HYDRA A: A NEW PICTURE

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Abstract

We present new, low-frequency images of the powerful FRI radio galaxy Hydra A (3C218), which lies at the center of the poor Abell cluster A780. Images were made with the Very Large Array at frequencies of 1415, 330, and 74 MHz, with resolutions on the order of 20″. The morphology of the source is seen to be more complex and larger than previously known, and extends nearly 8′ (530 kpc) in a North-South direction. The southern lobe is bent to the east and extends in that direction for nearly 3′ (200 kpc). We find that the northern lobe has a flatter spectral slope than the southern lobe, consistent with the appearance of greater confinement to the south. A comparison to X-ray observations of the thermal gas in this system shows that Hydra A is surrounded by dense, cool gas which extends well beyond the inner bright radio jets. This may be entrained cluster core gas which has been dragged out by buoyantly rising outer lobes.

1 Introduction

In the early days of radio astronomy, observations were made at long wavelengths to take advantage of the bright end of the synchrotron spectrum. As instrumentation improved and receivers became more sensitive, observers increasingly chose shorter wavelengths where the sources were weaker but the spatial resolution was better. Continuing advances in the sensitivity and resolution of interferometers as well as a variety of new data reduction techniques have inspired a return to low frequency observations. We are now able to study the low energy end of the relativistic particle population in large sources with good spatial resolution. These low energy particles can be used to trace the past life cycle of powerful radio galaxies.

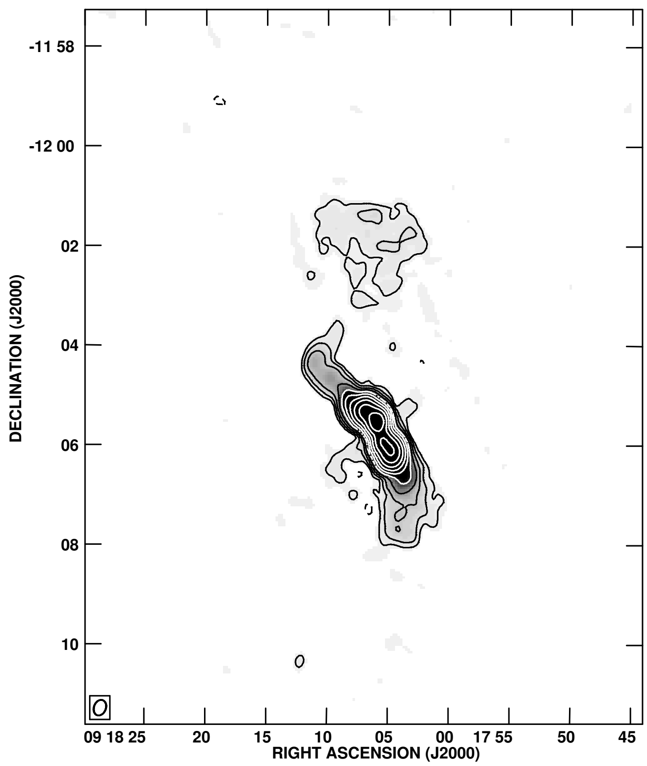

Figure 1: Contour image of Hydra A at 1415 MHz, using data from the C and D configurations of the VLA. Note the central bright core and jets typically seen in higher frequency images of this source. In addition we are just able to see the northern jet bending and then expanding into a diffuse lobe. The extensions to the east and west of the core are imaging artifacts, and extend throughout the image as a low level stripe. The dynamic range in the image is 5500:1, and the angular resolution is roughly 15″. The peak is 11.8 Jy beam^{-1} and the total flux at this frequency is S = 43 Jy. The contours are at multiples of the 5σ noise level, 0.0126 × (−1, 1, 2, 4, 8, 16 ..) Jy beam^{-1}.

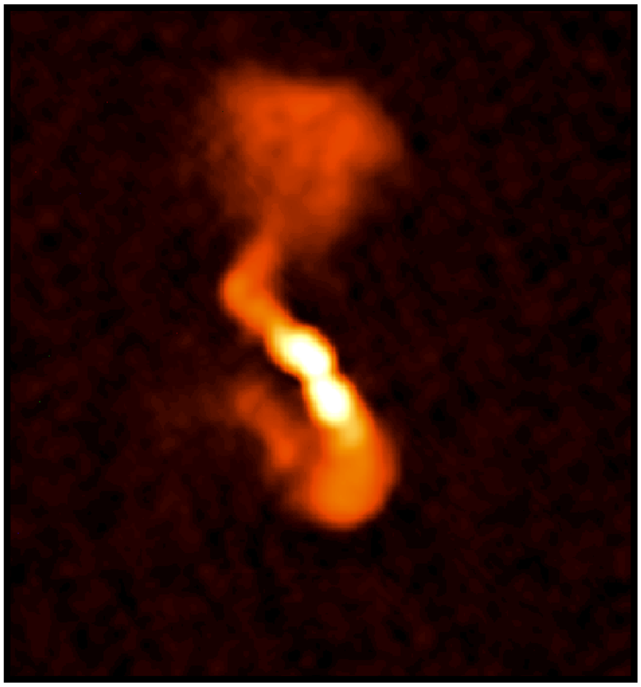

Figure 2: Image of Hydra A at 330 MHz, using combined data from the VLA in A, B, and C-configurations. Note the extended structure here, with the central core and bright jets extending further and turning sharply before expanding into diffuse lobes. The dynamic range in the image is 5000:1, and the angular resolution is 15″. The peak flux is 27.76 Jy beam^{-1} and the total flux is S = 157 Jy.

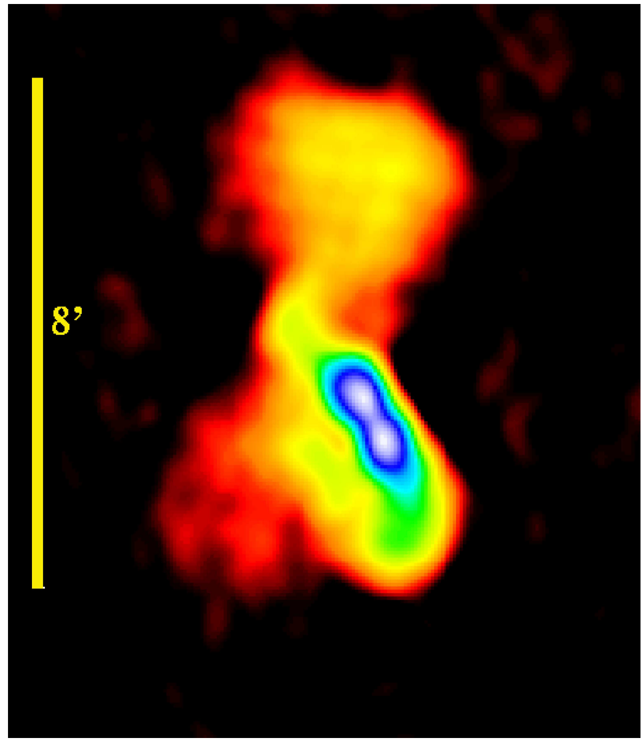

Figure 3: Image of Hydra A at 74 MHz, using data from the VLA in A configuration. Note that the southern lobe appears to be slightly more extended than in the 330 MHz map. The dynamic range in the image is 1450:1, and the resolution is roughly 25″. The peak flux is 96.95 Jy beam^{-1} and the total flux in the source is S = 546 Jy.

The radio galaxy Hydra A (3C218) is a well known, powerful FRI source located in the core of the poor galaxy cluster Abell 780 (Abell 1958) at a redshift z = 0.0542 (Dwarakanath et al. 1995; Owen, Ledlow & Keel 1995; Taylor 1996). Observations of this source at frequencies above 5 GHz reveal bright inner jets which trace an "S" shape (Taylor et al. 1990) and combined cover roughly 1.5′ in a north-south direction. The source has been mapped with low angular resolution ($\sim$ 45″) at 1500 MHz (Taylor et al. 1990), revealing a far more extended structure but obscuring its details. Although it is the seventh brightest source in the 3C catalog, Hydra A has not been imaged at any lower radio frequencies.

The cluster with which it is associated is a strong X-ray source and has been classified as a cooling flow cluster with a mass accretion rate of 300 $M_\odot$ yr^{-1} (David et al. 2001). Using data from the *Chandra* telescope, Sambruna et al. (2000) find a point source which is spatially coincident with the radio core, embedded in a diffuse X-ray halo. They interpret this as evidence for a low luminosity active galactic nucleus (AGN), with most of its optical/UV emission obscured by intrinsic reddening.

2 Radio data

Hydra A was observed in the C- and D-configurations of the very Large Array (VLA) at frequencies near 1415 MHz in 1988/1989 (see Fig. 1). Short observations in the A-, B-, and C- configurations of the VLA were carried out at frequencies near 330 MHz on various dates between 1990 and 1998 (see Fig. 2). A four hour observation at 74 MHz was made in the A-configuration of the VLA in 2002 (see Fig. 3). The data were mapped in `AIPS` using wide-field imaging techniques, which correct for distortions in the image caused by the non-coplanarity of the VLA over a wide field of view (the 3-D effect) by using a set of small overlapping maps, or "facets" to cover the desired image area (Cornwell & Perley 1992).

The new maps show that the well-known, bright inner

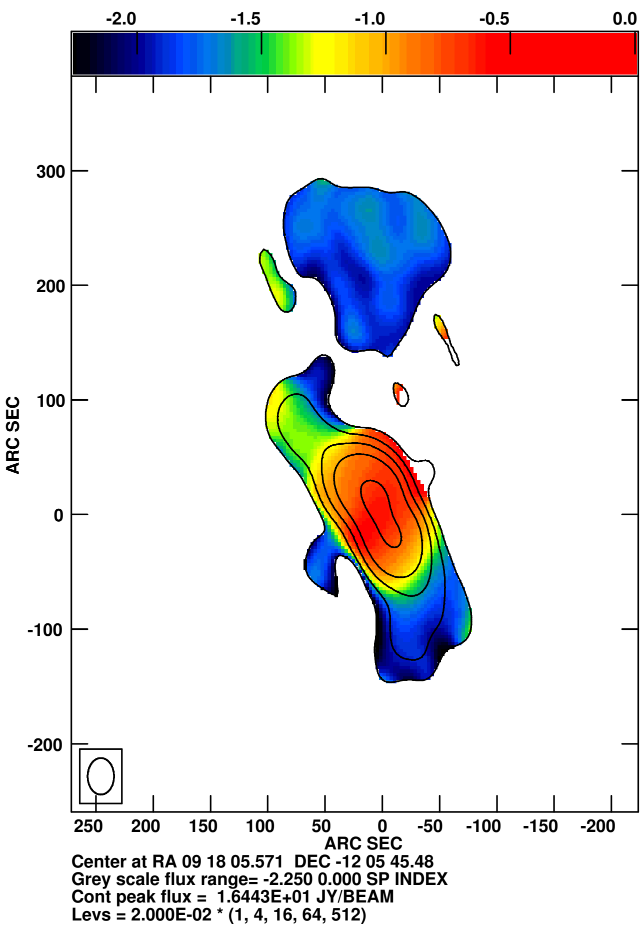

Figure 4: Spectral index map of Hydra A between 1415 MHz and 330 MHz is shown in color, with 1415 MHz contours overlaid. The input maps were clipped at 5σ to create this spectral index image, which has a resolution of $32'' \times 23''$. The contours are at multiples of $5\times$ the rms noise level in the 1415 MHz image, $0.020 \times (1, 4, 16, 64,$ and $512)$ Jy beam^{-1}. Errors in the spectral index at a 1σ level range from ± 0.03 at the core, to ± 0.04 in the jets and ± 0.08 in the northern lobe.

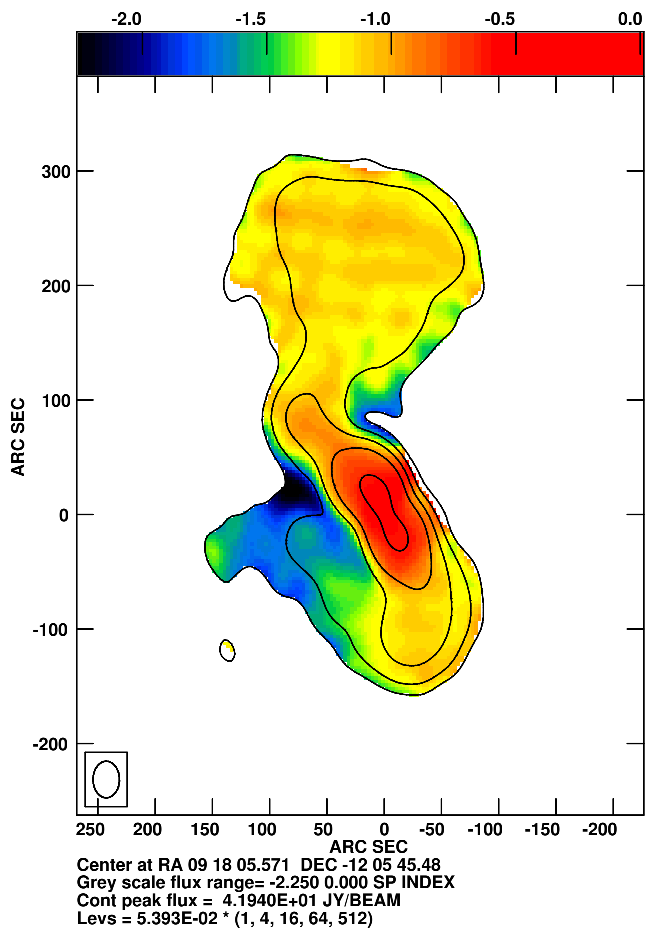

Figure 5: Spectral index map of Hydra A between 330 MHz and 74 MHz is shown in color, with 330 MHz contours overlaid. The input maps were clipped at 5σ to create this spectral index image, which has a resolution of $32'' \times 23''$. The contours are at multiples of $5\times$ the rms noise level in the 330 MHz image, $0.05393 \times (1, 4, 16, 64,$ and $512)$. Errors in the spectral index at a 1σ level are ± 0.03 near the core and through the jets, ± 0.04 in the northern lobe and as high as ± 0.1 at the end of the southern lobe.

jets of Hydra A are longer than previously seen, and extend for roughly $2'$ on both sides of the source. They then bend dramatically and end in diffuse lobes. The entire source covers nearly $8'$, or roughly 530 h_{50}^{-1} kpc (Lane et al. 2004). It is not yet known what fraction of FRI galaxies have similar diffuse extended structures visible at low frequencies, but they have been seen in a few other sources such as M87 in the core of the Virgo cluster (Owen, Eilek & Kassim 2000).

In order to enable a direct comparison between data at the three different frequencies, the data were tapered in the UV plane and a matching clean beam was imposed on all three frequencies(see Fig. 4 and 5). The synchrotron spectrum of the source has a relatively flat slope in the radio core, which steepens in the jets and lobes. The source is not symmetric; the northern lobe has a flatter spectral slope than the southern lobe at a given separation from the nucleus. The steeper spectral slope in the southern jet could be caused by a superposition of the jet and lobe emission along the line of sight. It may also be related to the greater confinement of the radio source to the south.

The source taken as a whole has a spectral slope only slightly steeper than the "typical" extragalactic source spectral index of $\alpha = -0.7$ (Bridle & Perley 1984); we find $\alpha_{74}^{330} = -0.83 \pm 0.03$ and $\alpha_{330}^{1415} = -0.89 \pm 0.03$

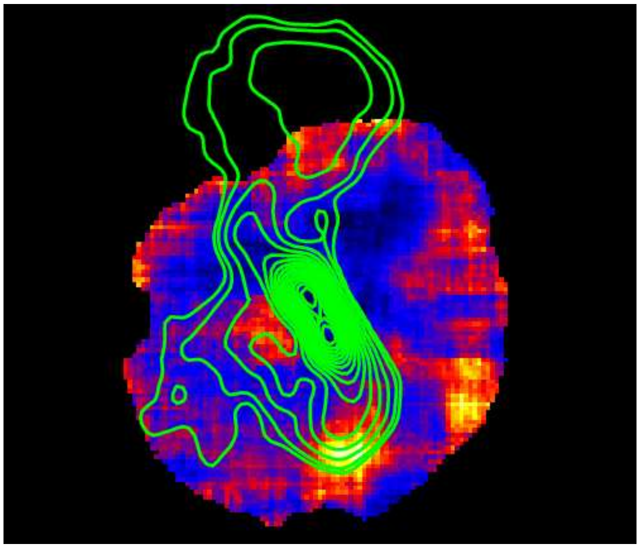

Figure 6: Temperature map from *Chandra* X-ray 0.3–1.0 keV data, with 74 MHz radio contours overlaid. The hot spot at the bend in the southern lobe is real at the 90% confidence level.

(errors are 1σ and we assume a 3% flux calibration precision at each frequency). These numbers are also consistent with previous estimates for spectral index in this source (e.g., $\alpha_{2.7GHz}^{5GHz} = -0.88 \pm 0.08$; Kühr et al. 1981). Using $\alpha_{74}^{300} = -0.83$ to interpolate the 74 MHz total flux to 178 MHz, we find that Hydra A has P_{178} = 1.6×10^{26} W Hz^{-1} sr^{-1}. This is in good agreement with previous estimates for this source (Taylor 1996).

3 Comparison to X-ray gas

Nulsen et al. (2002) use *Chandra* data to show that the cool, X-ray emitting gas in the central region of Hydra A extends beyond the 6 cm radio contours. A comparison of the same data (retrieved from the archive) to our new low frequency maps of Hydra A shows that the cool regions continue to align with the more extended radio emission as far out as we can trace them (see Fig. 6). The hotspot seen at the bend in the southern radio lobe is real at a 90% confidence level.

Acknowledgments

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