Faraday rotation variations along radio jets: the magnetic field in galaxy and group halos

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Abstract. Our modelling of FR I radio jets as decelerating, relativistic flows allows us to derive their orientations accurately. We present images of Faraday rotation for two of these these objects (3C 31 and NGC 315) and show that the fluctuations of rotation measure (RM) are larger in the fainter (receding) jets, as expected if the rotation occurs in the hot galaxy/group halos. The gas density is much lower in NGC 315 and the RM fluctuations are only just detectable.

Key words: galaxies: jets – radio continuum:galaxies – magnetic fields – polarization – MHD

1. Introduction

In our models of FR I radio jets as relativistic flows (Laing, Canvin & Bridle 2005), the observed differences in brightness and linear polarization between the jets close to the nucleus are produced by relativistic aberration and Doppler beaming and we can determine the inclination, θ. Given that we know the geometry and the external density profile (from X-ray observations), imaging of Faraday rotation measure (RM) can determine the distribution of magnetic-field irregularities in the surrounding hot plasma. In this paper, we summarize our RM imaging for two sources: 3C 31 (Laing & Bridle 2002) and NGC 315 (Canvin et al. 2005).

2. 3C 31

3C 31 is an FR I radio galaxy at a redshift of 0.0169 (0.344 kpc/arcsec for H_0 = 70 km s^{-1} Mpc^{-1}). Our models of the inner jets give an inclination of $\theta = 52°$. Our RM image, derived from 6-frequency observations between 1.365 and 8.4 GHz, is shown in Fig. 1(a), with an I image at the same resolution for comparison in Fig. 1(b). The $\mathbf{E}$-vector position angle is accurately proportional to λ^2 everywhere, indicating foreground rotation. There is structure in the RM image on a range of spatial scales from 5 – $>$50 arcsec and the RM fluctuations are higher by a factor of 2 – 3 on the counter-jet side (Fig. 1c and d). There is a small amount of depolarization on the counter-jet side. We estimate this by making a first-order linear approximation to the variation of degree of polarization, p, with λ^2: $p(\lambda^2)/p(0) \approx 1 + [p'(0)/p(0)]\lambda^2$ (Fig. 1e). We model the thermal X-ray emission as the sum of two components: one associated with the galaxy (core radius r_c = 3.6 arcsec), the second with the surrounding group, with r_c = 154 arcsec (Hardcastle et al. 2002). The Faraday rotation variations are therefore plausibly associated with the group component.

3. NGC 315

The giant FR I radio galaxy NGC 315 is at a redshift of 0.01648 (0.335 kpc/arcsec). We infer an angle to the line of sight of 38° (Canvin et al. 2005). Our RM images, derived from 5-frequency observations in the range 1.365 - 5 GHz, are shown in Fig. 2, together with profiles along the jet axis. The mean RM, and probably also a linear gradient along the jet are almost certainly Galactic. After removing these components, we detect RM fluctuations on scales of 10 – 100 arcsec, but the typical amplitudes are only $\approx$2 rad m^{-2} (Fig. 2e and f). The thermal X-ray emission from NGC 315 has a very small core radius, r_c = 1.55 arcsec (Worrall, Birkinshaw & Hardcastle 2003). In contrast to 3C 31, there is no detectable group component, so the external density on the

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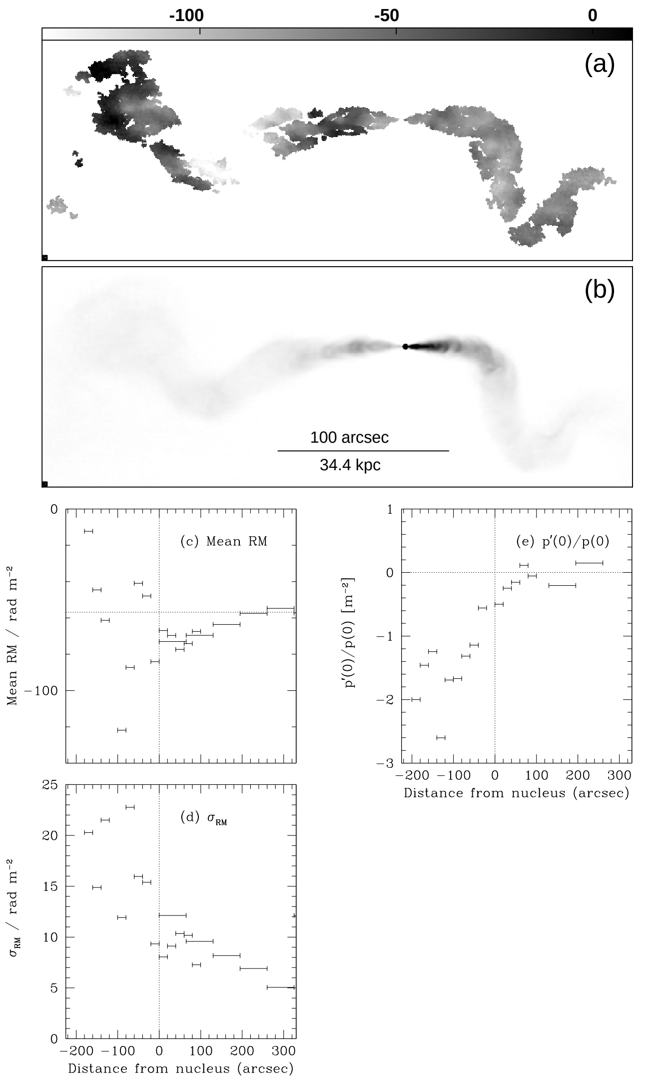

Fig. 1. RM and depolarization for 3C 31. All diagrams have the approaching (brighter) jet on the right.(a) RM image at a resolution of 1.5 arcsec, made using the Pacerman algorithm of Dolag et al. (2005). (b) I image of the same area. (c) Profile of mean RM, determined in boxes along the jet axis. (d) The rms RM, calculated over the same areas as in panel (c). (e) Profile of $p'(0)/p(0)$, as described in the text.

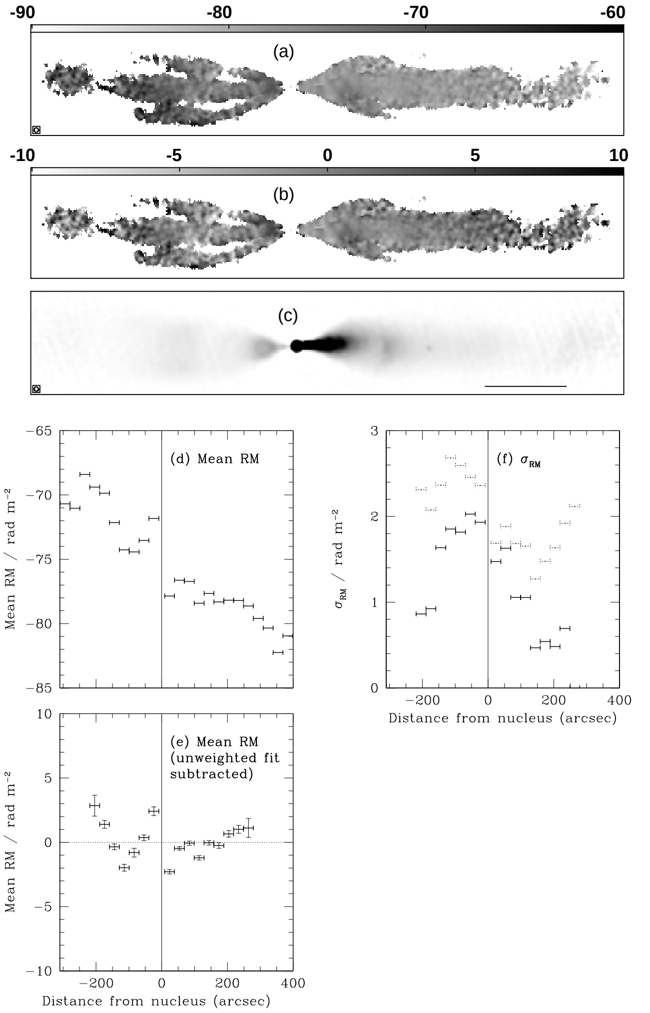

Fig. 2. RM data for NGC 315. All diagrams have the approaching jet on the right. (a) RM image at a resolution of 5.5 arcsec. (b) As (a), but with a linear variation subtracted. (c) I image covering the same area (a scale of 100 arcsec or 34.4 kpc is indicated by the horizontal line). (d) Profile of RM along the jet axis. (e) As (d), but with a linear variation subtracted and with low s/n data omitted. (f) The rms RM for the same data points as in panel (e). The dotted lines show the raw values; the full lines are the values after a first-order correction for fitting error.

scales we sample is likely to be very low. The small amplitude of the fluctuations and the fact that they are again larger for the receding jet are both qualitatively consistent with an origin in an, as yet undetected, hot gas component with a scale size ≈200 arcsec.

4. Summary

RM fluctuations in the two FR I radio sources we have observed must result primarily from foreground material. This is qualitatively consistent with relativistic jet models, which predict that the approaching jet appears brighter as a result of Doppler beaming and is also seen through less foreground magnetoionic material (Laing 1988); a quantitative test is in progress.

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