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Emission Lines from Jet Flows (Isla Mujeres, Q.R., México, November 13-17, 2000)
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DEEP VLT SPECTROSCOPY OF HIGH REDSHIFT RADIO GALAXY MRC 2104–242: EVIDENCE FOR A METALLICITY GRADIENT

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RESUMEN

En esta contribución vamos a presentar observaciones espectroscópicas profundas del VLT (siglas en inglés: Very Large Telescope) del halo gigante de líneas de emisión alrededor de la radiogalaxia MRC 2104–242 a $z = 2.49$. La morfología del halo viene determinado por dos regiones espaciales resueltas. Lyα se extiende por $> 12''$ a lo largo del radioeje, C IV $\lambda\lambda$ 1549 y He II λ 1640 se extienden por $\sim 8''$. El espectro total es típico para radiogalaxias de alto corrimiento al rojo. Es interesante notar que N V λ 1240 está presente en el espectro de la región asociada con el centro de la galaxia que contiene la radiofuente, la región del norte, mientras que está ausente en la región del sur. Usando un modelo de fotoionización simple, la diferencia en la emisión N V λ 1240 se puede explicar por un gradiente de metalicidad en el halo. Esto es consistente con un escenario en el cual el halo se formó por un "cooling flow" masivo o tiene su origen en los residuos de la fusión de dos o más galaxias. Sin embargo, también podrían ser importantes otros mecanismos como son las interacciones entre jets y nubes y los vientos debido a un "starburst".

ABSTRACT

In this contribution we will present deep VLT spectroscopy observations of the giant emission line halo around the $z = 2.49$ radio galaxy MRC 2104–242. The morphology of the halo is dominated by two spatially resolved regions. Lyα is extended by $> 12''$ along the radio axis, C IV $\lambda\lambda$ 1549 and He II λ 1640 are extended by $\sim 8''$. The overall spectrum is typical for that of high redshift radio galaxies. Interestingly, N V λ 1240 is present in the spectrum of the region associated with the center of the galaxy hosting the radio source, the northern region, while absent in the southern region. Using a simple photoionization model, the difference in N V λ 1240 emission can be explained due to a metallicity gradient within the halo. This is consistent with a scenario in which the halo is formed by a massive cooling flow or originates from the debris of the merging of two or more galaxies. However, other mechanisms, such as jet-cloud interactions or starburst-winds, could also be important.

Key Words: **COSMOLOGY: EARLY UNIVERSE — GALAXIES: ACTIVE — GALAXIES: EVOLUTION — GALAXIES: KINEMATICS AND DYNAMICS**

1. INTRODUCTION

High redshift radio galaxies (HzRGs) are often surrounded by giant halos of ionized gas, which radiate luminous emission lines in the rest frame UV/optical part of the spectrum (see McCarthy 1993 for a review). The typical emission line spectrum of HzRGs can best be explained assuming photoionization by a hidden quasar, with in some cases an additional contribution due to shock ionization by jet-cloud interactions (Best, Röttgering, & Longair 2000).

Because HzRGs are believed to be the progenitors of massive elliptical galaxies (e.g., Best, Longair, & Röttgering 1998) and have many observable components, they are a good tool for studying the formation of massive galaxies. An important question related to this concerns the origin of the halo. If the halo gas originates from outside the radio galaxy, it could be associated with the debris from galaxies merging (Heckman et al. 1986) or it could originate in a massive cooling flow from a cluster-type halo (Crawford & Fabian 1996). Alternatively, the gas could have been driven out by a starburst-wind or by shocks associated with the radio source. Studying the properties of the gas in detail may help to make a distinction between these or other scenarios.

In this contribution, we will first give a review of the object of our study, radio galaxy 2104–242 at $z = 2.49$, in § 2. Then, in § 3, we present the results of spectroscopic observations with the VLT and we will show that we have found evidence for a metallicity gradient in the extended emission line region in § 4. To conclude, we will discuss the origin of the halo of 2104–242 in § 5.

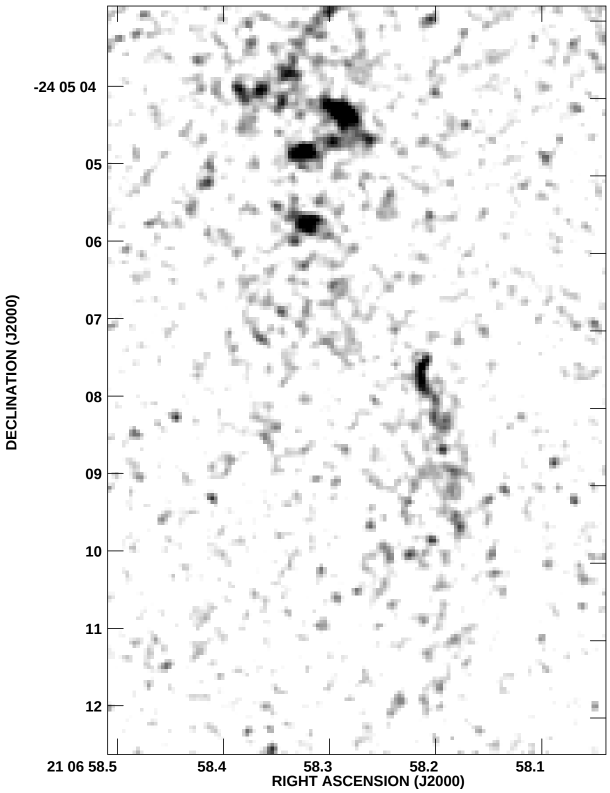

Fig. 1. WFPC2 V-band image of 2104–242 in gray scale (Pentericci et al. 1999). Some of the components in the top of this image are confused with the residuals from a spike of a nearby star.

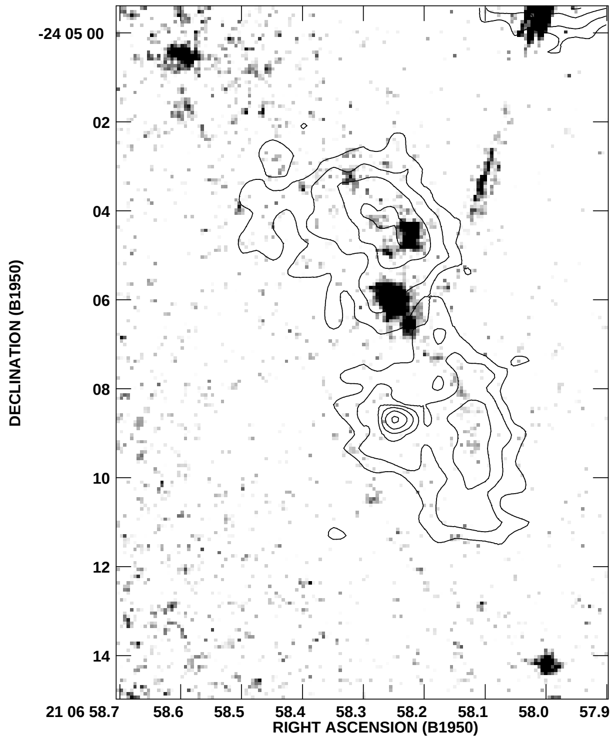

Fig. 2. NICMOS image of 2104–242 in gray scale overlayed with contours of the narrow band Lyα emission (Pentericci et al. 1999). The narrow feature in the upper right of this image is a spike of a nearby star.

2. MRC 2104–242

Radio source 2104–242 is identified with a galaxy at $z = 2.49$ and is one of the brightest known HzRGs in Lyα (McCarthy et al. 1990). Narrowband Lyα images show a total extent of $> 12''$ (136 kpc[1]) distributed in two distinct regions separated by $\sim 6''$. Because of the brightness and the spectacular morphology of the halo at the considerable redshift of $z = 2.49$, 2104–242 has been the subject of a number of different observational programs including HST-imaging (Pentericci et al. 1999) and VLT spectroscopy (Overzier et al. 2001).

HST WFPC2 V-band images of 2104–242 show that this galaxy actually consists of several smaller components, presumably in the process of galaxy-merging (see Figure 1). One of the bright components hosted by the northern Lyα region is prominent in near-infrared emission and therefore it is assumed to be the center of the galaxy hosting the radio source (Pentericci et al. 1999). The continuum of the nucleus and the other components in this region are not spatially resolved in our spectra, so we will refer to the whole region as the northern region. The southern Lyα region is associated with the narrow filamentary component of $\sim 2''$ clearly seen in Fig. 1. This component is oriented in close alignment with the direction of the radio axis (see Figure 2 for an *HST* NICMOS image overlayed with contours of the narrowband Lyα halo).

Spectroscopy shows that both Lyα regions have large FWHM (1000–1500 km s^{-1}), large rest-frame equivalent widths (330 and 560 Å) and a velocity difference of $\sim$ 500 km s^{-1} (McCarthy, Baum, & Spinrad 1996; Koekemoer et al. 1996; Villar-Martín, Binette, & Fosbury 1999). The two regions also emit other lines and faint continuum.

3. VLT SPECTROSCOPY

We used the FORS1 spectrograph on the 8.2m VLT Antu telescope (ESO-Chile) with a 1$''$-wide slit. The slit was positioned along the bright components and the filamentary structure seen in Figs. 1 and 2. The exposure time was 3×3600 s.

Figure 3 shows the two-dimensional spectra of Lyα, C IV and He II. C IV and He II are extended by $\sim 8''$ along the radio axis and Lyα is extended

[1]We adopt $H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0.1$. At $z = 2.49$ this implies a linear size scale of 11.3 kpc arcsec^{-1}.

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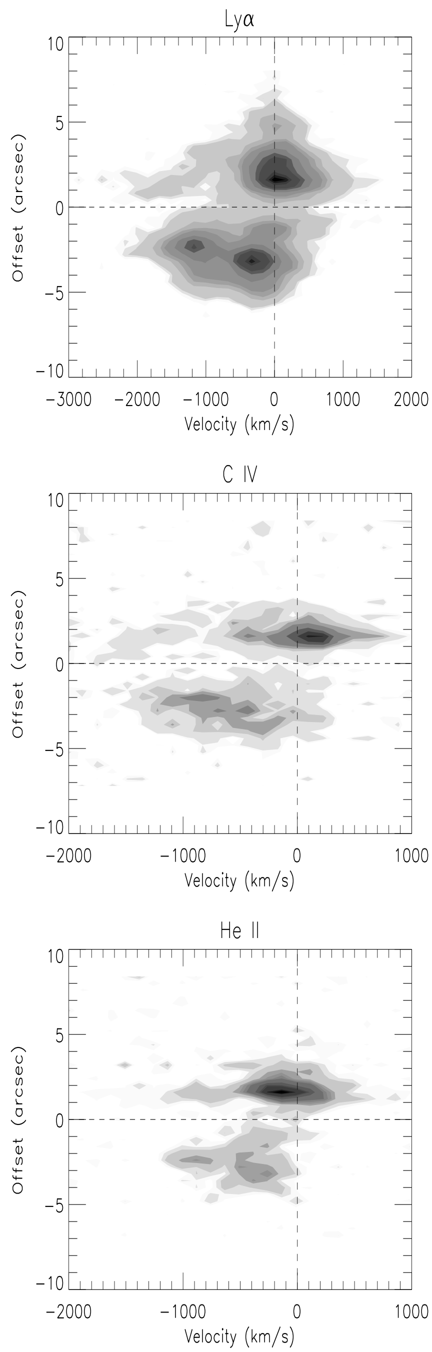

Fig. 3. The two-dimensional emission line structures of Lyα, C IV and He II. Offset zero was chosen in between the northern and southern regions. Velocity zero corresponds to the peak Lyα emission in the northern region.

by $> 12''$. We have compared the kinematic structure of these lines. The peak of the C IV emission in the northern region is redshifted with respect to that of Lyα by ~ 100 km s^{-1}, while that of He II is blueshifted by ~ 150 km s^{-1}. In the southern region,

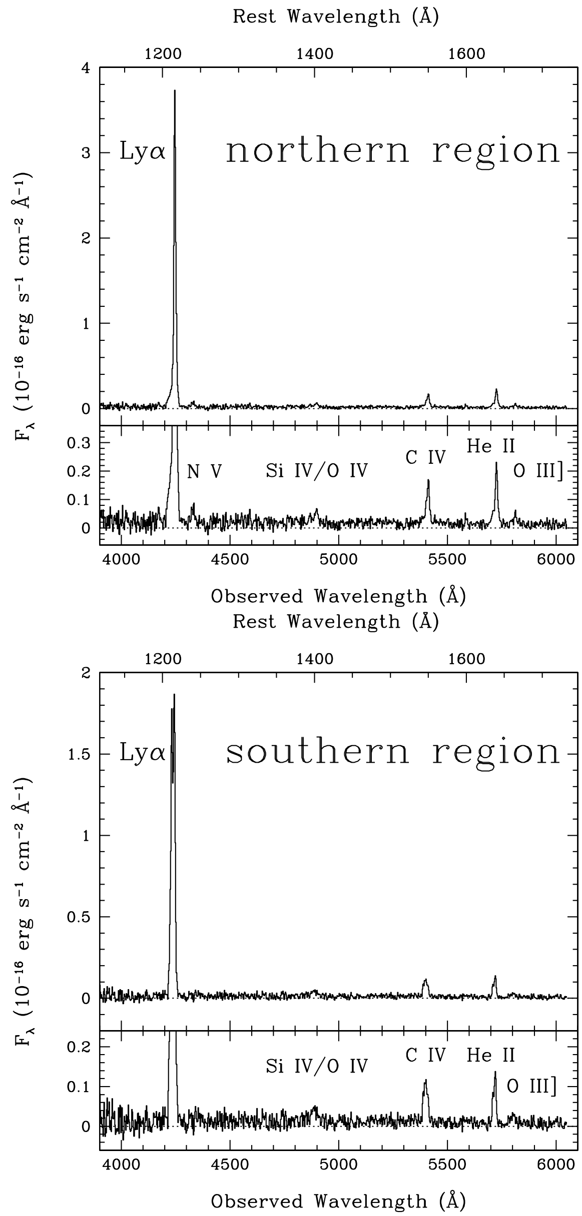

Fig. 4. Spectrum of the northern (top) and southern (bottom) emission regions of 2104–242.

Lyα shows two separate peaks shifted blueward from the northern region by ~ 1000 and ~ 500 km s^{-1}. This two-peak distribution is also seen in C IV and He II. The fact that it is observed in He II could indicate kinematical substructure in the halo, because He II is unsusceptible to absorption. Therefore, we conclude that the dip in the Lyα profile is not due to absorption.

Figure 4 shows the one-dimensional spectra of the northern and southern region of the emission line halo. Both regions show bright Lyα, C IV and

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He II and weak Si IV and O III. Interestingly, N V is detected in the northern region, but absent in the southern region. Within the errors, the emission line ratios of the two regions are the same, only those involving N V are discrepant. The N V/C IV and N V/He II line ratios are at least 4 and 3 times higher in the northern region compared to the southern. In § 4 we will show that this is evidence for a metallicity gradient within the halo.

4. EVIDENCE FOR A METALLICITY GRADIENT?

Vernet et al. (2001) found that HzRGs follow a sequence in N V/C IV versus N V/He II, parallel to the relation defined by the broad line regions (BLRs) of quasars found by Hamann & Ferland (1993). Hamann & Ferland (1993) showed that this sequence can be explained by a different metallicity of the BLRs. This could be due to variation in the evolutionary stage and intensity of the associated starburst. Vernet et al. (2001) found that the N V correlation and the strong N V emission in some HzRGs (e.g., van Ojik et al. 1994) are best explained by a model of photoionization and variation of metallicity. Therefore, we conclude that the difference in N V emission from the two regions can be explained only by a metallicity gradient within the halo. Using a metallicity sequence with quadratic nitrogen enhancement (N $\propto Z^2$) from Vernet et al. (2001) we find a metallicity of $Z \approx 1.5 Z_\odot$ for the northern region and an upper limit of $Z \leq 0.4 Z_\odot$ for the southern (Figure 5).

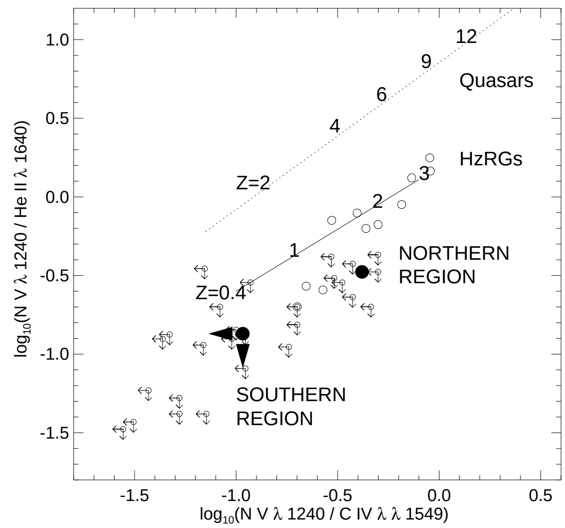

Fig. 5. N V/He II versus N V/C IV. The dotted line represents the metallicity sequence defined by quasars (Hamann & Ferland 1993), with the numbers indicating the metallicity in solar units. The solid line represents a metallicity sequence with N $\propto Z^2$ (ionization parameter $U = 0.035$, power law spectral index $\alpha = -1.0$) from Vernet et al. (2001). The two regions of 2104–242 are indicated. Small open circles indicate radio galaxies from the sample of De Breuck et al. (2000).

5. DISCUSSION

The supersolar metallicity of the gas associated with the central part of the galaxy implies that 2104–242 has experienced a period of intense star formation. Assuming that the difference in N V emission found within the halo is indeed due to a metallicity gradient, the emitting gas near the center and the gas further out are in different stages of evolution.

It has been suggested that the infall of gas by massive cooling flows is an important process in galaxy formation (Crawford & Fabian 1996). In this scenario, gas cools from a primordial halo surrounding the radio source and provides the material from which the galaxy is made. Fardal et al. (2001) examined cooling radiation from forming galaxies, estimating Lyα line luminosities of high redshift systems. They find that a significant amount of the extended Lyα emission can indeed arise from cooling radiation.

However, because the two regions of 2104–242 both show emission lines from other elements than H and He, at least some of the gas must already have been processed in stars in the past. Therefore, other mechanisms may be needed to explain the origin of the halo. The *HST* images of 2104–242 (Pentericci et al. 1999) support the idea that galaxies are formed by a process of hierarchical buildup (Kauffmann 1995). We have also found evidence for kinematical substructure within the halo. Therefore, the emission line halo may be the result of gas associated with intense merging of galaxies.

Alternatively, the gas in the halo could be the result of jet-cloud interactions, inducing extreme, nongravitational motions or it could have been expelled by a superwind following an enormous starburst. Binette et al. (2000) showed that radio galaxy 0943–242 is surrounded by a gas shell of low metallicity. They conclude that this gas has been expelled from the parent galaxy during the initial starburst at the onset of its formation.

We conclude that the emission line ratios are well explained by a combination of photoionization and a metallicity gradient. This is consistent with scenarios in which the halo is formed by gas falling onto the radio galaxy located at the center of a forming cluster or by gas associated with intense galaxy merging, but other mechanisms such as jet-cloud interactions or starburst-winds cannot be ruled out.

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