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3C radio sources as they've never been seen before

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Abstract. Low-radio-frequency observations played a remarkable role in the early days of radio astronomy; however, in the subsequent three or four decades their usefulness has largely been in terms of the *finding-frequency* of surveys. Recent technical innovation at the VLA has meant that *spatially well-resolved* imaging at low frequencies is now possible. Such imaging is essential to understanding the relationship between the hotspot and lobe emission in classical double radio sources, for example. We here present new images of 3C radio sources at 74 MHz and 330 MHz and discuss their implications.

1. Introduction

Low-frequency radio surveys play a key role in selecting samples of radio sources, dominated by optically thin synchrotron emission, which are free of orientation biases. Examples of such samples, which have been pivotal in advancing our understanding of the nature of radio sources, are the celebrated 3C sample (revised by Laing, Riley and Longair 1983) and very recently the much fainter 7C sample (Rawlings et al. 1998). Following recent technical innovation at the VLA, it is now possible to make spatially well-resolved images of radio sources at low frequencies: at 74 MHz, images can now routinely be made with an angular resolution of 25". It is in this low-frequency regime that models of the energy supply to the lobes from the hotspots in classical doubles may be tested, and where their energy budgets may be investigated, for example by the detection or otherwise of steep-spectrum halos surrounding these objects.

2. 3C 84 and its halo

The 74 MHz image (Fig. 1, left) shows a low surface brightness halo surrounding 3C 84. The signal to noise of the image is insufficient to reveal whether the halo has a definite boundary, though this does appear to be hinted at in the 330 MHz

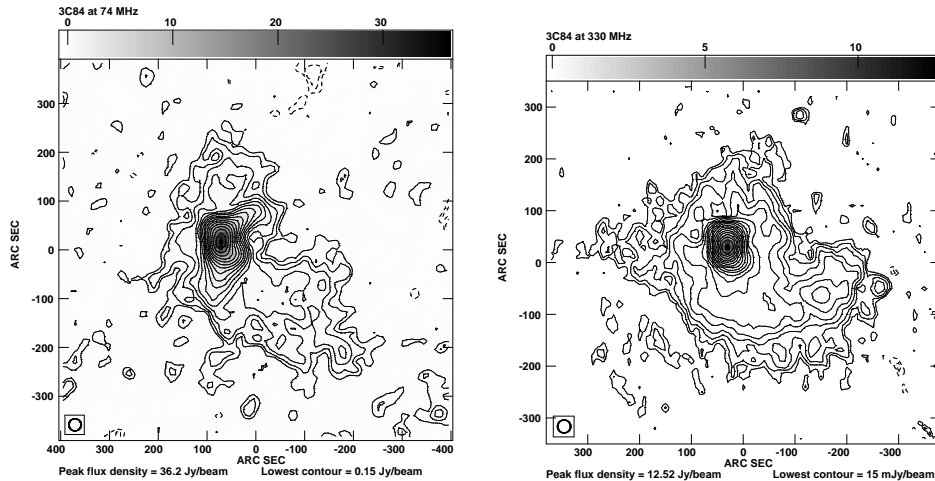


Figure 1. Images of 3C84 at 74 MHz and 330 MHz with $25''$ resolution.

image (see Fig. 1 right, and Burns et al 1992) and at 1.4 GHz [Ger de Bruyn, priv. comm.]. The spectrum of the halo is not particularly steep, averaging $\alpha_{330}^{74} \sim 1.1$ (defined such that the flux density S_ν at frequency ν is given by $S_\nu \propto \nu^{-\alpha}$), with (e.g. the region $200''$ west and $100''$ south of the core) in places a spectral index as flat as 0.7. However, curious new features are seen (only) in the 74 MHz image: protrusions apparently emanating from the core region (at 2 o'clock and 6 o'clock) have very steep spectra ($\alpha \gtrsim 2$). It is possible that these could be outflows from the core, or merely static structures with very strange spectra. A full analysis of these images and those of the other objects observed will be presented in Kassim, Perley & Blundell (in prep).

3. 3C 129 and its twin tails

While in the inner few arcmin this radio source is a wide-angle tailed source with oppositely directed jets close to the core (see Rudnick & Burns 1981) on larger scales the jets follow each other quite closely and have the appearance of a narrow-angle tailed source (see Fig. 2 and Kassim et al. 1993). The integrated spectral index of both the entire source, and of just the extended tails, between 74 MHz and 327 MHz is $\alpha \sim 1.1$.

4. 3C 219 and other classical doubles at low-frequency

Fig. 3 shows that the images of the classical double 3C 219 at 74 MHz and at 1.5 GHz are more remarkable for their similarities than for their differences. Just as in the cases of 3C 98 and 3C 390.3 we presented in Blundell et al. (1999b) there is no evidence of any extended emission at low-frequency which is not already seen at GHz frequencies; this appears to be the case for all the classical doubles imaged to date. Jenkins & Scheuer (1976) pointed out that if synchrotron cooling played a part in determining the spectral shapes of lobes, then *lobes should be*

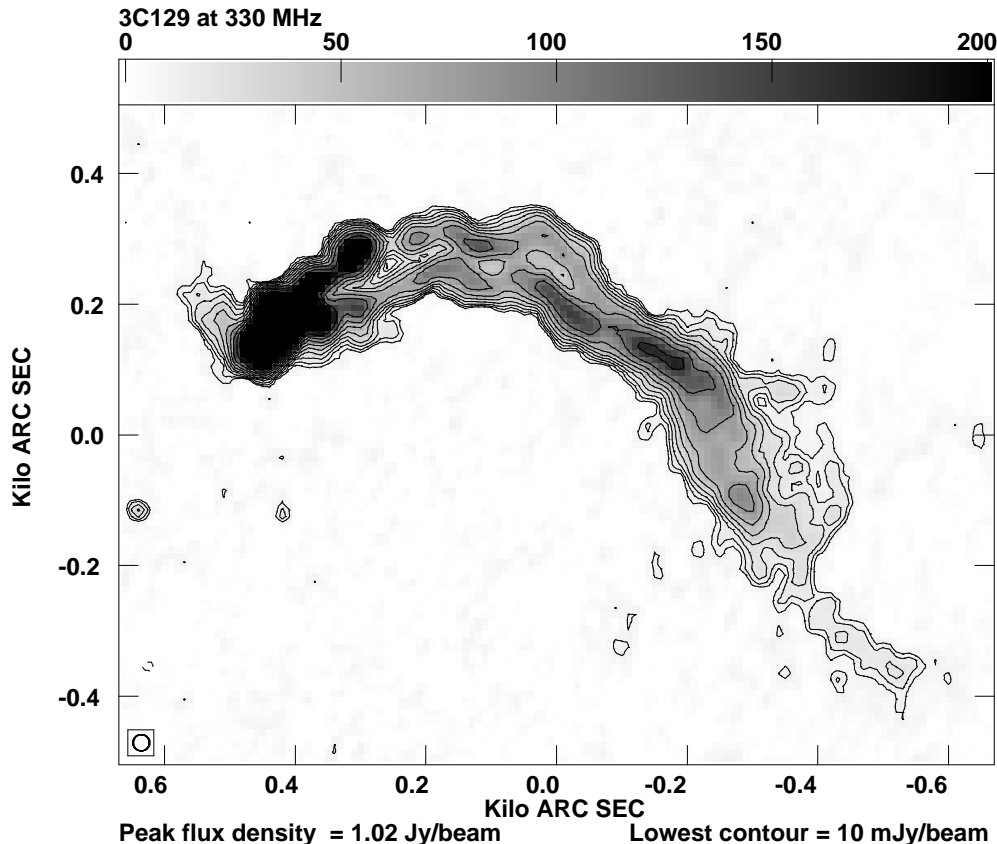


Figure 2. Image of 3C 129 at 330 MHz, showing the $\gtrsim 500$ kpc extent of its tails. The greyscale is saturated above 0.2 Jy/beam in order to emphasise the twin tails which appear to persist as two distinct entities over much of this distance.

observed to extend further at low frequency than at high frequency. Our images thus suggest that the Lorentz factor particles responsible for the 74 MHz emission are entirely co-spatial with those responsible for the 1.4 GHz emission.

In a recent paper, Blundell & Rawlings (2000) discussed a contribution to spectral steepening along the lobe from the hotspot to the core which is separate from the traditionally assumed simple synchrotron cooling picture. This contribution is particularly important in explaining spectral gradients measured a decade below fitted break frequencies, for example that in Cygnus A by Kassim et al. (1996). This comes from a gradient in magnetic field causing different parts of the underlying curved energy distribution to be ‘illuminated’ (see figure 4 in Blundell & Rawlings 2000) in the different regions along the lobe.

We conclude by noting that low-frequency observations of 3C radio sources have yet to reveal extended emission associated with a classical double source beyond that seen at GHz frequencies. Halos around the rather more amorphous types of object are not uncommon and in the case of 3C 84 close to the core

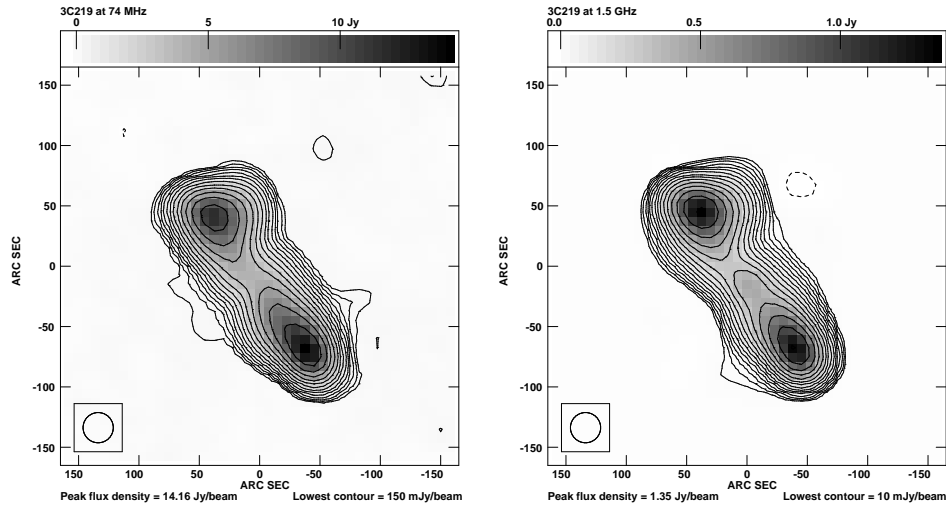


Figure 3. Images of 3C 219 at 74 MHz and 1.5 GHz with $25''$ resolution. These images, especially their silhouettes, are more remarkable for their similarities than for their differences.

discrete regions with very steep spectra ($\alpha \gtrsim 2$) have been discovered at 74 MHz. A full analysis of these data will appear in a forthcoming paper.

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References

- Blundell, K.M. & Rawlings, S., 2000, AJ, 119, 1111
- Blundell, K.M., Rawlings, S. & Willott, C.J., 1999a, AJ, 117, 677
- Blundell, K.M., Rawlings, S., Willott, C.J., Kassim, N.E. & Perley, R.A., 1999b, in *'Lifecycles of Radio Galaxies'*, New Astronomy Reviews eds J. Biretta et al. [astro-ph/9910158]
- Burns, J.O., Sulkanen, M.E., Gisler, G.R. & Perley, R.A., 1992, ApJ, 388, L49
- Jenkins, C.J. & Scheuer, P.A.G., 1976, MNRAS, 174, 327
- Laing, R.A., Riley, J.M., & Longair, M.S., 1983, MNRAS, 204, 151
- Kassim, N, Perley, R.A., Eriksen, W. & Dwarkanath, K.S., 1993, AJ, 106, 2218
- Kassim, N.E., Perley, R.A., Carilli, C.L., Harris, D.E. & Erickson, W.C., 1996, in *'Cygnus A – Study of a radio galaxy'*, p182, eds Carilli & Harris
- Rawlings, S., Blundell, K.M., Lacy, M., Willott, C.J. & Eales, S.A., in *'Observational Cosmology with the new radio surveys'*, eds M.N. Bremer, N. Jackson and I. Pérez-Fournon, Kluwer Academic Publishers, p171, (1998)
- Rudnick, L. & Burns, J.O., 1981, ApJ, 246, L69