Dark Energy Constraints from Lensing Tomography with LSST

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Large Synoptic Survey Telescope

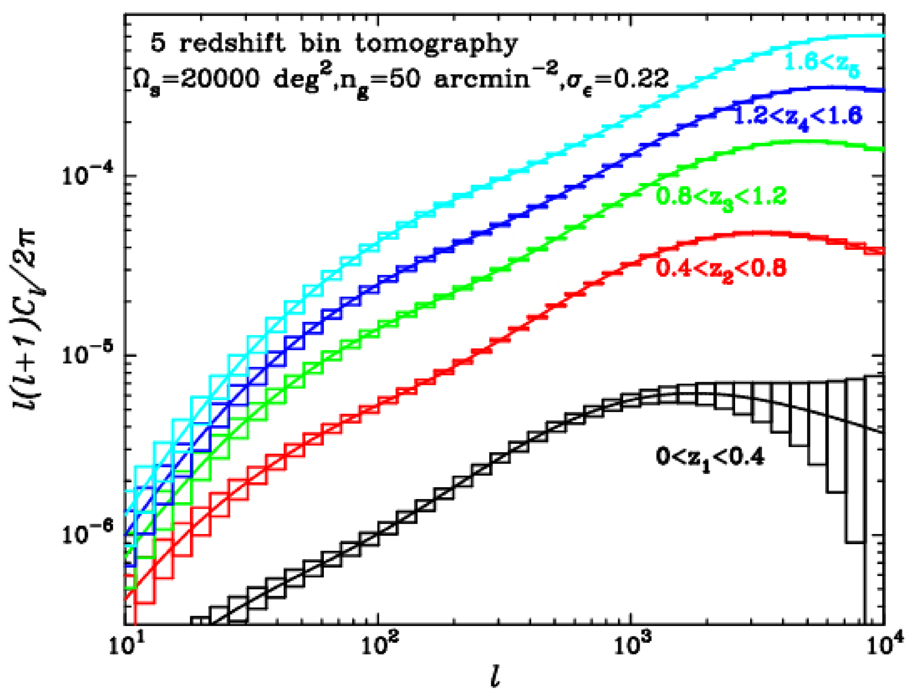
We estimate the dark energy constraints achievable with a weak lensing survey that could be carried out with the Large Synoptic Survey Telescope. The technique used in our forecasts is lensing tomography with the auto and cross power spectra of the lensing shear. The power spectra depend on the growth function and angular diameter distances, which are both sensitive to the equation of state of dark energy. We include the effect of statistical and some systematic errors in our parameter forecasts for LSST. We identify the limiting systematics in being able to achieve the precision possible with a survey that covers a large fraction of the sky. In this study we use only the simplest lensing statistics; the constraints can be improved by using other complementary measures from the same dataset.

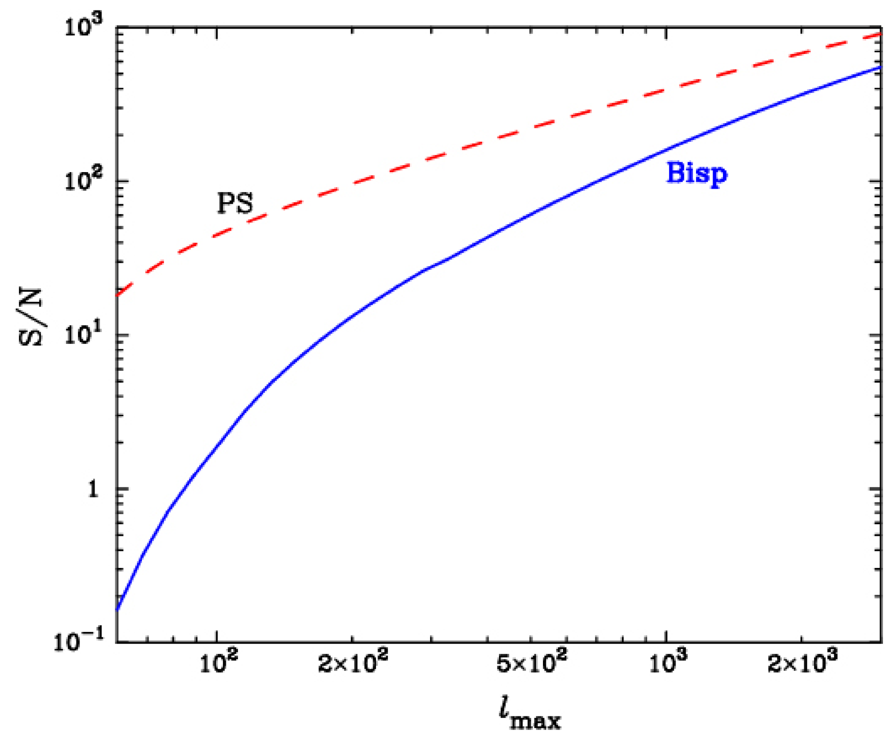
1. Lensing tomography

A multi-color deep imaging survey as offered from LSST is expected to provide photometric redshift information of distant galaxies beyond z=1. This additional information is extremely valuable in that it allows us to recover redshift information on the weak lensing by subdividing galaxies into several redshift bins – the so-called **lensing tomography** (Hu 1999, Huterer 2002, Hu 2002, Takada & Jain 2004, Takada & White 2004, Song & Knox 2004).

The top plot shows the lensing power spectra constructed from 5 redshift bins, as indicated. Only the 5 auto-power spectra of each redshift bin among the available 15 spectra are displayed, and the solid curves show the predictions for the concordance ΛCDM model. The power spectrum amplitude increases as one considers lensing effect on galaxies in higher redshift bin. The boxes show the expected one-sigma 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). It is clear that the unparalleled survey area of LSST allows a significant detection of the power spectra over a wide range of angular scales, from degree scales up to arcminute scales. The source redshift dependence of the power spectra is very sensitive to cosmological parameters including the equation of state parameters of dark energy.

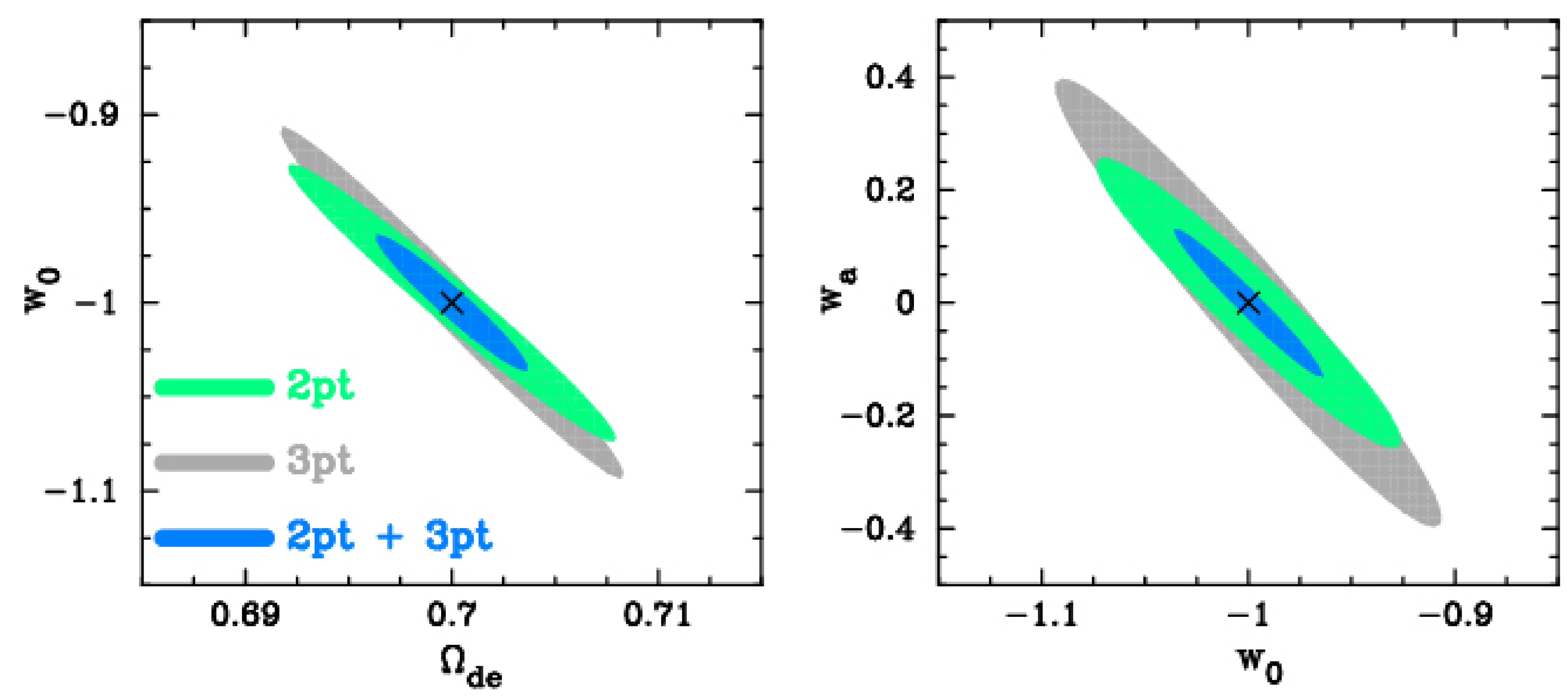
It is shown in Takada & Jain (2004) that the future survey also makes possible a significant detection of the bispectrum that carries the non-Gaussian signal in weak lensing, providing additional, complementary cosmological information to that from the power spectrum. To be more explicit, the bottom plot shows signal-to-noise ratio for measuring the lensing power spectrum and bispectrum against the maximum multipole l_{max}. It is clear that information on the bispectrum comes more from higher l modes than the power spectrum.





2. Forecasts for dark energy constraints

-- Usefulness of the non-Gaussian signal in weak lensing



Forecasted 68% C.L. constraints in two parameter space for the dark energy density parameter Ω_{de} and its equation of state parameters given by $w(a)=w_0+w_a(1-a)$. The concordance ΛCDM model is assumed for the fiducial model, and we considered angular models of 50<l<3000 and 7 cosmological parameters in the Fisher matrix analysis. It is also noted that we employed priors to the cosmological parameters expected from the Planck mission (see Takada & Jain 2004 for the details). The green, gray and blue contours show the constraints expected from the power spectrum tomography, the bispectrum tomography and the joint tomography of combining the two. **It is clear that the bispectrum tomography improves parameter constraints by a factor of 2 compared to just power spectrum tomography, reflecting that the non-Gaussian signal in weak lensing provides additional cosmological information that cannot be extracted by the power spectrum.** These constraints can be further tightened by adding other complementary probes such as supernovae (Hu 2002; Takada & Jain 2004; Song & Knox 2004).

More explicitly, to see why we have the complementarity from the power spectrum (PS) and bispectrum (Bisp) tomography, we consider variations in PS and Bisp around the fiducial ΛCDM model and mean source redshift z_m:

$$P_\kappa \propto \Omega_{de}^{-3.5}\sigma_8^{2.9} z_m^{1.6}|w_0|^{0.31} = \left(\Omega_{de}^{-1.22}\sigma_8 z_m^{0.54}|w_0|^{0.11}\right)^{2.9}$$

$$B_\kappa \propto \Omega_{de}^{-6.1}\sigma_8^{5.9} z_m^{1.6}|w_0|^{0.19} = \left(\Omega_{de}^{-1.03}\sigma_8 z_m^{0.26}|w_0|^{0.03}\right)^{5.9}$$

where we fixed the multipole to be l=1000. The second equality in equation above shows the parameter dependences relative to the dependence on σ_8. It is clear that the PS and Bisp have (slightly) different dependences on the parameters, leading to their complementarity for dark energy constraints (for example, the bispectrum amplitude more quickly decreases than the power spectrum does as one goes to higher redshift, since the non-Gaussianity in large-scale structure is more prominent at lower redshifts). In addition, these specific dependences of PS and Bisp will be used to disentangle cosmological information from various systematics in lensing measurements (Huterer, Takada et al. 2005).

3. Issues need to be investigated

There are some systematic uncertainties that need to be fully resolved during a coming decade so that the constraining power of cosmological parameters from a future survey is not compromised:

- Developing accurate theoretical predictions of lensing observables (especially for the bispectrum for all relevant triangles)
- Include non-Gaussian contributions to the covariances of PS and Bisp in the anaysis
- Effect of shear calibration error on cosmological errors
- Effect of photometric redshift inaccuracy
- PSF anisotropy correction (Jarvis & Jain 2004)
- Optimal way to use the B-modes measured in PS and Bisp as a monitor of the various systematics

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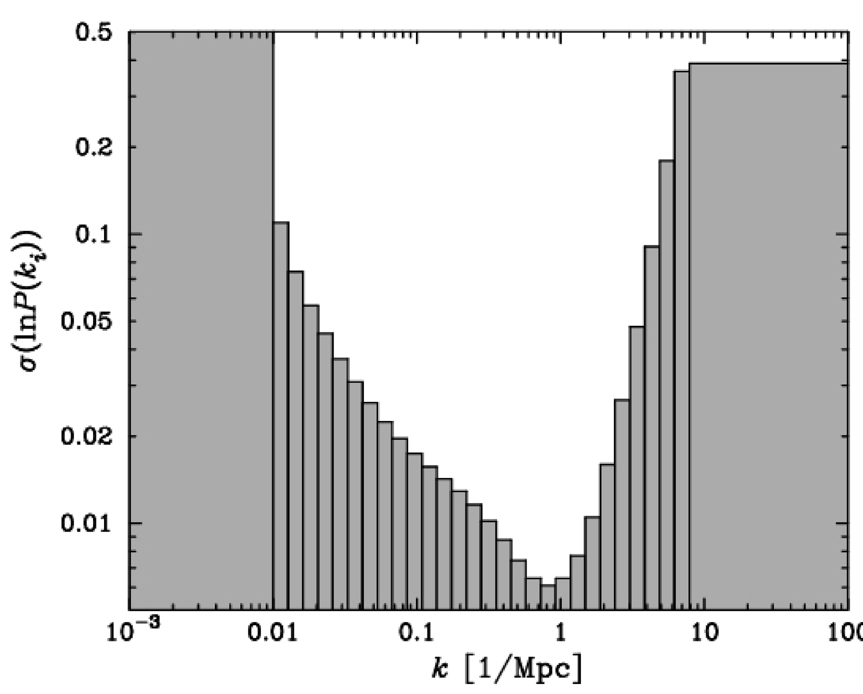
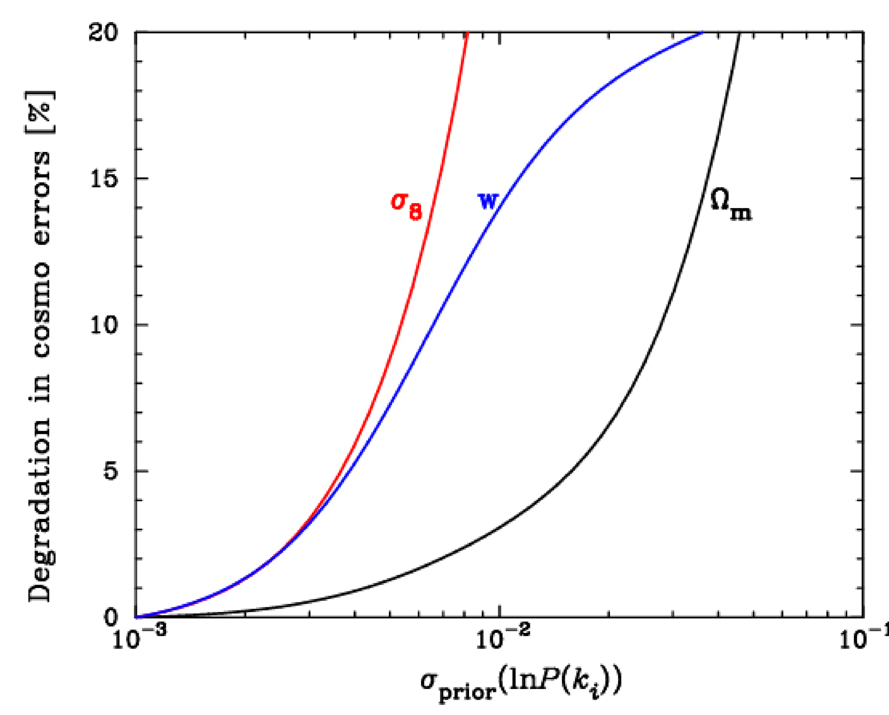
Here we discuss the first issue listed above: the required accuracy with which 3D matter power spectrum needs to be calibrated in order not to degrade the cosmological errors (Huterer & Takada 2004). The plot shows unmarginalized errors in the 30 binned matter power spectrum $P(k)$, where we assumed the cosmological parameters are perfectly known and considered 5 redshift bin lensing tomography and angular modes of 50<l<3000. It is apparent that the lensing information of our interest is most sensitive to mass fluctuations of k=1 Mpc^{-1} and, in other words, the matter power spectrum around this scale has to be most precisely calibrated.

The other plot shows how the random errors in $P(k)$ increase the errors in cosmological parameters Ω_{de}, w_0 and σ_8, relative to the marginalized error. The results indicate that $P(k)$ has to be calibrated with accuracy of a few percent (1% for σ_8, 5% for Ω_{de} and 2% for w_0) in order not to degrade the cosmological error by less than 10-20%. Interesting to note is that σ_8 is more degraded than Ω_{de} and w_0, since σ_8 depends on the lensing power spectrum solely though its dependence on $P(k)$, while the parameters Ω_{de} and w_0 also enter the lensing geometric factor that only depends on the cosmic expansion history. In other words, most information on dark energy parameters come from the geometric factor, provided the redshift distribution of galaxies is precisely known (see Huterer, Takada et al. 2005). While current accuracy in P(k) on relevant scales is about 5-10%, the level of 1-2% accuracy will be achievable with future numerical resources.





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