Baryon Oscillations and Dark Energy Constraints from Imaging Surveys

Derek Dolney

Bhuvnesh Jain

Masahiro Takada

Department of Physics and Astronomy

University of Pennsylvania

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1 Abstract

Baryonic oscillations in the galaxy power spectrum have been studied as a way of probing dark energy models. While most studies have focused on spectroscopic surveys at intermediate/high redshift, several multi-color imaging surveys have already been planned for the near future. In view of this, we study the prospects for measuring baryonic oscillations from angular statistics of galaxies binned using photometric redshifts. While baryonic features in the galaxy power spectrum alone allow one to constrain dark energy parameters, a measurement of the bispectrum allows one to additionally constrain a possibly scale dependent bias and mass power spectrum amplitude. Thus we can obtain robust constraints on dark energy models even from imaging surveys. We discuss the prospects for different survey parameters.

2 Theory

The dark energy formalism introduces a time dependent density described by the dark energy equation of state:

$$w(a) := \frac{p_{\mathrm{de}}}{\rho_{\mathrm{de}}} = -\frac{1}{3}\frac{d\ln\rho_{\mathrm{de}}}{d\ln a} - 1. \tag{1}$$

We parameterize the equation of state as

$$w(a) = w_0 + w_a(1-a). \tag{2}$$

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We suppose a biasing prescription to obtain the galaxy density contrast from the matter density:

$$\delta_{\mathrm{g}} \quad := \quad \frac{\delta n_{\mathrm{g}}}{\bar{n}_{\mathrm{g}}} \tag{3}$$

$$= \quad b_1 \delta + \frac{1}{2} b_2 \delta^2 + O(\delta^3). \tag{4}$$

We calculate the projected galaxy power spectrum using the Limber approximation:

$$P_l = \frac{1}{\bar{n}_{\mathrm{g}}^2} \int d\chi \left[p_{\mathrm{g}}(z) \frac{dz}{d\chi} \right]^2 \frac{1}{\chi^2} P_{\mathrm{g}} \left(\frac{l}{\chi} \right). \tag{5}$$

Similar for the projected galaxy bispectrum:

$$B(l_1, l_2, l_3) = \frac{1}{\bar{n}_{\mathrm{g}}^3} \int d\chi \left[p_{\mathrm{g}}(z) \frac{dz}{d\chi} \right]^3 \frac{1}{\chi^4} B_{\mathrm{g}} \left(\frac{l_1}{\chi}, \frac{l_2}{\chi}, \frac{l_3}{\chi} \right). \tag{6}$$

To $O(\delta^4)$, the galaxy bispectrum is

$$B_{\mathrm{g}}(k_1, k_2, k_3) \quad = \quad b_1^3 D^4 \left[2 F_2(k_1, k_2) P(k_1) P(k_2) + \text{cyclic } k_i \text{ permutations} \right]$$

$$+ \quad \frac{1}{2} b_1^2 b_2 D^4 \left[2 P(k_1) P(k_2) + \text{cyclic } k_i \text{ permutations} \right] \tag{7}$$

where

$$F_2(k_1, k_2) = \frac{5}{7} + \frac{1}{2} \frac{\mathbf{k}_1 \cdot \mathbf{k}_2}{k_1 k_2} \left(\frac{k_1}{k_2} + \frac{k_2}{k_1} \right) + \frac{2}{7} \left(\frac{\mathbf{k}_1 \cdot \mathbf{k}_2}{k_1 k_2} \right)^2 \tag{8}$$

is the second-order perturbation theory kernel. The power spectrum covariance for bin i with galaxy density $\bar{n}_i$ is

$$C_{l,l'} = \frac{2}{2l+1} \left[P(l) + \frac{1}{\bar{n}_i} \right]^2 \delta_{ll'}. \tag{9}$$

We calculate the bispectrum covariance as

$$C_{l_1 l_2 l_3, l_1' l_2' l_3'} = \Delta_{l_1 l_2 l_3 l_1' l_2' l_3'} \left[P(l_1) + \frac{1}{\bar{n}_i} \right] \left[P(l_2) + \frac{1}{\bar{n}_i} \right] \left[P(l_3) + \frac{1}{\bar{n}_i} \right], \tag{10}$$

using the appropriate combinatorial factor $\Delta_{l_1 l_2 l_3 l_1' l_2' l_3'}$. We assume that the likelihood function for the galaxy power spectrum and galaxy bispectrum is gaussian, and employ a Fisher matrix analysis to approximate the likelihood near the fiducial cosmological model defined by the parameters in Table 1. We use $2 \leq l_1 \leq l_2 \leq l_3 \leq l_{\mathrm{max}}$, where the small scale limit, l_{max}, is meant to represent the scale beyond which perturbation theory is unacceptable. Non-linear effects tend to erase baryon fluctuations, anyway. We define this (redshift-dependent) scale as $l_{\mathrm{max}} = k_{\mathrm{max}}/\chi(z)$, where k_{max} is defined by

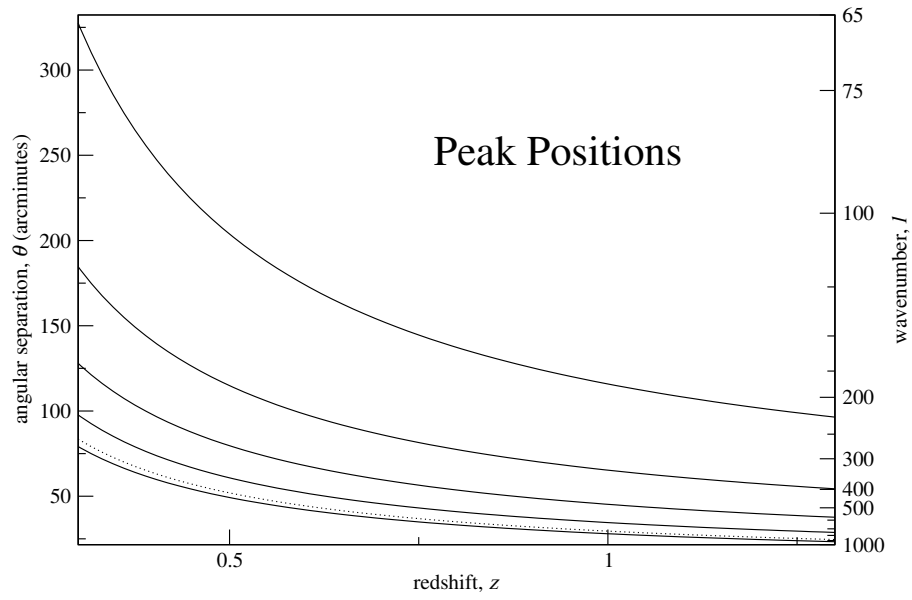$$\sigma^2 = \int_0^{k_{\mathrm{max}}} d^3 k \, P(k) = 1. \tag{11}$$

Figure 1: Angular separation and wavenumber of the first five peaks in the galaxy power spectrum induced by baryon oscillations as a function of galaxy redshift. The dotted line corresponds to our upper cutoff l_{max}.

| Parameter	Fiducial Value	Description
ω_{b}	0.023	Baryon Physical Density
ω_{d}	0.112	Dark Matter Physical Density
Ω_{de}	0.69	Dark Energy Density Parameter
w_0	-1	Equation of State Parameter (Eq. 2)
w_a	0	Equation of State Parameter (Eq. 2)
A_{s}	0.82	Scalar Fluctutation Amplitude at $k = 0.05/\mathrm{Mpc}$
n_{s}	0.979	Primordial Spectral Index at $k = 0.05/\mathrm{Mpc}$
α	0	Primordial Run $(= d\ln n_{\mathrm{s}}/d\ln k)$ at $k = 0.05/\mathrm{Mpc}$
b_1	0.998	First Order Galaxy Bias Factor (Eq. 4)
b_2	0	Second Order Galaxy Bias Factor (Eq. 4)
τ	0.143	Optical Depth
Ω_{m}	0.31	Matter Density
Ω_{b}	0.053	Baryon Density
Ω_{tot}	1	Total Density (Assume Flat Cosmology)
h	0.66	Current Hubble Parameter in Units of 100 km / s / Mpc
σ_8	0.88	Galaxy-Scale Fluctuation Amplitude

Table 1: Our fiducial cosmological model.
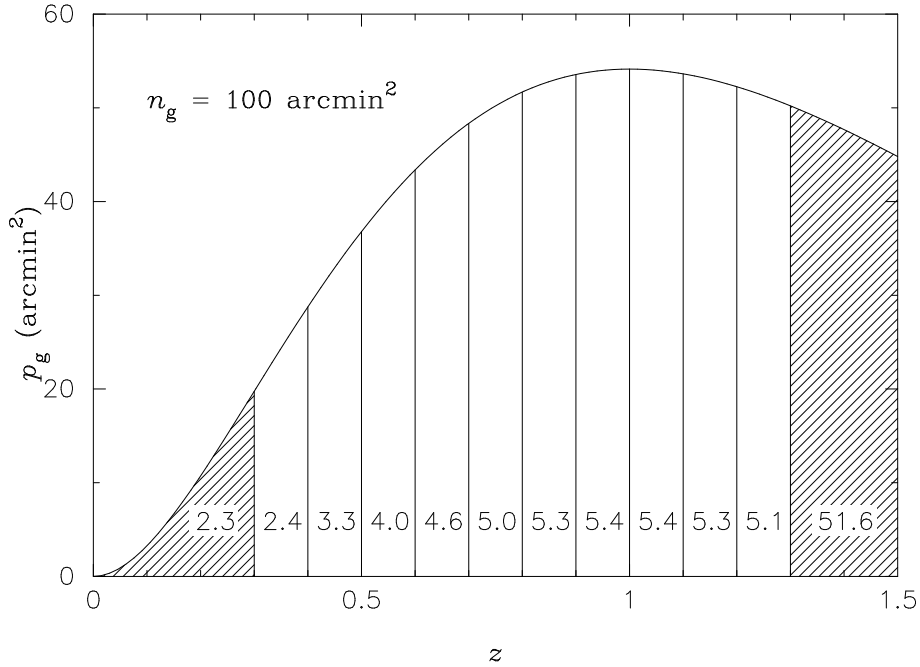
Figure 2: Galaxy redshift distribution and binning scheme employed in our analysis. The shaded regions were not used. The numbers indicate the galaxy number density (per arcmin^2) in each bin, with the last number representing the remaining galaxies from $z = 1.3$ to infinity.
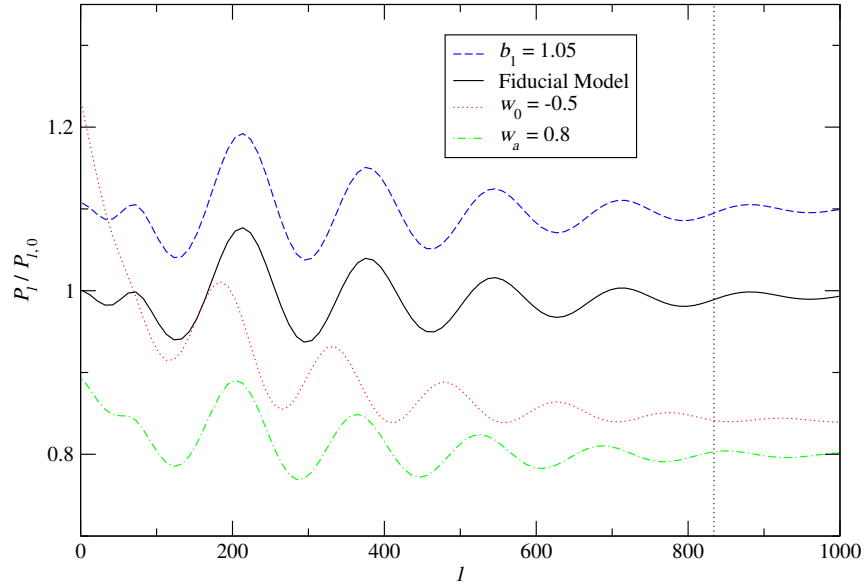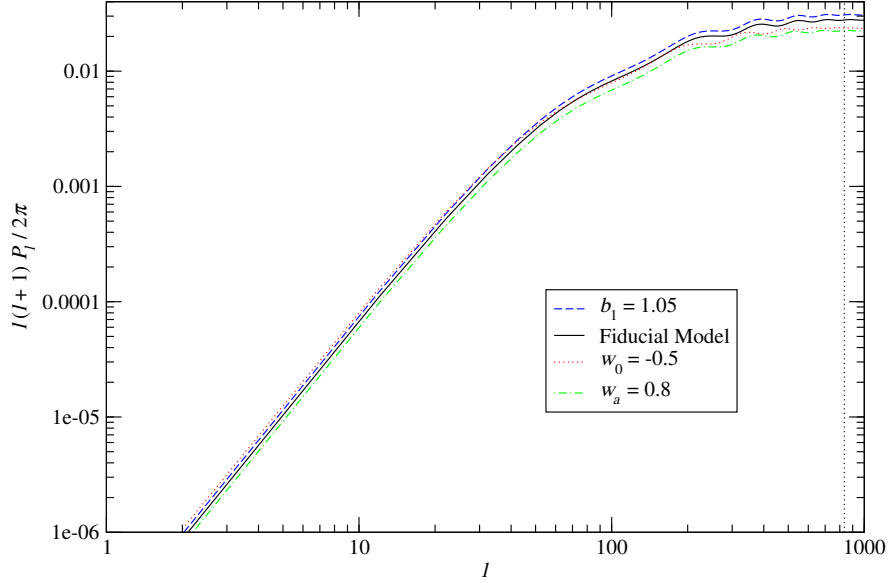
Figure 3: Variations of the projected galaxy power spectrum (Eq. 5) under different choices of parameters. In the lower panel, we divide by a smooth spectrum calculated using the "no-wiggles" transfer function of Eisenstein & Hu (1998). The vertical line indicates $l_{\max}$, the high-l limit of our perturbative approximation.
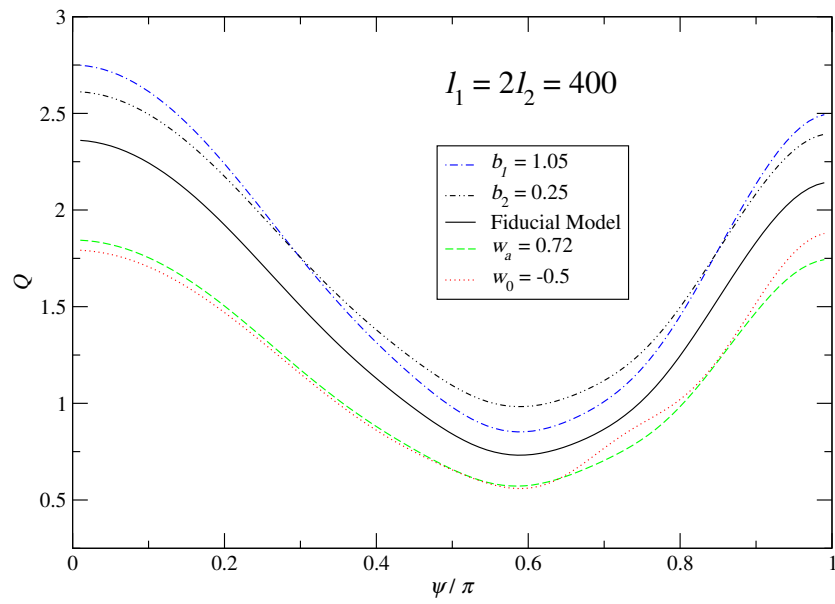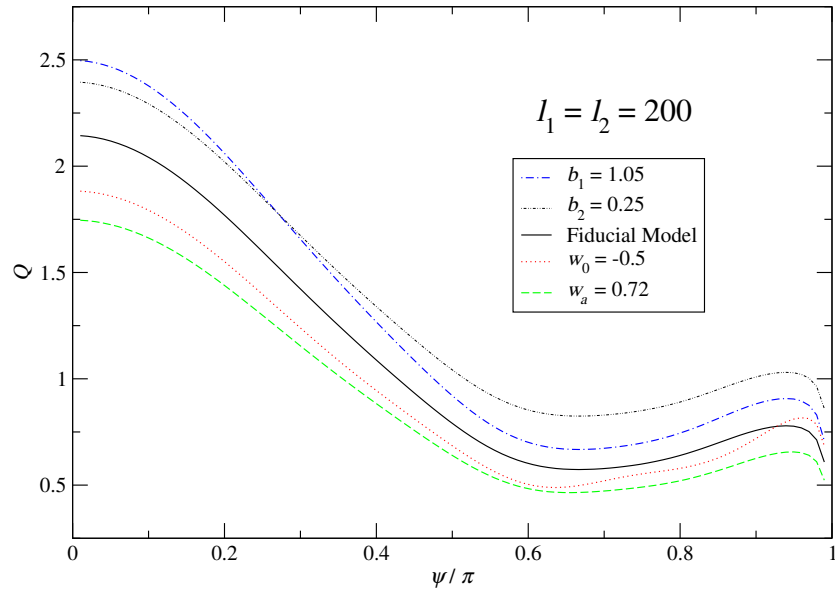
Figure 4: Configuration dependence of the reduced projected bispectrum for various parameters choices.

$P_g + B_g + 4$ year WMAP CMB

$P_g + 4$ year WMAP CMB

P_g

10 Redshift Bins

$z \sim 0.3 - 1.3$

$f_{sky} = 0.1$

1σ contours

$P_g + B_g$ + 4 year WMAP CMB + SNe

P_g + 4 year WMAP CMB + SNe

P_g

10 Redshift Bins

$z \sim 0.3 - 1.3$

$f_{sky} = 0.1$

1σ contours

$P_g + B_g$ + Planck CMB

P_g + Planck CMB

P_g

10 Redshift Bins

$z \sim 0.3 - 1.3$

$f_{\mathrm{sky}} = 0.1$

1σ contours

$P_g + B_g$ + Planck CMB + SNe

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