Probing the pc-scale environment of the powerful radio galaxy Hercules A

By N. A. B. GIZANI[1]†, M. A. GARRETT[2] AND J. P. LEAHY[3]

[1]Centro de Ciências Matemáticas, Universidade da Madeira, Campus Universitário da Penteada, 9000-390 Funchal, Portugal

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

[3]University of Manchester, Jodrell Bank Observatories, Nr Macclesfield, Cheshire SK11 9DL, UK

We present results from the preliminary analysis of combined EVN-MERLIN 18cm observations of the parsec-scale structure of the powerful radio galaxy Hercules A. The main goal of these observations was to detect any pc-scale jet emission on both sides of the central engine, to map the transition region between these and the kpc- scale jets with the highest possible resolution and to resolve the inner jets in detail. A faint but compact radio source, coincident with the optical centre of Hercules A was detected by the EVN.

1. Introduction

Hercules A is an extended source with total radio luminosity is $\sim 6.2 \times 10^{37}$ W. Its power density at 5 GHz, $P_{5\,GHz} = 6.9 \times 10^{25}$ WHz^{-1} sr^{-1} (assuming $H_\circ$=65 kms^{-1} Mpc^{-1} and $q_\circ$=0) classifies as intermediate between the two FR classes (Dreher *et al.* 1984). With a linear size of 540 kpc, a width of $\simeq$ 250 kpc and no compact hotspots, Hercules A possesses two jets which are quite different in appearance: The western jet shows partial or full ring-like features that form a linear sequence heading from the core to the lobes and follow an inner jet. VLA maps at $0''.5$ resolution revealed that the eastern jet has the highest luminosity found so far identified with an elliptical galaxy (Dreher *et al.* 1984).

Hercules A is identified with a very elongated cD galaxy (e.g. Sadun *et al.* 1993, Baum *et al.* 1996), with absolute magnitude -23.75 at the R-band.

Gizani (1997) presented extensive radio total intensity and polarization multi-band, multi-configuration VLA observations of Hercules A, as well as ROSAT PSPC and HRI X-ray observations. The multi-frequency observations were used to map the Faraday rotation field at high resolution ($1''.4$), and combined with the X-ray data on the gas distribution they enabled us to map the magnetic field of the cluster. Gizani (1997) – see also Gizani & Leahy (1999) – found that Hercules A exhibits a strong Laing-Garrington effect (Laing 1988; Garrington et al. 1988): the western side of the radio emission is more depolarized than the eastern side. 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. This is, most probably, the 'X-ray' hot (2.45 keV) gas, with the asymmetry being due to the western weak jet and associated lobe being behind the bulk of the gas while the other lobe (eastern) is in front. The X-ray observations have revealed an extended X-ray emission region elongated along the radio galaxy axis and a weak nuclear component. The estimated central proton density of $n_0 \approx 6.5 \times 10^3$ m^{-3} reveals a dense environment in which the radio source is situated. The cluster may be a cooling flow. The magnetic

† Present address: Kalymnou 13, 11251 Athens, Greece

field is decreasing with radius and Gizani (1997) has estimated a central value of $3 \lesssim B_{\circ}(\ \mu\mathrm{G}) \lesssim 9$ (see also Gizani & Leahy 1999).

Figure 1 shows a greyscale of the λ20-cm radio image (Gizani & Leahy 2000) superimposed with contours from the HRI, smoothed to 10-arcsec resolution.

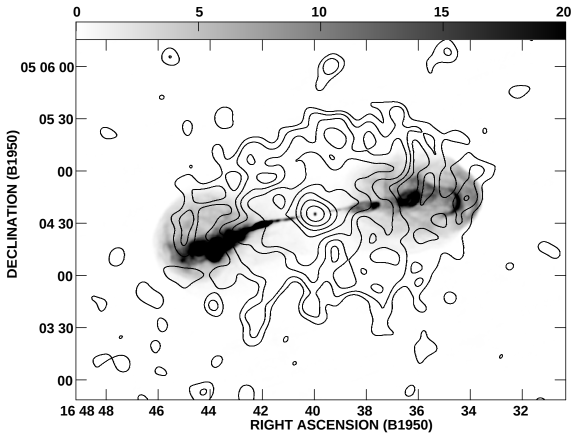

FIGURE 1. A grey-scale map of the Hercules A radio emission at 1.5 GHz with contours of the HRI X-ray image superimposed. The radio image has resolution 1.4 arcsec FWHM, and the greyscale range is 0 to 20 mJy. The HRI image has an effective resolution of 11.5 arcsec. Contours are separated by factors of $\sqrt{2}$ starting at 3.26×10^{-9} W m^{-2} sr^{-1}. The background level is 0.54×10^{-9} W m^{-2} sr^{-1} = 2.1 ct beam^{-1}.

The VLA data provide us with a good understanding of the kpc-scale radio structure of Hercules A. However, the inner jets of Hercules A and its optically thin, steep spectrum core, were unresolved with the VLA.

Gizani *et al.* (2000) studied the parsec-scale environment of this powerful radio source using the combined EVN–MERLIN interferometer at λ18cm. The main goal of the observations was to detect any pc-scale jet emission on both sides of the central engine, to map the transition region between them and the kpc-scale jets with the highest possible resolution and to resolve the inner jets in detail.

2. Results

Hercules A was observed with the EVN and MERLIN at λ18cm for 11 hours in November 1999. We have employed standard fringe-fitting and self-calibration techniques as well as phase referencing since the emission from the area of the core was so weak. The MERLIN and EVN datasets were initially imaged independently and were then combined for subsequent imaging.

The MERLIN observations detect only the most compact regions embedded in the south-eastern jet. An unresolved compact component is also observed, coincident with the optical centre of the galaxy (see Figure 2, bottom). MERLIN only detects about 20% of the total VLA flux density at this frequency, suggesting that much of the fainter, low-surface brightness emission is resolved. In the EVN observations, only the compact core is detected (Figure 2) with angular size $<$ 20 mas and a peak flux density of $\sim$ 14 mJy. This implies a brightness temperature in excess of 10^7 K.

From the EVN image (seen in more detail in Figure 3) there is an indication that the

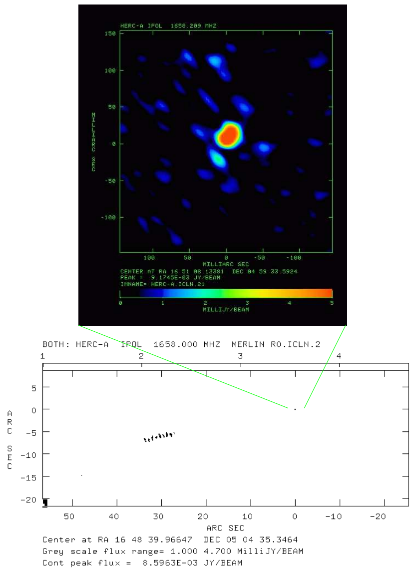

FIGURE 2. bottom picture: The MERLIN detection of the compact components in the core-jet region. Confusion from the extended structure of Hercules A causes the stripy appearance of the MERLIN image.. Top picture: The EVN image of the core of Hercules A.

core is slightly extended in the NW/SE direction. If this is indeed the case, then the VLBI structure within the core may be misaligned ($\sim 35°$) with the larger scale jets.

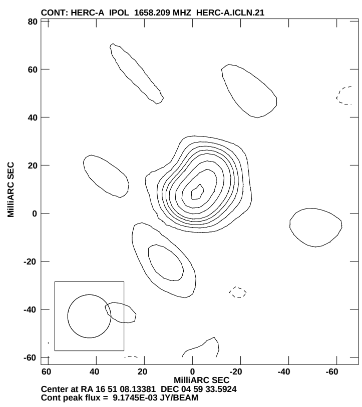

FIGURE 3. The contour image of the EVN detection of the core region at 0.02 arcsec resolution. There is an indication of emission in the NW/SE direction, possibly from the pc-scale jets.

3. Conclusions— Future Work

Gizani *et al.* 2000 have tried to shed some light in the structure of the central engine of this powerful AGN probing with high resolution the morphological asymmetry between the features of the two jets. Since Hercules A is very extended with a very bright eastern jet, confusion from the extended structure caused artefacts in the MERLIN image.

The EVN, on the other hand, did detect about 30% of the flux density from the core area at 0.02 arcsec resolution. However, the core remains largely unresolved as it is very weak. Slightly extended emission is detected elongated in the Northwest/Southeast direction, possibly arising from the pc-scale jets. Further, observations are required to confirm this and to further reveal the nature of this component.

These results are preliminary from a work in progress. We are also planning to combine our 20 cm VLA observations with our current MERLIN data in order to help MERLIN to detect the core area more clearly, since the 'borders' of the extended structure will be supplied by the VLA data. We are also planning to observe the core region with EVN at 6 cm to try and resolve the core. Finally we are planning infrared observations of the core, the inner jets and rings of the western lobe of Hercules A's radio emission.

4. Acknowledgements

NG acknowledges travel and maintenance support from the European Commission's TMR "Access to Large-Scale Facilities" programme, under contract ERBGCHT950012 in order to reduce the EVN+MERLIN data on Hercules A. NG would also like to acknowledge the grant PRAXIS XXI/BPD/18860/98 from the Fundação para a Ciência e a Tecnologia, Portugal.

REFERENCES

Baum, S. A., O'Dea, C. P., De Koff, S., Sparks, W., Hayes, J. J. E., Livio, M. & Golombek, D., 1996, *ApJ* **465**, L5.

Dreher, J. W. & Feigelson, E. D. 1984, *Nature* **308**, 43.

Garrington, S. T., Leahy, J. P., Conway, R. G. & Laing, R. A. 1988, *Nature* **331**, 147.

Gizani, N. A. B. 1997 *"Environments of Double Radio Sources associated with Active Galactic Nuclei."* PhD thesis, Jodrell Bank Observatories, University of Manchester, UK.

Gizani, N. A. B. & Leahy, J. P. 1999 *NewAR* **43**, 639 .

Gizani, N. A. B. & Leahy, J. P. 2000, *MNRAS* in prep.

Gizani, N. A. B., Garrett, M. A. & Leahy, J. P. 2000, in prep.

Laing, R. A. 1988, *Nature* **331**, 149.

Sadun, A. C. & Hayes, J. J. E., 1993, *Astr.Soc.Pac.Publ.* **105**, 379.