Number Counts as a Probe of Cosmology

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Number counts of galaxies and galaxy clusters offer a very promising probe of measuring the cosmological parameters (Ω_M, Ω_X and w). The idea is to measure abundances of these objects as a function of redshift, compare this to a theoretical prediction, and infer the values of cosmological parameters.

Let us assume that dN objects are observed in a redshift interval dz and a solid angle interval $d\Omega$. Then, in a flux-limited survey for clusters, one would effectively measure

$$\frac{dN}{dzd\Omega} = \frac{dV}{dzd\Omega}(z) \int_{M_{\rm min}} dM \frac{dn}{dM}(z, M)$$

where $n(z)$ is the comoving number density at redshift z, $V(z)$ is comoving volume out to that redshift, and $M_{\rm min}(z)$ is the minimum mass of objects detected. The dependence of $dV/dz\, d\Omega$ on matter and dark energy densities Ω_M, Ω_X is known. Comparison with theory, therefore, requires knowledge of the comoving number density of objects $n(z)$ (or equivalently dn/dM).

The number-count technique can be implemented in a variety of ways. Here we discuss two promising methods: counting clusters of galaxies detected through either the Sunyaev-Zeldovich (SZ) effect or X-ray observations [1], and measuring the velocity function of galaxies (and thereby dark halos) at high redshift [2].

1 Galaxy Cluster Surveys

Galaxy clusters are relatively simple, well understood objects as they are the largest collapsed structures in the universe. Clusters can be detected in various ways: through optical or X-ray observations or weak gravitational lensing of background objects, for example. A particularly promising avenue is finding clusters through the Sunyaev-Zeldovich (SZ) effect (the temperature distortions in the cosmic microwave background (CMB) due to Compton scattering of photons off the cluster gas). This technique has the advantage that the strength of the effect does not depend upon distance, and therefore can detect clusters out to high redshifts ($z \lesssim 3$).

To date, several dozen intermediate-redshift clusters have been detected (e.g. [3]), but proposed dedicated SZ [4] and X-ray (D. Lamb, provate communication) surveys are likely to increase this number to several thousand. To find the number of clusters in any given redshift interval, one needs to know their comoving density $n(z)$. This may be predicted using the semi-analytic formalism of Press and Schechter [5]

$$\frac{dn}{dM}(z, M) = \sqrt{\frac{2}{\pi}} \frac{\rho_M}{M} \frac{\delta_c}{\sigma^2(M, z)} \frac{d\sigma(M, z)}{dM} \exp\left(-\frac{\delta_c^2}{2\sigma_M^2 D^2(z)}\right) \quad (1)$$

where σ_M is the rms density fluctuation on mass-scale M computed at $z = 0$ and using linear perturbation theory, $D(z)$ is the growth factor for linear perturbations, ρ_M is the present-day matter density, and $\delta_c \approx 1.68$ is the linear threshold overdensity for collapse (modern extensions of the work of Press & Schechter yield only slight modifications to this formula). Note that the abundance depends exponentially on the growth of density perturbations and therefore may vary by many orders of magnitude over the redshift range of interest [6]. This dependence outweighs that of the cosmological volume.

Fig. 1 shows the estimated constraints on Ω_M and w (assuming a flat universe) for a sample of one hundred clusters with $0 < z < 3$ selected in a future Sunyaev-Zel'dovich survey and one thousand clusters with $0 < z < 1$ selected in a future X-ray survey [1]. These constraints are complementary (almost orthogonal) to those which halo counts (which are discussed below) or SNe Ia provide because the cluster counts primarily probe the growth of density perturbations, rather than the luminosity distance or the volume element.

2 Counts of Galaxies

Newman and Davis [2] have proposed a different variant of the classical "dN/dz" test that could measure fundamental cosmological parameters using data from the next generation of redshift surveys (in particular, the DEEP2 Redshift Survey, scheduled to start in 2002 at the Keck observatory). Using these surveys, one can measure the apparent abundance of galaxies as a function of their linewidth/rotation or velocity dispersion at both $z \sim 1$ and $z \sim 0$. These velocities are dominated by the potential well depths of the dark matter halos that the galaxies lie within; the observations may thus be compared to the predicted velocity function of dark matter halos, which may be obtained robustly from semi-analytic methods or simulations. The ratio of the comoving abundance of halos of a fixed rotational speed at $z \sim 1$ to $z \sim 0$ varies extremely weakly with cosmological model on galaxy scales ($< 1\%$ between OCDM and LCDM), effectively yielding a measure of the volume element alone [2]. The predicted velocity function is an excellent power law on galactic scales, providing a strong signature of any systematic effects. Newman & Davis (2001) have shown that using the observed velocity function, the effects of all major systematics may be measured and removed, leaving a randomly distributed residual error. High-resolution, large-volume redshift surveys such as DEEP2 also will make it possible to count clusters as a function of their velocity dispersion, providing constraints by a method similar to those described in the previous section (but without the h dependence that affects mass-limited studies).

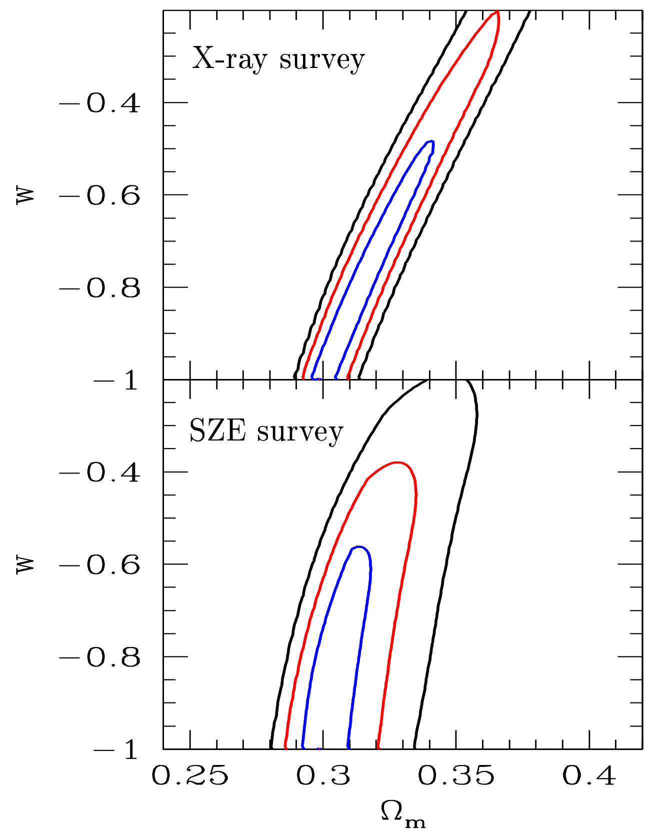
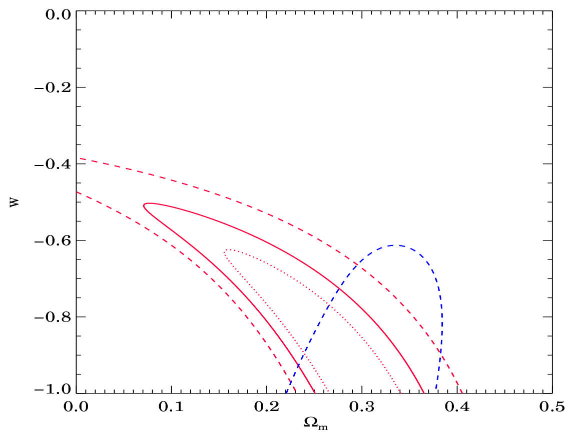


Figure 1: Projected one, two and three σ constraints on Ω_M and w in a flat Universe using counts of galaxy clusters (adopted from Ref. [1]) for an X-ray selected sample of one thousand clusters (top panel) or a Sunyaev-Zel'dovich selected sample of a hundred clusters (bottom), assuming that the value of h is known with precision.

Fig. 2 shows 95% constraints on Ω_M and w (flat universe) from DEEP2 galaxy counts under three different scenarios: "optimistic" (dotted red), "best bet" (solid red), and "pessimistic" (dashed red). Depending upon the scenario, it has been assumed that velocity statistics have been obtained for 5,000-20,000 galaxies with $0.7 < z < 1.5$, and the strength of cosmic variance and the systematic effects of incompleteness, baryonic infall, and measurement errors are weaker or stronger. Also plotted in blue is the 95% constraint which would result from measuring the abundance of clusters in DEEP2. Note that the redshift range for the DEEP survey roughly corresponds to the redshift range of the greatest sensitivity to dark energy [7].



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3 Conclusions

Number counts of galaxies or clusters provide a very promising and direct probe of cosmology, complementary to SNe Ia and CMB measurements. Control of systematic errors (due to incompleteness, uncertainties in the limiting mass, or uncertainties in theoretical modeling, for instance) will be critical. Number counts of clusters at high redshift are expected to impose significant constraints on cosmological parameters within the next few years.

References

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