Large Synoptic Survey Telescope
www.lsst.org

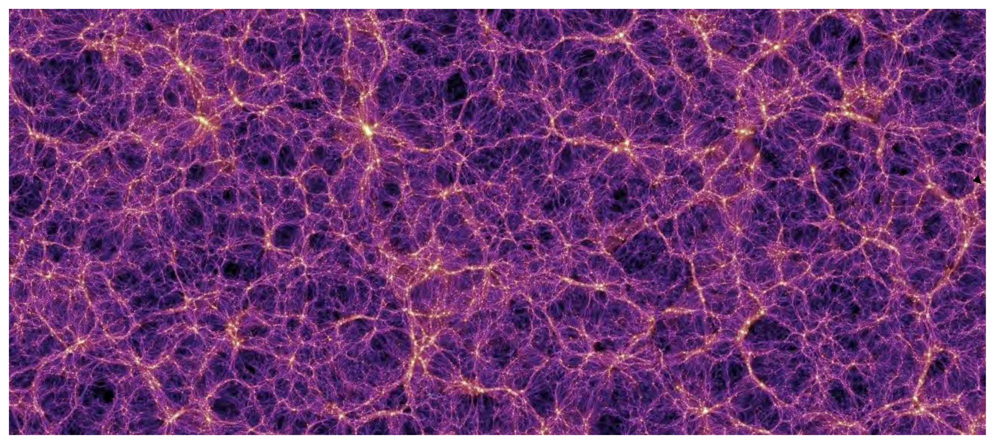
Weak Lensing Galaxy Shear Extraction Testing for LSST

M. James Jee[1], J. A. Tyson[1], D. Wittman[1], A. J. Connolly[2], G. Jernigan[3], J. R. Peterson[4], Z. Ivezic[2]
[1]UC Davis, [2]University of Washington, [3]UC Berkeley, [4]Purdue University

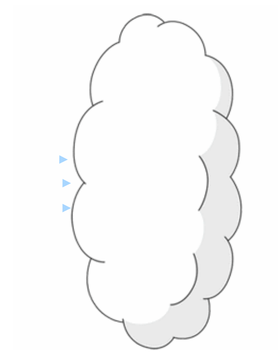
The accuracy and reliability of weak-lensing measurement for LSST depend on the level of the atmospheric turbulence of the site, the integrity of the design and fabrication of the optical system, the ability to describe and model both the atmospheric and instrumental characteristics, and the accuracy of the algorithm to remove these systematics and extract gravitational shears of galaxies. The key to systematics removal is the high-fidelity modeling and correction of the point spread function (PSF) on the delivered images. In this poster, we present the results of our on-going end-to-end shear extraction simulation efforts to investigate the impacts of the above factors on lensing signal measurement. First, we review our past accomplishments on the issue of accurate description and removal of the PSF effects using a principal component analysis method. Then, we present the results of our current shear extraction simulation using artificially sheared galaxy images. Finally, we discuss some key issues that need to be addressed in order to meet the requirement of the LSST weak-lensing science.

MOTIVATION

Cosmic shear

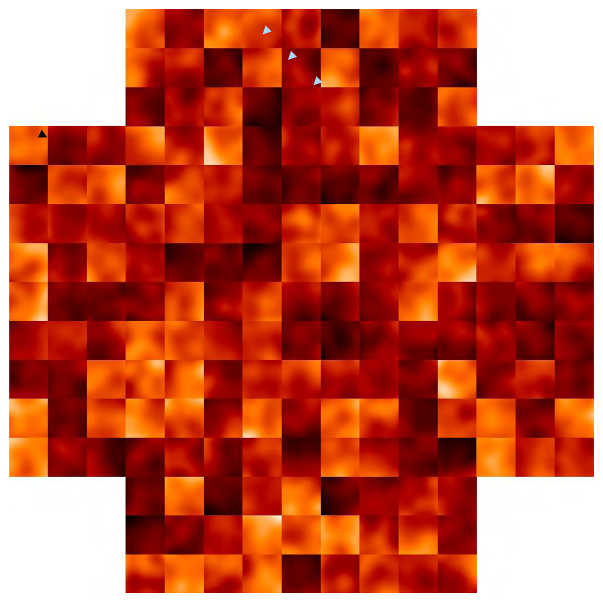


Atmospheric turbulence



Optical Aberration

Figure 1. Many sources of distortion in the optical path of photons.



Focal Plane Height Errors

Photons' paths are gravitationally deflected by large scale structures of the universe, which shears the observed shapes of galaxies. We use these subtle distortions to derive the cosmological parameters and also the properties of dark matter and dark energy. However, as illustrated in this cartoon, many other systematic effects also affect the shapes of the distant galaxies. Therefore, it is critical to disentangle the cosmological lensing effect from those of atmospheric turbulence, optical aberrations, Instrumental geometric distortions, focal plane height fluctuations, etc.

We investigate how well we can recover the gravitational lensing signal with LSST in the presence of these systematic effects by extensive image simulations.

SIMULATION OF LSST POINT SPREAD FUNCTION

Kolmogorov phase screen | ZEMAX optical model | Focal plane height error | Final PSF

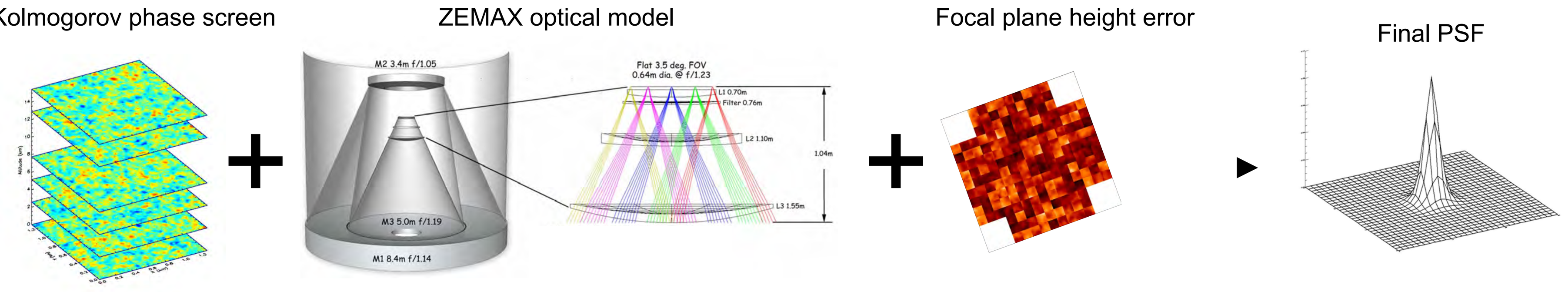


Figure 2. Generation of LSST PSF with models of phase screen, telescope and camera optics, and focal plane.

Various atmospheric and instrumental effects make the image of a point source look blurred with some characteristic anisotropy. In order to generate the input PSF, which we later use to convolve galaxy images, we simulate the atmosphere with six layer Komologorov phase screen and the optics with ZEMAX by modifying the focus according the realized height distribution. The most notable feature is the ellipticity discontinuity of the PSF across the CCD borders as shown in Figure 3. The sharp discontinuity arises because of the high sensitivity of the aberration to the focus errors (i.e., fast f-ratio) although the anticipated focal plane assembly precision exceeds the specifications of any existing detectors.

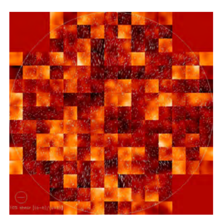


Figure 3. Ellipticity of LSST PSFs. We depict the ellipticity of the PSF with "whiskers" overlaid on the LSST focal plane tiled with 189 4k x 4k CCDs. The length of the stick is proportional to the ellipticity whereas the orientation is aligned with the direction of the elongation. The PSF ellipticity varies within a CCD because of the potato-chip effect (CCD surface distortion). While this variation within a physical CCD is continuous, the changes across the CCD borders are mostly discontinuous, reflecting the instrument's high sensitivity to focus.

FOCAL PLANE SCENARIOS

We simulated four scenarios, where the height errors are at the expected, moderately degraded, highly degraded, and extremely degraded levels. Because the fast f-ratio of the LSST sets low tolerance on the focus error, it is critical to examine the sensitivity of the shear recovery quality to the focal plane height errors.

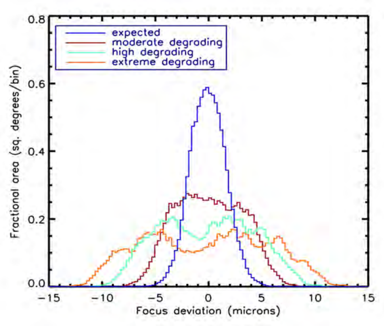


Figure 4. FP Height Distribution

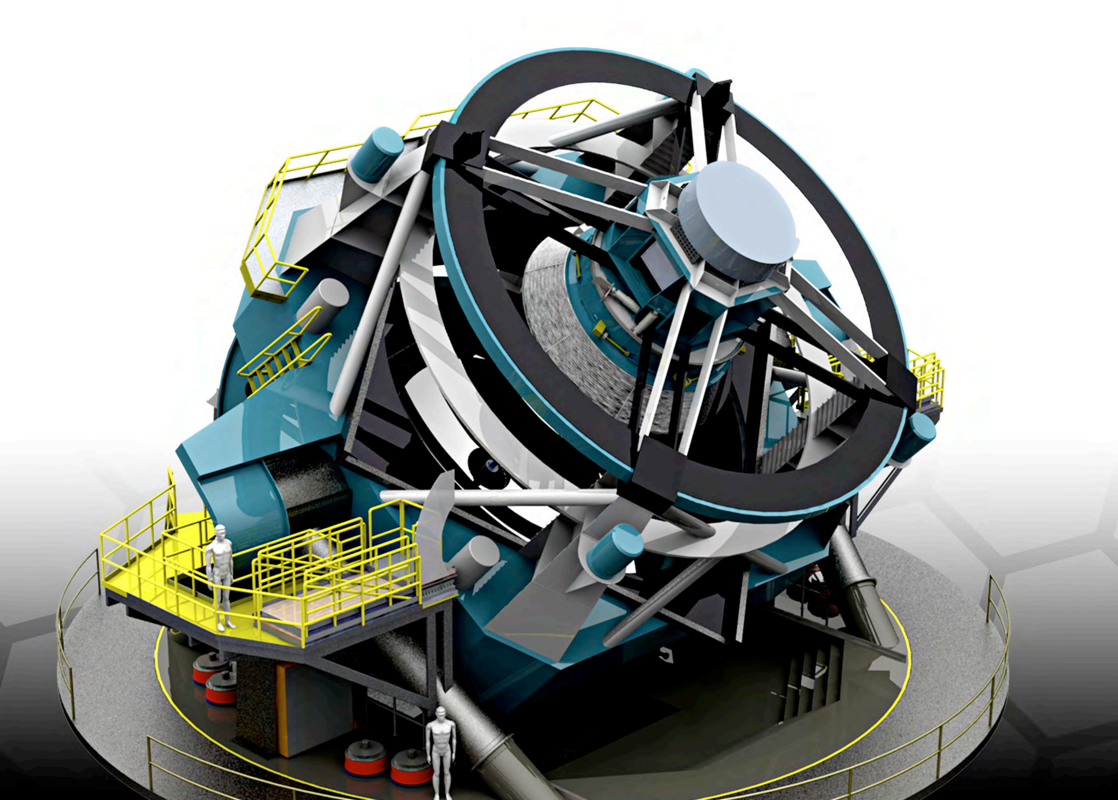


IMAGE CREATION AND SHAPE MEASUREMENT

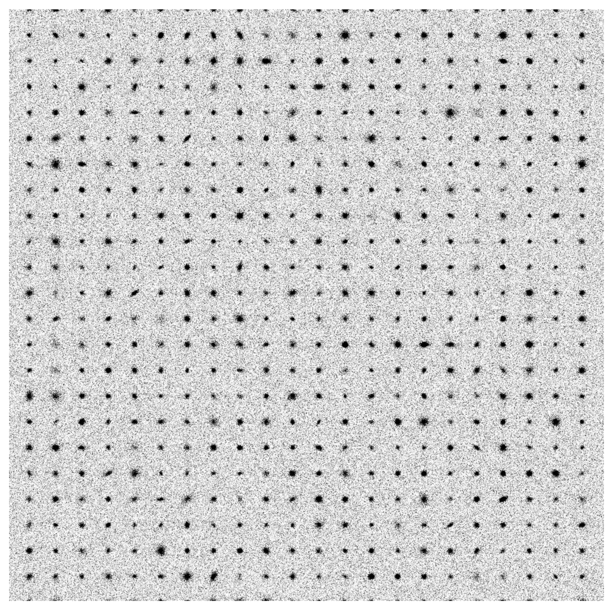


Figure 5. Postage Stamp Images of galaxies arranged in a 100 x100 layout (fraction Is shown).

Prior to shape measurement, practical shear extraction requires robust detection and deblending of objects, as well as high-fidelity PSF reconstruction from stellar images. To separate the issue of the ellipticity measurement from that of PSF reconstruction and detection/deblending of objects, our simulation follows the image generation scheme of GREAT08 (Bridle et al. 2010), where a small grid of 39x39 pixels is dedicated to each galaxy and one 4k x 4k image consists of a 100 x 100 layout of these postage stamp images. In addition, the galaxies are modeled as the sum of two (bulge and disk) components. Potentially, this analytic description of the radial profile can lead to bias in shear measurement because most lensing signal comes from faint blue galaxy population, whose morphology is poorly fit by this bulge+disk model. The shear test simulation with real galaxy images from HST images is being carried out, and the result will be reported in a forthcoming paper.

The LSST focal plane will be tiled with 189 CCDs, and thus we create 189 4k x 4k images each containing 100 x 100 postage stamps. Gravitational lensing shears are applied here at the image level. Then, these sheared images are convolved with spatially varying LSST PSF (Jee & Tyson 2010). Finally, we added noise to simulate the depth of real observations. The shape measurement program is given the input PSF at the location of each object. Among many algorithms, we choose to fit PSF-convolved elliptical Gaussians to determine the ellipticity (Jee et al. 2007).

RESULTS

We adopt the figure of merit used by GREAT08 as our quality measure of the current shear recovery test: $Q = \frac{10^{-4}}{\left\langle \left(\left\langle g_{ij}^{m} - g_{ij}^{t} \right\rangle_{j \in k} \right)^2 \right\rangle_{ikl}}$, where $g_{ij}^{m(t)}$ is the i^{th} component of the measured (input) shear, and j and k represent different input shear and observing condition, respectively.

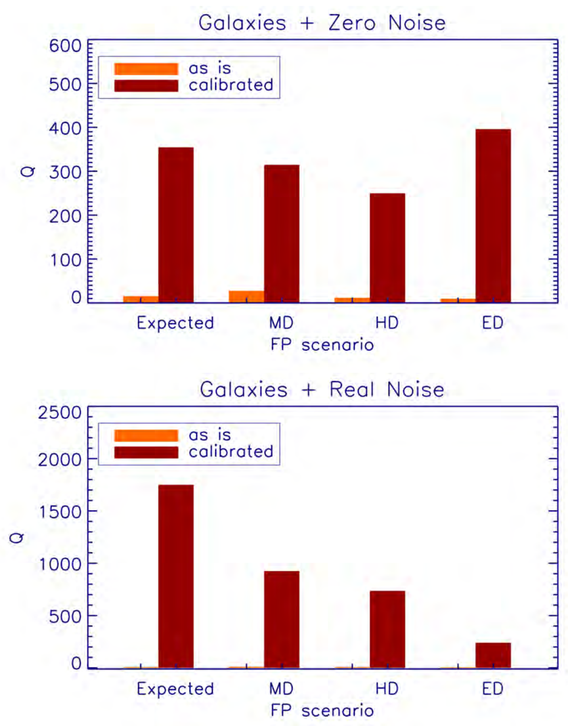


Figure 6. Shear Recovery Test Results

We determine Q separately for the four non-flatness scenarios: expected, moderately degraded (MD), highly degraded (HD), and extremely degraded (ED) cases.

Shear measurement is performed twice, before and after we add noise. The noiseless images enable us to look into the shear calibration bias due to the mismatch between model (here Gaussian) and real galaxy profile (here bulge + disk). Not surprisingly, the mismatch causes underestimation of the input shear because galaxy radial profiles tend to extend further than the Gaussian. We find that on average this bias amounts to ~10%, which limits the quality measure Q~20 for small shears (<< 0.1). When we apply a single multiplicative factor derived from a subset, Q increases to Q~300. This multiplicative factor only weakly depends on the focus deviation. Also, It is worth noting that in this noiseless galaxy image test the quality measure Q does not seem to correlate with the focal plane flatness.

However, strong dependence on focal plane flatness is found when the test is performed on galaxy images with realistic noise. Again, here we only derive a global multiplicative factor for shear calibration. If the LSST focal plane assembly meets the expected specification, we can achieve a remarkable performance Q~1700. This quality measure decreases for degrading focal plane flatness, and for our extreme scenario (ED), it becomes Q~200. Obviously, the presence of noise dilutes the lensing signal. As many authors suggest, it is possible to derive S/N-dependent calibration to further improve the agreement.

It may look counterintuitive that the quality measure for real noise is considerably higher than in the case for zero noise. This is because we use a global multiplicative factor for calibration and this scheme is Inadequate for zero noise galaxy images.

CONCLUSIONS & FUTURE PLANS

We have performed LSST shear recovery tests assuming different focal plane non-flatness scenarios closely following the procedure of the GREAT08 experiment. For galaxy images with realistic noise, we find that the shear recovery precision depends on the accuracy of the focal plane assembly. Our simulation shows that for the current expected focal plane non-flatness, a target precision Q>1000 (Amara & Refregier 2008) can be achieved when a simple, global multiplicative factor (derived from subsets of the simulation images) is applied. Even under the scenarios of moderate and large focal plane non-flatness, it appears that we can achieve this goal if more sophisticated calibration is provided. However, this optimistic view must be substantiated by more refined simulations including the following.

- Shear calibration using galaxy image properties and PSF (e.g., S/N, size, radial profile, PSF FWHM, etc.).
- Parallel study using real galaxy images based on HST data.
- Investigation on impacts of spurious detection and object deblending.
- Experiment with different shear measurement algorithms.
- Development of algorithms that do not depend on external calibration.

Note that the Q>1000 requirement is mandatory only in the absence of self-calibration effects by combining WL+BAO. Systematics are coupled across probes because of the shared large scale structure for BAO and WL; a joint analysis of the shear and galaxy over-densities for the same set of galaxies involves galaxy–galaxy, galaxy–shear, and shear–shear correlations. This can result in significantly reduced sensitivity of cosmological constraints to shear systematic error.

REFERENCES ◆ Amara & Refregier 2008, MNRAS, 391, 228 ◆ Bridle et al. 2010, MNRAS, 405, 2044 ◆ Jee & Tyson. 2010, PASP, submitted (arXiv:1011.1913) ◆ Jee et al. 2007, ApJ, 661, 728

January 2011

LSST is a public-private partnership. Design and development activity is supported in part by the National Science Foundation. Additional funding comes from private gifts, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.