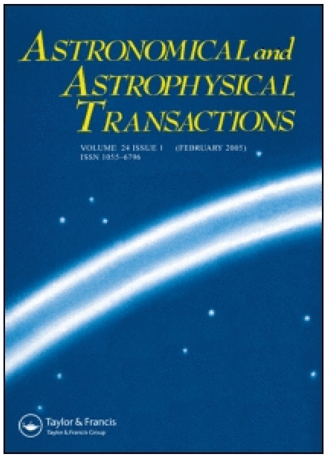

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3C120: total flux variations and evolution of the very-long-baseline interferometry structure

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3C120: total flux variations and evolution of the very-long-baseline interferometry structure

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Variability research results on the radio source 3C120 are presented using the data from international geodetic very-long-baseline interferometry (VLBI) observations at 2 and 8 GHz, the ongoing monitoring programme within the frequency range 4.8–36 GHz being carried out at the Crimean Astrophysical Observatory (Ukraine) and the Radio Astronomy Observatory of Michigan University (USA). The joint analysis of integral flux variations and milliarcsecond structures allowed us to detect flares at high frequencies accompanied by the appearance of new VLBI components seen at centimetre wavelengths. It is found that the flux variations of 3C120 at different frequencies are almost simultaneous, and the outburst in 1998 is accompanied by the birth of a new superluminal component. An activity cycle scenario based on the flux variation and structure analysis is discussed.

Keywords: Radio source; Flux variations; Very-long-baseline interferometry structure

1. Observations

1.1 *RT-22 and University of Michigan Radio Astronomy Observatory flux density monitoring at 4.8–36 GHz*

The observations were carried out with the 22 m RT-22 Crimean Astrophysical Observatory radio telescope at 22 and 36 GHz. The antenna temperatures from sources were measured by the standard ON–ON method described by Efanov *et al.* [1]. Before measuring the intensity, we determined the source position by scanning. The radio telescope was then pointed at the source alternately by the principal and reference (arbitrary) beam lobes formed during beam modulation and having mutually orthogonal polarizations. The antenna temperature from a source was defined as the difference between the radiometre responses averaged over 30 s at two different antenna positions. The flux density scale of observations was calibrated using DR 21, 3C 274, Jupiter and Saturn. Absorption in the Earth's atmosphere was taken into account by using atmospheric scans made every 3–4 h.

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The variability of extragalactic sources has been investigated with the 26 m radio telescope of the University of Michigan Radio Astronomy Observatory at 4.8, 8 and 14.5 GHz [2, 3].

The data combined with our earlier published data were supplemented with the observations made by other workers [4–7].

1.2 *Very-long-baseline interferometry observations at 2 and 8 GHz*

Simultaneous geodynamic measurements at 8.2 and 2.3 GHz are regularly carried out with the use of the global radio interferometre network. Since 1994 the RT-22 radio station at Simeiz has taken part in this programme. The observational sites have two main tasks: firstly, pointing a radio telescope at the source; secondly, tracking the source and signal recording in 14 channels, each of which has a 2 MHz bandwidth at the frequencies 8.2–8.6 and 2.2–2.3 GHz. The recording duration usually takes 60–300 s. 30–100 compact sources are usually observed in each session duration of 24 h. Each station performs 200–500 scans for this period. Then all the types are sent to one of the correlation centres: the Max-Planck-Institut für Radioastronomie (Bonn, Germany), the Haystack Observatory (Westford, Massachusetts, USA) or the US Naval Observatory (Washington, DC, USA). The fine structure of a number of compact extragalactic radio sources with active nuclei is obtained from very-long-baseline interferometry (VLBI) observations made on 16–17 January 2002, 6–7 March 2002, 8–9 May 2002, 24–25 July 2002, 25–26 September 2002, 11–12 December 2002 and 3–4 March 2003. The initial calibration was done at the National Radio Astronomy Astronomical Image Processing System using standard techniques. Self-calibration and hybrid mapping were carried out using DIFMAP [8].

2. Results

Complex analysis of integral emission variations of extragalactic sources and their structure on milliarcsecond scales can give a clue to the detection and understanding of important properties of active galactic nuclei.

3C120 is a powerful radio galaxy with a complex optical morphology, possibly the result of a merger [9]. The source is relatively nearby, located at a red shift of $z = 0.033$. The radio galaxy 3C120 is one of the first superluminal objects discovered with distinctive knots moving down the jet with relativistic speed; it appears to be one of the best sources to study the emission and propagation of relativistic jets in active galactic nuclei. Multiple-wavelength multiple-epoch observations suggest that this Seyfert 1 galaxy is probably the result of a merger and presents a jet in precession that originates from the accretion of material on to a super-massive central black hole [10]. The very-long-baseline array (VLBA) at 22 and 43 GHz revealed a very rich inner jet structure containing up to ten different superluminal components, with velocities between 2.3 and $5.5\,h^{-1}c$, mapped with a linear resolution of $0.07\,h^{-1}$ pc [11]. Linear polarization was also detected in several components, revealing a magnetic field orientation that varies with respect to the jet flow direction as a function of the frequency, epoch and position along the jet.

The first 86 GHz coordinated millimetre VLBA observations of 3C120 provided an angular resolution of 54 μarcsec, which for this source represents a linear resolution of $0.025\,h^{-1}$ pc [12]. Using a 16 month sequence of monthly polarimetric 43 GHz VLBA images of the radio galaxy 3C120, Gómez *et al.* [14] followed the motion of a number of features with apparent velocities between $(4.01 \pm 0.08)\,h_{65}^{-1}c$ and $(5.82 \pm 0.13)\,h_{65}^{-1}c$ [13].

The VLBI maps at 2 and 8 GHz obtained from observations on seven epochs during 2002.04–2003.17 are presented in figure 1. Because of the Doppler boosting effect the source

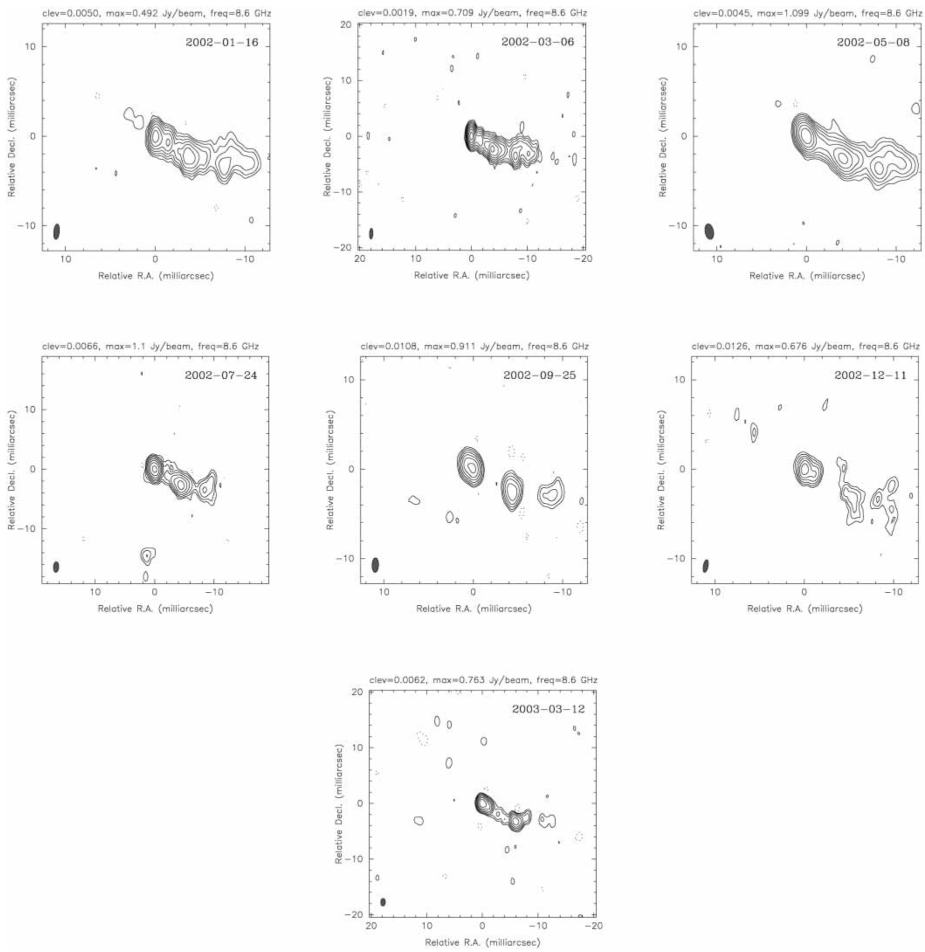

Figure 1. VLBI images of J0433 + 0521 at 8.6 GHz for seven different epochs. The contour levels increase in steps of a factor of 2. The peak and the level corresponding to the lowest contour are indicated above the maps.

demonstrates a one-sided structure. Using the standard Friedmann model of the Universe with the deceleration parameter and the Hubble constant $H_0 = 70\,h\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, the angular scale of 1 marcsec corresponds to $0.62\,h^{-1}$ pc. Being relatively close and highly active, 3C120 is one of the best targets for studying the properties of the inner jet region, since structure changes of the source on parsec scales can be detected within several months, while regular observations for several years allow us to track the jet evolution in detail, from the moment that they leave the VLBI core (as an optically thick base of the jet) to their disappearance due to synchrotron losses and limited level of sensitivity of the interferometer used.

Light curves at 4.8, 8, 14.5, 22 and 36 GHz of the source are presented in figure 2. It can be seen that the outbursts have delays at low frequencies. The estimated values of these delays for the flare in 1998 are listed in table 1. A possible mechanism responsible for the delays may have a connection with the large optical depth of the emission region, where the flare occurred, and also with changes in the optical depth with time. Having estimated the apparent velocity of moving plasma in the jet and using the measured delays, we can calculate the difference in the absolute core positions. The core is usually identified as a compact component with optical depth $\tau_s \geqslant 1$. This parameter allows us to estimate the luminosity, magnetic field and jet geometry properties.

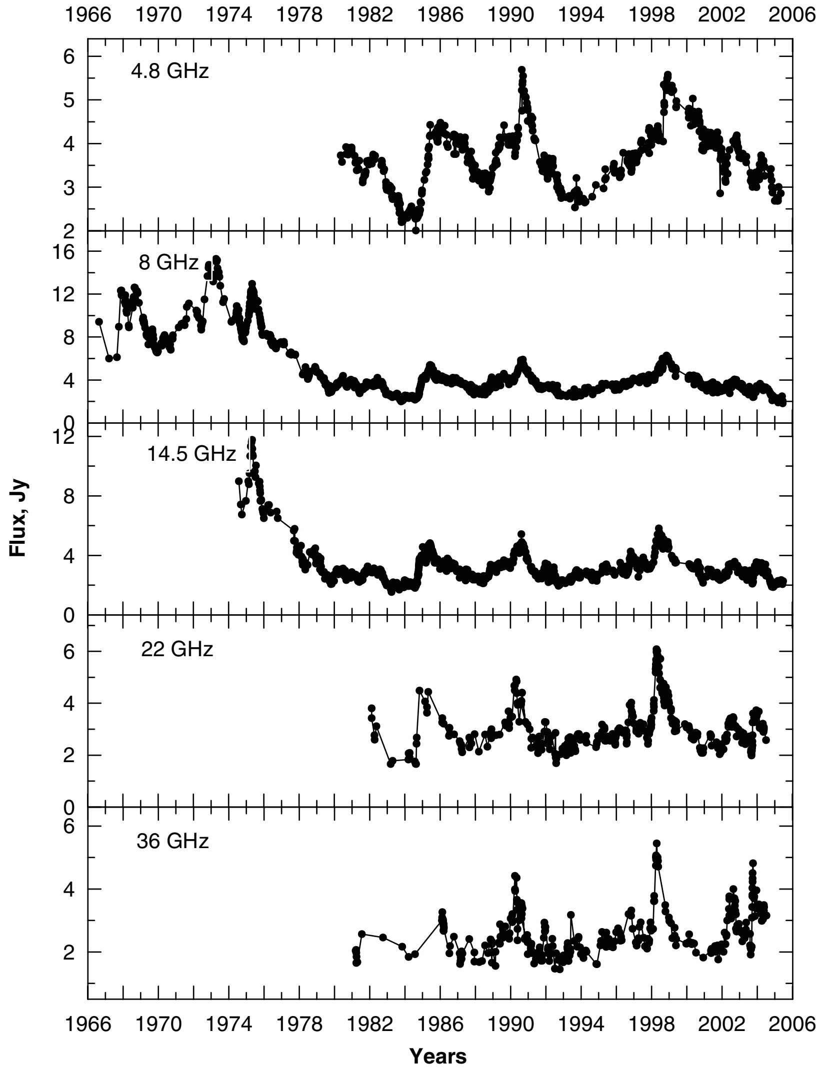

Figure 2. Light curves for 3C120 at 4.5, 8, 14.5, 22 and 36 GHz during the period from 1966 to 2006.

We performed a time series analysis of the radio light curves in the frequency range 4.8–36.8 GHz, using Shuster's method to search for periodicity. The parameters of the harmonics are given in table 2 (the first column gives the frequency of the analysed light curve, and the second column the period P of each harmonic).

Model fitting of the VLBI structure of 3C120 at 8 GHz was carried out using the 'modelfit' task in DIFMAP. Several one-dimensional Gaussian components were fitted to the source. The obtained models allowed us to identify the same components in different epochs. Figure 3 shows the separation from the core with time for the brightest jet component located at an angular distance of about 4 marcsec in January 2002. The results for this source in June 1999 were obtained by A. Fay (US Naval Observatory). Using the linear least-squares method we estimate the apparent velocity of this bright jet component as $3.03\,h^{-1}c$. Moreover, we can estimate the birth epoch of the component (1998.6 ± 0.3), which perfectly coincided with the peak seen in the monitoring data of RT-22 in Simeiz (figure 2). The shifts from the linear

Table 1. Delays in emission at different frequencies.

Frequency interval (GHz)	Delay (years)
36.8–22	0.03
22.2–14	0.08
14.5–8	0.31
8.0–4	0.24

Table 2. Cycles of activity at different frequencies.

Frequency (GHz)	Period (years)
36.8	6.6
22.2	9.0
	4.1
14.5	11.2
8.0	11.1
	7.8
	6.0
4.8	11.1

approximation have a quasiharmonic character and can be explained in terms of precession of the jet axis. This supposition can be tested when all the gap epochs are reduced. The non-zero part of the acceleration can be easily understood as a consequence of the geometry effects. It is also possible that the presence of relativistic shock waves moving down the jet and forcing the particles to accelerate may play some role [14].

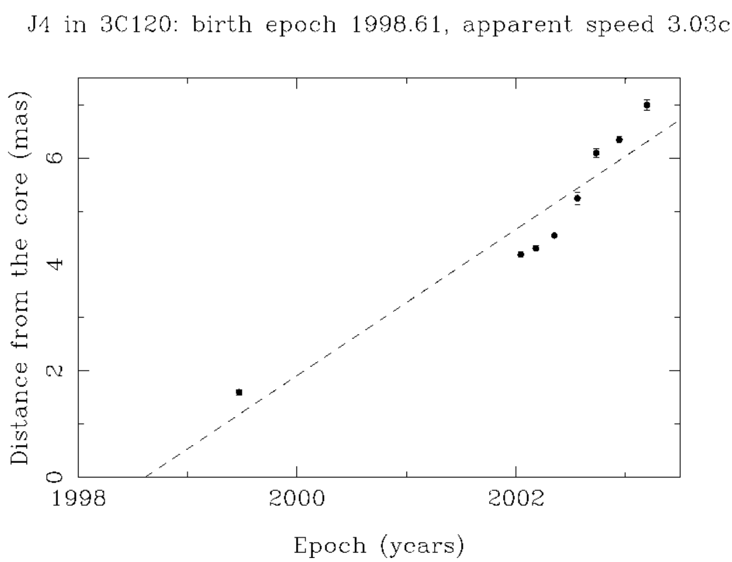

Figure 3. The brightest jet component separation versus time at 8 GHz. The apparent speed is 3.03c. The birth epoch is 1998.61 ± 0.3.

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