Large Synoptic Survey Telescope

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LSST as a Large-Scale Structure Telescope: Probing Cosmology and Galaxy Formation

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Abstract: The Large Synoptic Survey Telescope (LSST) will discover billions of distant galaxies in deep co-added *ugrizy* images over its primary ten-year survey. Binning these galaxies by photometric redshift and treating them as point sources will reveal their angular clustering, which traces the large-scale structure of the universe. A key feature in the galaxy angular correlation function is the Baryon Acoustic Oscillation (BAO) scale, which measures the expansion history of the universe and thereby probes the properties of dark energy. The growth of cosmic structure revealed by the number density of galaxy clusters as well as by non-linear growth in the small-scale galaxy power spectrum will distinguish between dark energy and modifications to General Relativity. The full angular power spectrum of galaxies contains additional information about neutrino masses, dark matter properties, and primordial non-gaussianity. Dividing billions of galaxies into subsamples based on distance and color will enable measurement of their cross-correlation functions, revealing the relationship between star-forming and passive galaxies and their host dark matter halos in exquisite detail as it evolves over billions of years of cosmic time.

Baryon Acoustic Oscillations

Cosmological density fluctuations in the early universe created sound waves in the photon-baryon fluid. At recombination, the formation of neutral hydrogen ended the coupling of photons to baryons, freezing these sound waves in place. This created a *standard ruler* at a scale equal to the sound horizon at recombination, a comoving scale of 150 Mpc. Because a significant fraction of the mass in the universe is baryonic, this scale remains imprinted in the large-scale structure of the galaxy distribution as a small excess of galaxies at a separation of 150 comoving Mpc from other galaxies. This baryon acoustic oscillation (BAO) appears in the galaxy power spectrum as a damped harmonic sequence, a series of wiggles. The angular scale of these wiggles measured as a function of redshift reveals the distance to those redshifts and hence the expansion history of the universe.

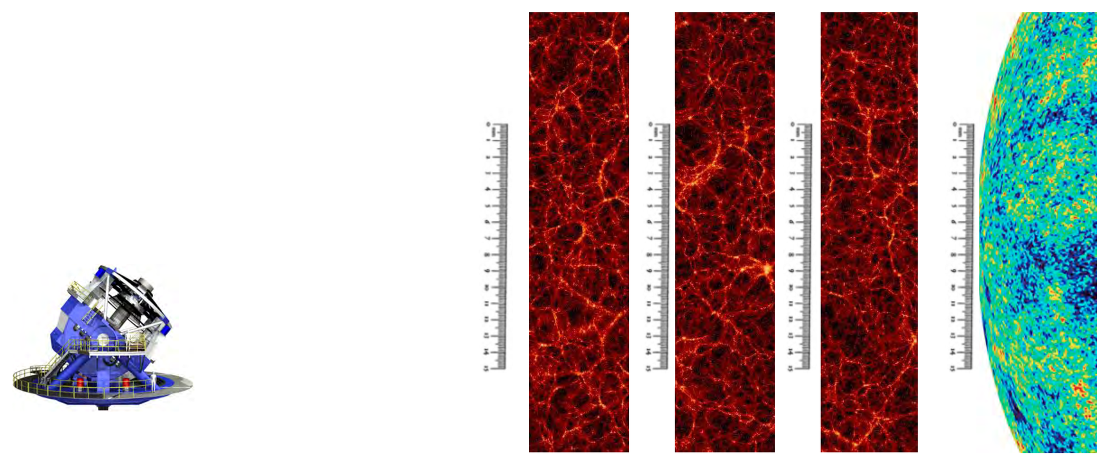


Figure 1: LSST will determine the BAO scale over $0<z<3$, providing the lever arm needed to measure the cosmic expansion. The comoving BAO scale is determined precisely by the CMB at z=1100.

LSST Photometric Redshift Precision and BAO Constraints

Photometric redshift (a.k.a. photo-z) errors can dilute the observed strength of the BAO signal (e.g., Abate et al. 2010). Nonetheless, Figure 2 shows that even with a conservative assumption of σ_z=0.05(1+z), LSST BAO can achieve percent level precision on eight co-moving distances between *z* = 0.6 and *z* = 3.1 with WMAP five-year priors. Stronger priors from Planck will further reduce the errors to around 0.5%. The right-hand side of Figure 2 shows that biases in photometric redshifts can also be constrained and demonstrates the method of photo-*z* self-calibration (Zhan 2006, Zhan et al. 2009). The photo-z calibration will be refined through cross-correlation with spectroscopic samples (Newman 2008, Matthews & Newman 2010).

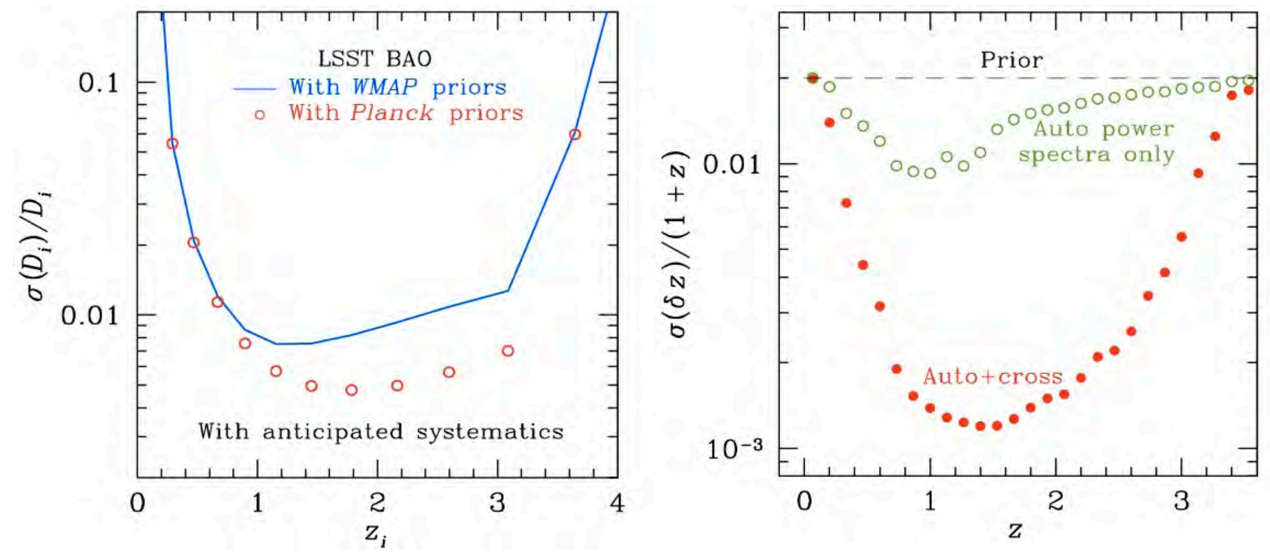
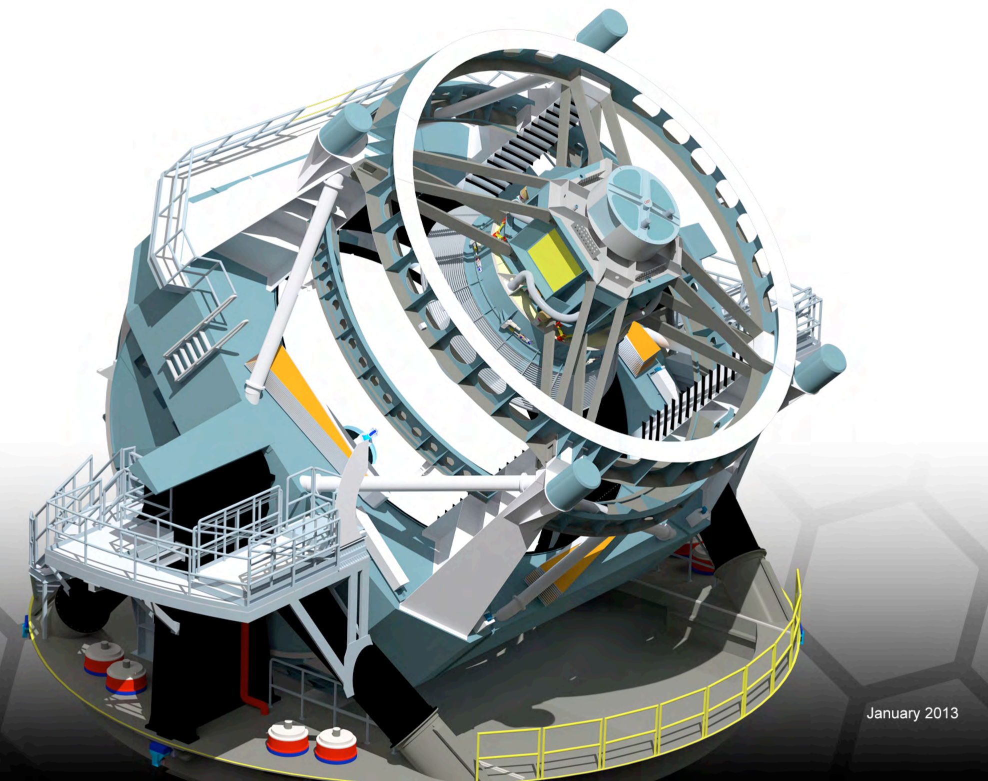


Figure 2: *Left panel*: Marginalized 1σ errors on the co-moving distance from LSST angular BAO measurements. The photo-*z* bias is assumed to be known within $\pm 0.2\sigma_z$. *Right panel:* Marginalized 1σ constraints on the photo-*z* bias parameters from the galaxy auto power spectra (open circles) 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. See the *LSST Science Book*, Chapter 13 for details.



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Dark Energy or Modified Gravity?

Is the late time acceleration of the universe caused by new physics in the form of dark energy or by the failure of General Relativity on large scales? LSST answer this question by probing both cosmic expansion and the gravitational growth of cosmic structure. Structure growth will be revealed by the number density of galaxy clusters as a function of redshift and by non-linear growth in the small-scale galaxy power spectrum. BAO is a particularly effective probe of cosmic expansion when combined with weak gravitational lensing (WL, which also probes the growth of structure) due to complementary systematic errors. A full description including discussion of systematics can be found in the LSST Dark Energy Science Collaboration *White Paper* (2012). Following the approach of Acquaviva & Gawiser (2010), we will first check for a statistically significant disagreement with the standard GR+ΛCDM model before determining parameters for dark energy or modified gravity models.

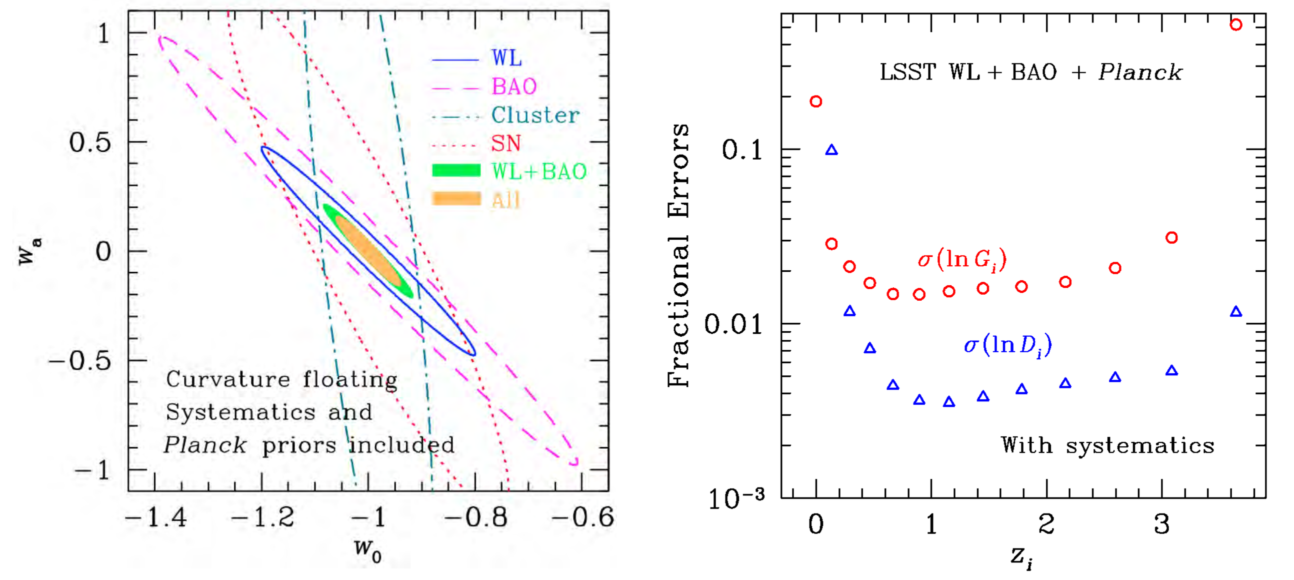

Figure 3: *Left panel*: Joint w_0–w_a constraints from LSST BAO (dashed line), WL (solid line), cluster counting (dash-dotted line), supernovae (dotted line), joint BAO and WL (green shaded area), and all combined (yellow shaded area). *Right panel:* Marginalized 1σ errors on the co-moving distance (blue triangles) and growth factor (red circles) from joint BAO and WL analysis. From *LSST Science Book* Figures 15.3, 15.2.

Further Probes of Cosmology: Neutrino Masses, Dark Matter Properties and Non-Gaussianity

Large-scale structure is far richer than just BAO information, and the full shape of the galaxy power spectrum will be used to improve cosmological constraints. Due to their very low particle masses, neutrinos were still relativistic in the early universe, allowing neutrino diffusion to suppress density perturbations on scales smaller than the neutrino free-streaming length. LSST will detect this suppression to measure a sum of neutrino masses as low as 0.05 eV, which can distinguish an "inverted" mass hierarchy, where the two most massive neutrino flavors have nearly equal masses, from a normal hierarchy. In a similar manner, if the primary dark matter is "warm" instead of "cold", the power spectrum measured by LSST will be suppressed at moderate scales. Finally, the possible presence of non-gaussian density perturbations from the inflationary epoch shortly after the Big Bang will be probed by galaxy clustering at the largest scales as well as higher order statistics such as the galaxy 3-point correlation function. See the *LSST Science Book*, Chapter 15 for details.

Tracing Galaxy Formation and Evolution

The large-scale structure of the galaxy distribution is also a sensitive probe of the dark matter halo masses of galaxies and of their evolution with redshift. This is revealed through the bias factor of a given sample of galaxies, which determines how strongly they cluster versus the dark matter particles themselves. Figure 4 offers one simulated example of how this information will be used by LSST to probe the relationship between galaxy color and dark matter halo mass (and halo occupation distribution) as a function of redshift.

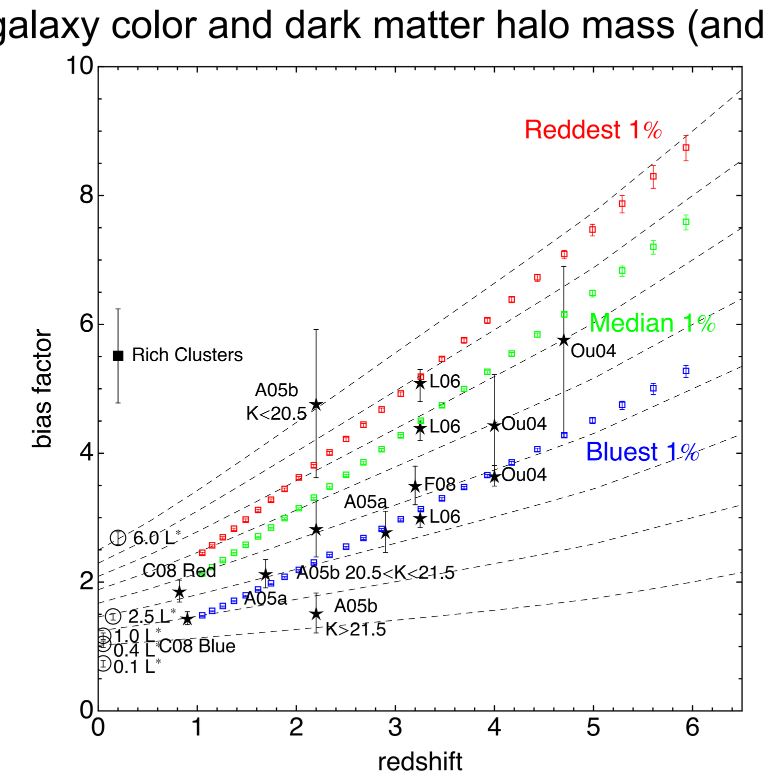

Figure 4: Evolution of galaxy bias versus redshift for three simulated LSST galaxy samples at 1 < z < 6. The three samples are selected to be the 1% of all LSST galaxies at each redshift that is the bluest/ median/reddest in rest-ultraviolet color. The dashed evolutionary tracks show the evolution in bias factor versus redshift based on the Sheth-Tormen conditional mass function. Points with error bars show a compilation of literature bias values. See *the LSST Science Book*, §9.5 for details.

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