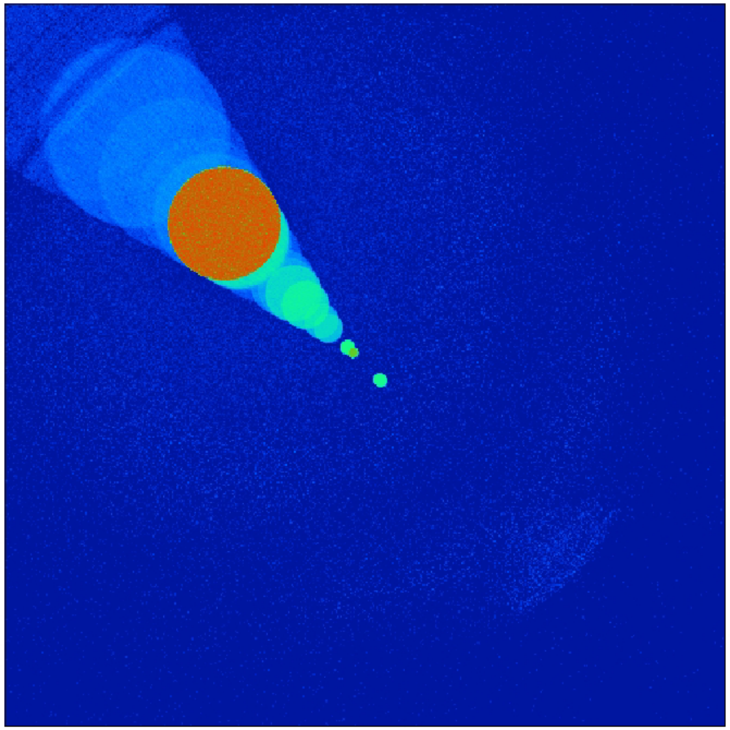


Camera Calibration Optical Configurations and Calculations

Keith Bechtol

Andy Scacco

Allesandro Sonnenfeld

Objectives

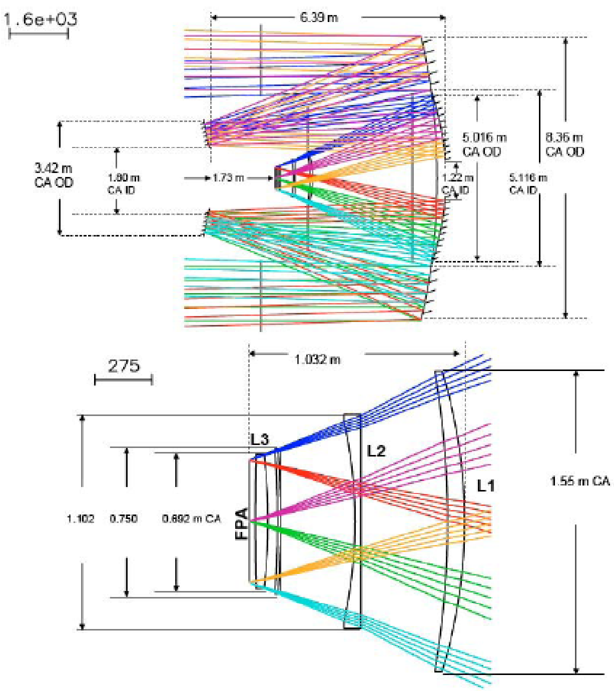
- Efficiently calibrate pixel response over entire camera focal plane to level ~ 0.1%
- Identify ghosting effects
- Model camera optics – *ZEMAX*

Propose two calibration techniques

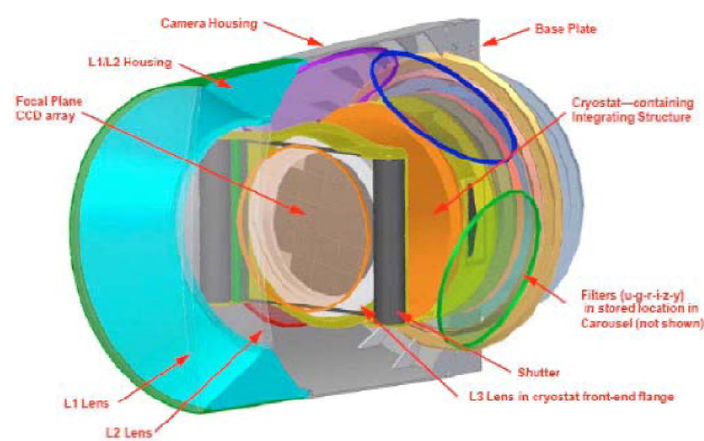
1) “Artificial Star” (Scacco and Sonnenfeld)

2) “Headlight” test beam

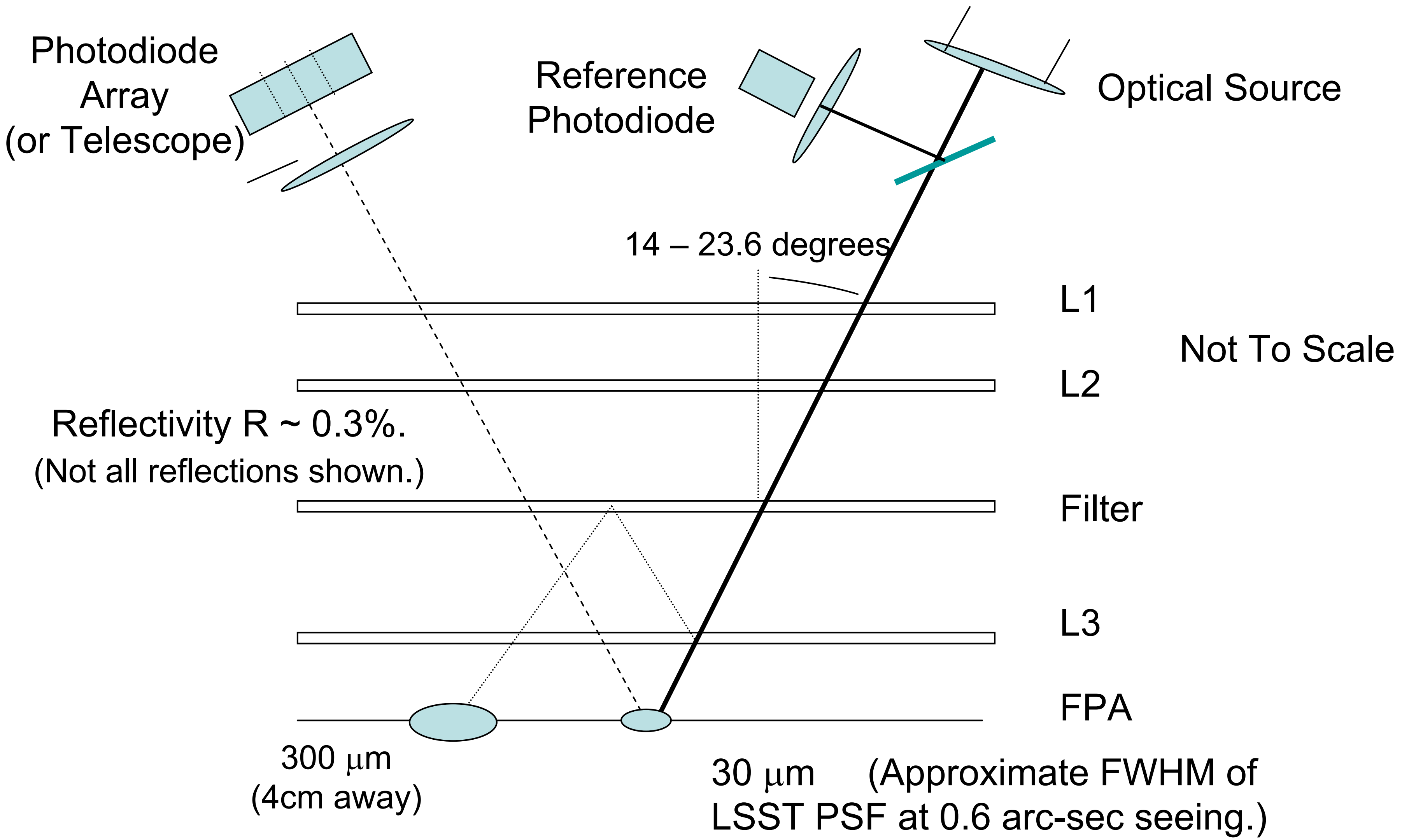
Optical Deck



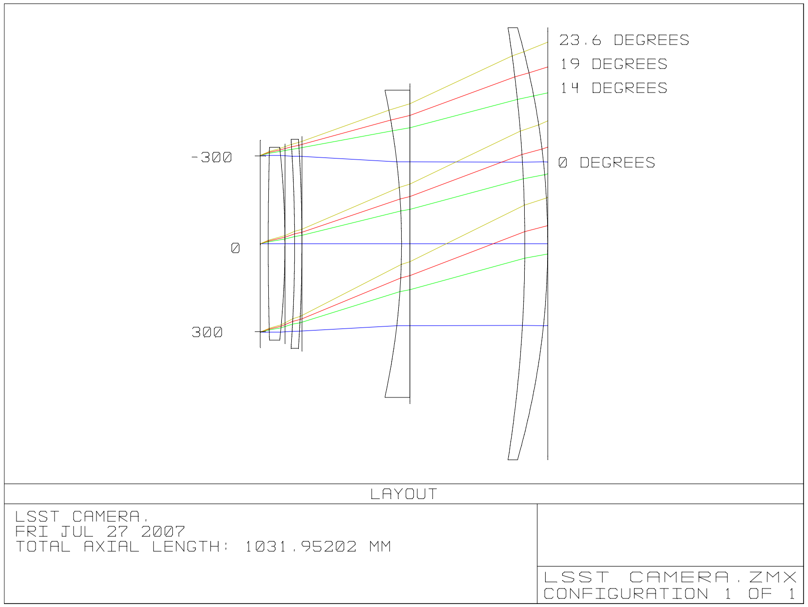
- Load standard LSST optical deck
- Consider only the camera
  - Three lenses
  - Filter
  - CCD surface



“Artificial Star” Calculations

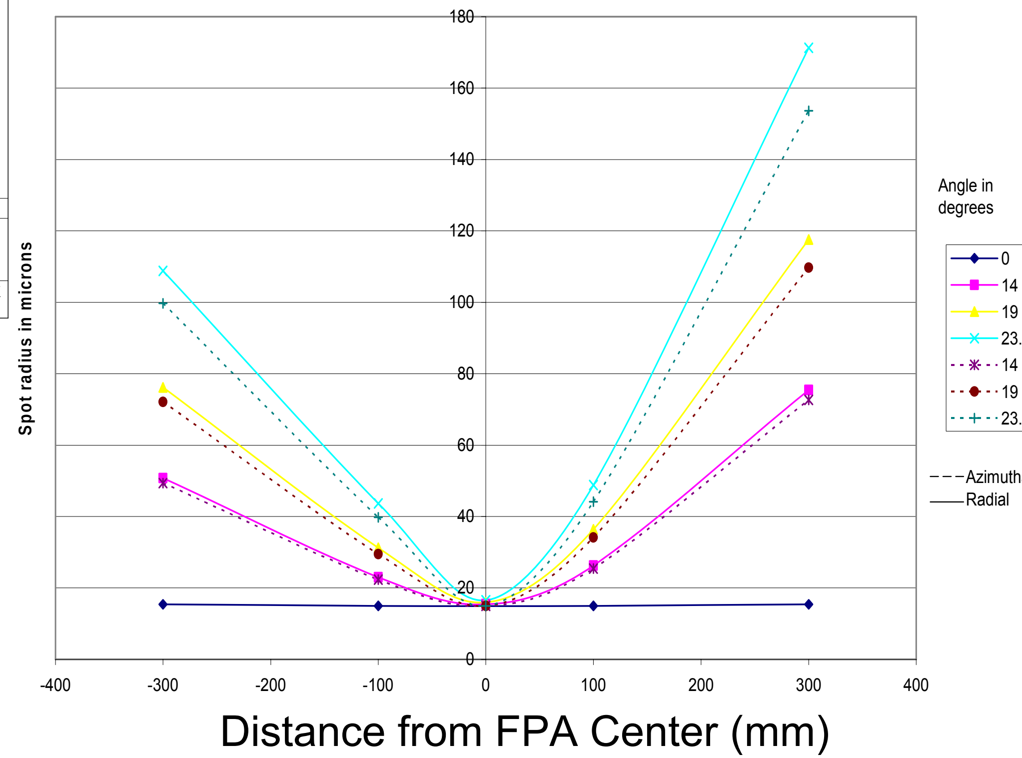


“Artificial Star” Calculations



Sequential ZEMAX Model

Focal Plane Spot Size



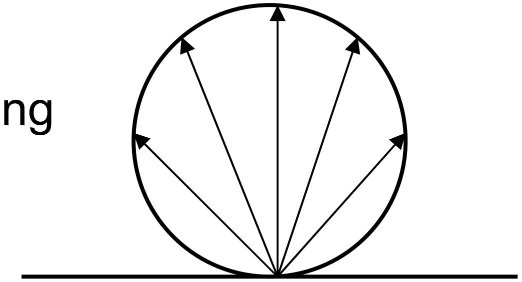
Focused pin-hole beam from quartz lamp and monochromator (length of optical source ≅ 1.4m).

Scacco and Sonnenfeld

Methodology

- "Headlight" test beam parallel to optical axis
- Run *ZEMAX* in non-sequential mode
- L1, L2, and L3
  - Quarter-wavelength magnesium-fluoride AR coating
- CCD treated as reflective surface
  - Scatter fraction = 0.33 (n = 3.6 for Si)
  - Lambertian angular distribution (scattered intensity is proportional to the cosine of the angle with surface normal)
  - Quarter-wavelength magnesium-fluoride followed by half-wavelength of lanthanum-oxide AR coating

Lambertian scattering



General Strategy

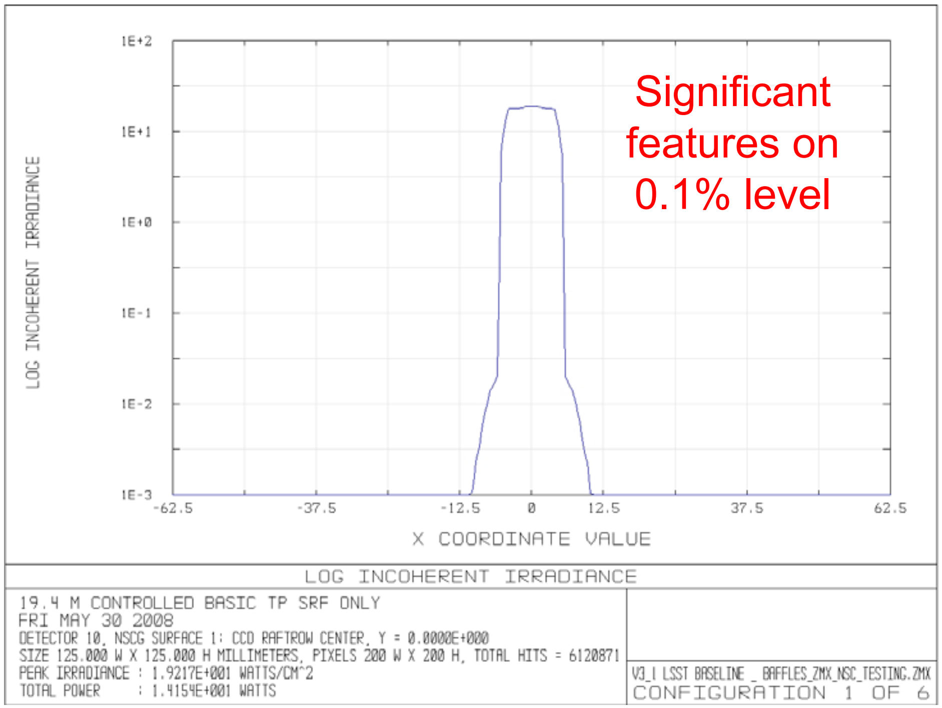
- Scan test beam over pixels in series of exposures
- Each pixel traces out beam intensity profile
- If the spatial profile of the test beam intensity does not change significantly over the characteristic size of the beam at the focal plane, we can compare the response of nearby CCD pixels

What is the optimal test beam size?

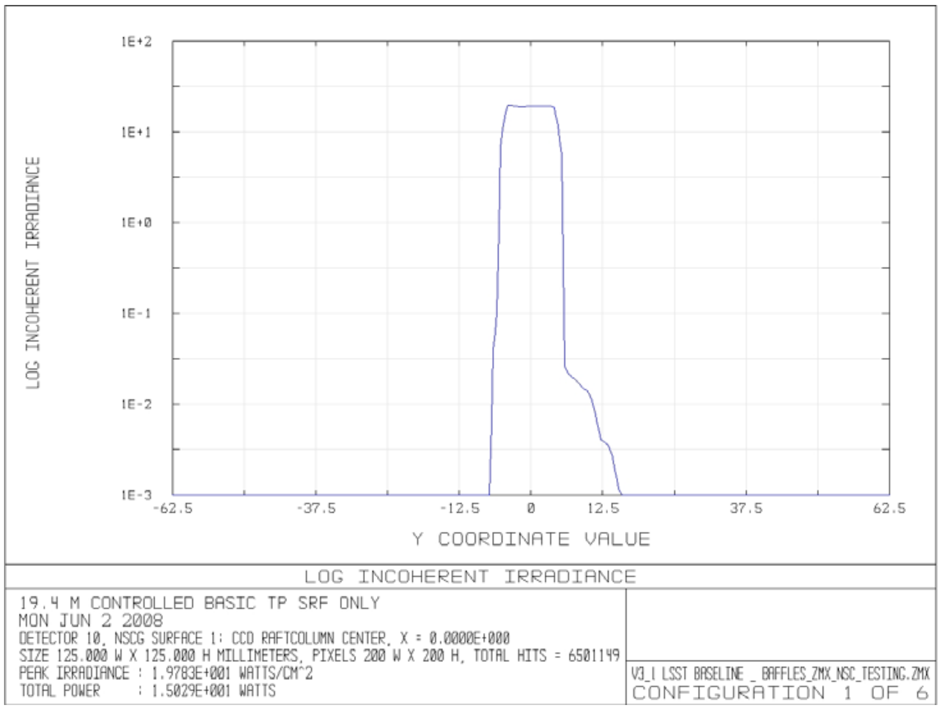
How should we scan the test beam?

1 cm Beam Intensity Profile

Test beam intensity profile at focal plane – radial slices



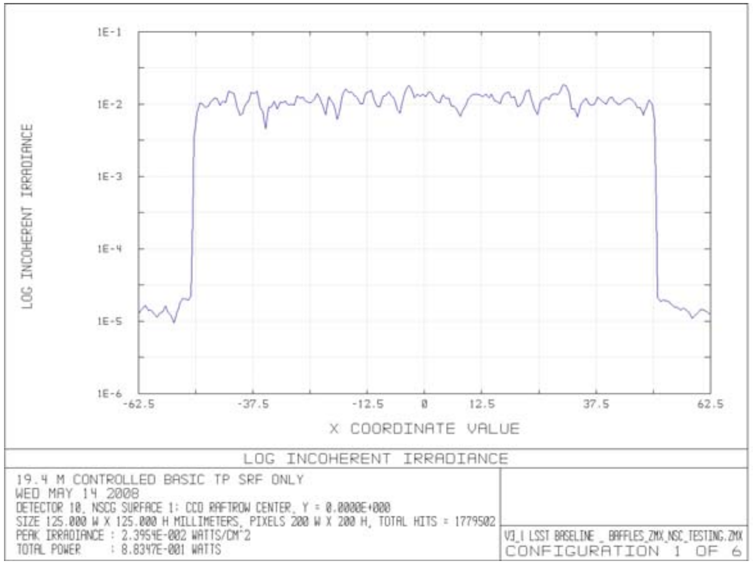
Center of focal plane (0,0)



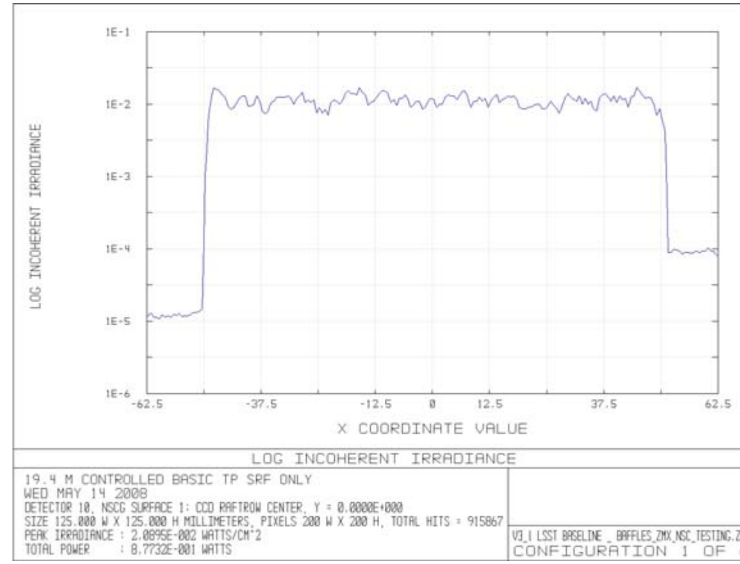
5 cm offset from center (5cm,0)

Notice rapid change in beam intensity profile!

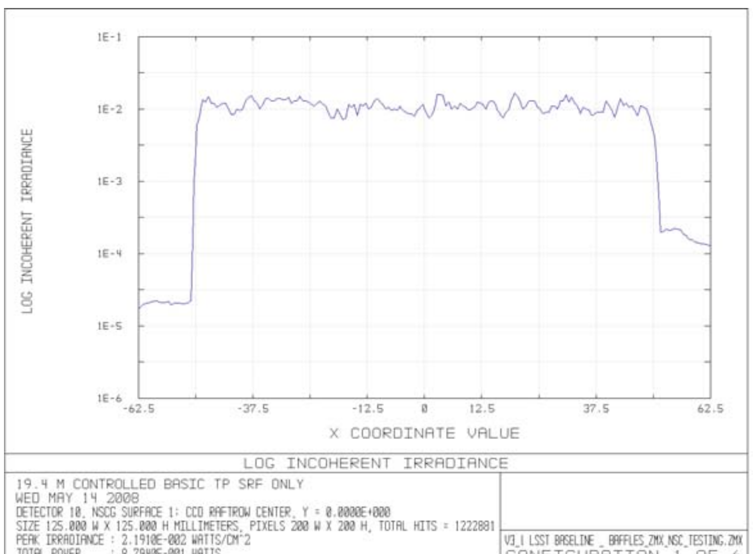
10 cm Beam Intensity Profile



Center (0,0)



Offset 250 cm
(250cm,0)



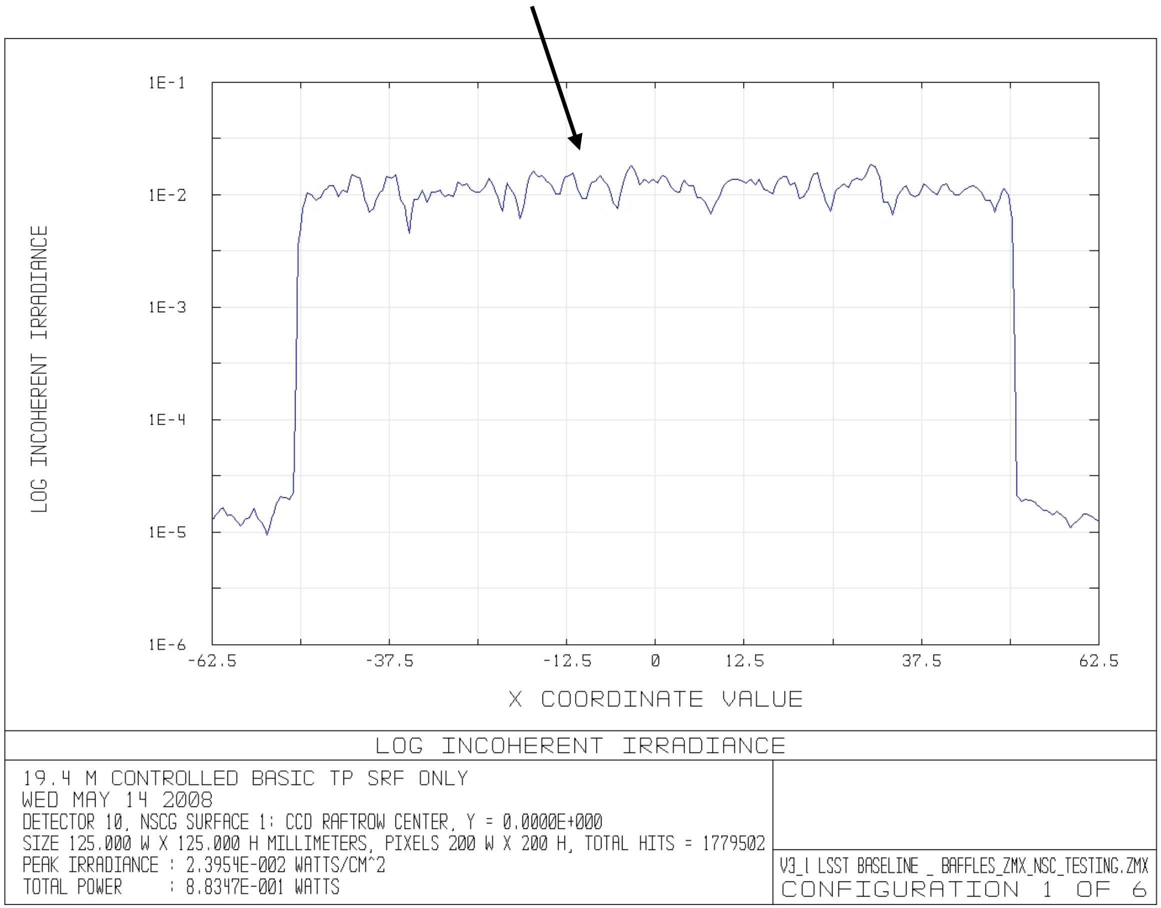
Offset 125 cm
(125cm,0)

Test beam intensity profiles at focal plane – radial slices

Intensity profile of larger test beam is more stable

A Comment on Statistics

Intensity fluctuations readily apparent in 20 minute simulation



Fortunately, we can do much better with a real test beam

Full well potential ~ 100000 e^-

High QE

Collect N ~ 40000 photons in single exposure

$\sigma = \mathrm{sqrt}(N)/N \sim 0.005$

With multiple exposures, can reach 0.1% level accuracy

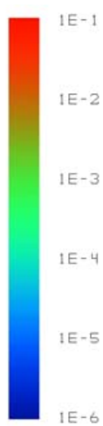
10 cm Beam Scoring Plane

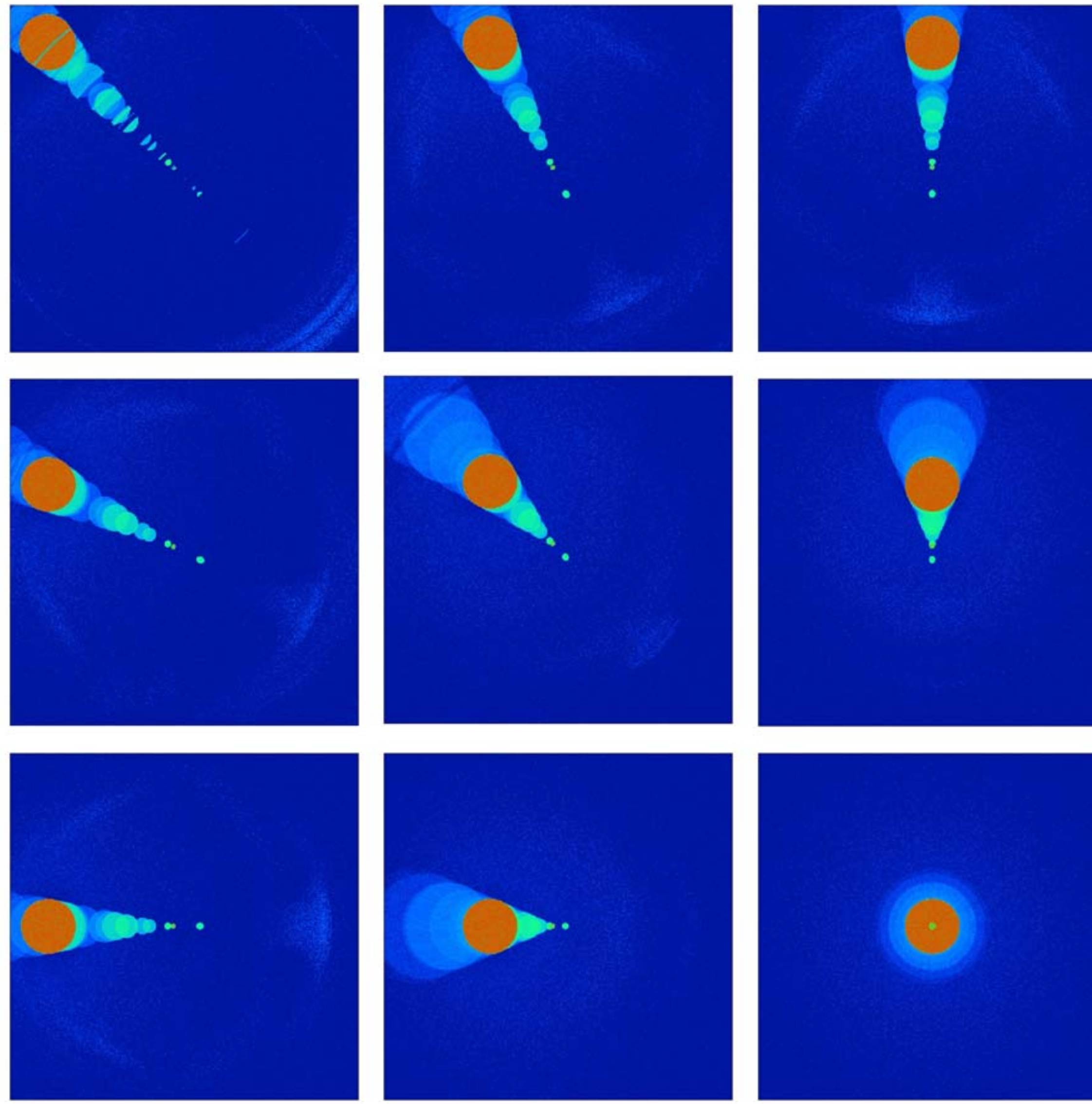
Center 10 cm diameter beam over a grid of positions

(250,250)	(125,250)	(0,250)
(250,125)	(125,125)	(0,125)
(250,0)	(150,0)	(0,0)

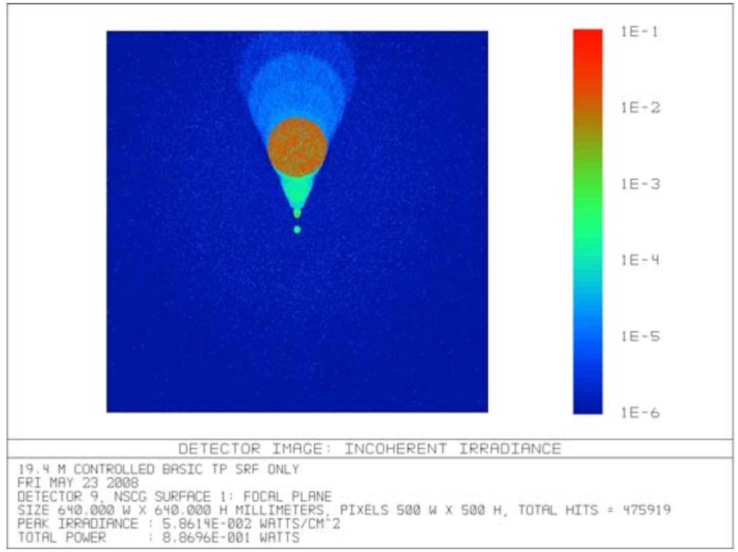
Test beam positions in cm

Plot incoherent irradiance (W / cm²) on log scale



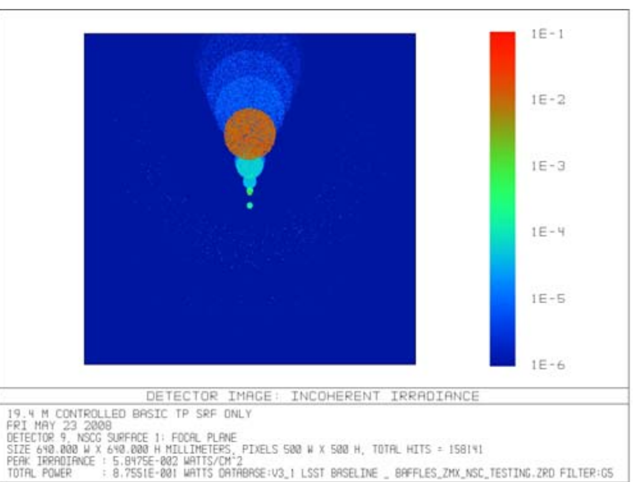


Ghosting Analysis

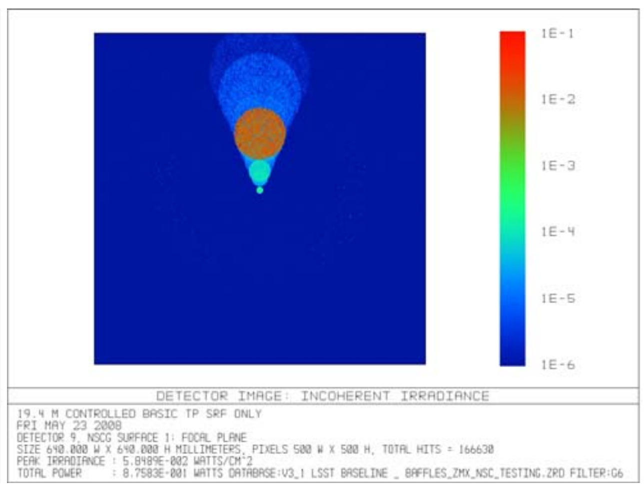


No filter

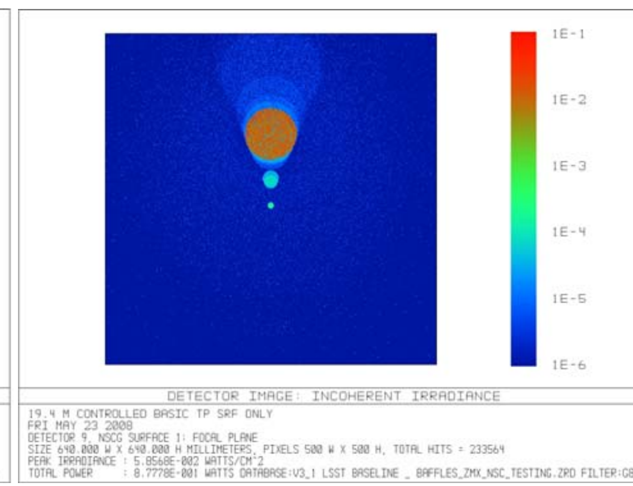
L1



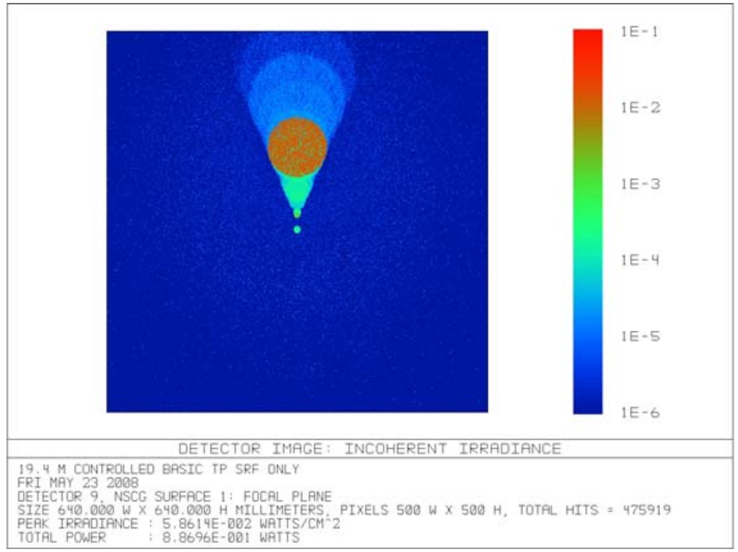
L2



L3

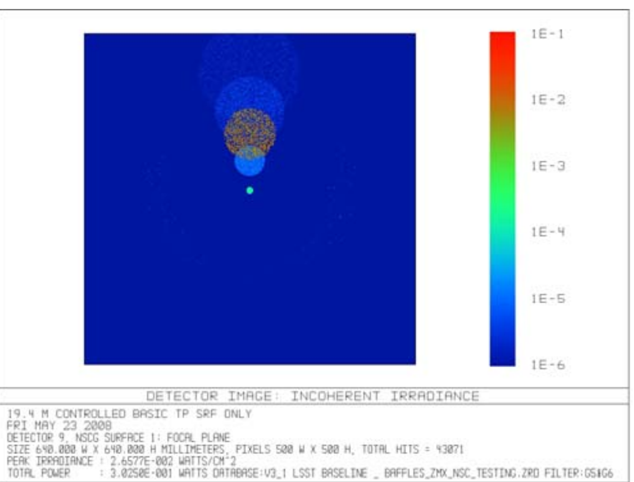


Ghosting Analysis

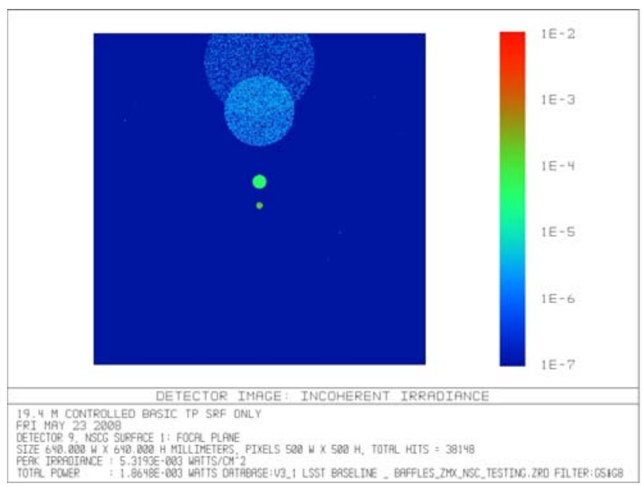


No filter

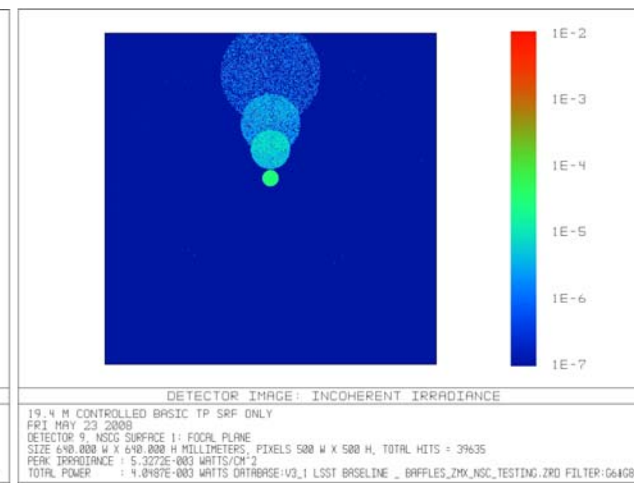
L1+L2



L1+L3



L2+L3

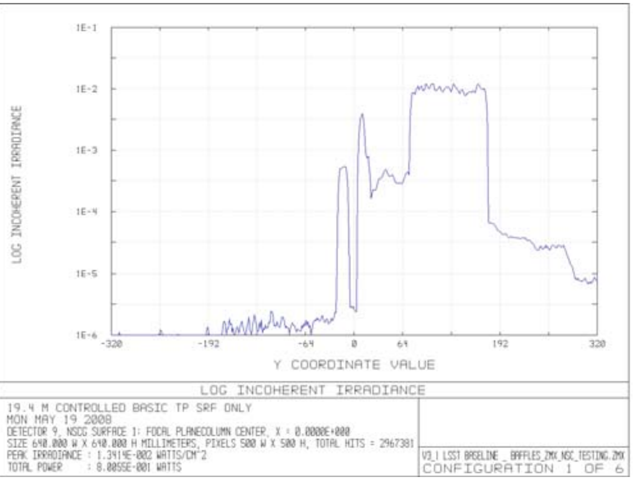


Wavelength Dependence

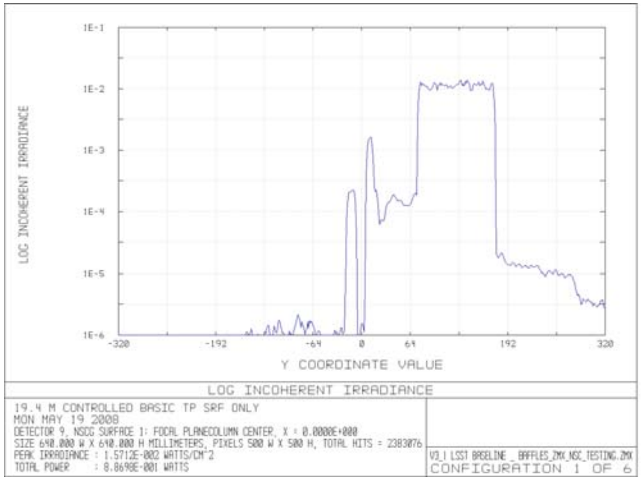
LSST camera range 400 - 1000 nm

AR coatings are wavelength dependent

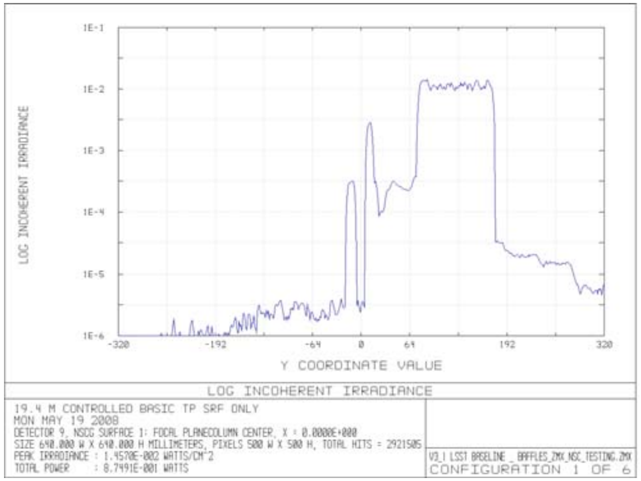
Optimize for 700 nm light



400 nm test beam



700 nm test beam



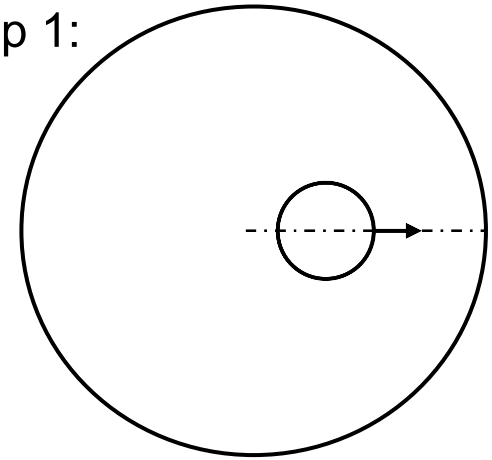
1000 nm test beam

Suggested Procedure

1. Produce test beam several cm in diameter
2. Scan outwards in radial direction
3. Fit shape of beam intensity profile
4. Scan in concentric circles

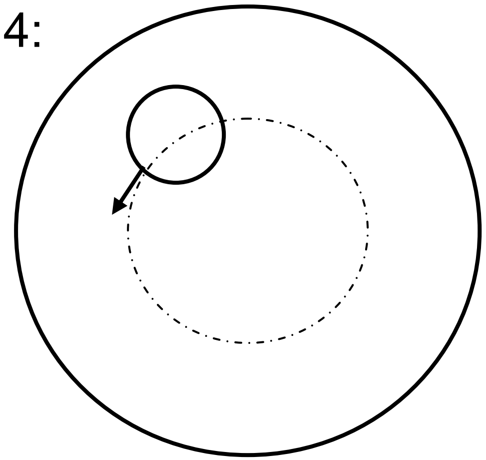
Relative calibration possible independent of exact model results

Step 1:



Beam intensity profile changes continuously while going outwards

Step 4:



Take advantage of azimuthal symmetry

Future Directions

- CCD surface most challenging element to model
  - Scoring pattern strongly dependent on CCD surface properties
  - Observe ghosts to understand CCD reflection
- Use ghost patterns to determine relative positions
- Include diffraction in simulations
- Use test beams of various wavelengths to parse QE from pre-amp gain