WAVELET ANALYSIS OF VARIABILITY OF THE RADIO SOURCE 3C120 IN CENTIMETER WAVELENGTH RANGE

Sukharev A.L.[1], Aller M.F.[2]

[1] Radio Astronomical Institute of National Academy Sciences of Ukraine, Observatory "URAN-4"
[2] Radio astronomical observatory of Michigan University, Ann Arbor, USA

ABSTRACT. 3C120 – radio galaxy with an active nucleus has been intensively studied for many years in a wide range of the electromagnetic spectrum. We used observational data for 1966-2010 years, obtained with the radio telescope at Michigan State University (UMRAO) at frequencies of 14.5, 8 and 4.8 GHz. To study the variability of the radio source, we used wavelet method for time series analysis. The main periods in three frequencies are ~4.5 years and 6-12 years (~0.7, 1.6 and 3.4 years for the short-periodic flux component). The delay between radio frequencies was calculated. The comparison between the change in periods of fluctuations of radio fluxes and dynamics of the jet was performed (image VLBI Mojave, 15.4 GHz). Based on the periods found, we conducted forecasting changes in the radio flux and compared the results with the observation data.

Keywords: 3C120, radio galaxy, flux variability.

1. Introduction

The studied radio source 3C120 (Mrk 1506) refers to the radio galaxy type FR I and is characterized by rapid and significant changes in luminosity in different ranges of electromagnetic waves. With redshift – 0.033 (Michel et al., 1988), distance to the object – 150 Mpc, the highest speed of jet components – 6.4c (Lister et al., 2013), and flat radio spectrum, 3C120 is a gamma-ray source.

2. Data processing

Initial data on three frequencies (14.5, 8, 4.8 GHz) were obtained on a 26-meter radio telescope of the University of Michigan. The method of data gathering and processing for the RT-26 is described in (Aller et al., 2001). The observation period is 1966-2010 (Figure 1). The average interval between samples is 7 days. The correlation coefficients between the radio frequencies are as follows: 0.88 (14.5-8 GHz), 0.70 (14.5-4.8 GHz), 0.86 (8-4.8 GHz).

In the process of data preprocessing for analysis the smoothing with moving average and detrending with polynomial were performed (Gaydyshev, 2001), followed by trigonometric interpolation. To isolate the short-periodic component (O-C), the FFT filtering was applied (Voskoboynikov, 2010). To search for periodicities in the data, we used continuous wavelet analysis with the Morlet function and wavelet filtering and reconstruction, which are described in detail in the following papers (Davidov, 2007; Smolentsev, 2010; Astafeva, 1996). Determination of time delay between data at different frequencies was performed using cross-correlation method (Rosenberg et al., 1994).

Figure 1: The 3C120 combined graphs for changes in radio fluxes at three frequencies

3. Wavelet analysis

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

The values of the periods in years are given in Table 1. The radio variability is divided into long-term (trend) and fast (O-C) components. The high-frequency part of the signals was isolated from trending periods and restored by the FFT filtering. Thus, we obtained the values of short periods which are hardly distinguishable on the original spectra.

As is seen from Table 1, the values of the long period are stable for the entire length of the time series, except that one at frequency 14.5 GHz. Most values of short periods change over time; moreover, the corresponding periods of oscillations occur in limited intervals of time. The phase activity (last column on the right) shows the time of maxima of global wavelet spectra in the frequency range (showing time distribution of full power of wavelet spectrum). Since the spectral composition of the signal changes over time, each time of maximum spectral power at the global spectrum corresponds to the value of period, which is the most strongly expressed at this time (Ryabov et al., 2012). Thus, using the visualization of wavelet spectrum as a series of "period-spectral power" graphs for each year separately, we can determine which periods make the largest contribution to the radio source's phase activity and compare them with VLBI maps.

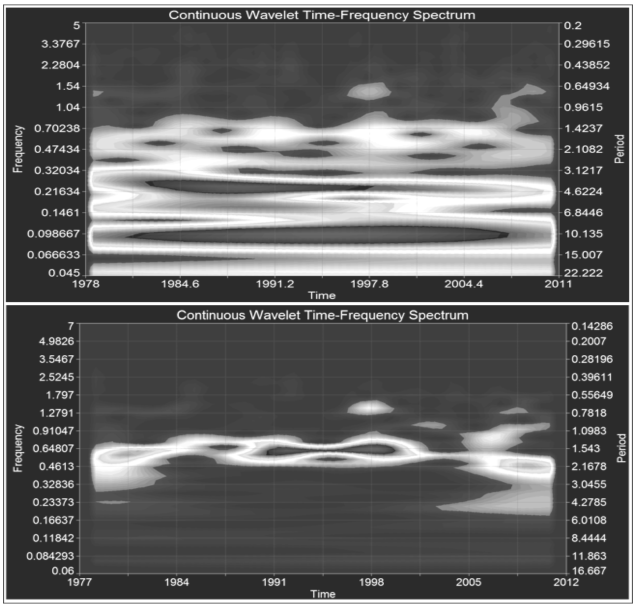

Figure 2: Wavelet spectra at a frequency of 14.5 GHz. The top graph represents the original series; the bottom one shows the short-periodic part, isolated by filtration (power spectrum)

Table 1: Table of periods for the radio source 3C120. Designations: Freq. – radio frequency; P_{max}, P_{min} – change interval period; T_{start}, T_{end} – time interval of existence period; PSD_{max}, T, PSD_{max} – maximum value of spectral power and its corresponding time; T, GWS_{max} – phase activity (the main is underlined).

3C 120, trend							
Freq.	P_{max}	P_{min}	T_{start}	T_{end}	PSD_{max}	T, PSD_{max}	T, GWS_{max}
14.5	4.6	3.8	1980.3	2008.5	195	1989.6	***1985.0***
	6.3	5.9	1979.0	1997.8	97	1989.2	1990.2
	10.1		1988.4	2009.9	198	1994.8	1998.0
8	4.3		1982.2	1996.5	230	1987.8	***1985.2***
	8.1		1990.4	2007.7	118	1991.1	1990.0
	12.4		1970.0	2005.0	1613	1979.0	1998.3
4.8	4.5		1983.3	1994.0	194	1988.4	***1986.0***
	10.0		1989.7	2009.2	401	1996.7	1989.3 2007.6
3C 120, O - C							
14.5	1.8	1.5	1979.3	1984.3	19	1980.8	1985.0
	1.6		1989.2	2000.7	29	1998.2	1992.0
	2.1		2005.5	2010.2	18	2008.7	***1998.2***
	0.8	0.7	1981.1	1985.1	3	1983.6	2003.7
	0.7		1996.3	1999.5	9	1997.8	2007.2
8	1.9	1.6	1978.7	2007.4	32	1979.5	1978.4
	3.4		1999.5	2008.4	43	2006.8	1985.1
	2.7	2.3	1979.1	1991.6	15	1980.1	1990.5
	4.1		1968.0	1974.8	19	1971.6	1999.8
	2.4		1970.8	1975.4	12	1973.4	2004.0
	1.2		1971.5	1975.7	8	1974.2	***2007.0***
4.8	3.3	2.7	1981.5	2006.5	10	1983.5	1981.6
	1.5	1.3	1988.7	1994.0	11	1991.2	1984.8
	1.6	1.3	1997.8	2007.2	4	1999.5	***1990.5***
	1.9	1.6	1998.7	2007.2	5	2001.4	1998.8 2002.1 2004.0

4. Forecasting changes in radio fluxes

Wavelet analysis showed the presence of cyclical component in the observed data. Thus, it made possible to build a parametric model (sine or damped sine wave) time series and predict the flux change outside of the available sample. For a number of components and their frequencies obtained from the spectral method (Scargle, 1982), we estimated the amplitude and phase of harmonics by the least squares method; the frequency, amplitude and phase were optimized by nonlinear approximation to the best values. The charts for original data (normalized) and the forecast are shown in Figure 3. The correlation coefficients and standard error of approximation are as follows: 0.90, 0.16 (14.5 GHz); 0.83, 0.41 (8 GHz); 0.94, 0.23 (4.8 GHz).

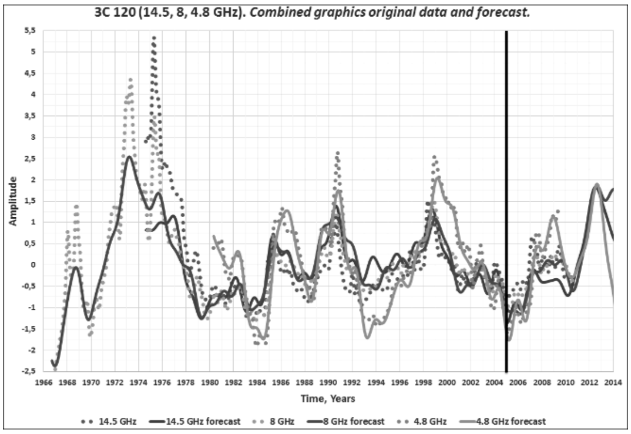

Figure 3: Charts of original data (indicated by dots) and parametric models (indicated by lines). The vertical line indicates the beginning of the forecast with 2005.2- 2014.0.

It is seen that after the beginning of the forecast, the coincidence with the original data deteriorates, but fortunately the forecast shows the total change in the data series. Perhaps, after 2010 there will be an increase in the flux of radio emission at three frequencies. This method of estimating the forecast time series is inferior in accuracy to modern methods based on neural networks, but it is much better in terms of speed of calculations for large data sets.

5. Time delays between the frequencies of observations

Between the data series, obtained at different frequencies, there are time delays. To determine their values, cross-correlation functions were computed. For frequency pairs 14.5-8, 14.5-4.8, 8-4.8 GHz the delay values were 51.1, 138.5, 58.4 days, respectively. However, the delay for the initial data contains the sum of oscillations with different periods. In the bands separate periods delay value varies with time. For example, in periods band ~6-4 years, change delay (in days) was: 146-292 (14.5-4.8 GHz); 36-146 (14.5-8 GHz); 18 – 109 (8-4.8 GHz). In periods band ~2-1 year, the delay value between frequencies decreases to the end of the series from 36 to 8 days. In periods band ~1.0-0.4 year the delay value ~22 days did not change with time (14.5-8 GHz).

6. Comparison of radio variability with VLBI maps

The observed activity in the radio source is the sum of contributions of radio-core and jet. In this paper, we attempt to relate changes in quasi-periodic radio flux with the movement of bright spots in the jet (MOJAVE Program) (Lister et al., 2009). They were used to compare the phase activity at a frequency 14.5 GHz (1998.2, 2003.7, 2007.2) as the closest to 15.4 GHz (at this frequency VLBI maps were constructed). An example is shown in Figure 4. On the maps for 1998 high brightness of the nucleus and jet components is seen. The period values are 0.7 and 1.5 years for O-C data and 4.2, 10.0 years for trending periods. On the maps for 2003 in jet dominates one outlying from core low brightness component, the period for O-C data is 1.7 years. On maps for 2007 also dominated outlying component, and a new, near the core, periods for O-C data – 1.2 and 2.0 years. When spots in the jet bright, in O-C spectrum more short periods, with the distance from the nucleus brightness diminishes spots and increase the value of periods O-C component. High spectral power trending periods corresponds to high brightness of the core. Therefore, it is the most likely that the rapid variability of the radio emission forms a jet activity and long-term – core source. It should be noted that the VLBI «core» is not a base of jet. Certain patterns can be extended to the observation period when sessions VLBI measurements were not.

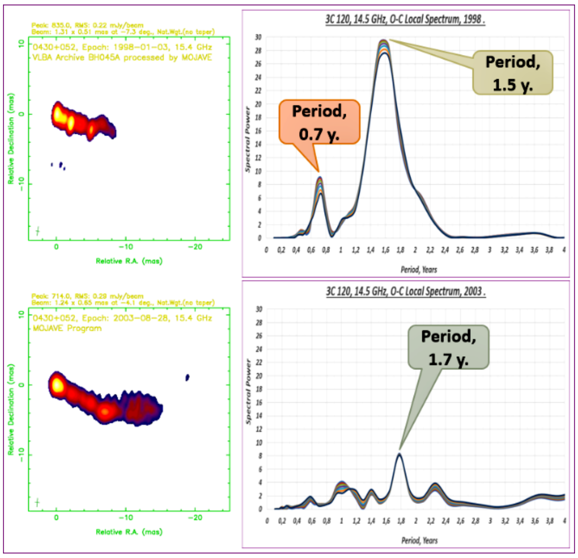

Figure 4: The figure shows VLBI maps to date 1998.01.03 (top) and 2003.08.28 (below) and the corresponding local wavelet spectra for the O – C data.

7. Results

The data processing based on wavelet analysis shows presence of some long-periodic (4-12 years) and short-periodic (0.7-3.4 years) components of the radio source. At a frequency 14.5 GHz periods of major fluctuations slightly decrease with time. For O-C components periods variation is 0.1-0.6 year. In short periods according to O-C data the highest spectral power was observed in the limited time at the moment of activation core and jet.

On the basis of quasi-periodic oscillations radio fluxes the forecast from 2005 to 2014 was calculated by means of parametric time series models. Up to ~2011 the forecast showed a good correspondence to real observation data, then an increase in flows at frequencies 14.5, 8, 4.8 GHz is likely to occur. The main phase of the radio source activity and form them «spectra periods».

Since the observed changes in flows composed of various sum of quasiperiodic processes were calculated the delay between the observing frequencies of not only the original series, but also in the bands of individual periods variability. The value varies with time delay and differs for different spectral bands.

Possible to assign from local wavelet power spectra of individual periods, which provide the main contribution to the phase of activity, allows us to «see» them with VLBI images of the coincidence of the observation time. Moving on jet bright components form fast quasiperiodic variations in the radio flux. Slow long-term flux changes, probably related to the activity of radio-core source. The advantage of long-term monitoring radio fluxes allows to use this relationship to a time when there was no regular VLBI observations (in catalog MOJAVE data from 1995). «Long waves» variable reflects macroscopic processes, changing accretion rate of gas shell to the core (Dibay, 1987), or instability in accretion disk. In paper (Cowperthwaite et al., 2012) they describe the possibility of destruction of the inner part of accretion disk in 3C120 before emissions of new components in the jet. Long-periodic variability may also be a result of the precession of the jet of radio source in presence of a double black hole (Caproni et al., 2004). The long period of 12.4 years, according to the data of optical monitoring of 3C120 may be explained by precession of the jet and coincides with the period value at a frequency 8 GHz (on 14.5 and 4.8 GHz similar values of long periods ~10 years).

Rapid variability of the radio flux can be explained by the shock waves moving in the jet. Interaction with superluminal jet component is manifested in form of forming a plurality of shock waves behind him (Marscher, 2008). A good description occurrence of short periods, model based on the magnetic dynamo (Meyer et al., 2002). In the radio source 3C120 some components of the jet close to the nucleus show a very small shift in a long time, which may be a result of «standing wave» in the interaction of forward and backward shock waves in the jet (Hiroki Nagakura et al., 2008).

References

Michel A.: 1988, *ASP Conf. Ser.*, **100**, 1423.
Lister et al.: 2013, *AJ,* **146**, 120.
Aller M.F. et al.: 2001, *BAAS*, **33**, 1516.
Gaydyshev I. *Data analysis and processing*, St. Petersburg, 2001.
Voskoboynikov Y. *Filtering of signals and images: Fourier and wavelet algorithms (with examples in Mathcad*), Novosibirsk Architectural University, 2010.
Davidov A.V. *Digital processing of signals: Thematic lectures*, Yekaterinburg, 2007.
Smolentsev N. *Wavelet-analysis in MATLAB*. DMK-Press, 2010.
Astaf'eva N.M.: 1996, *UFN*, **166**, № 11.
Rosenberg G.S. et al. *Ecology Prediction*, Tolyatti, 1994.
Ryabov M.I. et al.: 2012, *Odessa Astron. Publ.*, **25/2**, 132.
Lister et al.: 2009, *AJ*, **137**, 3718.
Scargle J.: 1982, *AJ*, **263**, 835.
Dibay E.A., *Active nuclei and stellar cosmogony*, Moscow University Press, 1987, p. 6-19.
Cowperthwaite P.S. et al.: 2012, *arXiv:1205.3175v1*.
Caproni A. et al.: 2004, *Mon. Not. R. Astron. Soc.*, **349**, 1218.
Marscher A.P.: 2008, *ASP Conf. Ser.*, **386**.
Meyer F. et al.: 2002, *arXiv:astro-ph/0207573*.
Hiroki Nagakura et al.: 2008, *AJ*, **689**, 391.