VARIABILITY IN THE SOUTHERN BLAZARS PKS 1921-293 AND PKS 2155-152

G.E. ROMERO *,† and J.A. COMBI *
Instituto Argentino de Radioastronomía

(Received 20 September, 1994; accepted 23 February, 1995)

Abstract. We report results of 1435 MHz rapid variability observations of the southern extragalactic sources PKS 1921-293 and PKS 2155-152. Both objects displayed variability in their flux densities on timescales of the order of one and two weeks, respectively. A brief discussion on the origin of this variability is presented, with a comparison of different models that could account for the observations.

1. Introduction

Since flux density variability on timescales of days at centimeter wavelengths was clearly established as a common property of compact extragalactic radio sources by Simonetti *et al.* (1985) and Heeschen *et al.* (1987), most of the northern blazars have been monitored with high temporal resolution at different radio wavelengths (see Krichbaum *et al.*, 1992 for a review). Conversely, the behaviour of southern sources remains up to now mostly unexplored. In order to fill this gap an extensive monitoring program is currently under way at the Instituto Argentino de Radioastronomía (IAR). Previous results for some selected objects have been already published by Luna *et al.* (1993) and Romero *et al.* (1994). In the present paper we present and discuss *inter*day variability observations of the southern BL-Lacertae objects PKS 1921-293 and PKS 2155-152.

The source PKS 1921-293 (also called OV-236) has been classified as a BL-Lac type object by Wills and Wills (1981) in spite of the presence of two narrow emission lines identified as [OII] and [OIII] $\lambda\lambda$ 3727, 5007 with a redshift $z = 0.352$, mainly due to its high degree of linear polarization and its strong radio (Dent and Balonek, 1980) and optical (Wills and Wills, 1981) variability. Ledden and O'Dell (1985) carried out measurements of the X-ray emission of the source with the Einstein Observatory finding a flux density value of ~ 0.56 μJy. The southern hemisphere VLBI experiment by Preston *et al.* (1989) was capable of resolving the object, which can be fitted by a single elliptical Gaussian with a flux density of 6.6 Jy and a maximum size of 5 mas at 2.3 GHz.

PKS 2155-152 (also known as OX-192) has been proposed as a BL-Lac object by Craine *et al.* (1976). It has displayed radio variability on timescales of months

* Fellow of CONICET.
† G.E. Romero, Instituto Argentino de Radioastronomía, C.C.5, (1894) Villa Elisa, Bs. As., Argentina.

Astrophysics and Space Science **229:** 23–32, 1995.

(Altschuler and Wardle, 1976; Giacani and Colomb, 1988). Burbidge and Hewitt (1992) give a redshift $z = 0.672$ for this object (see references therein). VLA observations by Wardle *et al.* (1984) show a source dominated by an unresolved component. Unfortunately, no VLBI observations are available for this active radio source.

In the next section we present our variability observations of these two interesting southern blazars obtained at 1435 MHz with one of the single-dish telescopes of the IAR.

2. Observations and Data Analysis

The observations were made during a lapse of four months in 1992, from Julian Date (JD) 2448818 to JD 2448951, with the facilities of the IAR. A 30 m single-dish telescope with a total power receiver of two channels was used. The observing central frequency was 1435 MHz, with a bandwidth of 20 MHz. At this frequency the HPBW of the antenna is 30 arc minutes. The temperature of the system was 90 K, the rms noise on a single record $\sim$ 60 mK, and the integration time was 0.48 s. The digitalized signal and the telescope position were simultaneously acquired by an IBM computer. All observations were performed at night in order to minimize both changes in telescope structure due to uneven heating and possible terrestrial interfering signals.

The sources under study and two strong, steep-spectrum, well-known non-variable radio sources (PKS 1932-46 and PKS 2152-69) were observed in each session. The flux density scale was determined assuming a value of 30.4 Jy for PKS 2152-69 (Wills 1975). Each measurement was obtained performing 9 'cross scans' through the source position. The scanning velocity was 10° per minute and the length of the scans was 4° (i.e. $\sim$8 HPBW). The standard reduction procedure was the same used in previous observations (see Luna *et al.*, 1993 and Romero *et al.*, 1994 for details). The final (rather conservative) errors are about $\sim$ 5 % of the mean flux density of the sources. The correct state of the receiver and related systems can be checked out by means of the light curves of the calibration sources which look like very stable throughout the whole observational campaign (e.g. Figure 2c).

The presence of variability over the given error bars can be tested with the criterion of Kesteven *et al.* (1976), which is usually applied in variability studies (e.g. Altschuler, 1982, 1983; Giacani and Colomb, 1988; Luna *et al.*, 1993; Romero *et al.*, 1994). According to this criterion a given source is classified as variable if the probability $P(x^2)$ of exceeding the value of

$$x^2 = \sum_{i=1}^{n} \epsilon_i^{-2} (S_i - < S >)^2 \tag{1}$$

TABLE I
Variability parameters

Source	$< S >$ [Jy]	n	μ_s [%]	Y [%]	FV	x^2	$P(x^2)$ [%]
PKS 1921-293	11.5	16	3.8	11.2	0.09	41.9	0.02
PKS 2155-152	3.3	23	12	35.9	0.2	101.3	<<0.1

by chance is < 0.1 %, and as nonvariable if this probability is > 0.5 %. For probability values such that 0.1 %$\leq P(x^2) \leq 0.5$ % the light curves must be inspected point-by-point in order to obtain a correct diagnostic. In Equation (1), n is the number of measurements, ϵ_i is the error corresponding to the measured value S_i of the flux density, and $< S >$ is the mean weighted flux density of the source given by:

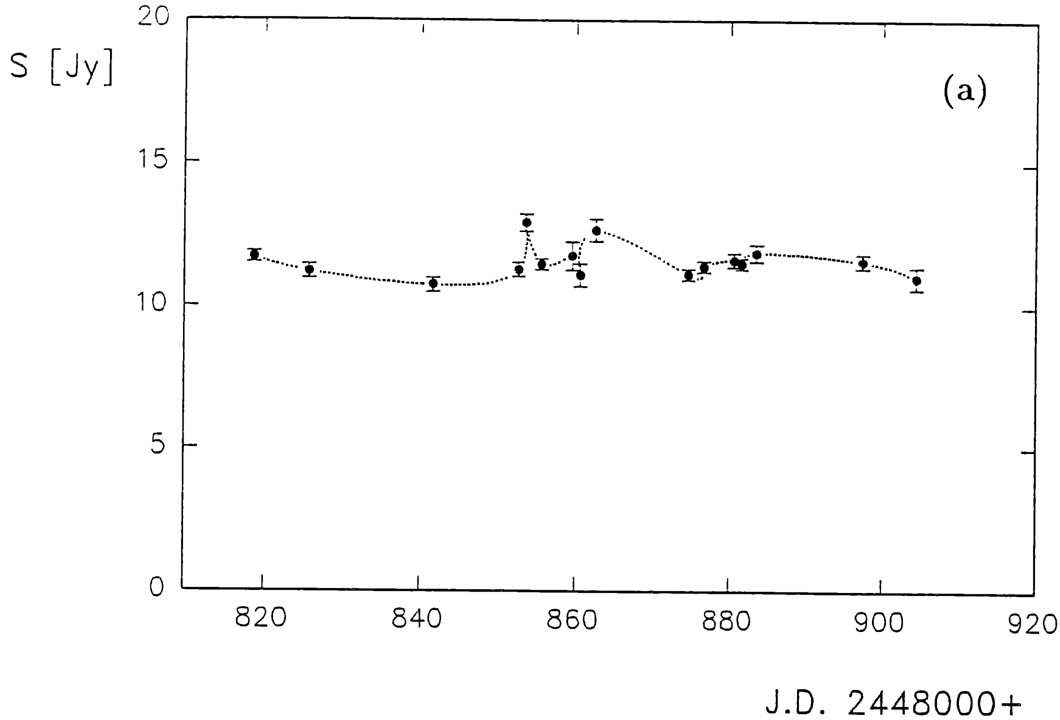
$$< S >= \frac{\sum_{i=1}^{n} \epsilon_i^{-2} S_i}{\sum_{i=1}^{n} \epsilon_i^{-2}}. \tag{2}$$

If errors are random, x^2 should be distributed as χ^2 with $n-1$ degrees of freedom. The application of this criterion to our data for PKS 1921-293 and PKS 2155-152 shows that both sources present variability in their light curves (see Table I).

3. Results

Light curves of both objects are shown in Figure 1. For each source we have also computed the fluctuation index $\mu = 100\,\sigma_S < S >^{-1}$, the variability amplitudes $Y = 3\sqrt{\mu_s^2 - \mu_{cal}^2}$ (where μ_s and μ_{cal} are the fluctuation indexes for source and calibrator respectively), and the fractional variability $FV = (S_{max} - S_{min})(S_{max} + S_{min})^{-1}$. The values of these parameters, together with the number of measurements n, the value of the variability estimator x^2 and its probability $P(x^2)$, are given in Table I.

Residual light curves, estimated as $R(t) = 100\,(S(t) - {<}S{>})\,{<}S{>}^{-1}$, have the same shape of the flux density ones, but they have the advantage of allowing a quick visual estimate of the magnitude of the variations. Figure 2 shows the residuals for both BL-Lac objects and for the calibration source PKS 2152-69 (in the case of PKS 1921-293 just the part of the curve where the variations are present is shown). The calibrator exhibits a very flat curve with a value of $x^2 \approx 0.9$ such that $P(x^2) \approx 92.4$ %, and there is consequently no variability over its error bars.



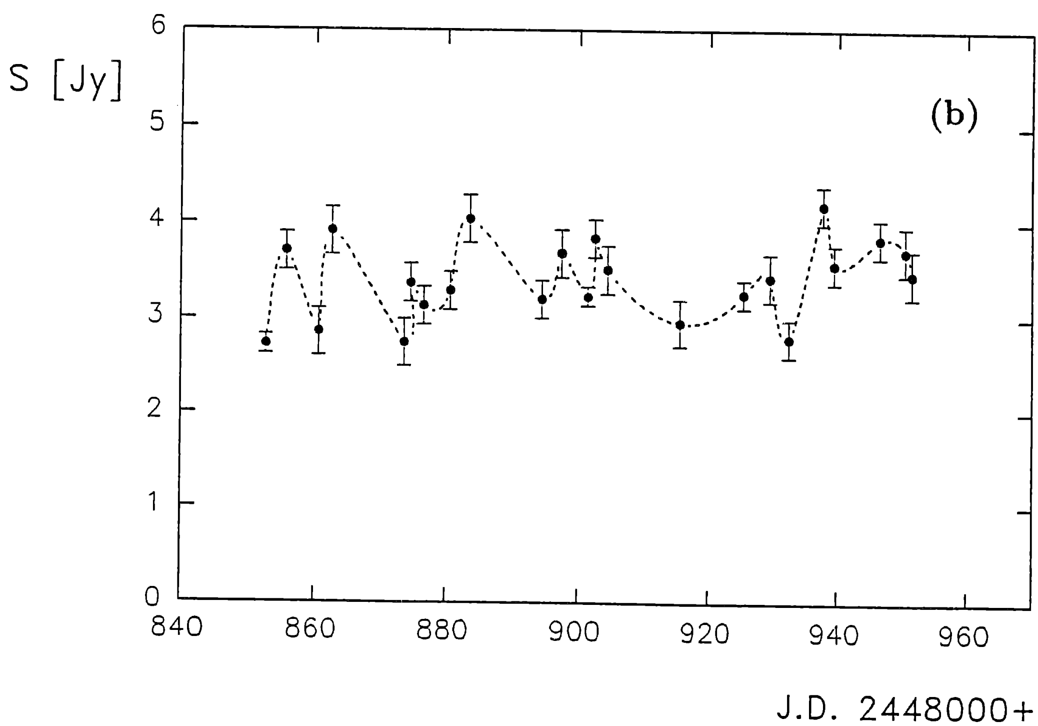


Fig. 1. Light curves for (a) PKS 1921-293 and (b) PKS 2155-152.

This confirms that the variability in PKS 1921-293 and PKS 2155-152 is real and not an effect of instrumental errors. A rapid view over the light curves shows that in the case of PKS 1921-293 the variability is concentrated in a lapse of the order of a

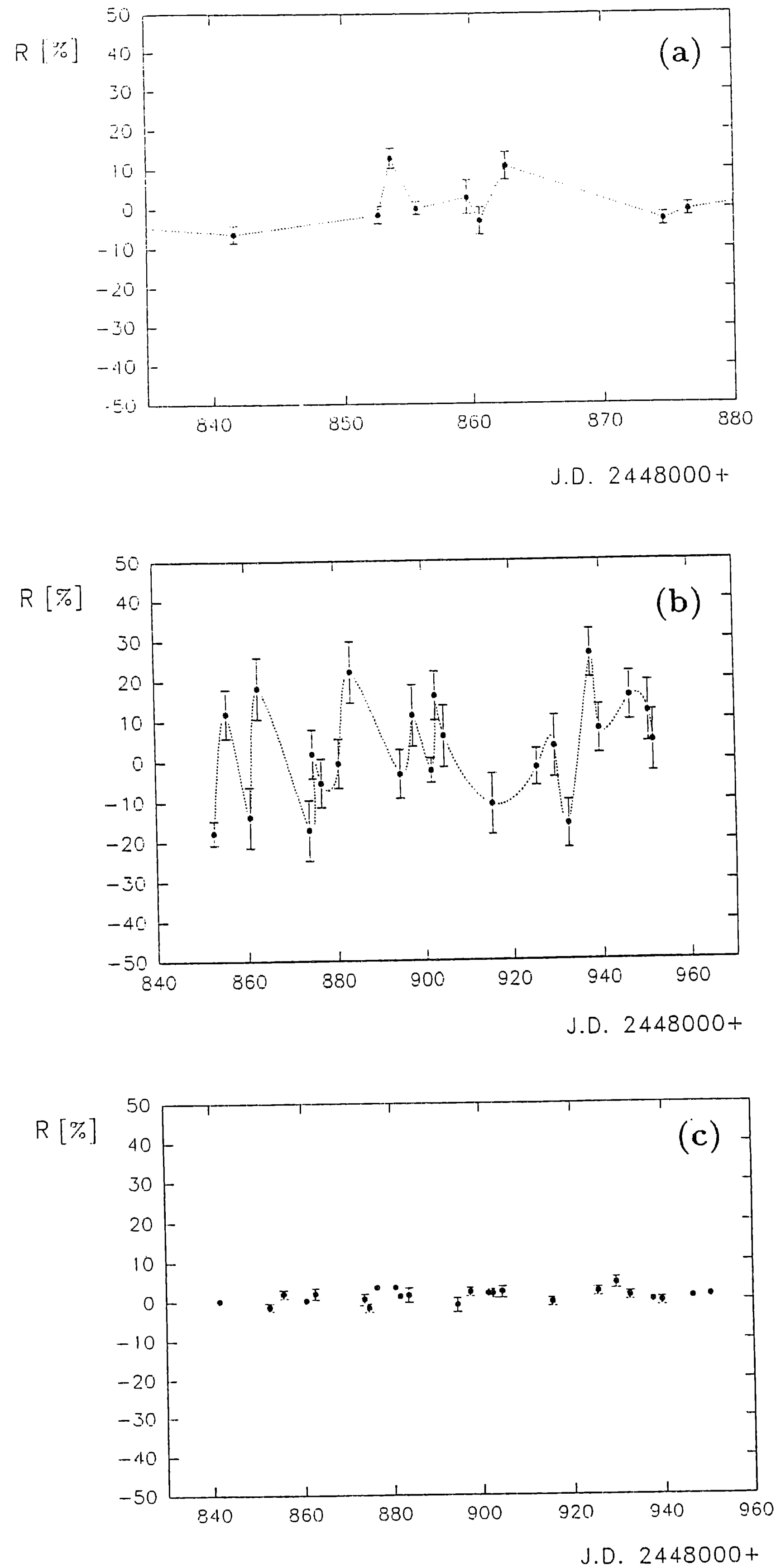


Fig. 2. Residuals 'light curves' for (a) PKS 1921-293 (just the period of activity), (b) PKS 2155-155, and (c) calibration source PKS 2152-69.

month, approximately from JD 2448841 to JD 2448874. Conversely, the variations are present throughout the whole observing period for PKS 2155-152. In the next section we shall outline the main possible interpretations for these behaviours.

4. Possible Interpretations

4.1. PKS 1921-293

The timescale of the variations for this source is $\tau \sim 7.5$ days. If this variability is interpreted as intrinsic to the source, the brightness temperature straightforwardly implied for the incoherent emitting synchrotron plasma in the object should be extremely high, say $T_B \geq 2.1 \times 10^{18}$ K (for $H_\circ = 75$ km s^{-1} Mpc^{-1} and $q_\circ = 0.15$ in a Robertson-Walker universe). This is 6 orders of magnitude greater than the inverse Compton limit for an incoherent synchrotron source. However, such a high brightness temperature can be reconciled with the standard picture of blazars introducing relativistic effects (e.g. Marscher, 1992). For instance, we can consider that the variability arises when a relativistic thin shock strikes a feature (e.g. an electron density inhomogeneity) in a jet which forms a small angle ψ with the line of sight. In such a case, the real brightness temperature of the plasma is related with the apparent value derived from variability data by $D_s \sim (T_{app}/T_B)^{1/5}$, where $D_s = \gamma_s^{-1}(1 - \beta_s \cos\psi)^{-1}$ is the Doppler factor of the shock, and $\gamma_s = (1 - \beta_s)^{-1/2}$ is the corresponding bulk Lorentz factor. In order to avoid the inverse Compton catastrophe in PKS 1921-293, Doppler factors $D_s \geq 18.5$ are required. For favorable viewing angles ψ such that $\cos\psi \sim \beta_s$, we have $D_s \sim \gamma_s$ and, consequently, the bulk Lorentz factor of the plasma should be at least of ~ 18.5. Bulk Lorentz factors derived by direct VLBI seem to fall mainly in the range $1 \leq \gamma_s \leq 20$ (Porcas, 1987), and there are theoretical reasons to think that $\gamma_s \sim 20$ represents an upper limit for bulk Lorentz factors in superluminal radio sources (Abramowicz 1992). Assuming the minimum value allowed for γ_s, we estimate the linear size of the feature along the jet from the observed variability timescale as $l \sim 1.6$ pc (see Romero *et al.*, 1995a for details of the model). Phase effects for the case in which the opening angle of the jet is lesser than the viewing angle introduce additional constraints that allow to compute the jet radius (in the assumption that the inhomogeneity fills the whole width of the beam, see Marscher 1992). We estimate $r_j \approx 0.09$ pc, which means that for a typical opening angle of $\sim 1°$ the shock was propagating at a distance of ~ 5 pc from the jet apex when it produced the variability. Thus, in this picture, the variability is originated in the parsec-scale jet when a relativistic shock 'illuminates' a feature in the underlying quiescent flow. Bending jets (Marscher, 1990, Gopal-Krishna and Wiita, 1992) represent another alternative. In all these models it is important that the thickness of the shocked region be considerably smaller than the size of the inhomogeneities (or the distance between bends) in such a way that the variations do not be smeared away by the shock propagation. If the shocks are produced at the injection point of the relativistic particles and then propagate down the jet, the distance at which the variations should occur is a strong constraint due to the progressive broadening of the shock during its propagation (see Blandford and McKee, 1976). The ratio between the thickness of the shocked region to the distance from the origin is ~ 0.16 for PKS 1921-293, a rather small value, which in the absence of additional multifrequency or polarimetric data would suggest certain caution in the applicability of the shock-in-jet picture.

Some problems of the shock-in-jet model, especially those of the thickness of the shock, can be avoided by abandoning the incoherent model for the emitting plasma. Benford (1992) has suggested that rapid variations could be the result of a coherent enhancement of the flux density produced when the relativistic beam finds on his path a low-density thermal plasma. Cavitons generated by plasma instabilities could then scatter coherently the electrons producing a fast variation without requirements of high bulk Lorentz factors for the emitting region. This alternative intrinsic approach needs some additional assumptions such as the presence of a thermal plasma with a density about a factor 10^{-2} lesser than the beam density in the innermost region of the source, and it certainly implies a rather dramatic change in our present view of the physical processes in AGNs, which strongly rests on the incoherent emission mechanism (Pacholczyk, 1970).

Alternatively, refractive effects by the interstellar medium on the light path can be considered as a possible cause of the variations. The standard model of refractive interstellar scintilliation (RISS) developed by Rickett (1986) and Blandford *et al.* (1986) cannot be applied to PKS 1921-293 because the variability observed in this source seems to be concentrated within a small period where just two peaks can be appreciated. However, this behaviour can be considered as the effect of an extreme scattering event produced by a small ionized structure in the interstellar medium which drifts through the line of sight with PKS 1921-293 originating a strong focusing with the consequent enhancement of the flux density (Fiedler *et al.*, 1987). In this picture, the two peaks observed in the light curve could correspond to the caustic formation process described by Romani *et al.* (1987). Typical parameters for these small features in the interstellar medium have been discussed by Romani (1988).

4.2. PKS 2155-152

The variability timescale for this source is $\tau \sim 15.5$ days. The derived brightness temperature is $T_B \geq 5.8 \times 10^{17}$ K. As we have outlined for PKS 1921-293, the variability of this object could be interpreted as the effect of the interaction of a relativistic shock with several features placed along the parsec-scale jet of the source. A bulk Lorentz factor $\gamma_s \sim 14.2$ and inhomogeneities of a typical size ~ 1.5 pc are required. The radius of the jet results $r_j \approx 0.11$ pc and the distance from the features to the jet's origin is then $x \sim 6.3$ pc. The ratio between the shock thickness and x is of ~ 0.11. The propagation of the shock through a turbulent jet can also reproduce this kind of behaviour in extragalactic radio sources (see, for instance, Marscher *et al.*, 1992). In Benford's picture the beam opens its way through the turbulent environment of the central accreting supermassive black hole where changes in density of the underlying plasma are the cause of the multiple suppression and restoring of the coherent emission which yields the variability.

An extrinsic alternative is also plausible in the case of this source. A succession of AU-sized clouds (e.g. thin filaments belonging to the expanding shell of an old supernova remnant) can produce such a kind of variability when passing through the line of sight with the mas central component of the source (see, for instance, Wambsganss *et al.*, 1989). In order to compute the electron density of these clouds the angular size at the observing frequency of the background source should be known.

5. Final Comments

In Section 4 we have mentioned how our variability data for PKS 1921-293 and PKS 2155-152 can be interpreted from both an intrinsic and an extrinsic-to-source point of view. Simultaneous radio and optical observations could provide a tool for deciding between both models, especially if the variations present a clear correlation. Multifrequency radio observations could also be used for testing the models: the amplitude of the variability should increase with the wavelength in the case of the refractive origin. Polarization information could be very useful in this task too; for instance, large rotations in the polarization position angle (more than 180°) are difficult to explain in an extrinsic way. Unfortunately, in the present case we are restricted to the total-power data available at the sole frequency of 1435 MHz. Any present discussion, consequently, should be circumscribed to the assumptions of each model and the circumstantial evidence about them.

Bulk Lorentz factors of the order of those required for the intrinsic approach have been already observed in a few sources, but they seem to be very exceptional (Porcas, 1987, and references therein). Conversely, the existence of small concentrations of ionized interstellar medium on the line of sight with the objects is a likely hypothesis. In fact, PKS 1921-293 ($l \approx 9.35°$, $b \approx -19.6°$) and PKS 2155-152 ($l \approx 40.65°$, $b \approx -48°$) are located behind the southern ridges of the Galactic Loops I and II respectively. These regions of enhanced continuum emission are usually considered as old supernova remnants (Berkhuijsen *et al.*, 1971; Blandford and Cowie, 1982). Clouds crushed by the expanding shock front of the explosion can produce filamentary structures in the outer ridges of the Loops (e.g. Elliott, 1970), which could be responsible for refracting the light from distant background sources with small angular sizes. Distances to the different Loops are in the range of 50-300 pc (Haslam *et al.*, 1971). At such distances, filamentary AU-sized clouds could produce the variations. These considerations, however, are not sufficient for establishing the origin of the observed phenomena.

In conclusion, the present observational data cannot provide enough elements of judgement to favour either an intrinsic or extrinsic cause for the flux density variations. In order to provide new evidence on the nature of the variability in these objects, we have included both sources in a day-to-day monitoring program currently under way at the IAR (Romero *et al.*, 1995b). Additionally, future multifrequency observations should be encouraged for a better understanding of the origin of this kind of variability.

Acknowledgements

We are grateful to S.E. Pérez-Bergliaffa and P. Benaglia for readings of the manuscript. The authors were partially supported during this work by two CONICET Research Grants.

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