Large Synoptic Survey Telescope

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Baryon Acoustic Oscillations in the LSST Photometric Survey

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Baryon acoustic oscillation (BAO) studies provide an important probe of dark energy, yielding constraints that are highly complementary to other methods such as weak gravitational lensing (WL) and very competitive with other proposed large surveys. By measuring the BAO scale in ugrizy-band photometric redshift-selected samples, LSST will determine the angular diameter distance to each of a dozen redshifts with percent-level errors. However, photometric redshift (a.k.a. photo-z) errors can dilute the observed strength of the BAO signal. We present preliminary work from Monte Carlo simulations of mock galaxy samples for LSST with luminosity-color-redshift distributions designed to agree with those from the GOODS survey, including simulations of the expected photo-z performance of LSST, calculations of constraints on cosmology and photo-z error distributions from BAO analysis from LSST.

Baryon Acoustic Oscillations

In the early universe the cosmological density fluctuations create sound waves which propagate through the photon-plasma fluid. When the temperature of the universe drops enough to allow the photons to travel freely, this effectively stalls these sound waves at the epoch of recombination. The distance these sound waves could travel in the time between the formation of the perturbations and the epoch of recombination imprinted a characteristic scale into the spectrum of density perturbations. Because the universe has a significant fraction of baryons, theory predicts that this *characteristic scale* will also be imprinted in the late-time spectrum of density perturbations. This results in the expectation that there will be a small excess of galaxies at this characteristic scale away from other galaxies. At recombination this scale is roughly 150 co-moving Mpc, and it appears in the power spectrum of density fluctuations as a damped harmonic sequence, a series of wiggles, which are known as the baryon acoustic oscillations (BAO). The position of these wiggles measured as a function of redshift reveals information about dark energy.

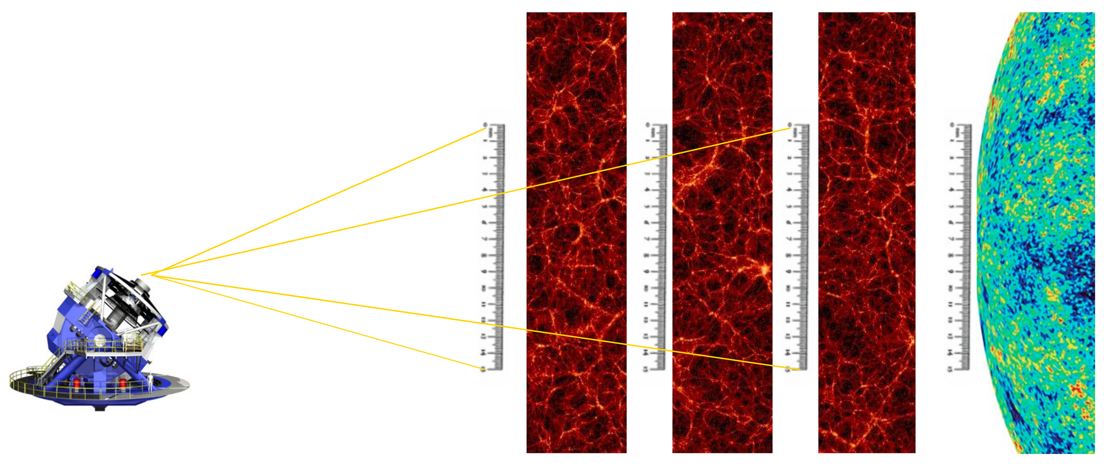

Figure 1: LSST will be able to measure the BAO scale over a range of redshifts providing the redshift lever arm needed to accurately measure the universal expansion. The same scale is also accurately measured by the CMB, effectively adding another data point at z=1000.

Direct 3D power spectrum computation

For the LAL/LPSC mock galaxy catalogs described here, we compute the power spectrum using a direct Fourier transform method as outlined in Blake et al. (2007). To measure the precision on the BAO scale we use the *wiggles only* method from Blake & Glazebrook (2003): dividing the measured power spectrum by a smooth reference power spectrum given by the Eisenstein & Hu (1998) no-wiggles fitting formula. The *wiggles only* power spectrum is then well approximated by a decaying sinusoid:

$$\frac{P(k)}{P_{ref}} = 1 + Ak\exp\left[-\left(\frac{k}{0.1h\mathrm{Mpc}^{-1}}\right)^{\gamma}\right]\sin\left(\frac{2\pi k}{k_a}\right)$$

where k_a represents the acoustic scale.

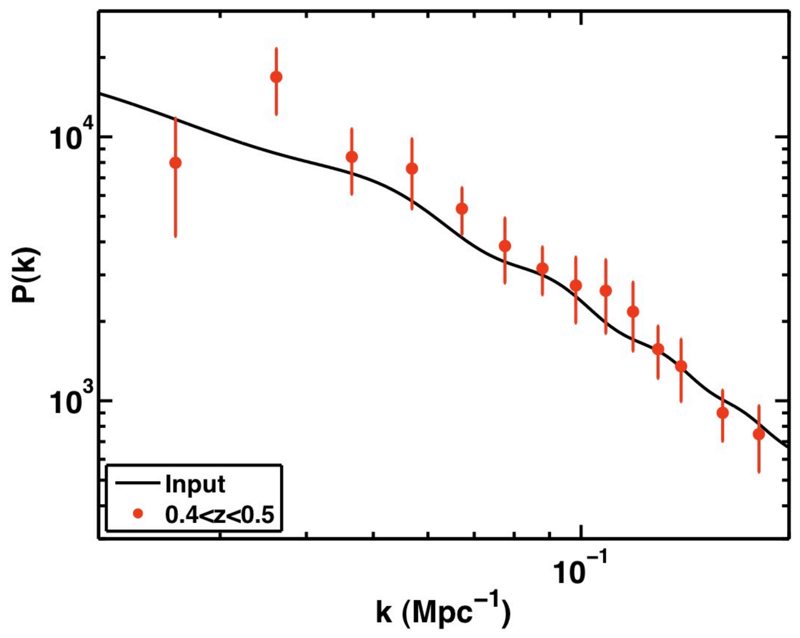

Figure 2: An example of a 3D power spectrum computed from the LAL/LPSC simulation described in this poster. For a redshift slice 0.4<z<0.5 over an area of just 8000 sq.deg. With the full set of observations, the significance of the BAO detection will be much higher The black line shows the fiducial cosmology: Ω_m=0.27, Ω_Λ=0.73, σ_8=0.8, h=0.71.

LAL/LPSC simulation of mock galaxy catalogs

We take a model linear theory matter power spectrum and generate Gaussian realisations of over-densities. Each over-density is populated with galaxies with properties drawn from distributions observed by the GOODS survey. Each galaxy is assigned a spectral energy density from a library created from interpolated CWW and Kinney empirical galaxy templates. We then calculate the observed apparent magnitudes in each LSST filter including the expected photometric and systematic errors. Photo-z's are reconstructed using a $\chi 2$ fitting technique using the galaxy luminosity function as a prior. At this stage we have simulated a survey covering 0.1 < z < 3 over nearly 8000 sq. deg and assuming 100 visits of the survey area.

LSST photometric redshift precision and BAO constraints

Figure 3 shows the expected performance for the LSST *gold sample* (*i*<25) at the ten year depth. These results are derived from simulations that reproduce the distribution of galaxy colors, and luminosities observed by the COSMOS (Lilly et al. 2009), DEEP2 (Newman et al. 2010, *in prep.*), and VVDS (Garilli et al. 2008) surveys. The simulations include the effects of evolution in the stellar populations, galaxy-type-dependent luminosity functions and reddening, redshift distribution and photometric errors. More details are available in the LSST Science Book.

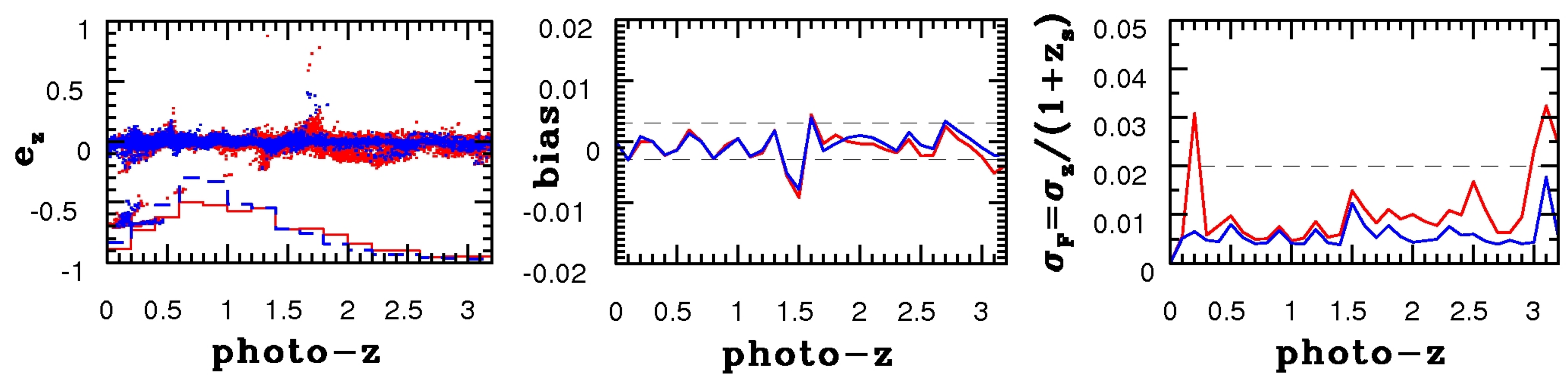

Figure 3: Illustration of the photo-z performance as a function of apparent magnitude and redshift, for a simulation based on the LSST filter set. Red points and curves correspond to a *gold sample* defined by *i* < 25, and blue points and curves to a subsample with *i* < 24. The photo-z error is defined as $e_z = (z_p - z_s)/(1+z_s)$. *Left panel:* e_z vs. photometric redshift. The two histograms show redshift distributions of the simulated galaxies. *Center panel:* the median value of e_z (i.e., the bias in estimated redshifts) as a function of redshift. *Right panel:* The rms, determined from the interquartile range of e_z, as a function of photometric redshift. The horizontal dashed line shows the science driven design goal.

LSST BAO can achieve percent level precision on nine co-moving distances between z = 0.29 and z = 3.1 with WMAP five-year priors (solid line). The BAO constraints are highly complementary to those from WL; please refer to the WL poster for details on the combined constraints. Stronger priors from Planck will further reduce the errors to around 0.5% (open circles). The right-hand side of figure 4 shows constraints on the photometric redshift bias parameter. Results of the full set of auto and cross power spectra between different redshift bins are shown in filled circles, and those of the auto power spectra are in open circles (only to demonstrate that most of the self-calibration of the photo-z error distribution is from the cross power spectra).

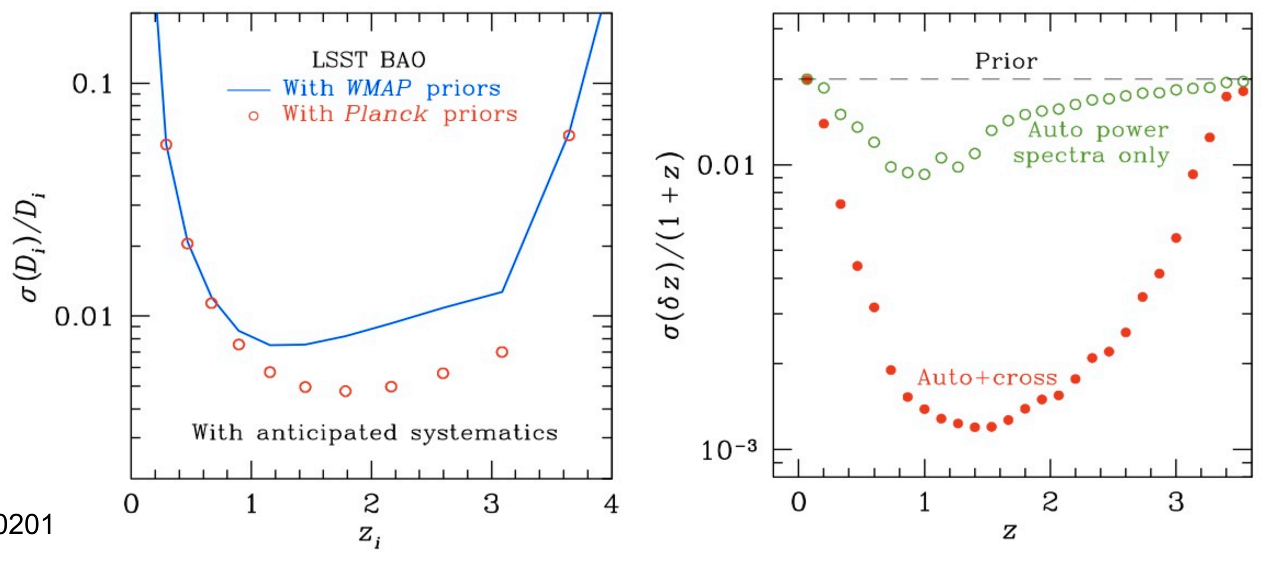

Figure 4: *Left panel*: Marginalized 1σ errors on the co-moving distance from LSST angular BAO measurements. The photo-z bias is assumed to be known within $\pm 0.2\sigma_z$. *Right panel:* Marginalized 1σ constraints on the photo-z bias parameters from the galaxy auto power spectra (open circles) and full set of galaxy auto and cross power spectra (filled circles). The thin dashed line marks the imposed weak prior on the photo-z bias.

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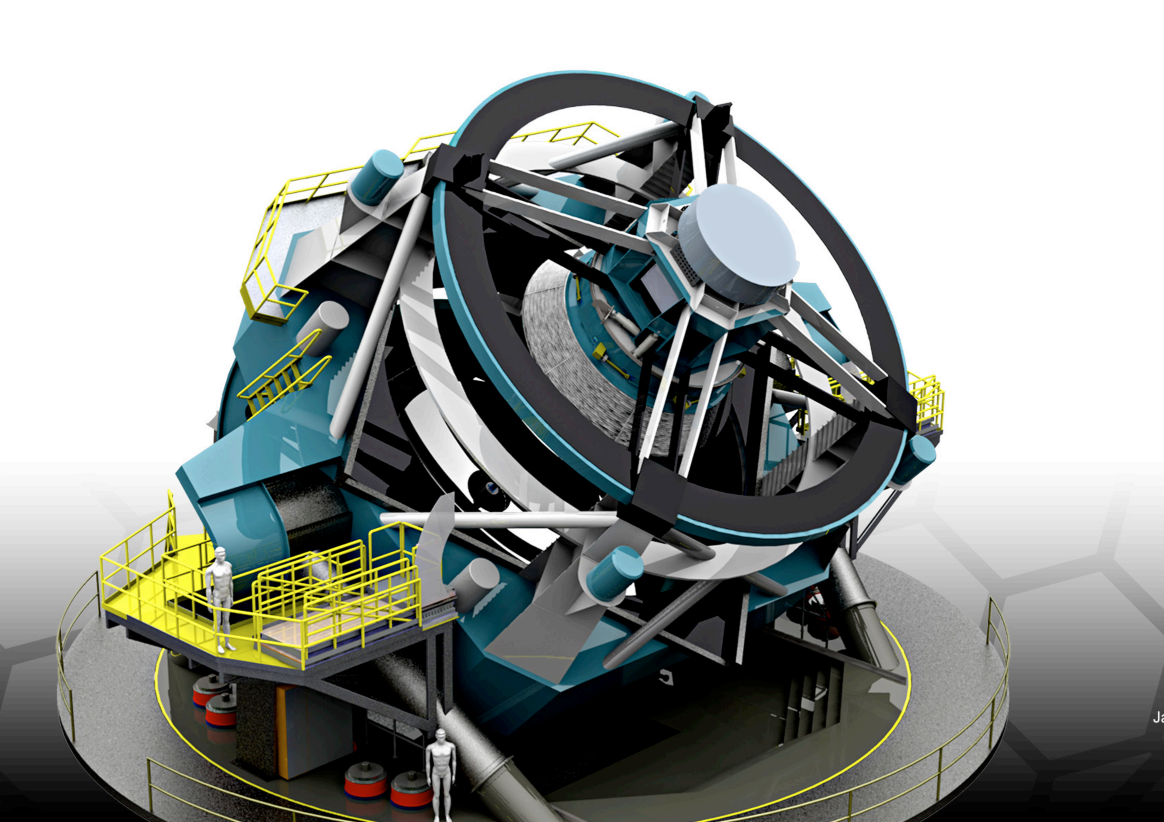

January 2011

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.