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The two sided parsec scale structure of the Low Luminosity Active Galactic Nucleus in NGC 4278

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Abstract. We present new Very Long Baseline Interferometry observations of the LINER galaxy NGC 4278 with a linear resolution of $\lesssim 0.1$ pc. Our radio data reveal a two sided structure, with symmetric S-shaped jets emerging from a flat spectrum core. By comparing the positions of the components in two epochs, we measure motions corresponding to apparent velocities $\lesssim 0.2\,c$, and to ages in the range $8.3 - 65.8$ years. From our measurements, we derive that NGC 4278 has mildly relativistic jets ($\beta \sim 0.75$), closely aligned to the line-of-sight ($2^\circ \leq \theta \leq 4^\circ$). We also present a flux density history for the source with data between 1972 and 2003. All these arguments indicates that the low power radio emission from NGC 4278 is emitted via the synchrotron process by relativistic particles accelerated by a supermassive black hole.

1. Introduction

Although objects hosting an Active Galactic Nucleus represent only a small fraction of the total number of extragalactic sources, there is growing evidence that some kind of nuclear activity at lower level might be a much more common feature among galaxies. Objects presenting spectral signature of such activity include low-ionization nuclear emission-line region, low luminosity Seyfert galaxies, and "transition nuclei", i.e. nuclei with spectra intermediate between LINERs and HII regions. These objects are grouped under the name of Low Luminosity Active Galactic Nuclei (LLAGN, Ho et al. 1997).

NGC 4278 is a nearby LLAGN. It has been investigated in detail at most wavelengths. In the optical, HST observations reveal a central point source and a large distribution of dust located north-northwest of the core (Carollo et al. 1997). Ionized nuclear gas typical of LINER is found in this galaxy by Goudfrooij et al.(1994), possibly associated to a more external ring of neutral hydrogen in PA 135° (Raimond et al. 1981).

Radio continuum observations on kpc scale have been carried out at frequencies between 5 and 43 GHz, revealing a compact source (Di Matteo et al. 2001; Nagar et al. 2000, 2001). Compactness and flat radio spectra suggest that the radio emission is non thermal, and in this respect the emission from NGC4278 seems to be very similar to that of powerful radio loud AGNs, such as QSO and BL Lacs; however, the total radio luminosity of the source is only $P_{1.4\mathrm{GHz}} = 10^{21.6}$ W Hz^{-1}, i.e. at least two orders of magnitude less than those powerful objects.

On parsec scale, early VLBI experiments at 18 cm and 6 cm have revealed a core dominated structure, with an elongated feature extending to the north-west and possibly to the south on scales of some 10 mas (Jones et al. 1981, 1982, 1984; Schilizzi et al. 1983). More recent observations with the VLBA at 6 cm reveal an extended core and an elongated region to the southeast on scales of a few milliarcsecond (Falcke et al. 2000). Giovannini et al.(2001) thanks to more short spacings provided by a VLA antenna in addition to the full VLBA, have also detected emission on the opposite side of the core. Bondi et al.(2004) also detect a trace of two-sided emission, although heavily resolved. Finally, VLBA phase-referenced observations have succeeded in detecting the source on sub-pc scale even at 43 GHz, but showing only a core and a hint of low level emission to the north (Ly et al. 2004).

In the present paper, we consider new VLBA observations at 5 and 8.4 GHz, taken on 2000 August 27 and compare the new 5 GHz image to Giovannini et al. (2001) data, discussing the morphology and the motion of components. For more details we refer to Giroletti et al. (2004).

NGC 4278 has a direct distance measurement of 14.9 Mpc (Jensen et al. 2003). At this distance, 1 mas corresponds to a linear scale of 0.071 pc. We define the spectral index α following the convention that $S(\nu) \propto \nu^{-\alpha}$.

2. Observations and Data Reduction

We observed NGC4278 at 5 and 8.4 GHz, with an 11 element VLBI array composed by the NRAO Very Long Baseline Array (VLBA) and a single 25 m VLA antenna for 10 hours. The observing run was performed on 2000 August 27, switching between 5 GHz and 8.4 GHz.

The correlation was carried out at the AOC in Socorro. The distribution tapes were read into the NRAO Astronomical Image Processing System (AIPS) for the initial calibration and the two frequencies were separated. After that, we followed the same scheme for the data reduction of both 5 GHz and 8.4 GHz data-sets. As a first step, we corrected our data entering the accurate position information obtained by Ly, Walker, & Wrobel(2004) (RA $12^h\ 20^m\ 06^s.825429$, Dec $29^\circ\ 16'\ 50''.71418$). We then performed the usual calibration stages (removal of instrumental single band delay, of phase and delay $R - L$ offsets, and bandpass calibration) using scans on 3C279. Thanks to the good data calibration and position information, we could obtain final images with only a few iter-

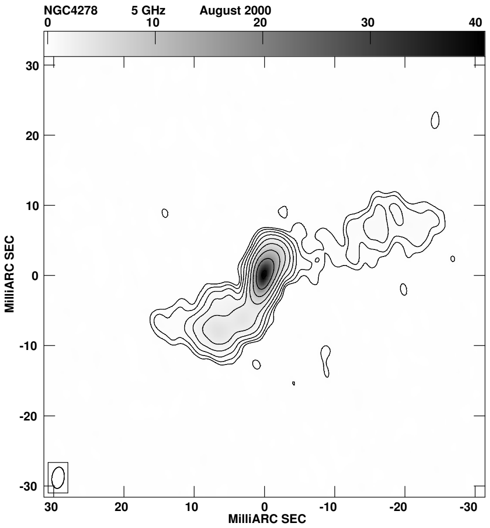

Fig. 1. VLBA+Y1 image of NGC4278 at 5 GHz. Contours are at (1, 2, 4, ..., 128) times the lowest contour which is 0.15 mJy/beam. The HPBW is 3×1.7 mas in PA -7°

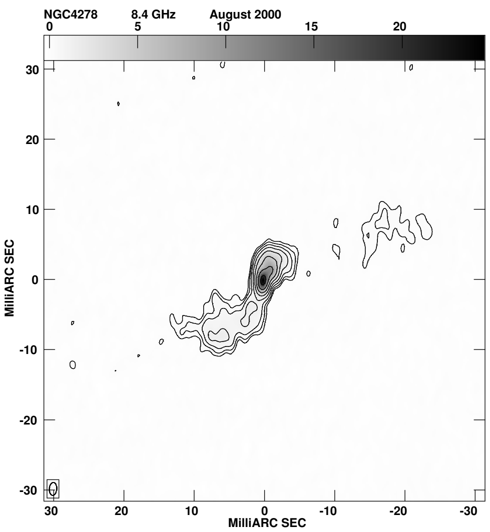

Fig. 2. VLBA+Y1 image of NGC4278 at 8.4 GHz. Contours are at (1, 2, 4, ..., 128) times the lowest contour which is 0.15 mJy/beam. The HPBW is 1.8×1.0 mas in PA -4°

ations of phase self-calibration. One cycle of amplitude self-calibration with a long solution interval (30 minutes) has also been performed before obtaining the final (u, v)−data.

We also re-analyzed VLBA+Y1 5 GHz data obtained in 1995 (22 July), taking advantage of the new position (Ly et al. 2004).

3. Results

The final images reveal a source dominated by a central compact component, with emission coming from either side (Figs. 1 and 2).

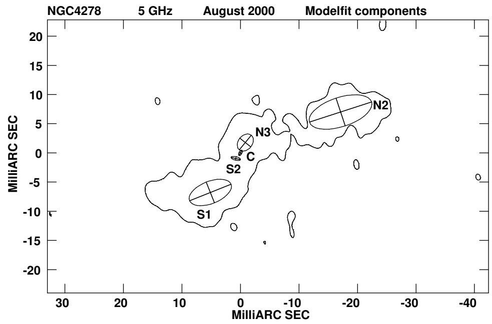

Fig. 3. Model components for epoch 2000.65, overlayed to the lowest contour from the 5 GHz image.

To the southeast, a jet-like feature extends for ∼ 6.5 mas in PA 155° (measured north to east), then progressively bends into PA 100°. In total, the jet is almost 20 mas long, which corresponds to ∼ 1.4 pc. On the opposite side, the main component is slightly elongated to the north in the 5 GHz map (Fig. 1), and the 8.4 GHz data clearly show a secondary component in PA −40° (Fig. 2). Then, this jet-like feature bends to the west turning into a diffuse, uncollimated, low brightness emitting region. In total, the source extends over ∼ 45 milliarcsecond, i.e. about 3 parsec. The total flux density measured in our images is 120 mJy at 5 GHz and 95 mJy at 8.4 GHz. If we compare these values with those obtained with the VLA in nearby epochs (162 mJy and 114 mJy, respectively), we find about a 20-25% offset, which can be ascribed to the VLBA resolving out some extended emission, probably in the western region. The monochromatic luminosity at 1.4 GHz is 3.18×10^{21} W Hz^{-1}, and 2.52×10^{21} W Hz^{-1} at 8.4 GHz.

The visibility data are well fitted by a five component model at both frequencies. The position and dimension of the components are illustrated in Fig. 3; our choice for labeling the components is based on their most likely epoch of ejection, as discussed in § 3.1. Besides being the most compact feature, component *C* presents also the flattest spectral index (α = 0.2) and its identification with the core is straightforward.

The same five component model that fits the 2000 epoch data has been applied to 1995 data set as well, allowing for the components to change in flux and position.

3.1. Component motion

If we compare data taken at the same frequency in different epochs, we can get information on the evolution of the source. Taking the position of the core (component *C*) as a reference, and assuming it is fixed, we have compared the position of the other components. We report the results in Table 1: column (1) labels the components, column (2) report the apparent velocity in units of c, and the corresponding age in years is given in column (3). The radial distance of each component has increased over the five years lag between the observations. The motion

Table 1. Component Motion at 5 GHz

Component	β_{app}	age (yrs)
C	reference	
S2	0.020 ± 0.006	29.1 ± 9.3
S1	0.030 ± 0.006	65.8 ± 12.4
N3	0.055 ± 0.004	8.3 ± 0.5
N2	0.171 ± 0.030	25.0 ± 4.8

is larger in the northwestern side; in particular, the largest displacement is found for component $N2$.

Assuming that the apparent velocity is constant for each component, we derive ages as reported in column (3) with respect to the 2000.652 epoch. $S2$ and $N2$ have ages that are consistent, and they must have been ejected together about 25 years before epoch 2000.652. $S1$ is the oldest component, and its counterpart in the main jet is not detected, probably being too distant and extended. Finally, $N3$ is the youngest component, ejected only three years before our first epoch of observations; it is likely that a corresponding component $S3$ has emerged in the counterjet but that it is still confused with the core. Note that the core is the only component whose flux density is larger in 2000.652 than in 1995.551.

4. Discussion

4.1. Jet orientation and velocity

Our images detect low level emission to the northwest with unprecedented resolution and sensitivity, both in the inner part of the jet, revealing the compact component N3, and at a larger distance, detecting $\sim$ 10 mJy of flux in the region N2. Thus, we classify NGC 4278 as a two-sided source, similarly to a few other LLAGN previously studied, e.g. NGC4552 (Nagar et al. 2002), NGC 6500 (Falcke et al. 2000), and NGC 3894 (Taylor et al. 1998).

Although the southern jet looks more collimated, the total flux density is larger in the northern components than in the southern ones. Moreover the high resolution 8.4 GHz image (Fig. 2) clearly shows that the inner jet is brighter in its northern part than to the south, and the apparent motion of the northern components are also larger than those of the southern ones. Therefore we assume that the main and approaching jet is the northern one.

To estimate the orientation θ and intrinsic velocity β of the jet, we will consider a simple beaming model, which assumes that components are ejected in pairs from the core at the same time, with the same intrinsic velocity and brightness; we apply this model to the components pair $N2/S2$, which have been ejected simultaneously according to our motion measurments (Table 1). In this model, the ratio between the arm length r and the proper motion μ of the two components are related by

$$R = \frac{\mu_{N2}}{\mu_{S2}} = \frac{r_{N2}}{r_{S2}} = \frac{1+\beta\cos\theta}{1-\beta\cos\theta}$$

From our modelfits we derive that $r_{N2}/r_{S2} = 7.2 \pm 0.2$ and $\mu_{N2}/\mu_{S2} = 8 \pm 3$, so we estimate that $4 < R < 10$. The

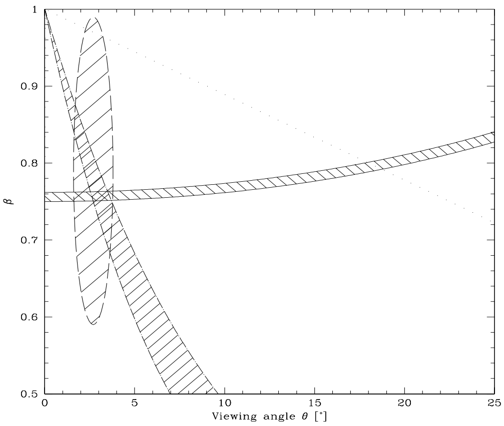

Fig. 4. (θ,β) plane for NGC 4278, as discussed in the text.

arm length ratio corresponds to selecting the hatched area between the two solid lines in the (β,θ)-plane (Fig. 4). The dot-dash lines represent the possible combination of β and θ resulting from the apparent separation velocity of the two components, which is expressed by the relation $\beta_{\rm sep} = (2\beta\sin\theta)/(1-\beta^2\cos^2\theta)$. Finally, since we measure motion on both sides and we know the source distance, we can directly solve for θ and β as discussed by Mirabel & Rodriguez(1994); this corresponds to the dashed ellipse centered on $\theta = 2.7°, \beta = 0.79$.

In principle, one could also consider the brightness ratio between the two components; however, as an effect of relativistic time dilation, we are watching the components at different stages of evolution. Since we know little on the time evolution of jet components, this hinders the possibilty to apply the brightness ratio argument; in any case, $S_{N2}/S_{S2} > 1$, consistent with our interpretation.

Based on the above analysis (Fig. 4), we find mildly relativistic velocities of $\beta \sim 0.76$ ($\Gamma \sim 1.5$), and an orientation close to the line-of-sight ($2° \lesssim \theta \lesssim 4°$). The resultant Doppler factor is $\delta \sim 2.7$; the small viewing angle explains also the bendings visible in both jets, as the amplification caused by projection effects of intrinsically small deviations, which are common in low power radio sources.

4.2. History of emission

From the result of the modelfit, small to moderate apparent velocities ($\lesssim 0.2\,c$) are found for the four jet components. Under the assumption of constant velocity, we derive that they must have been ejected from the core between 8.1 and 64.5 years before epoch 2000.652 (see Column [3] in Table 1).

However, these jet components are not to be confused with the hot spots demarcating the end of the jet as found in more powerful CSOs by Owsianik & Conway(1998), Peck & Taylor(2000), Giroletti et al.(2003). Therefore, a kinematic estimate of the real age of the source is difficult, and that of $S1$ can only be taken as a lower limit. The low brightness and large size of $N2$, as well as the non detection of $N1$, suggest that components are continually ejected from the core but

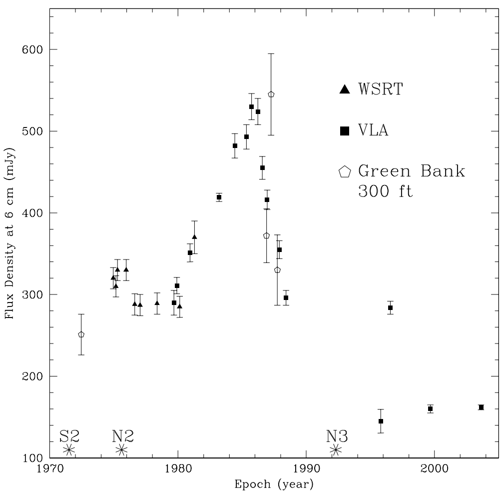

Fig. 5. Light curve for NGC 4278 at 5 GHz

that they soon disrupt, without being able to travel long distances and form kpc scale lobes.

We do not expect that this source may evolve into a kpc scale radio galaxy but that it will only periodically inflate slowly. The relatively low velocity jets discussed in § 4.1 can not bore through the local ISM and escape, as shown by the lack of hot spots, which are instead found in higher power CSOs. This behavior has to be ascribed to a low power central engine, which can not create highly relativistic jets.

In Fig. 5 we plot the flux density history for NGC 4278 at 6 cm, with data taken at the WSRT, the Green Bank 300 ft radio telescope and the VLA. A previous plot was published by Wrobel & Heeschen(1991), to which we add 12 points, from observations obtained between 1972 and 2003. The light curve shows that the source is variable, prone to both outbursts and low states. A burst is certainly present around 1985, while in more recent years the source has been showing less activity.

It is difficult to connect the burst with the ejection of new components, both because of the uncertainties related to the age of a single "blob", and the possible time lag between component ejection and total flux enhancement. It is clear however that the source presents a high degree of variability, possibly related to the presence of an active nucleus.

For a more detailed discussion see Giroletti et al. (2004).

5. Conclusions

In the present paper, we have presented new VLBA data for the nearby (d = 14.9 Mpc) LLAGN NGC 4278. Our data show a two-sided emission on sub-parsec scales, in the form of twin jets emerging from a central compact component ($T_B = 1.5 \times 10^9$ K), in much a similar way to what happens in more powerful radio loud AGNs.

By comparison with previous data, we discover proper motion for components in both jets, over a five years time baseline; we find low apparent velocities ($\lesssim 0.2\,c$) for the jet components and estimate the epoch of their ejection as $10 - 100$ years before our observations. Based on our analysis, we suggest that the north-west side is the approaching side, and that the jets of NGC 4278 are mildly relativistic with $\beta \sim 0.75$.

The central black hole in NGC 4278 is therefore active and able to produce jets, which are responsible for the bulk of emission at radio frequency in this LLAGN. However, the lifetime of components of $<$ 100 years at the present epoch and the lack of large scale emission, suggest that the jets are disrupted before they reach kpc scales.

The study of the flux density history at 6 cm between 1972 and 2003 shows a significant variability ($\gtrsim$ 100%) on time scales of a few years, which might be related to the ejection of new components. This subject needs to be explored for other LLAGNs as well, as it can give better insight about the state of the central black hole in these sources.

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