Extragalactic jets from every angle
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Using the methods of wavelet analysis and singular spectrum analysis in the study of the variability of flux of radio sources 3C120 and BL Lac in the radio range

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Abstract. We investigated the monitoring data of extragalactic sources 3C120 and BL Lac. This monitoring was held with University of Michigan 26-meter radio telescope. To study flux density of extragalactic sources 3C120 and BL Lac at frequencies of 14.5, 8 and 4.8 GHz, the wavelet analysis and singular spectrum analysis were used. Calculating the integral wavelet spectra revealed long-term components (11 - 4 years) and short-term components (3.4 - 0.7 years) in 3C120. BL Lac has long-period components of 7 - 8 years and short-term components of 1 - 4 years. Studying of VLBI radio maps (by the program Mojave) allowed investigating features of components movement relatively to the VLBI core. The data of radio astronomy observations were also investigated using singular spectrum analysis. This method does not use the analyzing function, so its calculations allow to distinguish various components of investigated series with a high accuracy. To get spectral power distribution depending on time in the studied narrowband components obtained by singular spectrum analysis, short-term Fourier transformation was used.

Keywords. galaxies: active, galaxies: jets

1. Introduction

In this paper BL Lac and radio galaxy 3C 120 are studied. The observations for 3C120 were taken by the radio telescope RT-26 Michigan Observatory, at frequencies of 14.5 GHz (1978 - 2011), 8 GHz (1966 - 2011) and 4.8 GHz (1980 - 2009). Observations of the source BL Lac were made at 14.5 GHz from 1974 to 2011, at frequency 8 GHz from 1968 to 2010, at frequency 4.8 GHz from 1980 to 2011. Details of the calibration methods and the methods of analysis are described in paper (Aller *et al.* 1985). Considering the bright knots in the jets 3C120 and BL Lac according to the data from the MOJAVE data base (Lister *et al.*, 2009), the existence of components receding gradually and components arising episodically at the same distances from the core was noted. In the articles of some authors (e.g., Jorstad et al. 2001, Britzen *et al.* 2008, Alberdi *et al.* 2000), the existence of stationary component in the jets which are in a fixed position was discussed. These bright knots were explained as standing shocks caused by the interaction of the jet with the environment.

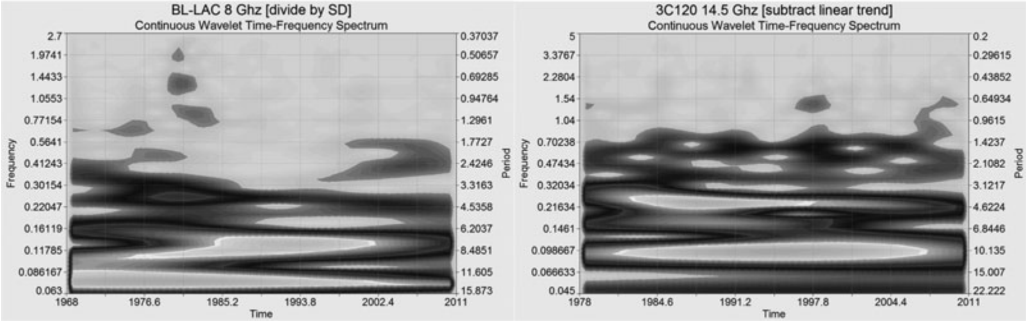

Figure 1. Continuous wavelet-spectrum of the initial smoothed data for BL Lac at 8 GHz (left) and 3C120 at 14.5 GHz (right).

2. Data reduction

Based on daily observations of flux average values of 7 days with an irregular grid of counting are defined. According to the histogram of distribution of time intervals between counting the interpolation interval in 0.02 years (7.3 days) has been chosen. With using a polynomial moving average (half-width an interval of 5 points) reduction of noise has been reached and random emissions have been removed. By means of trigonometric interpolation the data have been reduced to an even step on time. Allocation of short component in signals against the main period Fourier filtering (O – C) was used (Gaydyshev 2001).

3. Wavelet-analysis

Two-parameter analyzing function of one-dimensional wavelet transform is well localized both in time and frequency. This distinguishes it from the ordinary Fourier analyzing function which covers the entire time axis. Thus, it is possible to see the detailed structure of the process and the evolution of the harmonic components of the signal in time (Smolentsev 2010). We used a continuous wavelet transform based on Morlet function. On the wavelet spectra of the harmonic components of the signal are visible as bright spots, stretching along the time axis. The examples of the wavelet spectrum are shown in Fig. 1.

3C120. For a long time component of the flux at frequencies of 14.5 and 4.8 GHz manifestation of periods 11 and 4.4 years is marked. For data at frequency of 8 GHz periods in the range from 1.3 to 8 years are presented. On this frequency in the time interval of observations from 1966 to 1976, the source 3C 120 showed anomalous activity; at other frequencies observations in this period were not carried out. For the short-period component of the flux at all the frequencies the period 1.5 - 1.7 years is presented. At frequencies of 4.8 GHz and 8 GHz the periods of 3 - 3.4 years were found. At frequencies of 14.5, 8, 4.8 GHz, as well as at the frequency VLBI 15.4 GHz, one of the peaks of flux was observed in 1998 and we have identified long-period components of 11 years and 4 years, and short-period 3.4 and 1.5 years that were present at that time. Exactly in 1998 on the VLBI maps at this source formation of a new bright component in the jet is noted.

BL Lac. For a long-period component of the flux at all three frequencies the manifestation of periods 7.2 - 8.7 years and 4.1 - 4.7 years is marked. From short-period component periods of 1 to 3 years are marked. One of the short periods of 1 - 1.2 years, appears on all three frequencies, with maximum in 1982.

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4. The results of using the singular spectrum analysis

Using the singular spectrum analysis we decompose the original signal into a set of narrow-band filters, which include trend components, periodic components and noise signal (Alexandrov 2006). Using this set of narrow-band filters, the periods of sinusoidal oscillations in years were determined. To obtain spectral power distribution depending on time in study narrowband component obtained by analysis of a singular spectrum short Fourier transform was used, i.e., Fourier transform used a moving window where each window with overlaps calculated Fourier spectrum and as a result we get a step by step presentation of the temporal evolution of the spectral power and the frequency of the signal. Thus, it is possible to relate the formation of a certain period of time with the moment in which it was the highest.The main drawback of this method with the analyzing function such as Fourier or wavelet analysis is that there is some test function used for comparison with the original series. Singular spectrum analysis allows to avoid the test function, so its calculations allow us within high accuracy distinguish various components of the test series.

5. Summary

Data processing using wavelet analysis indicates the presence of long-period component and short component, time of their existence and the main phases of activity in radio sources in 3C 120 and BL Lac. In radio galaxy 3C120 among the long-period components the periods from 4 to 11 years are detected and the value of short periods is in the range of 1.5-3 years. Blazar BL Lac has a long-period component of 7-8.7 and 4-4.7 years, as well as short component of 1 to 3 years. The use of the singular spectrum analysis identified: (a) The source 3C 120 at all frequencies has three periods of 4-4.8 years and 1.9-1.4 years. Period of about 3 years was found at frequencies of 8 and 4.8 GHz. At a frequency of 8 GHz a period of 7.4 years is detected. (b) The source BL Lac has periods of 4-5 years and 1.5-2 years at all three frequencies. There is a period of 7 years at 8 GHz.

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