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The Multiwavelength Study of Two Unique Radio Galaxies

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Abstract. We present the usage of multi-frequency and multi-band radio, VLA, observations as well as X-ray observations in order to study the environment around two powerful radio galaxies, namely Hercules A and 3 C310. We study their environment both in pc- and kpc-scales. We have chosen these two radio galaxies as they present similar and unique characteristics, compared to the ones from our general knowledge about double radio galaxies associated with active galactic nuclei.

Key words. Galaxies: clusters: individual (Hercules A, 3 C310).

1. Introduction

Hercules A ($z = 0.154$, Gizani & Leahy 1999; Gizani & Leahy 2001a, b, c, in prep., Fig. 1) and 3C 310 ($z = 0.054$, van Breugel & Fomalont 1984, Fig. 2) are two radio galaxies with a similar and out of the ordinary behaviour: both sources appear with double optical nuclei (3C 310: Chiaberge *et al.* 1999; Hercules A: Baum *et al.* 1996). 3C 310 is smaller, less powerful than Hercules A.

They are classified as FR1.5 (Hercules A: Dreher & Feigelson 1984; 3C 310: Owen & Laing 1989). They have no compact hotspots and consist of sharply-bounded lobes. They are probably the only two radio galaxies that show large multiple circular radio features (ring-like structures) that are interior to the lobes and not just phenomena of the boundaries. A few of these rings are the largest material circles known anywhere. The projected magnetic field follows the edges of these features. They are steep spectrum sources of similar steepness. Their lobes present asymmetries with respect to brightness, depolarization and spectral index. Hercules A has a weaker radio core.

They are the hosts of clusters of galaxies (Hercules A: Feigelson & Berg 1983; 3C 310: Jenkins, Pooley & Riley 1977). 3C 310 has lower X-ray luminosity than Hercules A and for both sources the X-ray brightness profile can be described well if we assume contribution from a point source (Gizani & Leahy 1999; Hardcastle & Worrall 1999). While the intracluster medium in both the Hercules A and 3C 310 clusters (Abell and Zwicky respectively) has a similar temperature, it seems to be denser towards the center for the Hercules A cluster (see Leahy & Gizani 2002, for example).

The thermal pressure of the Hercules A cluster is larger than for the 3C 310 cluster and hence the confinement of its lobes by the intracluster medium is greater. The cluster thermal pressure at the distance of the radio lobes is typically an order of magnitude larger than the lobe minimum pressure for both radio galaxies (Leahy & Gizani 2001).

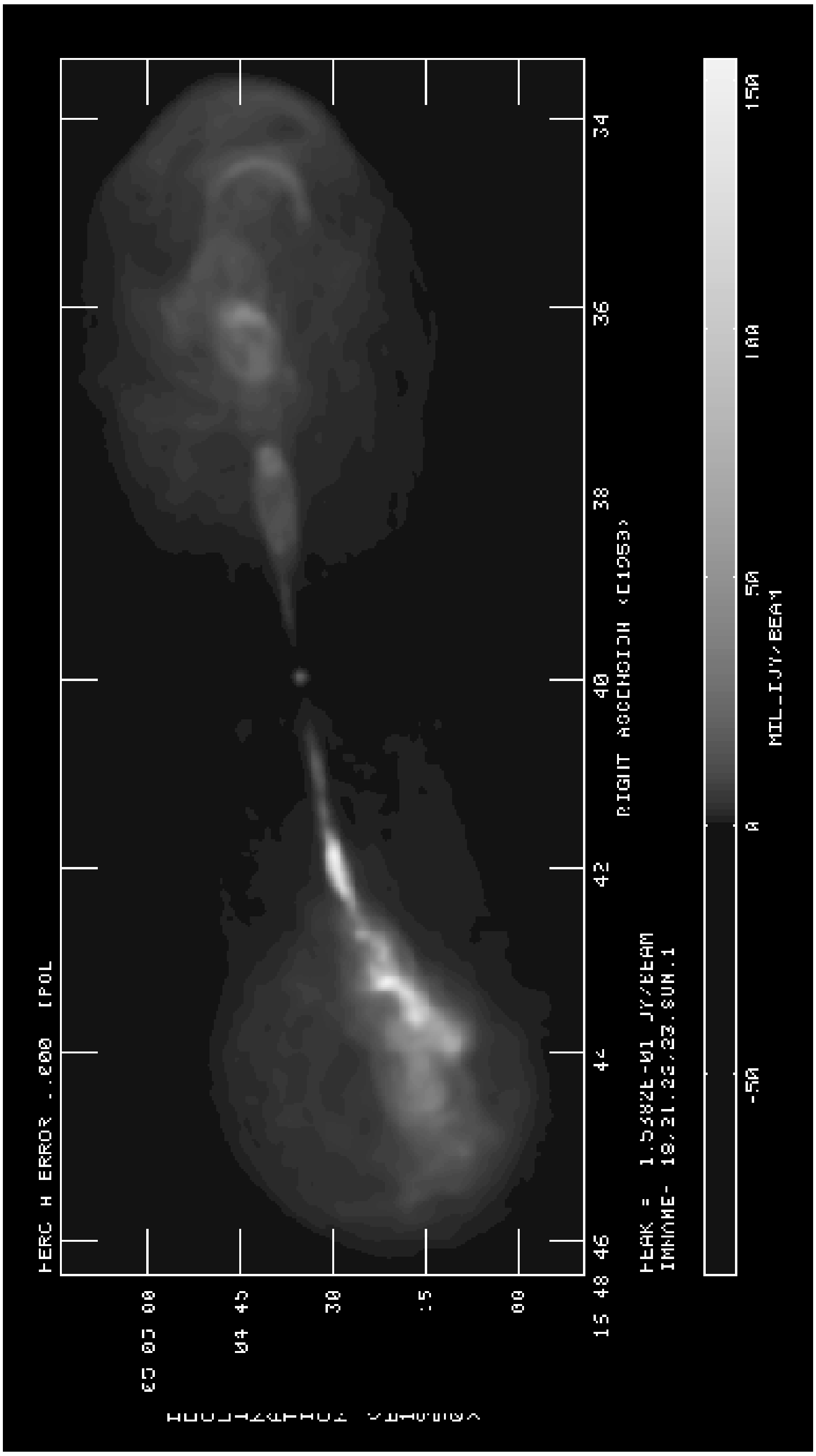

Figure 1. A grey scale VLA A+B+C map of the total intensity distribution of Hercules A at 20 cm created by combining the 4 frequency multiconfiguration data of the L-band at 1.4 arcsec. The presence of semi and/or full rings is apparent mostly in the western lobe.

2. The Environment

2.1 *Hercules A*

We have studied the **kpc-scale environment** of the powerful extragalactic radio source Hercules A in terms of the magnetic field of the intracluster gas in which the radio source is situated (Gizani & Leahy 1999; Gizani & Leahy 2002c, in prep). For this reason we have made VLA total intensity and polarization multiconfiguration observations at L- and X-bands. We have also retrieved and reprocessed the C-band data (Dreher & Feigelson 1984). In addition we have made ROSAT PSPC and HRI X-ray observations (Gizani & Leahy 2002a, in prep). The plan was to map the Faraday rotation field at high resolution (1.4 arcsec). We have found that Hercules A exhibits a strong Laing-Garrington effect (Garrington *et al.* 1988; Laing 1988). The X-ray observations have revealed an extended X-ray emission elongated along the radio galaxy axis and a weak nuclear component. The estimated temperature of the cluster is $kT = 2.45\,\mathrm{keV}$ and the central electron density is $n_\circ \simeq 7.8 \cdot 10^{-3}$ cm^{-3} which reveals a hot, dense environment. By model fitting the Faraday dispersion profile from the radio data and the surface brightness profile from the X-ray data, we have found that the depolarization is mainly caused by a centrally condensed medium in which Hercules A is embedded at $\simeq 50^\circ$ to the line of sight. The western weak jet and associated lobe is behind the bulk of the depolarizing gas while the bright eastern jet and lobe are in front. We have estimated a central value of the magnetic field of $3 \lesssim B_\circ(\,\mu\mathrm{G}) \lesssim 9$ (Gizani & Leahy 1999).

We are also working on the **pc-scale environment** of the radio galaxy. We have observed the central region of Hercules A at 18 cm using the EVN-MERLIN array (Gizani, Garrett & Leahy 2001, 2002 in prep.). A faint but compact radio source, coincident with the optical centre of Hercules A was detected by the EVN with total flux density of 14.6 mJy, angular size 18×7 mas and position angle $\simeq 139^\circ$. There is also evidence for extended emission in the NW-SE direction, most probably from the eastern pc-scale jet. If this is true then there is a misalignment between the direction of the pc-eastern and the aligned kpc-scale jets of $\simeq 35^\circ$. The MERLIN data still need further reduction before we combine them with our existing VLA data at 18 cm.

2.2 *3C 310*

For the **kpc-scale environment** study, there are no high resolution radio and X-ray observations on 3C 310. We are going to use the existing observations (van Breugel & Fomalont 1984) combined with new radio observations which we are planning to make.

Total intensity and polarization VLA maps at 4 arcsec resolution at 6 and 21 cm (van Breugel & Formalont 1984), have shown that there is a fine-scale structure consisting of shells (rings) and filaments embedded in large, diffuse, low-brightness lobes. A small jet is also emanating from the core to the north (see Fig. 2). The ring-like features and the filaments have longitudinal magnetic fields.

ROSAT pointed observations have confirmed an extended X-ray emission. The HRI data have shown that this emission is centered on the radio galaxy (Hardcastle & Worrall 1999).

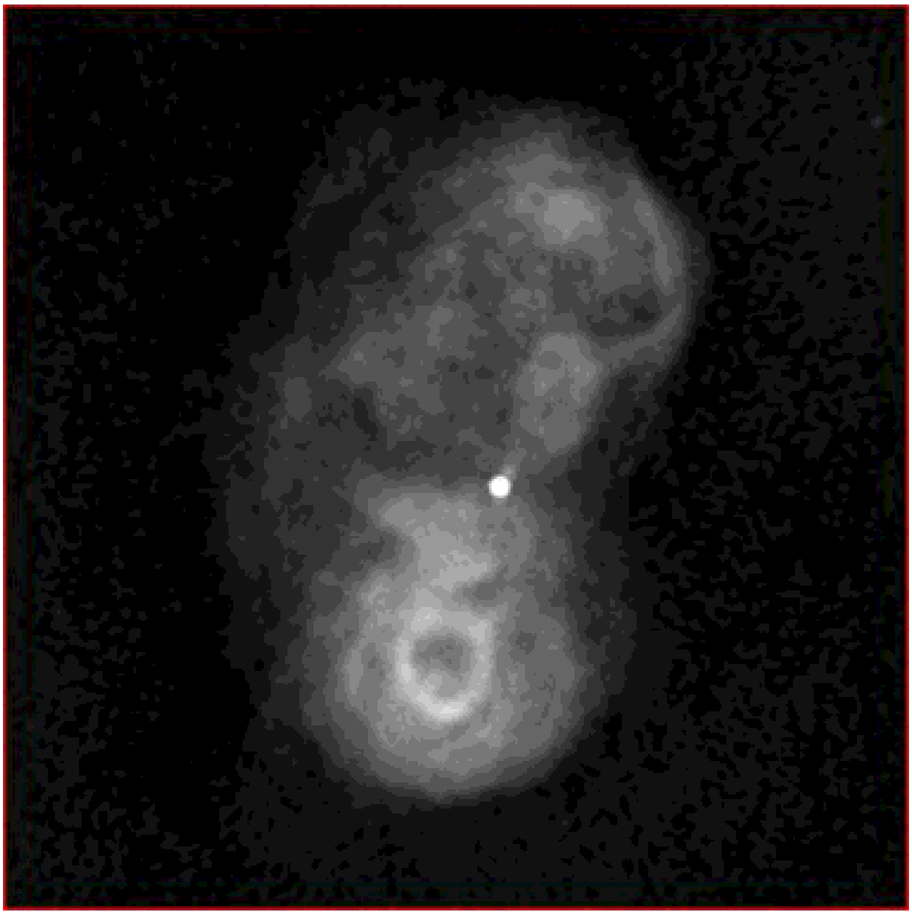

Figure 2. A grey scale VLA B+C map of the total intensity distribution of the radio galaxy 3C 310 at 1446 MHz at 4.0 arcsec (van Breugel & Fomalont 1984). The presence of ring-like features is apparent.

As can be seen from Fig. 2, the core is unresolved. The flux density of the core from the NRAO VLA Sky Survey (NVSS, Condon *et al.* 1998) at 21 cm is about 60 mJy at 45 arcsec (compared with 44 mJy at 20 cm, at 1.4 arcsec for Hercules A). To begin our study of the **pc-scale environment** we have already taken global VLBI as well as MERLIN data (Gizani & Garrett 2002 in prep) to resolve the core.

3. Conclusions

We are studying the two radio galaxies Hercules A and 3C310 as they are exceptional cases. Both radio sources have a similar behaviour and many differences from the usual morphology and characteristics of double radio sources associated with active galactic nuclei. In our case the determination of the unusual and similar structure and behaviour of these two radio galaxies, whether they originate in a similar fashion or not, will help to enrich our knowledge of the physical mechanisms dominating interior of the source and also in the medium in which the sources are situated. In other words we will try to find why these sources are different from the ones studied broadly. In addition this study will complement the Unified Theories.

For this reason we are planning observations in different wavelengths of the electromagnetic spectrum such as: HI observations of each radio galaxy with emphasis on their nuclear region; infrared observations of the ring-like and helical-structures of the radio emission of both radio sources; near IR polarimetric observations. X-ray follow-ups, where possible (Chandra Observations for 3C310, XMM observations of both sources); HST observations of 3C310; V, R, I-band observations to obtain a Hα map of the nuclear region; UV observations of the nuclear region as diagnostic of the ISM around the central region.

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