Astron. Astrophys. 326, 77–86 (1997)

ASTRONOMY AND ASTROPHYSICS

Search for intraday radio variability in EGRET blazars

G.E. Romero[1,2,⋆], **J.A. Combi**[1,2], **P. Benaglia**[1,⋆], **I.N. Azcárate**[1,⋆⋆], **J.C. Cersosimo**[3], **and L.M. Wilkes**[3]

[1] Instituto Argentino de Radioastronomía, C.C.5, (1894) Villa Elisa, Bs. As., Argentina
[2] Theoretical Physics Lab, Department of Physics, University of La Plata, C.C. 64, 1900 La Plata, Argentina
[3] University of Puerto Rico, Humacao Campus, Department of Physics and Electronics, CUH Station, Humacao, PR 00791

Received 26 February 1997 / Accepted 17 April 1997

Abstract. We present results of intraday variability observations at 5 GHz of the EGRET blazars 0202+14, 0235+16, 2230+11, and 2251+15. The BL-Lac object 0235+16 presented flux density variations of ~ 7 % over timescales of ~ 1.3 days. The source 0202+14 was also variable, although with smaller amplitudes. The behaviour of 0235+16 at short timescales is almost identical to that presented in previous intraday observations carried out in 1990, when the flux density of the source was 4 times higher. We discuss the possible origin of the ultra rapid radio variability in these sources within different possible scenarios.

Key words: radio continuum: galaxies – galaxies: active

1. Introduction

Intraday radio variability was discovered ten years ago during extensive monitoring campaigns of a complete sample of high-declination, flat-spectrum, extragalactic sources (Witzel et al. 1986, Heeschen et al. 1987, Quirrenbach et al. 1989a, Krichbaum et al. 1992). Since then rapid changes in flux density and polarization have been measured in a large number of compact radio sources at different declinations (e.g. Quirrenbach et al. 1992, Romero et al. 1995a). In some cases, the fluctuations in flux density and polarization are correlated (e.g. Quirrenbach et al. 1989b). Other sources, like 0716+71, have displayed correlated variability at radio and optical wavelengths (Wagner et al. 1990, Quirrenbach et al. 1991). The most dramatic variability event reported to date was a change of ~ 45 % in the flux density at 1.4 GHz of the southern blazar PKS 0537-441 over a timescale of ~ 3 hours (Romero et al. 1994). Most of the flat-spectrum radio sources, however, seem to vary in the range 2-5 % within a day. The origin of intraday variability is not well established. Since in many sources most of the radio flux comes from a very compact (~ 1 mas) core, refractive scintillation produced by the interstellar medium should contribute to the observed variability (Rickett 1986, Blandford et al. 1986). This contribution, however, is not dominant in those sources where correlated variations between the optical and radio bands have been observed. In these cases intrinsic models should be considered. Because of the very short timescales the phenomenon must be produced in a small region, probably located in the parsec-scale jet. The nature of this region varies from one model to other. Models based on relativistic shocks (Marscher 1990, Qian et al. 1991, Marscher et al. 1992, Romero et al. 1995b), lighthouse effects (Camenzind & Krockenberger 1992), and coherent emission processes (Benford 1992) have been invoked to explain intrinsic intraday variability at radio wavelengths.

The origin of the γ-ray emission of blazars is another important issue in current research of active galactic nuclei. Most models consider that the high-energy emission is due to upscattering of lower energy photons by beamed relativistic electrons and positrons in the innermost part of the jets. The seed photons can be produced by an X-ray emitting accretion disk (Dermer et al. 1992, Dermer & Schlickeiser 1993), reprocessed in a halo (Sikora et al. 1994, Blandford & Levinson 1995), or self-generated by the relativistic electrons by synchrotron mechanism (Marscher & Bloom 1992, Maraschi et al. 1992, Bloom & Marscher 1996). In several blazars γ-ray variability over short timescales have been observed (von Montigny et al. 1995). These timescales can be as short as a few hours at the EGRET range and even shorter at TeV energies. In particular, Mattox et al. (1997a) have reported a large increase in the $E > 100$ MeV flux of the blazar PKS 1622-297 in less than 7.1 hours (see also Mattox & Wagner 1996). Gaidos et al. (1996) observed two dramatic outbursts of TeV photons from Mrk 421, one with a doubling time of about one hour and other even fastest, which lasted $\sim$ 30 minutes. These extreme behaviours imply severe size constraints imposed by the opacity of the radiation field to pair production (Blandford & Levinson 1995, Becker & Kafatos 1995). If intraday radio variability is present in these kind of sources, it should be probably generated in a different region located farther in the jet. However, since γ-ray blazars are superluminal sources with radio flat spectra

Send offprint requests to: J.A. Combi, first address
⋆ Now at Instituto Astronômico e Geofísico (IAG). Univesidade de São Paulo, Av.M. Stefano 4200, CEP 04301-904 São Paulo, SP, Brazil
⋆⋆ Member of CONICET

and highly beamed emission they constitute privileged targets to search for intrinsic intraday radio variability. Consequently, observations with high temporal resolution at cm wavelengths of γ-ray blazars might provide useful data to improve our understanding of the physical processes in the inner jets and the possible relations between emission mechanisms at very different frequencies.

In this paper we present results of a search for intraday variability at 5 GHz in a sample of four low-declination γ-ray blazars: 0202+14, 0235+16, 2230+11, and 2251+15 (Mattox et al. 1997b). Two of these objects have been found variables by the EGRET instrument of the Compton Gamma Ray Observatory (CGRO) (see von Montigny et al. 1995). The object 0202+14 was detected by EGRET in 1992 (Fichtel 1994). It is a radio-flat, highly polarized source for which none redshift is known at present. 0235+16 is one of the most variable BL-Lac objects. It is a very compact source (Jones et al. 1984, Chu et al. 1996) with emission lines at z=0.94 and foreground absorption systems at z=0.85 and z=0.524. Strong emission lines have been also found at z=0.524. Recent discussions of the environment of 0235+16 are given by Nilsson et al. (1996) and Burbidge et al. (1996). The gravitational microlensing scenario for this blazar is presented by Stickel et al. (1988) and Abraham et al. (1993), among others. Kayser (1988) has pointed out some objections to a microlensing interpretation of the variability of the source. Superluminal components with apparent velocities of $\sim 30\ c$ have been detected (see Fan et al. 1996 and references therein), showing a high level of intrinsic activity in the object. The EGRET detection of 0235+16 was reported by Hunter et al. (1993), and results of new γ-ray observations are presented by Madejski et al. (1996). Extreme optical microvariability has been recently found by Rabbette et al. (1996) and Noble & Miller (1996). The origin of this latter phenomenon is probably related with some kind of activity (e.g. due to instabilities) in the accretion disk surrounding the supermassive central black hole of the blazar (see Noble & Miller 1996).

The detection of the quasars 2230+11 and 2251+15 at high γ-ray energies was reported by Nolan et al. (1993) and Hartman et al. (1993), respectively. 2230+11 is a superluminal source with a redshift z=1.037 and a high degree of linear polarization (Moore & Stockman 1981). The source 2251+15 is an optically violent variable (OVV) quasar with a redshift z=0.859. At VLBI resolution the core is formed by two components separated by $\sim$ 6 mas (Charlot 1991). Superluminal velocities $\sim 9\ c$ have been detected in this quasar (Fan et al. 1996).

In the next two sections we describe our intraday variability observations of these sources and present the corresponding results.

2. Observations

The observations were carried out with the NRAO 43-m telescope at Green Bank[1] during September 1996. The telescope was equipped with a 5 GHz-continuum receiver of single beam, corrugated, dual-hybrid mode feed. The bandwidth was 53 MHz and the system temperature $\sim$ 45 K. At the observing frequency the HPBW of the antenna is $\sim$ 6 arcmin. The observations were made at night, in order to reduce the effects of changes in telescope structure caused by heating and terrestrial interfering signals. Each observation of a single source consisted of two sets of cross-scans. The scans observed in each direction were averaged and the peak flux density was obtained by Gaussian fitting of the data. The flux density scale was fixed assuming a value of 5.8 Jy for the standard flux density calibrator 2105+42 (Baars et al. 1977). A set of three steep-spectrum ($\alpha < -0.5$), non-variable sources was observed with the same sampling interval than the target blazars for control and variability calibration purposes. The observed sources are listed in Table 1, together with their coordinates, galactic latitude, γ-ray flux at $E > 100$ MeV, radio spectral index computed between 4.8 GHz and 8 GHz, redshift, apparent superluminal velocity in units of c, and identification.

The final light curves have a temporal resolution of $\sim$ 1 hour. The errors quoted with the data along the paper are rms fluctuations of the flux densities obtained for each set of scans. In addition to these errors for individual source observations, small variations of the gain and sensitivity of the entire observing system over timescales of days can introduce a spurious low-level variability in the observed light curves. This effect can be removed using the variability observations of the calibration sources.

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation

3. Results

Results of the observations are presented in Fig. 1 as residual light curves $R(t) = 100(S(t)/ < S > -1)$, where $< S >$ is the mean flux density. Fig. 2 shows light curves of calibration sources. A percentage fluctuation index $\mu = 100\sigma_{\rm s}/ < S >$ has been estimated for each source. Fluctuations of the control sources provide a measure of the spurious variability introduced by the observing system during the campaign. The real variability of a given source can be estimated introducing variability amplitudes $Y = 3(\mu^2 - \mu_0^2)^{1/2}$, where μ_0 is the largest fluctuation index of the calibration sources. In the case of the present observations μ_0=0.65 %.

Variability parameters for the EGRET sources are given in Table 2. For each source, we list the number of points in the light curve, the mean flux density, the fluctuation index, the variability amplitude, the activity parameter $\dot{S}$, the variability timescale $t_{\rm v} = S_{\rm max}(dS/dt)^{-1}$, and the slope of the first order structure function $D^I(\tau) =< (R(t) - R(t+\tau))^2 >$. This latter parameter can be used to investigate the nature of the underlying physical process (e.g. Simonetti et al. 1985). Just two sources of our sample can be classified as variables: 0202+14 and 0235+16. Day-to-day flux density light curves of these objects are presented in Figs. 3 and 4. The variability of 0202+14 was rather small, with amplitudes of $\sim$ 3 % over timescales of $\sim$ 3.5 days. The source 0235+16 presented, instead, stronger variations with amplitudes up to 7 % over timescales of $\sim$ 1.3 days. The remain-

Table 1. Observed sources

Source	α_{1950} ($^{\rm h\ m\ s}$)	δ_{1950} ($^{\circ}\ '\ ''$)	b ($^{\circ}$)	$F_{\gamma}(E > 100$ MeV) (10^{-6}cm^{-2}s^{-1})	$\alpha_{\rm r}$	z	$\beta_{\rm app}$	Id
0106+13	01 06 12.08	13 02 33.4	−49.34	...	−0.59	0.059	...	G
0134+32	01 34 49.83	32 54 20.5	−28.72	...	−0.85	0.367	...	Q
0202+14	02 02 07.41	14 59 50.5	−44.04	0.3±0.1	−0.07	?	...	Q?
0235+16	02 35 52.62	16 24 04.0	−39.11	0.8±0.1	−0.50	0.940	30.0	BL
2134+00	21 34 05.12	00 28 25.3	−35.84	...	−0.76	1.936	...	Q
2230+11	22 30 07.81	11 28 22.7	−38.58	0.24±0.07	−0.26	1.037	18.0	Q
2251+15	22 51 29.52	15 52 54.3	−38.18	0.8±0.1	−0.02	0.859	9.0	Q

G: Radio galaxy, Q: QSO, BL: BL Lac object

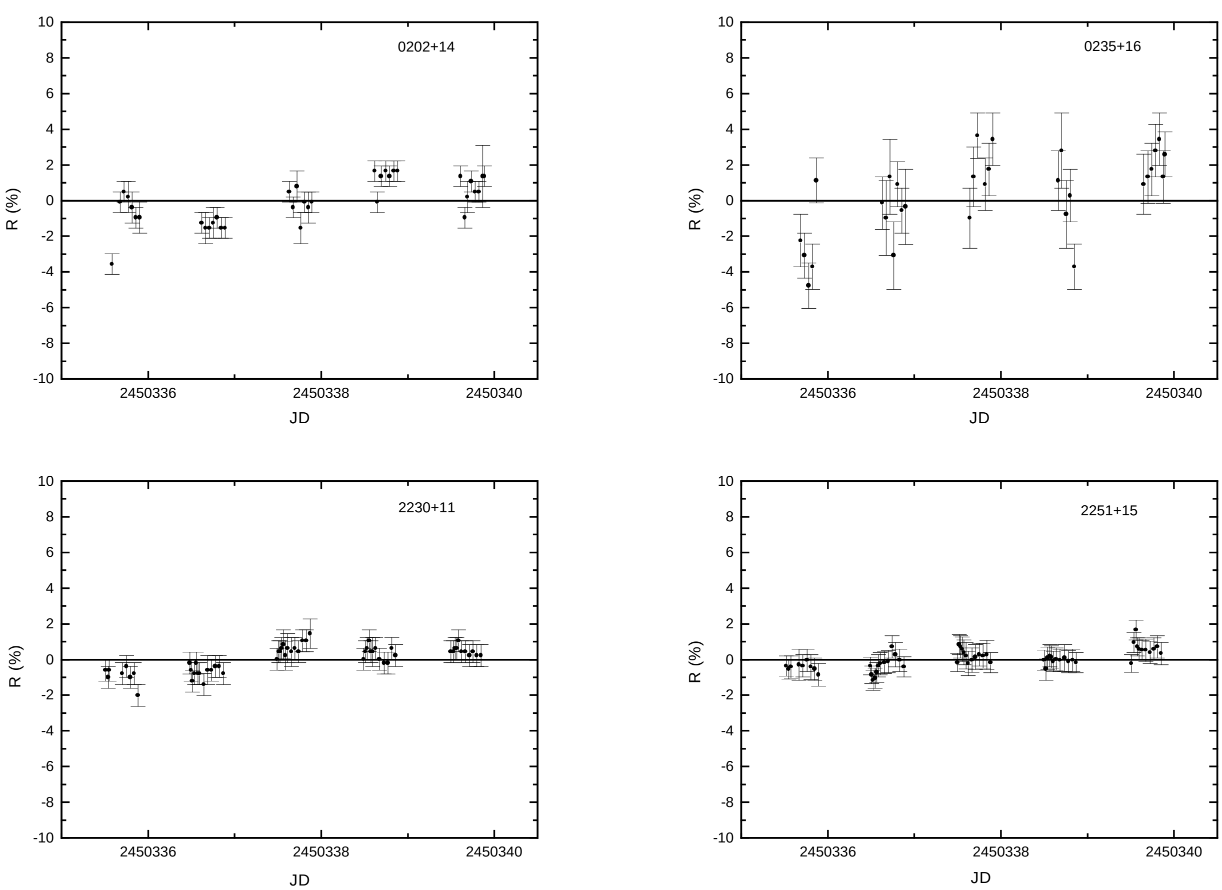

Fig. 1. Residual light curves for target sources.

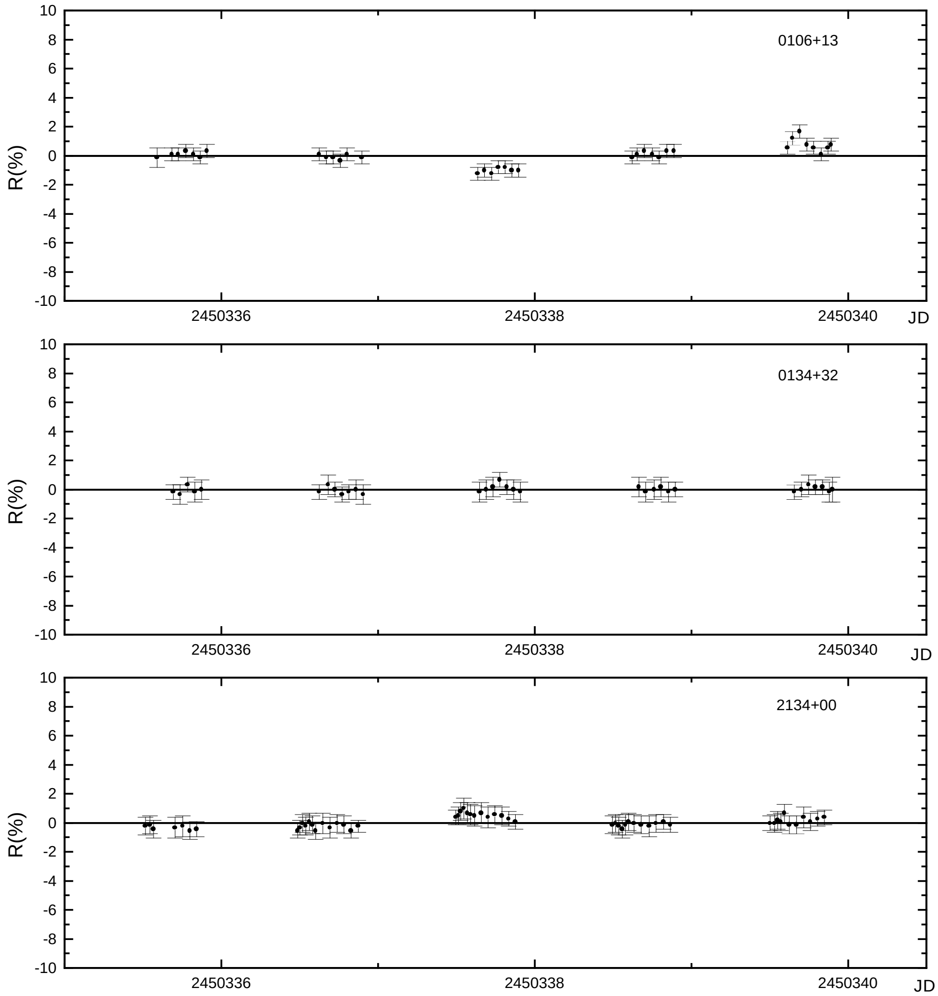

Fig. 2. Residual light curves for steep spectrum sources.

Table 2. Variability parameters for EGRET sources

Source	n	$< S >$ (Jy)	μ (%)	Y (%)	$\dot{S}$ (Jy/hour)	$t_{\rm v}$ (hours)	m
0202+14	36	3.45	1.27	3.27	0.042	83	1.7
0235+16	30	0.47	2.43	7.02	0.015	32	1.0
2230+11	55	4.90	0.70	...	...	...	...
2251+15	56	15.99	0.54	...	...	...	...

ing sources, 2230+11 and 2251+15, did not display flux density changes within the instrumental errors.

The sources 0235+16 and 2251+15 were observed by Quirrenbach et al. (1992) in April 1990 as a part of a search for intraday variability at 5 GHz with the 100-m telescope of the MPIfR in Effelsberg. The results obtained in that opportunity were almost identical to those above mentioned. This is particularly interesting if we notice that observing techniques, campaign durations, and values of μ_0 were almost identical, whereas, however, the state of the sources were quite different during both observations. In April 1990 the object 0235+16 had a mean flux density at 5 GHz of $\sim$ 1.9 Jy and displayed variability amplitudes of $\sim$ 6.5 %, with μ_0=0.7 %. More than six years later the flux density decreased to 0.47 Jy and the intraday variability parameters remained at the same level. The source 2251+15 increased its flux density from $\sim$ 10.4 Jy to $\sim$ 16 Jy while its fluctuation index stayed at the level of $\sim$ 0.5 %. This constancy of the relative amplitudes of intraday variability through very different states, if confirmed as a common property of blazars by further observations of other sources, could introduce an important constraint to possible models for the phenomenon.

In the next section we briefly discuss the behaviour of the variable sources of our sample during the last years, with particular attention to 0235+16 which seems to be the most interesting case. After that, in Sect. 5, we will consider the problem of the origin of the observed intraday variability.

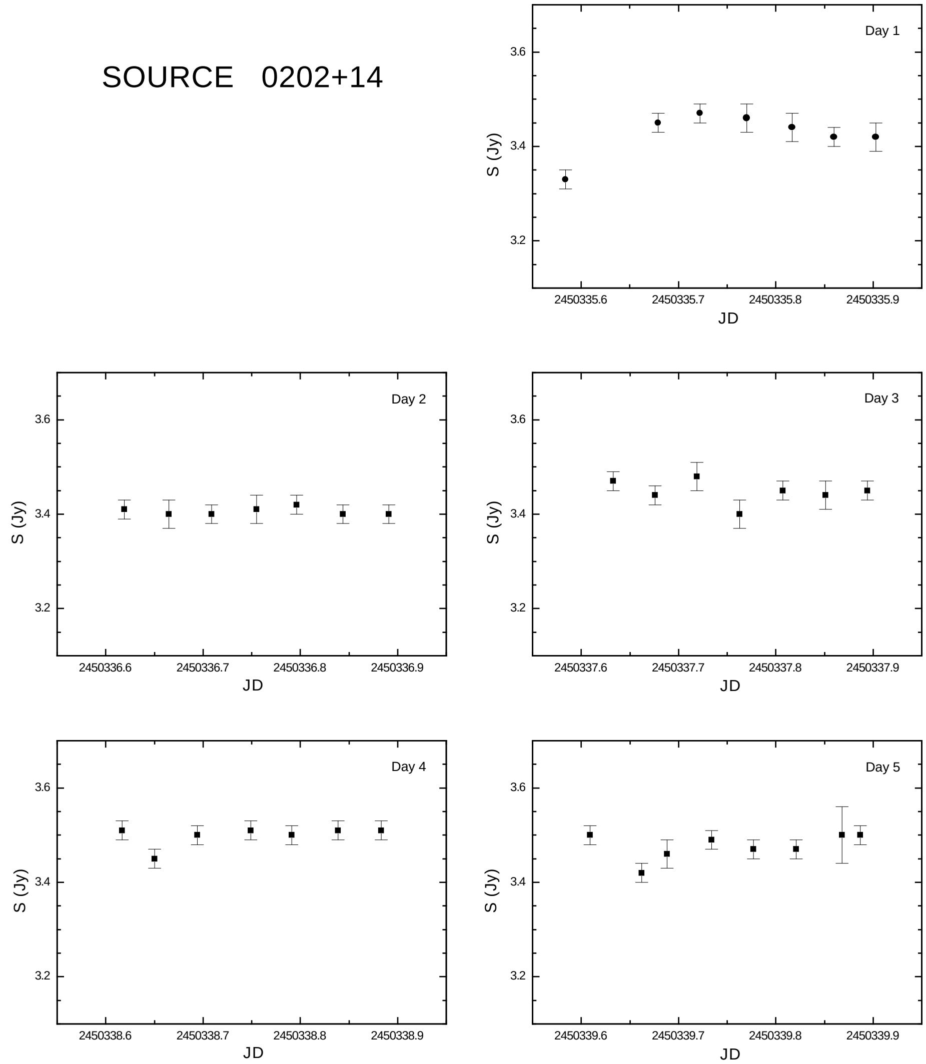

Fig. 3. Day-to-day flux density light curves for 0202+14.

4. Behaviour on larger timescales

Both 0202+14 and 0235+16 have displayed significant variability at 5 GHz over timescales of several months during recent years. Fig. 5 shows the flux density light curves at 4.8 GHz of these objects from September 1993 till March 1996, obtained from the University of Michigan Radio Astronomy Observatory Database. The source 0202+14 varied smoothly with fluctuations of $\sim 15\%$ over the last 3 years. Very much dramatic changes can be observed instead in the light curve of 0235+16. The flux density of this latter source decreased from ~ 2.3 Jy in September 1993 to 1.3 Jy in March 1994, and then grew up to 2.4 Jy in January 1995. Since then the flux has been decreasing up to its current value of 0.47 Jy.

This kind of behaviour can be explained in the context of shock-in-jet models (Marscher & Gear 1985; Hughes et al. 1985, 1989; Marscher 1990) which are based on the standard relativistic jet model of active radio sources (Blandford & Konigl 1979, Marscher 1980). When a shock is created in an otherwise steady jet (which is confined to a cone of constant opening angle) the time evolution of the flux density is given by the superposition of two components: $S(t) = S_{\rm s}(t) + S_{\rm j}$, where $S_{\rm j}$ is the steady contribution of the jet and $S_{\rm s}(t)$ is the variable shock component. If the jet is adiabatic with a relativistic electron distribution $N(E) = NE^{-p}$, valid for $\gamma_{\rm min}mc^2 < E < \gamma_{\rm max}mc^2$, the shock emission evolves in the way described by Marscher & Gear (1985). In a first stage Compton losses are dominant and the flux density is $S_\nu \propto x^{[(11-p)-s(p+1)]/8}\nu^{-p/2}$, where x is the distance from the shock to the jet apex and the magnetic field has been assumed to fall as $B(x) \propto x^{-s}$. Synchrotron losses soon dominate and the spectrum shifts toward lower frequencies. At this stage the flux obeys the proportionality $S_\nu \propto x^{-[4(p-1)+3s(p-2)]/6}\nu^{-p/2}$, at all optically thin frequencies. As the evolution of the shock continues, the magnetic field decreases whereas the thickness of the emission region behind the shock enlarges, in such a way that radiative losses become unimportant and the shock evolves to an adiabatic stage where $S_\nu \propto x^{[2(5-2p)-3s(p+1)]/6}\nu^{-(p-1)/2}$.

The adiabatic-loss stage of the above outlined model matches very well the behaviour of 0235+16 between September 1993 and March 1994. In order to explain the subsequent

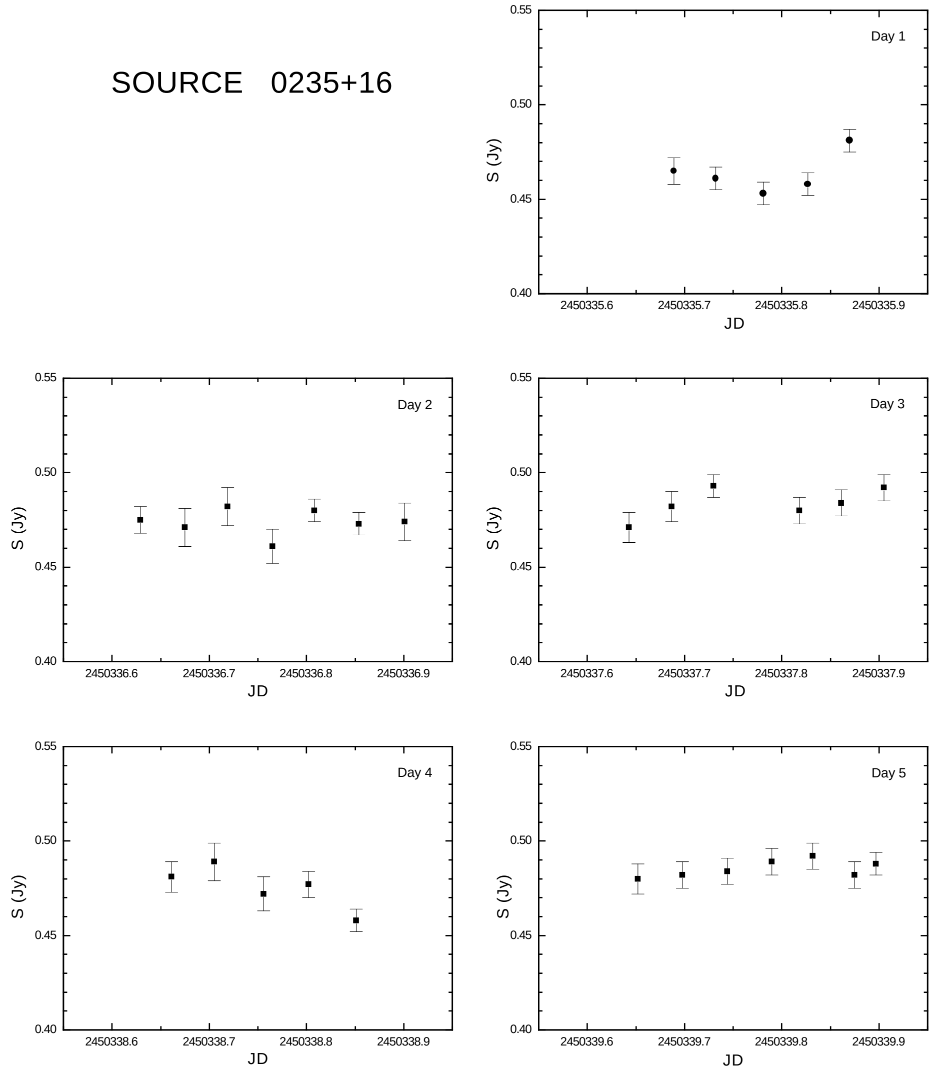

Fig. 4. Day-to-day flux density light curves for 0235+16.

enhancement observed in the light curve we can modify the model to include the effects of the interaction of the shock with a density inhomogeneity in the jet (see Romero et al. 1995b for details). Inhomogeneities in the particle density of the parsec-scale jet are naturally expected as a consequence of the development of Kelvin-Helmholtz instabilities with dominant axisymmetric mode contribution (Hardee 1990, Romero 1995). We adopt here a specific model with a transverse shock propagating down a relativistic adiabatic jet with $N(E) = NE^{-2}$ (according to the observed spectral index) and a Gaussian density profile for the energy distribution of the electrons in the interposed inhomogeneity. The shock has a Lorentz factor $\gamma = (1-\beta^2)^{-1/2}$ and the jet forms an angle θ with the line of sight. In order to keep the brightness temperature in the shocked component below 10^{12} K, a Doppler factor $\delta = [\gamma(1-\beta\cos\theta)]^{-1} \geq 2$ must be adopted. In accord with VLBI observations which show a very compact source (Jones et al. 1984) we assume $\cos\theta \sim \beta \sim 1$, and then $\delta \approx \gamma$. For a mild Lorentz factor γ=5 the linear size of the inhomogeneity is $\sim$ 4 pc and the brightness temperature in the shock's frame reduces to $\sim 1.3 \times 10^{10}$ K (we assume throughout the paper H_0 = 100 km s^{-1}Mpc^{-1} and q_0=0.5). Fig. 6 shows the best fits of the observational data for models with (a) magnetic field behind the shock predominantly parallel to the shocked front (dashed curve, s=1), and (b) dominant magnetic field parallel to the jet axis (solid line, s=2). A χ^2-test determines that the second model fits better the flux density behaviour of the source. This model is also more appropriate to describe the polarization of the source, which did not significantly change during the flux density outburst, because the field is not amplified when it is perpendicular to the shock front.

The shock-in-jet model provides a suitable description of the behaviour of 0235+16 over timescales of months to years (see also O'Dell et al. 1988 for a discussion of earlier outbursts). Any attempt to explain intraday variability in this scenario must take into account the fact that the fluctuation index over very short timescales in 0235+16 remains constant independently of the state of the source. As we mentioned, this introduces a severe constraint.

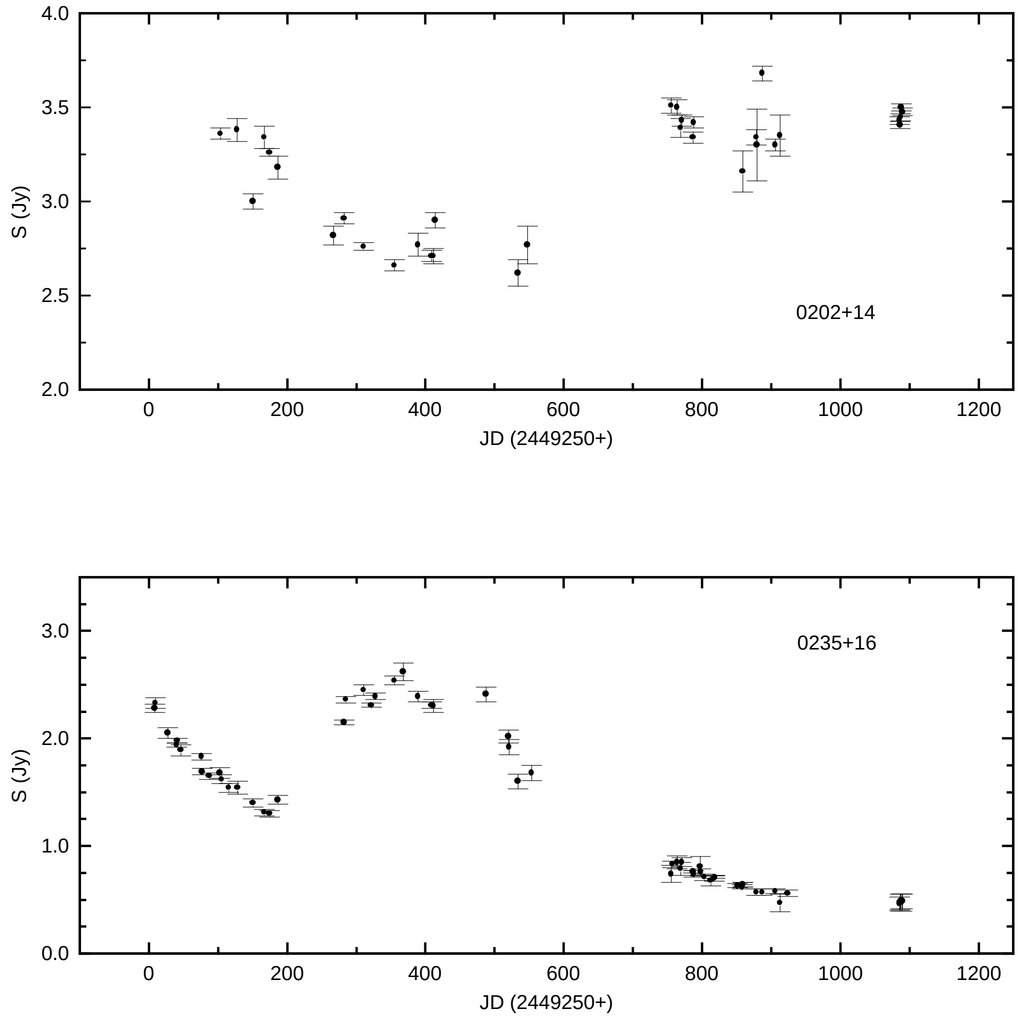

Fig. 5. Flux density recent history for 0202+14 and 0235+16 at 4.8 GHz from Michigan Observatory Database. The observations of the present paper have been added for completion (after a small flux correction due to the difference of observing frequencies).

5. Intraday variability

Intraday variability can be intrinsic to the sources or caused by propagation effects. We will consider the observed variability of 0235+16 in three possible scenarios: intrinsic shocked-in-jet models which are a natural extension of the model discussed in the previous section, superluminal gravitational models, and models based on refractive effects of the interstellar medium.

5.1. Shocks

Marscher (1990) has suggested that minor fluctuations superposed on the larger flux density flares can occur over short timescales in the shock-in-jet model when the shock encounters small turbulent features, like eddies, during its evolution along the jet. Numerical simulations (Marscher et al. 1992) have demonstrated that the dominant effect of the turbulence is to produce small fluctuations around the mean flux density as the shock moves down the jet. Detailed models, however, are limited by our scarce knowledge of the physics of hydromagnetic turbulence in relativistic compressible plasma flows.

In the case of 0235+16, where the viewing angle seems to be extremely small, we have that the size of the eddies would be of $\sim t_{\rm v} c\gamma^2(1+z)^{-1}$, where $t_{\rm v}$ is the observed variability timescale. The minimum possible Lorentz factor results fixed by the condition that in the shock's frame the brightness temperature does not exceed the Compton limit. Since for $t_{\rm v} \sim$ 1.3 days we have $T_{\rm B} \gtrsim 6.2 \times 10^{17}$ K, the Lorentz factor must be $\gamma \gtrsim 15$ for 0235+16. Adopting $\gamma \sim 15$, a value considerably larger than that assumed in the previous section, the size of the eddies is ~ 0.1 pc. In order to produce well-defined fluctuations in the flux density the thickness of the shocked region should be significantly thinner than this size, let's say $\triangle x_s \sim$ 0.01 pc. Since $\triangle x_s$ increases with the distance x traveled by the shock as $\triangle x_s \sim x\gamma_{\rm sj}^{-2}$, where $\gamma_{\rm sj}$ is the Lorentz factor of the shock in the jet-flow frame (Blandford & McKee 1976) and the energy of the shock declines gradually, it is clear that the same shock cannot be responsible for the variability observed in

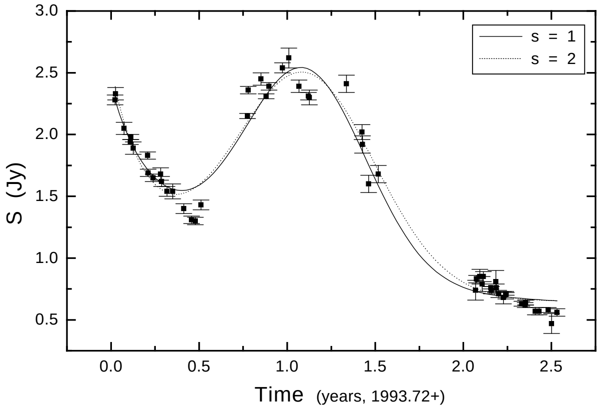

Fig. 6. Recent flux density evolution of 0235+16 fitted by shock-in-jet models with magnetic field behind the shock parallel to (a) the shock front (dashed curve) and (b) the jet axis (solid line).

1990. Besides, it seems unlikely to have exactly the same level of turbulence in very different parts of the jet. A multiple-shock model also present several difficulties if we demand that the percentage fluctuations on short timescales remain at a constant level. In first place, it is not clear how successive similar shocks could be locally generated in the parsec-scale jet. In addition, one would expect that the turbulence level should be modified by the passage of the shocks, in such a way the second shock could hardly produce fluctuation amplitudes similar to those of the first shock. In second place, even if similar shocks can be produced, they should be deformed by differential deceleration in the turbulent flow and generate, consequently, flux variations with different amplitudes (see Marscher 1990). Additional difficulties are introduced by phase effects and have been discussed by Marscher (1992).

In summary, shocks, which are very attractive to explain the large outburst, seem to be not very plausible to account for the intraday variability in 0235+16 at present. This situation, however, could change if the fluctuation index significantly varies in future observations.

5.2. Superluminal microlensing

The presence of MgII absorption features at z=0.524 in the spectrum of 0235+16 has led to several authors to discuss the characteristics of this object within a gravitational lensing model (e.g. Stickel et al. 1988, Abraham et al. 1993). However, the observed large radio outbursts cannot be explained by microlensing caused by stars in the intervening galaxy (see Kayser 1988 for a discussion on this point). By other hand, microlensing could produce the fast flickering observed at short timescales if the lensed source is not the core but a small superluminal component, like a relativistic shock in the jet. Superluminal microlensing models have been developed by Gopal-Krishna & Subramanian (1991) and Romero et al. (1995c) to explain intraday variability in some sources. When a shock with Lorentz factor γ and superluminal velocity in the plane of the lens (a star, planet or brown dwarf placed in the foreground galaxy) is gravitationally magnified, the observed flux density changes as $S(t) = S_0 A(t)$, where $A(t)$ is the total amplification produced by the contributions of all microimages (see Romero et al. 1995c for analytic expressions and details). The timescale of the flux fluctuations is $\sim 6.7 \times 10^{-16}(r_{\rm s}/{\rm cm})\gamma^{-1}(1 + {\rm z_s})$ days, where $r_{\rm s}$ is the radius of the background source. If the optical depth to microlensing is sufficiently high, several successive magnifications will produce a flickering light curve. The range of possible masses of the lenses is constrained by the requirement that the Einstein radius be larger than the source radius in the lens plane. Using the timescale of the variability observed in 0235+16 and assuming as before (Sect. 4) that $\gamma \sim 5$, we find $r_{\rm s} \sim 1.6 \times 10^{-3}$ pc and $M_{\rm len} \gtrsim 0.03\ M_{\odot}$, i.e. the shock must be very small and the lenses can be any kind of stars. If we are seeing the jet nearly head-on and the opening angle is $\sim 1^{\circ}$, the shock should be at $x \sim 0.1$ pc from the jet apex. For the largest value of γ inferred from VLBI observations of superluminal motions in the source, $\gamma \sim 30$ (Fan et al. 1996), we have $r_{\rm s}$ ~0.01 pc, $x \sim 0.6$ pc and $M_{\rm len} \gtrsim 1.5 M_{\odot}$. In both cases the shock must be lensed very close to the core, at the beginning of its path. After a short time the shock evolves in such a way that it is not any more small enough to be microlensed by stars and the mechanism fails in producing intraday variability during long periods. Once again one can introduce several similar shocks, but then similar objections to those mentioned in the previous subsection arise.

5.3. Refractive effects

All VLBI experiments show that 0235+16 is extremely compact, being unresolved at mas resolution in the range from 0.4 GHz to 22 GHz. Very high resolution (< 0.2 mas) maps obtained by Jones et al. (1984) at 22 GHz show that ~ 60 % of the total flux density comes from an unresolved core smaller than 0.1 mas at this frequency. By other hand, the absence of diffractive scintillation in this source implies a minimum angular size $\sim$ 0.01 mas at 2.7 GHz (Scheuer 1976). All this suggests that a size of $\sim$ 0.08 mas is not unreasonable for 0235+16 at 5 GHz. Refractive effects are then unavoidable.

When refractive scintillation is produced by an extended scattering medium the diameter subtended by the image of the source is a function of distance from the observer in such a way that a wide range of scales contribute to the flux density fluctuations yielding a first order structure function $D^I(\tau)$ linear in τ, for τ small (see Blandford et al. 1986). This behaviour is presented by the structure function of 0235+16, which slope in the $\log D^I - \log \tau$ space is m=1. An estimate of the expected fluctuation index is given by $\mu \sim [D^I(t_{\rm v})]^{1/2} \approx 3.7 \pm 0.9$ %, a value compatible with the observations. At large galactic latitudes the scattering is produced in a galactic disk of scale height $H \approx 500 \csc b$ pc. The relative velocity which induces the variability is dominated by the orbital Earth's velocity and the velocity of the sun, typically ~ 50 km s^{-1} (Rickett 1986). The timescale of the fluctuations is then $t_{\rm v} \sim 10\ \theta_{\rm mas}(\csc \mid b \mid)$ days $\approx$ 1.3 day for 0235+16 ($\theta_{\rm mas} \approx 0.08$ and $b \approx -39^{\circ}$). The model is also consistent with the constancy of the level of percentage fluctuations because the spectrum of the interstellar electron density is not expected to change over timescales of a few years.

The rapid variability of 0202+14 could be also due to refractive effects. In this case the structure function shows a dependence closer to $D^I(\tau) \propto \tau^2$, which is proper of scattering produced in a single screen which crosses the line of sight joining the source and the observer (Blandford & Narayan 1985). In this single-scale model the timescale is simply the crossing time of the density perturbations, $t_{\rm v} \sim L_{\rm pc}\theta_{\rm mas}/v_{\rm km\ s^{-1}}$. For $\theta_{\rm mas} \sim 1$ and $v_{\rm km\ s^{-1}} \sim 50$ we have $L_{\rm pc} \sim 170$ as a representative distance to the screen. The size scale of the density fluctuations on the screen will be in such a case $l \sim \theta L \approx 0.17$ AU. Since the line of sight to this source pass through the edge of galactic Loop II, the electron density fluctuations could be small clouds or filamentary structures associated with this old supernova remnant.

6. Final comments

The simplest explanation for the rapid variability observed in 0202+14 and 0235+16 is refractive scintillation. In the case of 0235+16 this interpretation can also account for the fact that the fluctuation index has remained nearly constant during large changes of the total flux density occurred in the last years. However, interpretations based on relativistic shock fronts moving down the parsec-scale jet and gravitational microlensing cannot be completely ruled out. The existence of relativistic shocks in the jet is supported by the detection of superluminal components and the temporal evolution of the total flux density over timescales of months and years, while the presence of an intervening foreground galaxy is clear. Future simultaneous radio-optical intraday variability observations could provide a definitive answer.

Several variability studies at different wavelengths (Reich et al. 1993, Valtaoja & Teräsranta 1995, Poht et al. 1996) show that γ-ray outbursts precede radio outbursts or occur in the initial phases of a high radio frequency flare. Consequently, the γ-rays seem to be produced when a shock is formed near the core. The subsequent radio outburst follows from the shock evolution far out along the jet. Even in this scenario no correlations between radio intraday variability and fast variations in the γ-ray flux should be expected. The rapid variable γ-ray emission (as observed in 3C279, for instance) originates in the smallest region which is transparent to pair production, a region located at distances of $\sim 10^{-3}$ pc from the central black hole (see Becker & Kafatos 1995, also Blandford & Levinson 1995). Instead, intraday radio variability, if considered as intrinsic to the source, is produced in a different small region located behind the shock front far down the parsec-scale jet, where the plasma is transparent to cm-wavelengths and turbulence produces small eddies in the flow. The intraday variations will be random fluctuations around the mean flux density, with no simultaneous or quasi-simultaneous correlations with fast flux changes at γ-ray energies above a few MeV. If the jet is formed by an electron-positron plasma, however, some correlation might be expected at COMPTEL energies due to local variations of the annhilation rate (see Romero 1996 for a detailed discussion). If the γ-ray flare points out the formation of a new shock in the inner jet, some time after its detection by EGRET (weeks or months depending on the Lorentz factor of the shock) the intraday fluctuation index at cm-wavelengths should be significantly increased. If the relative amplitude and the timescales of this variability remains nearly constant through very different states of the overall source, as our observations show for the particular cases of 0235+16 and 2251+15, then the shock-in-jet models should explain how the shocked region can keep a thickness small enough to yield well defined fluctuations over relatively large distances on the inner jet of the blazars. Beyond these problems, in many sources the simplest picture for radio intraday variability seems to be one related with refractive processes in the interstellar medium.

Acknowledgements. We thank the kind hospitality of the NRAO staff at Green Bank during the observations and especially Dana Balser and Ron Maddalena for their assistance. It is also a pleasure to thank Dr. John Mattox for useful remarks which helped us to improve the original manuscript. This research has made use of the data from the University of Michigan Radio Astronomy Observatory which is supported by the National Science Foundation and by funds from the University of Michigan. J.C.C. thanks J. Torres, Dean of the Humacao Campus of UPR, for travel support. L.M.W. is supported by Office of Navy Research, Grant N0014-94-1-1065 and Cooperative Agreement HDR 9153687. Partial support from CONICET is also gratefully acknowledged. This research was also partially supported by ANPCT, GRANT PMT-PICT 0388.

References

Abraham R.G., Crawford C.S. Merrifield, M.R., et al. 1993, ApJ 415, 101
Baars J.W.M., Genzel R., Pauling-Toth I.I.K., Witzel A. 1977, A&A 61, 99
Becker P.A., Kafatos M. 1995, ApJ 453, 83
Benford G. 1992, ApJ 391, L59
Blandford R.D., McKee C.F. 1976, Phys. Fluids 19, 1130
Blandford R.D., Königl A. 1979, ApJ 232, 34
Blandford R.D., Narayan R. 1985, MNRAS 213, 591
Blandford R.D., Narayan R., Romani R. 1986, ApJ 301, L53
Blandford R.D., Levinson A. 1995, ApJ 441, 79
Bloom S.D., Marscher A.P. 1996, ApJ 461, 657
Burbidge E.M., Beaver E.A., Cohen R.D., et al. 1996, AJ 112, 2533
Camenzind M., Krockenberger M. 1992, A&A 255, 59
Charlot P. 1991, A&A 229, 51
Chu H.S., Baath L.B., Rantakyrö F.T., et al. 1996, A&A 307, 15
Dermer C.D., Schlickeiser R., Mastichiadis A. 1992, A&A 256, L27
Dermer C.D., Schlickeiser R. 1993, ApJ 416, 458
Fan J.K., Xie G.Z., Wen S.L. 1996, A&AS 116, 409
Fichtel C.E. 1994, ApJS 90, 917
Gaidos J.A., Akerlof C.W., Biller S., et al. 1996, Nat 383, 319
Gopal-Krishna, Subrahmanian K. 1991, Nat 349, 766
Hardee P.E. 1990, in Parsec-Scale Radio Jets, ed. Zensus J.A. and Paerson T.J., Cambridge University Press, Cambridge, p. 266
Hartman R.C., Bertsch D.L., Dingus B.L., et al. 1993, ApJ 407, L41
Heeschen D.S., Krichbaum T., Schalinski C.J., et al. 1987, AJ 94, 1493
Hughes P.A., Aller H.D., Aller M.F. 1985, ApJ 298, 301
Hughes P.A., Aller H.D., Aller M.F. 1989, ApJ 341, 54
Hunter S.D., Bertsch D.L., Dingus B.L., et al. 1993, A&A 272, 59
Jones D.L., Baath L.B., Davis M.M., et al. 1984, ApJ 284, 60

Kayser R. 1988, A&A 206, L8
Krichbaum T., Quirrenbach A., Witzel A. 1992, in Variability in Blazars, eds. Valtoaja E. and Valtonen M., Cambridge University Press, Cambridge, p. 330
Madejski G., Takahashi T., Tashiro M., et al. 1996, ApJ 459, 156
Maraschi L., Ghisellini G., Celotti A. 1992, ApJ 397, L5
Marscher A.P. 1980, ApJ 235, 386
Marscher A.P., Gear W.K. 1985, ApJ 298, 114
Marscher A.P. 1990, in Parsec Scale Radio Jets, eds. Zensus J.A., Pearsen T.J., Cambridge University Press, Cambridge, p. 236
Marscher A.P. 1992, in Physics of Active Galactic Nuclei, eds. Duschl, W.J. and Wagner, S.J., Springer-Verlag, Heidelberg, p.510
Marscher A.P., Bloom S.D. 1992, in Proc. of the Compton Observatory Science Workshop, eds. Schrader C.R., Gehrels N., Dennis B., NASA cp-3137, p. 346
Marscher A.P., Gear W.K., Travis J.P. 1992, in Variability in Blazars, eds. Valtoaja E. and Valtonen M., Cambridge University Press, Cambridge, p. 85
Mattox J.R., Wagner S.J. 1996, in Blazar Continuum Variability, eds. Miller H.R., Webb J.R., Noble J.C., ASP Conf. Series 110, p.352
Mattox J.R., Wagner S.J., Malkan M., et al. 1997a, ApJ 476, 692
Mattox J.R., et al. 1997b, ApJ, in press
Moore R.L., Stockman H.S. 1981, ApJ 243, 60
Nilsson K., Charles P.A., Pursimo T., et al. 1996, A&A 314, 754
Noble J.C., Miller H.R. 1996, in Blazar Continuum Variability, eds. Miller H.R., Webb J.R., Noble J.C., ASP Conf. Series 110, p.30
Nolan P.L., Bertsch D.L., Fichtel C.E., et al. 1993, ApJ 414, 82
O'Dell S.L., Dennison B., Broderick J.J., et al. 1988, ApJ 326, 668
Pohl M., Mücke A., Reich W., et al. 1996, in Blazars Continuum Variability, eds. Miller H.R., Webb J.R., Noble J.C., ASP Conference Series, Vol 110
Qian S.J., Quirrenbach A., Witzel A., et al. 1991, A&A 241, 15
Quirrenbach A., Witzel A., Krichbaum T., et al. 1989a, Nat 337, 442
Quirrenbach A., Witzel A., Quin S.J., et al. 1989b, A&A 226, L1
Quirrenbach A., Witzel A., Wagner S., et al. 1991, ApJ 372, L71
Quirrenbach A., Witzel A., Krichbaum T., et al. 1992, A&A 258, 279
Rabbette M., McBreen B., Steel S., et al. 1996, A&A 310, 1
Reich W., Steppe H., Schlickeiser R., et al. 1993, A&A 273, 65
Rickett B.J. 1986, ApJ 307, 564
Romero G.E., Combi J.A., Colomb F.R. 1994, A&A 288, 731
Romero G.E. 1995, ApSS 234, 49
Romero G.E., Benaglia P., Combi J.A. 1995a, A&A 301, 33
Romero G.E., Combi J.A., Vucetich H. 1995b, ApSS 225, 183
Romero G.E., Surpi G., Vucetich H. 1995c, A&A 301, 641
Romero G.E. 1996, A&A 313, 759
Scheuer P.A.G. 1976, MNRAS 177, 1p
Sikora M., Begelman M., Rees M. 1994, ApJ 421, 153
Simonetti J.H., Cordes J.M., Heeschen D.S. 1985, ApJ 296, 46
Stickel M., Fried J.W., Khür H. 1988, A&A 198, L13
Valtoaja E., Teräsranta H. 1995, A&A 297, L13
von Montigny C., Bertsch D.L., Chiang J., et al. 1995, ApJ 440, 525
Wagner S., Sanchez-Pons F., Quirrenbach A., et al. 1990, A&A 235, L1
Witzel A., Heeschen D.S., Schalinski C., et al. 1986, Mitt Astron. Ges. 65 , 239

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.