Weak Lensing Cosmology with LSST: Three-Point Shear Correlations

Large Synoptic Survey Telescope

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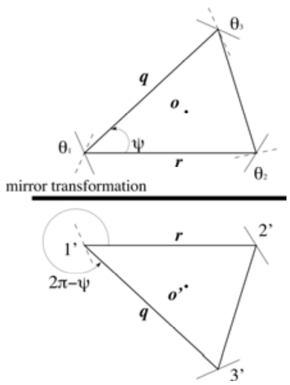
We present an analysis of the three-point correlation function for weak lensing shear data. The shear three-point function is an independent measurement from the two-point function and thus adds to the total signal-to-noise obtainable from weak lensing data. Furthermore, it is shown that the constraints on cosmological parameters are along somewhat different degeneracies than the two-point function, so the combination of the two statistics is significantly more powerful than either one individually. Predictions of the constraining power are given for the proposed Large Synoptic Survey Telescope (LSST). We also present the actual marginal detection from the 75 square degree CTIO Lensing Survey and the E/B mode analysis of this dataset.



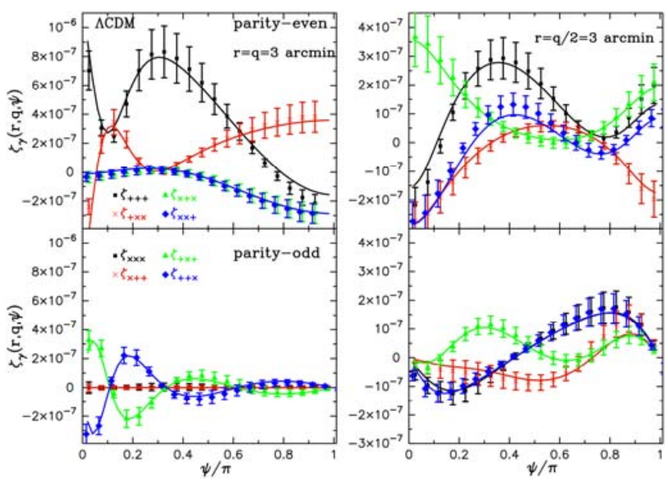
The Three-Point Correlation Function

The three-point shear correlation function is distinctly more complicated for weak lensing studies than the two-point function and corresponding derived statistics like the popular aperture mass statistic. However, the extra complications are worthwhile, since three-point function can probe aspects of the shear field, such as non-Gaussianity, which the two-point statistics cannot.

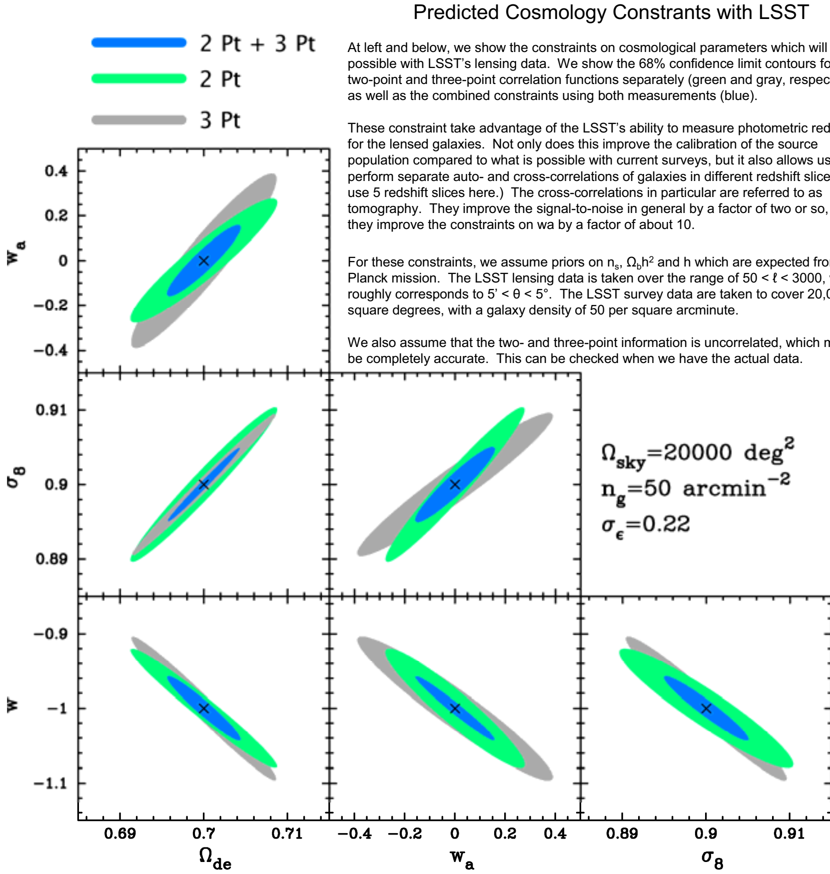
First, geometry of triangles dictates that the three-point function is a function of three parameters: for example (q,r,ψ) in the diagram at left.

Second, the shear at each vertex has 2 components. Thus, the full three-point function has 8 combinations of these, leading to 8 separate correlation functions. These can be divided into parity-odd and parity-even functions corresponding whether they change sign under the transformation $\psi \rightarrow 2\pi-\psi$.

The predicted values of the 8 functions for ΛCDM cosmology are plotted below as a function of ψ for two values of (r,q). The symbols + and x refer to the two shear components relative to the center of the triangle.



Predicted Cosmology Constrants with LSST



At left and below, we show the constraints on cosmological parameters which will be possible with LSST's lensing data. We show the 68% confidence limit contours for the two-point and three-point correlation functions separately (green and gray, respectively), as well as the combined constraints using both measurements (blue).

These constraint take advantage of the LSST's ability to measure photometric redshifts for the lensed galaxies. Not only does this improve the calibration of the source population compared to what is possible with current surveys, but it also allows us to perform separate auto- and cross-correlations of galaxies in different redshift slices. (We use 5 redshift slices here.) The cross-correlations in particular are referred to as tomography. They improve the signal-to-noise in general by a factor of two or so, and they improve the constraints on wa by a factor of about 10.

For these constraints, we assume priors on n_s, $\Omega_b h^2$ and h which are expected from the Planck mission. The LSST lensing data is taken over the range of $50 < \ell < 3000$, which roughly corresponds to $5' < \theta < 5°$. The LSST survey data are taken to cover 20,000 square degrees, with a galaxy density of 50 per square arcminute.

We also assume that the two- and three-point information is uncorrelated, which may not be completely accurate. This can be checked when we have the actual data.

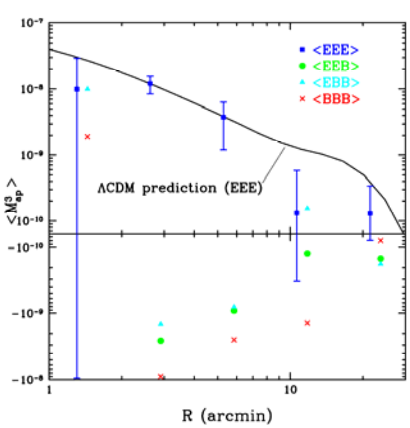
Current Measurements

We have developed a fast algorithm for calculating the three-point correlation function using a tree algorithm. In the limit of large number of galaxies N, the calculation time scales as N ln(N), rather than N^3 for the naïve direct calculation. This improvement is already important for current surveys and will be critical for a survey with as many galaxies as the LSST will observe.

For plotting purposes, we combine the measurements in a way that captures most of the lensing information in a single function of one variable, the aperture-mass-cubed statistic, $\langle M_{ap}^3 \rangle(R)$. This function only includes the pure E-mode correlation information. There are three similar functions which contain B-mode information (both pure, and mixed). Since lensing produces a pure E-mode shear field, these other functions are useful measures of systematic contaminations in the data.

As a demonstration of the technique, we have measured this statistic for the CTIO weak lensing survey, which has about 2 million galaxies, and covers 75 square degree. These results are shown to the right, along with the predicted value for the convergence ΛCDM model. The B-mode and the mixed modes are all consistent with zero, while the E-mode is non-zero at the 95% confidence level, and is consistent with the convergence model.

We will be able to use the same algorithm on the LSST data. The LSST data will provide a much higher signal-to-noise measurement of this statistic, which will therefore be able to provide good constraints on cosmology, as described in the upper right panel. However, even with our fast algorithm, there are still some computational challenges to address in making such a measurement from the enormous amount of data which LSST will produce.



Discussion

It is clear from the above plots that the constraints on cosmology using the LSST weak lensing measurements will be an enormous improvement over the current state of the art. Furthermore, the three-point correlation function constrains the parameters in a slightly orthogonal direction to that of the two-point correlation function. Thus, when the two statistics are combined, the overall contours are much smaller than for either one separately.

It should be noted that the contours above are all quite narrow in one direction. For example, the 1-σ uncertainty in the narrow direction on the w_0-w_a plane is only 0.02. Since other observations with LSST (baryon acoustic oscillations and SNe) and other experiments will constrain the parameters with different degeneracy directions than these, combining their constraints with the weak lens results from the LSST will lead to very tight overall constraints.

We should also point out that the results presented here assume that the systematic errors in the lensing data can be reduced to the level of the statistical errors. This requires more than an order of magnitude improvement over the current results. While this is a significant challenge, recent progress in the algorithms for PSF correction and interpolation, as well as the excellent precision of the LSST optics and detectors, make us confident that the systematics can be controlled to the necessary degree.

Finally, three-point statistics are not the only probes of non-Gaussianity in the dark matter distribution. Peak statistics, higher order correlation functions (four-point, etc.), and direct estimates of the mass probability distribution function are also useful in this regard, and we plan on making measurements of all of these. Since each of these statistics probe somewhat different aspects of the dark matter, combining all of them will result in even more precise constraints of the various cosmological parameters.

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