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MULTIFREQUENCY RADIO OBSERVATIONS OF THE VARIABLE QUASARS 0133+476, 0235+164, 1749+096, AND 2131−021

CHRISTOPHER P. O'DEA
National Radio Astronomy Observatory,[a] Edgemont Road, Charlottesville, Virginia 22903

WILLIAM A. DENT AND WAYNE M. KINZEL
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

THOMAS J. BALONEK
Department of Physics and Astronomy, Colgate University, Hamilton, New York 13346

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ABSTRACT

Observations of the long-term variability of four BL Lacertae type quasars, 0133 + 476, 0235 + 164, 1749 + 096, and 2131 − 021, at 2.7, 7.9, 15.5, 31.4, and 89.6 GHz are presented. These quasars exhibit large variations in both total flux density and polarization on time scales of less than 3 months and are the four most variable objects in linear polarization at 2.7 GHz in our monitoring program of ~100 sources. The variations in polarized flux density and position angle in these objects are not clearly correlated with those of the total flux density. Simple one- and two-component models for polarization variability are discussed and rejected, and multiple-component models may be required to explain the complexity of the variations. The inferred direction of the magnetic field in the cores is approximately parallel to the position angle of the radio-source structure on scales of milliarcseconds to arcseconds. The ~1900° linear rotation in the polarization position angle at 2.7 GHz in 1749 + 096 suggested by Altschuler is probably not real. We suggest instead that the position angle varied gradually by ~110° over a period of one year. The spectral evolution of selected outbursts in these four quasars is examined. The outbursts appear to be produced in inhomogeneous regions and their evolution may require continuing particle injection and/or a special geometry (i.e., a jet) in the active region. Following Jones *et al.* we classify the outburst evolution as being dominated by either changes in source structure or scale size. No clear examples of a change in electron-energy spectra are found. The position of the spectral break in 1749 + 096 may change with time. In some sources the outburst spectra broaden with time. The time delays between the peak of an outburst at millimeter and centimeter wavelengths are sufficiently long to cause an apparent anticorrelation between the variability in the two frequency regimes. Thus, we caution against the use of data with a limited time baseline to infer relationships between high- and low-frequency variability.

I. INTRODUCTION

This paper is part of a series on multifrequency observations of compact variable radio sources. Earlier papers discussed the quasars 1921 − 29 (Dent and Balonek 1980) and 1308 + 326 (O'Dea, Dent, and Balonek 1983), the four polarization rotators 0048 − 097, 0607 − 157, 0727 − 115, and 2200 + 420 (O'Dea *et al.* 1983), and the active galactic nucleus 3C 84 (Dent *et al.* 1983; O'Dea, Dent, and Balonek 1984). Here we present the results of a long-term study at 2.7, 7.9, 15.5, 31.4, and 89.6 GHz of the four BL Lacertae type quasars 0133 + 476, 0235 + 164, 1749 + 096, and 2131 − 021. These sources are the four most variable objects in linear polarization at 2.7 GHz in our monitoring program of ~100 sources. The combination of the extensive frequency coverage as well as the long time baseline (up to 10 yr in some cases) allows us to study the radio variability in more detail than was previously possible. These observations complement other studies of variable radio sources, e.g., VLBI observations and single-epoch broadband spectra, and are necessary for further progress in the understanding of the nature of these sources (cf. Wiita 1985).

In this paper, we describe the evolution of the spectra of selected radio outbursts and discuss some general properties of the variability. We discuss the linear-polarization observations at 2.7 GHz and examine the constraints these observations place on models for the variability.

II. OBSERVATIONS AND RESULTS

Observations of 0133 + 476, 0235 + 164, 1749 + 096, and 2131 − 021 were obtained as part of an extensive study of the radio variations in a sample of ~100 extragalactic variable radio sources. Flux-density and linear-polarization measurements were made at 2.7 GHz at intervals of 3–4 months with the NRAO 91 m telescope (Kapitzky 1976). Flux-density measurements were made at 7.9 and 15.5 GHz at intervals of about 1 month with the Haystack Observatory 120 ft antenna (Dent *et al.* 1974; Dent and Kapitzky 1976; Balonek 1982), and at 31.4 and 89.6 GHz at intervals of roughly 3 months with the NRAO 36 ft telescope (Dent and Hobbs 1973; Hobbs and Dent 1977). The telescope parameters and observing techniques are described in the above references. The numerical values of the observations will be published elsewhere and are also available from the authors. The individual sources are discussed below.

a) 0133+476 (DA 55, OC 457)

This source is a BL Lac object (Strittmater *et al.* 1974) with a redshift of $z = 0.859$ (Lawrence *et al.* 1986). There is no evidence for any extended structure larger than ~1″ at centimeter wavelengths (Ulvestad *et al.* 1981; Perley 1982).

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VLBI measurements suggest that the core consists of a single inhomogeneous component whose orientation is a function of wavelength (Marscher and Shaffer 1980; Weiler and Johnston 1980; Pearson and Readhead 1981). At 5 GHz, the core has an angular diameter (Gaussian FWHM) of 1.5×1 milliarcsec (mas) at a position angle of $\sim 144°$ (Pearson and Readhead 1981).

The source is a well-known active variable at centimeter wavelengths (Bignell and Seaquist 1973; Altschuler and Wardle 1976; Kesteven, Bridle, and Brandie 1976; Dent and Kapitzky 1976; Andrew *et al.* 1978; Webber, Yang, and Swensen 1980; Aller *et al.* 1985; Waltman *et al.* 1986). Our multifrequency measurements of total flux density (Fig. 1(a)) show at least four major (and several minor) outbursts during the roughly ten year span of the observations. The outburst time scales (particularly the delays) become progressively longer at longer wavelengths. The amplitude of the outbursts is largest near ~ 15–31 GHz. At 2.7 GHz, the polarization position angle χ exhibited three of the four largest fluctuations on time scales of less than 3 months during periods of decreasing total flux density (Fig. 1(b)).

The VLBI position angle remained constant at $\sim 140°$ during 1978 (Weiler and Johnston 1980; Pearson and Readhead 1981), while the polarization position angle varied by over $\sim 100°$. Thus, there are no temporal changes in the *orientation* of the milliarcsecond structure which could be responsible for the polarization position-angle variations.

When the 2.7 GHz position angle (measured after 1979 when the polarization was relatively stable, Fig. 1(b)) is corrected for Faraday rotation using a rotation measure of 28 rad m^{-2} (Rudnick and Jones 1983) we obtain an intrinsic angle of $\sim 66°$. This implies a magnetic field orientation for transparent emission of $\sim 156°$, which is midway between the VLBI core orientations of $\sim 170°$ at 1.67 GHz (Marscher and Schaffer 1980) and $\sim 144°$ at 5 GHz (Weiler and Johnston 1980; Pearson and Readhead 1981). Thus, the inferred magnetic field direction is roughly parallel to the VLBI structure.

Some changes in position angle occurred during periods of relatively constant polarized flux density $S_{\rm P}$, while some changes in polarized flux density occurred during periods of relatively constant position angle. Thus, the changes in position angle do not seem to be generally correlated with changes in polarized flux density. However, the rapid position-angle changes in mid-1977 and in 1978 were associated with local minima in the polarized flux density.

Altschuler (1980) reported a linear rotation of the polarization position angle of $\sim 62°$ at 8 GHz between May and November 1974. This occurred near the onset of the outburst which began in early 1973 and peaked in early 1974 at 8 and 15.5 GHz (Fig. 1(a); see also Altschuler and Wardle 1976). This rotation was not seen at 2.7 GHz (Fig. 1(b), and Altschuler and Wardle 1976).

The evolution of the 1973–1974 outburst is shown in Fig. 1(c). The pre-outburst spectrum in 1973.4 was relatively flat between 2.7 and 31.4 GHz. The entire spectrum rose by 1974.1, peaked between 8 and 15.5 GHz, and became inverted ($\alpha \sim 0.5$; where $S \propto \nu^{\alpha}$) between 2.7 and 8 GHz. The spectrum broadened, while the spectral peak remained between 8 and 15 GHz. There was an additional minor outburst or shoulder at higher frequencies in late 1974 (Fig. 1(a)). By 1975.4 the spectrum was once again relatively flat out to 31.4 GHz and was steeper about 31.4 GHz ($\alpha \sim -0.8$). The spectrum then fell while maintaining its overall shape until roughly 1975.9, after which a new outburst began at millimeter wavelengths.

The evolution of the 1978–1980 outburst (Fig. 1(d)) is similar to that of the 1973–1974 outburst. The 1978.9 epoch spectrum peaked near 31.4 GHz. The spectral peak moved to lower frequencies with time, peaking near 8 GHz in 1979.5 and 2.7 GHz in 1980.3. The spectrum was much flatter than during the 1973–1974 outburst. Once again, the outburst spectrum broadened with time.

b) AO 0235+164

0235 + 164 is a BL Lac object with two optical absorption-line systems at redshifts of $z = 0.524$ (Rieke *et al.* 1976) and $z = 0.851$ (Burbidge *et al.* 1976). There is no evidence for extended structure larger than $\sim 1''$ at centimeter wavelengths (Ulvestad *et al.* 1981; Perley 1982; Ulvestad, Johnston, and Weiler 1983; Ulvestad and Johnston 1984), though at 327 MHz there is evidence for a ~ 0.3 Jy halo of angular size ~ 3–$6''$ (Gopal-Krishna 1977; cf. Stannard and McIlwrath 1982). VLBI measurements at 5 GHz show a compact core of angular diameter $\theta \sim 0.5$ mas (Weiler and Johnston 1980) and an extended 'jet-like' feature of angular size $\theta \sim 5.4$ mas at a position angle of $\sim 45°$ (Baath *et al.* 1981). Observations at higher resolution (~ 0.1 mas) at a wavelength of 1.3 cm show simple structure—most of the flux density is in an unresolved core and there is a weak 0.7 mas extension at an angle of $+7°$ (Jones *et al.* 1984). The rotation measure is ~ 57 rad m^{-2} (Rudnick and Jones 1983).

This source has been extremely active at all wavelengths at which it has been studied (Altschuler and Wardle 1976; Ledden, Aller, and Dent 1976; Rieke *et al.* 1976; Andrew *et al.* 1978; Spangler and Cotton 1981; Altschuler *et al.* 1984; Aller *et al.* 1985; Waltman *et al.* 1986; Gear *et al.* 1986) and two separate optical-radio events may be correlated (Balonek and Dent 1980; Balonek 1982). Dennison *et al.* (1984) have noted that 0235 + 164 is one of the few sources whose outbursts can be followed from high to low frequencies. The brightness temperature of the large 1976 outburst was estimated to be $T_{\rm B} \sim 10^{15}$ K (Ledden, Aller, and Dent 1976). 0235 + 164 is also the prototypical polarization position-angle rotator. Three separate episodes of linear rotation have been reported (Ledden and Aller 1979; Altschuler 1980; Aller, Hodge, and Aller 1982).

At least six outbrusts in total flux density can be seen between 1976 and 1983 (Fig. 2(a)). The amplitude of the outbursts increases with increasing frequency between 2.7 and 15.5 GHz and then is relatively constant (given the undersampling of some outbursts and the measurement uncertainties) between 15.5 and 89.6 GHz.

The variations in position angle (Fig. 2(b)) are undersampled, but are not obviously correlated with those of total or polarized flux density. Since there is no obvious preferred polarization angle, no comparison can be made with the VLBI structure. The high noise level in the polarized flux densities obscures any correlation (or lack thereof) with the total flux densities. Polarization observations at 4.8, 8.0, and 14.5 GHz with better time resolution show qualitatively similar behavior (Aller, Aller, and Hodge 1981; Aller and Aller 1984).

The radio spectrum is generally flat out to ~ 300 GHz (e.g., Jones *et al.* 1981; Ennis, Neugebauer, and Werner 1982; Landau *et al.* 1983; Gear *et al.* 1985). The spectral

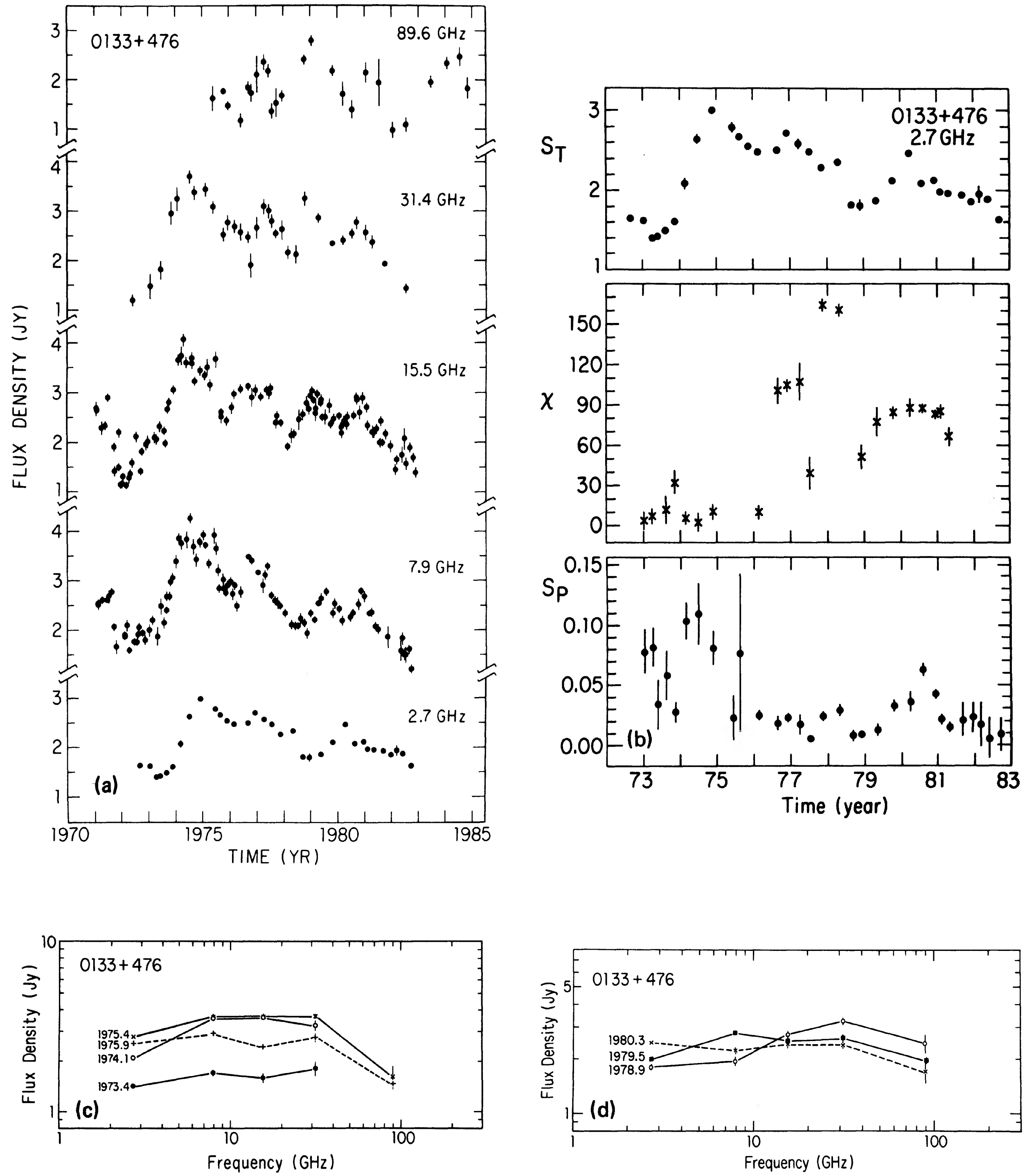

FIG. 1. (a) 0133 + 476: The total flux density at 89.6, 31.4, 15.5, 7.9, and 2.7 GHz as a function of time. (b) 0133 + 476: The 2.7 GHz total flux density S_T, polarization position angle χ, and polarized flux density S_P as a function of time. The position angle is shown only when its 1σ error is less than 14°. (c) 0133 + 476: The radio spectrum at four epochs. (d) 0133 + 476: The radio spectrum at three epochs.

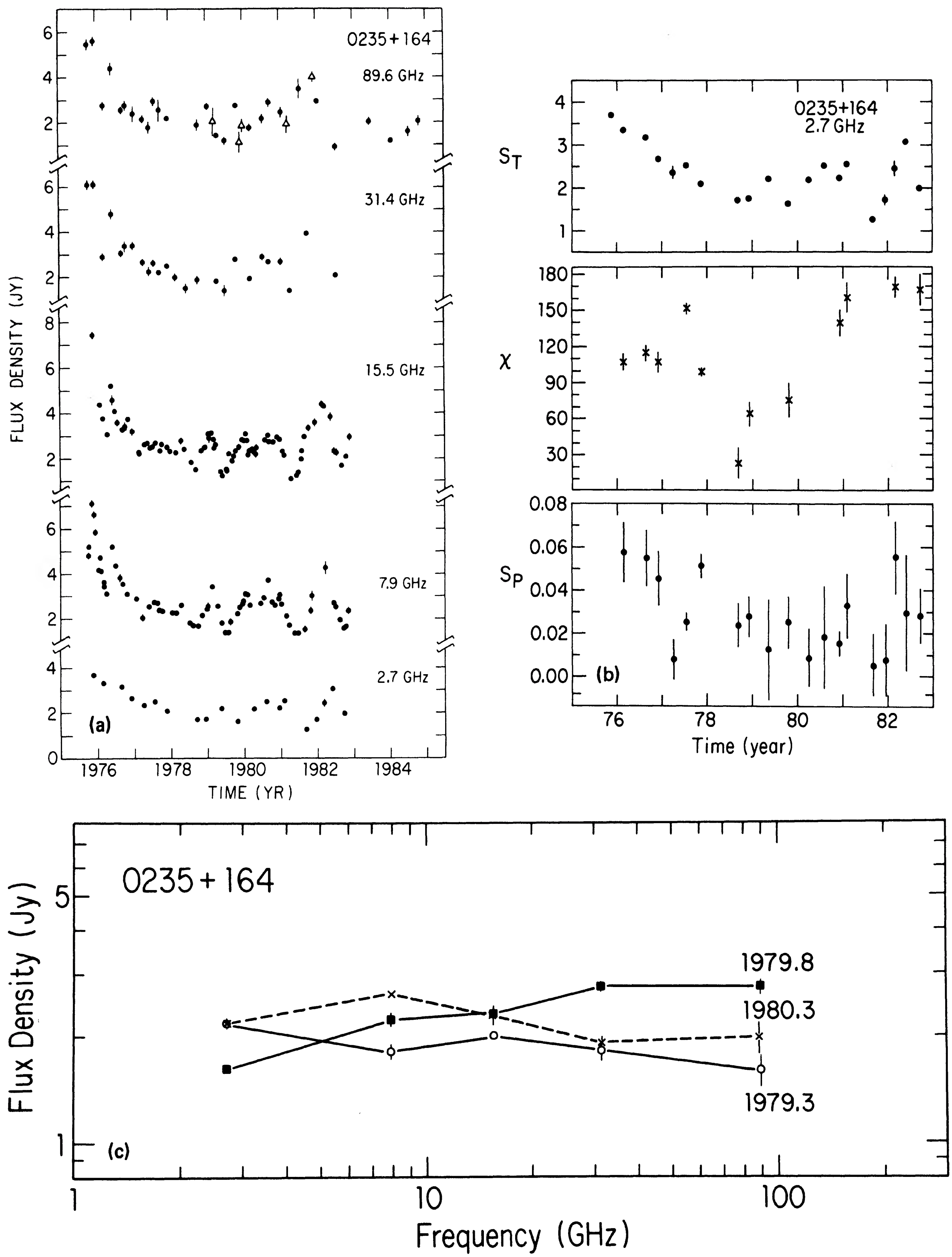

FIG. 2. (a) 0235 + 164: The total flux density at 89.6, 31.4, 15.5, 7.9, and 2.7 GHz as a function of time. The measurements at 89.6 GHz denoted by triangles were taken at FCRAO (see Balonek 1982 for details). (b) 0235 + 164: The 2.7 GHz total flux density S_T, polarization position angle χ, and polarized flux density S_P as a function of time. The position angle is shown only when its 1σ error is less than 14°. (c) 0235 + 164: The radio spectrum at three epochs.

evolution of the large outburst in 1975–1976 has been discussed by Ledden, Aller, and Dent (1976) and so will not be discussed here. The 1979.3 epoch spectrum was relatively flat (Fig. 2(c)), though the total flux density at 2.7 GHz was 'high' due to the presence of a previous outburst which had decayed at millimeter but not yet at centimeter wavelengths. The 1979.8 spectrum shows both the presence of a new outburst which increased the flux density at millimeter wavelengths and a decline in total flux density at 2.7 GHz as the previous outburst decayed. Between 1979.8 and 1980.3 the peak of the new spectral component evolved from 31 GHz to about 8 GHz.

c) 1749+096 (OT 081, 4C +09.56)

This source is a BL Lac object of unknown redshift (Strittmater *et al.* 1974). A core of angular diameter $\theta \sim 0''.0002$ has been detected by Weiler and Johnston (1980) at 5 GHz. There is evidence for extended structure on angular scales of ~ 1–$10''$ with a flux density of ~ 0.03 Jy at 1.4 GHz (Ulvestad and Johnston 1984). The rotation measure is ~ 105 rad m^{-2} (Rudnick and Jones 1983).

The source is strongly variable in both flux density and polarization at centimeter wavelengths (Altschuler and Wardle 1976; Andrew *et al.* 1978; Kesteven, Bridle, and Brandie 1976; Aller, Aller, and Hodge 1981; Balonek 1982; Aller and Aller 1984; Aller *et al.* 1985; Waltman *et al.* 1986). Our high-frequency data for this source (Fig. 3(a)) are rather sparse and the most complete coverage is at 2.7 GHz, where at least five outbursts in total flux density are seen between 1973 and 1983 (Fig. 3(b)). The variability time scale increases with increasing wavelength.

The variations in polarized flux density (Fig. 3(b)) mimic those in total flux density, and the fractional polarization increased slightly at the peak of the outbursts. The position angle varied significantly on time scales of less than 3 months. The jumps in position angle are undersampled, but do not appear to be correlated in any simple way with the total or polarized flux-density variations.

The spectral evolution of the 1981–1982 outburst is shown in Fig. 3(c). The 1981.05 spectrum peaked near 10 GHz. Between 1981.05 and 1981.54 the peak in the spectrum shifted upwards in frequency to ~ 30 GHz as the flux density increased between ~ 7.9 and 90 GHz and decreased at 2.7 GHz. By 1981.93, the spectral peak had shifted back to ~ 10 GHz and decreased in amplitude as the outburst decayed.

The flux-density measurement of 0.9 ± 0.5 Jy at ~ 300 GHz in 1981.9 (Landau *et al.* 1983; see also Gear *et al.* 1984) is consistent with the existence of a break in the spectrum at ~ 100 GHz at that time (Fig. 3(c)). However, the 2.6 ± 0.5 Jy measurement in 1980.3 (Ennis, Neugebauer, and Werner 1982) is consistent with a flat spectrum out to ~ 300 GHz. Thus, the position of the spectral break appears to change with time.

Altschuler (1980) has suggested that there was a linear rotation of the position angle at 2.7 GHz of $\sim 1900°$ between February and November of 1974, giving a rotation rate of $\sim 6.4°$ per day. However, in order to produce such a large rotation, at least one multiple of 180° must be added between adjacent measurements since Altschuler's data points are separated by roughly multiple intervals of 30 days.

In order to examine the reality of this rotation, we have compared our 2.7 GHz data (Fig. 3(b)) with those of Altschuler and Wardle (1976). During the roughly two years over which the two observing programs overlap, there are four occasions where the observations were made within eight days of each other. The derived position angles agree to within the 1σ errors in all cases, and in three cases the difference is less than 5°. For measurements separated by longer times, the differences in the position angles are larger, though the same general trends in the position-angle variations are seen. These facts are not consistent with the 6.4° per day rotation rate suggested by Altschuler (1980).

A subset of both data sets has been plotted in Fig. 3(d) assuming that the difference in position angle between adjacent points is less than 90°. Between November 1973 and November 1974 there was a gradual change in position angle of $\sim 110°$ ($\sim 0.3°$ per day). A weighted least-squares fit of a straight line to the data (also shown in Fig. 3(d)) produces a reduced chi-square of 1.1 for 7 degrees of freedom. A weighted least-squares fit of a line to the data from February to November 1974, assuming that the rotation suggested by Altschuler (1980) is correct, produces a much poorer fit, with a reduced chi-square of 5.2 for 4 degrees of freedom. Thus, it is unlikely that the $\sim 1900°$ linear rotation suggested by Altschuler is the correct interpretation.

d) PKS 2131−021 (4C −02.81)

This BL Lac object has a redshift of $z = 0.557$ (Wills and Lynds 1978). At centimeter wavelengths there is a weak (peak intensity ~ 0.05 Jy per beam at 1.4 GHz), secondary component located 3″ from the compact core at a position angle of $\sim 135°$ (Perley 1982). There are currently no VLBI data available for this source.

The multifrequency observations presented here (Figs. 4(a) and 4(b)) start in mid-1975 and show the source to be an active variable in both flux density and polarization (see also Aller *et al.* 1985). Outbursts in total flux density occurred over time scales of ~ 1–2 yr and are delayed by ~ 6–12 months at 2.7 GHz with respect to the higher frequencies. The outburst amplitudes peak above 15.5 GHz.

The variations in polarized flux density at 2.7 GHz (Fig. 4(b)) did not follow those of total flux density. Over the course of the ~ 7 yr duration of the observations, the position angle varied over a total range of at least 100°, including a jump of $\sim 80°$ between 1976.92 and 1977.26 that was not accompanied by significant variations in the polarized flux density.

Although the observed position-angle variations are large, an 'average' angle of $\sim 44°$ can be defined. The intrinsic angle of $\sim 37°$ (corrected using the rotation measure of ~ 10 rad m^{-2} given by Simard-Normandin, Kronberg, and Button 1981) suggests an orientation of the magnetic field (for transparent emission) of $\sim 127°$, which is close to $\sim 135°$, the position angle of the secondary component (Perley 1982).

The evolution of the 1976–1978 outburst is shown in Fig. 4(c). Between 1975.9 and 1976.9 the spectrum rose nearly vertically at frequencies above ~ 8 GHz. During this time the 2.7 GHz total flux density decreased slightly (probably in response to the decay of a previous outburst which had propagated to centimeter wavelengths). The 1977.3 epoch spectrum shows that the decline in the flux density at millimeter wavelengths had already begun by the time the flux density peaked at 2.7 GHz. Balonek (1982) has suggested a possible correlation between the optical and radio activity during this outburst.

III. DISCUSSION

In this section the relevance of these observations to our understanding of the physical conditions in variable radio

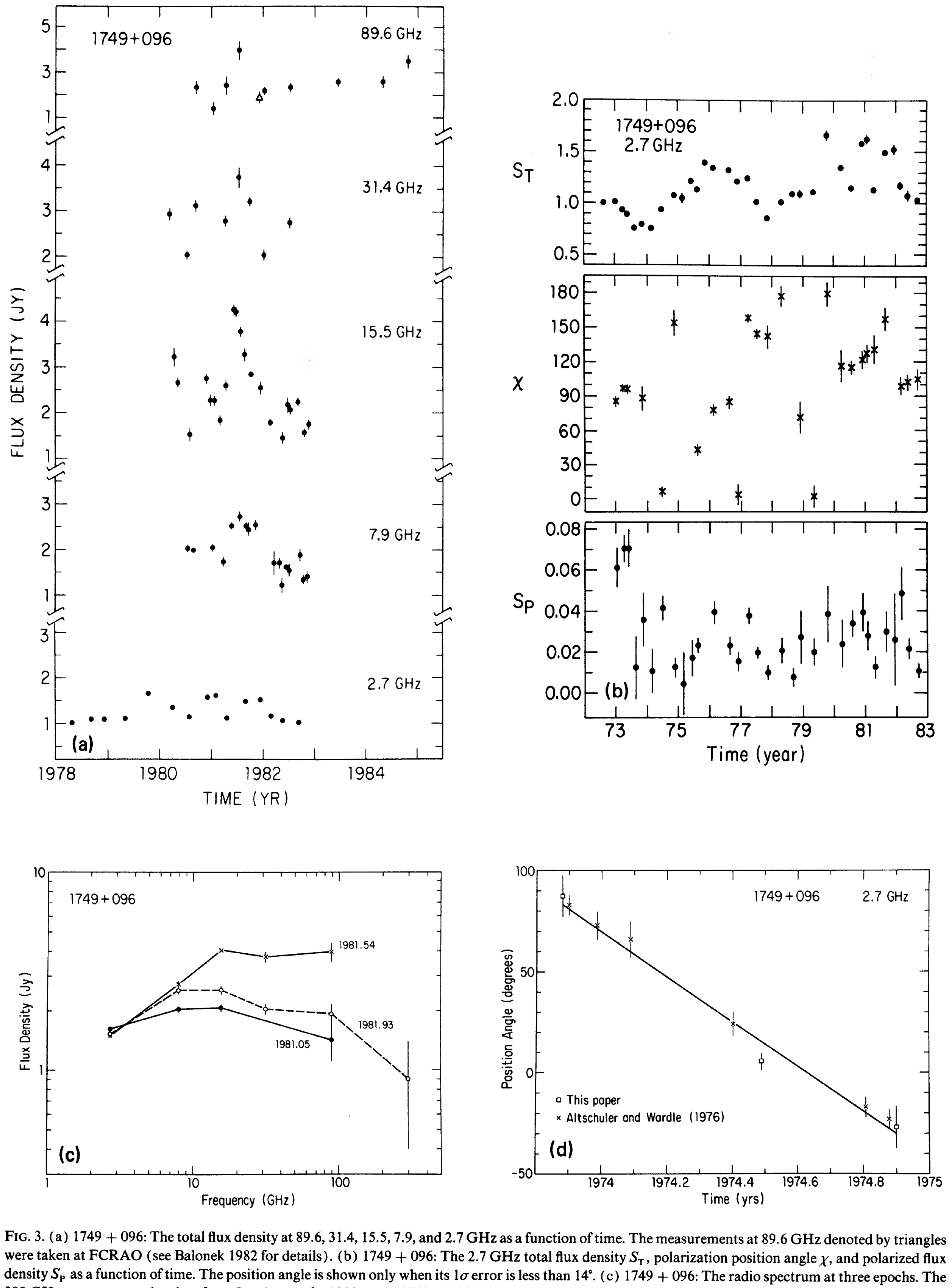

FIG. 3. (a) 1749 + 096: The total flux density at 89.6, 31.4, 15.5, 7.9, and 2.7 GHz as a function of time. The measurements at 89.6 GHz denoted by triangles were taken at FCRAO (see Balonek 1982 for details). (b) 1749 + 096: The 2.7 GHz total flux density S_T, polarization position angle χ, and polarized flux density S_P as a function of time. The position angle is shown only when its 1σ error is less than 14°. (c) 1749 + 096: The radio spectrum at three epochs. The 300 GHz measurement is taken from Landau *et al.* (1983). (d) 1749 + 096: The polarization position angle at 2.7 GHz as a function of time. Data from Altschuler and Wardle (1976) are also plotted. The straight line is a weighted least-squares fit to the data.

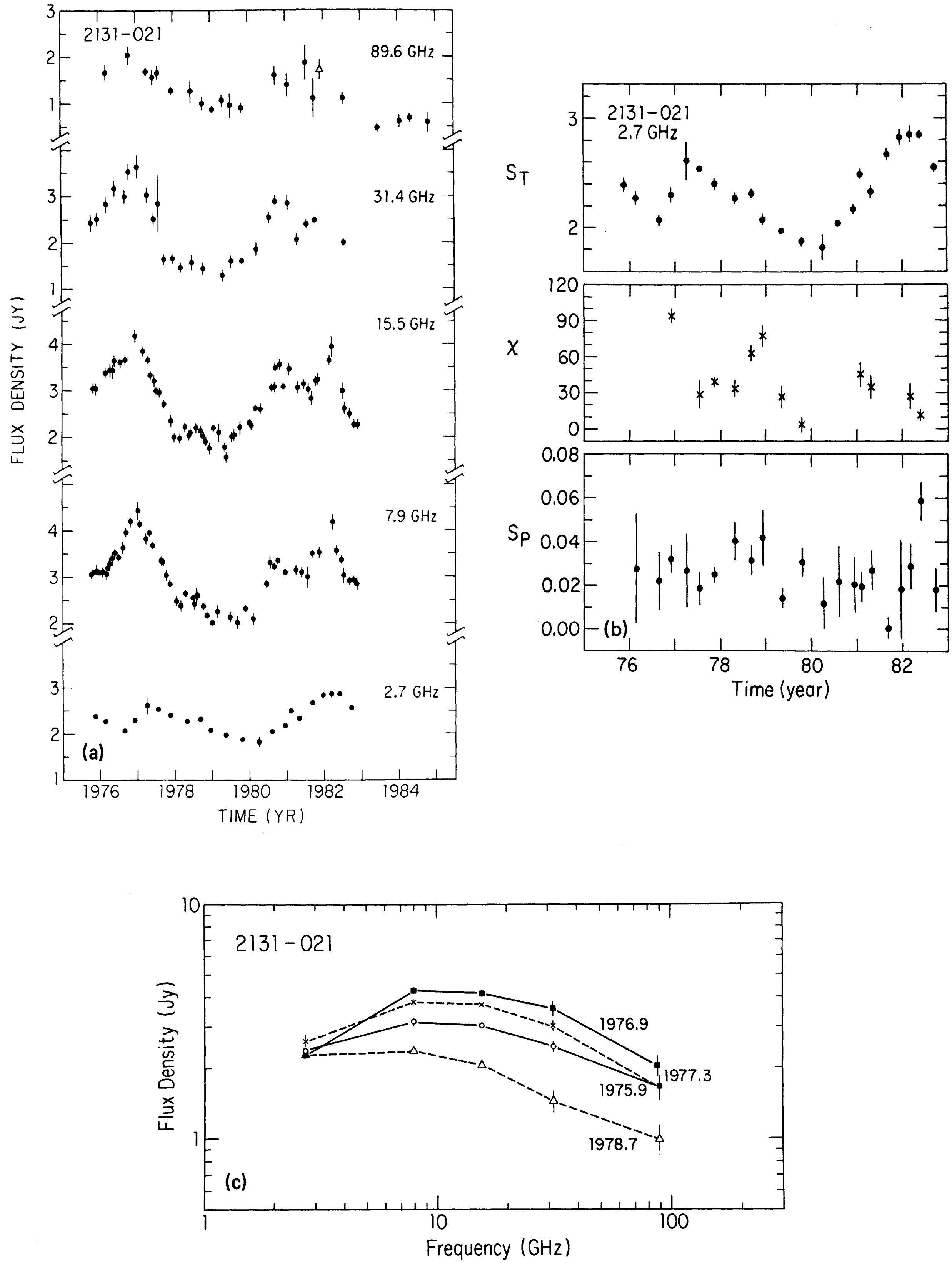

FIG. 4. (a) 2131 − 021: The total flux density at 89.6, 31.4, 15.5, 7.9, and 2.7 GHz as a function of time. The measurements at 89.6 GHz denoted by triangles were taken at FCRAO (see Balonek 1982 for details). (b) 2131 − 021: The 2.7 GHz total flux density S_T, polarization position angle χ, and polarized flux density S_P as a function of time. The position angle is shown only when its 1σ error is less than 14°. (c) 2131 − 021: The radio spectrum at four epochs.

sources is examined. In some cases, the observations presented in this paper are combined with those in previous papers in this series in order to make more general arguments. The sample of sources involved is still small and biased and caution should be exercised in extending these conclusions to other sources.

a) Broadband Spectral Evolution

If the outbursts occur within a single physical region, then the broad shape of the outburst spectra implies that the emitting region is inhomogeneous (Hoyle and Burbidge 1966; Condon and Dressel 1973; de Bruyn 1976; Marscher 1977a). If the outburst is composed of multiple subcomponents, then, unless each subcomponent is seen at a different stage of spectral evolution, this implies that the physical conditions in the radio source vary from point to point; i.e., once again that the emitting region is inhomogeneous. The alternative is that the intrinsic electron-energy spectrum is responsible for the broad shape, e.g., a relativistic Maxwellian energy distribution (Wardle 1977; Jones and Hardee 1979), or a power law with energy index $\gamma \sim 1$, and high- and low-energy cutoffs (Marscher 1977b). However, the evidence generally favors the inhomogeneous-component interpretation of the broad spectra (e.g., Marscher 1977b; Marscher and Shaffer 1980; Spangler 1980; Ennis, Neugebauer, and Werner 1982).

The outburst spectra in these sources tend to evolve toward lower frequencies fairly smoothly, with a smaller change in amplitude than that expected in the simple expanding cloud models (van der Laan 1966; Pauliny-Toth and Kellermann 1968). This suggests that continuing injection is occurring (Peterson and Dent 1973; Aller, Aller, and Hodge 1981) possibly in a shock in a jet (Marscher and Gear 1985, hereafter referred to as MG; Hughes, Aller, and Aller 1985) and/or that the particles expand primarily in one direction, i.e., along a jet, reducing expansion losses (Pacholczyk 1981).

It has been recognized for some time that the quantitative details of the spectral evolution fail to match those of the simple expanding source models. The plethora of very detailed theoretical models emphasizes the point that there is not yet a clear consensus as to which geometries and physical processes are important in these objects. Jones *et al.* (1981) have suggested that flux-density variations can be categorized as being due to changes in source structure, scale size, or slope of the electron-energy spectrum. This seems to be a useful way to gain a first-order impression of the relevant physical processes and we take this approach here.

There is no clear evidence in any of these sources for a change in the spectral index of the transparent portion of the spectrum of the outburst. Thus, radiative cooling resulting in changes in the slope of the electron-energy spectrum does not appear to be generally important in these sources at centimeter wavelengths (though 2134 + 004 is a counterexample, Jones *et al.* 1981). In 0133 + 476 (this paper), 0727 − 115, and 2200 + 420 (O'Dea *et al.* 1983) the outburst spectrum appears to broaden with time. This could be interpreted as a change in the source structure; e.g., an increase in the inhomogeneity of the emission region as particles expand or diffuse out of the region in which they were accelerated. The classification of 0235 + 164 and 2131 − 021 is less clear, but these sources appear to evolve with little change in spectral shape, consistent with a change in the size scale of the emission region. Other examples of sources which exhibit spectral evolution consistent with a change in scale size are 0048 − 097 (O'Dea *et al.* 1983), and 1921 − 29 and 3C 454.3 (O'Dea, Dent, and Balonek 1985 and references therein). Clearly, more sources will need to be classified in this manner for further progress to be made.

These data can also be interpreted within the context of the 'shock in a relativistic jet' model developed by MG. According to MG, the outburst goes through three distinct phases, each dominated by a different electron-energy-loss mechanism and characterized by a different signature to the spectral evolution. MG suggest that during the first phase inverse Compton losses dominate and the flux density rises at all frequencies with little change in the frequency of the peak. During the second phase, synchrotron losses dominate and the peak flux density increases as the frequency of the spectral peak decreases (for $-0.5 > \alpha > -0.75$). During the third phase, adiabatic losses dominate and the flux density of the peak decreases as the frequency of the peak decreases. Presumably, the outburst completes the inverse Compton phase at frequencies higher than 90 GHz (MG). Our observations show that between ~ 90 and ~ 30 GHz the flux density of the outburst increases as expected in the synchrotron-loss phase. The observations are also consistent with a transition between the synchrotron and adiabatic phases between ~ 30 and ~ 15 GHz, after which the evolution is dominated by adiabatic losses. Thus, the data are in qualitative agreement with the MG model. However, the outburst spectra should exhibit the steepening characteristic of synchrotron energy losses. Yet, there is currently no clear evidence at frequencies below 90 GHz for steepening in the spectra of the outbursts in most sources. However, spectral steepening is observed in outbursts in some blazars at higher frequencies (e.g., Gear *et al.* 1986). In addition, spectral steepening could be masked by the blending of outbursts at frequencies below 90 GHz.

In these four quasars, the time for the spectral peak of the outbursts to propagate from millimeter to centimeter wavelengths is ~ 1 yr. Since the time scale between outbursts in these active sources is also on the order of 1 yr, the spectrum 'ripples' as the centimeter-millimeter-wavelength regions respond to different outbursts; e.g., the flux density at millimeter wavelengths may increase, while the flux density near 1–3 GHz may decrease. This can give the appearance of an anticorrelation or lack of correlation between the activity at millimeter and centimeter wavelengths if only a short time baseline of data is available.

b) Physical Conditions in the Source

We can make rough estimates of the global physical parameters of the region which peaks near 30 GHz within the context of the standard uniform spherically symmetric synchrotron source model (Jones, O'Dell, and Stein 1984; Marscher *et al.* 1979; Marscher 1983). For a typical outburst at 31.4 GHz in 0133 + 476 we obtain a linear diameter from the variability time scale of $d \sim 0.9$ pc and a brightness temperature of $T_B \sim 10^{11}$ K assuming $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 0.0$. Since there is not an inverse Compton problem, we adopt a Doppler factor of $\delta = 1$. Assuming a radio spectral index of $\alpha = -0.75$ and a lower limit to the electron Lorentz factor of $\Gamma = 30$ (Wardle 1977), we obtain a magnetic field of $B \sim 0.1$ G and a relativistic electron density of $n \sim 3 \times 10^3$ cm^{-3}. The lifetime of an electron radiating at 30 GHz in a 0.1 G field is $t_l \sim 3.5$ yr, which is just long enough to be consistent with the lack of observed spectral steepening in the outbursts.

c) Constraints on Theoretical Models for Polarization Variability

These four quasars exhibit changes in both the total flux density and polarization on time scales of less than 3 months. In general, the polarization varied on shorter time scales than the total flux density, and no strong correlations between polarization and flux density are apparent. The position angles varied over a range of at least ~ 100–$180°$. The details of the variations are different from source to source and no clear pattern is obvious. Since the polarization variations are undersampled, a detailed comparison of the observations with the various theoretical models is not practical. However, some general qualitative comparisons can be made with theoretical models.

Simple opacity changes (e.g., Aller 1970; Takarada 1970) appear to be ruled out as an explanation for the position-angle changes in these sources for a number of reasons. (1) The position-angle variations are occasionally much greater than 90° (see also Aller, Hodge, and Aller 1982). (2) The position-angle changes are not correlated in a simple way with the total flux-density variations (see also Komesaroff *et al.* 1984; Jones *et al.* 1985). (3) The position-angle changes are not generally associated with minima in the fractional polarization (see also Aller *et al.* 1985).

The simple two-component model (e.g., Björnsson 1982; Komesaroff *et al.* 1984) fails for the same reasons as does the opacity-effects model.

Rotating-source models have been discussed as a possible explanation for the polarization rotators (e.g., Ledden and Aller 1979; Pineault 1980; Komesaroff *et al.* 1984). However, this class of model seems unlikely to be able to reproduce the high brightness temperatures calculated for these sources unless the emission is also highly beamed.

Relativistic aberration effects from accelerating relativistically moving sources have been suggested by Blandford and Königl (1979) and discussed by Björnsson (1982). This model has the advantage of being able to reproduce rotations of up to 180°. However, for most magnetic field geometries, the rapid jumps in position-angle rotation are predicted to be coincident with minima in the fractional polarization, as in the two-component model (Björnsson 1982). A related model has been suggested by Königl and Choudhuri (1985) in which a shock wave propagates down a jet with a helical magnetic field. The position-angle jumps in this model are also expected to be associated with minima in the fractional polarization. However, since a strong association of position-angle jumps with minima in the fractional polarization is not observed, these models also seem unlikely.

None of the simple one- or two-component models discussed here appears to be consistent with the qualitative features of the data. It is possible to add complexity to the models, for example, by invoking the existence of *many* relativistically moving clouds. In one class of multiple-component model, stochastic polarization variations are produced (e.g., Moore *et al.* 1982; Jones *et al.* 1985). Jet models in which turbulent flow is important should also be examined (e.g., Jones 1986).

In $0133+476$ and $2131-021$ (this paper), and $1308+326$ (O'Dea, Dent, and Balonek 1983), the inferred direction of the magnetic field in the core is aligned with the position angle of the source structure. This is consistent with the general trend found for compact sources (e.g., Rusk and Seaquist 1985; Jones *et al.* 1985). VLBI polarization maps should reveal whether or not the parsec scale jets have axial magnetic fields as do their one-sided counterparts on the kiloparsec scale (e.g., Bridle and Perley 1984).

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