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Clustering of galaxies around quasars at $z \sim 4$

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Abstract. We conduct a survey for Lyman break galaxies (LBGs) and Lyman alpha emitters (LAEs) in the environs of six and 17 $z \sim 4$ quasars respectively, probing scales of $R \lesssim 9\,h^{-1}$ Mpc. We detect an enhancement of galaxies (both LBGs and LAEs) in quasar fields, a positive and strong quasar-galaxy cross-correlation function, consistent with a power-law shape, and a strong galaxy auto-correlation function in quasar fields. The three mentioned results are all indicators that quasars trace massive dark matter halos in the early universe.

Keywords. galaxies: active, galaxies: high-redshift, galaxies: quasars: general, cosmology: large-scale structure of universe, cosmology: early universe.

1. Introduction

The strong observed clustering of $z > 3.5$ quasars indicates they are hosted by massive ($M_{\rm halo} \gtrsim 10^{12}\,h^{-1}\,{\rm M}_{\odot}$) dark matter halos (Shen *et al.* 2007). This should manifest as strong clustering of galaxies around quasars. Previous works on high-redshift quasar environments, mostly focused at $z > 5$, have failed to find convincing evidence for these overdensities. Most of previous works aim to detect overdensities of galaxies around individual or at most a handful of quasars, and the large statistical fluctuations expected from cosmic variance could explain why they have been inconclusive. One strategy for overcoming this complication is to target a large sample of quasars, and focus on measuring the quasar-galaxy cross-correlation function.

2. Galaxy overdensity and quasar-galaxy cross-correlation function

We observed six quasar fields with VLT/FORS1 to search for LBGs at $z = 3.8$. We detected 44 LBGs in quasar fields, while only 28.6 LBGs are expected in the same volume in blank fields (computed using the galaxy luminosity function (LF) at $z \sim 4$ from Ouchi *et al.* 2004b). This implies a LBG overdensity of 1.5 in quasar fields (Garcia-Vergara *et al.* 2017). Additionally, we observed 17 quasar fields with VLT/FORS2 to search for LAEs at $z = 3.9$. We detected 25 LAEs, while only 17.3 LAEs are expected in the same volume in blank fields (computed using the galaxy LF at $z \sim 4$ from Ouchi *et al.* 2008). This implies a LAE overdensity of 1.4 in quasar fields (Garcia-Vergara *et al.* subm.).

We also measure the volume-averaged quasar-galaxy cross-correlation function using both the LBG and LAE samples. For both LBG and LAE, we do detect a strong

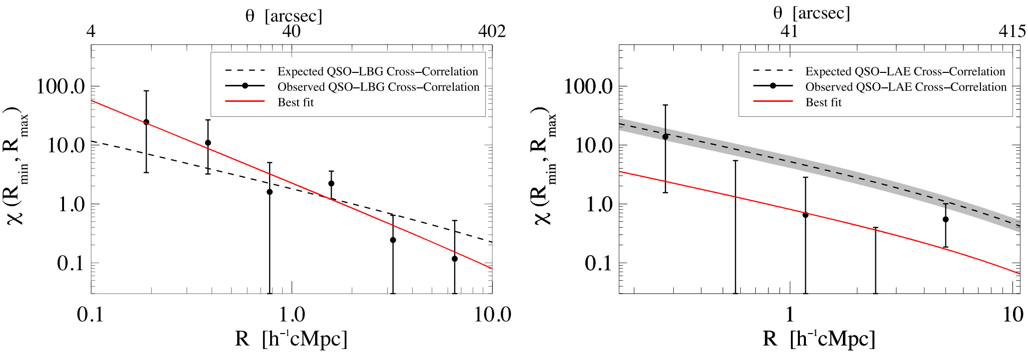

Figure 1. Quasar-galaxy cross-correlation function computed using the LBG sample (left panel) and the LAE sample (right panel). We show our measurement (filled circles) with 1σ Poisson error bars and its best fit (red curve). The dashed black line shows the theoretical expectation computed assuming a deterministic bias model. The gray shaded region in the right panel indicates the 1σ error on the theoretical expectation.

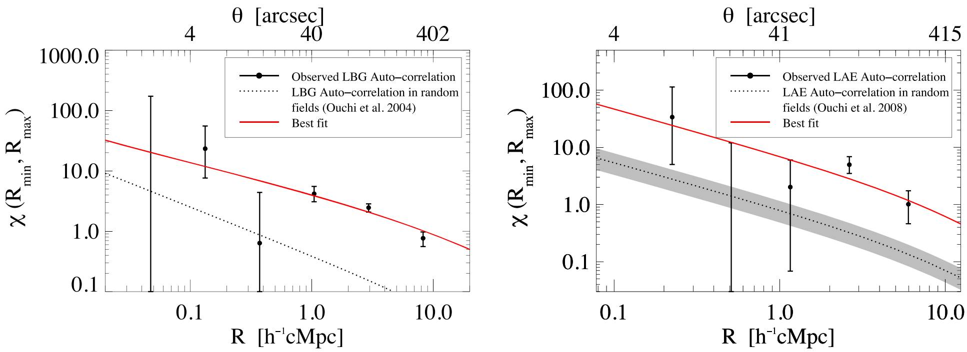

Figure 2. Galaxy auto-correlation function in quasar fields, computed using the LBG sample (left panel) and the LAE sample (right panel). We show our measurement (data points), its best fit (red curve), and the galaxy clustering in blank fields at $z\sim 4$ (dotted black curve).

quasar-galaxy cross-correlation function, consistent with a power-law shape indicative of a concentration of galaxies centered on quasars (see Fig. 1). We compare the observed clustering with the expectation from a deterministic bias model, and find that our measurements are in good agreement in the case of LBG, but fall short of the predicted overdensities by a factor of 2.1 in the case of LAEs. Some possible explanations for this last discrepancy are related with i) the possibility that galaxies in the Mpc-scale quasar environments are on average significantly more dusty, or ii) the possibility of a larger ($R \gtrsim 9\,h^{-1}$ Mpc) scale overdensity in quasar fields (for details see Garcia-Vergara *et al.* subm.).

3. Galaxy auto-correlation function in quasar fields

If quasars reside in overdensities of galaxies, then we expect the galaxy auto-correlation to be enhanced compared with blank fields. We measure the galaxy auto-correlation function in our fields, and compare it with the galaxy clustering in blank fields. For both, LBGs and LAEs we find that galaxies in quasar fields are significantly more clustered compared with their clustering in blank fields (see Fig. 2).

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