RADIO-ASTRONOMY

USING THE METHODS OF WAVELET ANALYSIS AND SINGULAR SPECTRUM ANALYSIS IN THE STUDY OF RADIO SOURCE BL LAC

G.I.Donskykh[1], M.I.Ryabov[2], A.L.Sukharev[2], M.Aller[3]

[1] Department of Astronomy, I.I.Mechnikov Odessa National University, Odessa, Ukraine
[2] Odessa observatory "URAN-4" of the Radio-astronomical institute NAS, Odessa, Ukraine
[3] Radio observatory of Michigan University, Ann Arbor, USA

ABSTRACT. We investigated the monitoring data of extragalactic source BL Lac. This monitoring was held with University of Michigan 26-meter radio telescope. To study flux density of extragalactic source 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 allowed revealing long-term components (~7-8 years) and short-term components (~ 1-4 years) in BL Lac. 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 can solve the task of allocating trend, detection of periodic components and band-pass filtering (reconstruction of time series from quantity of main components, the last corresponds to individual bands of periods on time-frequency spectra or Fourier spectra). Singular spectrum analysis 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.

Key words: BL Lac, jet.

1. Introduction

In this paper BL Lac is studied. The observations were taken by the radio telescope RT-26 Michigan Observatory, at frequencies of 14.5 GHz (1974–2011), 8 GHz (1968–2010) and 4.8 GHz (1980–2011). A graph of flux density BL Lac on three frequencies is presented at Figure 1. 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 (eg, 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.

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).

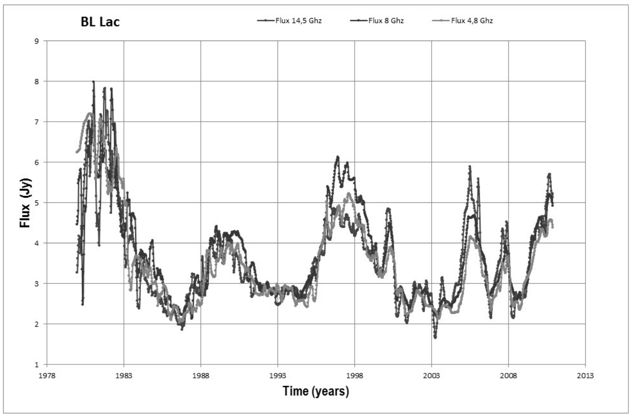

Figure 1: A graph of flux density BL Lac at three frequencies

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 example of the wavelet spectrum is shown in Fig. 2.

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. The phases of activity in BL Lac for the long period component were at a frequency of 14.5 GHz – 1980 and 2006, at the frequencies of 8 GHz and 4.8 GHz – 1981. For the short-period component phases of activity were at a frequency of 14.5 GHz – 1981 and 2006, at 8 GHz – 1975, 1980 and 2006, at 4.8 GHz – 1981 and 1996. From 1968 to 1974. at frequency of 8 GHz, blazar BL Lac showed the highest activity. We have no data on the other two frequencies for this time interval. Another peak of flux density at all three frequencies was observed from 1980 to 1982.

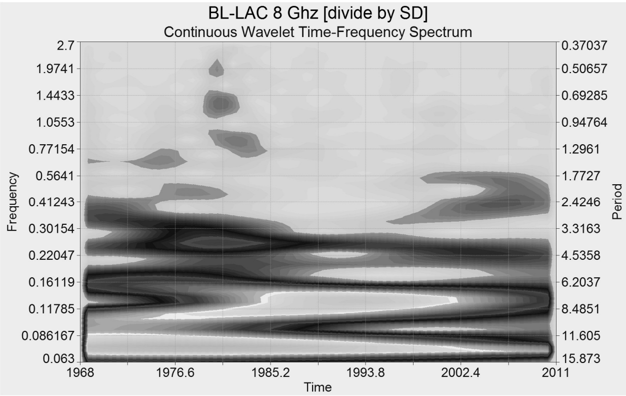

Figure 2: A continuous wavelet-spectrum of the initial smoothed data for BL Lac at a frequency of 8 GHz

4. 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. Examples of the obtained main components are shown in Figures 3 and 4.

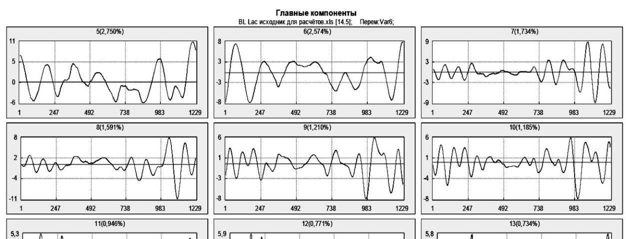

Figure 3: The main components for BL Lac at 14.5 GHz (1D)

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.

The use of the singular spectrum analysis identified that 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. Periods obtained by analysis of the singular spectrum are shown in Table 1.

Table 1. Periods obtained by analysis of the singular spectrum for BL Lac

14.5 GHz	8 GHz	4.8 GHz
8	7	7
5 – 4	4.8 – 4	4
2.7 – 2.5	3.2	3
1.6 – 1.3	2	2.3 – 1.5
	1.3	

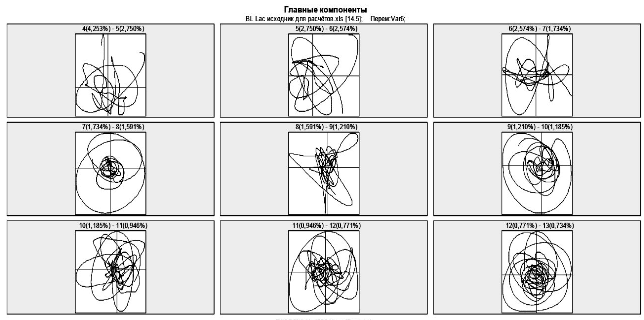

Figure 4: The main components for BL Lac at 14.5 GHz (2D)

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 source BL Lac.

The use of the singular spectrum analysis identified:

– 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 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.

The obtained data were compared with the results of VLBI monitoring MOJAVE during the period 1995-2012 at frequency 15.4 GHz, that allows us to investigate the structure of emissions during periods of maximum activity. In the jet of investigated source the existence of certain structures, moving with time and the existence of bright knots arising in the same distances from the core were indicated.

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