THE GALACTIC MAGNETIC FIELD IN THE QUASAR 3C 216

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Received 1999 February 25; accepted 1999 July 21

ABSTRACT

Multifrequency polarimetric observations made with the Very Long Baseline Array of the quasar 3C 216 reveal the presence of Faraday rotation measures (RMs) in excess of 2000 rad m\(^{-2}\) in the source rest frame in the arc of emission located at \(~140\) mas from the core. Rotation measures in the range \(-300\) to \(+300\) rad m\(^{-2}\) are detected in the inner 5 mas (\(~30\) pc). While the rotation measure near the core can be explained as being caused by a magnetic field in the narrow-line region, we favor the interpretation for the high RM in the arc that it is caused by a "local" Faraday screen produced in a shock where the jet is deflected by the interstellar medium of the host galaxy. Our results indicate that a galactic magnetic field of the order of \(~50\) \(\mu\)G on a scale greater than 100 pc must be present in the ambient medium.

Key words: galaxies: active — galaxies: individual (3C 216=0906+430) — galaxies: ISM — galaxies: jets — galaxies: nuclei — radio continuum

1. POLARIMETRIC PARSEC-SCALE OBSERVATIONS OF HIGH-RM RADIO SOURCES

While typical extragalactic radio sources have Faraday rotation measures (RMs) of order 10 rad m\(^{-2}\) at arcsecond resolution, there exist \(~30\) sources with RMs in excess of 1000 rad m\(^{-2}\) (see Taylor, Barton, & Ge 1994; Carilli et al. 1997; Athreya et al. 1998). Approximately 40\% of such sources are unresolved at arcsecond resolution. The parsec-scale study of the RM distribution in these radio sources exhibiting an excess of RM is important to understand the scale at which such high RMs originate and to explain the origin of the phenomenon itself. High rotation measures could originate either within the source itself, given a sufficiently dense thermal component, or they could be caused by an external Faraday screen of thermal gas and magnetic field.

A large fraction of radio sources with high RM on the arcsecond scale, i.e., \(~40\%\) of the total, are compact steep spectrum (CSS) radio sources, while the rest are extended radio galaxies. For a few extended radio galaxies, such as Cygnus A and Hydra A, both located at the center of clusters of galaxies, it has been proposed that a highly magnetized intracluster gas is responsible for the high RM detected (see, respectively, Dreher, Carilli, \& Perley 1987; Taylor \& Perley 1993).

Recent polarimetric observations of a few high-RM radio sources carried out at parsec-scale resolution with the Very Long Baseline Array (VLBA) revealed that the RM distribution differs considerably from source to source. In the CSS quasar OQ 172 (Udomprasert et al. 1997), the high RM observed on the arcsecond scale originates within the central parsecs, where values of about 40,000 rad m\(^{-2}\) are observed. It is therefore likely that the nuclear environment (i.e., the narrow-line region or NLR) is responsible for the high RM observed. Taylor (1998) studied four quasars with normal to low RMs on the arcsecond scale and for three of them found RMs in excess of 1000 rad m\(^{-2}\) within a few mas of the core, while the RM drops abruptly by more than an order of magnitude farther along the parsec-scale jet. Again, it is likely that the nuclear environment is responsible for the RM distribution observed. Similar results were obtained also for 3C 138 (Cotton et al. 1997). Finally Aaron, Wardle, \& Roberts (1998) studied the RM distribution in the CSS quasar 3C 309.1, found small RMs and little depolarization, and concluded that the NLR environment in this quasar is "normal" and uniform.

The quasar 3C 216 was found to have high RMs in the single-dish surveys of Tabara \& Inoue (1980) and in VLA observations made by Taylor, Ge, \& O'Dea (1995). In this paper, we present and discuss the parsec-scale RM distribution based on multifrequency polarimetric VLBA observations carried out at 3.6 and 6 cm.

3C 216 is associated with an optically polarized quasar located at \(z = 0.668\). This object is peculiar, since it exhibits properties typical both of blazars and CSS sources. Detailed observations carried out at parsec-scale resolution (Barthel, Pearson, \& Readhead 1988; Venturi et al. 1993) revealed superluminal motion in the inner part of the VLBI jet, which argues in favor of a small orientation of the VLBI structure to the line of sight. The parsec- and kiloparsec-scale radio emissions are misaligned by \(~110^\circ\). High-frequency VLA polarimetric observations (Taylor et al. 1995) showed that the source is strongly polarized and that the high RM originates mainly in the arcsecond core and in the northeastern component. In particular, their results indicate that the polarized flux in the nuclear components peaks at \(~150\) mas southeast of the core.

A Hubble constant \(H_0 = 65\) km s\(^{-1}\) Mpc\(^{-1}\) and \(q_0 = 0.5\) will be used throughout this paper. With this choice of the cosmological parameters, at the distance of 3C 216, 1 mas corresponds to 6.1 pc.

2. OBSERVATIONS AND DATA REDUCTION

The observations performed on 1996 November 3 were carried out at four frequencies in the 3.6 and 6 cm bands (see Table 1) using the 10-element VLBA of the NRAO.\(^3\) Both right- and left-circular polarizations were recorded using 1 bit sampling for four widely spaced intermediate fre-
Fig. 1.—Full-resolution images of 3C 216 at (left) 6 and (right) 3.6 cm. The restoring beam is $2.65 \times 1.75$ mas in position angle $0\degree$. Contour levels start at 0.4 and 0.5 mJy beam$^{-1}$ and increase by factors of 2 up to 410 and 512 mJy beam$^{-1}$ at 6 and 3.6 cm, respectively.

The VLBA correlator produced 16 frequency channels/IF in every 2 s integration. Amplitude calibration for each antenna was derived from measurements of the antenna gain and system temperatures. The polarization calibration was performed following a procedure suggested by Cotton (1993). Global fringe fitting was performed using the Astronomical Image Processing System (AIPS) task FRING, an implementation of the Schwab & Cotton (1983) algorithm. The fringe fitting was performed using a solution interval of 4 minutes, and a point-source model was assumed. Next, a short segment of the cross-hand data from the strongly polarized calibrator 3C 345 was fringe-fitted to determine the right-left delay difference, and the correction obtained was applied to the rest of the data. Once delay and rate solutions were applied, the first and last channels were omitted, and the data were averaged in frequency over the remaining 7 MHz. The data from all sources were edited and averaged over 30 s intervals using DIFMAP (Shepherd, Pearson, & Taylor 1994; Shepherd 1997) and then were subsequently self-calibrated within AIPS.

### Table 1

| Source    | Observing Frequency (GHz) | BW (MHz) | $\Delta t$ (s) | Scan (minutes) | Time (minutes) |
|-----------|---------------------------|----------|----------------|----------------|----------------|
| 3C 216    | 8.114, 8.309, 8.506, 8.594| 7        | 2              | 16             | 208            |
|           | 4.616, 4.654, 4.854, 5.096| 7        | 2              | 16             | 224            |
| 0552 + 398| 8.114, 8.309, 8.506, 8.594| 7        | 2              | 5              | 63             |
|           | 4.616, 4.654, 4.854, 5.096| 7        | 2              | 5              | 67             |
| 3C 286    | 8.114, 8.309, 8.506, 8.594| 7        | 2              | 6              | 6              |
|           | 4.616, 4.654, 4.854, 5.096| 7        | 2              | 5              | 5              |
| 3C 345    | 8.114, 8.309, 8.506, 8.594| 7        | 2              | 6              | 12             |
|           | 4.616, 4.654, 4.854, 5.096| 7        | 2              | 6              | 12             |

**Notes.**—Col. (3): Total spanned bandwidth. Col. (4): Integration time output from correlator. Col. (5): Approximate time of scan. Col. (6): Total integration time on source.
Finally, the strong, compact calibrator 0552+398 was used to determine the feed polarizations of the antennas. We assumed that the VLBA antennas had good quality feeds with relatively pure polarizations, which allowed us to use a linearized model to fit the feed polarizations. Once these were determined, the solutions were applied to snapshot observations of 3C 286 and 3C 345. 3C 286 has been observed to have a polarization angle of 30° (Cotton et al. 1997), so a single right-left phase difference was applied to all 3.6 and 6 cm frequencies to correct the polarization angles to this value. As a check on the absolute polarization angle calibration, 3C 345 was also imaged. Components along the jet of 3C 345 lie parallel to the jet axis at 6 cm (Cawthorne et al. 1993; Taylor 1998). Assuming that this

\[\text{TABLE 2} \]

\[\begin{array}{cccccc}
\text{Observing Frequency} & \text{FWHM} & \text{rms} & \text{S}_{\text{core}} & \text{S}_{\text{jet}} & \text{S}_{\text{arc}} \\
(\text{GHz}) & (\text{mas}) & (\text{mJy beam}^{-1}) & (\text{mJy}) & (\text{mJy}) & (\text{mJy}) \\
\hline
4.805 & 2.65 \times 1.75, 0' & 0.07 & 513.5 & 86.1 & 83.5 \\
8.381 & 2.65 \times 1.75, 0' & 0.10 & 707.6 & 73.2 & 32.9 \\
\end{array}\]

\textit{Notes.—} Col. (2): Restoring beam of the images presented in Fig. 1. Col. (3): The rms noise level in the final image. Col. (4): Core flux density. Col. (5): Flux density of the inner 30 mas of the parsec-scale jet. Col. (6): Flux density of the bent component located at \(\sim\) 140 mas.
emission. Our image also indicates that the parsec-scale jet
peaks at $D_1$ the core is not straight, but wiggles with an amplitude of
8°. The jet has a knotty structure, with two brightness
extension of the parsec-scale radio emission in 3C 216 out
to ~140 mas from the core was first revealed by European
VLBI Network 50 and 18 cm observations (Fejes, Porcas, &
Akujor 1992), and its detailed morphology was first imaged
at 18 cm in a global VLBI experiment (Akujor, Porcas, &
Fejes 1996). Our images agree even in the details of the
earlier 18 cm image. The $(u, v)$ coverage and resolution of
our data do not allow us to image the subkiloparsec radio
emission beyond the arc. From the comparison of our
images and those available in the literature having
resolutions ranging from a fraction of an arcsecond (Taylor
et al. 1995) to 30 mas (Fejes et al. 1992) to the milliarcsecond
resolution of the images presented in this paper, we suggest
that the radio emission from the subkiloparsec-scale jet and
arc continues to the southwest and feeds the southwestern
knot visible on the arcsecond scale (see images in Fejes et al.
1992 and in Taylor et al. 1995). This suggestion is consistent
with the polarization properties of 3C 216 on the arcsecond
scale. Taylor et al. (1995) found that the bright knot located
1° southwest of the core is less depolarized than the north-
eastern one, and it is therefore expected to be closer to the
observer.

We computed the point-to-point spectral index of the
parsec-scale components in 3C 216 between 3.6 and 6 cm, $\alpha_1^{3.6} \approx v^{-0.6}$. To this aim, we used images made with the
same $(u, v)$ coverage and convolved with the same restoring
beam. In Figure 2, the 6 cm total intensity contours are
superposed on the gray-scale image of the spectral index in
the inner 30 pc. As is clear from the figure, the northernmost
component of the parsec-scale morphology has the most
inverted spectrum, with $\alpha_1^{3.6} = -0.6$. The spectral index
steepens along the inner jet. Peaks in the spectral index
distribution, i.e., flattening of the spectrum, coincide with
brightness peaks along the jet.

The arc of emission at ~140 mas from the core has a
considerably steeper spectrum in our two bands. Compari-
sion of the total flux in the arc derived from our images leads
to a value of the spectral index of $\alpha_1^{3.6} \approx 1$. The point-to-
point distribution (not shown here) is irregular, and regions
of flatter spectrum are located in between the arc brightness

![Arc Spectrum](image)

**FIG. 3.—Spectrum of the arc in 3C 216 in the wavelength range 3.6–18 cm. The 18 cm flux density was estimated from the image published by
Akujor, Porcas, & Fejes (1996).**

remains the case over time, we found that the jet component
was within 5° of the expected value at 6 cm. Of prime
importance to this experiment are the relative angles
between frequencies, and these were preserved by applying
a constant correction to all frequencies within each band.

### 3. RESULTS

#### 3.1. Total Intensity Images and Parsec-Scale Morphology

Our total intensity VLBA images were obtained using all
frequencies in both the 3.6 and 6 cm bands. This pro-
vided a very good $(u, v)$ coverage and allowed high-
sensitivity imaging. Natural weighted total intensity images
at 6 and 3.6 cm are shown in Figure 1. Details about the
images are given in Table 2.

In both bands, the parsec-scale structure of 3C 216
extends ~140 mas in P.A. ~150°, southeast of the nor-
thernmost, most compact component, which we assume to be
the core, as our data demonstrate (see below). The images in
both bands show that the jet within the first 40 mas from
the core is not straight, but wiggles with an amplitude of
~8°. The jet has a knotty structure, with two brightness
peaks at ~7 and ~15 mas from the core dominating the jet
emission. Our image also indicates that the parsec-scale jet

### TABLE 3

| Observing Frequency (GHz) | FWHM (mJy beam⁻¹) | rms (mJy/beam⁻¹) | $P_{core}$ (mJy) | $m_{core}$ (%) | $P_{K1}$ (mJy) | $m_{K1}$ (%) | $P_{K2}$ (mJy) | $m_{K2}$ (%) | $P_{arc}$ (mJy) | $m_{arc}$ (%) |
|---------------------------|-------------------|-----------------|-----------------|---------------|----------------|---------------|----------------|---------------|----------------|---------------|
| 4.854                     | 2.65 x 1.75, 0°   | 0.14            | 1.5             | 0.3           | 1.8            | 6             | 2.9            | 21            | 14.4           | 29            |
| 8.309                     | 2.65 x 1.75, 0°   | 0.18            | 3.9             | 0.6           | 1.7            | 6             | 2.2            | 20            | 8.6            | 30            |

**Note.**—Col. (2): Restoring beam of the images presented in Figs. 2, 4, 5, 7, 8, and 9. Col. (3): The rms noise in the final polarized image. Col. (4): Polarized flux density of the core. Col. (5): Fractional polarization for the core. Col. (6): Polarized flux density of knot K1. Col. (7): Fractional polarization for knot K1. Col. (8): Polarized flux density of knot K2. Col. (9): Fractional polarization for knot K2. Col. (10): Polarized flux density of the arc. Col. (11): Fractional polarization for the arc.
peaks. We compared our flux measurements with the 18 cm image published in Akujor et al. (1996) after tapering our images to match the published 18 cm image, and we derived the spectrum of the arc using the information in these three bands. The result is plotted in Figure 3. The spectrum is almost flat between 18 and 6 cm, with $\alpha_{18} \approx 0.2$, then steepens to a value of $\alpha_{6} \approx 1$.

3.2. Polarization Images and Rotation Measure Structure

The fractional polarization and polarization percentage values are reported in Table 3, and the image of the polarized flux (gray scale) with superposed total flux density contours is given in Figures 4 and 5 for the 6 cm image (inner jet and arc, respectively) and in Figure 6 for the inner region in the 3.6 cm image. The total intensity and polarized intensity images used to derive the values in Table 3 were made using a single IF at both frequencies at matching resolution. To this aim, we made a uniformly weighted image at 6 cm and a naturally weighted and tapered image at 3.6 cm.

As is clear from Table 3 and from the images, the polarized intensity of the parsec-scale radio emission of 3C 216 varies considerably along the structure. The core region is complex. The morphology of the polarized emission is very similar in both bands and consists of three components, one coincident with the radio core and the other two, labeled K1 and K2 in Figure 6, along the inner jet, located respectively at 4 mas and 6 mas from the core. The core is very weakly polarized, while components K1 and K2 are polarized at 6% and 20% in both bands. The core appears to depolarize by a factor of $\sim 2$ between 3.6 and 6 cm. The arc of emission is strongly polarized, at $\sim 30\%$ in both bands. Our results indicate that no depolarization is found between 6 and 3.6 cm in the inner jet and in the arc of 3C 216.

The orientation of the projected magnetic field (already corrected for the RM) is shown in Figures 7 and 8 for the core and inner jet and for the arc respectively. The magnetic field is parallel to the jet axis near the core and in knot K2, while it is oriented perpendicular to the jet axis in knot K1.
The orientation of the magnetic field also shows some structure in the arc (see Fig. 8) and tends to remain parallel to the outer edge. The high polarization percentage in the arc and the orientation of the magnetic field vector, coupled with its morphology, suggest a strong interaction with an external medium.

We derived the RM in 3C 216 between 6 and 3.6 cm. Our result is shown in Figure 9, where total intensity contours at 6 cm are superposed on a false-color map of the RM. The RM values derived over the whole region imaged are in the range from about $-100$ to about 800 rad m$^{-2}$. Since the RM in the rest frame of the source depends on the redshift through the simple relations $R_{\text{int}} = R_{\text{abs}}(1+z)^2$, in the case of 3C 216 the intrinsic RM is in the range of about $-280$ to about 2200 rad m$^{-2}$.

The observed RM in the inner jet region is low, from about $-100$ to about 100 rad m$^{-2}$. It flips from $105 \pm 8$ rad m$^{-2}$ to about $-99 \pm 12$ rad m$^{-2}$ from the core to the polarized knot K1 at $\sim 4$ mas (see Fig. 6), then it changes back to $\sim 100$ rad m$^{-2}$ in knot K2. The fits to the polarization angle, derived using all four frequencies in the two bands, are shown in Figure 10. The change in sign of the RM requires a magnetic field reversal in the inner jet region. The largest observed RM values, ranging from $\sim 500$ to $\sim 800$ rad m$^{-2}$, are found in the arc, in agreement with the RM distribution on the arcsecond scale (Taylor et al. 1995).

Fits of the RM to the observed polarization angle versus $\lambda^2$ for the arc are given in Figure 11. In both regions, the variation of the position angle is well fit by a $\lambda^2$ law. We note that the galactic contribution to the measured RM is in the range $0$–$10$ rad m$^{-2}$ (Simard-Normandin, Kronberg, & Button 1981) and therefore negligible.

4. DISCUSSION

Our study on the parsec-scale polarimetry and RM structure in the CSS quasar 3C 216 shows that the arc of emission located at $\sim 140$ mas from the core exhibits the most extreme properties, with an intrinsic RM in excess of 2000 rad m$^{-2}$. The RM in the core region, on the other hand, is an order of magnitude smaller and ranges from about $-300$ to about 300 rad m$^{-2}$ with at least two sign reversals. The polarization percentage is also much higher in the arc than in the core region, independent of our two observing bands.

Since no depolarization is found in the jet or in the arc between 3.6 and 6 cm, even while the polarization angle changes by more than 100° in the arc, the most likely mechanism for the high RM observed in 3C 216 is the presence of an external screen. Internal Faraday rotation is ruled out, as it would imply also considerable depolarization with frequency (Burn 1966), which is not observed. The lack of depolarization also argues against more complex situations, such as an external screen with mag-
magnetic field tangled on scales less than the beam size (see Feretti et al. 1995 for a brief review on the subject). The situation in the core itself is less clear, since there is very low fractional polarization, and there is evidence of depolarization.

If our assumption is correct, then the intrinsic RM is related to the electron density \( n_e \) (cm\(^{-3}\)), to the component of the magnetic field parallel to the line of sight, \( B_{||} \) (\( \mu \)G), and to the depth of the screen \( d \) (kpc) through the formula

\[
\langle \text{RM} \rangle = 812 \ n_e B_{||} d \ \text{rad m}^{-2}.
\]

4.1. The Core and the Inner Jet

The screen responsible for the RM distribution in the inner jet region of 3C 216 is most likely the NLR, given that it is all contained within a distance of \( \sim 5 \) mas from the core, a projected distance of \( \sim 30 \) parsec. From the intrinsic RM obtained in our observations, i.e., \( |\text{RM}_{\text{int}}| \sim 300 \ \text{rad m}^{-2} \), and assuming a depth of 10 pc, we derive \( n_e B_{||} \sim 35 \ \text{cm}^{-3} \ \mu \text{G} \). With this constraint, we can derive an estimate of the component of the magnetic field parallel to the line of sight for the NLR of the order of \( 10^{-2} \ \mu \text{G} \), as suggested by Taylor (1998), only if we assume an electron density of the order of \( 3 \times 10^3 \ \text{cm}^{-3} \), a lower limit for the density of the NLR. The sign reversal of the RM in the inner jet region, however, suggests that the magnetic field could be tangled on the assumed 10 pc scale, which implies stronger fields than estimated here.

These properties are different from the results reported in Taylor (1998) for a sample of quasars, in which Faraday RMs in excess of \( 1000 \ \text{rad m}^{-2} \) are found within the first 10–20 pc from the quasar core and drop considerably farther out. Our results are unexpected, considering that the inner region of 3C 216 shares the same global properties as the sources in the Taylor sample, such as superluminal motion and low fractional polarization. These similar properties would lead to the conclusion that we are observing the same type of sources, all seen at a small viewing angle.

One explanation for this inconsistency is that the resolution of our 3C 216 images is too low to allow us to separate the core from the jet beginning, and therefore we lack information on the properties of the true core. The
depolarization of the core between 3.6 and 6 cm could also indicate large RM gradients within the beam. The RM distributions of Taylor (1998) were derived between 8 and 15 GHz, consequently with higher resolution. To test this hypothesis, we made high-resolution 3.6 cm images of the total intensity image are $-0.4, 0.4, 0.75, 1, 1.5, 10, 20,$ and $30 \text{ mJy beam}^{-1}$.

![3C216 B-Vectors at 6 cm](image1)

Fig. 7.—Projected magnetic field orientation of the core and inner jet components at 6 cm after correcting for the RMs shown in Fig. 9. The resolution is $2.65 \times 1.75 \text{ mas in P.A. = 0}\circ$. Contours of the total intensity image are $-0.4, 0.4, 1, 1.5, 20,$ and $30 \text{ mJy beam}^{-1}$.

at higher resolution and higher frequency are needed to investigate whether the Faraday rotation in the core of 3C 216 follows the behavior that now seems common in quasar cores.

4.2. The Arc

The external screen responsible for the high Faraday rotation in the arc must be located quite far from the central engine. As stated in Venturi et al. (1993), the superluminal motion in the inner 6 pc argues in favor of a small angle of the parsec-scale jet to the line of sight, i.e., $\theta \lesssim 20\circ$. The global morphology on the parsec scale does not indicate misalignments or bending after the first few parsecs, so it seems reasonable to assume that the arc where the jet bends is still seen at the same angle. If our assumptions are correct, the true distance of the arc from the core of 3C 216 is $\sim 2.5$ kpc. Such a distance could still be within the NLR, though it would be a somewhat extreme situation (Netzer 1991; Fanti et al. 1995), or it could be within the interstellar medium, possibly inside a shell surrounding the radio emission. Another possibility is that the arc is the result of a shock between the radio emission and the external medium. Under this hypothesis, the Faraday screen would be “local,” in a thin sheet of shocked gas around the radio emission. In the following, we will consider both frameworks and discuss their implications.

4.2.1. Galactic Faraday Screen

Under the assumption that the Faraday screen has a depth of the order of a kiloparsec, for a value $\langle RM \rangle = 2000$ rad m$^{-2}$, we obtain $n_e B_\parallel \sim 2.5 \text{ cm}^{-3} \mu G$. The interstellar gas density at this distance from the nucleus in high-redshift objects is not known. Studies carried out at X-ray energies on low-redshift galaxies indicate the existence of hot coronae around galaxies, with densities of the order of $10^{-1}$ cm$^{-3}$ and core radii of the order of few kiloparsecs (Forman, Jones, & Tucker 1985; White & Sarazin 1988; see also Fanti et al. 1995 for a brief review on this topic). If we assume that the same condition holds also in distant ellipticals and quasars, such density would lead to a magnetic field strength in the interstellar medium (for the component parallel to the line of sight) of $\sim 25 \mu G$. Assuming that the field is ordered (as the positive RM throughout the arc suggests) but not entirely along the line of sight, then a more accurate estimate for the magnetic field strength is $\sim 25 \sqrt{3} \sim 43 \mu G$. A very similar value was found for the magnetic field in the galactic gas surrounding M87 (Owen, Eilek, & Keel 1990).

4.2.2. Bow Shock Faraday Screen

The subkiloparsec-scale morphology of 3C 216, characterized by a very faint jet, which flares into the southern arc and bends westward here, suggests that the arc could be the working surface of a subkiloparsec jet in the galactic medium and that the magnetized screen responsible for the Faraday rotation would be a thin layer of compressed galactic medium. A similar bow shock has been reported on a somewhat larger scale for Cygnus A (Carilli, Perley, & Dreher 1988). The interaction between the jet and the compressed ambient medium could be responsible for the jet deflection. We note here that with a viewing angle of $\sim 20\circ$, as we have assumed throughout the paper, the apparent bend of $\sim 90\circ$ corresponds to an intrinsic bend of $\sim 75\circ$.

Under this hypothesis, the smoothness of the RM distribution suggests a plausible depth of 100 pc for such a
Fig. 9.—Rotation-measure image of 3C 216 with contours of 6 cm total intensity superposed.
screen. This leads to an estimate of the product \( n_e B_{||} \sim 25 \text{ cm}^{-3} \mu \text{G} \). If the average density out of the shocked region is 0.1 cm\(^{-3}\) (as justified in § 4.2.1) and with a compression factor of 4 for a strong adiabatic shock, the electron density just behind the shock is 0.4 cm\(^{-3}\), thus leading to an estimate of \( B_{||} \sim 60 \mu \text{G} \) in the shocked region. The galactic magnetic field outside the shock is expected to be \( \sqrt{3} \sim 26 \mu \text{G} \). Given the uncertainties in the assumptions made, we can say that these two estimates are in agreement.

The external density could be much higher than assumed here if the jet is deflected by interaction with a dense molecular cloud in the NLR. For this reason, the value we derive for the galactic magnetic field in 3C 216 under this assumption should be considered an upper limit. However, three-dimensional hydrodynamic simulations of deflected cosmic jets (de Young 1991) show that jet-cloud interactions are not a stable mechanism for jet deflection, even with an optimal geometry and choice of parameters for the deflection. This mechanism considerably reduces the jet speed on a short timescale \((t < 10^7 \text{ yr})\) and leads to the cloud eroding on timescales \( \gtrsim 10^7 \text{ yr} \). Furthermore, de Young (1991) argues that such interaction would not result in a coherent observable bent jet. This is not in agreement with the radio emission in 3C 216, which indicates that the subkiloparsec-scale jet is smoothly bending and leading into the arcsecond-scale emission in the source, as we have pointed out in § 3.1.

Using equipartition arguments, with the standard assumptions (i.e., filling factor \( \phi = 1, k = 1 \) and integrating between 10 and 100 GHz) and using the spectral index \( \alpha_{1.6}^2 = 1 \) derived in § 3.1, we derive an equipartition magnetic field in the arc \( B_{\text{arc}} = 1.3 \text{ mG} \) and an internal non-thermal pressure \( P_{\text{int}} = 2.6 \times 10^{-7} \text{ dyne cm}^{-2} \).

5. CONCLUSIONS

Detailed polarimetric studies of compact sources on the parsec scale have demonstrated that there is a variety of mechanisms that can add RMs in excess of 1000 rad m\(^{-2}\). These range from the NLR on scales of a few parsecs (e.g., OQ 172, Udomprasert et al. 1997, and probably in the core of 3C 216 as well) to galactic magnetic fields organized on scales of hundreds to thousands of parsecs (see § 4.2) to cluster magnetic fields organized on scales of tens of kiloparsecs (e.g., 3C 295, Perley & Taylor 1991). Clearly measuring an integrated RM by itself is not sufficient to determine the nature of the Faraday screen.

Given the parsec-scale morphology of 3C 216, we favor the bow shock model to explain the change in the jet direction and the presence of high Faraday RMs. In this picture, magnetic fields of \( \sim 50 \mu \text{G} \) organized on scales of greater than 100 pc are required.

The authors wish to thank D. Dallacasa for the many discussions while this paper was in progress. R. Fanti and C. P. O’Dea are warmly acknowledged for helpful comments on the manuscript.

This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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