SUPERCLUSTERS WITH SUNYAEV-ZELDOVICH EFFECT SURVEYS

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A simple analytic model for the angular correlation function of clusters identified in upcoming Sunyaev-Zeldovich (SZ) effect surveys provides the expected fraction of pairs of clusters close on the sky which are also close along the line of sight. In a ΛCDM model and for clusters with specific flux difference larger than 200 mJy at 143 GHz, this fraction is at least 50% for angular separations smaller than 20 arcmin. It is therefore feasible to use SZ surveys to compile catalogues of superclusters at any redshifts. A large sample of superclusters can valuably constrain models of structure formation.

1 Introduction

Superclusters are regions with mass overdensities, averaged on scales larger than a few megaparsecs, of order a few; their cluster members indicate the presence of intense dynamical activity and thus provide evidence that structure form hierarchically on supercluster scales. [2,11,12] In N-body simulations, the non-linear evolution of gravitational clustering enhances the peculiar velocity of dark matter halos in supercluster regions by $\sim 40-50\%$. [13] Superclusters are therefore ideal for kinematic SZ effect searching. [4,15] Sometimes, less massive but faster clusters produce Cosmic Microwave Background (CMB) fluctuations due to the kinematic effect larger than the most massive but slower clusters. [4] Measurements of the kinematic effect are of great interest, because the high velocity tail of the cluster peculiar velocity distribution is a sensitive discriminator of cosmological models. [1]

Cluster surveys based on the SZ thermal effect will produce catalogues of thousands clusters at any redshift in the next few years. [3] Clusters are not randomly distributed on the sky. I show that, in the currently most fashionable cosmological models, the fraction of close pairs on the sky, which are physical associations, is substantial. If we define superclusters as regions containing two or more close clusters, this result proves that using SZ cluster surveys to compile catalogues of superclusters at any redshift is feasible.

2 Close pairs of clusters

Assuming that the gas fraction f_g in clusters does not evolve in time, a cluster with mass M and mean electron temperature T_e produces a variation of the CMB specific surface brightness at frequency ν , $S_\nu \propto f_g M T_e/\Delta\Omega$, where $\Delta\Omega$ is the solid angle subtended by the cluster. The surface brightness of the SZ effect does not suffer the usual $(1+z)^4$ dimming: it is independent of redshift. The CMB flux difference is

$$F_\nu \propto \frac{f_g M T_e}{d_A^2(z)} \tag{1}$$

where d_A is the angular diameter distance. If the electron temperature is proportional to the cluster mass, a flux threshold translates into a mass threshold

$$M_{\rm th}(z, F_\nu^{\rm th}) \propto d_A^{6/5}(z)(F_\nu^{\rm th})^{3/5} \tag{2}$$

where we have assumed a mass-temperature relation $T_e \propto M^{2/3}$. The differential redshift distribution of clusters detected in SZ surveys is

$$\eta(z, F_\nu^{\rm th})d\Omega dz = d\Omega dz \frac{c}{H_0}\frac{d^2(z)}{E(z)}\int_{M_{\rm th}(z,F_\nu^{\rm th})}^{\infty} \frac{dn(M,z)}{dM}dM \tag{3}$$

where $d(z) = (1+z)d_A(z)$, $E^2(z) = \Omega_0(1+z)^3 + (1-\Omega_0-\Lambda_0)(1+z)^2 + \Lambda_0$, $dn(M,z)/dM$ is the comoving number density of clusters with mass in the range $(M, M+dM)$ at redshift z, and the other symbols have the usual meaning.

The probability of finding two clusters with mass M_1, M_2 at redshift z_1, z_2 and comoving separation r_{12} is proportional to

$$\zeta(r_{12}, M_1, M_2, z_1, z_2)dA_1 dA_2 = dV_1 dV_2 \frac{dn(M_1,z_1)}{dM_1}dM_1 \frac{dn(M_2,z_2)}{dM_2}dM_2[1+\xi(r_{12}, M_1, M_2, z_1, z_2)] \tag{4}$$

where $dA_i = dM_i dz_i d\Omega_i$, $d\Omega_i$ is the infinitesimal solid angle, $dV_i = (c/H_0)d^2(z_i)d\Omega_i dz_i/E(z_i)$ is the infinitesimal comoving volume and

$$\xi(r_{12}, M_1, M_2, z_1, z_2) = b(r_{12}, M_1, z_1)b(r_{12}, M_2, z_2)\xi_m(r_{12}, z_1) \tag{5}$$

is the two-point correlation function of clusters; $b(r, M, z)$ is a scale dependent bias factor.[5] The correlation function of dark matter $\xi_m(r, z)$, evolved into the non-linear regime, is the sum of two contributions due to dark matter particles within the same halo and within different halos[14] and can be computed with a convenient fit.[10] The probability of detecting two clusters at angular separation θ is proportional to

$$\begin{aligned}\psi(\theta)d\Omega_1 d\Omega_2 &= d\Omega_1 d\Omega_2 \int \zeta(r_{12}, M_1, M_2, z_1, z_2)dM_1 dM_2 dz_1 dz_2 \\ &= d\Omega_1 d\Omega_2 \eta_0^2\,[1+w(\theta)]\end{aligned} \tag{6}$$

where $\eta_0 = \int_0^\infty \eta(z, F_\nu^{\rm th})dz$, and $w(\theta) = \Xi_0(\theta)/\eta_0^2$ is the angular correlation function of clusters. Clustering and biasing information are contained in the function

$$\begin{aligned}\Xi_0(\theta) &= \left(\frac{c}{H_0}\right)^2 \int_0^\infty n(z_1)\frac{d^2(z_1)}{E(z_1)}dz_1 \times \\ &\times \int_0^\infty n(z_2)b_{\rm eff}(r_{12}, z_1)b_{\rm eff}(r_{12}, z_2)\xi_m(r_{12}, z_1)\frac{d^2(z_2)}{E(z_2)}dz_2\end{aligned} \tag{7}$$

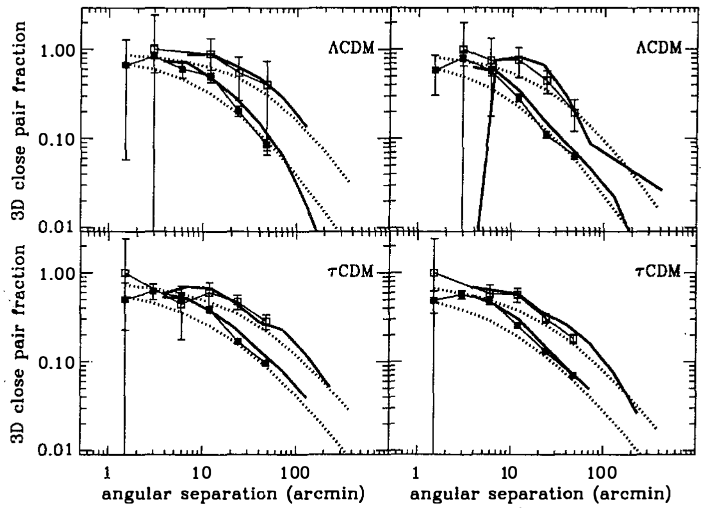

Figure 1: Fraction of cluster pairs with comoving separation < 16.0 (10.7) h^{-1} Mpc for the ΛCDM (τCDM) model (squares). Upper (lower) curves are for $F_\nu^{\rm min} > 200$ (50) mJy. Left (right) panels are for $\nu = 143$ (353) GHz. Bold lines correspond to $\varphi_0(\theta)$ computed directly from the N-body simulations. Dotted lines are the corresponding analytic functions. Error bars assume Poisson statistics.

where

$$n(z) = \int_{M_{\rm th}(z)}^{\infty} \frac{dn(M,z)}{dM} dM \tag{8}$$

and

$$b_{\rm eff}(r,z) = n^{-1}(z) \int_{M_{\rm th}(z)}^{\infty} b(r,M,z) \frac{dn(M,z)}{dM} dM. \tag{9}$$

I compare my analytic model with the lightcone outputs of the Hubble volume simulations which consider a ΛCDM and a τCDM cosmology with $(\Omega_0, \Lambda_0, h, \sigma_8) = (0.3, 0.7, 0.7.0.9)$ and $(1, 0, 0.5, 0.6)$, respectively.[7] Both models assume a power spectrum shape parameter $\Gamma = 0.21$.[8] I consider the *NO* lightcone outputs, which cover $\pi/2$ sr and have depth $z = 1.46$ (ΛCDM) and 1.25 (τCDM). I adopt fits to the dark matter halo mass function[7] and to the effective bias factor[9] measured in the Hubble volume simulations.

The fraction of cluster pairs with angular separation θ in excess to a Poisson distribution due to gravitational clustering is

$$\varphi_0(\theta) = \frac{w(\theta)}{1 + w(\theta)}; \tag{10}$$

$\varphi_0(\theta)$ also indicates the fraction of pairs of clusters which are roughly at the same redshift, because $\xi(r_{12}) \sim 0$ unless $z_1 \sim z_2$.

Figure 1 shows that the $\varphi_0(\theta)$ derived from the simulations (bold lines) and the actual pair count (squares) with cluster member three-dimensional comoving separation smaller than 16 (10.7) h^{-1} Mpc for the ΛCDM (τCDM) model is satisfactory. The agreement between the simulations and the analytic model (dotted lines) at small separations can probably be improved with a better model of the scale dependent bias factor. Figure 1 shows that the analytic model predicts that more than $\sim 60\%$ of pairs with angular separation $\theta < 10$ arcmin are physical associations in the shallow survey $F_\nu^{\rm min} > 200$ mJy. The N-body simulations indicate that this lower limit is actually larger. Because of the larger number of clusters per square degree, the fraction of pairs close in three dimensions drops to $\sim 30\%$ in the deeper survey $F_\nu^{\rm min} > 50$ mJy; this fraction is still substantial.

3 Conclusion

One of the main purposes of SZ cluster surveys is to constrain the cosmological model with the cluster redshift distribution. As the SZ effect is redshift independent, SZ cluster catalogues will not have any information on the cluster distances (see however Diego's [6] suggestion). In large area SZ surveys, which will contain thousands clusters and where one needs to choose a subsample of clusters for follow up optical observations, rather than selecting a random sample from the two-dimensional catalogue, we suggest to measure the redshift of clusters in close pairs. Because the probability that clusters close on the sky are also close along the line of sight is substantial, this strategy will provide, at the same time, the redshift distribution of clusters and a catalogue of superclusters. The cosmological discriminator will be the cluster sample; the redshift distribution of superclusters can constrain the cluster bias function or the evolution of the dark matter correlation function. Moreover, when the measurements will be feasible, a catalogue of superclusters will enable us to constrain the high velocity tail of the peculiar velocity distribution of clusters.

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