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OBSERVATIONS OF RADIO GALAXY MRC 1138-262: MERGING GALAXIES EMBEDDED IN A GIANT Lyα HALO

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RESUMEN

La radio galaxia MRC 1138-262 a $z = 2.16$ probablemente es una galaxia de mayor brillo en el cúmulo que se encuentra un estado inicial de evolución. Aquí presentamos observaciones del luminoso halo de líneas de emisión y de las componentes estelares de esta radio galaxia. Las imágenes ópticas de banda angosta en Hα muestran un halo mucho más pequeño con una morfología muy diferente al halo Lyα. Proponemos un modelo en el que la parte interior del halo está fotoionizada directamente por iluminación del núcleo activo de la galaxia o por fotones UV de estrellas jóvenes. Lejos del núcleo ($\sim$ 25 kpc) hay una región de emisión Lyα muy aumentada. En esa posición es probable que la ionización por choques sea importante según indica la curvatura del radio jet. La espectroscopía de varias nubes de contínuo en el halo muestra que, aunque hay diferencias entre las características de emisión y de absorción de espectros de varias regiones, éstas tienen propiedades similares a las galaxias con “Lyman-break”. Esto es evidencia adicional en favor de un escenario en que galaxias masivas se forman jerárquicamente a partir de bloques más pequeños.

ABSTRACT

The radio galaxy MRC 1138-262 at $z = 2.16$ is most likely a brightest cluster galaxy in an early stage of evolution. Here we present observations of the luminous emission line halo and the stellar components of this radio galaxy. Optical narrow-band imaging shows a very extended ($\sim$ 160 kpc) and luminous Lyα halo. Infrared narrow band imaging reveals a much smaller Hα halo with a morphology very different from that of the Lyα halo. We advocate a model in which the inner part of the halo is photoionized by direct AGN illumination or by UV photons from young stars. Far from the nucleus ($\sim$ 25 kpc), there is a region of greatly enhanced Lyα emission. At this location, it is likely that shock ionization is important as indicated by a bend in the radio jet. Spectroscopy of several continuum clumps in the halo shows that, although there are striking differences between the emission and absorption features of the spectra of various regions, they have properties similar to those of Lyman-break galaxies. This is further evidence for a scenario in which massive galaxies form hierarchically from smaller building blocks.

Key Words: **GALAXIES: HALOS — GALAXIES: HIGH-REDSHIFT — GALAXIES: INDIVIDUAL (MRC 1138-262) — GALAXIES: JETS — INTERGALACTIC MEDIUM**

1. INTRODUCTION

In this paper we present observations which were obtained as part of our campaign to search for clusters around high redshift radio galaxies (HzRGs). There are several indications (e.g., Pentericci et al. 1999) that powerful HzRGs tend to be in the center of forming clusters. MRC 1138-262 at redshift 2.16 is one of the best candidates for such a search. The indications for 1138-262 being at the center of a cluster include (a) the very clumpy morphology as observed by the *HST* (Pentericci et al. 1998), reminiscent of model predictions for a massive merging system (Carlberg 1994); (b) the extremely distorted radio morphology and largest radio rotation measure (6200 rad m^{-2}) in a sample of more than 70 HzRGs, indicating that 1138-262 is surrounded by a hot, clumpy and dense magnetized medium (Carilli et al. 1997). On the basis of these arguments we targetted 1138-262 for a cluster search using narrow band imaging and multi object spectroscopy. These observations resulted in the discovery of a structure of 14 Lyα emitting galaxies in the region of this radio galaxy (Pentericci et al. 2000). Here we present additional results from these observations that shed light on the origin of the emission line gas, the ionization processes and the constituents of the presumably young galaxy.

2. OBSERVATIONS AND RESULTS

Using optical broad and narrow band images, obtained at the 8.2-m ESO VLT[3] Antu telescope with

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[3]This research is based on observations carried out at the European Southern Observatory, Paranal, Chile.

TABLE 1

OBSERVATION LOG

Technique	Date	Config	Time (hours)
Optical Imaging	April 1999	Bessel B	0.5
		O II 3814 Å	4.0
Optical Spectroscopy	March 2000	Mask A	5.5
		Mask B	6.0
Infrared Imaging	March 1999	K_s	1.5
	March 2000	2.07 μm	6.0

FORS1, we found 50 objects that were candidates for galaxies with large Lyα equivalent width at $z = 2.16$ (Kurk et al. 2000). Multi-object spectroscopy with the same instrument gave redshifts for 15 candidates (Pentericci et al. 2000). We have also obtained infrared broad and narrow band images with ISAAC at the Antu telescope to search for Hα emitting companions of the radio galaxy. Table 1 summarizes the dates and integration times of these observations. The optical and infrared observations are also very suitable to study MRC 1138-262 itself: from the optical imaging we have obtained a detailed map of the Lyα halo, from the spectroscopy deep spectra of several components of the galaxy and from the infrared imaging a map of the Hα halo.

2.1. *Optical imaging*

Image reduction resulted in 6′.8×6′.8 narrow and broad band images with seeing 0″.9 and 1σ limiting AB magnitude per square arcsecond of 27.8 and 28.1 respectively.

The B-band image (see grayscale in Figure 1) shows that MRC 1138-262 has a very clumpy morphology, quite unlike modern-day massive ellipticals. Instead, there are 7 seperate barely resolved knots in a 15″×10″ region, some aligned with the direction of the radio jet axis. In Fig. 1 these components are labeled by lowercase letters. Component ‘a’ is identified with the nucleus, hosting the AGN of the radio galaxy.

We have obtained a Lyα emission image of the radio galaxy from the difference between the narrow and the broad band image. The Lyα emission map (contours in Figure 1) strikingly shows the enormous size of the halo encompassing all the continuum clumps. Most continuum clumps have a counterpart in the Lyα map, but the peak of the Lyα emission does not coincide with the most luminous continuum source (‘a’), but with a much fainter one (‘d’).

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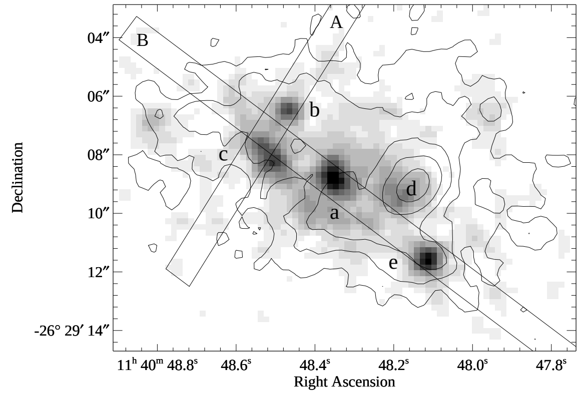

Fig. 1. B-band image of 1138-262 (grayscale) overlayed with contours of Lyα emission. Also shown are the locations of two slits used for spectroscopy, labeled with upper case letters. Lower case letters label the various parts of the radio galaxy, as in Pentericci et al. (1997).

2.2. *Infrared Imaging*

The reduced 2′.5 × 2′.5 narrow and broad band images have an average seeing of 0″.5 and 1σ limiting AB magnitude per square arcsecond of 23.9 and 24.0 respectively.

Contrary to the B-band image, the K_s-band image shows one main bright unresolved component, accompanied by two small clumps in the North East direction. This structure coincides with the nucleus and components ‘b’ and ‘c’ in the optical image.

From the narrow and broad band images we have constructed an Hα emission image in the same way as the optical Lyα emission image. The Hα morphology is very different from the Lyα morphology. The Hα emission is dominated by the bright unresolved nucleus. It has a westward extension of about 5″, which we associate with component ‘d’. There are three more faint Hα emission regions, of which two are coinciding with a local enhancement of Lyα emission.

2.3. *Optical Spectroscopy*

We used several FORS1 masks to observe the candidate Lyα emitters near MRC 1138-262 and in two masks we employed one central slit to observe several clumps of the radio galaxy. The positions of these central slits are shown in Fig. 1. The spectra cover a wavelength range from approximately 3180 to 5550 Å and the 1″ slitwidths gave a resolution of ~ 5 Å corresponding to about 400 km s^{-1}. The slits in mask A and B each cover at least three components in the halo of the radio galaxy. Figure 2 shows the complex intertwined two-dimensional spectrum of the Lyα lines from the components in the slit of

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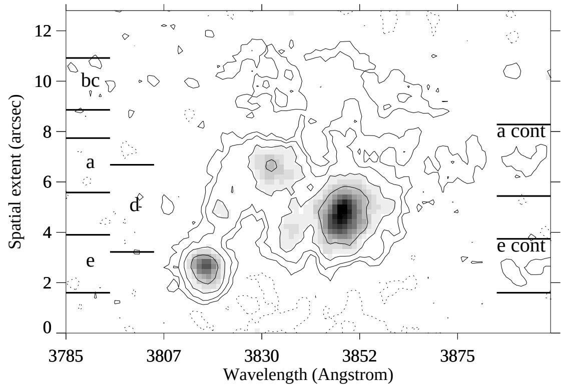

Fig. 2. Contour plot of the Lyα region of the slit in mask B. Aperture limits are indicated by thick straight lines for the individual components denoted by their names inside the apertures.

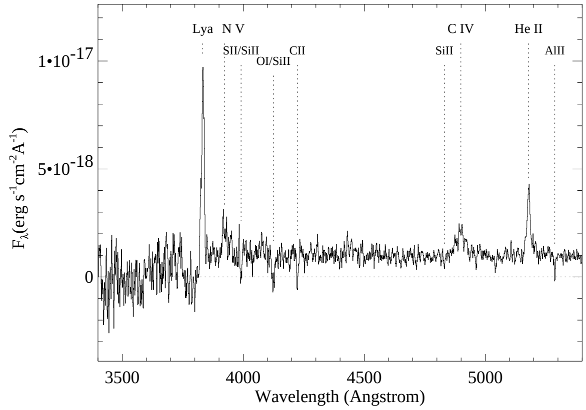

Fig. 3. Spectrum of component 'a' in mask B. Emission lines are indicated. The continuum shows several interstellar absorption lines.

mask B. All components observed show Lyα emission, but components 'a' and 'b' also have continuum emission with interstellar absorption lines. Components 'c' and 'e' do show a continuum but no absorption lines are detected, despite the good s/n. Component 'a' (see Figure 3 for its one-dimensional spectrum) is the only one possessing metal emission lines.

3. DISCUSSION

The fact that Lyα and Hα emission are radiated by the same source but transported in a different way—Lyα is a resonant line, while Hα is not—gives us the opportunity to study the combined presence of neutral hydrogen as a scattering medium and dust as an absorbing medium. In most astrophysical cases where hydrogen is photo-ionized, the transition from $n = 2$ to 1 is believed to be optically thick (Case B recombination, Osterbrock 1989). This dictates a Lyα/Hα ratio in the range of 8 to 12 depending on temperature and density of the gas. The Lyα/Hα ratio we detect in the halo of MRC 1138-262 varies with position, but is always smaller than 8 (see Figure 5).

It is striking that there is only weak Lyα present at the position of the strongest Hα clump with an observed Lyα/Hα ratio of ~ 0.015. The presence of strong continuum emission here suggests ionization by UV radiation from hot stars or alternatively from the nearby AGN. The Lyα photons are resonantly scattered by large amounts of neutral hydrogen and possibly absorbed by dust, while the Hα photons are relatively unaffected by these two processes.

The second region of interest is the Lyα peak, which is situated at the position where the radio jet has been bent, as shown in Figure 4. We propose as the likeliest explanation that the radio jet encounters a relatively dense medium at this location. Propagation through the dense clump changes the jet direction while driving shocks into the medium thereby ionizing hydrogen gas. This behaviour is reminiscent of that in 3C277.3 (van Breugel et al. 1985) where the radio jet is observed to bend at the position of highest ionization gas clump. The Lyα/Hα ratio in this region is on average about 4 and at its peak at a value of 7.6, close to the expected value for Case B recombination. Since this is far from any continuum clump, it is not surprising that less neutral hydrogen and/or dust is present.

Apart from three smaller regions with mean Lyα/Hα ratios of 0.6, Hα is not detected anywhere else within the Lyα structure, leading to lower limit Lyα/Hα ratios from 0.1 to 2.0. A significant part of the Lyα emission in these regions is probably scattered emission and no Hα is expected here. The Lyα/Hα ratio of all emission measured is 2.0. A correction for galactic extinction raises this ratio by about 15%. McCarthy, Elston, & Eisenhardt (1992) determined Lyα/Hα ratios for two radio galaxies at $z = 2.4$ by spectroscopy and they find extinction corrected values of 4.7 and 3.5, slightly higher than our value of 2.3. We conclude that, although the Lyα/Hα ratio in the powerful radio galaxy MRC 1138-262 has extremely low values in one place due to scattering and very high values in another due to the absence of a scattering medium, the average ratio is still a factor ~ 3 below the recombination value, implying that at least some dust is present.

The nucleus is the sole component observed which exhibits the metal emission lines N V, C IV

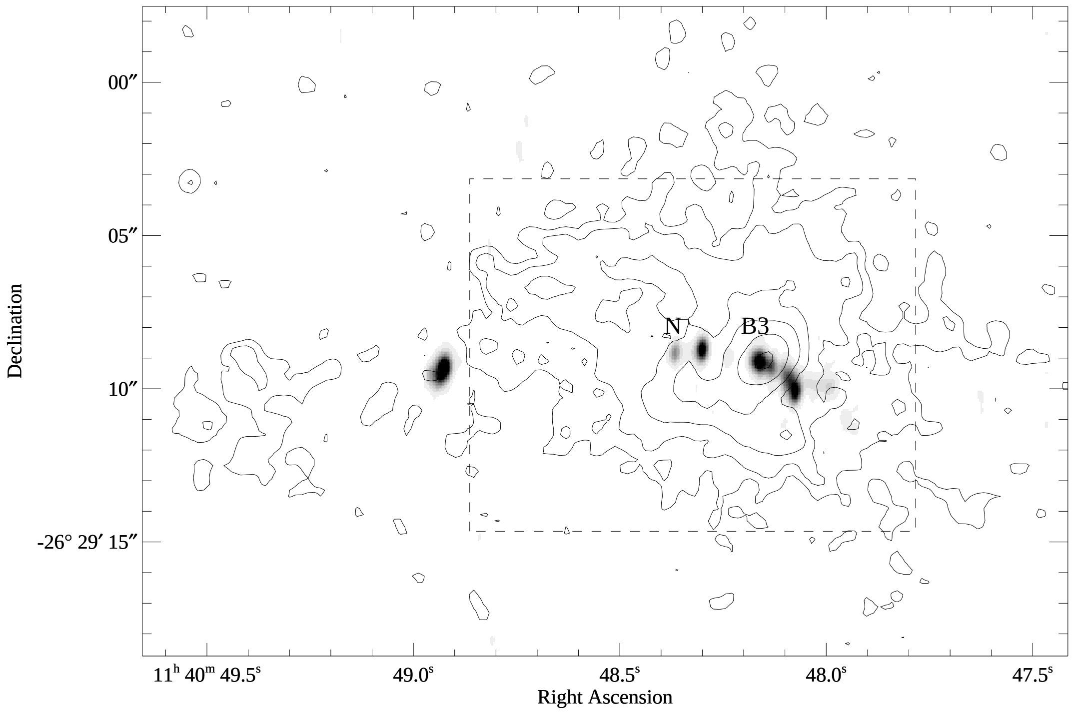

Fig. 4. Contour plot of the Lyα emission with radio continuum emission at 8.1 GHz superimposed in greyscale. Contours are a geometric progression in steps of 2, starting from 2 times the background rms noise. The nucleus (N) and the radio knot where the jet bends (B3) are indicated, following Pentericci et al. (1997). The rectangle is enlarged in Fig. 5.

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and He II. Using the ratios of these lines as metallicity indicator (Vernet et al. 2000), we derive that this clump's metallicity is three times solar. From the absence of detectable metal emission lines in other clumps with strong Lyα emission, we surmise that there are differences in metallicity among the clumps, consistent with the metallicity gradient measured in MRC 2104-242 (Overzier et al. 2002, these proceedings).

The spectra of two continuum components show absorption lines due to interstellar metal elements. The absorption lines in the central clump are redshifted with respect to the Lyα line by $\sim$ 1100 km s^{-1}. This is different from what is observed in the HzRG 4C41.17, where the absorption is blueshifted with respect to the emission (Dey et al. 1997). The equivalent widths of these lines are comparable with the lines in the restframe UV spectrum of MS 1512-cB58 (Pettini et al. 2000) and an average spectrum of 11 high-redshift galaxies in the Hubble Deep Field (Lowenthal et al. 1997).

4. CONCLUSION

Observations of the giant ionized gaseous halo which encompasses the continuum clumps of 1138-262 suggest that hydrogen in this system is ionized by two main sources. In the nucleus, the UV radiation originates either in the AGN itself or in massive young stars. Near the bend in the string of radio emission knots, shocks in the ambient medium caused by the radio jet can explain the origin of the ionizing radiation. Apart from small starburst regions which emit some Hα further away from the nucleus, Hα is not detected in the large Lyα halo. We conclude that the Lyα emission observed far from any continuum sources is scattered radiation and that there is dust present in the radio galaxy which absorbs some of the scattered Lyα photons. The high metallicity derived from the emission line ratios in the spectrum of the nucleus supports this conclusion.

The characteristics of the interstellar absorption lines found in two continuum components are similar to the absorption lines measured in the restframe UV spectra of Lyman-break galaxies (LBGs). We propose, therefore, that the components in the halo of 1138-262 are small galaxies in various stages of evolution, some resembling LBGs, which are falling in into the potential well of this system. Such a scenario would agree with the simulations of hierarchical formation models for massive galaxies (e.g., White & Frenk 1991). Extrapolating on the basis of

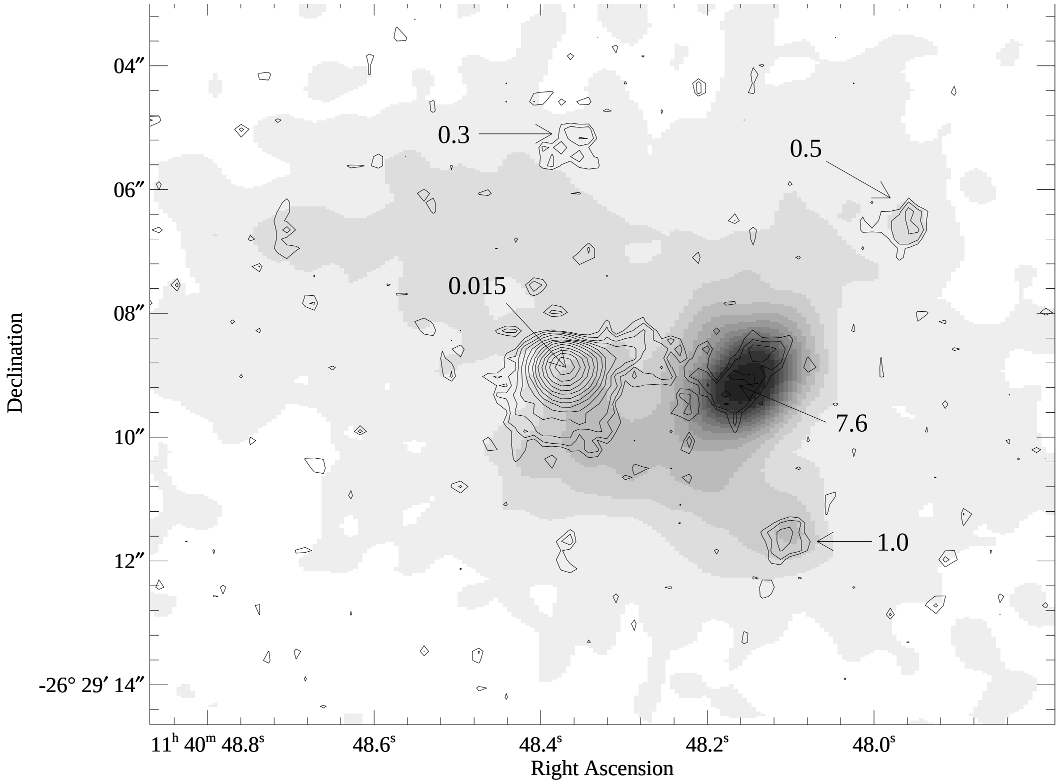

Fig. 5. Close-up of the boxed region in Fig. 4. The Hα emission is represented by contours, which are geometrically progressing in steps of $2^{1/2}$, starting from 2 times the background rms noise. The underlying greyscale represents the Lyα emission. Lyα/Hα ratios are indicated: the minimum of 0.015 at the nucleus and the maximum of 7.6 at the location of the bend in the radio jet, average values of 0.3, 0.5 and 1.0 for three presumed starburst regions.

these models from $z = 2.2$ to the present, 1138-262 would be transformed into a tranquil but bright elliptical galaxy surrounded by its cluster companions.

The new images and spectra obtained with the VLT show that the complex system of stars, gas and ionizing radiation, which we call MRC 1138-262, contains significant amounts of neutral hydrogen gas, but has also stellar components with properties similar to that of LBGs. This is further evidence that MRC 1138-262 at $z = 2.16$ is a galaxy in the process of formation by hierarchical merging of LBGs.

REFERENCES

Carilli, C. L., Röttgering, H. J. A., van Ojik, R., Miley, G. K., & van Breugel, W. J. M. 1997, ApJS, 109, 1
Carlberg, R. G. 1994, ApJ, 433, 468
Dey, A., van Breugel, W., Vacca, W. D., & Antonucci, R. 1997, ApJ, 490, 698
Kurk, J. D. et al. 2000, A&A, 358, L1
Lowenthal, J. D. et al. 1997, ApJ, 481, 673
McCarthy, P. J., Elston, R., & Eisenhardt, P. 1992, ApJ, 387, L29
Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, (Mill Valley, CA: University Science Books)
Overzier, R., Röttgering, H., Kurk, J., & De Breuck, C. 2002, RevMexAA(SC), 13, 203 (this volume)
Pentericci, L., Röttgering, H. J. A., Miley, G. K., Carilli, C. L., & McCarthy, P. 1997, A&A, 326, 580
Pentericci, L. et al. 1998, ApJ, 504, 139
__________. 1999, A&A, 341, 329
__________. 2000, A&A, 361, L25
Pettini, M., Steidel, C. C., Adelberger, K. L., Dickinson, M., & Giavalisco, M. 2000, ApJ, 528, 96
van Breugel, W., Miley, G., Heckman, T., Butcher, H., & Bridle A. 1985, ApJ, 290, 496
Vernet, J. et al. 2000, A&A, submitted
White, S. D., & Frenk, C. S. 1991, ApJ, 379, 52

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