Violently variable blazar 0524+034 as seen by EVN, VLBA, and VSOP

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Abstract

The blazar 0524+034 has been identified as a violently variable, possibly IDV source, by the survey conducted with the RATAN–600 radio telescope, with variability timescale ranging from a week to several years. The quasi-simultaneous 6 cm VSOP and 2 cm VLBA observations have been conducted in 2002. Based on these and our previous VLBI measurements we conclude that the object has a compact core–jet structure with a bent mas-scale jet extending to about 3 mas toward P.A. about $-90°$. The combination of VLBA and VSOP data allows us to trace the base of the compact jet at the mas scale which is likely to be responsible for the rise in total flux density detected by RATAN before the epoch of VSOP observation. On the basis of available data we discuss possible intrinsic and extrinsic reasons of the rapid variability.

Observations

Single dish long- and short-term broad-band total flux spectra observations (Figures 1, 2) were made at 31, 13, 7.7, 3.9, 2.7, and 1.4 cm, simultaneously at all frequencies, with the RATAN 600 m ring radio telescope (for the method of observations and data processing see Kovalev et al. 1999; Gorshkov et al. 2000). The horizontal localization of the stationary antenna horns at the RATAN–600 provide the spectral responses during 1–2 minutes in the transit mode of meridional observations.

In 1999, February and September, we observed this object with the European VLBI Network at 6 cm (see images in Figure 3). Observations were done with the EVN+ array of 9 antennas: Effelsberg 100 m, HartRAO 25 m, Jodrell Bank 26m, Medicina 32 m, Noto 32 m, Phased Westerbork, Shanghai 25 m, Torun 32 m, Urumqi 25 m.

In 2002, February and March, 2 cm VLBA and 6 cm VSOP observations were preformed. A VLBA image is presented in Figure 3. Unfortunately, only 3 ground-based telescopes successfully participated in the VSOP run (Mopra 22 m, Hobart 26 m, and Shanghai 25 m). Thus, the data are not enough to construct a map with sufficient dynamical range; we used the (u,v) model fit to estimate parameters of the structure.

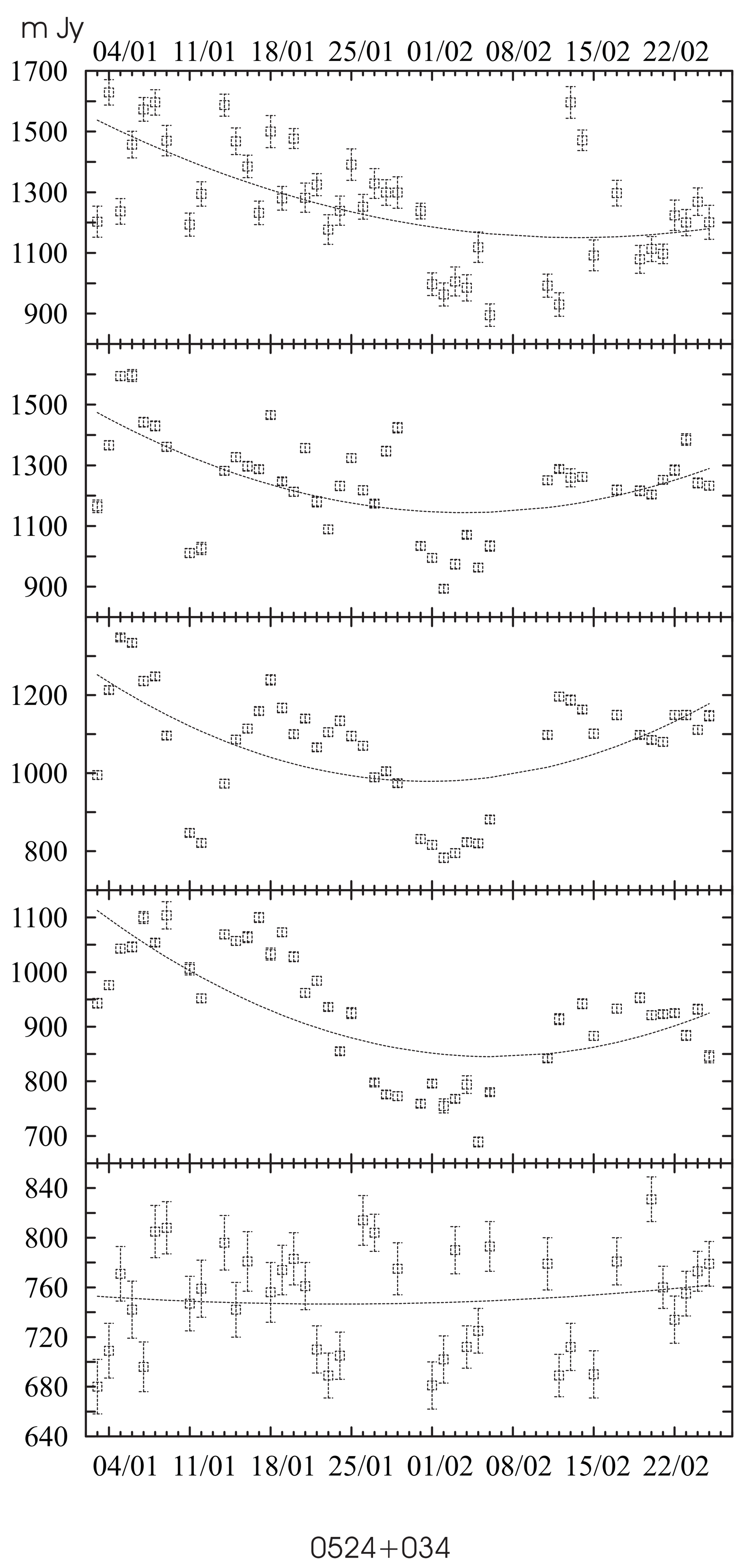

Figure 2. Light curves based on daily RATAN–600 observations of 0524+034 at 21.7, 11.1, 7.7, 3.9, 2.3 GHz (top to bottom, respectively) in January and February, 1998. The characteristic time scale of $\sim$ 10 days was revealed by observations at the four highest frequencies. Correlation between the light curves at these frequencies was found to be more than 99%.

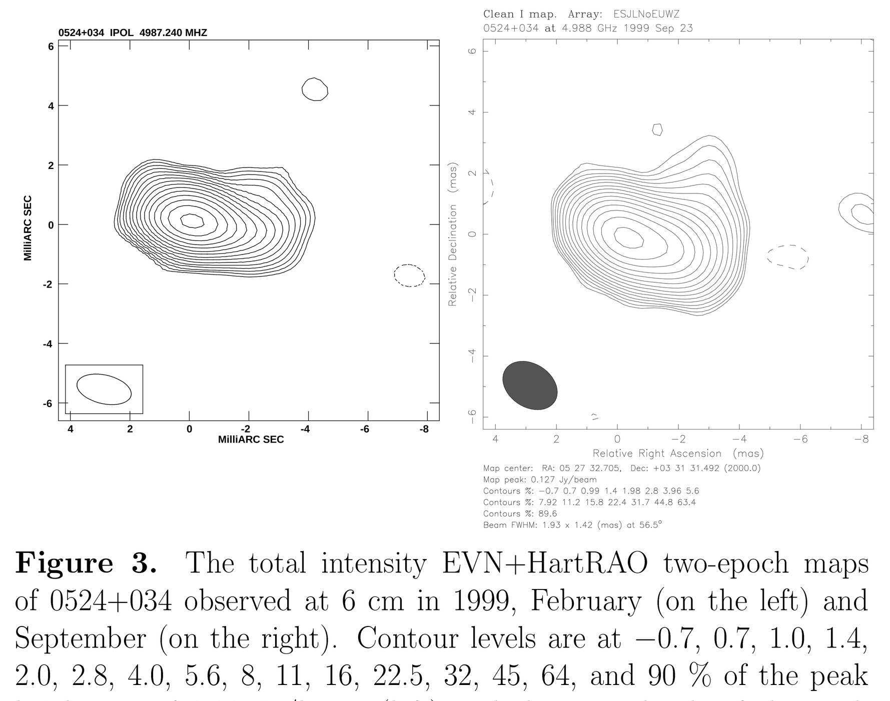

Figure 3. The total intensity EVN+HartRAO two-epoch maps of 0524+034 observed at 6 cm in 1999, February (on the left) and September (on the right). Contour levels are at -0.7, 0.7, 1.0, 1.4, 2.0, 2.8, 4.0, 5.6, 8, 11, 16, 22.5, 32, 45, 64, and 90 % of the peak brightness of 0.20 Jy/beam (left) and the same levels of the peak brightness of 0.13 Jy/beam (right).

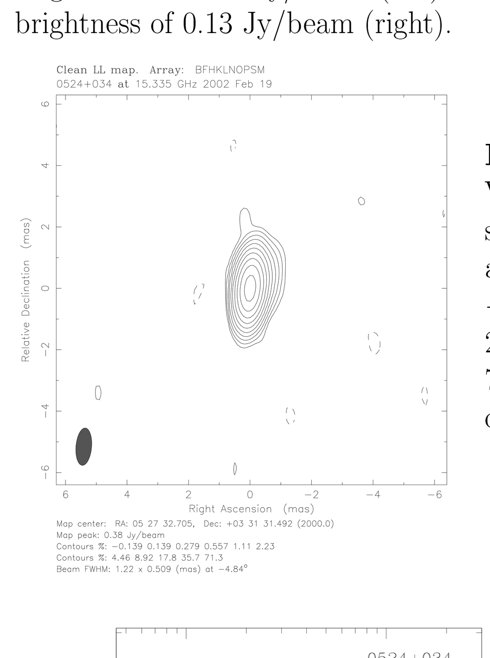

Figure 4. The total intensity VLBA map of 0524+034 observed at 2 cm in 2001, February. Contour levels are at -0.14, 0.14, 0.28, 0.56, 1.1, 2.2, 4.5, 8.9, 17.8, 35.7, and 71.3 % of the peak brightness of 0.38 Jy/beam.

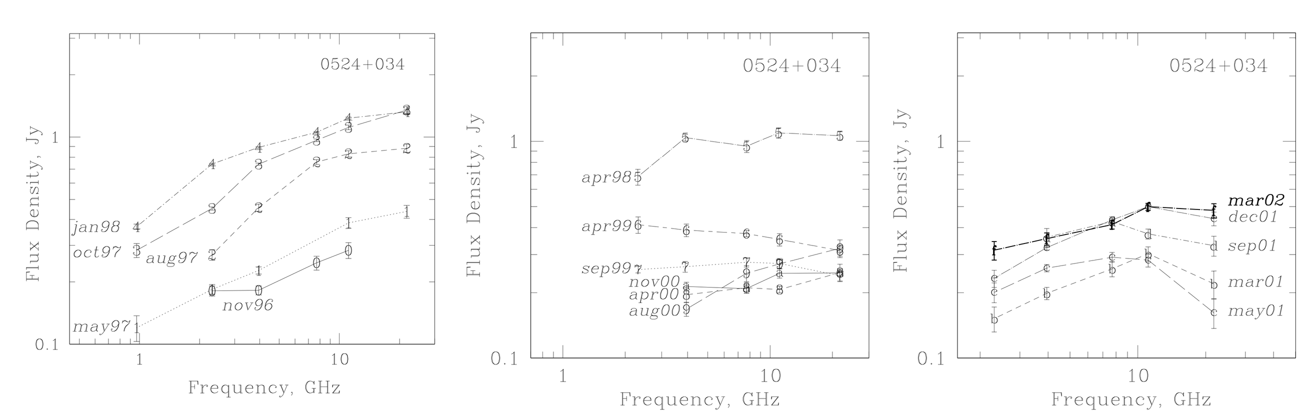

Figure 1. Long-term RATAN–600 broad band spectrum variability of 0524+034. The observations presented here cover the period from November 1996 through March 2002. The ascending flux density is presented on the left panel; descending, on the central; the recent flare, on the right.

Results and Discussion

The object 0524+034 was first detected in the Zelenchuk survey in 1979, and later its flux was found to vary by a factor of more than ten with a characteristic time scale of several years (see Figure 1). The source can be identified as a BL Lacertae object (its optical spectrum contains no emission lines, Chavushyan et al. 2000). A flux density variability on a time scale less than ten days was found in the simultaneous spectra observations carried out with the RATAN–600 radio telescope in 1998 (Figure 2).

The recent broad-band spectrum measurements were conducted nearly to the EVN+ experiment. The rapid changes of the broad-band spectrum were confirmed, although the flux had dropped several times since 1998. We have made an analysis of the first and the second order structure function and correlation function for available multi frequency light curves. Rapid variability in the source 0524+034 with a time scale of about six days was detected. The variations bear the character of shot noise and result from damping pulses of white noise with a limited spectrum. The variations are correlated at all frequencies at which variability parameters can be determined, including the optically thick part of the spectrum. In this part of the spectrum, we observe an increase of the correlation time scale. For the variable component, we infer power index of the initial electron energy distribution $\gamma = 1.4$. This possibly most compact feature should be located in the immediate vicinity of a central engine, as it comes from the VLBA–VSOP estimation of core-jet spectral indexes (see below). In addition to this highly variable component, 0524+034 has two stationary or slowly varying components, one of which has $\gamma = 2.4$ in the optically thin part of the spectrum, what is also consistent with the VLBA–VSOP results.

Comparison of the integrated flux, measured with the EVN+, VLBA, and VSOP, with the results of simultaneous RATAN–600 observations confidently gives that more than 90 percent of the total emission of 0524+034 is coming from the mas scale. This result points to the fact that the slowly variable component of the total spectrum at cm wave lengths, as well as the rapidly variable one, are emitted from the compact jet.

The source shows a compact, one-sided core-jet structure at a position angle of about $-90°$ (Figures 3, 4). An analysis of the derived multi-component jet model confidently indicates that the jet is beginning to curve at a distance of several mas from the VLBI core. The 15 GHz VLBA image (Figure 4) confirms a core-dominated structure, but does not present adequately the jet. From the comparison of the quasi-simultaneous VLBA and VSOP data at 2 and 6 cm, it is evident that the extended component, visible in the EVN+ 5 GHz image, has a steep spectrum with $\alpha < -0.7$ ($S_\nu \sim \nu^\alpha$). This infer power index of the electron energy distribution to be $\gamma > 2.4$, meanwhile the VLBI core spectrum is flat.

The high variability phenomenon, regardless of its intrinsic or extrinsic nature, is the strongest indication of the compactness of the source. Our estimates of the VLBI core angular size are consistent with this. We got from the VLBA 2 cm observations the upper limit 0.14 mas on it and from the VSOP 6 cm data, 0.3 mas.

Intrinsic Scenario Outline: The simultaneity of the rapid variations over a broad frequency range and the fact that the mean spectrum of the variable component coincides with the spectrum of a homogeneous, spherically symmetric source suggest the importance of acceleration of electrons and amplification of the magnetic field, whereas adiabatic expansion can be neglected. We suppose that precession of the relativistic jet can be one of the possible mechanisms to account for the observed milliarcsecond structure evolution and the strong long–term variations of the spectrum. The detected rapid changes may be interpreted as a propagation of a shock in the inhomogeneous jet plasma.

Extrinsic Scenario Outline: The angular resolution of our VSOP and ground-based VLBI experiments was insufficient to resolve a possible "average" scattering angular scale (cf. Dennison et al. 1993). However, given an extreme variability in the source 0524+034, one cannot exclude a possibility of enhanced scattering due to the presence of "above-average" inhomogeneities along the line of sight. Unfortunately, we cannot verify the widely expected (but yet to be confirmed directly) λ^2-law of the image broadening because of insufficient resolution of the present study. Space VLBI with a higher orbit is needed to answer this question.

Interpretation of IDV phenomenon by interstellar scintillations becomes very successful through a number of perfect works done last years (see, e.g. Kedziora-Chudczer et al. 2001, Dennett-Thorpe & de Bruyn 2002, and contributions to this meeting). Available data for 0524+034 do not rule out this possibility. A search for an annual modulation of the IDV (see, e.g. Jauncey & Macquart 2001; Rickett, et al. 2001) for 0524+034 could be a critical test for intrinsic/extrinsic scenario.

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