A Study of Distant Lyα Emitters in Overdense Regions

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Abstract. Recently, we conducted a Very Large Telescope (VLT) large program to search for forming clusters by looking for overdensities of Lyα emitters around high redshift radio galaxies. In total seven proto-clusters were discovered, including a proto-cluster around the radio galaxy MRC 0316–257 at $z \sim 3.13$. This structure has an excess of Lyα emitters by a factor of 3 as compared to the field, and the derived mass is 2–5 $\times 10^{14}$ $M_{\odot}$. The Lyα emitters in the proto-cluster are on average bluer than Lyman Break Galaxies (LBGs). Also, the galaxies are faint (sub L_*) and small (half light radii < 1.7 kpc, which is smaller than the average size of LBGs). This might indicate that, at least a fraction of, Lyα emitters could be young ($\sim 10^6$ yr), nearly dust-free, forming galaxies.

1 VLT Large Program: Overdense Regions in the Early Universe

Forming clusters of galaxies (proto-clusters) could provide information on the formation of large scale structure in the early Universe. Since a substantial number of galaxies can be detected at the same redshift and features in the spectral energy distribution can be studied systematically by choosing the appropriate filters, they are also ideal places to study galaxy evolution. By comparing proto-cluster galaxies to field galaxies, changes in in galaxy properties as a function of environment can be studied.

An important issue is where to search for these proto-clusters. During the last decade evidence has accumulated that high redshift radio galaxies (HzRGs, $z > 2$) are forming brightest cluster galaxies at the centers of clusters or proto-clusters (for an overview, see e.g. [21]). Supporting evidence includes: (i) HzRGs are amongst the most massive ellipticals in the early Universe [9,5], (ii) they can have extreme radio rotation measures, indicative of dense hot gas [3] and (iii) radio galaxies at $0.5 < z < 1.5$ lie in moderately rich clusters [8,1,2]. A pilot project conducted on the Very Large Telescope (VLT) to search for a proto-cluster around radio galaxy PKS 1138–262 at $z = 2.16$ resulted in the detection of 15 Lyα emitters within 1000 km s^{-1} of the central radio galaxy [11,15]. This provided direct evidence that distant luminous radio galaxies can be used as tracers of proto-clusters.

We initiated a VLT large program to search for Lyα emitters around HzRGs. To select the most likely progenitors of cD ellipticals, the radio galaxies in this program satisfied the following criteria: large radio luminosities, and bright optical and IR continua. To be able to find Lyα emitters, the redshift of the radio

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Table 1. Overview of the observed radio galaxy fields. The Table shows the name of the radio galaxy, its redshift, the number of candidate Lyα emitters in the imaging ('IMG'), the number of spectroscopically confirmed Lyα emitters, excluding the radio galaxy ('SPC') and the velocity dispersion of the confirmed cluster members.

Name of RG	z	IMG	SPC	Δv (km s^{-1})	Notes
MRC 2048–272	2.06	16	2	N/A	High extinction
PKS 1138–262	2.16	70	14	~ 1000	See [11,15,10]
MRC 0052–241	2.86	73	37	~ 900	
MRC 0943–242	2.92	~ 70	29	~ 800	
MRC 0316–257	3.13	85	31	~ 625	
TN J2009–3040	3.15	20	11	~ 470	Radio loud quasar from [4]
TN J1338–1942	4.10	50	32	~ 350	See [20] for more details
TN J0924–2201	5.19	~ 20	6	N/A	

galaxies had to be suitable for Lyα imaging with the available VLT/FORS narrowband filters. Two objects at high redshift (radio galaxies at $z = 4.1$ and one at $z = 5.2$) were added and for which a custom narrowband filter was purchased.

In total, 20 nights on the VLT and 2 nights on Keck in 2001–2003 were used to observe 7 radio galaxy fields with redshifts up to 5.2. In these fields, roughly 400 candidate Lyα emitters were found, of which 162 were confirmed to be Lyα emitters near the redshift of the radio galaxy (Table 1). All six fields studied to sufficient depth turned out to be overdense in Lyα emitters, as compared to blank field surveys. The galaxy overdensities in the narrowband filters are 3–5. The structures have sizes of > 3 Mpc and masses of 10^{14-15} $M_\odot$ [10,20].

In Sect. 2, we will describe the observations of one of the radio galaxy fields, the field of 0316–257, in detail. In Sect. 3, we will discuss the properties of the Lyα emitters.

2 An Overdensity Around MRC 0316–257 at $z = 3.13$

One of the targets in our program was the radio galaxy MRC 0316–257. There were several additional reasons that this radio galaxy was chosen. First of all, it was already known that the object had two spectroscopically confirmed companions [12]. Secondly, the redshift of the radio galaxy ($z = 3.13$) allows for an efficient search for Lyman Break Galaxies (LBGs) and for [OIII] λ 5007 Å emitters using a K-band narrowband filter mounted on an infrared camera.

2.1 Imaging and Spectroscopy

The field surrounding 0316–257 was imaged in a narrowband for 6.5 hours, and 1.3 hours in both V and I with the VLT/FORS2 camera. As part of an imaging