RADIOASTRONOMY

THE STUDY OF EXTRAGALACTIC SOURCES 3C 446 AND 3C 345 WITH USING THE SINGULAR SPECTRUM AND WAVELET ANALYSIS

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ABSTRACT. We investigated the data of monitoring of flux density of extragalactic sources 3C446 and 3C345, which was held on 26-meter radio telescope of University of Michigan at frequencies 14.5, 8 and 4.8 GHz. The data of observations were investigated using singular spectrum analysis and wavelet-analysis. According to the results of wavelet analysis for each year of observations, graphics of "spectra periods" were built to determine the contribution of individual periods in the activity of the radio source. The results obtained with two different methods showed a good correlation between them. For a long time component of the flux the periods of ~ 5 – 9 years were found. For short term components the periods of ~ 1 – 4 years are presented. The results obtained using two different methods were compared with VLBI radio maps, which were obtained by the program MOJAVE. The changes of periods over time are associated with certain physical processes in the system "core – accretion disk – jet" and with appearing of new bright components (knots) in the jet.

Keywords: AGN, jet.

1. Introduction

The source 3C 446 is located at the distance 10138 Mpc. It refers to optically violently variable quasars.

Blazar 3C 345 is located at a distance of 3473 Mpc. This source refers to the radio loud quasars. Some authors (eg, Lobanov & Roland, 2005) assume the existence in the source of binary systems of supermassive black holes. In the article (Caproni & Abraham, 2004) the discovery of precession in jet of source 3C 345 is reported.

2. Data reduction

In this paper 3C 446 and 3C 345 are studied. The observations were taken by the radio telescope RT-26 Michigan Observatory, at frequencies of 14.5 GHz, 8 GHz and 4.8 GHz. Graphs of flux density 3C 446 and 3C 345 at three frequencies are presented at Figures 1 and 2. Details of the calibration methods and the methods of analysis are described in paper (Aller et al., 1985).

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).

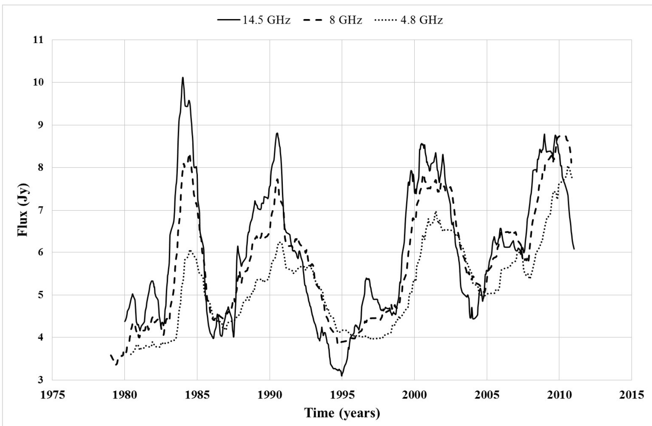

Figure 1: A graph of flux density 3C 446 at three frequencies

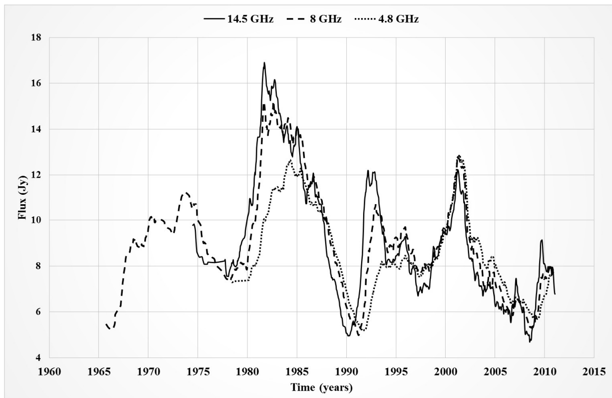

Figure 2: A graph of flux density 3C 345 at three frequencies

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 examples of the wavelet spectrum are shown in Fig. 3 and 4.

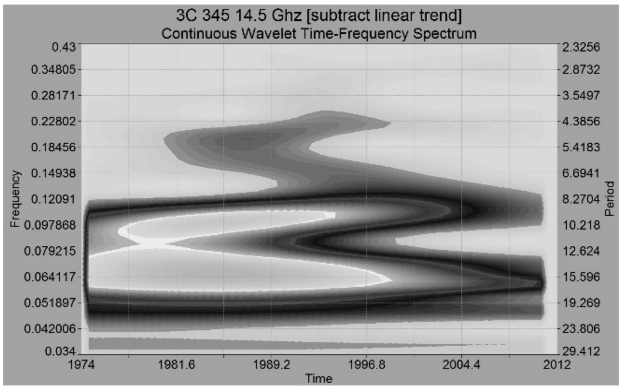

Figure 3: A continuous wavelet-spectrum of the initial smoothed data for 3C 345 at a frequency of 14.5 GHz

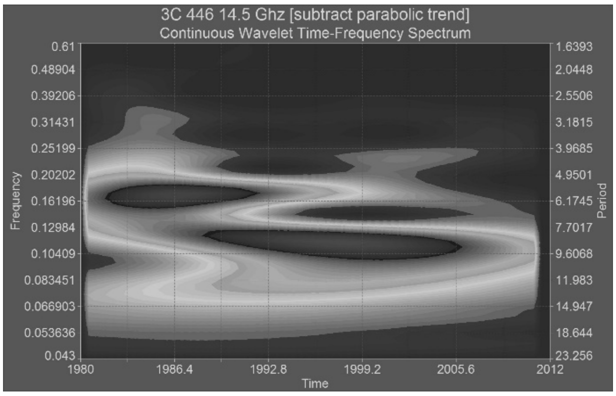

Figure 4: A continuous wavelet-spectrum of the initial smoothed data for 3C 446 at a frequency of 14.5 GHz

Periods and times of the manifestation obtained by wavelet analysis for the sources 3C 345 and 3C 446 are shown in Tables 1 and 2.

At all three studied frequencies for a longtime component of the source 3C 345 the presence of periods in the range of ~ 9 – 12.7 and 16 years is characterized. At frequencies 14.5 and 8 GHz the periods in the range ~ 4.6 – 6.1 years are present. For a short periodic component at all frequencies periods ~ 1.3 – 1.7 and 3 – 4 years are marked. The long ~ 16-year period is marked at all three frequencies and had a maximum of spectral power at 14.5 GHz in 1985, at 8 GHz – in 1988, and at 4.8 GHz – in 1994. The spectral power of 16-year period, was the highest at a frequency of 8 GHz.

Table 1. Periods obtained by wavelet-analysis for 3C 345

Frequency (GHz)	Period (years)	Beginning of the period	End of the period	Maximum spectral power	Date of maximum spectral power
The trend					
14.5	16.4-15.9	1976.8	2004.8	3545	1985.7
	10.5-9.1	1980.2	1998.0	3180	1984.6
	5.3-4.6	1984.4	1991.3	808	1987.5
8	16.1-12.7	1969.6	2007.5	4050	1988.8
	12.7-9.3	1969.6	2004.5	2800	1985.1
	6.5-6.1	1970.4	2000.7	707	1994.8
4.8	16.3-15.9	1984.5	2005.3	3200	1994.6
	9.3-8.7	1983.4	2004.3	890	1992.4
O-C					
14.5	4.0-3.4	1980.4	1999.4	384	1993.0
	1.7-1.5	2001.5	2009.1	46	2008.8
	1.4-1.2	1982.6	1992.3	44	1985.1
8	5.0-4.2	1970.0	2003.4	188	1995.0
	2.7	1971.1	1983.5	42	1976.6
	3.0	1990.1	2007.8	118	1994.2
	1.3	1979.0	1986.0	34	1981.8
	1.7-1.3	1968.2	1975.1	7	1970.5
4.8	4.0	1979.1	2006.0	32	2002.7
	1.3	1981.8	1986.2	8	1984.3

Table 2. Periods obtained by wavelet-analysis for 3C 446

Frequency (GHz)	Period (years)	Beginning of the period	End of the period	Maximum spectral power	Date of maximum spectral power
The trend					
14.5	5.8	1981.7	1995.2	1037	1986.7
	8.8	1997.6	2008.4	1092	1998.6
8	6.0	1981.4	1994.0	343	1986.2
	9.2	1997.0	2008.6	808	1998.8
4.8	5.8	1983.0	1993.7	114	1986.9
	9.2	1996.7	2009.0	407	2000.1
O-C					
14.5	3.0–2.7	1981.0	1998.5	175	1983.6
	2.0–1.3	1988.5	2001.8	32	1990.1
	2.1–1.9	2005.5	2010.3	10	2009.0
	0.8	2000.4	2005.6	7	2001.2
8	2.4–2.1	1980.8	1989.8	8	1983.5
	1.7	2002.5	2009.2	7	2008.4
	1.7–1.1	1988.7	1995.3	4	1991.9
4.8	2.7–2.4	1985.6	2008.7	7	2006.8
	1.4–1.2	1998.8	2008.3	0.7	2000.0

For a long time component of the source 3C 446 at all three frequencies by the presence of periods of 6 and 9 years is characterized. For a short time component at all frequencies the long 6-year period had a maximum of spectral power in 1986. The spectral power of this period was the highest at a frequency of 14.5 GHz. Another long ~ 9-year period had a maximum of spectral power at frequencies of 14.5 and 8 GHz in 1998, and at a frequency of 4.8 GHz – in 2000.

4. “Period – spectral power” dependence

As a result of the wavelet analysis "period – spectral power" graphs were build for each year of observation. They allow to define the periods, making the largest contribution to the formation of phase of activity of the investigated source and the time and duration of their existence.

To study the structure of radio sources in the periods of maximum activity, the VLBI maps from the database MOJAVE for the period 1995 -2012 at the frequency of 15.4 GHz (Lister et al., 2009) were investigated.

Figures 5 and 6 show examples of “period – spectral power” dependence graphs for long term and short-term components of source 3C345 during one phase of its increased activity in 2001 (see. Figures 5 and 6). From these graphs we learn that at this time the periods of ~ 9.2 and 16 years (trend), and the period of ~ 1.7 years (O-C) are seen.

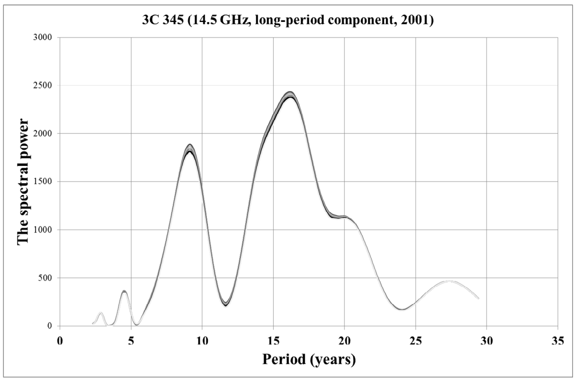

Figure 5: “Period – spectral power” dependence graph for phase of activity for the source 3C 345 in 2001 at a frequency of 14.5 GHz (trend component).

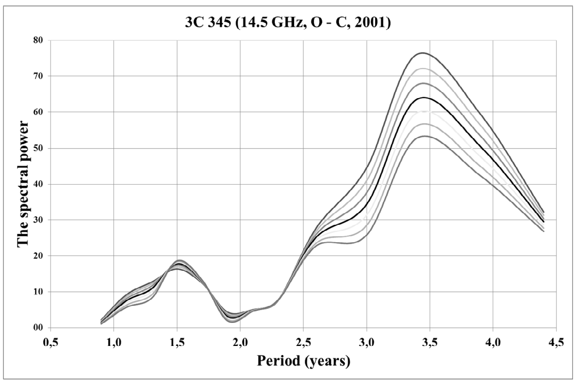

Figure 6: “Period – spectral power” dependence graph for phase of activity for the source 3C 345 in 2001 at a frequency of 14.5 GHz (O-C component).

At the VLBI maps (MOJAVE) for that epoch of observations structural changes in the jet 3C 345 are visible (see. Fig. 7).

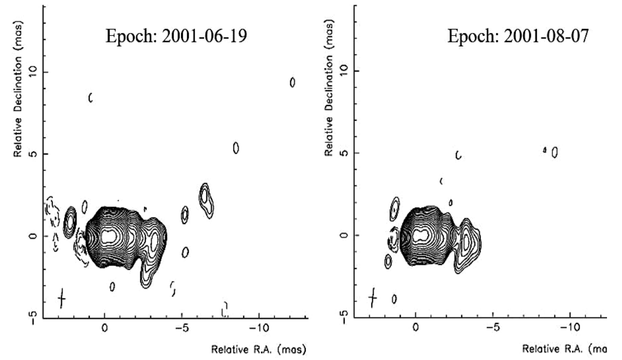

Figure 7: VLBI maps of the source 3C 345 during one of its phases of activity.

Figures 8 and 9 show "period-spectral power" graphs for the source 3C 446 in the phase of its increased activity in 2008. At this time the periods ~ 8.7 years (long-period) and ~ 1.9 years (short-period) are presented. The VLBI maps MOJAVE for this epoch of observations are shown in Figure 10.

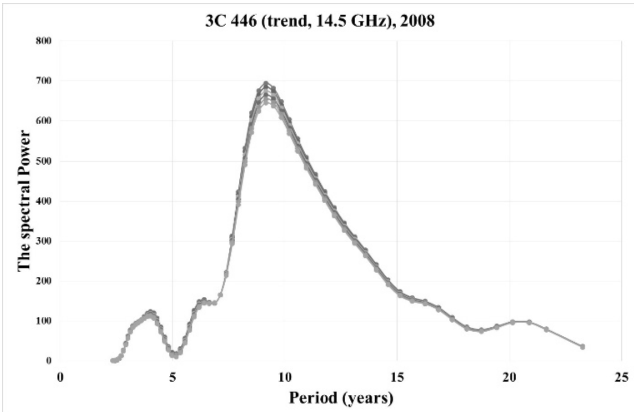

Figure 8: “Period – spectral power” dependence graph for phase of activity for the source 3C 446 in 2008 at a frequency of 14.5 GHz (trend component).

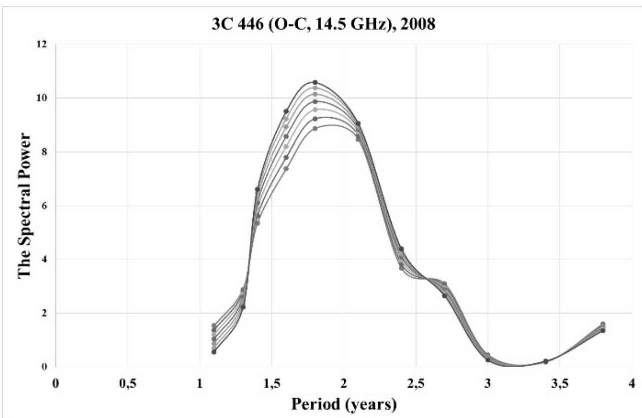

Figure 9: “Period – spectral power” dependence graph for phase of activity for the source 3C 446 in 2008 at a frequency of 14.5 GHz (O-C component).

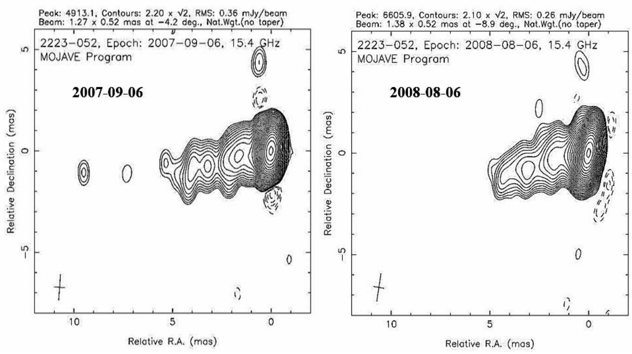

Figure 10: VLBI maps of the source 3C 446 during one of its phases of activity.

5. 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 principal components are shown in Figures 11 and 12. The eigentriples (principal components) with the numbers 2 – 11 correspond to the required harmonics, and the eigentriples with numbers equal to or greater than 12 are noise.

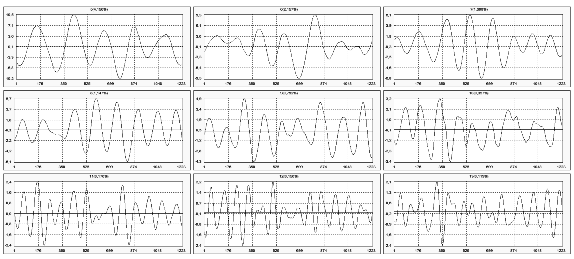

Figure 11: The principal components for 3C 345 at 14.5 GHz (one- dimensional diagram)

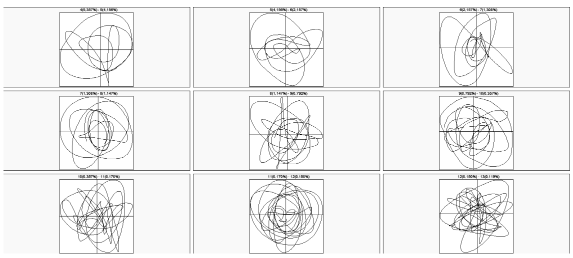

Figure 12: The principal components for 3C 345 at 14.5 GHz (two-dimensional diagram)

The main drawback of methods 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.

Periods for sources 3C 345 and 3C 446 obtained by singular spectrum analysis are shown in Tables 3 and 4. The dates of maximum activity are the same for several periods are typed in bold.

Table 3: Periods obtained by singular spectrum analysis for 3C 345.

Frequency 14.5 GHz		
8.1	2(18,34%), 3(6,80%)	**1983.4,** 1984.3**,** **1987.8**, 1993.1
6.1	4(5,36%)	1982.4, 1985.8
4.9	5(4,16%)	**1987.9**, 2001.1
4.1	6(2,16%)	**1983.8**, **1996.9, 2000.7**
3.5	7(1,31%)	**1983.6**, **2000.2**
3.1	8(1,15%)	**1987.4**, **1989.6**
2.7	9(0,79%)	**1987.9, 1997**
2.4	10(0,36%)	**1987.2**, **1989.6**, **2007.8**
1.7 – 1.9	11(0,17%), 12(0,15%)	**1983.4**, 1988.1, **1989.9**, **1997.3, 2000.7**, **2007.8**, 2008.5
Frequency 8 GHz		
15.1	1(27,94%),2(25, 73%)	1977.8, **1981.3**, 1984.9, 1987.9, 1992.7
10	3(12,36%), 4(6,33%)	1989.6, **1995.2**, **1997**, 2001.7
6	4(6.33%), 5(3,23%), 12(0,17%)	**1981.5, 1995.2**, **1995.9**, **1998.6,** 2000.8, 2001.7
4.3	6 (1,498%)	1997.95
3.3 – 3.8	7(1,28%), 8(1,16%), 11(0,44%),12(0, 17%)	**1972.8**, **1981.5**, 1983, 1989.8, 1991.6, **1997.6**, **1998.6**, **2002.6**
2 – 2.7	9(0,78%), 10(0,62%), 12(0,17%)	**1972.9**, **1981.5**, **1998.4**, **2002.6**
Frequency 4.8 GHz		
Period (years)	**Principal components**	**Date of maximum activity**
4.3	5(1,85%), (1,20%)	1985.4, **1987.9**, 1999.1, **2000.9**
2.7	7(0,73%), (0,56%), 9 (0,22%)	**1998.3**, **2000.9**, **2001.1**, 2004.9, **2006.6**
1.8 – 2.2	9(0,22%),10(0,2 0%), 11(0,19%),12(0, 15%)	**1998.5**, **2000.5**, **2006.5**

Table 4. Periods obtained by singular spectrum analysis for 3C 446.

Period (years)	**Principal components**	**Date of maximum activity**
Frequency 14.5 GHz		
10.4	1(27,62%), 2(25,24%)	**1984.6**, 1988.8, **1992.9**, 1994.7, 2004.6
5.2	3(16,12%), 4(8,88%)	**1983.1, 1984.7**, 1994.1, 1996.1
4.1	5(2,99%), 8(0,74%)	**1983**, **1989.1**, **1992.6**, 1995.2, 2000.8, **2006.9**
2.6 – 3	6(2,14%), 7(1,88%), 8(0,74%)	**1983**, **1985, 1989.1**, **1992.6**, 1995.8, 1998.7, 1999.9, **2006.9**, 2007.1
2.3	9(0,35%)	2000.3
1.7 – 2	10(0,28%), 11(0,25%), 12(0,24%)	**1983.1, 1984.6**, **1985, 1985.2,** 1985.9, 1989.9, **1992.6**, 2005.3
Frequency 8 GHz		
10.6	1(28,00%), 2(26,22%)	1996.7, **2000.9**
5.3	3(13.41%), 4(7,64%), 6(1,87%)	1983.2, **1983.9**, **1990.4**, **2000.7**, **2009.7**
4.25	5(3,95%), 8(0,85%)	**1983.8**, **1985.5, 1990.4**, **1995.9**
2.7 – 3	6(1,87%), 7(1,52%), 8(0,85%), 11(0,23%)	**1983.9**, **1985.6, 1990.3,** 1991.9, 1994.5, **1995.9**
1.9	9(0,41%), 10(0,38%)	**1985.3**, **1990.9**, 1992.1, **1995.9**, **2009.7**
1.5	12(0,17%)	**1983.9**, **1995.8**
Frequency 4.8 GHz		
10.2	1(30,61%), 2(29,51%)	**1995.6**, **1998.9, 2000.8**, **2006.2**
5.1	3(9,38%), 6(0,88%), 7(0,70%), 8(0,56%), 11(0,14%)	**1983.7, 1984.8**, **1995, 1995.7**, **1997.4**, **2001.4, 2007.2**
4.1	4(4,18%), 5(2,15%)	1985, **1993.9**, **1994.3**, **2000.6**, **2001.5**, 2004.6
2.6 – 2.9	6(0,88%), 7(0,70%), 8(0,56%), 11(0,14%)	**1983.7**, **1984.8, 1994.9, 1995.3**, **1997.4**, **2001.6**, **2007.2**
2	9(0,29%), 10(0,28%)	**1993.9, 2000.4**
1.6	11(0,14%), 12(0,10%)	1985.8, **1995.6**, **1998.6**, **2001.8**

The common manifestation of several periods at the same time corresponds to maximum amplitude of flux.

Summary

We investigated the data of monitoring of flux density of extragalactic sources 3C446 and 3C345, which was held on 26-meter radio telescope of University of Michigan at frequencies 14.5, 8 and 4.8 GHz. The data of observations were investigated using singular spectrum analysis.

In investigated sources trend components were found in the range ~ 6 – 10 years (3C345) and 5 – 9 years (3C446). Short-component is characterized by manifestation of periods ~ 1.2 – 5 years (3C 345) and 0.8 – 3 years (3C 446). It is assumed that the long-period components correspond to the core activity, and short-components correspond to structural changes in the jet. Data analysis was carried out by two supplementing each other methods: wavelet analysis and singular spectrum analysis. Wavelet analysis is based on the Fourier transform, while the singular spectrum analysis does not use the analyzing function. The results of calculations of the singular spectrum analysis of fluxes of extragalactic sources were compared with the results of the wavelet analysis. The results obtained with two different methods showed a good correlation between them. The obtained data were compared with the VLBI maps (database MOJAVE) to study the evolution of component in the jets of the quasars studied. There was found the relationship of manifestation of certain periods of variability with changes in the jet.

References

Alexandrov F.I.: 2006, Development of software system for automatic selection and forecast of additive components of time series in the framework of the “Caterpillar SSA”, Publishing House of St. Petersburg State University.

Aller H.D. et al.: 1985, *ApJS*, **59**, 513.

Caproni A., Abraham Z.: 2004, *Proc. of the International Astronomical Union*, Issue IAUS **222**, 83.

Gaydyshev I.: 2001, *Analysis and data processing (the special directory)*, St.Petersburg Publishing house.

Lister M.L. et al.: 2009, *AJ*, **138**, Issue 6, 1874.

Lobanov A.P., Roland J.: 2005, *A&A*, **431**, N 3, 831.

Smolentsev N.: 2010, *Veyvlet-analiz in MATLAB*, DMKPress.