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Robert A. Laing and Katherine M. Blundell

The large-scale structure of 3C 31

R.A. Laing[1,2], P. Parma[3], M. Murgia[4], L. Feretti[3], G. Giovannini[3], A.H. Bridle[5] & R.A. Perley[6]

[1]*Oxford University, Astrophysics, 1 Keble Road, Oxford, OX1 3RH, UK*

[2]*SSTD, CLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK*

[3]*Istituto di Radioastronomia del CNR, via Gobetti 101, 40129 Bologna, Italy*

[4]*Dipartimento di Fisica, viale B. Pichat 6/2, 40127 Bologna, Italy*

[5]*NRAO, Edgemont Road, Charlottesville, VA 22903-2475, USA*

[6]*NRAO, PO Box O, Socorro, NM 87801, USA*

Abstract. The results of a multifrequency VLA imaging study of the nearby radio galaxy 3C 31 are briefly summarized. The transition between jets and lobes is much more complex than was apparent from earlier observations, and is associated with significant variations in spectral index. We demonstrate that the known depolarization asymmetry in 3C 31 is caused by foreground Faraday rotation in the halo of the host galaxy, but the details of the associated field and density structure are not yet clear.

1. Introduction and images

The nearby FR I (Fanaroff & Riley 1974) radio galaxy 3C 31 (NGC 383; $z = 0.0167$) is one of the brightest of its class and has previously been imaged at cm wavelengths by Burch (1977, 1979), Strom et al. (1983) and Fomalont et al. (1980). In parallel with the modelling of its inner jets described in Laing & Bridle (these proceedings), we have made a detailed multifrequency study of the source using the VLA in all of its configurations at 6 frequencies from 1.365 to 8.43 GHz. Images have been made at resolutions ranging from 5.5 to 0.25 arcsec. In this paper, we highlight the morphology of the outer lobes, the spectral-index distribution and the rotation-measure structure.

Fig. 1 shows an image of the large-scale structure of 3C 31 at 1.4 GHz with a resolution of 5.5 arcsec FWHM. Spectral-index and depolarization between 1.4 and 5.0 GHz are displayed at the same resolution in Fig. 2 and higher-resolution images of total intensity and rotation measure for the central region of the source are given in Fig. 3.

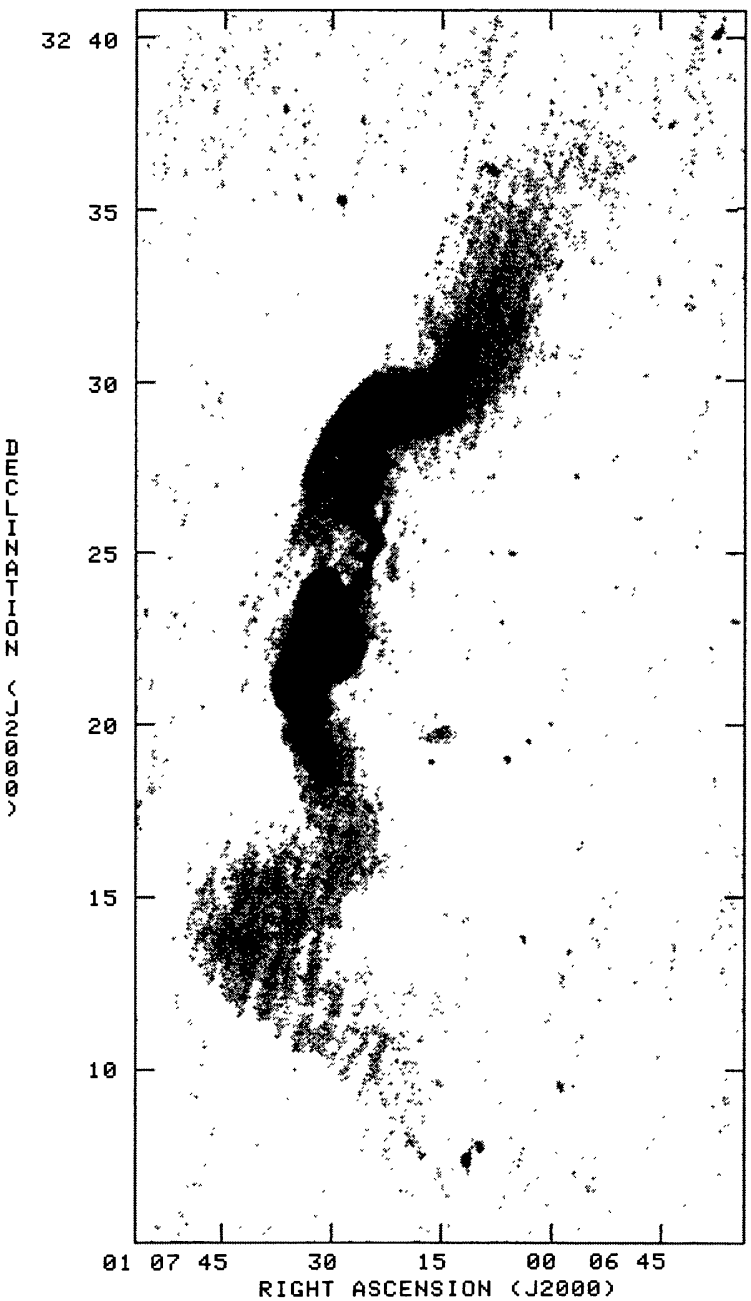

Figure 1. A grey-scale plot of the large-scale structure of 3C 31 at 1.4 GHz with a resolution of 5.5 arcsec FWHM.

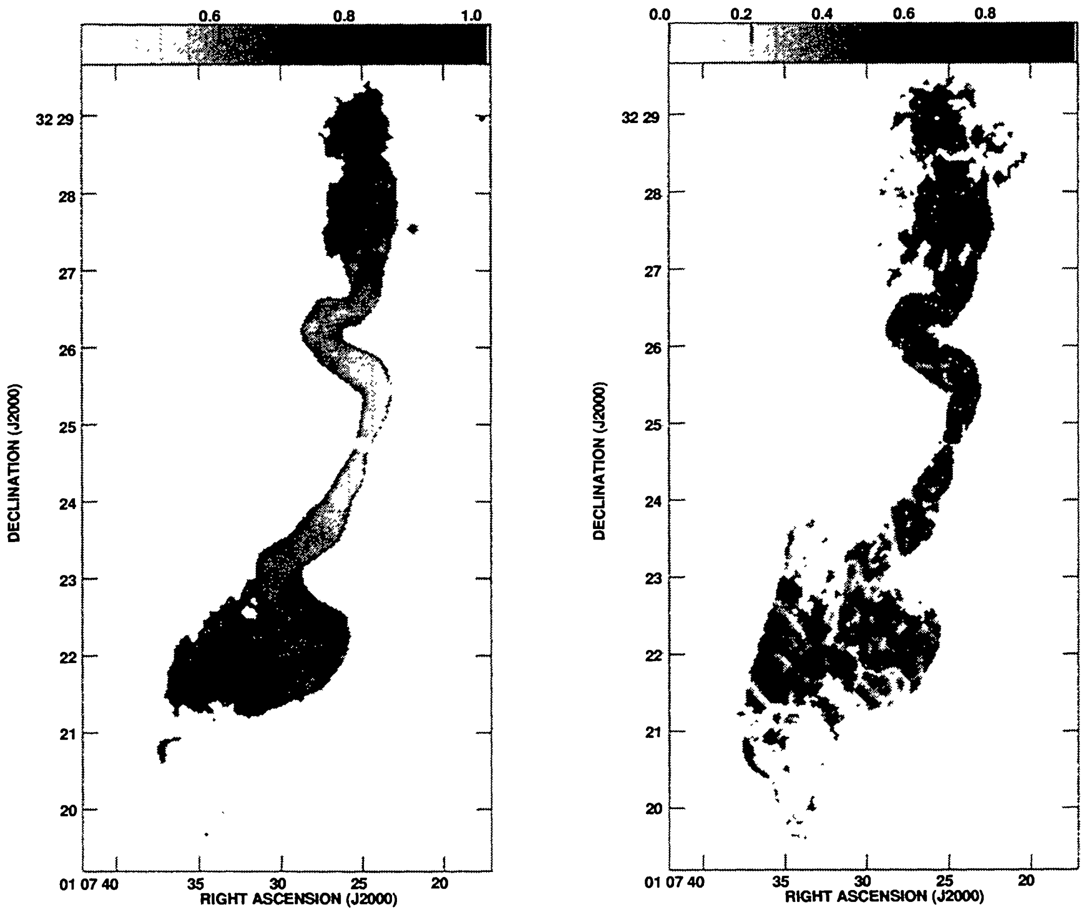

Figure 2. 3C 31 observed with a resolution of 5.5 arcsec FWHM. Left panel: spectral index, α, between 1.4 and 5.0 GHz. The grey-scale range is $0.4 < \alpha < 1.0$, with α defined in the sense $S \propto \nu^{-\alpha}$. Right panel: depolarization $p_{1.4\,\mathrm{GHz}}/p_{5.0\,\mathrm{GHz}}$.

2. Morphology

The most interesting new points apparent from Figs 1 and 3 are:

1. filamentary structure is ubiquitous on all scales;

2. the transition between jets and lobes is more complex than was previously thought: the jets appear to retain distinct identities as they bend and widen within the more diffuse lobes;

3. the S lobe shows a remarkable straight edge between declinations of $32^\circ\ 21'$ and $32^\circ\ 24'$ (J2000): this bears no obvious relation to any known feature in the surrounding hot gas (Komossa & Böhringer 1999).

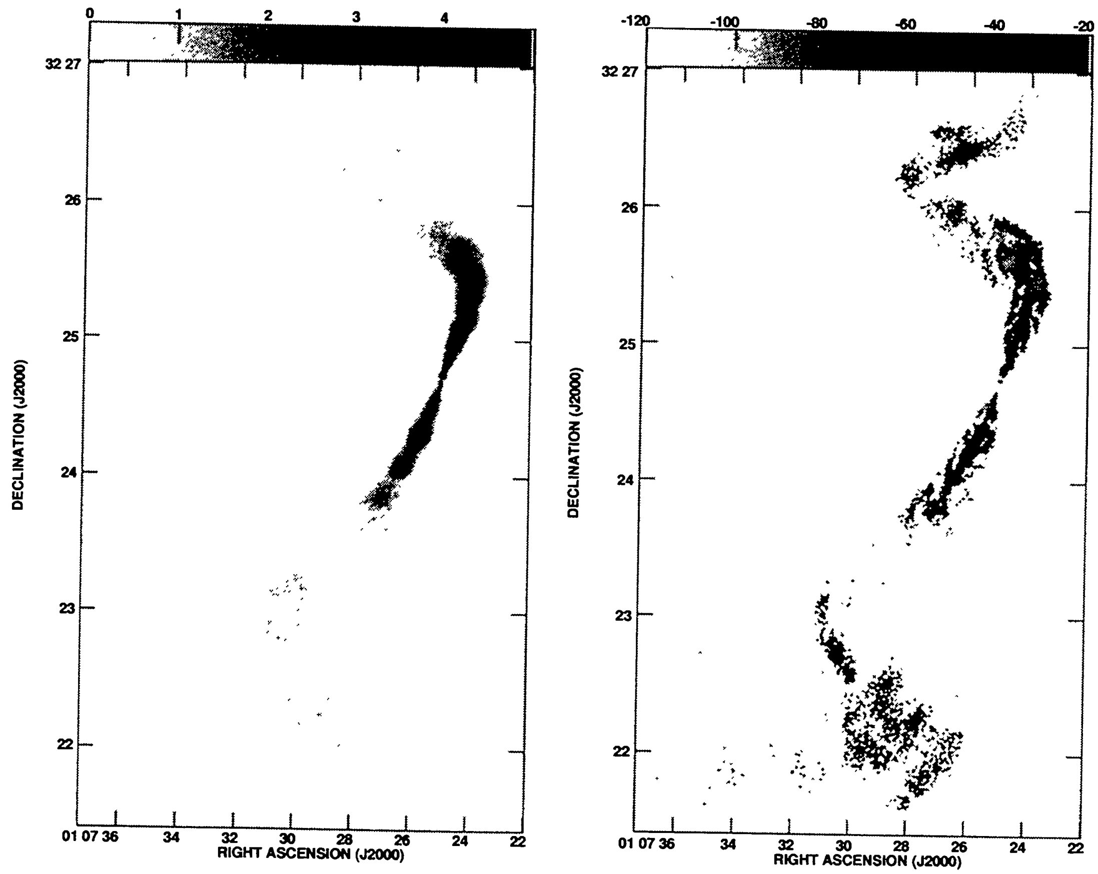

Figure 3. 3C 31 observed at 1.4 GHz with a resolution of 1.5 arcsec FWHM. Left panel: total intensity (0 – 5 mJy / beam area). Right panel: rotation measure (-120 to $-20\,\mathrm{rad\,m^{-2}}$). Note that the amplitude of the fluctuations in RM is higher by a factor ≈ 2 to the S of the nucleus compared with the N.

3. Spectrum

Close to the nucleus, the jets have spectral indices $\alpha = 0.55$ ($S_\nu \propto \nu^{-\alpha}$) and there is no evidence for any deviation from a power-law spectrum between 1.4 and 8.4 GHz. Further out, there is some evidence for spectral steepening at the edges of the jet. In the southern lobe (Fig. 2, left panel), it is clear that the spectrum does not simply steepen monotonically away from the nucleus. Rather, a flat-spectrum jet is surrounded by steeper-spectrum lobe emission (cf. Rudnick, these proceedings).

4. Faraday rotation and depolarization

3C 31 has been known to have a depolarization asymmetry (in the sense that the southern lobe depolarizes much more rapidly with increasing wavelength) since the observations by Burch (1979) and Strom et al. (1983). This is analogous to the effect first found in FR II sources, which is most easily explained if the nearer jet appears brighter because of Doppler boosting and is also seen through less magnetoionic material (Laing 1988). Attempts to demonstrate that this medium is actually in front of the source have been hampered by lack of spatial resolution, especially at the higher redshifts characteristic of FR II sources.

At a resolution of 5.5 arcsec FWHM, 3C 31 indeed shows a substantial depolarization asymmetry (Fig. 2; right panel). At 1.5 arcsec FWHM, however, the depolarization is entirely resolved and the **E**-vector position angles are accurately proportional to λ^2, indicating that foreground Faraday rotation is indeed responsible. A 6-frequency rotation measure image (Fig. 3) shows that the RM fluctuations are substantially larger in the S lobe and that the typical scale of fluctuations is ~ 2 kpc. The RM variation is qualitatively consistent with the idea that the brighter (N) jet is on the near side of the source, but detailed modelling is still unsatisfactory. The core radius inferred for the group gas associated with 3C 31 is 4.4 arcmin (Komossa & Böhringer 1999), so the variation of RM across the nucleus is too rapid to be explained by simple models in which the magnetic field scales with the group gas density and the angle to the line of sight is $\approx 50°$, as deduced from our jet models (Laing & Bridle, these proceedings). The most likely solution is that there is a second, more centrally concentrated gas component: this is not ruled out by existing ROSAT observations (Komossa & Böhringer 1999) and could be detected straightforwardly by *Chandra*.

5. Summary

We have made extensive VLA observations of the nearby radio galaxy 3C 31 at frequencies ranging from 1.4 to 8.4 GHz. Our initial results show that the emission appears filamentary on all scales, that the spectral structure is complex and that the previously-known depolarization asymmetry results from foreground Faraday rotation.

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