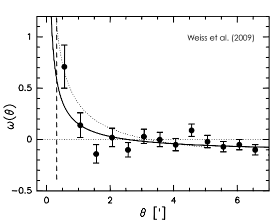
Clustering and halo masses of 870-μm selected submm galaxies

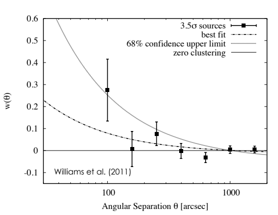
Ryan C. Hickox[1], Julie L. Wardlow[2], Adam D. Myers[3], Ian Smail[1],
and the LESS collaboration
[1]Durham University [2]University of California, Irvine
[3]University of Wyoming

Abstract

We present a measurement of the spatial clustering of 870-μm selected submillimeter galaxies (SMGs) at $1 < z < 3$. Using data from the Laboca ECDFS Submm Survey (LESS), we employ a novel technique to measure the cross-correlation between SMGs and galaxies, using full the full probability distributions for photometric redshifts of the galaxies. From the observed projected two-point correlation function we derive the linear bias and characteristic dark matter halo masses for the SMGs. We detect clustering in the cross-correlation between SMGs and galaxies at the >4σ level. We show that SMGs at $1 < z < 3$ are indeed strongly clustered and reside in dark matter halos of mass ~a few x 10^{12} h^{-1} Mpc, very similar to the typical halos for optical quasars. This represents the most precise measurement to date of the clustering of ~850-μm selected SMGs. The results support evolutionary scenarios in which SMGs and QSOs are intimately linked, and confirms that SMGs are consistent with being the progenitors of local massive elliptical galaxies.

1. Background



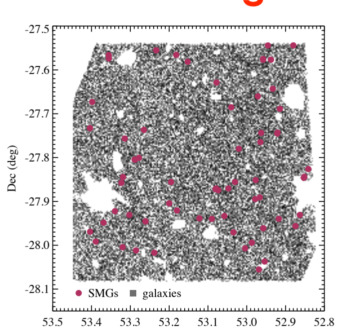


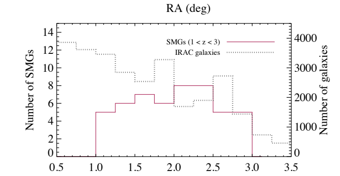
SMGs are the most powerful star-forming systems in the Universe and are most commonly found at redshift z ~ 2, in the epoch of peak star formation and quasar activity (e.g, Wardlow et al. 2011).

Measurements of the spatial clustering of SMGs are essential for understanding the relationship between rapid star formation and environment, and for tracing the role of SMGs in the evolutionary history of galaxies. However, previous measurements which have measured the spatial autocorrelation of SMGs (e.g., Blain et al. 2004, Weiss et al. 2009, Williams et al. 2011) have been limited by the small areas and sample sizes in submm surveys, and so have found at best marginal evidence for spatial clustering.

To determine the real-space clustering of the SMGs, we measure their two-point *cross-correlation* with galaxies in the same field, for which the larger sample size significantly improves the statistical power of the measurement. We employ a new technique that makes use of photometric redshift information to associate SMG-galaxy pairs in comoving distance, maximizing the signal-to-noise.

2. SMG and galaxy samples





Our samples of 74 SMGs and ≈40,000 galaxies are taken from the Extended Chandra Deep Field South. Sky positions of the two samples are shown on the left.

SMGs: SMGs are detected at 870 microns with the LESS survey (Weiß et al. 2009). Detailed identification of IR and optical counterparts was performed by Biggs et al. (2011) and Wardlow et al. (2011). Half of the SMGs have spectroscopic redshifts, primarily from an ongoing campaign with VLT VIMOS/FORS (M. Swinbank & A. Danielson). The remaining SMGs have photometric redshifts as determined by Wardlow et al. (2011). We restrict our clustering analysis to 50 SMGs at $1 < z < 3$, with a median redshift of 2.0 (see redshift distribution at left).

Galaxies: Galaxies are selected in deep IRAC observations of ECDFS. Photometric redshifts are determined for all galaxies, along with full redshift probability density functions(PDFs) that are used extensively in the SMG-galaxy cross-correlation analysis.

3. Cross-correlation method and results

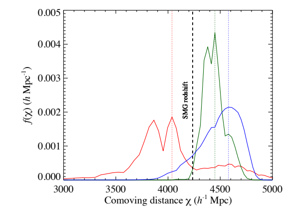
To determine the real-space SMG-galaxy cross-correlation, we employ the method of Myers et al. (2009), as implemented recently by Hickox et al. (2011) for quasars in the Boötes field. We compute the projected cross-correlation function $w_p(R)$, taking into account the likelihood $f_{i,j}$ (see right) that each SMG and galaxy are associated in redshift space. The projected correlation function is then given by (Myers et al. 2009):

$$w_p(R) = N_R N_Q \sum_{i,j} c_{i,j} \frac{D_Q D_G(R)}{D_Q R_G(R)} - \sum_{i,j} c_{i,j}$$

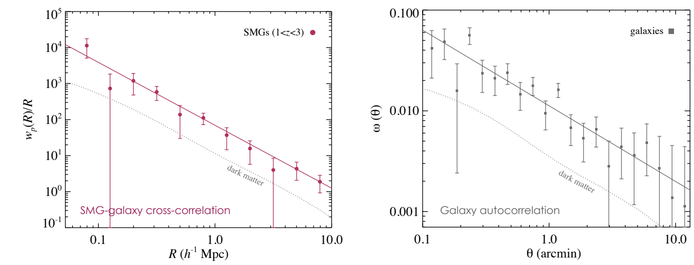
where

$$c_{i,j} = f_{i,j} \Big/ \sum_{i,j} f_{i,j}^2$$

and D_QD_G and D_QR_G are the number of quasar-galaxy and quasar-random pairs, respectively.

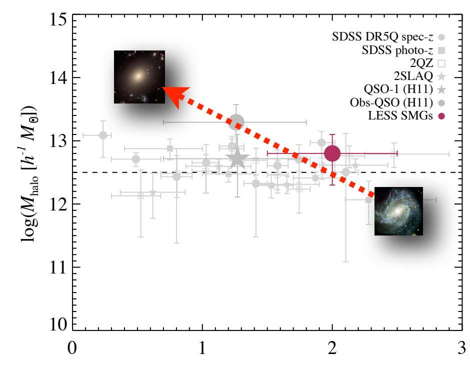


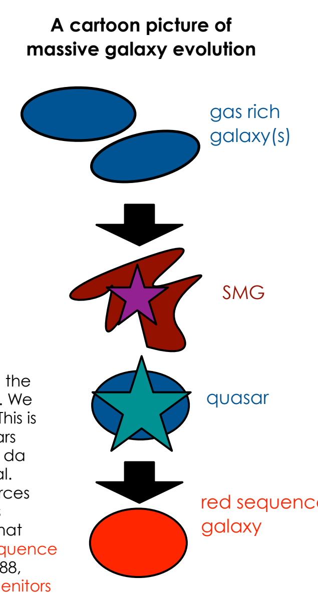
Probability density functions $f(\chi)$ vs. comoving distance for three IRAC galaxies in the sample (along with the redshift of a sample SMG). The $f(\chi)$ curves are normalized so that $\int f(\chi)\, d\chi = 1$. In the correlation analysis, SMG-galaxy pairs are weighted by $f_{i,j}$, which is defined as the value of $f(\chi)$ for the galaxy j at the redshift of the SMG i.



The left panel shows $w_p(R)$ for the SMG-galaxy cross-correlation, along with the best-fit power-law model for the cross-correlation with $r_0 = 5.2 \pm 0.8$ h^{-1} Mpc and $\gamma = 1.74 \pm 0.20$. The dotted line shows $w_p(R)$ for dark matter in a cosmology with $(\Omega_m, \Omega_\Lambda, h, \sigma_8) = (0.3, 0.7, 0.7, 0.84)$, calculated using HALOFIT (Smith et al. 2003). The ratio of these two yields $b_{SMG}b_{gal}$, where b_{SMG} *and* b_{gal} are the linear bias of the SMGs and galaxies, respectively. We then calculate the angular autocorrelation function ω(Θ)of the galaxies at the redshifts of the SMGs (right panel), and divide by the ω(Θ) for the dark matter to obtain b_{gal},. Together, these two measurements yield $b_{gal} = 1.74 \pm 0.13$ and $\mathbf{b_{SMG} = 3.35 \pm 0.82}$, corresponding to a autocorrelation length for the SMGs (assuming $\gamma = 1.8$) of $\mathbf{r_0 = 7.7^{+1.8}_{-2.3}\ h^{-1}}$ **Mpc**.

4. Halo masses and evolution





(Adapted from Hickox et al. 2009)

Having obtained b_{SMG}, we can estimate M_{halo} for the SMGs using the relation between linear bias and halo mass of Sheth et al. (2001). We obtain a halo mass for the SMGs of **log M_{halo} [h^{-1} M_{sun}] $12.8^{+0.3}_{-0.5}$**. This is consistent with previous measurements of the clustering of quasars selected in the optical (e.g. Croom et al. 2005, Myers et al. 2006, da Angela et al. 2008, Ross et al. 2009) and mid-infrared (Hickox et al. 2011). The clustering is also consistent with luminous *Herschel* sources (Cooray et al. 2010) and is stronger than for fainter far-IR emitters (Amblard et al. 2011). These results are consistent with the idea that powerful star-forming activity may be part of an evolutionary sequence that also includes rapid black hole growth (e.g. Sanders et al. 1988, Hopkins et al. 2008), and suggest that SMGs are indeed the progenitors of today's massive red sequence galaxies. In the future, by combining these measurements with estimates of the space density of SMGs it will be possible to determine the lifetimes of powerful starbursts and further understand their role in the evolution of massive galaxies.

References

Amblard, A. et al. 2011, Nature, 470, 510
Biggs, A.D. et al. 2011, MNRAS in press (arXiv:1012.0305)
Blain, A.W. et al., 2004, ApJ, 611, 725
Cooray et al. 2010, A&A, 518, 22
Croom, S.M. et al. 2005, MNRAS, 356, 415
da Angela, J. et al. 2008, MNRAS, 383, 565
Hickox, R. C. et al. 2009, ApJ, 696, 891
Hickox, R.C. et al. 2011, ApJ, 731, 117
Hopkins, P.F. et al. 2008, ApJS, 175, 356
Myers, A.D. et al. 2006, ApJ, 638, 622
Ross, N.P. et al. 2009, 697, 1634
Sanders, D.B. et al., 1988, ApJ, 325, 74
Sheth, R.K, Mo, H.J. & Tormen, G. 2001, MNRAS, 323, 1
Wardlow, J.L. et al, MNRAS in press (arXiv:1006.2137)
Williams, C.C. et al. 2011, ApJ in press (arXiv:1103.3703)
Weiß, A. et al. 2009, ApJ, 707, 1201

Acknowledgements

This work is made possible by all the members of the LABOCA Extended Chandra Deep Field South Survey collaboration. R.C.H. is supported by an STFC Postdoctoral Fellowship.