Large Synoptic Survey Telescope

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LSST Probes of Dark Energy with Weak Lensing: Ground versus Space

M. James Jee[1], J. A. Tyson[1], Z. Ivezic[2], D. Wittman[1]

[1]UC Davis, [2]Univ. of Washington

Weak lensing provides a clean probe of dark matter, constraining models of dark energy by measuring the evolution of the cosmic shear. The power of a lensing survey for cosmology depends on the total number of resolved distant galaxies and the sky coverage of the survey. Galaxy shape measurement depends on galaxy angular size, delivered PSF, and limiting surface brightness. At the same surface brightness, the number density of usable galaxies is a factor of 2-3 higher in space because of the diffraction-limited seeing. However, a carefully designed, wide-field, large-aperture ground-based telescope (~0.7" median seeing in *r* band) can surpass space-based observatories in the total yield and sky coverage. The larger number of images per galaxy obtained by such a survey would greatly aid control of systematics. For a quantitative estimate of LSST performance, we are carrying out a suite of WL simulations including atmospheric turbulence, telescope aberrations, and detector focal plane height fluctuations assuming worst-case scenarios. Our results show that the residual PSF correlation function for the LSST main survey is below statistical errors for angular scales of interest for cosmology. These results are valid for a galaxy number density ~40 per arcmin^2. Although a space-based survey could reduce the error of the shear power spectrum relative to the LSST at small scales ($l > 10^4$), where the baryonic effect complicates interpretation, the LSST outperforms a space survey at large scales, where errors are dominated by sample variance, and the primary cosmological information lies.

1. Introduction

The Large Synoptic Survey Telescope (LSST) will perform multi-color deep (27.6 in *r* band) imaging survey of ~20,000 square degree area, providing high-fidelity photometric redshift and shape measurements of several billion galaxies. We display the anticipated amplitude and noise of the shear power spectra based on the ΛCDM cosmology and the current parameters of the estimated performance of LSST in *Figure 1*.

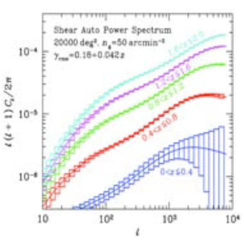


Figure 1. Five cosmic shear power spectra constructed from five different redshift bins. Here, *l* is the multi-pole moment of the distribution on the sky, and the vertical scale is proportional to the rms fluctuation of the power spectrum per log interval in *l*. Only the 5 auto-power spectra of each redshift bin among the available 15 co-spectra are displayed, and the solid curves show the predictions for the concordance ΛCDM model. The boxes show the expected 1-σ measurement error due to the sample variance and intrinsic ellipticities (the sample variance is dominant at about *l* < 1000, while the intrinsic ellipticities are dominant at *l* > 1000). In fact, a larger number of redshift bins will be enabled by LSST leading to more auto- and cross-spectra.

In this poster, we review the merits and drawbacks of the LSST-type ground-based weak-lensing surveys with respect to space-based surveys in probing dark energy, and present our on-going image simulation of the LSST, which addresses the question: how well can we control systematics arising from anisotropic point spread functions (PSF) induced by optical aberrations, focal plane height fluctuation, and atmospheric turbulence?

2. Weak-lensing Probes of Dark Energy: Space versus Ground

The Dark Energy Task Force (DETF) report (Albrecht et al. 2006), which supports weak-lensing as potentially the most promising method for probing dark energy, presents a fair comparison between space- and ground-based approaches. We summarize the relative merits and drawbacks of the two kinds mentioned in the report in Table 1.

Table 1. Ground versus space surveys in weak-lensing study of dark energy (Albrecht et al. 2006).

Parameter	Space	Ground
large collecting power and large field of view	prohibitively expensive	feasible with current technology
number density of usable galaxies at a given surface brightness	space resolution allows shape measurement from small galaxies	atmospheric turbulence limits the size of usable galaxies
photometric redshift	deep NIR imaging improves photo-z accuracy and reliability	harder to get deep and full sky NIR photometry
systematics control	sharper PSF provides leverage	fast repeated observation provides leverage

The virtue of a space mission is high angular resolution and access to low-background near-IR, increasing the number density of usable galaxies with reliable photo-z information 2-3 fold with respect to ground-based observations. The primary merit of a ground-based survey is a high throughput with a large field of view, enabling rapid repeated mapping of a full hemisphere of a sky, reducing sample variance. The impact of these relative merits on the statistical errors in the cosmic shear power spectrum are estimated by Jain, Jarvis, and Bernstein (2006) using the nominal performance parameters of future space- and ground-based surveys (*Figure 2*). A space-based survey could reduce the error of the shear power spectrum relative to the large survey telescope at small scales ($l > 10^4$), where the baryonic effect complicates interpretation. A large survey telescope like LSST outperforms a space survey at large scales, where the errors are dominated by sample variance, and where the primary cosmological information lies.

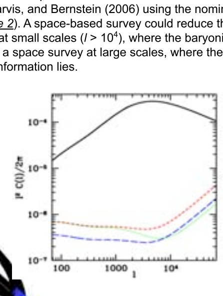
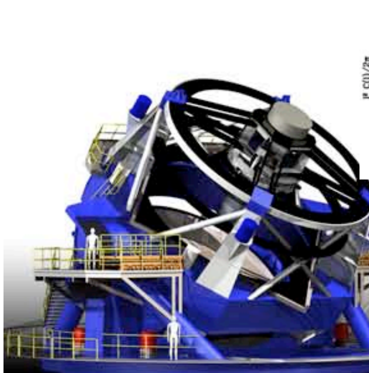
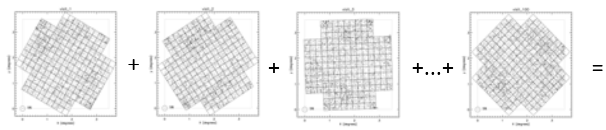


Figure 2. Statistical errors of the cosmic shear in future space- (green) and ground-based (red and blue) surveys. The blue line is for the LSST-like survey performance while the red line shows the case when the survey area is reduced by a factor of 5 to match the area of the space-based survey considered here. This plot is a reproduction of Figure 1 in Jain, Jarvis, and Bernstein (2006).



3. Systematics Control in LSST

Figure 2 illustrates that future ground-based weak-lensing surveys are required to control systematics below the statistical errors (<<10^{-6}) in order to use the cosmic shear measurement for dark energy study. This point is also highlighted in the DETF report: "*Performance of a Large Survey Telescope mission depends critically on control of systematic errors in both shape measurement and photometry.*" The level of the PSF anisotropy correction requirement is high for ground-based observations, and some authors consider it highly challenging to obtain ~40 galaxies per arcmin^2 (Massey et al. 2007). However, what is often disregarded is the increase of the number of usable galaxies due to the lower surface brightness limit with large ground-based telescopes. The power of LSST in turning some systematic errors into statistical errors by rapid revisits of the same patch of the sky enables us to reliably extract shear information from these faint objects.



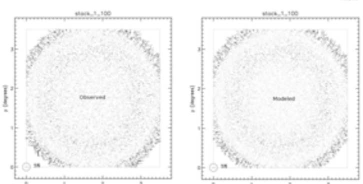


Figure 3. Power of *many exposures* of LSST. We simulated 100 exposures of the same field by including the atmospheric turbulence, the optical aberrations, and the focal plane height variations. In each exposure, the spatial variation of the PSF is discontinuous across the chip gaps (see Jee et al. 2009 for simulation details). Because an object is observed multiple times at different locations on the focal plane, the resulting PSF is much rounder and uncorrelated with neighboring PSFs.

We show in *Figure 3* the LSST PSF pattern that appears in single visits and the final co-added image. In Jee et al. (2009) we demonstrated that we can model the PSF for individual single exposures through chip-by-chip interpolation with a sufficient level of accuracy to meet the science requirement, and here we discuss the results on the final co-added image. Because we fixed the optics and the focal plane errors throughout the simulation, we still observe a residual pattern in the final stacked image as shown. Using the final PSF model obtained by stacking 100 individual PSF models, we are able to bring the residual PSF correlation further down to < 10^{-8} (*Figure 4*).

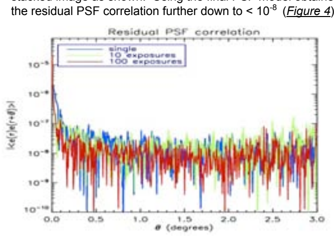


Figure 4. PSF ellipticity correlation. The residual PSF correlation is < 10^{-7}, which is consistent with the statistical limit.

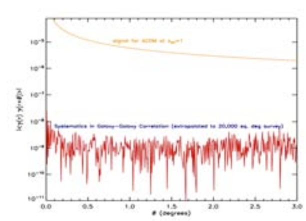


Figure 5. Shear-shear correlation from galaxies. Because there is no input shear, the residual amplitude should be consistent with the statistical noise as observed.

4. Conclusions and Future Work

The small residual ellipticity correlation of the PSFs (*Figure 4*) does not guarantee that we can perform equally well with galaxies. Even if one has a perfect knowledge of a PSF, the issue of optimally extracting a shear from PSF-convolved galaxies has been a constant subject of debate. In our previous simulation (no field rotation), we found that even with a perfect PSF the measured shape of small galaxies still possesses the "memory" of the input seeing (Jee et al. 2009). Part of this problem, often called centroid bias, has been discussed in the literature (Kaiser 2000, Bernstein & Jarvis 2002). *Figure 5* shows the shear-shear correlation derived from galaxies in the current simulation. Unlike our previous simulation where the systematic floor sets the limit at ~5x10^{-6}, the current result shows that ***the amplitude of the galaxy shear correlation function is consistent with the statistical errors set by the finite number of galaxies. Our next simulation, which expands the current one 10 fold to cover 100 deg^2 area, will include xy dithered exposures. In addition, the new images will contain artificial shears ranging from 10% to sub-percent level to investigate the LSST's shear recovery performance from cluster scale to cosmic shear.***

References

•Albrecht, A., et al. 2006, arXiv:astro-ph/0609591 •Bernstein, G.~M., & Jarvis, M. 2002, *AJ*, 123, 583 •Jain, B., Jarvis, M., & Bernstein, G. 2006, *JCAP*, 2, 1 •Jee, M.J., et al. 2009, *BAAS*, 41, 371 •Kaiser, N. 2000, *ApJ*, 537, 555

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