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Subaru Spectroscopy of the Giant Lyα Nebula around 1243+036

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Abstract.
We present our new spatially-resolved, optical spectroscopy of the giant Lyα nebula around the powerful radio galaxy 1243+036 (=4C+03.24) at $z = 3.57$. The nebula is extended over ~ 30 kpc from the nucleus, and forms a pair of cones or elongated bubbles. The high-velocity (~ -1000 km s^{-1}; blueshifted with respect to the systemic velocity) Lyα-emitting components are detected at both sides of the nucleus along its major axis. We discuss possible origin of the nebula; 1) the shock-heated expanding bubble or outflowing cone associated with the superwind activity of the host galaxy, 2) halo gas photoionized by the anisotropic radiation from the active galactic nuclei (AGN) and 3) the jet-induced star-formation or shock. The last possibility may not be likely because Lyα emission is distributed out of the narrow channel of the radio jet. We show that the superwind model is most plausible since it can explain both the characteristics of the morphology (size and shape) and the kinematical structures (velocity shift and line width) of the nebula although the photoionization by AGN may contribute to the excitation to some extent.

1. Introduction

It is well known that images of the rest-frame UV and optical continua are elongated preferentially along the radio axis in powerful radio galaxies (PRGs) at redshift (z) > 0.6 (e.g., Chambers et al. 1987; McCarthy et al. 1987); the so-called alignment effect. Indeed, many high-z ($z > 2$) PRGs (HzPRGs) show the alignment effect, and its origin has been in debate in this decade. Various models have been proposed to explain the alignment effect; e.g., (1) scattering of the anisotropic radiation from the central engine of an AGN (e.g., Cimatti et al. 1998), (2) the jet-induced star formation (e.g., Chambers et al. 1987; McCarthy et al. 1987), and (3) the jet-induced shock heating (e.g., De Breuck et al. 2000). In these models, active galactic nuclei (AGNs) play some important roles to create an extended aligned continuum emission at various wavelengths.

An alternative idea, a pair of elongated bubbles or bi-directional cones associated with the superwind/starburst activity of the host galaxy, is proposed to explain a figure-8 shaped extended nebula in MRC 0406-244 (Taniguchi et al. 2001; see also Rush et al. 1997; Pentericci et al. 2001). We can explain the alignment effect in terms of the superwind/starburst phenomena if the accretion disk around the super massive blackhole, which defines the axis of the radio jet, is nearly co-planer to the host gas disk, which defines the axis of the superwind. Since some of these objects are known to experience vigorous star formation activity (e.g., Dey et al. 1997), this new mechanism can be regarded as one of several possible ideas.

Study of such superwind nebulae in the high-z universe seems very useful to understand the formation and evolution of galaxies from a general point of view. The reason for this is that galaxies are expected to experience a galactic wind (i.e., a powerful initial superwind in a late phase of galaxy formation), which is considered to play significant roles to determine global characteristics of present-day massive elliptical galaxies (e.g., Arimoto & Yoshii 1987). Since we know many HzPRGs even at redshift $z \gtrsim 3$ (e.g., Röttgering 1993, 1996; van Ojik et al. 1994) thanks to their powerful radio emission, their superwind activities can be used to probe the early star formation history in their host galaxies. Powerful 8-10 m-class telescopes enable us to investigate them in detail.

In this paper, we focus our attention on one HzPRGs, namely 1243+036 (= 4C+03.24), at $z = 3.6$, which has an aligned Lyα nebula, and is one of the highest-z objects known to show an alignment effect (see, e.g., Lacy et al. 1994). According to van Ojik et al. (1996; hereafter vO96), the observational properties of the nebula can be summarized as follows[1]. (a) This object is surrounded by a huge Lyα halo which extends over 135 kpc. (b) Its Lyα luminosity amounts to $L(\mathrm{Ly}\alpha) \simeq 10^{44.5} h_{0.5}^{-2}$ ergs s^{-1}. (c) Its morphology shows the alignment effect. (d) Its kinematical properties show the presence of the following two components; i) the high-velocity width component with FWHM (full width at half maximum) $\simeq 1500$ km s^{-1} at -1100 km s^{-1} (blueshifted), and ii) the halo component with FWHM $\simeq 250$ km s^{-1}. In addition, recent near-infrared high-resolution images for the rest-frame UV-optical continua and redshifted [OIII]4959, 5007Å have revealed closely-aligned continuum and line emission along the narrow channel of the radio jet (van Breugel et al. 1998; Pentericci et al. 1999). Although the close spatial coincidence between the UV/optical and radio emission strongly suggests a possibility of the radio jet-induced alignment component in this object, the fan- or cone-like appearance of the Lyα nebula seems to indicate the presence of another nebula component within the same object. Therefore it is interesting to investigate this object in more detail and to explore its origin unambiguously.

2. Observation and Results

Observations were made with the FOCAS imager/spectrometer and the 8.2m Subaru telescope. A 300 second V-band image, which includes the redshifted Lyα emission, was obtained under a seeing (FWHM) of 0.″6. Then, a 0.″8 long slit was placed on the peak of the V-band image at a position angle (PA) of 152°.

[1]In this paper, we assume a Hubble constant of $H_0 = 50$ km s^{-1} Mpc^{-1} and a deceleration parameter of $q_0 = 0.5$ for consistency with the previous study of vO96. With these cosmological parameters, 1 arcsecond corresponds to 6.8 kpc at a distance of 1243+036.

A single 1800 sec exposure was taken to give a spatially-resolved redshifted Lyα spectrogram around 5560Å at a resolution of 0.″3 in space and 2.81Å in wavelength per pixel (or 150 km s^{-1} at the redshifted Lyα emission). Note that, although the slit position (centered on the peak of the Lyα emission) and its orientation (PA=152°) are the same for vO96 and ours, the slit widths (2.″5 for vO96 and 0.″8 for ours) and the velocity resolutions (150 km s^{-1} for vO96 and 600 km s^{-1} for ours) are different.

In Figure 1, we compare our V-band image with the radio continuum and Lyα images of vO96. Although a narrow-band image of vO96 shows extended Lyα emission only toward the SE of the nucleus, our V-band image shows an extended nebula toward both the NW and the SE of the nucleus. Our V-band filter bandpass covers the whole redshifted Lyα emission, and the contribution of the continuum emission should be almost negligible for the extended component. The reason for this apparently different appearance might be a mismatch of vO96's filter bandpass; i.e., the NW component is blueshifted at 5541Å or bluer for the most part (see Figure 2 below), and thus out of the transmission bandpass of 5541Å– 5601Å of their narrow-band filter.

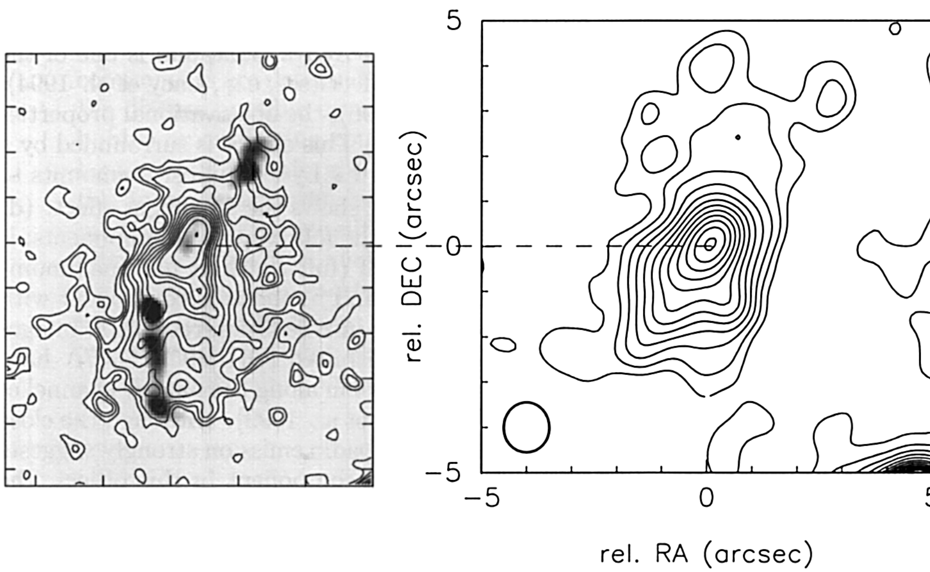

Figure 1. Our V-band image of 1243+036 (right), which includes the redshifted Lyα emission, compared with the narrow-band Lyα image (contours), overlaid on the radio 8GHz image (gray scale), of vO96 (left) at a same scale. The V-band image is smoothed by Gaussian convolution to enhance the weak emission at outer parts of the nebula; the effective seeing (after the smoothing) is 1.″1 FWHM, as shown by a circle at the lower left corner.

Our Lyα spectrogram reveals complicated structures of the nebula both in space and in velocity (Figure 2). The main components we will focus on here are: (I) the compact nucleus component, (II) the extended near-systemic component at both sides of the nucleus, and (III) the extended blue components at both sides of the nucleus, as summarized below.

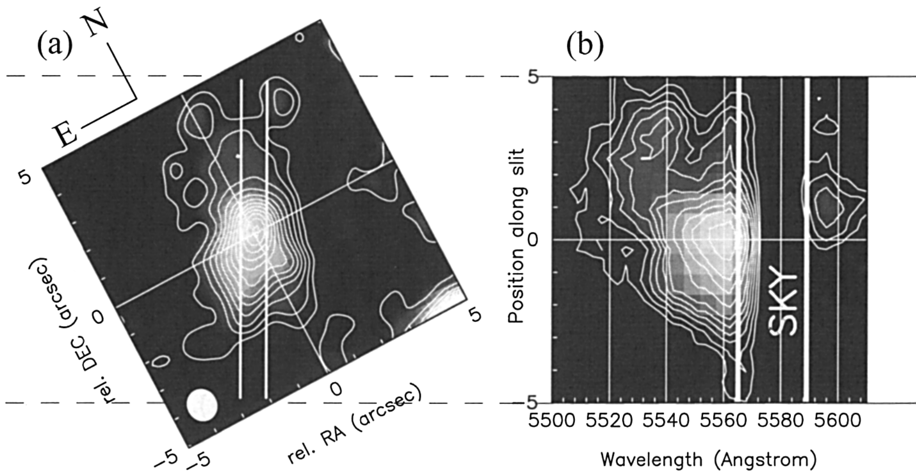

Figure 2. Our two-dimensional Lyα spectrogram (right) is shown as well as the slit position overlaid on our V-band image (left). The V-band image is rotated so that the slit position, indicated by two lines at the nebula center, is seen vertically. The spectrogram is smoothed by 4 by 4 pixel running average to enhance the outer weak emission. After the smoothing, the effective resolution is 1.″2 in space which is almost comparable to that of the smoothed imaging data, and the velocity resolution is 600 km s^{-1}. The wavelength region where no information is available due to residual strong [O I] sky emission at 5577Å is masked out.

(I) The component at $< \pm 1''$ around the peak of the Lyα emission shows an evident blue-asymmetric profile with its peak at 5560Å, being consistent with the report by vO96 (at 5557Å). The blue wing emission can be traced down to -1400 km s^{-1} in the rest frame of the galaxy. Its intensity peak corresponds spatially to that of the rest UV-optical continuum emission with which the radio core showing a flatter spectrum is associated (vO96; van Breugel et al. 1998; Pentericci et al. 1999).

(II) The extended component whose velocity is close to the systemic one is found at both sides of the nucleus, and can be traced out to $\pm$ (4-5) $''$ from the nucleus. vO96 detected an "outer halo" component extending out to $\pm 10''$ on both sides of the nucleus at almost systemic velocity. This component has a narrow line width ($\simeq$ 250 km s^{-1} FWHM) and shows a large-scale velocity shear of as much as ± 225 km s^{-1} (vO96). Our near-systemic component appears to be consistent with this component, given our lower velocity resolution.

(III) The blueshifted component at the SE extends up to $2''$ from the nucleus and shows a strongly blue-shifted velocity of $\simeq -1000$ km s^{-1}. At the opposite side of the nucleus (NW), another blue component is detected which is much more extended ($\simeq 4''$– $5''$ from the nucleus) and shows a much wider velocity width ($\simeq$ 1900 km s^{-1} FWHM after correction for the instrumental resolution). The velocity curve shows the bluest velocity of -1400 km s^{-1} at $\simeq$ 2.″5 NW, and the velocity decreases in the outer regions ($\simeq -1000$ km s^{-1} at $\simeq 5''$ NW).

3. Discussion

We discuss plausible origins of the alignment effect observed in 1243+036. There are some pieces of evidence indicating that other mechanisms than the one related to a radio-jet act to excite the extended nebula in 1243+036. First, the near-infrared high-resolution images for the rest-frame UV-optical continua and redshifted [OIII]4959, 5007Å revealed closely-aligned continuum and line emission along the narrow channel of the radio jet (van Breugel et al. 1998; Pentericci et al. 1999). Although this indicates the importance of the radio jet activity to the alignment effect, the Lyα nebula of this galaxy is extended much more widely than the region of the aligned continuum (Figure 1). Second, the extended components are blueshifted at both sides of the nucleus. The jet-induced extranuclear shock, if any, should show a pair of blueshifted and redshifted components at each side of the nucleus because symmetric propagation of a jet and its counter jet is expected. This is inconsistent with the observations. Therefore it seems very likely that the effect of the radio jet onto the extended nebula cannot explain the excitation of the whole Lyα nebula.

Another idea of the origin of the widely extended Lyα nebula is circumgalactic matter ionized by the anisotropic hard radiation from the AGN. If this is the case, the matter irradiated by the AGN radiation is required to be distributed over a large volume ($\simeq$ 60 kpc) at a violent kinematical status to explain the velocity shift of $\simeq -1000$ km s^{-1} together with a large velocity dispersion of 1000 - 2000 km s^{-1}. One possibility may be that such violent gaseous systems are tidally-induced structures formed through a putative merger event. Note, however, that even nearby luminous mergers show neither the large overall velocity difference nor the high velocity dispersion as seen in 1243+036 (Mihos & Bothun 1998; Hibbard & Yun 1999). Another candidate for the extended matter is the remaining sub-galactic clumps from the epoch of galaxy formation. However, the range of the clump velocity dispersion would be 300 km s^{-1} or less because gaseous clumps with a higher velocity dispersion have difficulty assembling to form a galaxy. Therefore, this possibility appears less promising.

An alternative idea for the origin of the blue-shifted extended Lyα nebula is a shock-excited nebula associated with a superwind outflow. Our V-band image reveals a pair of elongated bubbles or cone-like structures extending into opposite directions from the nucleus. Similar extended nebulae are often seen around starburst galaxies with superwind/superbubble activity, such as M82 and Arp 220 (e.g., Heckman et al. 1990), and also around a high-z ($z = 2.4$) radio galaxy MRC 0406-244 (e.g., Taniguchi et al. 2001). If 1243+036 is a similar case, the projected velocity field of the nebula would show two components at different velocities each of which corresponds to either the front or rear surface of the expanding bubble or outflowing cone (e.g., Heckman et al. 1990), rather than a single blueshifted component as observed. If the galaxy is surrounded by a dusty halo, which is often found around HzPRGs (van Ojik et al. 1997), the redshifted emission from the rear surface of the bubble may be attenuated due to the longer path through the halo. Therefore the blueshifted and extended components at both sides of the nucleus can be explained by the expanding bubble model. The top of the expanding bubble, if not blown out to form a conical outflow (e.g., Heckman et al. 1990), will show a single line-of-sight velocity. If the superwind or superbubble around 1243+036 expands almost within the sky plane, then the observed velocity would be blueshifted from the systemic velocity within the bubble, and it goes back closer to the systemic one at the tip. Wider velocity width may be due to the kinematical disturbance at the shock front of the bubble. Since the superwind model can reproduce the observed morphological and kinematical properties of the nebula in qualitative ways, this model seems more plausible than the AGN model, although the photoionization by an AGN may contribute to the excitation to some extent.

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