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Rotation Measure and Opacity Asymmetry in 2134+004

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Abstract: Based on the free–free absorption (FFA) model of gigahertz peaked spectrum (GPS) sources, we explain both Faraday rotation asymmetry and opacity asymmetry consistently between two components of a GPS quasar 2134+004. The FFA model assumes dense plasma around the central core to produce FFA, and the difference of path lengths in the plasma toward each component could cause these asymmetries. The component that is closer to the observer has a shorter path length, and consequently, smaller opacity of FFA and lower Faraday rotation. In a simple case, the ratio of Faraday rotation between two components is a function of the ratio of path length, and is the same as the ratio of opacity. Then these two ratios are shown to be essentially the same by our observations. We could thus distinguish between near-side and far-side components by the asymmetries.

Keywords: dense matter — galaxies: jets — galaxies: magnetic fields — plasmas — polarisation

1 Introduction

Gigahertz peaked spectrum (GPS) sources have a simple radio spectrum of a peak in the GHz frequency region. They are intrinsically small (<1 kpc) and show low variability (e.g. O'Dea 1998). The low frequency cutoff has been ascribed to synchrotron self-absorption (SSA). Snellen et al. (2000) claimed SSA by the correlations between peak frequency, peak flux, and angular size, assuming an equipartition magnetic field. Bicknell, Dopita, & O'Dea (1997), however, argued that these correlations could be explained by free–free absorption (FFA), assuming a bow shock model. Recent observations have shown direct evidence of absorption features (e.g., Walker et al. 2000; Kameno et al. 2000). Mutoh et al. (2002) proposed a method to discriminate these absorption mechanisms via the polarisation properties of synchrotron emission. Although the polarisation observations are not enough to show clear evidence, they suggest the case of FFA.

Among the GPS sources studied by Mutoh et al. (2002), 2134+004 shows the least significant profile of FFA (see Figure 4 of Mutoh et al. 2002). The source is one of the brightest quasars at centimetre wavelengths, being identified with an 18th magnitude object at a redshift $z = 1.936$. The radio spectrum shows a typical GPS at a peak frequency of 5 GHz, having no extended structure (e.g., Pauliny-Toth et al. 1989). Its variation at radio wavelengths is relatively small, 2% in standard deviation at 5 and 8 GHz, and 5% at 15 GHz, from monitoring by the University of Michigan Radio Astronomy Observatory (UMRAO). Taylor (2000) showed a double structure separated by 2 mas, each of them having different Faraday rotation (rotation measure: RM). The double component seems almost the same (symmetrical) at lower frequencies in total intensity. However, their RM properties are not symmetrical with each other.

We present here the general concept to explain both RM and opacity asymmetries based on the FFA model, dealing with the case of 2134+004 as an example. In Section 2 we present the model to explain the double structure, followed by a discussion in Section 3.

2 RM and Opacity Asymmetry

We made multifrequency polarisation observations with the VLBA at 5, 8, and 15 GHz on January 13, 2002. The instrumental polarisation is calibrated by 3C 84, and the polarisation angle by BL Lac. Figures 1 and 2 give the resultant distribution of RM and opacity τ of FFA, respectively. In deriving the opacity, we apply equation (1) of Kameno et al. (2001).

RM is proportional to electron density n_e, a line of sight component of the magnetic field $B_{//}$, and path length l. Although both n_e and $B_{//}$ are a function of l which extends from the emitting region to the observer, we assume that those parameters are the same toward the two components outside of the source (e.g., Asada et al. 2002). The fine structure of mas scale in RM is then attributed to the dense plasma around the source, where differential Faraday rotation and FFA occur.

In a first order approximation, we consider a spherical distribution of the dense plasma around the core. As jets emanating from the core generally have a viewing angle not equal to 90°, the path lengths to jets within the plasma are different from each other. The path length l_A for the approaching jet is shorter than that of l_R for the receding jet, as they are on the near side and far side, respectively,

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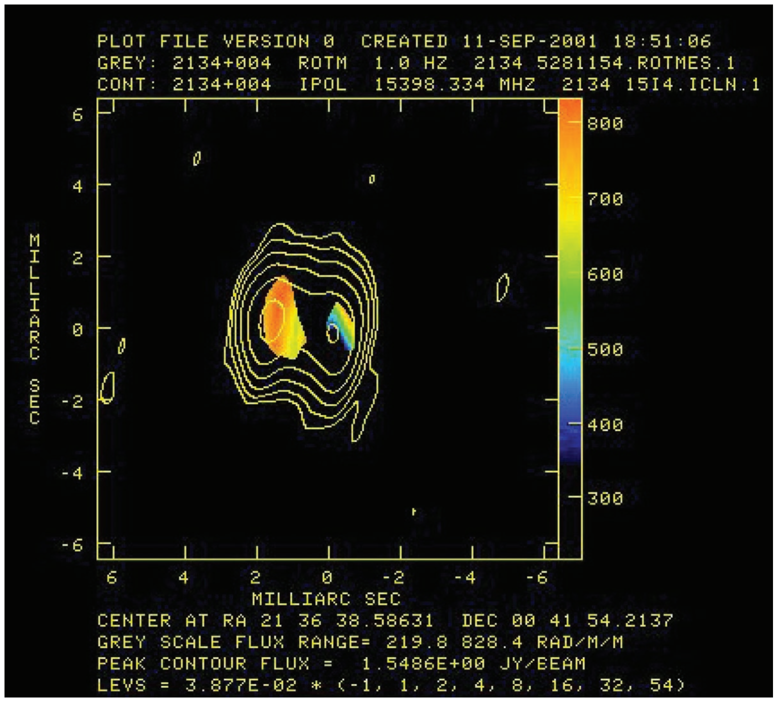

Figure 1 RM distribution superimposed on the contour map of the total intensity at 15 GHz. The colour code shows RM in rad m^{-2}

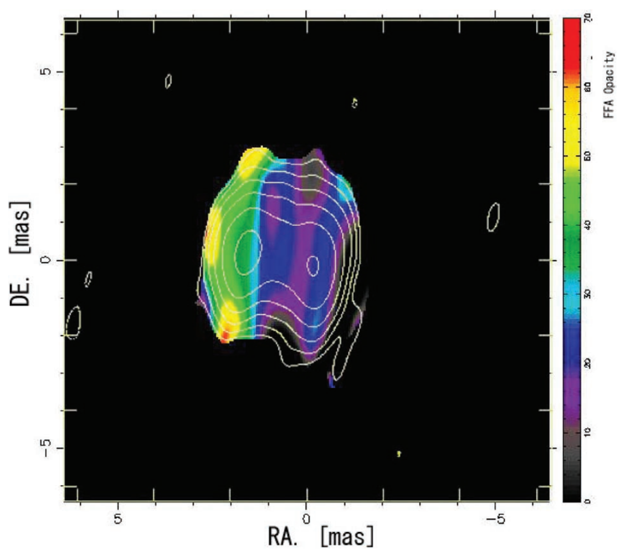

Figure 2 Opacity distribution of FFA superimposed on the same contour map in Figure 1. The colour code shows the FFA opacity defined by formula (1) of Kameno et al. (2001).

from the observer. The ratio $\mathrm{RM_R/RM_A}$ (hereafter the subscripts A and R represent those relating to approaching and receding jets, respectively) is then >1 and approximately equal to l_R/l_A. Furthermore, as the τ of FFA is proportional to n_e^2, l, and $T_e^{-3/2}$, τ_R/τ_A is approximately equal to l_R/l_A, where T_e is the electron temperature of the plasma. Therefore, the ratios $\mathrm{RM_R/RM_A}$ and τ_R/τ_A should be almost equal to each other. Averaging over the components at around the peak intensity, we derive $\mathrm{RM_R/RM_A} = 2.0 \pm 0.2$ and $\tau_R/\tau_A = 1.7 \pm 0.6$.

These ratios are essentially the same within the errors, and this supports the interpretation above. Following this interpretation, we can naturally distinguish between approaching and receding jets. Here, we assume the FFA model to derive opacity, although the number of observing frequencies is limited. The data reduction and analysis will be described elsewhere in detail.

3 Discussion

As all parameters n_e, $B_{//}$, and T_e are a function of l, $\mathrm{RM_R/RM_A}$ is not exactly equal to l_R/l_A, and is the same as the ratio of τ_R/τ_A. Because the path to the receding jet goes through the denser region close to the core, these two ratios are presumably >1. It should be noted that even if FFA does not work predominantly, we could distinguish between the approaching and receding jets by the asymmetry in RM and the opacity distribution. On the other hand, in the case of SSA, relativistic electrons have almost no effect on the Faraday rotation, and hence there would not be correlation between the RM asymmetry and the absorption features. Further studies of these asymmetries will reveal features of the inner core region.

The eastern component of 2134+004 may not be the receding jet, but the core. The western component has a steep spectrum between 8 and 15 GHz, while the eastern component shows an inverted spectrum. As the western component is optically thin, we register the three images assuming the positions of the peak intensity of this component are the same. Although the registration is not accurate, it is obvious that the eastern component has a larger RM and a flat or inverted spectrum, while the western component has a smaller RM and a steep spectrum, resulting in the two ratios >1, if the FFA model could be applied. This correlation between RM and absorption asymmetries in turn would support FFA, when confirmed by the other GPS/compact steep spectrum sources.

It cannot be ruled out that an ionised screen may provide the RM but the spectra of the individual components are due to SSA. We need more observations at different frequencies to derive more accurately the RM and opacity τ for many sources. Then, we will see whether there is a correlation between RM and opacity τ or not.

The western component is probably the approaching jet or lobe closer to us than the core or receding jet (or lobe). The absorber might be a torus around the core, particularly in the case when the eastern component is the core. We also need high resolution observations to identify jets and core.

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