Cosmology and Galaxy Formation from Small-Scale Galaxy Clustering in the Sloan Digital Sky Survey

Kevork Abazajian (T-8), Zheng Zheng (Ohio State and Institute for Advanced Study), Idit Zehavi (University of Arizona), David Weinberg (Ohio State), Josh Frieman (Fermilab and University of Chicago), and Andreas Berlind and Michael Blanton (New York University); ***kaba@lanl.gov***

Over the last several years, halo occupation models of galaxy bias have led to substantial progress in characterizing the relation between the distributions of galaxies and dark matter. Gravitational clustering of the dark matter determines the population of virialized dark matter halos, with essentially no dependence on the more complex physics of the subdominant baryon component. Galaxy formation physics determines the halo occupation distribution (HOD), which specifies the probability $\mathcal{P}(\mathcal{N}|\mathcal{M})$ that a halo of virial mass $\mathcal{M}$ contains $\mathcal{N}$ galaxies of a given type, together with any spatial and velocity biases of galaxies within halos. Given cosmological parameters and a specified HOD, one can calculate any galaxy-clustering statistic, on any scale, either by populating the halos of N-body simulations or by using an increasingly powerful array of analytic approximations.

The 2dF Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS) allow galaxy clustering measurements of unprecedented precision and detail, making them ideal data sets for this kind of modeling. In [1], we developed and applied a cosmologically general model of galaxy clustering at all scales to analyze cosmological constraints from cosmic microwave background (CMB) measurements coupled with a measure of the projected two-point correlation function ($w_p(r_p)$) while allowing the HOD and cosmological parameters to vary simultaneously. This investigation complements analyses that combine CMB data with the large-scale *power spectrum* measurements from the 2dFGRS or SDSS. Such analyses use linear perturbation theory to predict the dark matter power spectrum, and they assume that galaxy bias is scale-independent in the linear regime. It also complements HOD and cosmological parameter determination approaches using galaxy-galaxy lensing in the SDSS and their combination with Lyman-α forest clustering in the SDSS quasar sample. Our analysis draws on data that extend into the highly nonlinear regime, and in place of scale-independent bias it adopts a parameterized

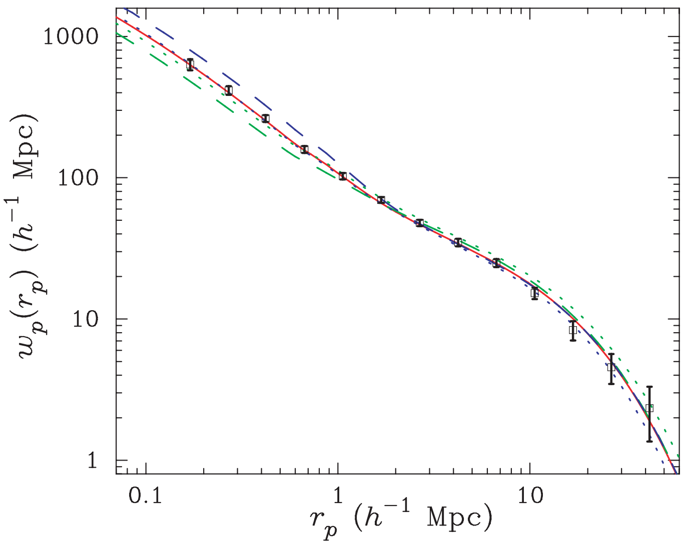

Figure 1*—*
Shown are the projected correlation function $w_p(r_p)$ of M_r<-21 galaxies from the SDSS Large Scale Structure sample 12 (points with 1σ diagonal errors) and the best fit two-parameter HOD model (solid). Also shown are predicted $w_p(r_p)$ models with Ω_c (dotted) and σ_8 (dashed) at ±3σ from their best fit values.

form of the HOD motivated by theoretical studies of galaxy formation.

We use a volume-limited subsample of the SDSS with 26,015 galaxies and magnitudes brighter than the threshold M_r<-21 [2]. To measure the likelihood space allowed by the data, we use a Markov Chain Monte Carlo (MCMC) method. After burn-in, the chains typically sample 10^5 points, and convergence and likelihood statistics are calculated from these.

We find that combining small-scale galaxy clustering in the SDSS with CMB observations provide one of the most precise techniques for measuring the cosmological parameters as well as the HOD of galaxies, despite the introduction of additional parameter uncertainty of the HOD. The statistical likelihood distributions for the standard LCDM cosmology are shown in Fig. 1, and the two-dimensional contours of the canonical cosmological parameter space of the amplitude of perturbations on small scales (σ_8) and total matter density in units of the critical density (Ω_m) are shown in Fig. 2.

The key potential sources of systematic uncertainty in these results are from the mass function of halos and their bias relative to the dark matter, both incorporated here as fits from results of high-resolution numerical simulations. These are both being studied through high-resolution numerical simulations in Theoretical Division (T-8 and T-6) at Los Alamos National Laboratory.

Analyses of multiple classes of galaxies will allow consistency checks on any cosmological conclusions, since different classes will have different HODs but should yield consistent cosmological constraints. By drawing on the full range of galaxy clustering measurements, joint studies of galaxy bias, and cosmological parameters will sharpen our tests of the leading theories of galaxy formation and the leading cosmological model. With this current analysis alone, we have found that the combination of CMB anisotropies and small-scale galaxy clustering statistics simultaneously provides one of the best constraints on parameters describing the cosmology and the occupation of galaxies in their halos.

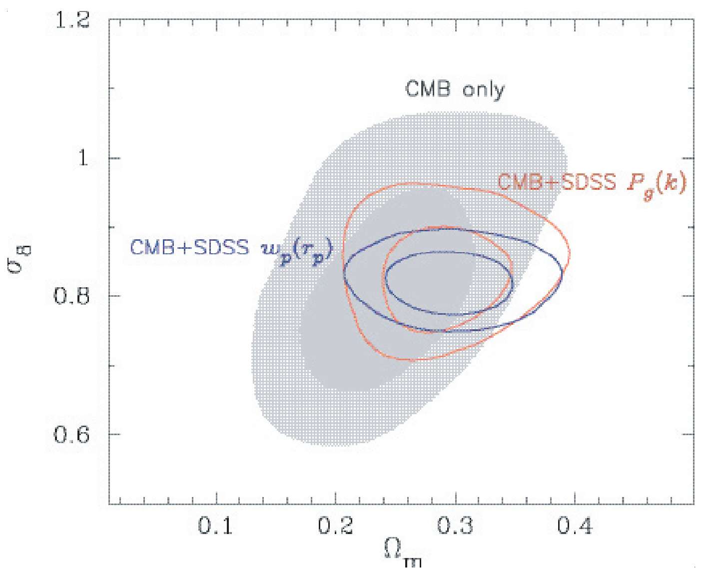

***Figure 2*—Shown are the marginalized 68% and 95% C.L. contours in the amplitude of fluctuations (σ_8) vs the cosmological matter density in units of the critical density (Ω_m) for the AP+ACBAR+CBI+VSA (CMB) data alone (gray shaded), from the CMB + SDSS 3D $P_g(k)$ (orange/light-gray lines) and CMB + SDSS $w_p(r_p)$ (blue/dark-gray lines) from the HOD analysis presented here.**

[1] K. Abazajian et al., "Cosmology and the Halo Occupation Distribution from Small-Scale Galaxy Clustering in the Sloan Digital Sky Survey," Los Alamos National Laboratory report LA-UR-04-1126 (2004) [arXiv:astro-ph/0408003].
[2] I. Zehavi et al. [The SDSS Collaboration], "The Luminosity and Color Dependence of the Galaxy Correlation Function," [arXiv:astro-ph/0408569].