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A Multi-Frequency VLBI Polarization Study of the CSS Quasar 3C 309.1

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Abstract. We discuss the rotation measure properties of the CSS quasar 3C 309.1, determined from high dynamic range, large field of view VLBA images at several frequencies between 1.4 and 15 GHz. We consider the general properties of the ambient medium by considering the structure of the Faraday screen across various parts of the radio source.

1. Introduction and Observations

The quasar 3C 309.1 ($z = 0.905$, implying 1 mas $= 4.1h^{-1}$ pc) is one of the largest and most luminous members of the class of compact steep spectrum (CSS) radio sources (van Breugel, Miley, & Heckman 1984; Fanti et al. 1985). Sources in this class are believed to lie in very dense environments which depolarizes the radio emission at longer wavelengths. The source is also believed to lie at the center of one of the most massive cooling flows known (Forbes et al. 1990). Such sources are expected to show very large rotation measures.

We have observed 3C 309.1 at nine frequencies between 1.4 and 15 GHz. Our images at 15 GHz are given in Aaron (1996), the 8.4 and 5 GHz maps in Aaron (1996) and Aaron, Wardle, & Roberts (1997, hereafter AWR97). From these maps, we have constructed maps of rotation measure and depolarization between 8.4 and 5 GHz (shown in AWR97) and between 1.662 and 1.499 GHz. The depolarization ratio DP is defined as the ratio of the fractional polarization at the higher frequency to that at the lower frequency. Between the two low frequencies, we find little structure in the rotation measure map. The RMS over the entire field is only 21 rad m^{-2}. The rotation measure is typically ~ 60 rad m^{-2}, with slightly lower values in the lobe region. The depolarization ratio shows a typical value of about 1.1, again with little structure.

2. Rotation Measure and Depolarization

As we have finite resolution in our images we must consider, not a single value of the rotation measure, but a spectrum $F(\rho)$ of values, which is related to the observed polarization as a function of wavelength via a Fourier transform. If we assume the rotation measure spectrum is a gaussian centered at some value ρ_0 with a standard deviation σ_{RM}, then $\chi_{\text{obs}} = \chi_0 + \rho_0\lambda^2$ and $p_{\text{obs}}(\lambda^2) = e^{-2\sigma_{RM}^2\lambda^4}$. Hence, the rotation of the electric vector as a function of frequency (the apparent rotation measure) provides information about the central value of the rotation

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measure spectrum, and the depolarization ratio gives the width of the spectrum. By measuring both, we may understand the structure of the ambient medium.

3. Discussion

For 3C 309.1, we find small rotation measures and little depolarization or gradients in rotation measure which would depolarize the source at lower resolution. The rotation measures are smaller than those found in other CSS objects, e. g., 3C 216 and 3C 119 (these Proceedings, p. 113 and 109 respectively), and in other cooling flow sources (Taylor, Barton, & Ge 1994). In the higher frequency observations, we find a depolarization ratio of about 1.3 in the lobe, implying dispersions of about 100 rad m^{-2} on scales smaller than our 5 GHz beam, about $10h^{-1}$ pc. This is somewhat larger than the width of the apparent rotation measure distribution on scales larger than the beam, which has an RMS of ~ 50 rad m^{-2}. Across region B, the depolarization ratio is unity. In the low frequencies, the lobe depolarization ratio drops to values suggesting $\sigma_{RM} \sim 10 - 20$ rad m^{-2} on scales smaller than $\sim 40h^{-1}$ pc. This is fairly uniform across the entire source, and is consistent with the dispersion in apparent rotation measure.

The basic picture of the rotation measure spectrum of 3C 309.1 that emerges from this study is as follows. Across the entire source, the spectrum is dominated by a narrow component, typically peaked at about 60 rad m^{-2}, with dispersion of about 10 rad m^{-2} on scales smaller than about 40 pc. The central value of this component is a weak function of position. Across the lobe, wider spectral components are superimposed on this dominant spectrum, with dispersions of $\sim$ 100 rad m^{-2} on scales smaller than 10 pc. These small pockets of high dispersion do not appear associated with the inner jet or with region B, both of which show depolarization ratios near unity in both frequency regimes. Finally, across the core, the spectrum is very broad, depolarizing the core at frequencies below 8.4 GHz. These findings suggest that the spectrum of the magnetic field and electron density fluctuations in the ambient medium of 3C 309.1, most likely the NLR, is fairly uniform. The lobe expansion drives shocks into the ambient gas on small scales, contributing the large dispersions on small angular scales.

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