Weak Lensing with LSST

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Constraining dark energy parameters with weak lensing is one of the primary science goals of the LSST. The LSST Weak Lensing Science Collaboration has been formed with the goal of optimizing the weak lensing science by optimizing the survey cadence; working with Data Management to insure high-quality pipeline processing which will meet our needs; developing the necessary analysis tools well before the onset of data-taking; participating in high-fidelity simulations to test the system end-to-end; and analyzing the real dataset as it becomes available.
We review the major weak lensing probes, the two- and three-point shear correlations, and how they constrain dark energy parameters. We also review the possibility of going beyond dark energy models and testing gravity with the LSST data. To realize the promise of the awesome LSST statistical precision, we must ensure that systematic errors are kept under control. We summarize the major sources of systematics and our plans for mitigation. We address these sources of systematics and corresponding mitigation strategies.

1. Weak Lensing

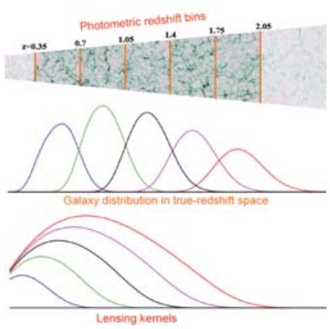
Gravitational lensing is the deflection of light, due to a mass concentration intervening between source and observer. A spectacular example of *strong* gravitational lensing is shown next to the LSST logo at the top of this poster: a blue background galaxy is seen multiple times, stretched around a ring centered on a massive cluster of galaxies. However, strong lensing happens only along the densest lines of sight in the universe. *Weak* lensing extends this idea to any line of sight by examining ensembles of background galaxies. This poster focuses on *cosmic shear*, or weak lensing by large-scale structure. The LSST Weak Lensing Science Collaboration will also use weak lensing to study clusters and galaxies.

Weak lens shear depends on source-lens observer geometry as well as the lens mass structure, so it probes cosmology in two different ways. This enables going beyond testing dark energy models, to testing gravity itself.

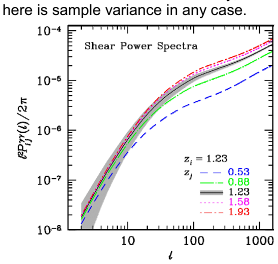
2. Cosmic Shear

The primary cosmic shear statistic is the two-point shear correlation function, or its Fourier transform, the power spectrum. Shear increases with source redshift due to larger distances and more intervening structure. We can get information from both the autocorrelations and cross-correlations of redshift shells.

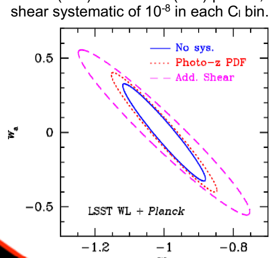
With 3 billion galaxies, the LSST dataset will yield very precise measures of the two-point function. To illustrate this, we present a series of photometric redshift bins from a mock LSST survey (ten bins evenly spaced from z=0 to 3.5, of which five are shown below). The top panel represents the angular and redshift distribution of source galaxies, the middle shows the true redshift distribution of the photometric redshift slices (allowing for errors of 0.05(1+z) per galaxy), and the bottom panel shows the lensing kernel, or sensitivity to intervening structure as a function of redshift, for each slice.



Next, we compute the shear power spectra. Below: auto-power spectrum for z=1.23 (solid curve) and sample cross power spectra (dot and dash curves). The forecast errors (shaded) assume 50 galaxies arcmin^{-2}. Detailed simulations show that 35 is more likely, but the dominant error here is sample variance in any case.



Finally, we compute the resulting constraints on dark energy. In the figure below, the solid blue error ellipse is the forecast for the 2-point statistic alone, but without any systematics included. The dotted ellipse is after allowing for uncertainty in the bias and scatter in the photometric redshifts, at the required level of 0.0025(1+z) and 0.0035(1+z) per bin, respectively (Ma et al 2006). The dashed line allows for an additive shear systematic of 10^{-8} in each C_l bin.



We note that the 3-point function is an independent measurement, which will further improve constraints. The 2- and 3-point functions also have different degeneracies in cosmological parameter space, so the joint constraints are significantly stronger than from the 2-point alone (Jarvis et al 2005).

3. Tests of Gravity

LSST enables going beyond dark energy models, to testing gravity itself. Weak lensing data can be used to simultaneously reconstruct both the distance-redshift relation, which depends on the expansion history, H(z), and the growth-redshift relation, which depends on both the expansion history and the gravitational-force law. Assuming Einstein gravity (and spatially smooth dark energy) one can use the distance-redshift relation to predict the growth-redshift relation. Non-Einstein gravity can lead to a discrepancy between the observed growth-redshift relation and this predicted one, which is testable with LSST (Lue et al. 2004, Song 2005, Knox et al. 2006).

4. Systematics

The challenge in reaching these goals lies in controlling systematic errors to a level comparable to the statistical uncertainties. We present a nonexhaustive list of possible systematics, including the potential threat, current progress, and possible mitigation for each.

Photometric redshift errors: this is perhaps the most serious concern, as the levels assumed at left are quite ambitious. Note that actual bias and scatter are not as important as *knowing* the bias and scatter (Ma et al 2006). Therefore we are developing ways to characterize the *true* redshift distribution of any photometric redshift slice, independently of the photometric redshift algorithm; see the LSST poster by Newman et al.
Shear calibration: the STeP project has shown that the best current methods are good to about a percent (Massey et al 2006). Over the next decade, the LSST Weak Lensing Science Collaboration must develop or identify a method which performs several times better. We will build on the continuing progress of the STeP project, and take it further with blind analyses of high-fidelity mock LSST data. Huterer et al (2006) have presented a framework for budgeting multiplicative and additive errors which will be useful in this context.
Spatio-temporal variations: variations in seeing, combined with imperfect shear calibration, will add power on scales larger than an LSST field (3.5 deg). We are performing a Vale & White (2004) type analysis of a full 10-year LSST survey (this survey is detailed in the Pinto et al LSST poster). Because each field will be observed hundreds of times, with a FWHM<0.7" constraint, variations are likely to be small; however, additional reductions could be achieved by constraining the scheduler to minimize variation as well.
Spurious shear from the atmosphere: Wittman (2005) showed that, given the standard 1 star arcmin^{-2} to diagnose the point-spread function (PSF), the residual shear in short (15 s) exposures with an 8-m telescope (Subaru), was well below the cosmological signal on small scales and averaged down with additional exposures, easily meeting LSST requirements. This assumed perfect correction for PSF effects given imperfect knowledge, and did not address large scales, so more detailed studies are still required.
Intrinsic alignments are thought to exist at some as-yet-unknown level. By cross-correlating different redshift bins, we remove the intrinsic-intrinsic contribution, but the lensing-intrinsic contribution remains (i.e., resident galaxies are intrinsically aligned to the same potential which lenses the background galaxies). We will be exploring mitigation strategies such as template fitting (King 2006).

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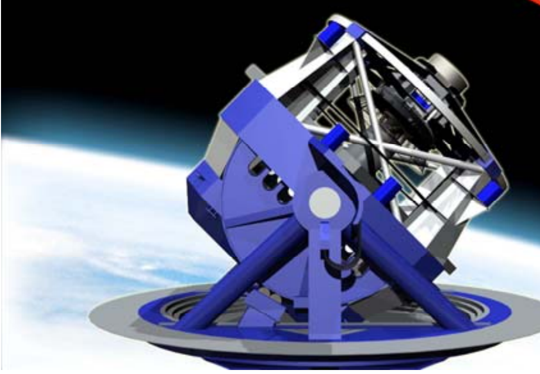

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