THE ASTROPHYSICAL JOURNAL, 248:L5–L8, 1981 August 15

RADIO POLARIZATION ROTATORS: BL LACERTAE AND 0727−115

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Received 1981 March 9; accepted 1981 April 28

ABSTRACT

Rotations in the polarization position angles over substantially more than 180° have been observed in BL Lac and 0727−115 at centimeter wavelengths. The broad-banded nature of the phenomenon eliminates frequency-dependent mechanisms as a possible cause, and the large range of the rotations is not consistent with relativistic-aberration type models. The most straightforward explanation for the origin of the apparent rotations is a rotating or a revolving structure in the radio emitting region.

Subject headings: BL Lacertae objects — polarization — rotation

I. INTRODUCTION

During the 1975 outburst in AO 0235+164, the polarization position angle (P.A.) at centimeter wavelengths rotated with time over nearly 180° in an apparently linear manner (Ledden and Aller 1979). A straightforward explanation of the phenomenon is an apparent rotation of the magnetic field structure in the radio emitting region of the source, although Blandford and Königl (1979) were able to make a quantitative fit of the data with a model invoking an aberration effect in a relativistic jet directed near the line of sight. An alternative model involving emitting regions in a supermassive accretion disk has been proposed by Pineault (1980). Since the discovery of this phenomenon in AO 0235+164, we have found rotations in three other sources, 0607−157, 0727−115, and BL Lac (Aller, Aller, and Hodge 1981); Altschuler (1980) has presented evidence for the phenomenon in four additional objects.

This *Letter* describes the observational results for two sources which have exhibited rotations with time of their polarization P.A.'s over a range of more than 360°. The key point raised by these data is that a true physical rotation or quasi-circular motion in the source emitting region appears necessary to explain the observed large range of P.A. Mechanisms such as the acceleration-aberration scenario discussed by Blandford and Königl (1979) cannot produce apparent rotations of more than 180°. A mechanism for generating large amplitude apparent rotations by the spiral motion of a compressed region in a relativistic jet is discussed elsewhere (Hodge, Aller, and Aller 1979).

II. OBSERVATIONS

The measurements were made at 4.8, 8.0, and 14.5 GHz using the University of Michigan 26 m paraboloid. Typically, 8 observations over a 30 minute period were made each observing day at 4.8 and 8.0 GHz and 16 observations at 14.5 GHz; but during the recent activity in BL Lac, the source was monitored steadily over several 8 hour periods in a search for intraday variability. The observing technique, radiometers, and polarimeters are discussed elsewhere (Aller 1970; Aller, Aller, and Hodge 1981). In the figures, the curves drawn through the data are smoothing cubic splines (Reinsch 1967).

The 0727−115 measurements are presented in Figure 1 as 2 week averages of the data. In the P.A. panel, the uncertainties shown are differential errors derived from the standard errors of the Stokes parameters, and only measurements with uncertainties of less than 14°3 ($P/\sigma_P > 2$) have been included. This source lies close to the galactic plane and has not been optically identified, but the behavior of the flux density variability is typical of extragalactic variable sources.

The interesting feature of the data presented here is the systematic change with time in the polarization P.A. which began in mid-1977. The average rate of change has been +106° per year, but the change did not occur in a linear manner as it appeared to do in the case of AO 0235+164. Although the first year of data is consistent with a steady rate of rotation, the remainder of the changes in P.A. appear to occur in a series of jumps. The largest differences between consecutive P.A.'s in Figure 1 are: +55° in 1978 April, +70° in 1979 January, +82° in 1979 June, and +68° in 1980 September. Inclusion of noisier P.A. data (up to $\sigma_\chi = 25°$) in the plot does not change the trend of the P.A.'s. They have been plotted so that the differences between consecutive data points are always less than 90°, but in the case of the 1979 June jump a 180° ambiguity may exist. The data are consistent with a total range of 390°, but the range could have been only 210° if the jump in 1979 June was toward decreasing P.A. The degree of polari-

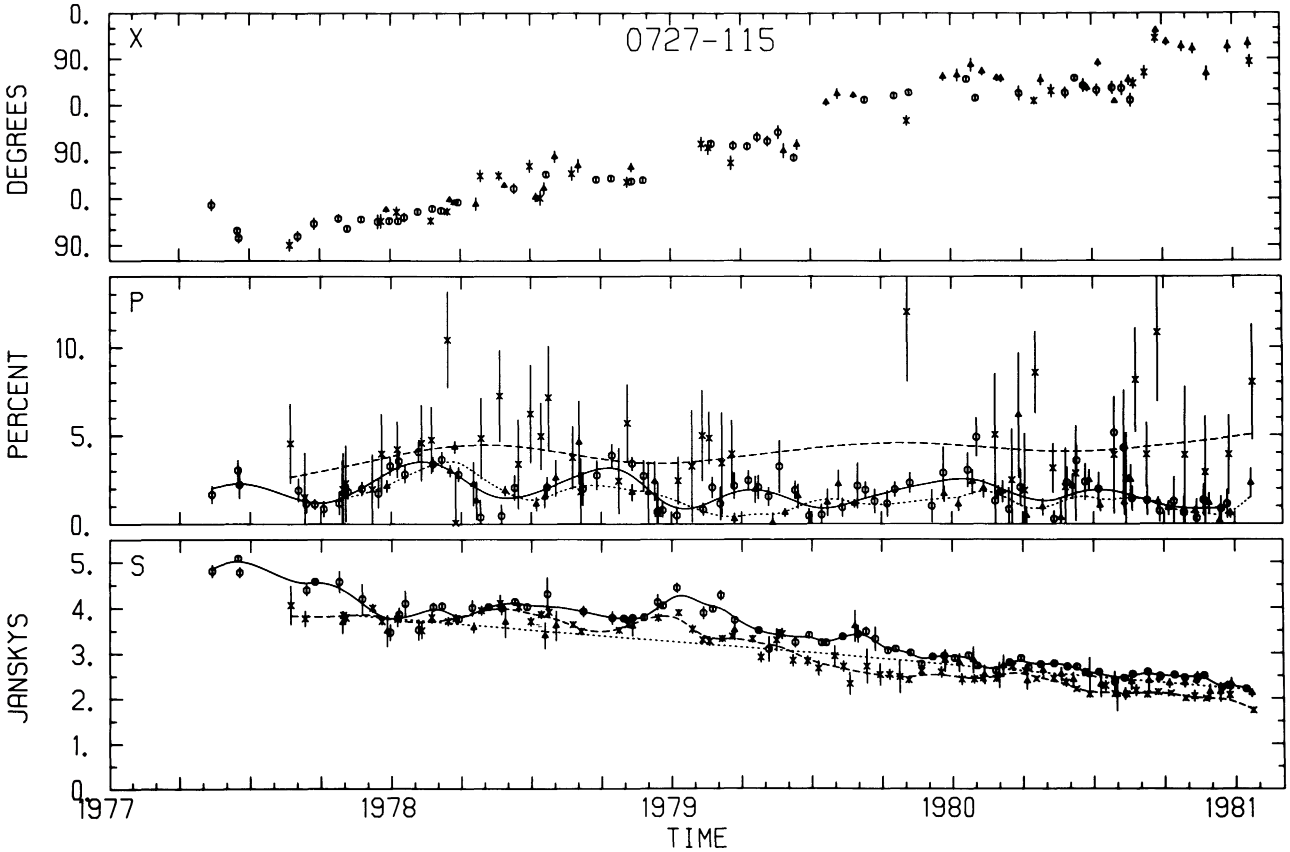

FIG. 1.—The total flux density, degree of polarization, and polarization P.A. of 0727−115 vs. time. Two-week averages of the data at three frequencies [4.8 GHz (Δ), 8.0 GHz (o), and 14.5 GHz (x)] are shown with dotted, solid, and dashed curves, respectively. Curves are omitted from the P.A. plot to avoid biasing the reader's interpretation. Note that the P.A. scale repeats every 180°.

zation at 4.8 and 8.0 GHz appears to have fluctuated with a time scale of the order of half a year with the times of the minima in 1978 and 1979 corresponding to the jumps in P.A. The measurements at 14.5 GHz are too noisy to show this effect.

The results for BL Lac are shown in Figure 2 as daily averages of the measurements. The format is the same as in Figure 1, except that polarized flux density is plotted instead of the degree of polarization. Position angle measurements with uncertainties of more than 14°.3 have been excluded. BL Lac was relatively inactive for several years (Aller, Aller, and Hodge 1981), and the time period shown here starts when BL Lac was at its minimum ($S_\nu \approx 2$ Jy) at all three observing frequencies.

The total flux density of BL Lac increased slowly during the last third of 1979, exhibited a small outburst in 1980 January, and then had an extended period of intense activity which peaked in 1980 July and August. During this activity, the flux density never increased with frequency more steeply than ν^{+1}, which appears to be a common property of sources which undergo repeated or prolonged periods of particle injection or acceleration (e.g, Aller, Aller, and Hodge 1981). The polarized flux density exhibited complex variations during the period, with significant changes in time scales as short as 1 day, but the degree of polarization never exceeded 5%.

The large change in polarization P.A. occurred at 8.0 and 14.5 GHz in 1980 May and June just as an outburst in flux density was reaching its peak at these two frequencies. The total range of the observed rotation in May and June was 440° in a 38 day period, and the data are consistent with another rotation by 180° in August. The rate of change of the P.A. was not constant. The polarization P.A. at 4.8 GHz apparently did not exhibit the large rotation in May and June seen at the higher frequencies. Both before and after the May-June period, the P.A.'s at all three frequencies varied over a range of more than 90°, and many of these fluctuations may not have been resolved in time by the observations. Note that after 1980 June the 8.0 and 14.5 GHz P.A.'s differ by 360° from the 4.8 GHz data.

III. DISCUSSION

We have now found four radio sources (one unidentified, one QSO, and two BL Lac type objects) which

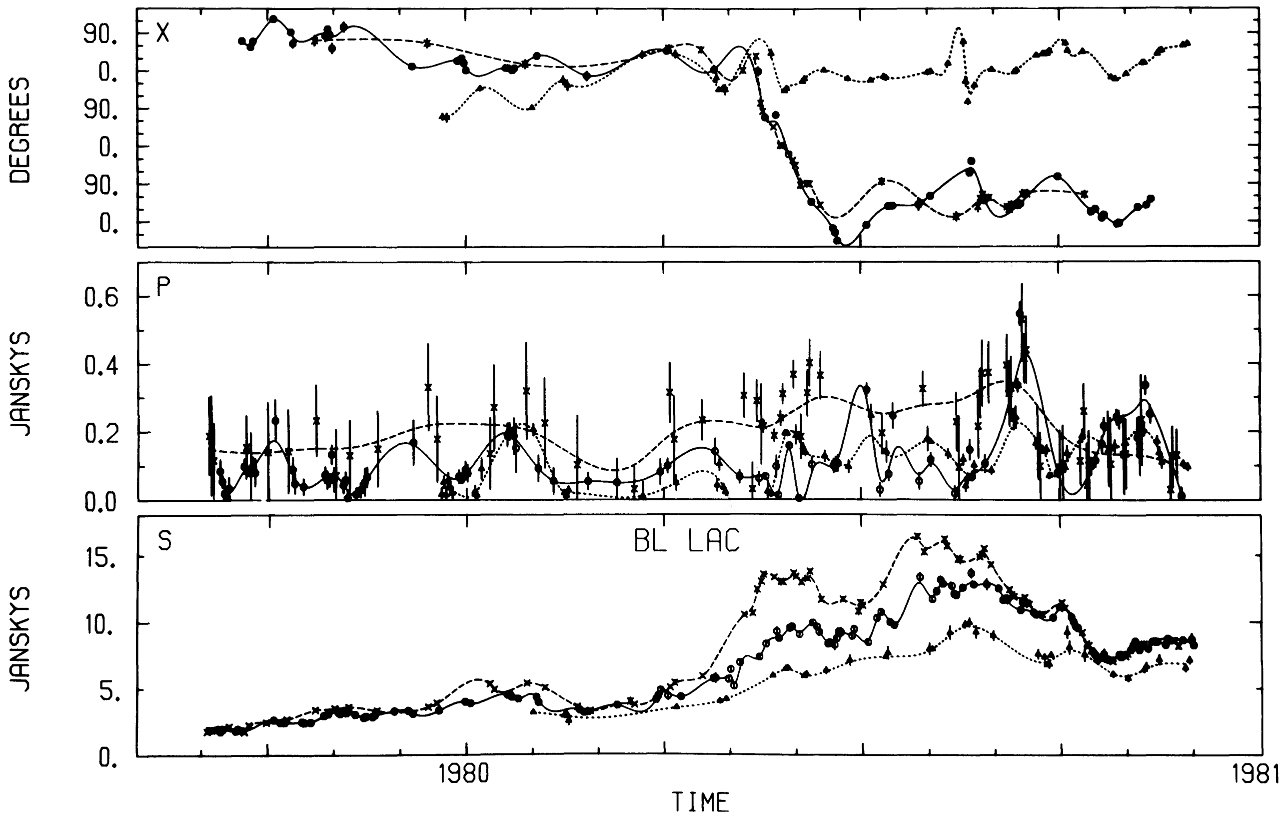

FIG. 2.—Daily averages of the observations of BL Lac at 4.8, 8.0, and 14.5 GHz. From top to bottom, the panels show the polarization P.A., the polarized flux density, and the total flux density.

have exhibited a large rotation with time (Ledden and Aller 1979; Aller, Aller, and Hodge 1981). Other examples of this phenomenon may have been missed because closely spaced measurements are required to detect the more rapid rotators (BL Lac rotated through more than 90° in less than 10 days). Even with a small number of examples, we have found a range of more than a factor of 30 in the observed rotation rates, and the detailed behavior of the P.A.'s are quite different among these sources. However, one common characteristic is that, in each case that a rotation has been observed, the total flux density had recently reached a maximum during an outburst, or the flux density was steadily declining.

Frequency-dependent mechanisms, such as Faraday rotation or synchrotron self-absorption effects, cannot produce the same rotation in P.A. with time at two or more frequencies (Ledden and Aller 1979). The large range of the rotation (more than 180° in the two cases discussed here) also eliminates as an explanation the acceleration-aberration mechanism proposed by Blandford and Königl (1979). A rotating magnetic field associated with a spinar or accretion-disk type phenomenon can produce large rotations. Pineault (1980, 1981) has investigated the polarization properties of flares on relativistic accretion disks and has predicted variations in polarization P.A. which are qualitatively similar to those observed in 0727−115 and BL Lac. However, the high intensity of the observed emission from BL Lac requires relativistic motion or expansion of the emitting region (Mutel, Aller, and Phillips 1981), and it is not clear that this can be reconciled with models involving direct emission from a central rotating object. An alternative mechanism is the apparent rotation produced by a compressed region spiraling about the line of sight in a relativistic jet which is directed toward the observer (Hodge, Aller, and Aller 1979). This mechanism also produces variations in the degree of polarization, similar to those observed in 0727−115, as the angle between the compressed region's motion and the line of sight changes.

The positive spectral index of the total flux density during the outbursts in BL Lac is indicative of a partially opaque core in the source (e.g., Condon and Dressel 1973; Marscher 1977), and we suggest that the absence of the rotation at 4.8 GHz results because the site of the rotation is located deep in the emitting region, where the larger opacity at 4.8 GHz prevents it from being observed. The rotation was only visible in BL Lac in the time interval when one would expect to be able to see deepest into a source during its active state (between the initial maximum in 1980 May and the appearance of the next outburst in late 1980 June). In the case of 0727−115, we see no clear evidence for opacity effects in either the flux density or the polarization data. High time resolution observations of other rotators are needed to establish the underlying characteristics of the rotation phenomenon, and VLBI polarization measurements would be useful in locating the site of the phenomenon in the objects.

We thank the staff of the University of Michigan Radio Observatory, T. Seling, G. Latimer, and K. Holmes, who were directly responsible for obtaining much of the data presented here. This work was supported by the National Science Foundation under grant AST 78-24192.

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