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Interstellar Refractive Scintillation and Intraday Polarization Angle Swings

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Abstract Intraday polarization angle swings of $\sim 180°$ observed in two sources (QSO 0917+624 and QSO 1150+812) are discussed in the framework of refractive interstellar scintillation by a continuous interstellar medium. Model-fits to the $I-$, $Q-$ and $U-$ light curves were made for both sources. It is shown that for the case of 0917+624 both the intraday intensity variations and the polarization angle swing of $\sim 180°$ could be explained consistently in terms of a four-component model, which comprises one steady and two scintillating polarized components and one further non-polarized scintillating component. The polarization angle swing of $\sim 180°$ observed in 1150+812, which occurred when the polarized flux density was almost constant, could not be explained in terms of refractive scintillation by a continuous medium and might be due to other mechanisms (e.g., scintillation by interstellar clouds).

Key words: radio continuum: galaxies – polarization: intraday variability – scattering: refractive scintillation – quasars: individual: QSO 0917+624 and 1150+812

1 INTRODUCTION

For the study of intraday variability (IDV, hereafter) of compact extragalactic flat-spectrum radio sources (Krichbaum et al. 2002; Witzel 1992; Wagner & Witzel 1995; Qian et al. 1991; Qian et al. 2001a; Qian et al. 2002) polarization properties are important. Generally, the observed amplitude of variation is significantly larger, while the observed time scale is much shorter, in the polarization than in the intensity. The relationship between the intraday variations in polarization and intensity in a broad-band may provide important clues to the origin of these variations (e.g., Qian et al. 2002). For explaining the intraday polarization variation both intrinsic models (Qian et al. 1991, 2002; Gopal-Krishna & Wiita 1992; Marscher et al. 1992) and scintillation models (Rickett et al. 1995, 2002; Simonetti 1991; Qian 1994a, 1994b; Qian et al. 1995, 2001a, 2001b) have been considered. In these studies rapid polarization angle swings of $\sim 180°$ on timescales of $\lesssim 1$ day may be of particular interest, because these rare events could be suggestive of the responsible physical processes and very useful to further understanding of the physics of IDV. Up to now, two such angle swing events have been observed: one in QSO 0917+ 624 (Quirrenbach et al. 1989) at 6 cm, one in QSO 1150+812 (Kochenov & Gabuzda 1999) at 2 cm. Both intrinsic and extrinsic (scintillation) mechanisms have been proposed.

Quirrenbach et al. (1989) suggested that the polarization angle swing event observed in QSO 0917+624 may be caused by a relativistic shock propagating along the jet and illuminating its helical magnetic field. This is an 'intraday-version' of the model proposed by Königl & Choudhouri (1985) to interpret polarization angle swing events with time scales of months or years observed in extragalactic radio sources. This interpretation is based on the relativistic aberration effects when the transverse component of the magnetic field rotates along the jet in a regular manner. Very recently, Qian & Zhang (2003, 2004) have further investigated this intrinsic mechanism.

Qian et al. (1991, 2002) considered a two–component model, in which a relativistic shock propagates along the jet, producing a variable component with its degree and angle of polarization varying in time. Vector combination of this shock component with another steady polarized component could then give rise to the angle swing. The main characteristic of this shock model is that both the degree and the angle of polarization of the shock component are variable. This shock model could explain the general behaviour of intraday variations in polarization and in total flux density, including the complicated relationships (correlation and anti-correlation) between the variations in total and polarized flux density, the polarization angle swings and the transformations between the different correlations. It was shown that the degree and angle of polarization of the shock component are required to vary only over a small range. Gopal-Krishna & Wiita (1992) suggested that the relationship between the variations in total flux and polarized flux observed in IDV sources (correlation and anti–correlation) could be explained by thin relativistic shocks moving along slightly curved trajectories. In their model the degree of polarization of the shock component changes due to relativistic aberration.

Rickett et al. (1995) proposed a scintillation model to explain the intraday variations of intensity and polarization observed in 0917+624. However, the event of polarization angle swing of $\sim 180°$ observed in this source could not be interpreted and was suggested to be due to a low-level intrinsic activity. On the other hand, how the refractive scintillation and the intrinsic variability could 'coordinate' their roles to produce the polarization angle swing was not clarified. This significantly limits its general application to intraday polarization variations that show polarization angle swings. The problem seems to be related to the fact that in the case of scintillation any single component keeps a constant degree and angle of polarization while its total and polarized fluxes fluctuate due to refractive scattering. Moreover, two scintillating polarized components could not 'concert' their variations to produce a continuous polarization angle swing of $\sim 180°$ through refractive scattering by a turbulent screen.

Simonetti (1991) suggested that the polarization angle swing event observed in 0917+ 624 could be interpreted in terms of refractive focusing by an interstellar shock passing in front of the source. Two polarized components (here we designate them as A and B) were assumed in the source, having their polarizations differing by $\sim 90°$, and only one of the components (Component A) is affected by the shock. As the shock passes across the line of sight, the preshock first makes Component A strongly focused, causing a rapid increase of its intensity (and also polarized flux). At this stage the angle of polarization of the source will be approximately that of Component A. Then, when the postshock passes across the line of sight it makes Component A defocused, causing a rapid decrease of its intensity (and polarized flux). At this stage the source polarization angle is aprroximately that of Component B. In this interpretation, the variation of polarization angle is discontinuous. However, if one branch of the polarization angle light curve is moved by 180°, then we will see an apparently ∼180° swing. This model can only explain a 'jump' of ∼180°, but not a continuous variation in the angle. Simonetti (1991) suggested that in order to explain the observed angle near the middle of the swing, some other mechanism (intrinsic or focusing by another cloud) is needed. In addition, we should point out that the corresponding 'jump' in the total flux density, predicted by the model to accompany the angle swing, has not been observed.

Thus, it is clear from the above description that until now intraday polarization angle swings of ∼180° have not been explained in terms of refractive interstellar scintillation by a continuous medium or in terms of interstellar refractive focusing – defocusing by interstellar clouds, although these two mechanisms have been invoked to explain intraday variability of total and polarized flux density (Rickett et al. 1995; Qian et al. 2001a, 2001b; Wambsganss et al. 1989). Wambsganss et al. showed that focusing and defocusing effects by an ensemble of interstellar clouds can explain the IDV of total flux density (for example, for the IDV event observed in 1989 in 0917+624). However, they did not discuss the associated polarization variations using such a model. In particular, we should point out that the focusing – defocusing effects by interstellar clouds have been applied to interpret rapid intensity variations of extragalactic radio sources with timescales of weeks and months (extreme scattering events) by Fiedler et al. (1987, 1994) and Clegg et al. (1988, 1996, 1998), but the potential role of this mechanism for polarization variations still needs to be investigated.

Accordingly, it is clear that, if scintillation is considered to be a generally applicable mechanism for IDV of extragalactic radio sources, then it is necessary to seek an interpretation in terms of scintillation, of polarization angle swings of ∼180°. In this paper we will investigate the conditions under which intraday polarization angle swing of ∼180° could arise from refractive scintillation by a continuous interstellar medium.

2 POLARIZATION ANGLE SWING EVENT OF 0917+624

2.1 Recapitulation of Characteristics

In the following we will consider some specific models to explain the polarization angle swing of ∼180° observed in QSO 0917+624. Here we first describe the properties of this event. This event, observed at 6 cm by Quirrenbach et al. (1989), is shown in Fig. 1. The data are taken from Quirrenbach et al. (2000), in which the original data were re-analysed. The event has a time scale of ∼ 1 day.

Figure 2 shows the derived light curves of the Stokes parameters Q and U, and the Q–U track, showing the rapid variations of the Stokes parameters.

The figures show some interesting properties: the rapid polarization angle swing of ∼180° occurred during a ∼1 day period (JD24407525.0 – 7526.5). During the rapid swing, the polarized flux density reached a minimum near the midway of the swing with two peaks on either side. The full amplitude is only ∼8 mJy. This behaviour of polarized flux density is not much different from the variations in the time interval ∼7524.0 – 7525.3, when the position angle is nearly constant. The total flux variation is more irregular, having more peaks during the entire IDV event.

A consistent explanation of all the observed properties (the polarization angle swing, the variations in total and polarized flux density) seems difficult. Qian et al. (1991, 2002) have proposed a shock model for explaining all these variations together. In their model both variation of polarization degree and polarized flux of the shock component are invoked.

In the framework of refractive scintillation, the models proposed by Simonetti (1991) and Rickett et al. (1995) are suggestive, although they cannot explain the continuous polarization angle swings. In the following we try to find a scintillation model for the polarization angle swing of ∼180° observed in 0917+624.

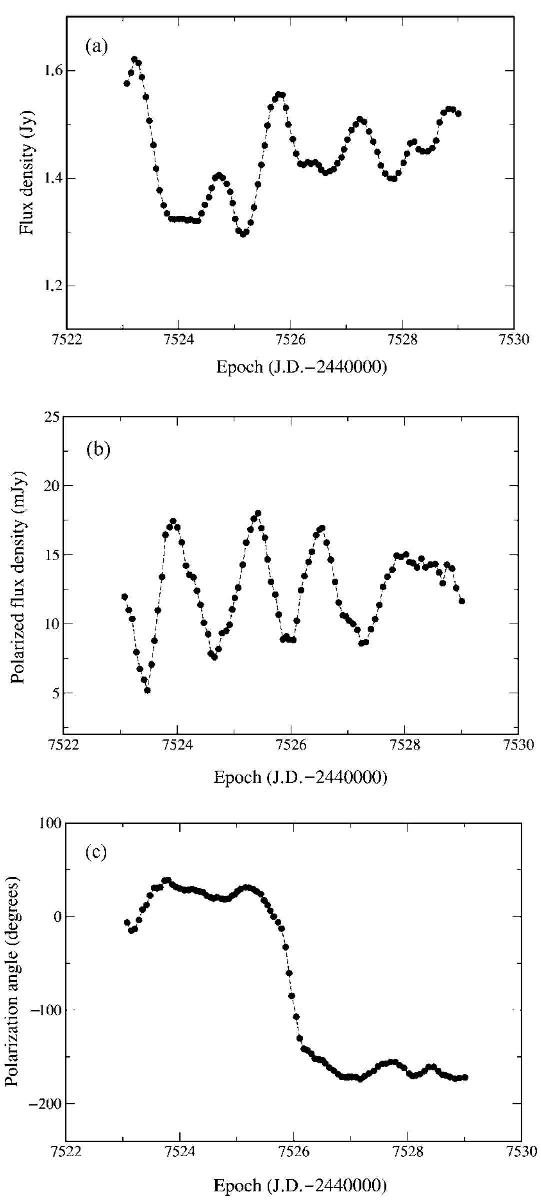


Fig. 1 0917+624: polarization position angle swing event observed at 6 cm in 1989. From top to bottom: the light curves of total flux density (Jy), polarized flux density (mJy) and polarization position angle.

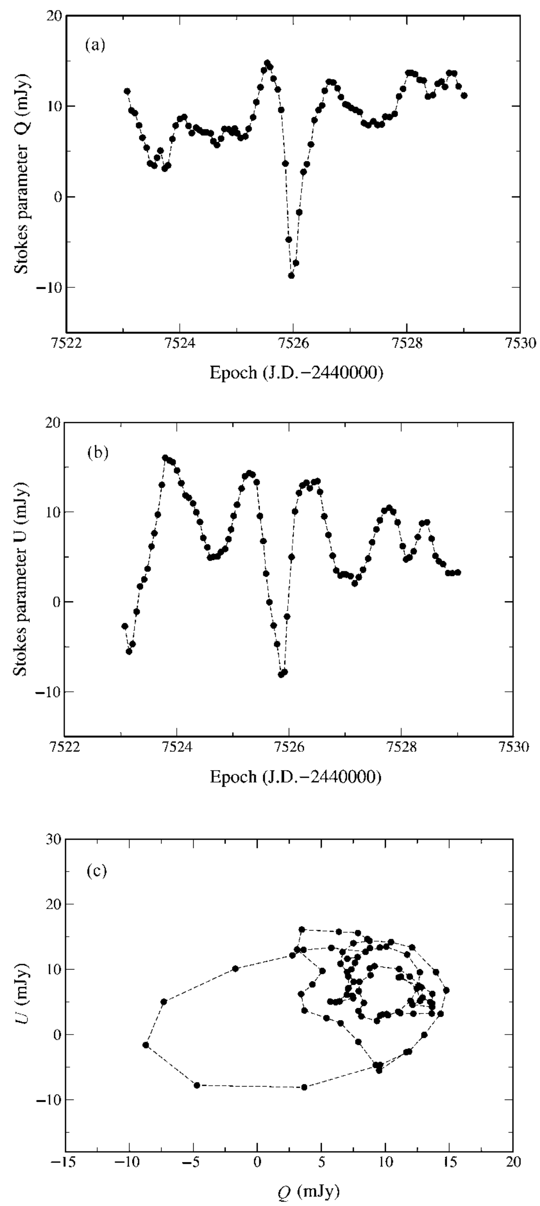


Fig. 2 0917+624: variations of the Stokes parameters Q and U, and the $Q-U$ track.

Let us consider a two polarized component model of the source, in which the two components have nearly perpendicular angles of polarization. We also assume, as is usual, that their angles of polarization are kept constant and only their polarized flux densities vary with time. In this case we find through trial calculations that no matter how we vary their polarized fluxes, their vector combination can never produce a *continuous* polarization angle swing of $\sim 180^\circ$. Thus, in order to interpret a continuous swing, (at least) one more polarized component is needed with its polarization angle significantly different from those of the two variable components (also see Simonetti 1991). Based on this experience we have constructed some specific models to try to explain the observed polarization angle swing.

2.2 A 3-component Model

As shown above, in order to explain a *continuous* polarization angle swing of $\sim 180^\circ$ at least three polarized components are needed.

To compare the characteristics of the polarization angle swing events observed in 1150+812 and 0917+624, we would first make some model–fits to the Q– and U–light curves, based on a full fit to the I–light curve (Rickett et al. 1995), and then discuss some particular models for a full fitting of both the Q– and U–light curves. We consider a 3-component model: one steady non-scintillating polarized component (designated Component–1) and two scintillating polarized components (Component–2 and –3). Models containing more than three polarized components are too complex and will not be considered here. We assume that Component–2 and –3 are variable only in their polarized fluxes while their polarization angles remain constant. Thus the observed polarization should be equal to the vector combination of the three components. The equations for the Stokes parameters Q and U are:

$$I(t) = I_0 + \delta I(t) = I_0 + \delta I_2(t) + \delta I_3(t), \tag{1}$$

$$Q(t) = Q_0 + \delta I_2(t)\cdot m_{q2} + \delta I_3(t)\cdot m_{q3}, \tag{2}$$

$$U(t) = U_0 + \delta I_2(t)\cdot m_{u2} + \delta I_3(t)\cdot m_{u3}. \tag{3}$$

Here

$$I_0 = I_1 + \bar{I}_2 + \bar{I}_3, \tag{4}$$

$$Q_0 = I_1\cdot m_{q1} + \bar{I}_2\cdot m_{q2} + \bar{I}_3\cdot m_{q3}, \tag{5}$$

$$U_0 = I_1\cdot m_{u1} + \bar{I}_2\cdot m_{u2} + \bar{I}_3\cdot m_{u3}, \tag{6}$$

$$m_{q1} = p_1 \cos 2\chi_1, \tag{7}$$

$$m_{u1} = p_1 \sin 2\chi_1, \tag{8}$$

$$m_{q2} = p_2 \cos 2\chi_2, \tag{9}$$

$$m_{u2} = p_2 \sin 2\chi_2, \tag{10}$$

$$m_{q3} = p_3 \cos 2\chi_3, \tag{11}$$

$$m_{u3} = p_3 \sin 2\chi_3, \tag{12}$$

(p_1, χ_1), (p_2, χ_2) and (p_3, χ_3) are the degrees and angles of polarization of Component–1, –2 and –3, respectively. I_1 is the intensity (flux density) of the steady component–1, $\bar{I}_2$ and $\bar{I}_3$ are the average flux density of the scintillating components 2 and 3. I_0, Q_0 and U_0 are the averages of the Stokes parameters (I, Q, U). For 0917+624 they are: $I_0 = 1.4352$ Jy, $Q_0 = 8.38$ mJy and $U_0 = 6.74$ mJy. Correspondingly, $p_0 = 0.75\%$ and $\chi_0 = 19^\circ.44$.

We point out that the formulism given above involves a critical assumption that the observed polarization variations are all due to the intensity scintillation of the polarized components 2 and 3; i.e., there is no non–polarized scintillating component, which could contribute to the variation in the total flux density. In order to decompose the observed fluctuation of intensity δI(t) into δI_2(t) and δI_3(t), it is assumed that the fluctuations of Component–2 and Component–3 are completely correlated with a time lag of τ (Rickett et al. 1995), i.e.,

$$\delta I_3(t) = A{\cdot}\delta I_2(t+\tau). \tag{13}$$

In this case the Fourier transformation of δI_2 is related to the Fourier transformation of δI:

$$\delta {I_2}^+(f) = \delta I^+(f)[1 + A{\cdot}\exp(-2\pi i f\tau)]^{-1}, \tag{14}$$

where f is the frequency of the Fourier spectrum. Given a pair of values for A and τ, $\delta {I_2}^+$(f) can be calculated as follows. The Fourier transformation δI^+(f) of the observed δI(t) can be written as:

$$\delta I^+(f) = \mathrm{Re}(f) + i\mathrm{Im}(f), \tag{15}$$

where Re(f) and Im(f) represent the real and imaginary part, respectively. Then we can derive the real part (Re$_2(f)$) and imaginary part (Im_2(f)) of $\delta {I_2}^+$(f):

$$Re_2(f) = \frac{Re(f)[1 + A\cos(2\pi f\tau)] - Im(f)A\sin(2\pi f\tau)}{[1 + A\cos(2\pi f\tau)]^2 + [A\sin(2\pi f\tau)]^2}, \tag{16}$$

and

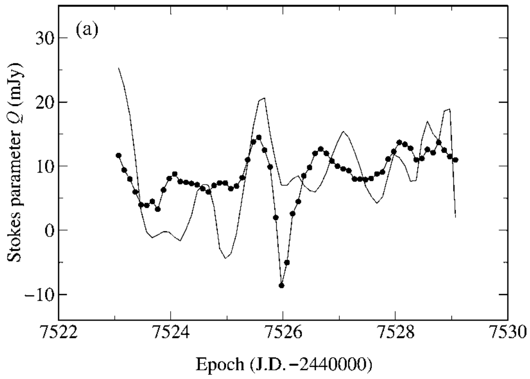
$$Im_2(f) = \frac{Re(f)A\sin(2\pi f\tau) + Im(f)[1 + A\cos(2\pi f\tau)]}{[1 + A\cos(2\pi f\tau)]^2 + [A\sin(2\pi f\tau)]^2}. \tag{17}$$

Thus using an inverse-Fourier transformation we can obtain δI_2(t) and then δI_3(t). After that we can solve the Eqs. (2) and (3) by a least–square–fit to obtain the values of (m_{q2}, m_{u2}) and (m_{q3}, m_{u3}).

We point out that for different values of A and τ, different combination of (m_{q2}, m_{u2}; m_{q3}, m_{u3}) or ($p2$, χ_2; $p3$, χ_3) can be obtained. An optimum combination could be chosen by minimizing the fitting errors for the Q– and U–light curves. Although this criterion (or constraint) is not very sensitive, we found that for very small values of A (for example A$\leq$0.1) high values of the degree of polarization ($\geq$30%) would be required. As will be shown below, such high degrees of polarization are useful for the interpretation of polarization angle swing events. Considering these factors we chose the pair of values: A=0.1 and τ=0.22 days for an illustrative model. In this case we have:

$$\begin{array}{llll} m_{q2} = -0.01262, & m_{u2} = -0.05052 \text{ or } p_2 = 0.05207, & \chi_2 = -52.01^\circ \\ m_{q3} = 0.3130, & m_{u2} = -0.1263 \text{ or } p_3 = 0.3375, & \chi_3 = -10.99^\circ. \end{array}$$

This 3-component model completely fits the fluctuation in the total intensity. The model–fits to the light curves of Q and U are shown in Fig. 3. It is clearly seen that while this model can well explain the variation shown in the U–light curve, it cannot well explain the Q–light curve, especially during the swing period (J.D. 2447525.0–2447536.5, the deep dip). That is, it cannot explain the polarization angle swing. Similar results have been previously obtained by Rickett et al. (1995), but they did not give the model-fits in terms of Q– and U– light curves.



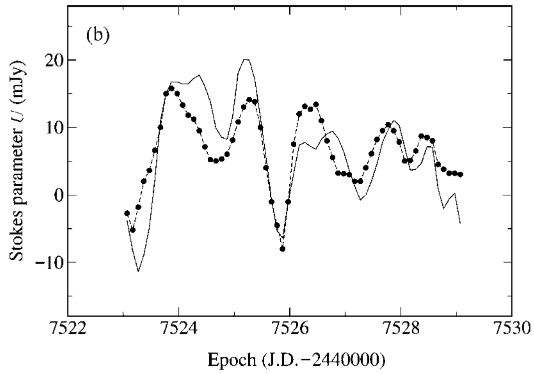


Fig. 3 0917+624: model-fits to the observed light curves of Q (a) and U (b) by a 3-component model. Solid lines – model; dot–dashed lines – observation.

2.3 A Model-Fit to the Swing Event

As shown above the 3-component model proposed above cannot explain the polarization angle swing of $\sim 180°$ observed in 0917+624, while the "normal" polarization variations outside the swing period are explained quite well. As we have already pointed out, this model is based on the assumption that the total intensity variation is solely due to the scintillation of the two polarized components (Components 2 and 3). This may be the main reason for the failure of the model to reporduce the polarization angle swing, while the total intensity variation is well fitted. This may imply that there is some part of the intensity variation that is caused by a non-polarized scintillating component and that one more component is required in order to fit both the intensity fluctuation and the polarization angle swing. However, this would considerably increase the complexity of the model-fit and it is difficult to determine the model parameters. Therefore, in the following we only consider the following question: what kind of variations in the polarized flux density of Components-2 and -3 can explain the polarization angle swing? In fact, in order to fit both the total intensity variation and the polarization angle swing (and also the polarization variations outside the swing period), a fourth non-polarized scintillating component (designated Component–4) has to be introduced (see below) and this will necessarily result in some changes in the values of the model parameters. Our trial calculations show that if all the model parameters derived in the last section for Component–1, –2 and –3 are used, the derived scintillation of Component–4 would be too high. This is mainly due to the small degree of polarization degree of Component–2 ($p_2 \approx 0.05$). Thus, to obtain a reasonable solution we should adopt a higher degree of polarization of 0.25 for Component–2. This is the only parameter, the value of which is modified. The values of the other parameters are all retained.

In this case we can easily find the required variations in the polarized flux densities of Component–2 and –3 for fitting the polarization angle swing. The method is as follows.

We rewrite Eqs. (2) and (3):

$$Q(t) = Q_0 + \delta I_{p2}(t) \cos 2\chi_2 + \delta I_{p3}(t) \cos 2\chi_3, \tag{18}$$

$$U(t) = U_0 + \delta I_{p2}(t) \sin 2\chi_2 + \delta I_{p3}(t) \sin 2\chi_3, \tag{19}$$

where δI_{p2}(t) and δI_{p3}(t) represent the polarized flux fluctuations from Component–2 and –3. Since (Q_0, U_0), (χ_2, χ_3) and (Q(t), U(t)) are known, from the above equations (δI_{p2}(t),

δI_{p3}(t)) can be obtained. They represent the required variations of the polarized flux density of Component–2 and –3, which can fully fit the observed polarization variations (including the polarization angle swing and the polarization variations outside the swing period).

The two light curves obtained for the polarized flux fluctuations (δI_{p2} and δI_{p3}), and their corresponding flux fluctuations (δI_2(t) and δI_3(t)) are shown in Fig. 4. Figure 5 shows the fit to the total flux density and the residual intensity fluctuation. It can be seen that in the present case the polarization variations are fully fitted (particularly the polarization angle swing), while the total intensity is not well fitted. Also, the residual intensity fluctuation shown in Fig. 5b might be regarded as a non-polarized scintillating component (Component–4).

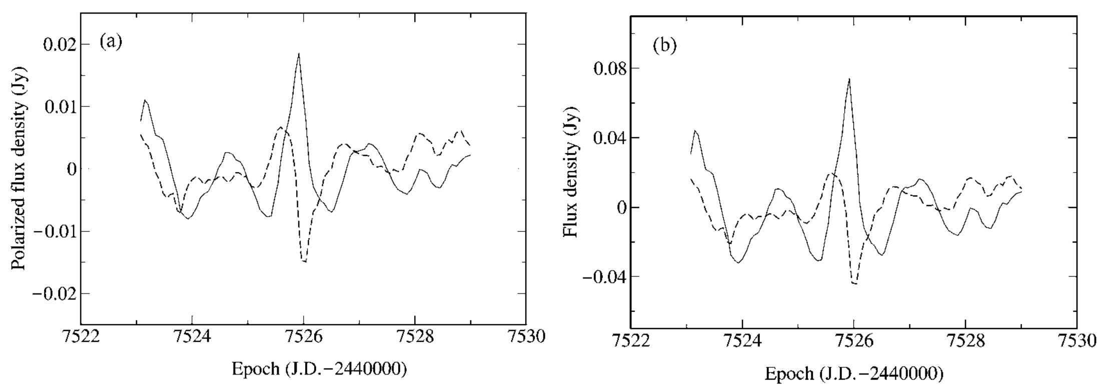


Fig. 4 0917+624: (a) modeled fluctuations of the polarized flux density of Component–2 and Component–3, [δI_{p2} (solid line) and δI_{p3} (dashed line)] for the full fitting of the observed polarization variations including both the polarization angle swing and the 'normal' polarization variations outside the swing period; (b) the corresponding flux fluctuations of Component–2 and –3 [δI_2 (solid line) and δI_3 (dashed line)].

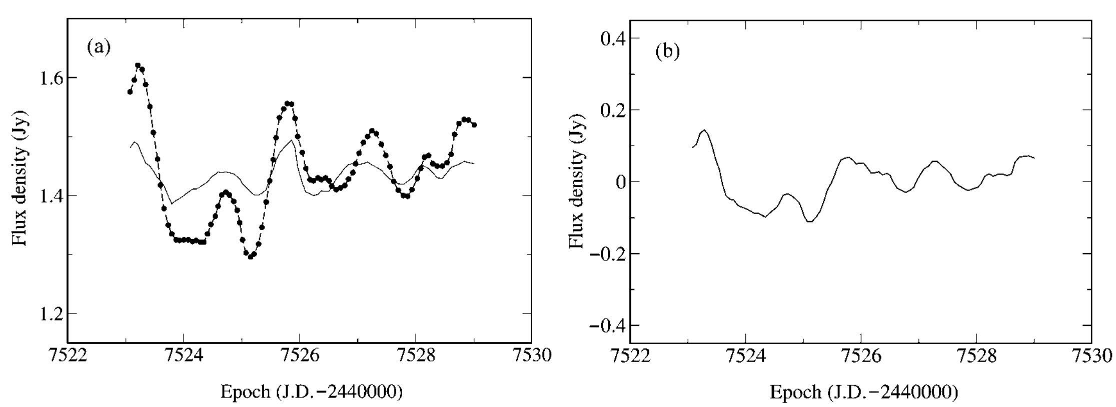


Fig. 5 0917+624: (a) model-fitting to the total intensity variation, dot-dashed line – observation, solid line – model fit for ($I_0 + \delta I_2 + \delta I_3$); (b) the residual fluctuation, which might indicate the existence of a non-polarized scintillating component (Component–4).

From the model fitting results we can see that for the case of 0917+624, the observed polarization angle swing and the polarization variations outside the swing period can be interpreted solely in terms of refractive scintillation, although an additive non-polarized scintillating component is required to explain the total intensity variation. This contrasts the case of 1150+812 in which the polarization angle swing cannot be explained in terms of refractive scintillation (see below).

Since a 4–component model is required, there are too many free parameters involved and it is not possible to find a unique solution. Therefore, our model is only an illustration showing under what conditions the polarization angle swing and the total flux variation can be explained consistently. In particular, the light curves of δI_2, δI_3 and δI_4 shown in Figs. 4 and 5 should be closely related to the 2-dimensional scintillation pattern of the interstellar medium, and the angular sizes and relative positions of the components. The consistency between these light curves remains to be investigated.

Future observations (especially VLBI polarization observations with very high spatial resolution) are desirable to check these conditions, especially to find out whether there are two variable polarized components or only one variable polarized component producing polarization angle swings. Recently, Qian & Zhang (2003, 2004) have shown that in the latter case intrinsic mechanisms may be preferable, especially relativistic aberration effects in helical magnetic fields.

3 POLARIZATION ANGLE SWING EVENT OF 1150+812

In addition to the polarization angle swing observed in 0917+624, there is another one observed in QSO 1150+812 at 2 cm by Kochenov & Gabuzda (1999). This detection of a swing of $\sim 180°$ is significant, because it was observed in a different source by different authors. Therefore, it firmly confirms the real existence of the phenomenon of intraday polarization angle swing in extragalactic radio sources. Thus, any satisfactory model proposed for interpreting intraday intensity and polarization variability should explain all these variations, including in particular the polarization angle swing events.

The event of rapid polarization angle swing of $\sim 180°$ observed at 2 cm is shown in Fig. 6. Figure 7 shows the light curves of the Stokes parameters Q and U, and the Q–U track, with the rapid variations in Q and U during the swing. This event has been discussed in Qian & Zhang (2004) in terms of relativistic aberration effects. Here we recapitulate its interesting properties: (a) The observation lasted for $\sim$24 hours. During the entire period the variability index is 1.04% (rms–variability amplitude 13.8mJy; average flux 1.3272 Jy). (b) The variability index of polarized flux density is 9.2% (rms–variability amplitude 2.86 mJy, average polarized flux 30.94 mJy). (c) During the most rapid swing period (from 20h to 25h) the polarized flux density was almost constant: for the five observational points the average of polarized flux density is 31.4 mJy with a standard deviation of 0.4 mJy. That is, the polarization angle swing occurred when the polarized flux density was not varying. This is in contrast to the case of 0917+624, where the swing occurred when the polarized flux had a variation amplitude similar to that outside the swing period.

3.1 A 3-Component Model

Following the procedure described above when fitting the polarization variability of 0917+624, we can do the same thing for the polarization variability of 1150+812. We shall again use the procedure of Fourier − inverse Fourier transformation to produce a 3-component model, in which the total intensity variation is fully fitted. In this case, we have: $I_0 = 1.3272\,\mathrm{Jy}$, $Q_0 = -26.73\,\mathrm{mJy}$, $U_0 = 0.8455\,\mathrm{mJy}$, $p_0 = 0.0020$, and $\chi_0 = 89^\circ.09$.

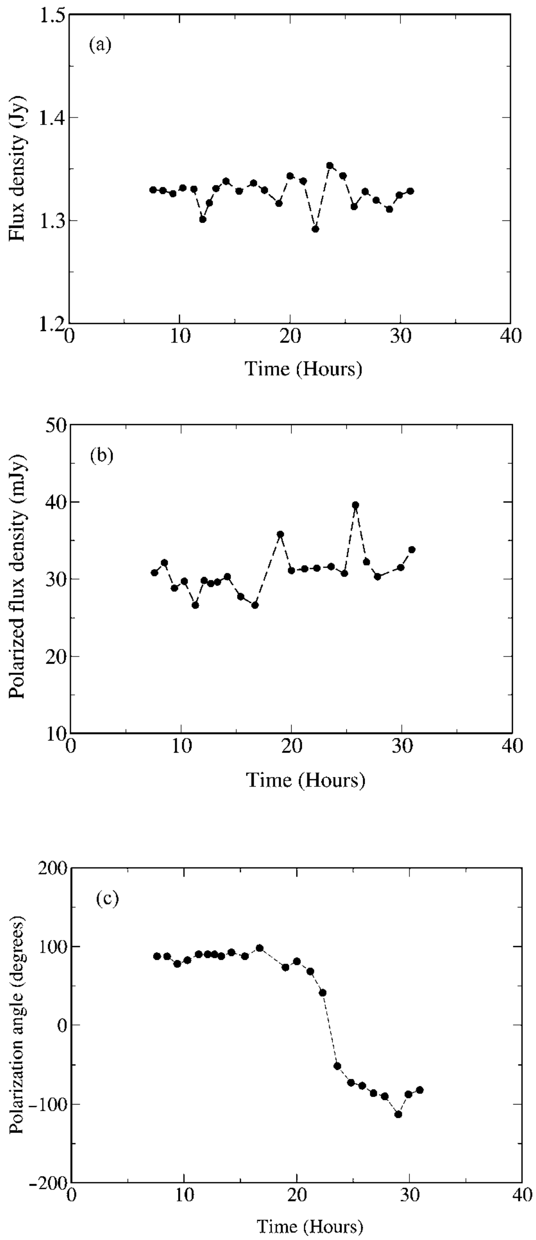


Fig. 6 1150+812: light curves of flux density, polarized flux and polarization angle for the polarization angle swing event.

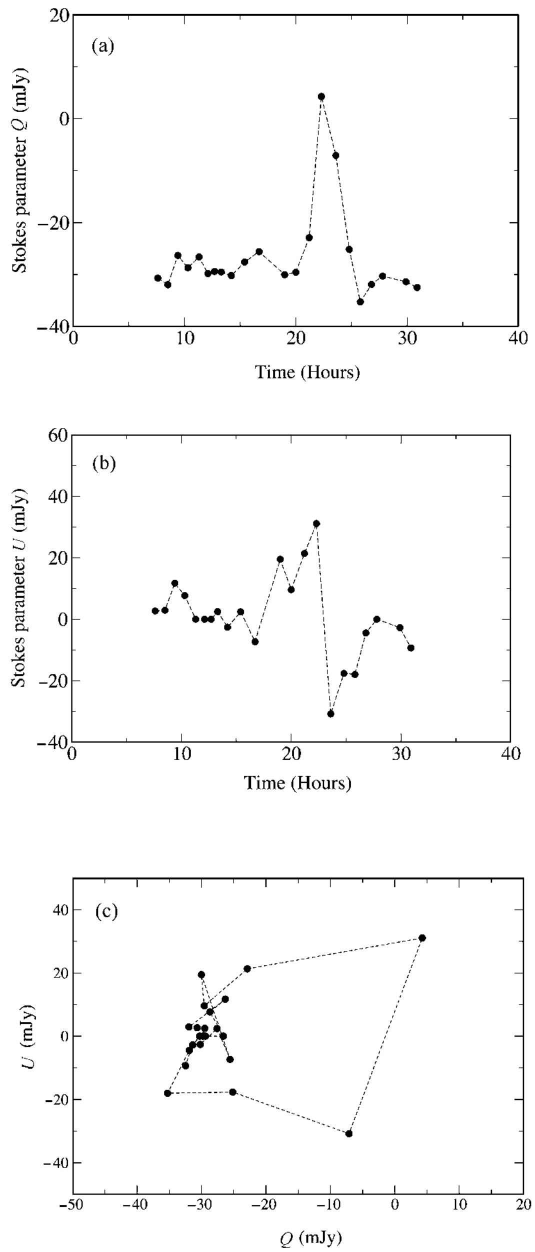


Fig. 7 1150+812: light curves of the Stokes parameters Q and U, and the Q–U track.

In the process of the fitting by a 3-component model, it was found that plausible models can be obtained only for some pairs of values of (A, τ). For example, for A<0.8 and τ<0.8 hours, the degree of polarization of Component–2 or –3 would have to be higher than 60%, which are not acceptable. However, appropriate values of (A, τ) do exist that would lead to acceptable values of polarization. We shall adopt A = 1.2 and τ = 0.8 hours for an illustrative discussion. In this case the optimal fitting to the polarization gives the following values:

m_{q2} = –0.07062, m_{u2} = –0.5257, p_2 = 0.5305, χ_2 = 131°.18

m_{q3} = 0.001955, m_{u3} = –0.5019, p_3 = 0.5020, χ_3 = –44°.89

It is clear that such a 3-component model fitting requires very high degrees of polarization for both components 2 and 3. VLBI polarization observations of extragalactic radio sources (for example, Gabuzda & Cawthorne 2000a; Gabuzda et al. 2000b) have shown that the observed degrees of polarization are typically in the range from 2% (cores) to 30% (jet components). Occasionally much higher values of ∼60% are observed (Gabuzda & Cawthorne 1996). Thus the high values of ∼50% required in the 3–component model fit seem possible, though marginally.

The fitting results for the Stokes parameters Q and U are shown in Fig. 8. It can be seen that the variation in U is fitted quite well. Nevertheless, the modeled light curve of Q is almost at a constant level, and the prominent jump observed in Q is not reproduced. Thus the 3–component model cannot fit the polarization angle swing of 1150+812, while it can fully fit the variation in the total flux density.

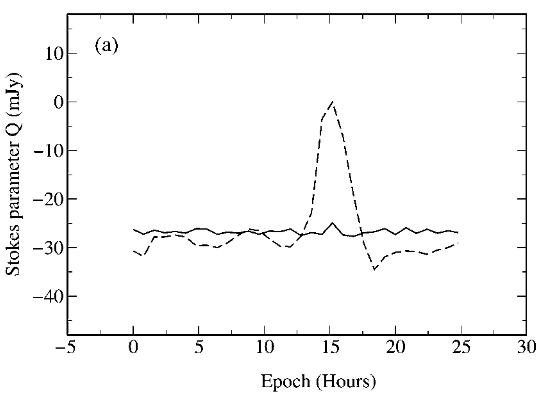


Fig. 8 1150+812: model fittings to the observed Stokes parameters Q (a) and U (b) by a 3-component model. Dashed line – observation; solid line –model.

Similar to the case of 0917+624, this is again due to the assumption that the intensity variation is caused entirely by the scintillation of the two polarized components (Component–2 and –3) and thus the 3–component model which fully fits the intensity variation of 1150+812 is not able to fit its polarization angle swing.

3.2 A Model-Fit to the Swing Event

Like the swing event of 0917+624, in order to fully explain the polarization angle swing of 1150+812, we would have to introduce a non-polarized scintillating component (Component–4). In this case, all the values of the model parameters for Component–1, –2 and –3 are retained. Equations (15) and (16) are used to solve δI_{p2}(t) and δI_{p3}(t) which are able to produce the observed polarization angle swing. The results of (δI_{p2}, δI_{p3}) and the corresponding (δI_2, δI_3)

are shown in Fig. 9. The result of the model-fit to the total intensity variation and the residual intensity fluctuation are shown in Fig. 10. The light curves of δI_{p2}, δI_{p3}, and δI_2, δI_3 do not show a scintillation pattern, rather, they show large bumps during the swing period.

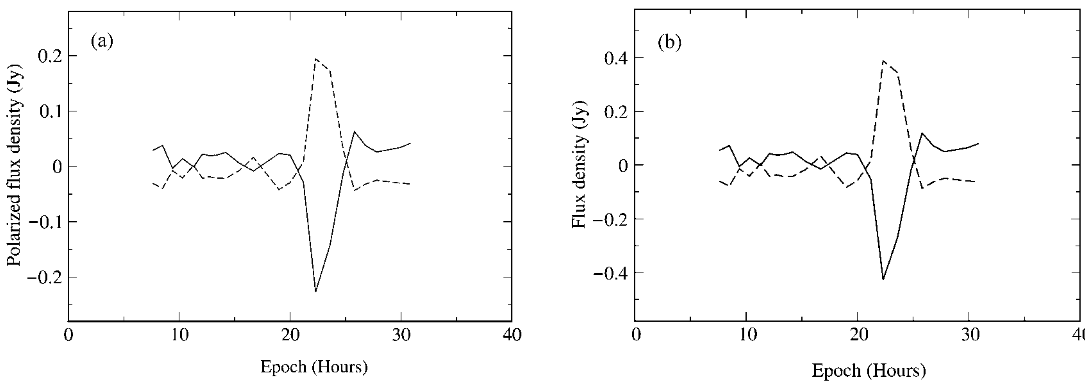


Fig. 9 1150+812: (a) modeled light curves of the polarized flux density of Component–2 (solid line) and Component–3 (dashed line) required for fully fitting the polarization variation of both the swing event and the polarization variation outside the swing period; (b) the corresponding modeled light curves of the flux density of Component-2 and -3.

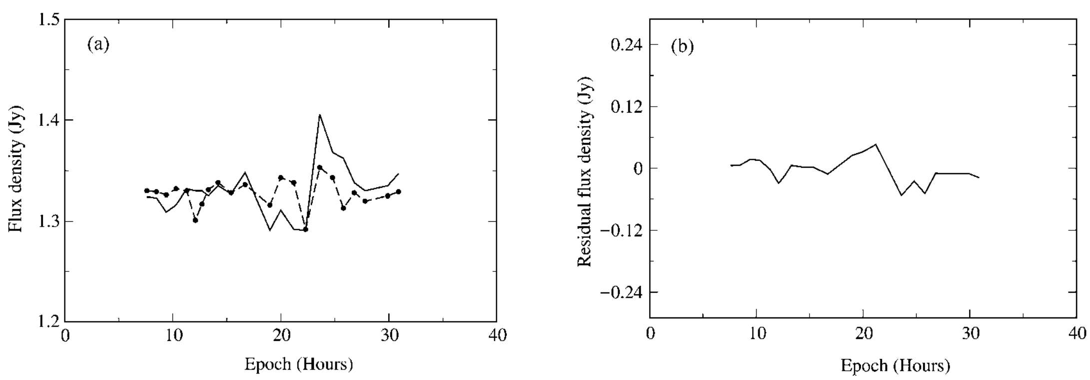


Fig. 10 1150+812: (a) model fitting to the total flux density variation, dot-dashed line – observation; solid line – model fit; (b) the residual flux density fluctuation.

It can be seen from Fig. 9 that the light curves δI_{p2} and δI_{p3} (or δI_2 and δI_3) are almost at constant levels outside the swing period, while during the swing period δI_{p2} (or δI_2) has a deep dip, and δI_{p3} (or δI_3) has a sharp peak. This unexpected result implies that the modeled light curves shown in Fig. 9 are not similar to fluctuations caused by refractive scintillation. In other words, this clearly suggests that the refractive scintillation mechanism described above (for example, Rickett et al. 1995) could not provide a plausible explanation of the polarization angle swing of 1150+812. This result may be closely related to the fact that the polarization angle swing of 1150+812 occurs at a time when the polarized flux density is almost constant. In other words, this swing event can only be explained by a mechanism which does not produce the variation in the polarized flux density. That is why the derived δI_{p2} and δI_{p3} shown in Fig. 9 vary in opposite directions during the swing period.

4 DISCUSSION AND CONCLUSIONS

We have shown in Sections 2.2 and 3.1 that in the framework of refractive scintillation by a continuous interstellar medium, a 3-component model cannot fit well the observed light curves of the Stokes parameters (I, Q, U) of both 0917+624 and 1150+812. Thus their polarization angle swings of $\sim 180°$ cannot be explained. The reason is that this type of models has a basic assumption that all the variations in intensity are produced by the polarized components (Component–2 and –3). So, a specific model which can completely fit the variation in the total intensity cannot explain the polarization angle swing. We have considered a particular 4–component model in which a non-polarized scintillating component is additionally introduced. We have found that for the case of 0917+624, such a model could explain both the polarization angle swing and the intensity variation, and both the two scintillating polarized components need to have a high degree of polarization of 20%–30%. Further investigations are required to study the relations between the light curves of the three scintillating components (their angular sizes and relative positions) and the 2–dimensional scintillating pattern.

However, for the case of 1150+812 it is found that even a 4–component model fails to explain the polarization angle swing of $\sim 180°$ in the framework of refractive scintillation. This is mainly due to the polarization angle swing occurred when the polarized flux density was almost constant. This is in contrast to the case of 0917+624, where the swing occurred when the polarized flux varied similarly as outside the swing period. Therefore, our conclusion is that refractive scintillation by a continuous interstellar medium cannot explain the swing event observed in 1150+812 and that refractive focusing by interstellar clouds (Clegg et al. 1996; Fiedler et al. 1987; Wambsganss et al. 1989) or intrinsic models (Qian & Zhang 2004) should be considered.

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