Large Synoptic Survey Telescope

Cosmology with Shear-Selected Galaxy Clusters

Z. Haiman (Columbia), S. Wang (Columbia/Brookhaven), J. Khoury (MIT/Columbia), J.F. Hennawi (UC Berkeley/Princeton), M. May (Brookhaven), D.N. Spergel (Princeton), J.A. Tyson (UC Davis)

Abstract

LSST can identify over a hundred thousand galaxy clusters from weak lensing shear maps. This cluster sample will have statistically well-controlled mass estimates, and can place precise and robust constraints on cosmological parameters. We use a Fisher matrix approach to forecast the level of these constraints. We utilize cosmological N-body simulations to include the mass-shear relation, including its scatter and false projections, in our mock selection procedure. We find that by combining measurements of the evolution of cluster abundance, (dN/dz), and the spatial power spectrum, (P[k]), degeneracies among cosmological parameters, and also between cosmological parameters and systematic errors in the analysis, can be broken, yielding percent-level constraints on individual parameters. We focus on the evolution of the dark energy equation of state, $w_a \equiv dw/da$, and on a measurement of the neutrino mass m_ν. Combining the cluster data with CMB anisotropy measurements by Planck results in tighter constraints than possible from either experiment alone. The LSST cluster constraints are also complementary to those from LSST shear tomography and from SN studies.

1. Cluster Selection

- **Weak gravitational lensing (WL)** is the small distortion of the images of background galaxies by the foreground mass distribution, quantified for small distortions by the tangential shear γ_T. The benefit of WL selection of clusters for cosmological studies is that the mass-observable relation (i.e. between shear and spherical mass), as well as its scatter, can be accurately calibrated from simulations. The details of an eventual selection procedure that also depends, e.g., on galaxy properties of WL cluster candidates, will have to be understood to comparable accuracy to avoid systematic biases.
- **Selection criterion.** Galaxy clusters can be selected as a set of peaks in a smoothed two-dimensional shear map. Using a filter with angular scale θ_G we identify peaks above a threshold ν_T corresponding to a multiple of the noise, $\gamma_T = \nu_T\sigma_e$. Here σ_e is the uncertainty in the mean intrinsic ellipticity of the galaxies within a smoothing aperture. N-body simulations were used (*Hennawi & Spergel 2004, astro-ph/0404349*) to quantify the statistics of the correspondence between *real clusters* and *peaks* in the shear map, for various choices of filter shapes and size, and for various values of ν_T.
- **Selection efficiency:** The correspondence between peaks and clusters is spoiled by (a) missing a fraction of the real clusters, and by (b) false detections of over-dense structures, projected along the line of sight. These effects are quantified by the *completeness c* (fraction of clusters that produce peaks with $\nu \geq \nu_T$), and the *purity p* (fraction of peaks that correspond to real clusters).
- **Tomography and Optimal Filtering:** The simulations were used to show that the selection efficiency can be significantly improved by (a) making use of the photometric redshifts of the background galaxies (tomography) and by (b) using a matched filter that weighs the contribution of the lensing from different redshifts to the shear signal, optimized given the redshift distribution of the background sources. Tomography can also be used to determine the redshift of the detected clusters, and increases the detection efficiency by a factor of two for low-mass, high-redshift clusters (Fig.1).
- **Parameters:** We adopt ν_T=4.5, which corresponds to *c=0.7 (Hamana et al., astro-ph/0310607)*, and *p=0.75 (Hennawi & Spergel 2004)*. These statistics can be computed ab-initio and increase only statistical errors on the derived cosmological parameters.

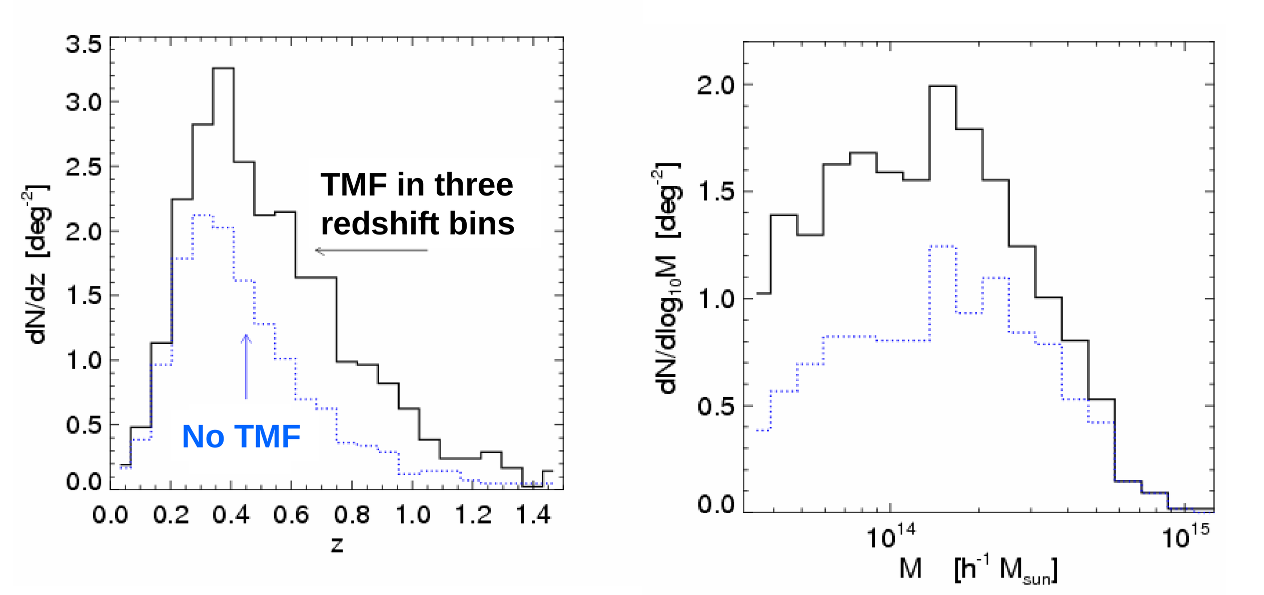

Figure 1: Cluster selection from tomography. *The redshift and mass distribution of clusters detectable as peaks in a two-dimensional shear map at S/N≥4.5, with and without tomograhpic matched filtering (TMF). The TMF technique boosts the number of detectable clusters at high redshifts and low masses by a factor of ~two (from Hennawi & Spergel 2004).*

	dN/dz	P(k)	dN/dz +P(k)	Planck	dN/dz + P(k)+ Planck
$\Delta(\Omega_{DE})$	0.008	0.012	0.0037	0.035	0.0033
$\Delta(\Omega_m h^2)$	0.038	0.032	0.0059	0.0012	0.00024
$\Delta(\sigma_8)$	0.005	0.034	0.0038	0.041	0.0037
$\Delta(w_0)$	0.079	0.16	0.037	0.32	0.036
$\Delta(w_a)$	0.13	0.72	0.12	1.0	0.093
$\Delta(\Omega_b h^2)$	0.001	0.008	0.0009	0.00014	0.00010
$\Delta(n_s)$	0.04	0.062	0.021	0.0035	0.0022

Table 1: Constraints on Dark Energy Evolution. *Uncertainties (1σ) available on various cosmological parameters from the abundance and power spectrum of LSST clusters. Results were obtained from a Fisher matrix analysis, calibrated with numerical simulations. Also listed are constraints from CMB anisotropies measured by Planck, and from the LSST and Planck data in combination (Wang et al. 2004). The dN/dz constraints assume a prior from WMAP on $\Omega_b h^2$ and n_s (no other priors).*

	P(k)	dN/dz	P(k) + dN/dz	P(k) + WMAP	P(k) + Planck	P(k) + dN/dz + WMAP	P(k) + dN/dz + Planck
$\Delta(\Omega_{DE})$	0.011	0.032	0.0054	0.0074	0.0066	0.0034	0.0029
$\Delta(\Omega_m h^2)$	0.036	0.53	0.026	0.0034	0.0013	0.0028	0.00070
$\Delta(\sigma_8)$	0.026	0.068	0.0032	0.017	0.013	0.0029	0.0027
$\Delta(w_0)$	0.10	0.13	0.031	0.058	0.042	0.027	0.025
$\Delta(\Omega_\nu h^2)$	0.0045	0.072	0.0034	0.0012	0.00065	0.0011	0.00029
$\Delta(\Omega_b h^2)$	0.0080	0.091	0.0068	0.00091	0.00011	0.00088	0.00011
$\Delta(n_s)$	0.079	0.89	0.070	0.022	0.0031	0.020	0.0027

Table 2: Constraints on Neutrino Mass. *Uncertainties on cosmological parameters, as in Table 1, but including a variable neutrino mass. The equation of state w(a), was assumed to be constant (Wang et al. 2005).*

2. Error Forecasts

- **Survey.** We assume the survey covers 18,000 square degrees, and detects clusters to a redshift *z=1.4* (out to which photometric redshifts will be available). For the dN/dz test, we computed the number of clusters in redshift bins of Δz=0.05. For the P(k) test, we used redshift bins of Δz=0.2. We adopt the fitting formula for the mass function from Jenkins et al. (2001), which results in a total of ~200,000 clusters. We assume the power spectrum of the clusters is boosted according to the halo bias of Sheth & Tormen (2002).
- **Fisher Matrix Formalism.** We computed the 1σ uncertainties in a 7-dimensional parameter space (with the parameters listed in column 1 in Tables 1 and 2). We employed the Fisher matrix formalism, and assumed a fiducial ΛCDM cosmology with Ω_m = 0.3, Ω_{DE} = 0.7, Ω_b = 0.045, w_0=-1, w_a=0, Ω_ν = 0, h=0.7, σ_8 = 0.9, and n_s=1. We studied constraints on the evolution of the dark energy equation of state *w(a)* (Table 1) and the contribution of neutrinos to the energy density Ω_ν (Table 2). A flat universe was assumed ($\Omega_m + \Omega_{DE}$ = 1).

3. Conclusions

- **Dark Energy.** We find $\Delta\Omega_{DE}$ = 0.0037, Δw_0=0.037 and Δw_a=0.12 from LSST clusters alone. These numbers include a 50% increase in errors from the uncertainties on completeness and purity, and are marginalized over all other parameters. We find that d*N/dz* contains most of the information on w_a, while *P(k)* substantially improves the constraints on w_0. Adding Planck to the LSST data results in relatively modest improvements (Table 1, from *Wang et al. 2004, astro-ph/0406331*).
- **Neutrinos.** We find $\Delta\Omega_\nu$ = 0.0034 from LSST clusters alone, corresponding to a limit on the sum of all neutrino species Σm*=0.36* eV. Most of the information on neutrinos is in *P(k),* but adding information from *dN/dz* results in ~30% improvement. Adding WMAP or Planck data further improves the Ω_ν constraints by a factor of 3 or 10, respectively. LSST+Planck results in the limit Σm*=0.031* eV. Since this is above current lower limits on the mass of at least one neutrino species from atmospheric neutrino oscillation (~0.05eV), detection of a non-zero neutrino mass is guaranteed at this sensitivity (Table 2; from *Wang et al. 2005, in preparation*).

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