HI Absorption in 3C236

By J. E. CONWAY[1]
AND R. T. SCHILIZZI[2]

[1]Onsala Space Observatory, Onsala, Sweden

[2] Joint Institute for VLBI in Europe, Postbus 2, 7990 AA Dwingeloo, The Netherlands

We present the results of VLBI HI absorption imaging of the central region of the giant radio galaxy 3C236. The atomic absorption is associated only with the Eastern lobe of the central 2kpc mini-double structure. There is relatively narrow (FWHM 50 km/s) but high opacity absorption associated with the tip of the Eastern jet, and much broader (FWHM 200 km/s) but lower opacity gas covering the rest of the lobe structure. The HI absorption is interpreted in terms of a jet-ISM interaction. HST imaging shows a large dust disk; the radio jets may lie close to the plane of this disk and be interacting with it.

1. Introduction

The z=0.1 radio galaxy 3C236 is the prototype of the rare class of giant radio-galaxies which have overall projected size $>$ 1Mpc. It is still the largest example of this class and has a total projected size of 3.9 Mpc as shown on low frequency WSRT maps (see Fig1). However in addition to this outer structure the source also contains relatively bright radio emission from a central region of 2kpc in extent. Early VLBI maps suggested an unusual core-halo structure for this emission. However recent continuum VLBI mapping (Conway 1999, Schilizzi et al 2001) shows that the structure is similar to many Compact Steep Spectrum sources, with a core, jet and two lobes. Given this morphology 3C236 may be considered as belonging to the class of double-double radio sources (Kaiser et al 2000), although in the case of 3C236 the ratio in size between the outer and inner doubles is much larger than many other examples. It is natural to consider 3C236 and other double-doubles as sources showing recurrent activity.

Van Gorkom et al (1989) using the VLA first detected redshifted HI absorption toward the central continuum structure of 3C236. The peak opacity was estimated as 0.03 and the total velocity width as approximately 400km/s. In order to more accurately locate the position of the atomic absorption global VLBI observations using the phased VLA, VLBA and Bonn were carried out in 1995. A preliminary report on these observations has previously been presented by Conway(1999).

2. Results

Figure 2 shows the results of the HI absorption observations. In plotting the velocities a redshift of z= 0.0988 was assumed (Sandage 1967). An alternative estimate of z= 0.1005 ± 0.0005 has been made by Hill et al (1986), if instead this redshift is adopted all velocities in Fig 2 should be reduced by approximately 500 km/s.

HI absorption was detected only toward the Eastern part of the source; with no signs of absorption toward the West lobe. There is relatively narrow (FWHM 50km/s), but high opacity ($\tau \approx 1$) absorption associated with the tip of the East lobe. Further back from the tip of the jet (see Fig 2b,c,d) there is a FWHM 50-70 km/s wide ≈ 0.1 opacity velocity component plus much wider low opacity absorption. There appears to be a slight gradient in the centroid velocity of the absorption going from South to North across the lobe. To the North (see Fig 1b) the absorption profile seems split into two components.

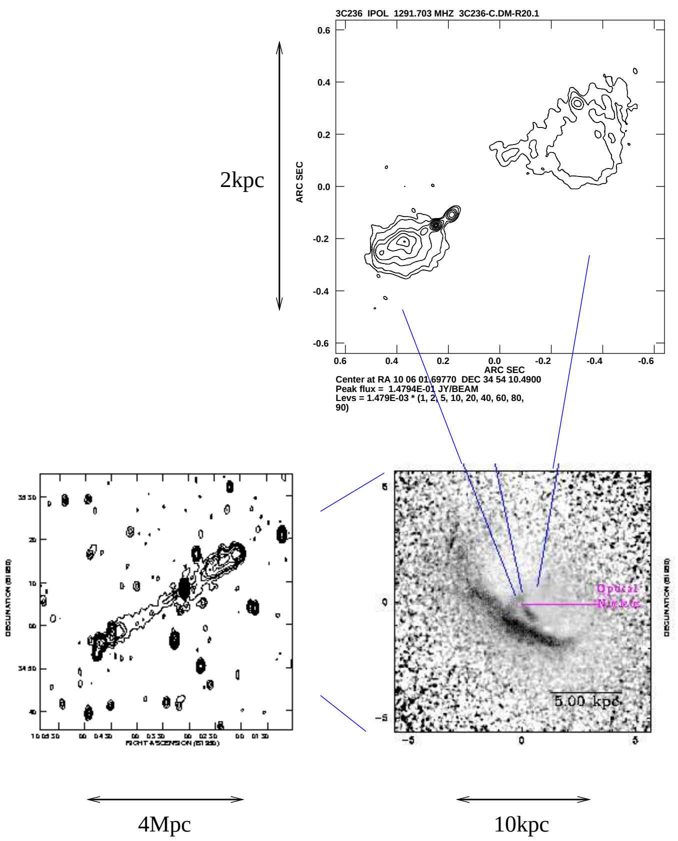

FIGURE 1. Structure of 3C236. a) VLBI 22cm wavelength continuum image. b) HST absorption at 7000Å(De Koff et al 2000). c) WSRT continuum image at wavelength 92cm

Towards the back part of the lobe (see Fig 2e) only wide low opacity absorption is seen. Finally low opacity $\tau = 0.02$, FWHM ≈ 50 km/s absorption (see Fig 2f) is seen toward the continuum component identified with the core (Schilizzi et al 2001).

The HI column density in the narrow component at the tip of the jet is approximately $2 \times 10^{22}(T_{spin}/100K)$ cm^{-2} while further back in the lobe (figs 2b,c,d) it is $\approx 2 \times 10^{21}(T_{spin}/100K)$ cm^{-2}. The column density toward the core component is $4 \times 10^{20}(T_{spin}/100K)$ cm^{-2}.

3. Discussion

In many cases VLBI observations have shown that HI absorption is associated with the nucleus of the AGN and has been interpreted as arising in a edge-on disk of 10pc -100pc radius which is perpendicular to the radio jet (van Langevelde et al 2000, Conway et al 1999). However there are other cases in which the HI absorption appears to be associated with a jet-cloud or jet-ISM interaction. One of the best examples of this phenomena is in the Seyfert galaxy IC5063 (Morganti et al 1998, Oosterloo et al 2000). 3C236 appears to belong to this second class of source. Indeed in 3C236 the continuum structure of the Eastern lobe is strikingly similar to that predicted by numerical simulations of jet-

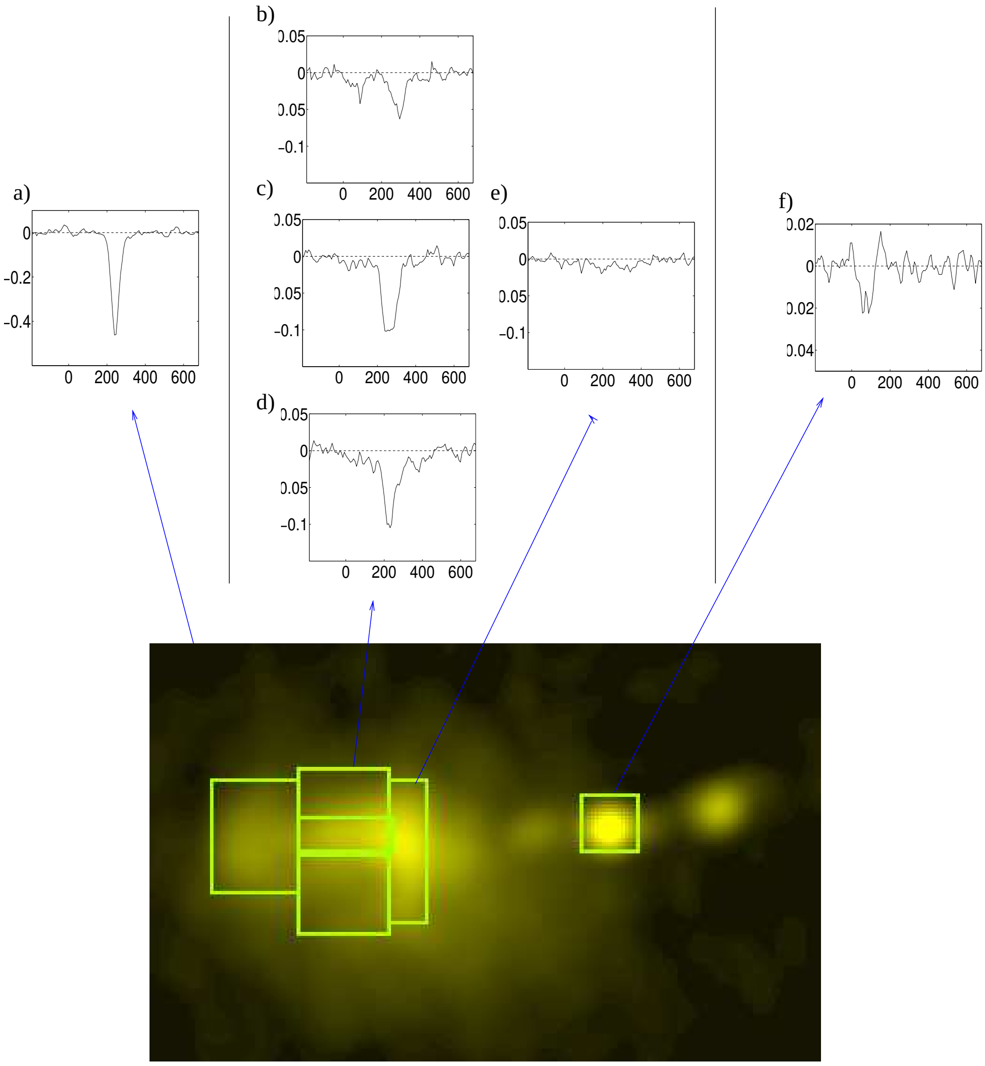

FIGURE 2. Grayscale shows a rotated version of the continuum emission in the Eastern part of the source. a) to f) show the absorption spectra within different regions of the source. The y-axis plots absorbed flux fraction ($e^{-\tau} - 1$). A velocity of zero corresponds to the optical systemic redshift of z=0.0988 (Sandage 1967). Note that the vertical scales of plots b,c,d,e are the same but are different from those in a and f.

cloud interactions (e.g Steffan et al 1997), with a jet-spine surrounded by a cocoon. Such models also predict reconfiguration shocks in the jet which could correspond to the knotty jet structures we observe in 3C236,

In 3C236 as in IC5063 there is both a narrow absorption at the tip of the jet and broader absorption covering most of the radio lobe. In 3C236 however the broad and narrow absorptions are centred on the same velocity whereas in IC5063 the narrow absorption is blue-shifted. The reason for the narrow absorptions is unclear, one might initially expect the largest velocity dispersions at the end of the jet. One possibility is that the shock driven into the surrounding gas is radiative (Bicknell, Dopita & O'Dea, 1997) and this radiation is sufficient to dissociate hydrogen molecules along the line of sight. Most of the gas column toward the jet tip would then be be undisturbed by the passage of a shock but would be atomic and give relatively narrow high opacity HI absorption. Further back along the lobe (see Fig 2b,c,d) the absorption would contain a wider component because at these places the shock would have had time to reach a significant fraction of the photo-dissociated atomic foreground gas. Still further back the shock would have had time to reach all of the atomic gas and there would only be low opacity broad absorption.

A final interesting parallel with IC5063 is that in both sources there is an HST dust disk (see Fig 1). which is not orientated perpendicular to the radio jets. Given projection effects the 3D relationship between disk and jet is unclear but in both cases the jet could be orientated relatively close to the disk plane (say 30°). In this case interactions could occur between the jets and isolated clouds just below and above the disks.

It is interesting to speculate as to why 3C236 has structure both on Mpc and kpc scales. We note that any mechanism needs to explain why the distances from core to Eastern and Western hotspots in the kpc double are significantly different yet of the same order of magnitude. The interrupted jets of the inner double cannot be caused by the jets axis precessing into the plane of a dust disk, because WSRT images show that the jet ejection axis has stayed constant for $> 10^7$ years. A more attractive possibility is instead that nuclear gas fed from a galaxy-galaxy interaction has recently interrupted ('smothered') the jets. Although there is no obvious companion galaxy the feeding event may have occurred some time ago. The resulting nuclear gas disk might then precess as it settles in the elliptical galaxy potential, until it reached an orientation in which it interrupted the jets. A careful consideration of the timescales involved is necessary to see if this is a feasible mechanism. A final possibility that cannot be excluded is that the central engine simply switched off for a time but recently restarted and is now fighting its way out of the dense galactic nucleus again.

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