VARIABILITY FEATURES OF THE RADIO SOURCE OT 081 IN CENTIMETER WAVELENGTH RANGE

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ABSTRACT. OT 081 – BL Lac object, intensively studied for many years in a wide range of the electromagnetic spectrum. We used observational data for 1999-2011 years, obtained on radio telescope at Michigan State University (UMRAO) at frequencies 14.5, 8, 4.8 GHz. For the study variability of the radio source used wavelet method of time series analysis. The values of main periods at three frequencies are ~2.6 and 1.2 years. The shortest periods with values ~0.9, 0.6, 0.4 years were shown in small time intervals (1.5 years). For harmonic components isolated by filtration, determined delay between radio frequencies. Obtained comparison of change between periods fluctuations of radio fluxes and dynamics in the radio jet (image VLBI Mojave, 15.4 GHz).

Introduction

Studied radio source OT 081 (1749+096) is a BL Lac objects, which are characterized by rapid and significant changes of luminosity over all range of electromagnetic spectrum, as well as a continuous optical spectrum and polarization. OT 081 is located in the constellation Ophiuchus, the redshift – 0.322 [1], distance – 1230 Mpc, the largest speed of jet component – 7.9c [2], radio spectrum is flat, OT 081 is a powerful gamma ray source.

Data processing

Original data on three frequencies (14.5, 8, 4.8 Ghz) were obtained on a 26-meter radio telescope of the University of Michigan. Methods of observations and data processing on RT-26 is described in article [3]. Observation period, 1999-2011 years (Figure 1). The average time interval between data points is 7 days. The correlation coefficients between frequencies: 0.90 (14.5-8 Ghz), 0.76 (14.5-4.8 Ghz), 0.92 (8-4.8 Ghz).

In the process of preparing data for analysis conducted smoothing by local spline regression method [4]. To search periodicities in the data used continuous wavelet analysis with the Morlet function and wavelet filtering, a detailed description of which is referred in literature [5, 6, 7]. Defining the time delay between the data at different frequencies is performed using cross-correlation method [8].

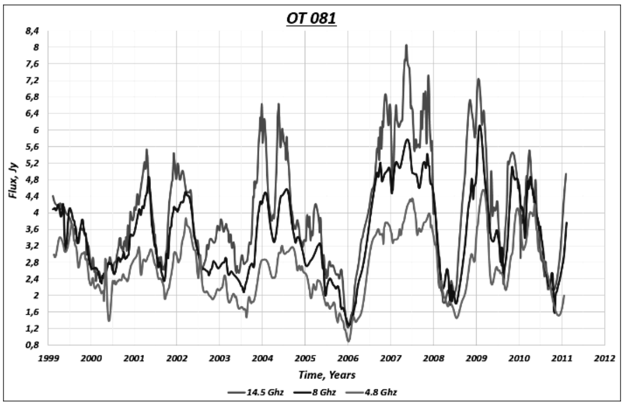

Figure 1: OT 081, graphs of radio fluxes at three frequencies of observations

Wavelet analysis

As a result of the analysis were obtained coefficient matrix of the continuous wavelet transform, representing a surface in three-dimensional space. Usually, they are replaced by projections on the plane "frequency-time" with the contour line, allows tracking changes over time in the frequency spectrum. Examples of wavelet spectra are shown in Figure 2.

By results of wavelet analysis, periods on three frequencies have similar values ~2.6 (main) and ~1.2 years. At frequencies of 14.5 and 8 Ghz, value of the main period is changes about ~0.3 years. At a frequency of 14.5 Ghz is allocated a weak five-year period (wave with two vertices 2002.1 and 2008.0), maybe it's the harmonic of main period. Elements of the spectra corresponding to the value of the period ~0.9-0.4 years represent sequentially located splash of radio flux with a decrease in the period to the end of time series.

Phase of activity defined by the time of maximum in global spectra averaged over frequency (show the distribution of total power spectral density of the signal over time), used for communication with variation of periods and change in VLBI structure of radio source. Below is a table of periods (Table 1).

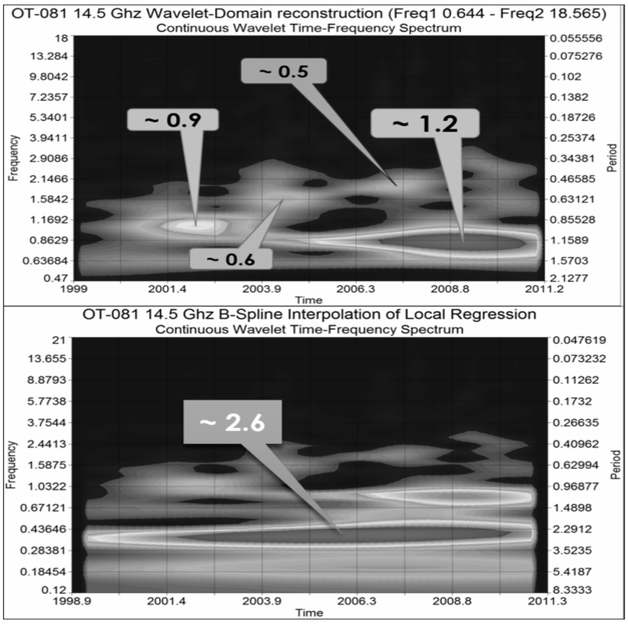

Figure 2: Wavelet spectra at a frequency of 14.5 GHz. The bottom graph – the original time series, the top – the short period allocated by filtration. Flags indicate periods in years.

Table 1. Table periods for radio source OT 081

OT 081							
Freq.	P_{max}	P_{min}	T_{start}	T_{end}	PSD_{max}	T, PSD_{max}	T, GWS_{max}
14.5	2.7	2.4	2000.2	2010.0	527	2006.1	2004.3 2008.0
	1.2		2006.5	2010.6	250	2008.8	
	0.9	0.5	2001.5	2008.1	68	2002.0	
8	2.7	2.5	2000.4	2009.8	325	2006.0	2002.3 2009.2
	1.2		2006.6	2010.7	137	2008.6	
	0.9	0.4	2001.4	2010.5	32	2002.5	
4.8	2.6		2000.3	2009.8	360	2006.2	2002.1 2009.3
	1.2		2006.4	2010.5	162	2008.8	
	1.4	0.4	1999.7	2010.5	23	2003.1	

Designation: Freq. – frequency of observations (in Ghz); P_{max}, P_{min} – interval of period (in years) change; T_{start}, T_{end} – time interval of period existence; PSD_{max}, T, PSD_{max} – maximum value of the spectral power and the corresponding time; T, GWS_{max} – phase activity (main underlined).

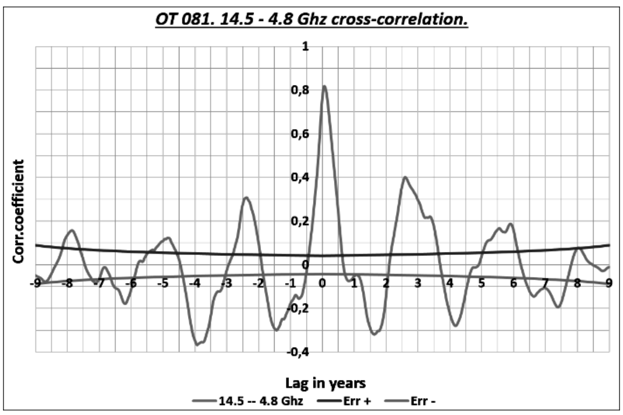

Figure 3: Cross-correlation function with the confidence intervals for frequencies pair 14.5 and 4.8 Ghz. The time delay – 22 days.

Table 2. Values of the time delay in days

Delay between frequencies, in days			
Freq. pair	Lag, orig	Lag, $P_{2.6}$	Lag, $P_{1.2}$
14.5 -- 8	14,5	22,0	22,0
14.5 -- 4.8	22,0	44,0	29,2
8 -- 4.8	7,3	29,2	7,3

Lag orig – delay for the original series; Lag, P2.6 – delay in the period band 2.6 years; Lag, P1.2 – delay in the period band 1.2 years.

Delay between frequencies

Using wavelet filter been allocated data for comparison in periods bands 2.6~1.2 years. Below chart shows an example of cross-correlation function (Figure 3) and a table of analysis results (Tabl.2).

Comparison of the radio emission variability with VLBI maps

In this work, we attempt to relate changes in quasi-periodic oscillation of radio flux with passage of bright spots in the jet. Each phase of activity correspond to forming her periods [9]. At times moments indicated in Table 1 were constructed local power spectra for each year individually. When comparing the local spectra with 15.4 GHz VLBI maps (MOJAVE Program [10]) evidently, that transit of each new bright spot on jet significantly alters the signal spectrum. Appropriate examples are given in Figure 4.

When the activity is low jet, intensity more at long period, when in jet appear bright components, increased intensity of a short period. When jet activity is high, intensity short period is greatest. Short splash may correspond to double components near the VLBI «core» source. Therefore most likely that the rapid variability of the radio emission forms a jet activity and long-term – core activity. Certain patterns can be extended to observation period when sessions VLBI measurements were not.

Results

Processing data showed the presence quasi-periodic components with periods ~2.6 and 1.2 years, as well as short-term fluctuations of flux with decreasing period of ~0.9-0.4 years, which appear on the tops of the main wave variability. Harmonic with 1.2 years period, intense in the second half of the investigated data. Period 2.6 years (14.5, 8 Ghz) slightly varies with time (0.2, 0.3 years). Obtained values of time delays. For original and filtered data in the period band 1.2 years for their sum frequency pairs 14.5-8 and 8-4.8 Ghz alike approximate delay between the extreme frequencies of 14.5-4.8 Ghz. At the time range trigonometric polynomials with periods found in good agreement with the original data, which shows their stability over time. The error in determining periods of ~0.08 years. A comparison of the periods of variability with changes VLBI structure showed that the bright

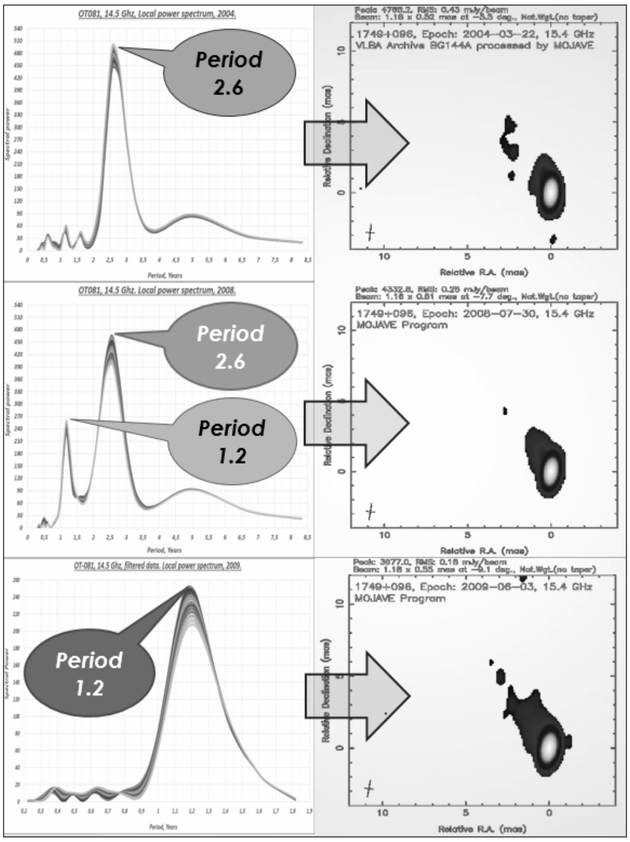

Fig.4. Changing periods and corresponding VLBI structure of radio source OT 081. In VLBI image (2004.03.22) activity jet weak and prevails during 2.6 years, the image (2008.07.30) is active new component in jet, to the period of 2.6 years, 1.2 years is added, the image (2009.06.03) activity jet high, 1.2 year period has the greatest spectral power.

components of the jet shape fast quasi-periodic variations in the radio flux. Longer flow changes, probably related to the activity of the nucleus of the radio source. Jet of radio source has a complicated, curved structure, perhaps a bimodal velocity distribution in the jet [11]. To explain the variability of BL Lac objects are often used models of shock waves interaction superluminal component with jet [12]. Motion of the components in the jet OT 081 on curved trajectory indicates the possible applicability of binary black hole model [13]. In this case, in addition to the precession of the jet, satellite can create tidal perturbations in the accretion disk and the vibrations that affect the variability of the radio flux [14].

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