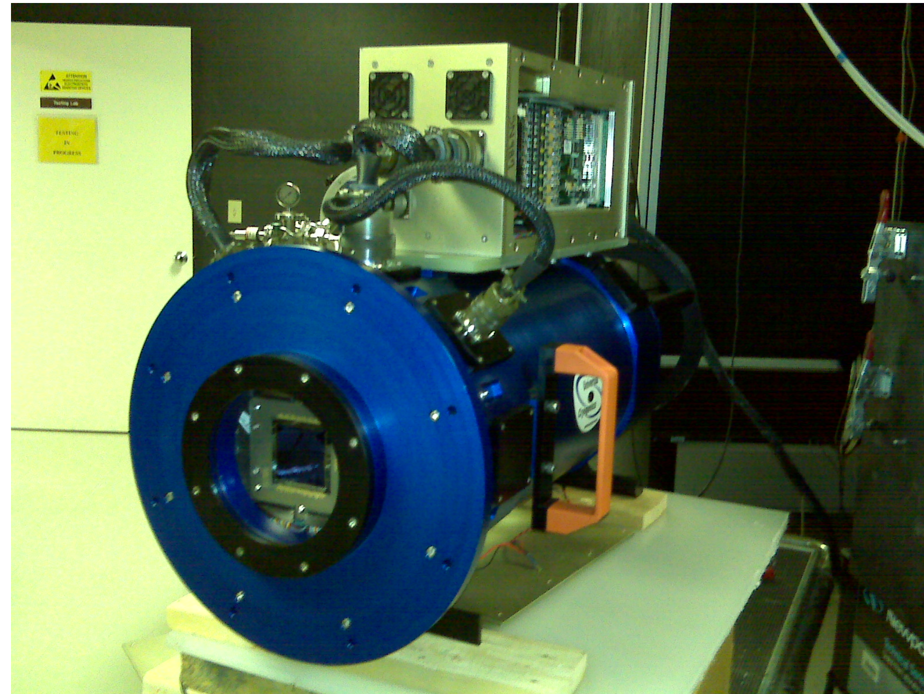
Fast Optics System Mechanical/Optical Layout

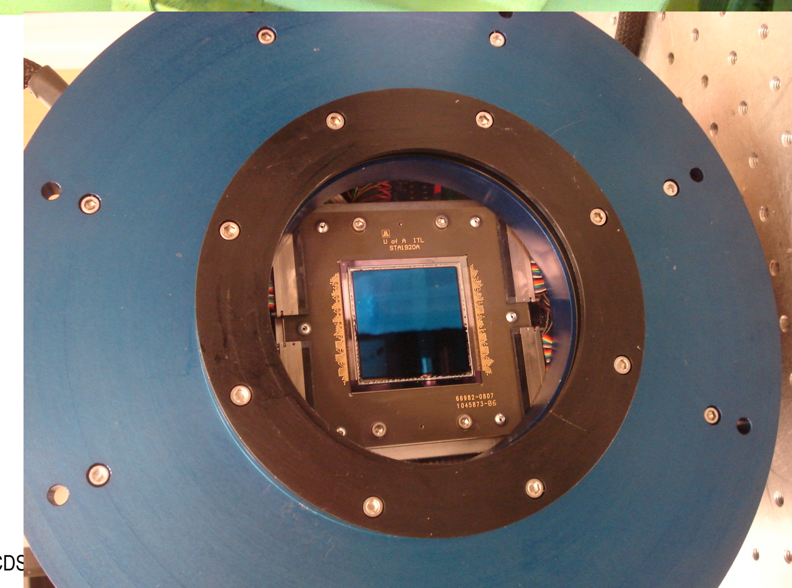


Dewar System – 16 channels, 4kx4k pixels, 10um pixels, 100um thick



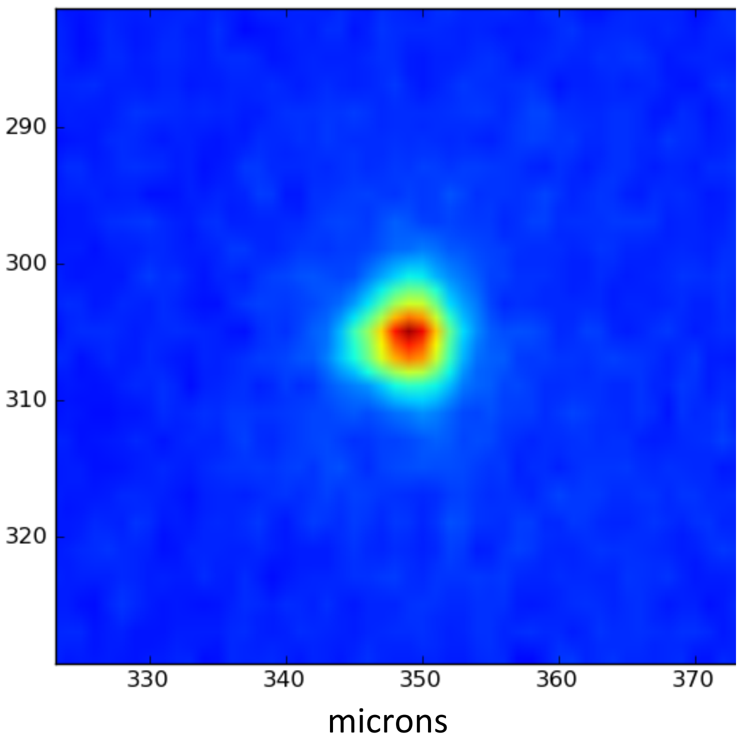


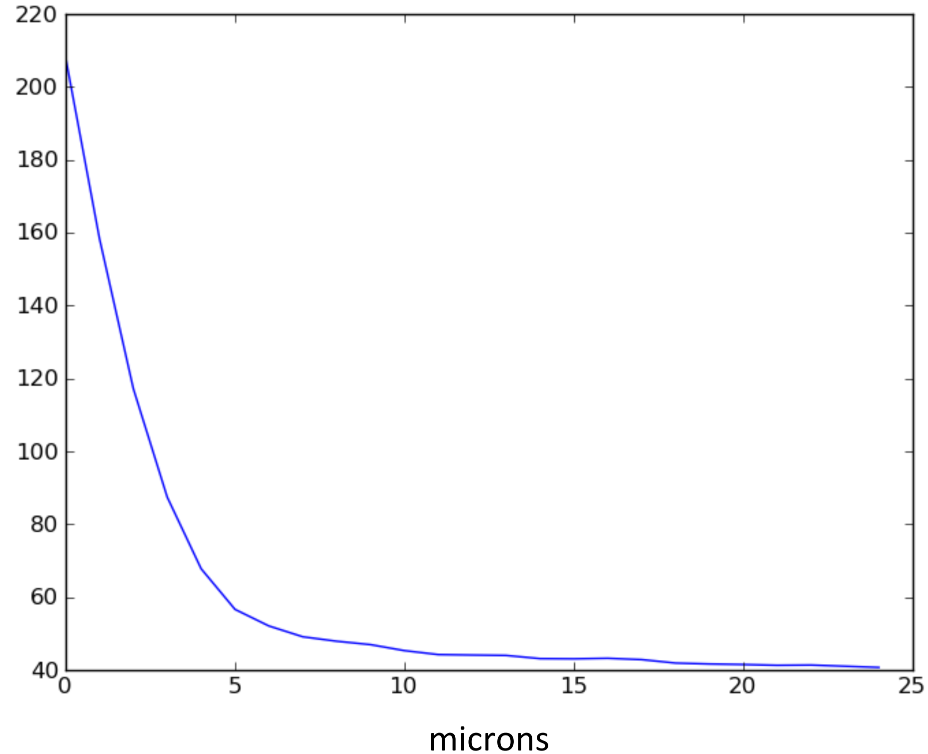




Lab tests of f/1.2 reimager optics

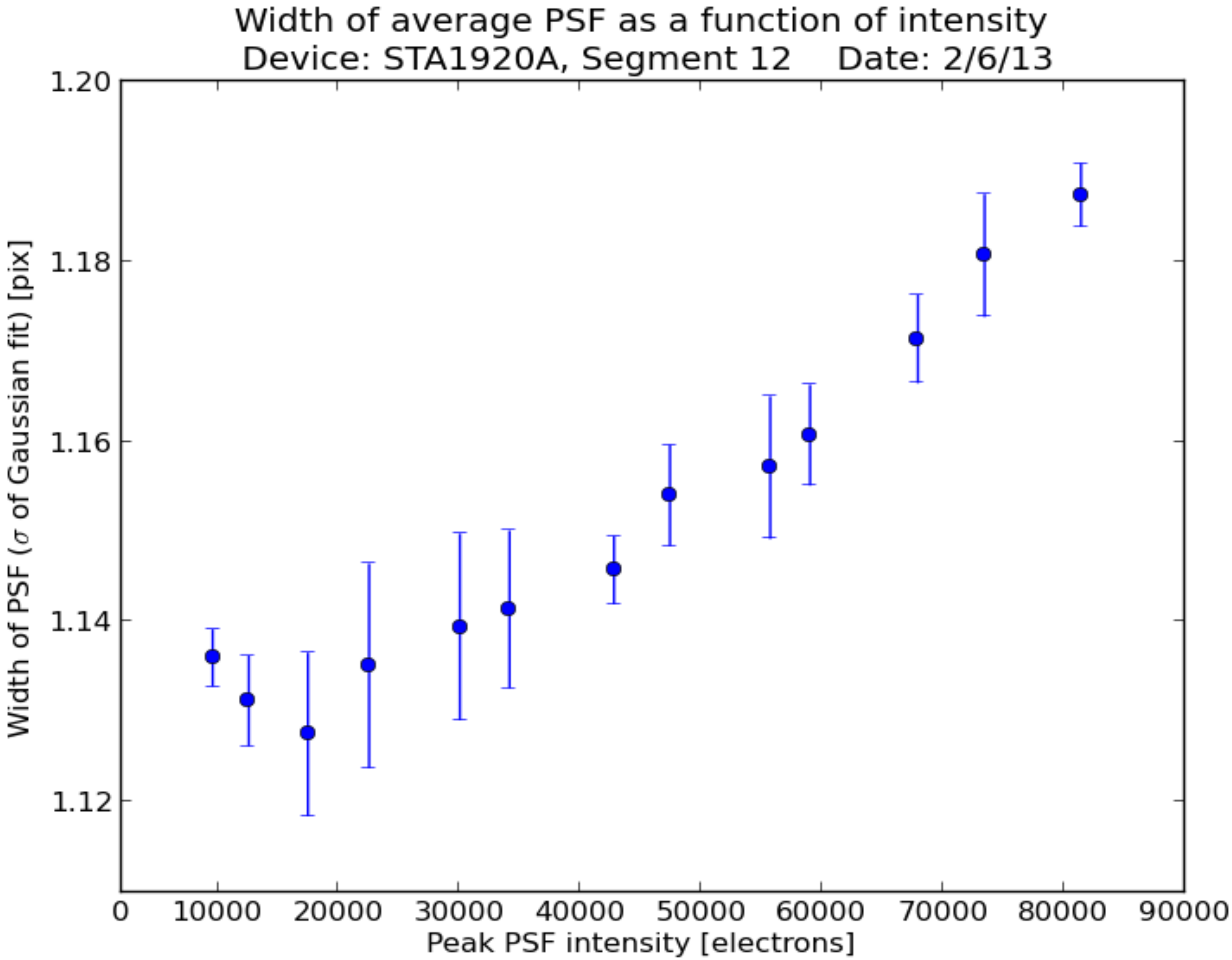
Illuminate with 5 micron diameter hole. Image output focal plane



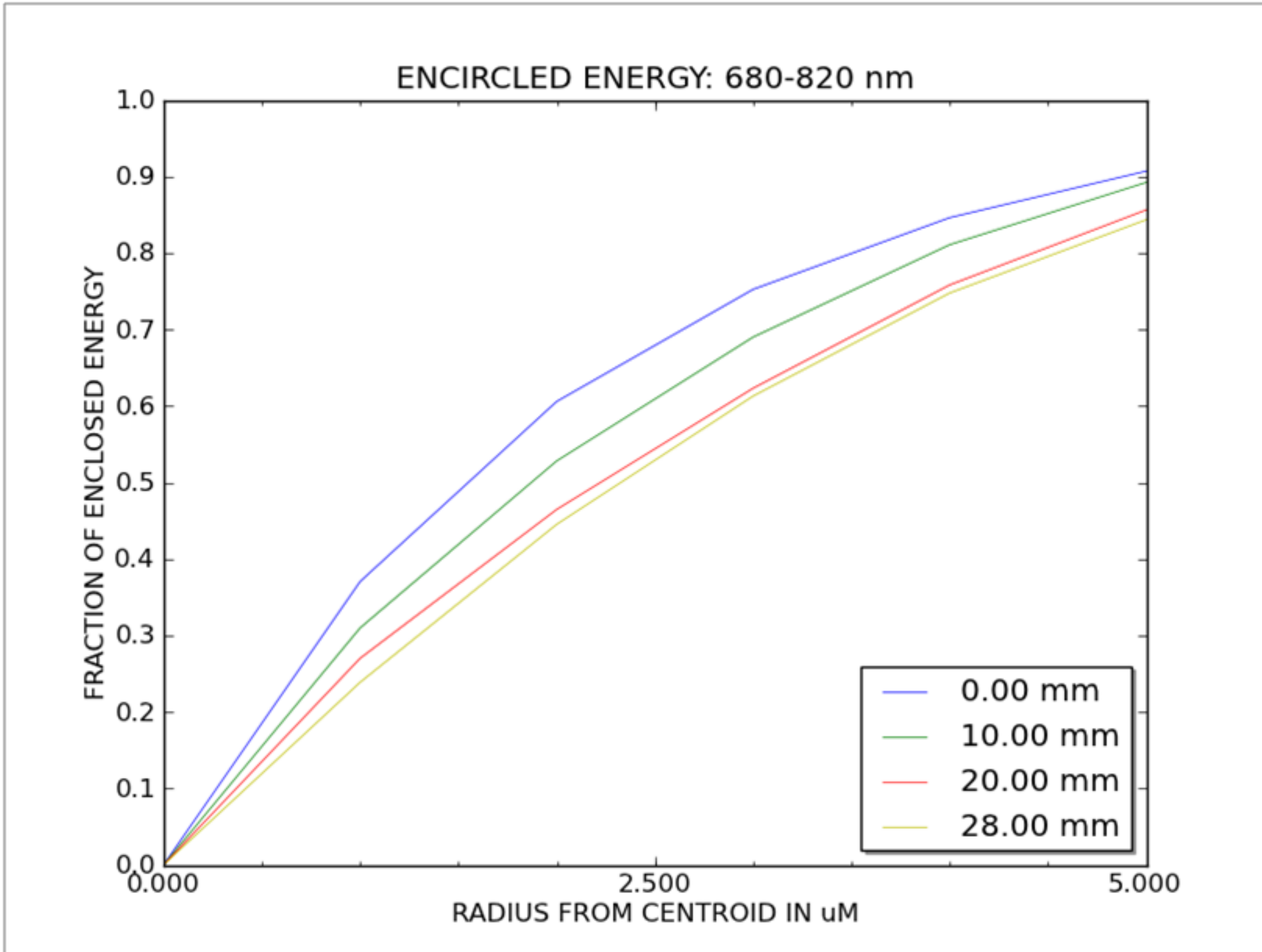


Half width at half maximum of the average profile is 1.86 microns.
This is well within the design specs.

PSF width dependancy on intensity



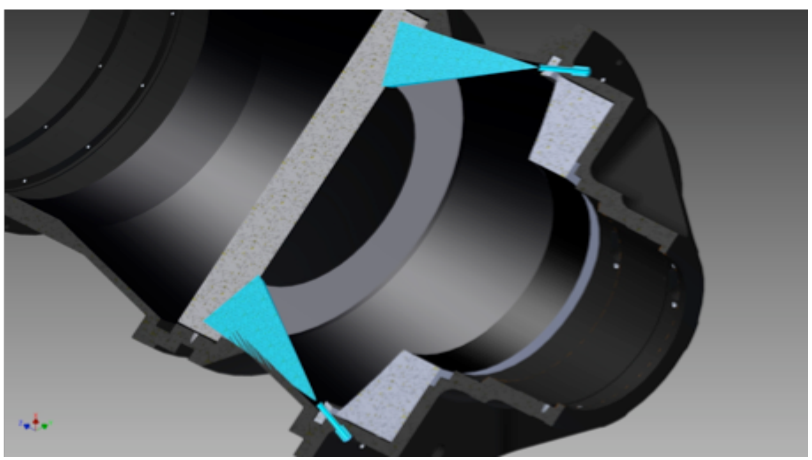
Measured performance for a point source (i-band)



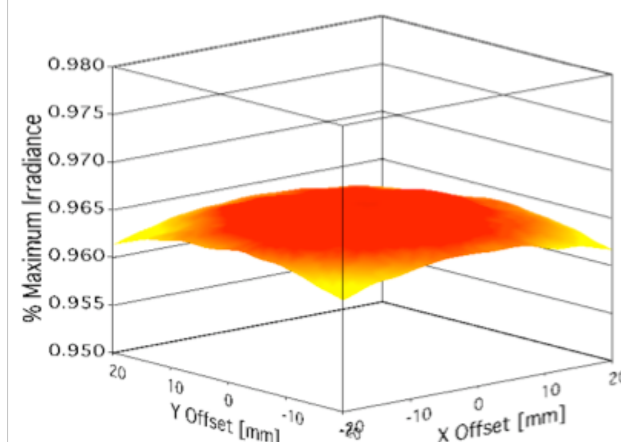
Simulating the diffuse night sky

In addition to the stars and galaxies (with their black body spectrum provided by the scattering sphere illumination of the reticule), we must simulate the diffuse night sky and its complex spectrum. This will be done via a spectral engine consisting of a scanning monochromator and light modulator. The spectral engine will have a 650-1200nm range with 3nm FWHM spectral resolution.

The complex sky emission spectrum, dominated by multiple vibration-rotation bands, as well as the LSST filter (rizy) transmission curve, will be simulated with the spectral engine. Constant illumination over the focal plane is achieved by injecting “sky” light in the pupil plane:



Cut-away drawing showing fiber optic sky light injector positioning within the LSST Beam Simulator.



ZEMAX simulated focal plane irradiance of 4 points sources in the pupil plane.

Ghost Images

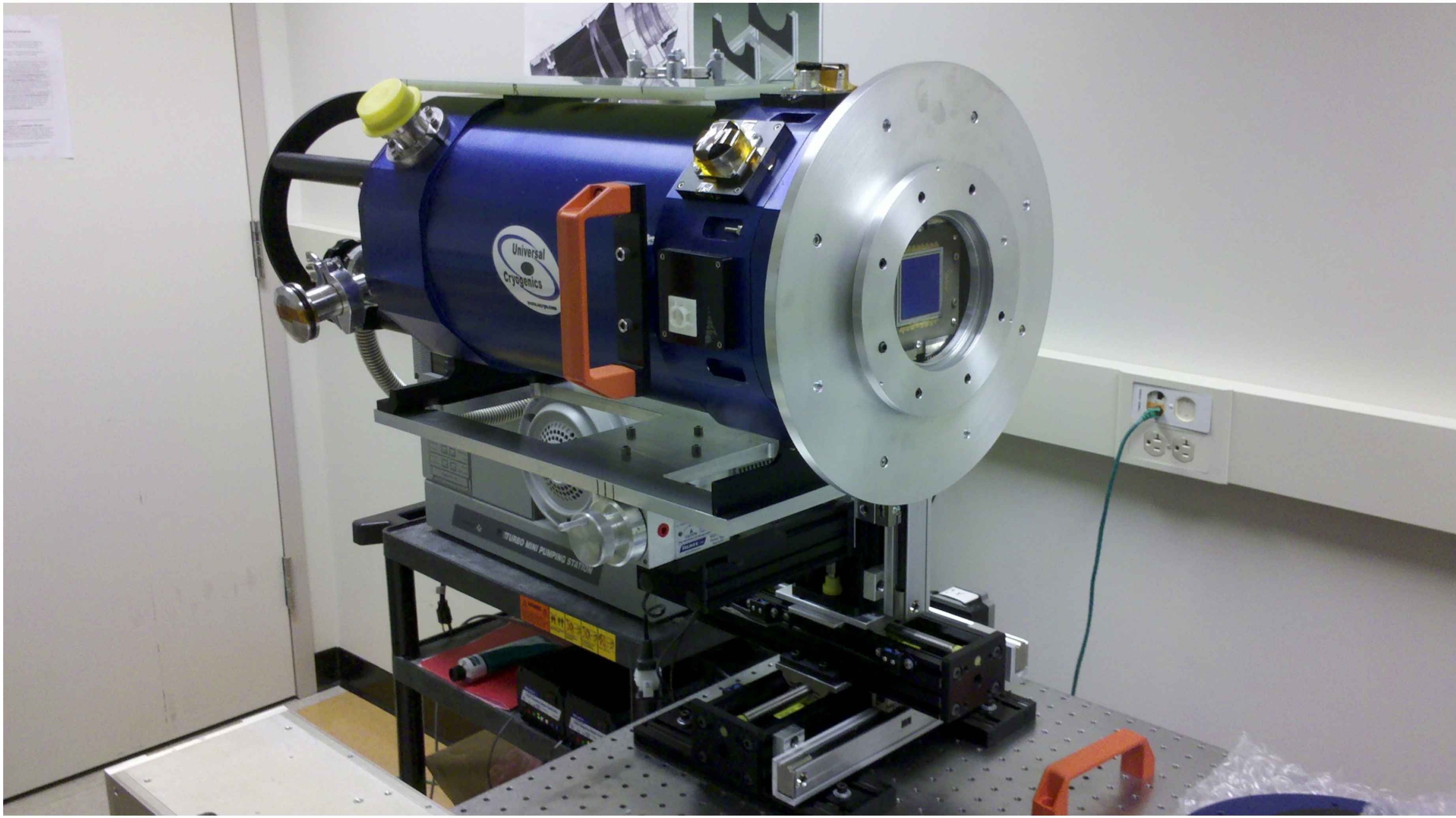
Since the system is telecentric, light will be reflected back by the sensor all the way to the spherical mirror and will return almost on its own path to form a second image near the primary image.

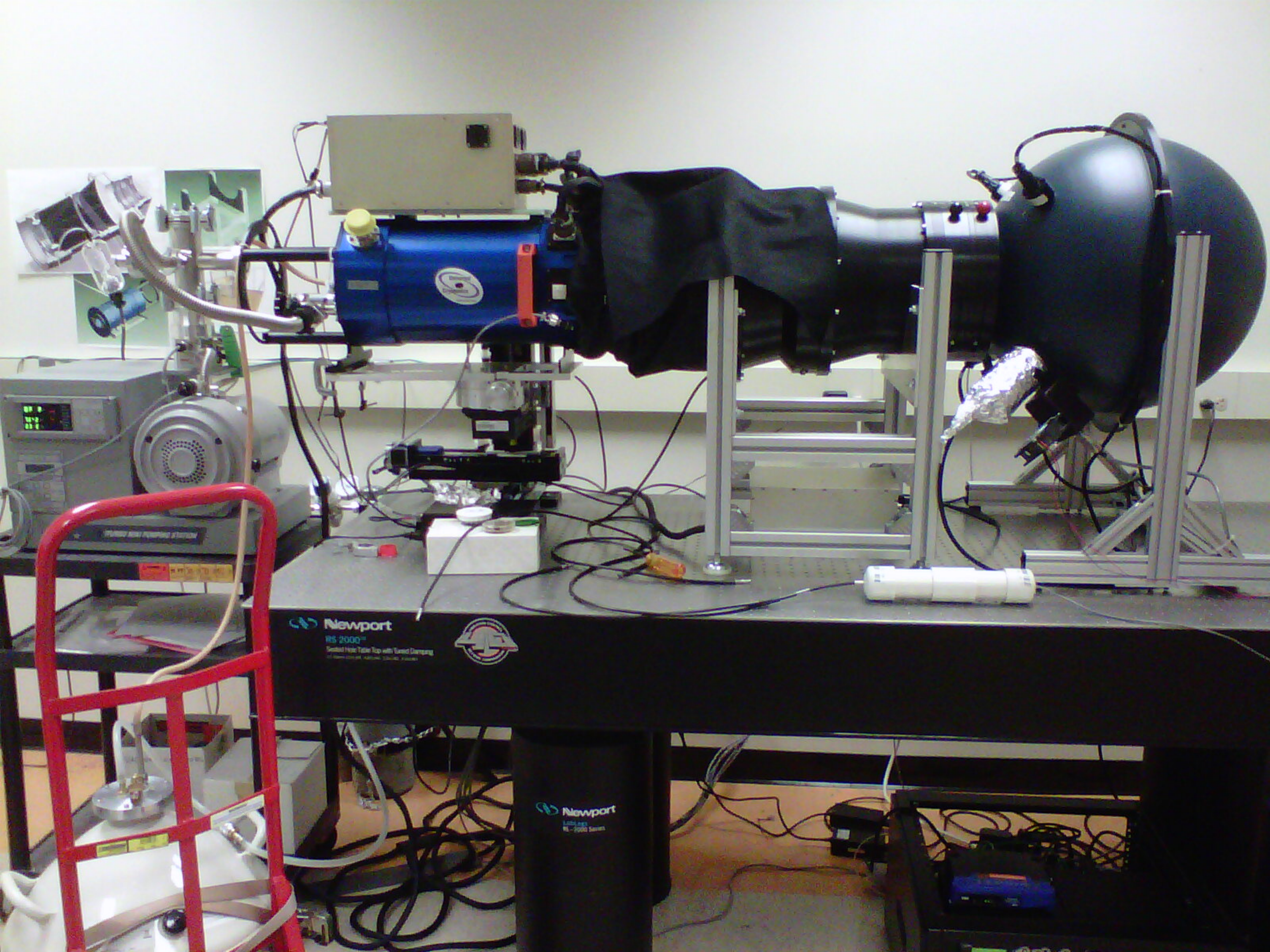
Reflection on the reticule can potentially give a focused ghost image. This is an inherent problem in doubly telecentric systems. The beam splitter window actually helps to reduce the problem.

The ghost light is spread over a much larger area than the in-focus PSF by the ratio 3 sq.mm / 20 sq. microns = 1.54e4.

Spot diagrams of ghost images are larger than 2mm in diameter and about eight magnitudes fainter than the source image.

Dewar on 2μm resolution x,y,z,θ stage

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