Large Synoptic Survey Telescope

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LSST Cosmological Probes

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The final LSST catalog will include six-band (ugrizy) photometry and shape information for several billion galaxies filling a huge volume of space and providing unparalleled insight into the distribution of dark matter and baryons from the nearby universe out to Gpc scales. The richness of this data will allow for a number of different techniques (weak lensing, BAO, cross-correlations, galaxy cluster, supernovae, etc.) to be used simultaneously and over several photometric redshift slices. This will provide crucial interlocking cross checks on each of the individual measurements, reducing the overall sensitivity to systematic errors and tightening the resulting cosmological constraints. More generally, the statistical power of this data set will allow us to go beyond merely constraining the standard LCDM cosmology and test for more exotic possibilities like modifications to General Relativity or spatial and redshift variations in dark energy. This poster summarizes the current best estimates for how well LSST will address each of these questions.

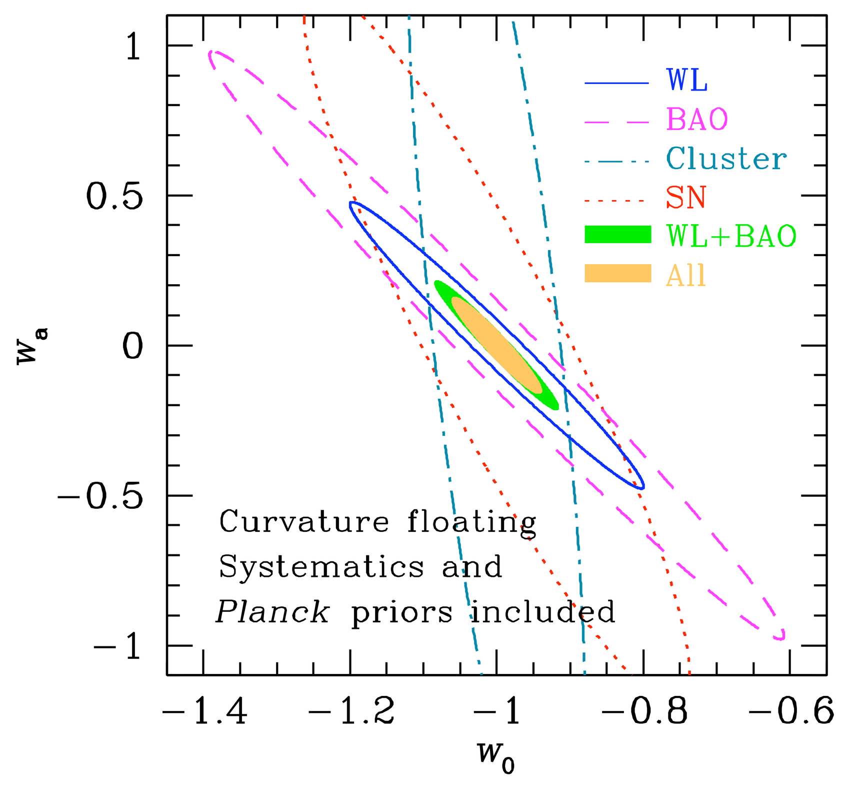
Multi-Pronged Analysis

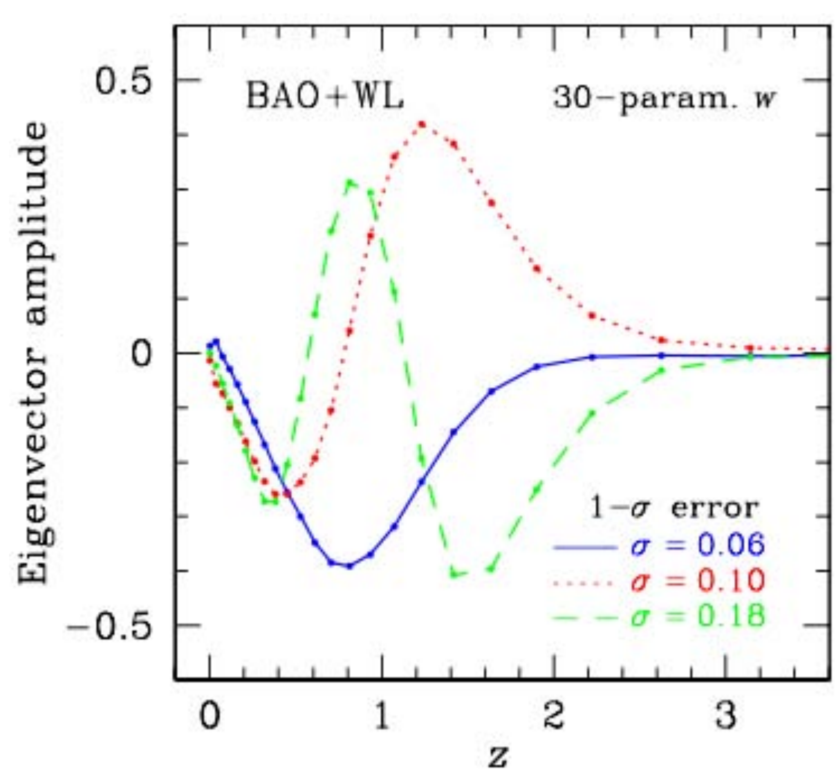
The lack of multiple complementary precision observations is a major obstacle in developing lines of attack for dark energy theory. LSST will address this problem via the powerful techniques of weak lensing (WL) and baryon acoustic oscillations (BAO) in addition to SNe, cluster counts, and other probes of geometry and growth of structure. This multi-pronged approach enables not only cross checks of the result from each technique but also detections of unknown systematics and cross-calibrations of known systematics. Consequently, one can achieve far more robust constraints on cosmological parameters and confidently explore the physics of the Universe beyond what we know now.

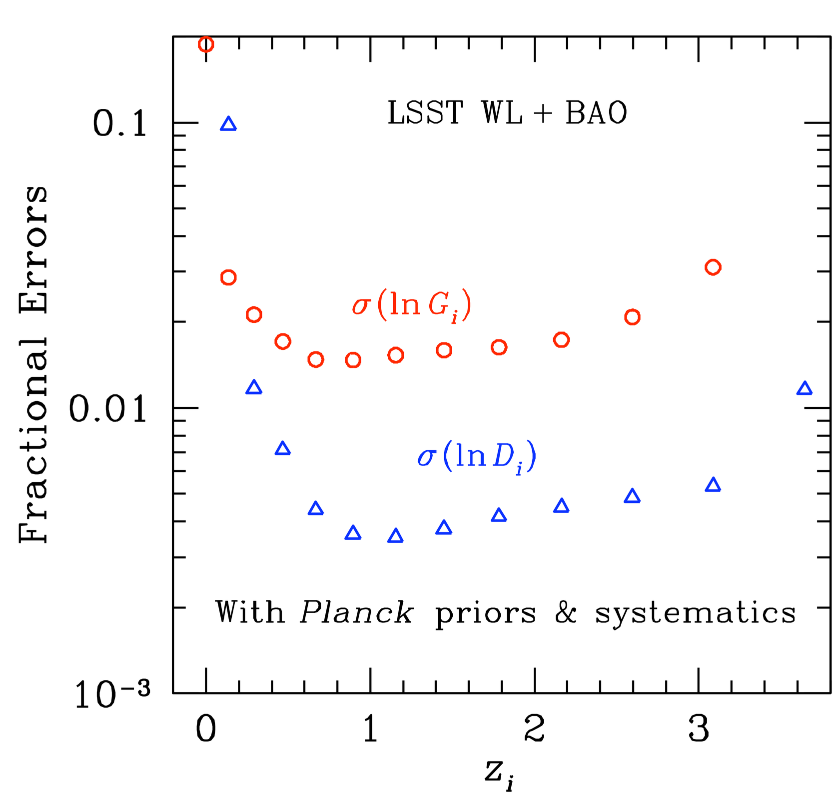
We begin by looking at the dark energy model considered by the Dark Energy Task Force (Albrecht et al. 2006), where the dark energy EOS is given by $w = w_0 + w_a(1 - a)$. The **upper figure** shows the w_0-w_a constraints combining four LSST probes of dark energy: BAO, cluster counting, supernovae, and WL. The cluster counting result is from Fang & Haiman (2007) and the supernova result is based on Zhan et al. (2008). Because each probe has its own parameter degeneracies, the combination of any two of them can improve the result significantly. When all the four probes are combined, the error ellipse area decreases by ~30% over the joint BAO+WL result.

The w_0-w_a model significantly underestimates the full capabilities of Stage 4 surveys (Albrecht & Bernstein 2007), such as LSST. More generally, one may allow the EOS to vary independently at different redshifts and let the data determine the EOS eigenmodes and their errors, which can then be used to constrain dark energy models. The **middle figure** presents the best determined dark energy EOS eigenmodes and their errors from LSST BAO+WL for a 30-dimensional EOS model (Albrecht & Bernstein 2007; Albrecht et al. 2009). The best constrained mode is effectively w at z ~ 0.8, the next mode, the slope of w from z ~ 0.3 to 1.1 and so on. By considering these modes, we can understand the strengths and weaknesses of the survey in differentiating between different dark energy models.

Alternatively, we can consider dark energy properties as derived from the distance-redshift and growth-redshift relations. By measuring these relations directly rather than constraining the parameters of a particular model, we can confront any set of dark energy models on an equal footing and potentially distinguish dark energy from modified gravity (above, right). The **lower figure** shows that joint LSST BAO and WL can achieve ~0.5% precision on the distance and ~2% on the growth factor from z = 0.5 to 3 in each interval of Δz ~ 0.3 (Zhan et al. 2009).

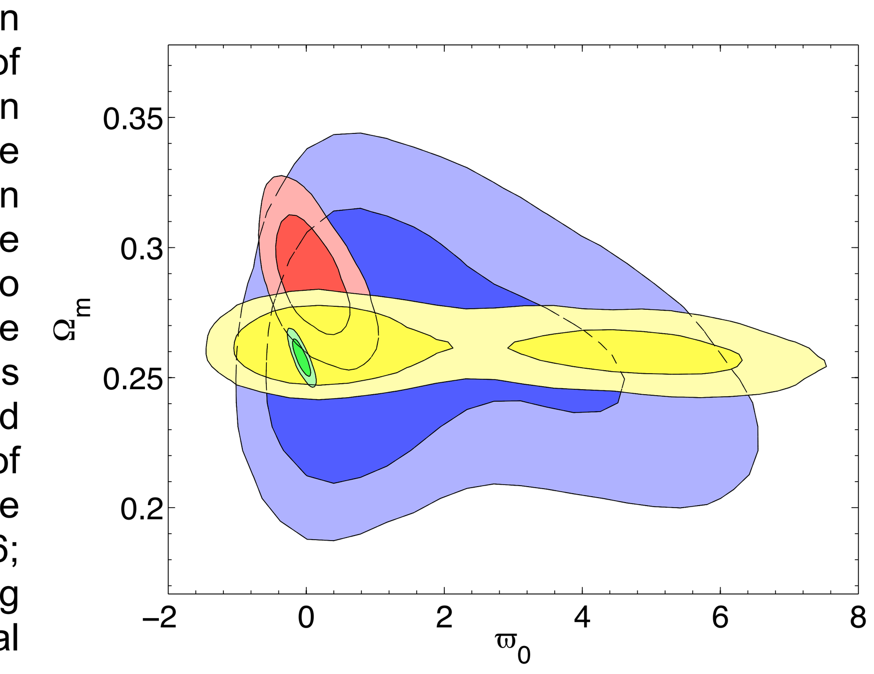






Modified Gravity

The acceleration of the Universe is such an unexpected feature that it has spawned a number of explanations. The simplest solution is found in Einstein's General Theory of Relativity (GR), in the form of the infamous cosmological constant. In addition to this possibility, there is an even more radical solution: modifying gravity itself. Although no compelling theory currently exists, suggestions include modifications to GR arising from extra dimensions, as might be expected from string theory braneworld models. There are potentially measurable effects of such exotic gravity models that LSST could probe (e.g., Lue et al. 2004; Song 2005; Ishak et al. 2006; Knox et al. 2006a; Zhang et al. 2007), and finding evidence for extra dimensions would signal a radical departure from our present view of the Universe.



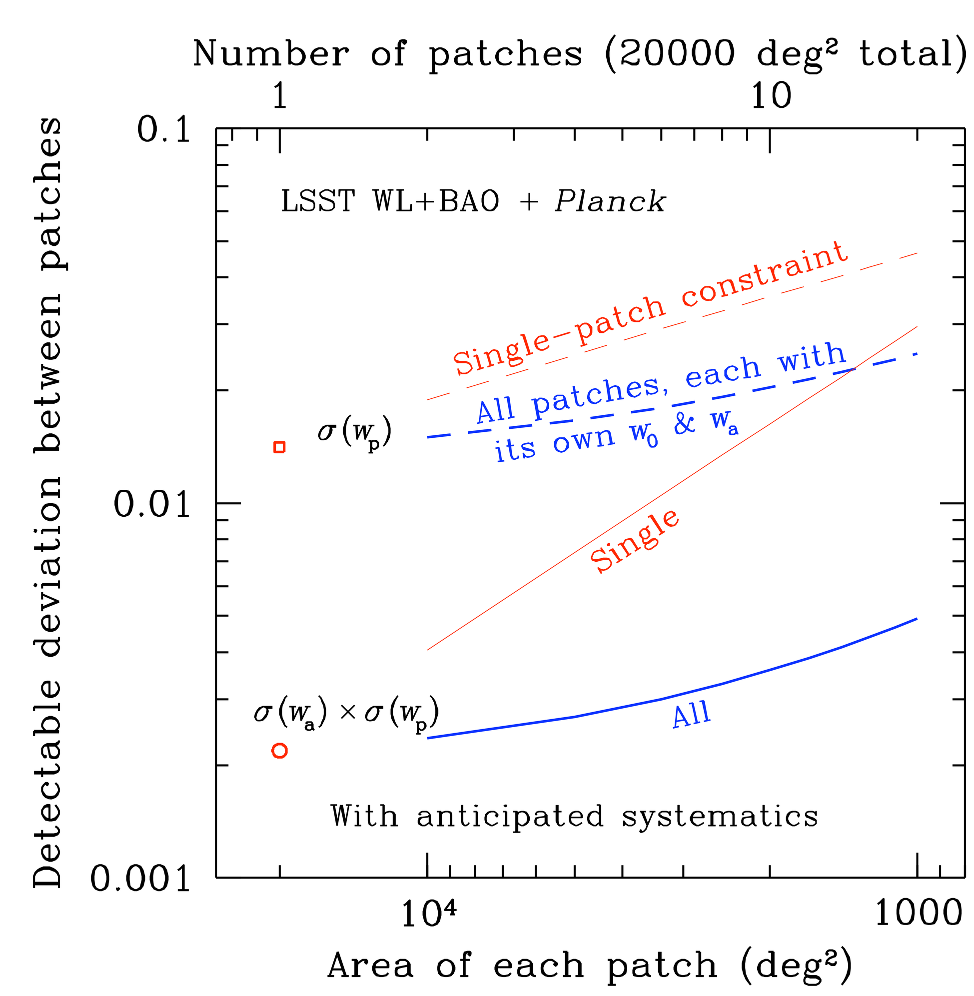
In GR, the potential fluctuations (ψ) are equal to the curvature perturbations (ϕ). For modified gravity, one expects that the Poisson law is modified, changing the laws for ψ and ϕ. WL and spectroscopic galaxy surveys together can provide consistency tests for the metric perturbations, density fluctuations, and velocity field in the GR framework (e.g., Zhang et al. 2007; Song & Dore 2008). The difference between ψ and ϕ can be characterized (Daniel et al. 2009) by the *slip*: ϖ, where $\psi(k,a) = (1 + \varpi(k,a))\phi(k,a)$.

If we consider a model where ϖ is a simple known function of time, the **above figure** (from Daniel et al. 2009) shows how LSST can significantly improve on current data. The blue contours show the projected 68% and 95% contours in the Ω_M-ϖ_0 plane for the 5-year WMAP data. Adding current weak lensing and ISW data yields the red contours. Mock CMB data from *Planck* produces the yellow contours. Finally, the addition of WL measurements from an LSST-like survey tightens the constraints to the green region.

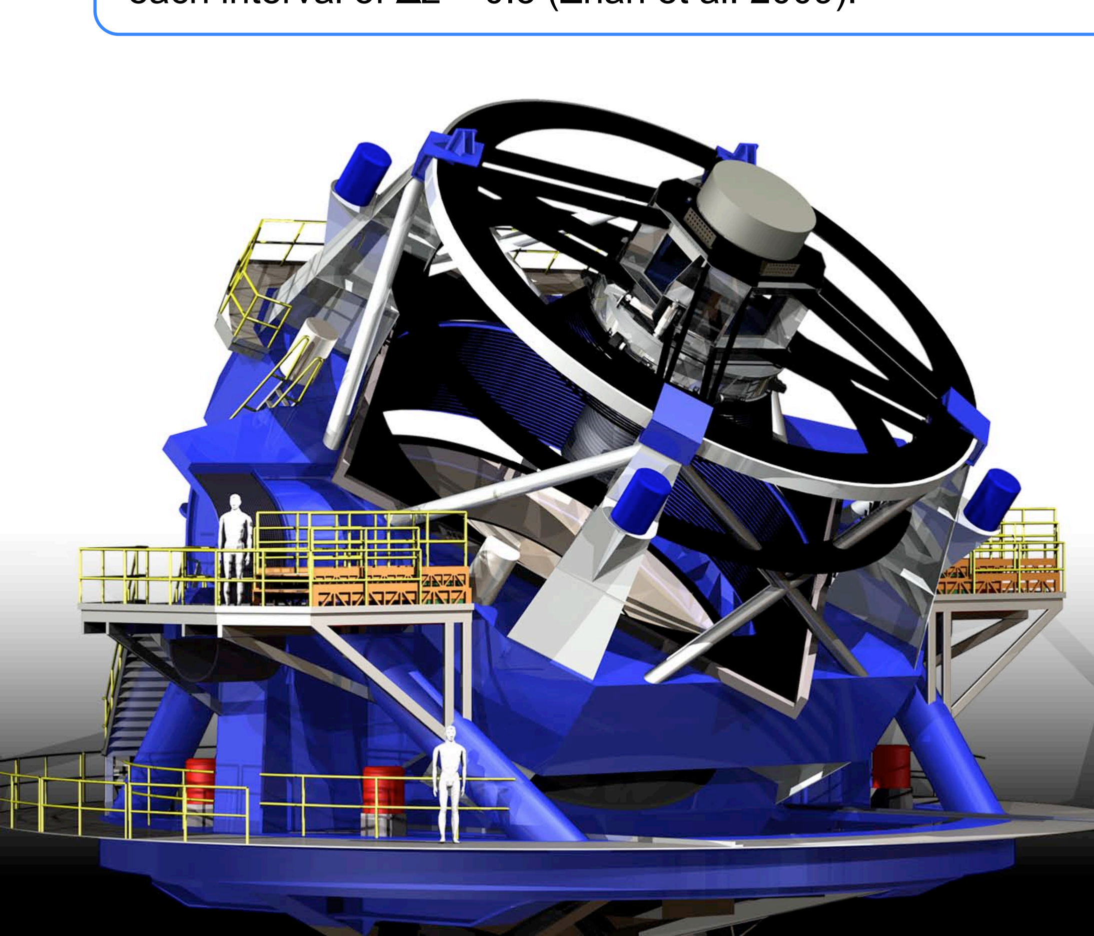
Dark Energy Anisotropy

By providing measurements of WL shear, BAO, and other observables in different directions on the sky covering ~100 degree scales, LSST will address specific questions related to clustering on the largest scales. These range from the clustering of dark energy to exotic models that require horizon scale tests. Because of its wide and deep coverage, the 20,000 square degree LSST survey of billions of galaxies has the power to test isotropy to percent level precision.

LSST is well-suited for testing dark energy anisotropy. Its wide survey area enables one to measure dark energy properties in many patches and to potentially detect their variations across the sky; its deep imaging not only results in more usable galaxies for more accurate measurements of the distances and growth function, but also allows one to probe the differences in the evolution of dark energy properties across the patches.



The results of dark energy anisotropy tests using the joint LSST BAO (galaxy power spectra) and WL (shear power spectra) analysis are shown in the **figure above** (from Zhan et al. 2009), where we let each patch of sky have its own w_0 and w_a in this section. The rest of the parameters are assumed not to vary from patch to patch and, thus, are shared among the patches. We find only a small degradation in sensitivity to the dark energy EOS parameters that are allowed to vary independently in up to ~10 different patches of the LSST survey area, if the other marginalized cosmological parameters are shared between patches. Each patch achieves nearly the same precision of measurement of the dark energy parameters as the full survey. For comparison, the red curves labeled "single" are for independent determination of all parameters for each patch. The single patch (w_p) line (and the single patch error product) is what one would get from just doing the LSST survey over that smaller patch area.



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