LSST Image Quality and Effects Seen Through the Atmosphere

C. F. Claver (NOAO), S. Asztalos (LLNL), A. Becker (U. Washington), J. G. Jernigan (LBL), S. M. Kahn, J. R. Peterson (SLAC), L. Rosenberg (LLNL), V. Margoniner (UC Davis), J. A. Tyson (UC Davis), D. Wittman (UC Davis)

Large Synoptic Survey Telescope

ABSTRACT

The 8.4m Large Synoptic Survey Telescope (LSST) is a new 3.5 degree field of view facility for the purpose of studying the nature of dark energy and matter along with the time varying nature of the optical universe. These science missions require precise knowledge and control of both the size and shape of the point spread function (PSF) delivered by the LSST. Here, we present analyses of three areas of image quality that are critical to the LSST: 1) the stability and angular correlation of the stellar PSF second moments as seen through a turbulent atmosphere typical of a high quality observing site and the baseline LSST optical design, 2) the ability to recover a synthetically induced gravitational shear signal on Hubble Deep Field data modified to mimic seeing and telescope aberrations, and 3) the effects of chromatic atmospheric refraction through the LSST filters on image shape and field registration. For the stability, angular correlation and chromatic refraction studies we compare our simulations with data obtained on modern new technology telescopes.

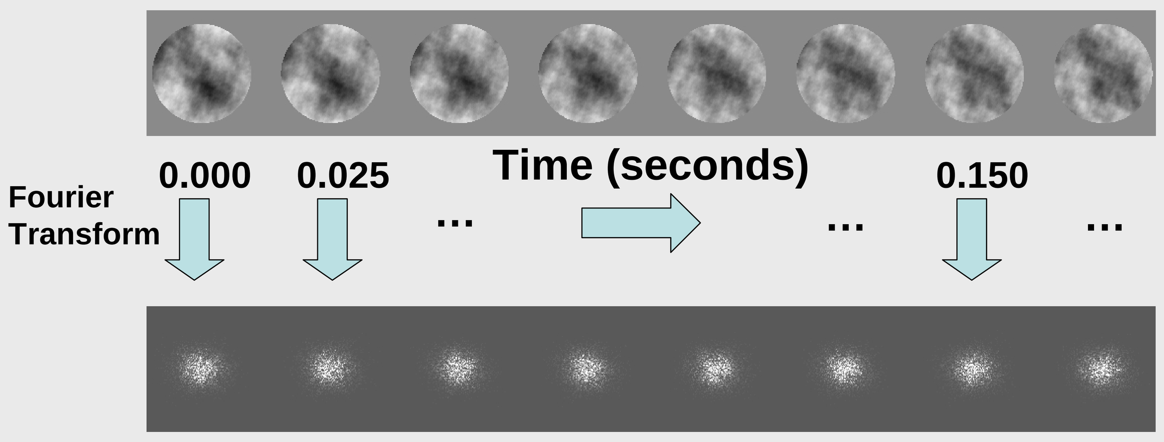
Ellipticity definition from 2nd intensity moments

$$e1 = \frac{(ixx - iyy)}{(ixx + iyy)} \qquad e2 = \frac{2(ixy)}{(ixx + iyy)}$$

$$e = \sqrt{e1^2 + e2^2}$$

1) PSF Ellipticity Angular Correlation:

Turbulent OPD

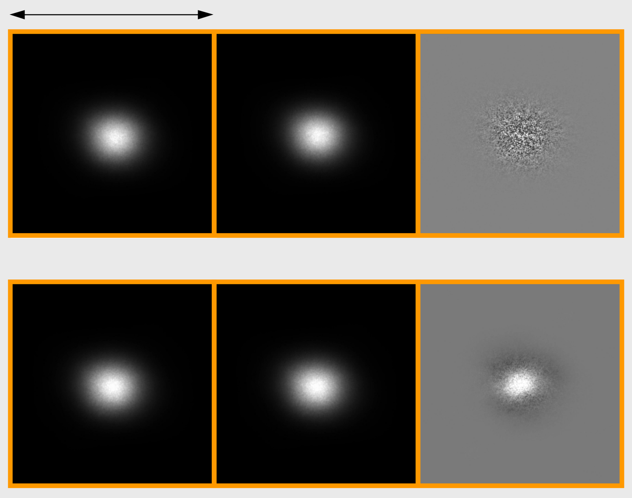


Point Spread Function

$$\sum_{t=0}^{10sec}$$

10 second integration

3.2 arcsec

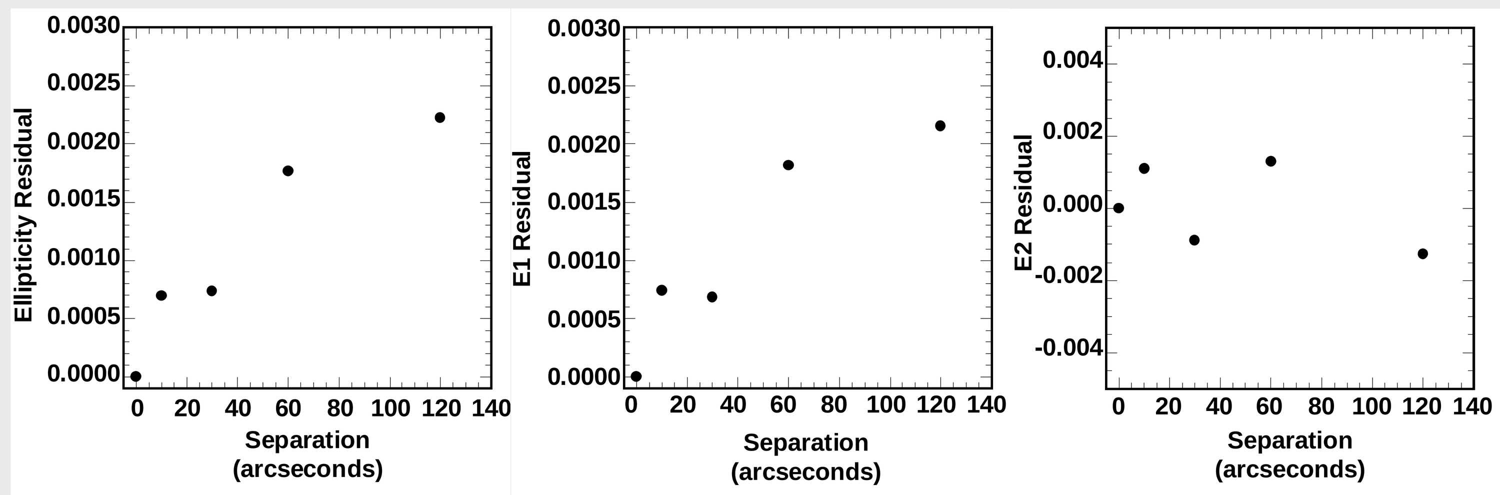


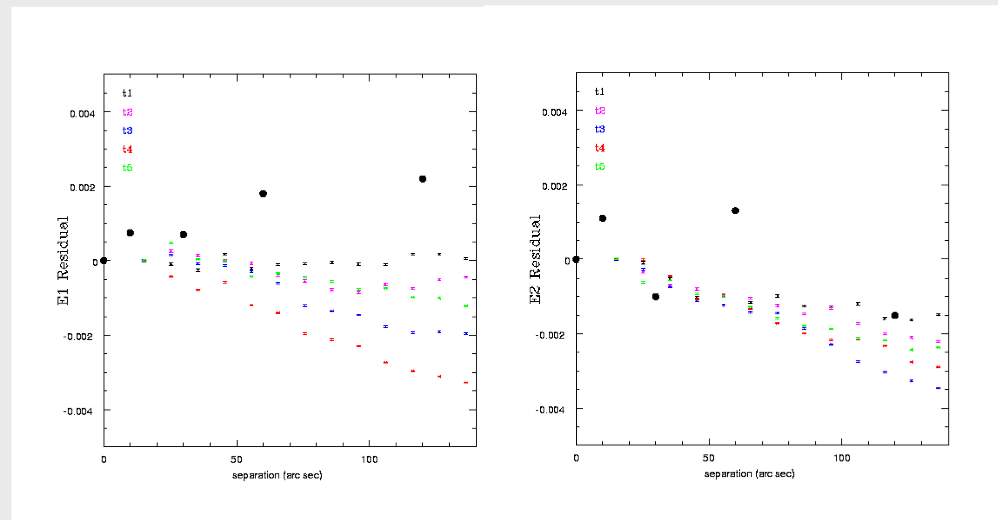
10" separation

120" separation

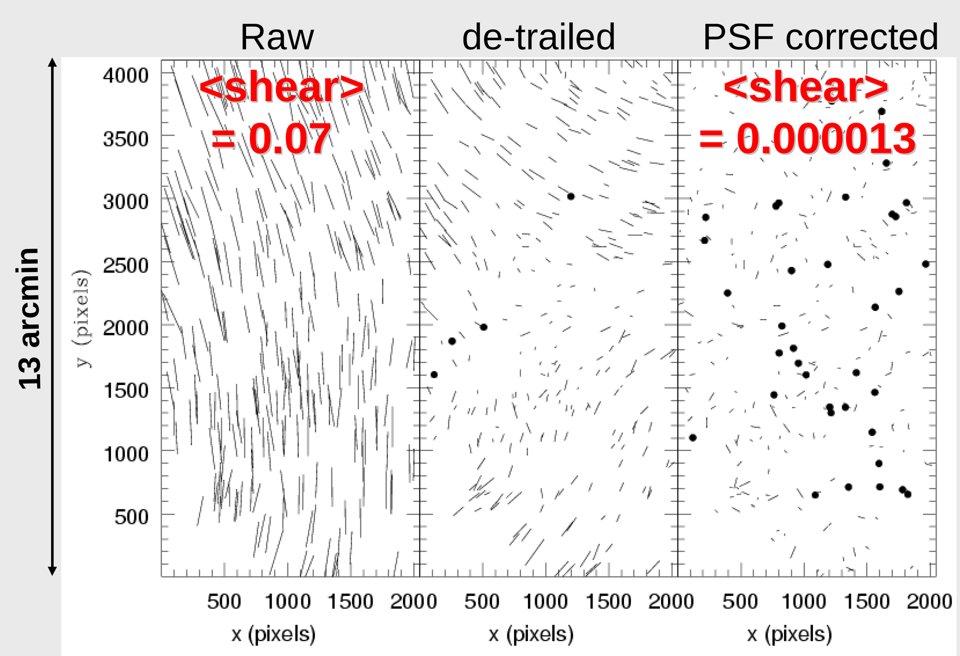
On Axis Image | Off Axis Image | Difference Image

Ellipticity Residual versus Angular Separation





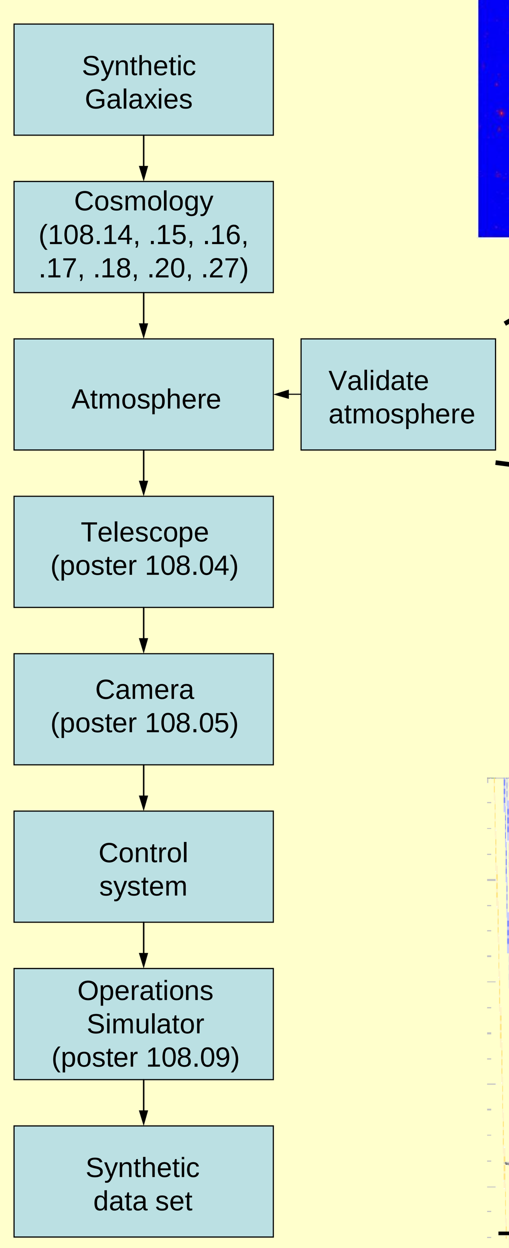
Subaru 10sec exposures show ellipticity residual amplitudes (colored points) consistent with model results (black points).

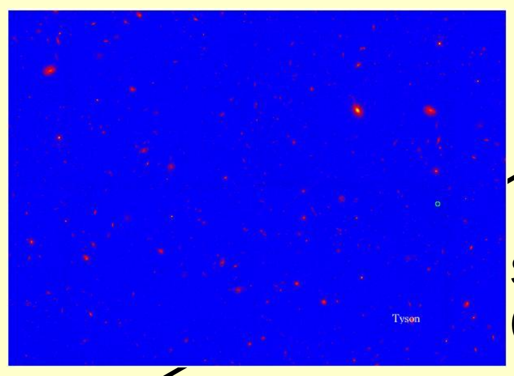


The three panel diagram above shows ellipticity vectors from Subaru prime focus images. These data demonstrate that modern technology telescopes meet the demanding LSST PSF shape requirements. Note the high angular correlation over several arcminutes in the center panel after the data have corrected for image trailing.

2) High Fidelity Simulation Development

Modeling Process Flow





Synthetic Sky (Galaxies+Stars)

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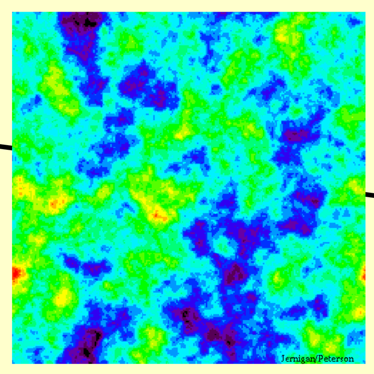

Atmosphere Phase Screen

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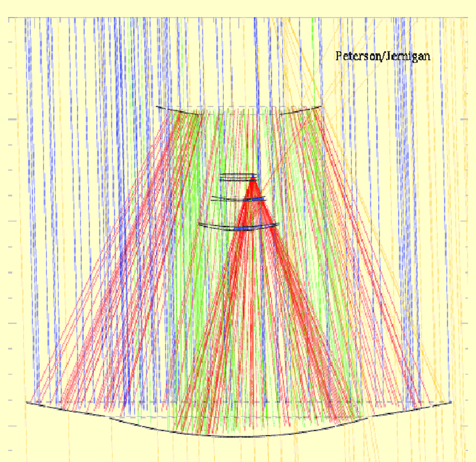

Telescope Raytrace

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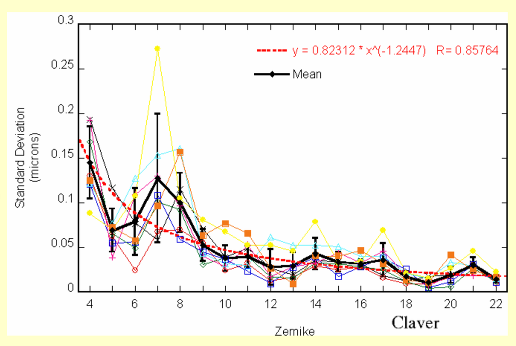

Residual Optical Aberration Spectrum

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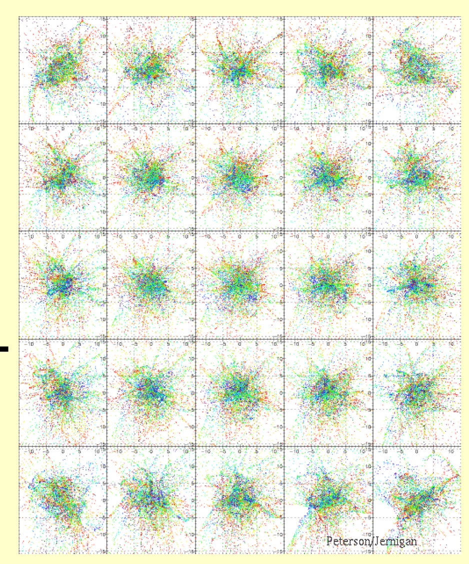

Field Dependent PSFs

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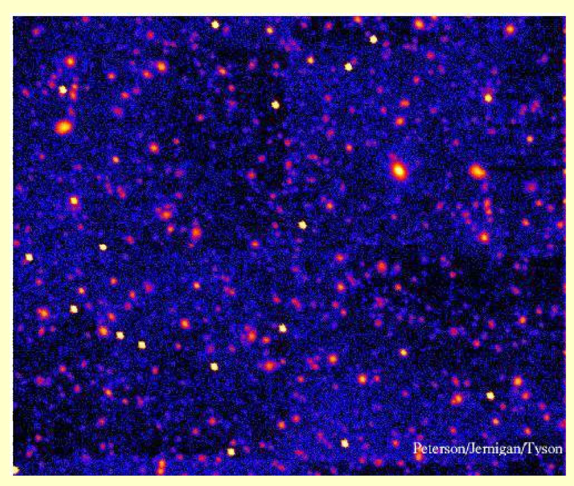


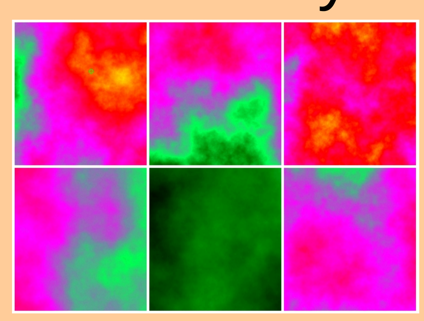
Synthetic Data Set

Atmosphere Model Validation with Arroyo

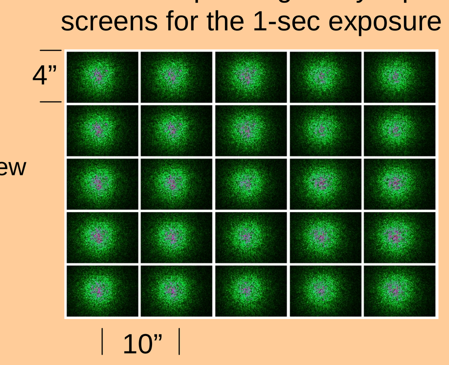
Arroyo Simulation Summary
- **FOV – 70”**
- **Integration time – 1 sec**
- **Image Size – 4”**
- **Image Pixel Size – 1006x1006**
- **Image Separation – 10”**
- **Wind speed at 10 km – 30 m/s**
- **Sky model from Ellerbroeck et. al.** 2002 JOSA A19 1803
- **Phase screen pixelation – 0.02 m, r_0 = 0.25 m**

Arroyo: a software package developed for the TMT. It's highly flexible: e.g., atmospheric parameters can be taken from a file of Cerro Tololo observations. These atmospheric parameters then predict well the observed width of the PSF. The present storage requirements of the atmospheric phase screens limit the field-of-view to 10' X 10' (about the size of a single LSST CCD chip) for reasonable atmospheric parameters.

A program is underway to parallelize the program operation to allow complete atmospheric simulation of the full 3.5degree X 3.5degree LSST field of view.



The corresponding 6-Layer phase screens for the 1-sec exposure



3) Ellipticity from Atmospheric Refraction

Atmosphere Parameters

Altitude (m)	T (C)	P (mm Hg)	H_2O (mm Hg)
1000	10	670	8
2000	7	600	8
3000	5	520	8

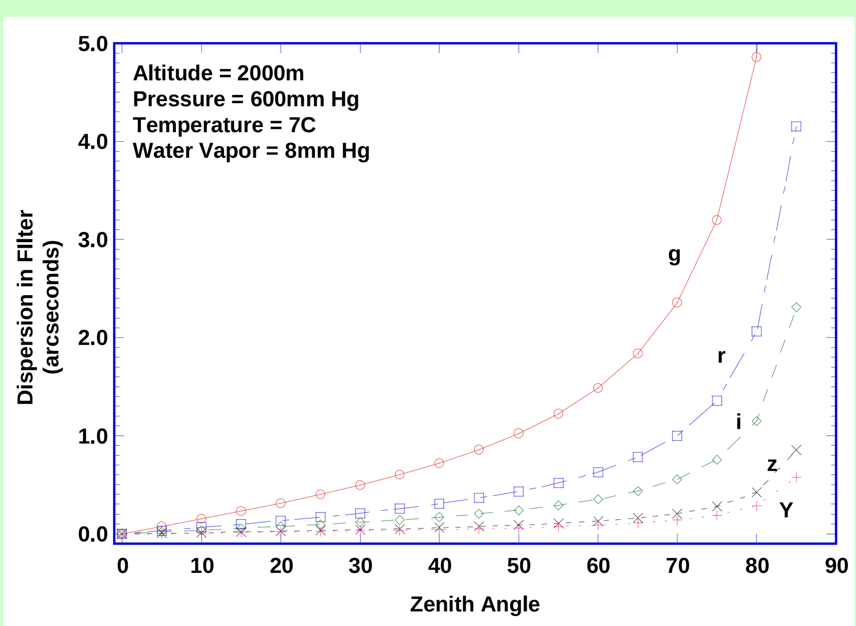
Filter Passband Definitions

filter	lambda1	lambda2
g	400	559
r	545	703
i	689	862
z	845	946
Y	946	1040

Semi-minor axis: $ixx = \frac{1}{2}(Seeing\ FWHM)$

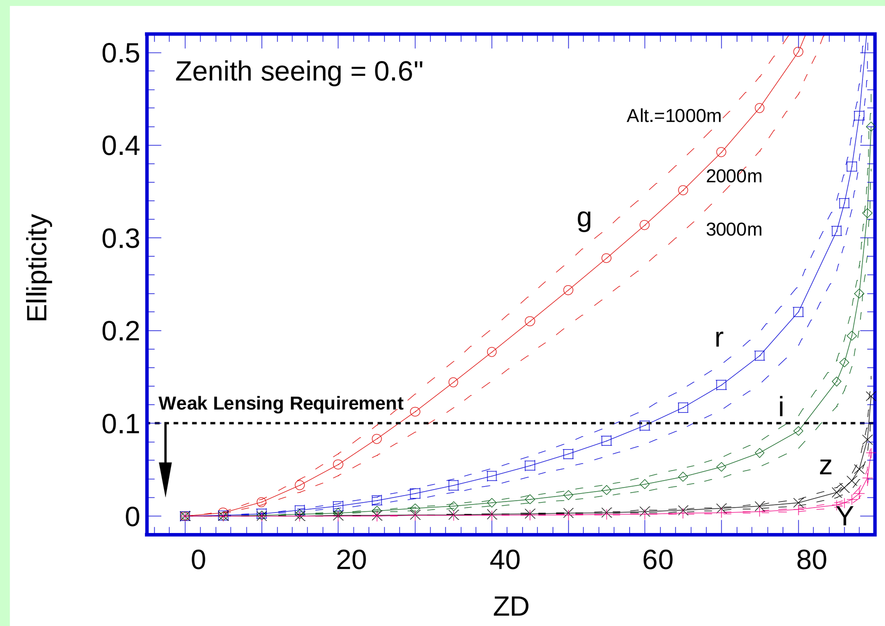
Semi-major axis: $iyy = \frac{1}{2}\sqrt{(Seeing\ FWHM)^2 + DAR^2}$

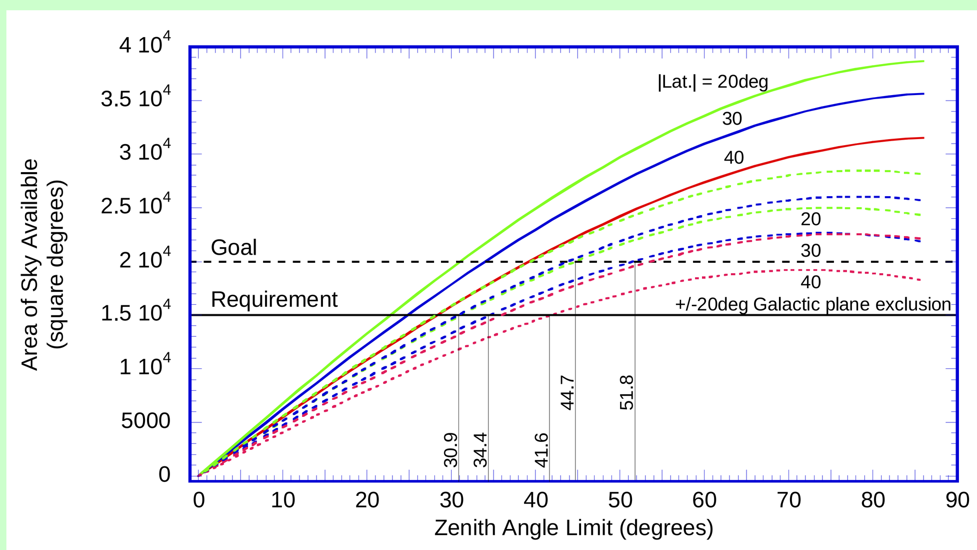
Refraction calculation based on description in Filippenko, 1982, PASP, v94, p715:



The LSST requires the raw PSF ellipticity not exceed 0.1. The effects of atmospheric dispersion limits the angle away from zenith where this requirement can be met. The figure at right shows the available sky area for three observatory latitudes with (dotted) and without (solid) exclusion for source crowding in the galactic plane. The vertical drop lines indicates the zenith angle needed to meet the LSST area coverage requirements and goals.

In the figure below the PSF ellipticity from atmospheric dispersion is shown for each of the 5 spectral bands the LSST will likely use. For each spectral band three observatory altitudes are plotted. The information combined from this plot and the one above show that with the exception of the g band the LSST ellipticity and sky coverage requirements can be met *without* any atmospheric dispersion correction. This greatly simplifies the camera design (see poster 108.05)





JOHNS HOPKINS UNIVERSITY

BROOKHAVEN NATIONAL LABORATORY

RESEARCH CORPORATION

THE UNIVERSITY OF ARIZONA.

UC DAVIS University of California, Davis

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNIVERSITY OF WASHINGTON

SLAC

NOAO