Large Synoptic Survey Telescope

Cosmology with Photometric Baryon Acoustic Oscillation Measurements

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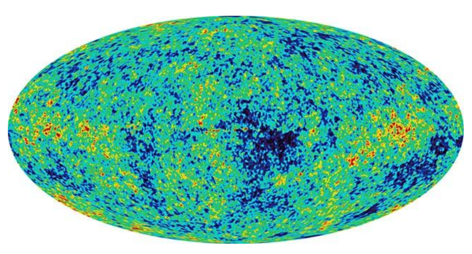
LSST will obtain photometric redshifts for 4 billion galaxies with the distribution peaking around z = 1 and approximately 10% of the galaxies at z > 2.5. It will achieve percent level precision on the angular diameter distance at 11 redshifts logarithmically spaced between z = 0.3 to 3.6 with a CMB-calibrated standard ruler -- baryon acoustic oscillations (BAO) in the galaxy (and matter) power spectrum. By themselves, LSST BAO will provide weaker constraints on the dark energy equation of state parameters, w_0 and w_a, than LSST weak lensing (WL). However, because one can calibrate the error distribution of photometric redshifts with galaxy power spectra and determine the galaxy bias with galaxy and WL shear power spectra, a joint analysis of LSST BAO and WL will reduce the error ellipse area in the w_0 –w_a plane to one sixth of that by LSST WL alone.

1. Baryon Acoustic Oscillations: A Standard Ruler

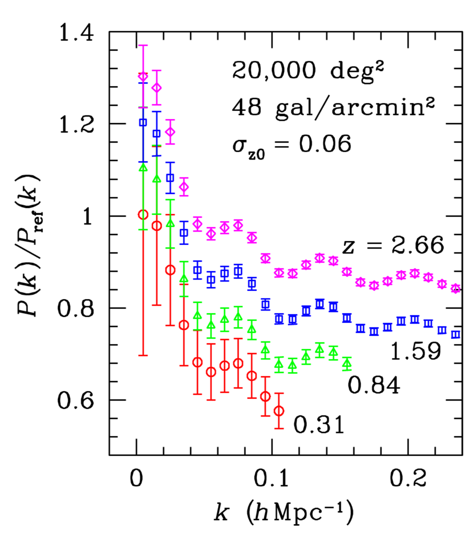
In the tightly coupled photon-plasma fluid prior to recombination, acoustic waves, supported by the photon pressure, create a characteristic scale – the sound horizon R_S in matter distribution. Afterward, the sound speed of the neutral gas practically drops to zero, and thus the imprint of R_S at recombination, e.g., BAO, is frozen (but still evolves gravitationally) in the matter and later galaxy correlation functions. The sound horizon at recombination can be determined accurately with CMB, so that BAO becomes a very promising standard ruler for measuring the angular diameter distance and Hubble parameter (e.g. Eisenstein, Hu, & Tegmark 1998, ApJ, 504, L57).



Cosmic Microwave Background
(NASA/WMAP Science Team)

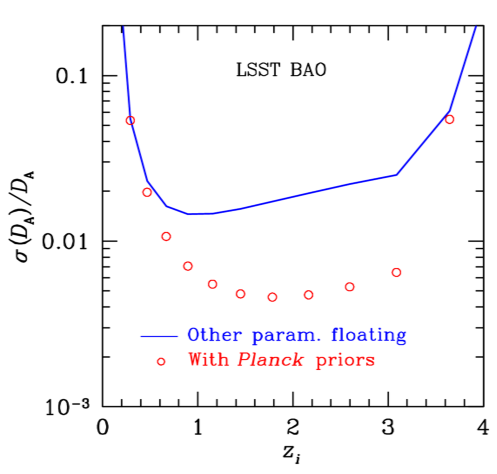
Sound horizon at recombination

R_S ~ 150 Mpc



LSST Galaxy Power Spectrum

Angular scales of BAO $\Delta\theta$ as a function of redshift



Angular Diameter Distance

$D_A = R_S / \Delta\theta$

Constraints on ω_m, Ω_K, w_0, w_a, …

Spectroscopic surveys: radial scales of BAO Δz

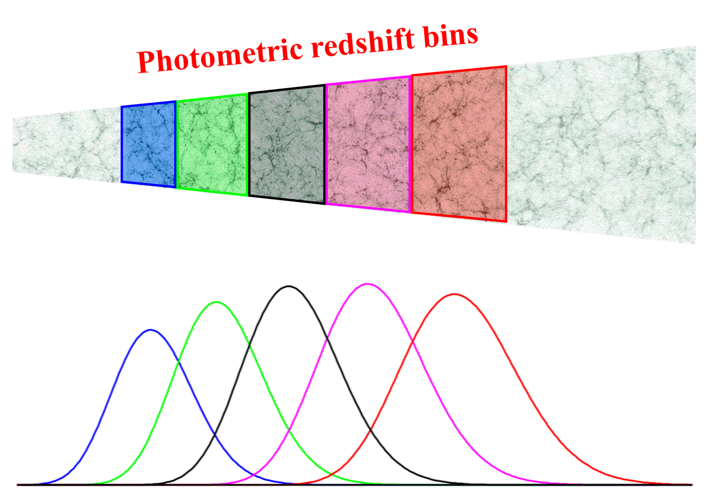
Hubble Parameter

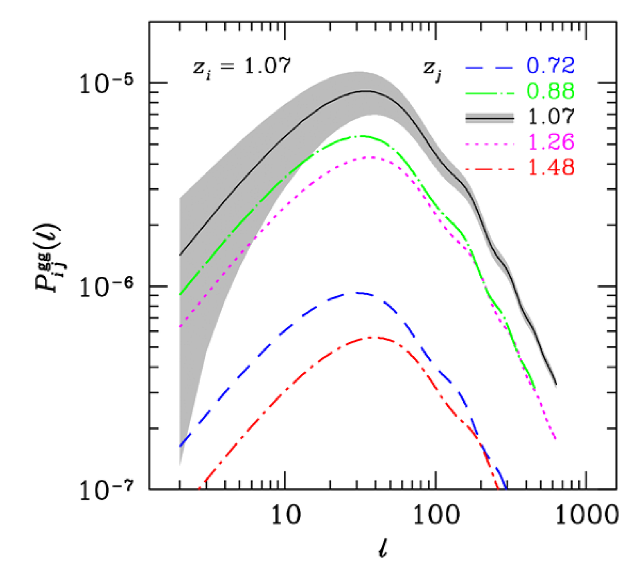
$H = c\,\Delta z / R_S$

2. Angular Galaxy Power Spectrum

Owing to its deep photometry and wide survey area, LSST will be able to obtain billions of galaxies with photometric redshifts (photo-zs) over a huge survey volume. This sample will allow for accurate measurements of the BAO features in the angular galaxy power spectra and place useful constraints on cosmological parameters.

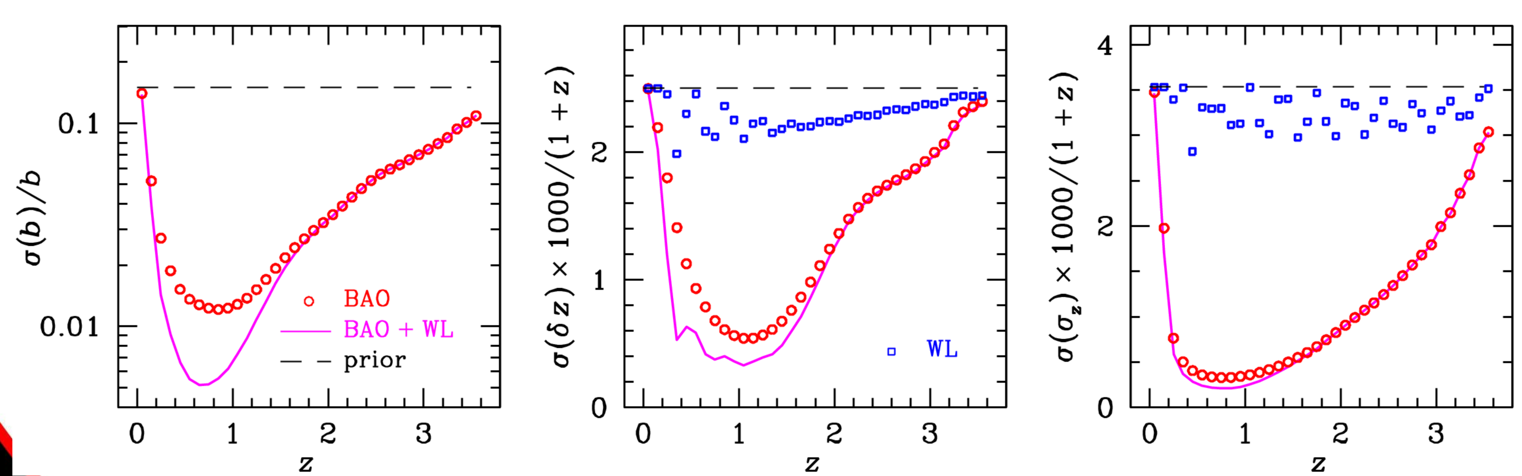
The kernel of the galaxy power spectrum is given by the true-redshift distribution of galaxies binned by their photo-zs, which can have considerable overlap with each other. Hence, one can measure not only the auto power spectrum in each photo-z bin but also the cross power spectrum between two different photo-z bins.





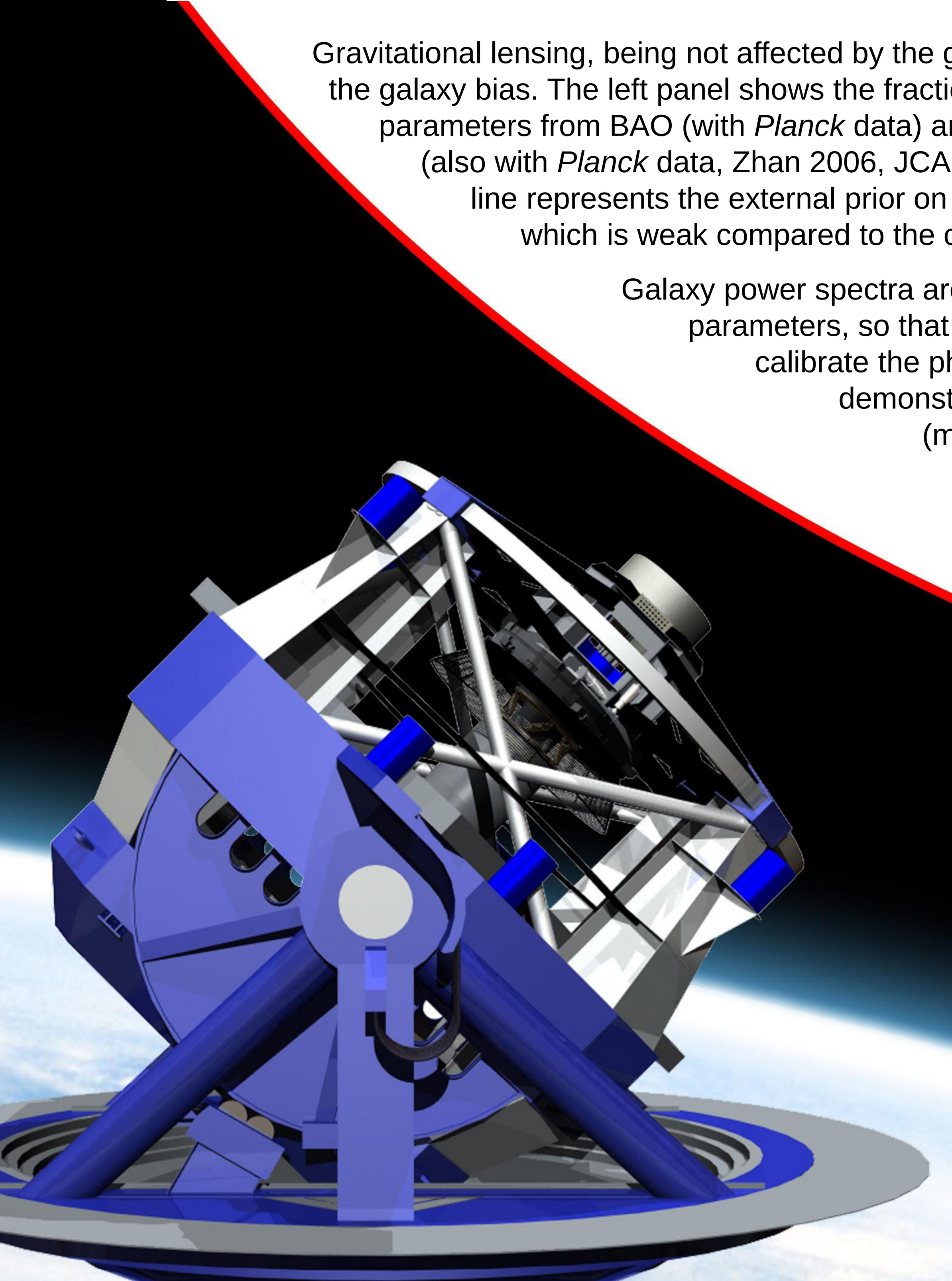
Left: Photo-z bins and the true-z distribution of galaxies. We assume that the photo-z bias $\delta z = 0$ and the photo-z rms σ_z=0.05(1+z) per galaxy. *Right*: The galaxy auto power spectrum of bin *i* at z~1.07 (solid line) and cross power spectrum between bin *i* and bin *j* (broken lines). The BAO features are prominent at *l* ~ several hundred. The grey area indicates the statistical error of the auto power spectrum at each multipole.

3. Calibrating the Photo-z Parameters and Galaxy Bias

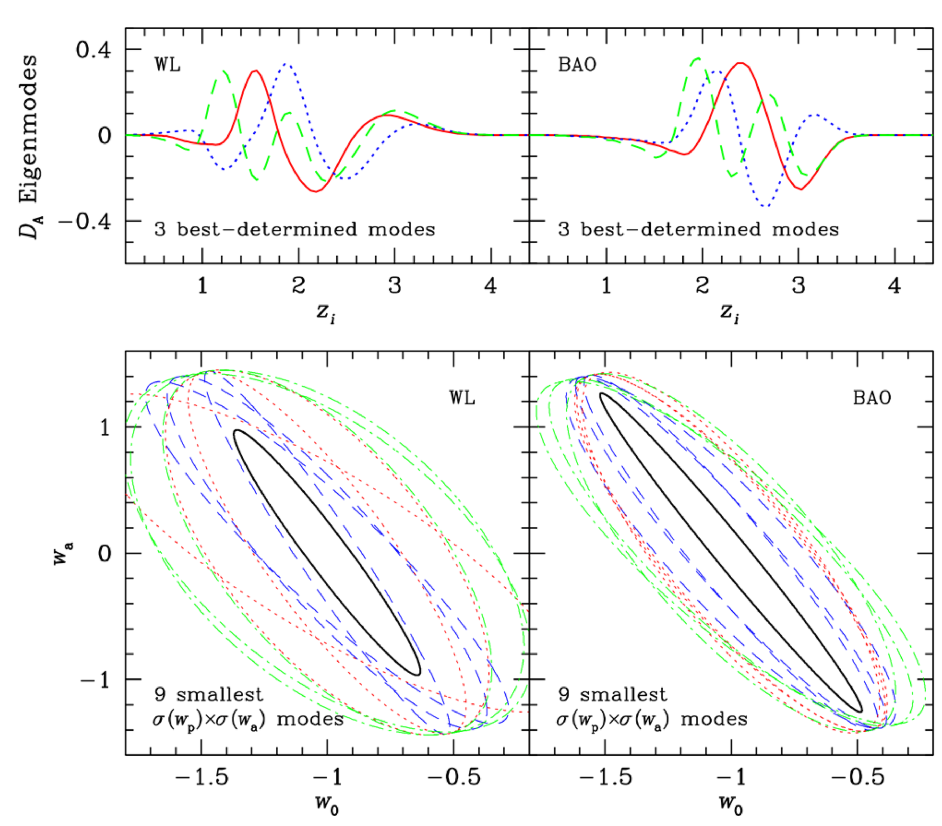


Gravitational lensing, being not affected by the galaxy bias, can help constrain the galaxy bias. The left panel shows the fractional error on the galaxy bias parameters from BAO (with *Planck* data) and from joint BAO and WL (also with *Planck* data, Zhan 2006, JCAP, 08, 008). The thin dashed line represents the external prior on the galaxy bias parameters, which is weak compared to the constraints.

Galaxy power spectra are sensitive to the photo-z parameters, so that they can be used to self-calibrate the photo-z parameters. This is demonstrated for the photo-z bias (middle panel) and rms error (right panel).



4. Distance Eigenmodes

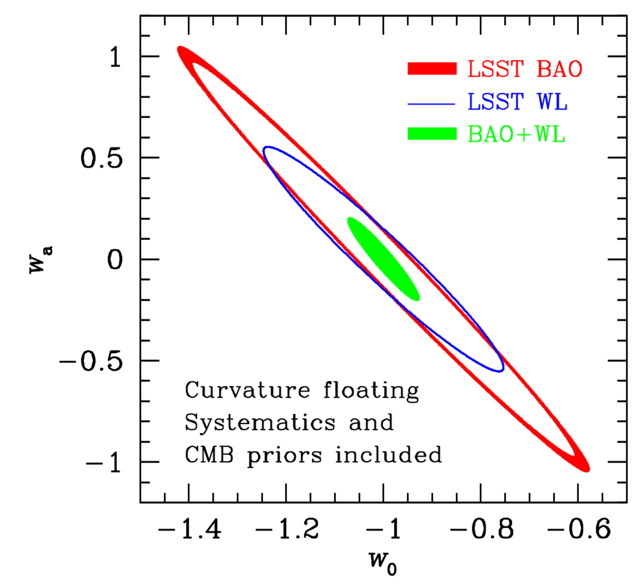


The upper panel of the figure on the left shows the 3 best-determined distance modes from LSST WL and BAO, respectively. The WL modes are more concentrated at lower redshifts than the BAO modes, because WL measures the fluctuations at lower redshifts than the source galaxies and because the galaxy power spectra are truncated more at lower redshifts to reduce the impact of the nonlinear evolution. Although in general BAO places tighter constraints on individual D_As than WL, the WL modes shown actually have smaller errors than the BAO modes.

The lower panel presents uncorrelated w_0 and w_a [$w = w_0 + w_a\, z\,(1+z)^{-1}$] constraints from 9 D_A eigenmodes (in 3 groups) of each technique. Weak priors on cosmological parameters and $\sigma_P(w_0) = \sigma_P(w_a) = 1$ are applied. The linear growth rate parameters and the galaxy bias parameters are marginalized. The solid contours include the contributions of all D_A modes. The BAO error ellipses are relatively narrow but in the same general direction, whereas the WL ones are oriented differently. As such, the effect of combining all the BAO modes is mostly in reducing the area of the error ellipse without much change in the marginalized errors of w_0 & w_a.

5. Dark Energy Constraints

The constraints on w_0 and w_a from LSST BAO are weaker than those from LSST WL. However, a *joint* analysis of BAO and WL data benefits from the extra information in the galaxy—shear power spectra, the calibration of the linear galaxy bias, and the calibration of photo-z parameters by the galaxy power spectra (Zhan 2006, astro-ph/0605696). It tightens the constraints considerably. This plot is for 10-year survey.



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