# STUDY ON THE VARIABILITY OF BLAZAR 3C345 IN RADIO FREQUENCY RANGE

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ABSTRACT. 3C345 – intensively studied for many years in a wide range of the electromagnetic spectrum. Since 1965, the RT-26 radio telescope of the University of Michigan at frequencies of 14.5, 8 and 4.8 GHz conducted long-term monitoring of the radio source. Applied method of wavelet- analysis, allowed investigating changes in the harmonic signal components over time. For the main trend component period is 16 – 6 years, for the short-time component: 4.7 – 1.7 years. Based on global wavelet spectra in frequency range, calculated "spectra periods", characterizing the basic phases of the source activity and compared with VLBI.

## Introduction

3C345 blazar (z = 0.595) shows variability in a wide range of wavelengths, from radio to X-rays. 3C345 has extended jet in which moves bright components with speed 2 – 20 c. The trajectories of these components curved on parsec scales. Their curvature decreases with distance from the core. The study of the variability of the radio flux makes a significant contribution to the understanding of the mechanisms of formation and kinematics of a relativistic jet.

## Data processing

Initial data at three frequencies (14.5, 8, 4.8 GHz) were obtained at 26-m radio telescope of the University of Michigan (original data provided by M.F. Aller). The method of obtaining and processing data on the PT-26 is described in [1]. Observation interval 1965 – 2011 years (Figure 1).

The average interval between counting is 7 days. In preparing the data for analysis was conducted smoothing with polynomial moving average, subtraction trends and trigonometric interpolation. [2] The variability of the radio emission is divided into long-term (trend) and fast (O-C) components. FFT filtering is used for extract O-C components from signal [3].

## WAVELET-analysis

If the frequency spectrum of the analyzed signal varies greatly in the time interval, then Fourier transform shows only average frequency values with a constant resolution. The use of continuous wavelet-transform possible to study the change of harmonic components of the signal over time. Details of the methodology written in works [4, 5, 6, 7].

Wavelet-spectrum of an one-dimensional signal – a surface in three-dimensional space. Often used its projection to the frequency-time plane with the isolevels showing change of intensity of amplitudes at different scales and in time (figure 2, 3). Visualization of ranges is executed in logarithmic coordinates. Existence harmonic component in a signal is shown by horizontal strips. Inclinations and bends of strips show change of the periods in a signal.

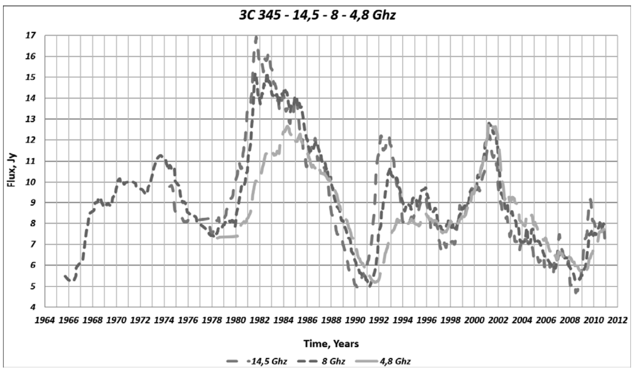



Figure 1: Plots of change in radio flux at frequencies of 14.5, 8, 4.8 GHz for source 3C345.

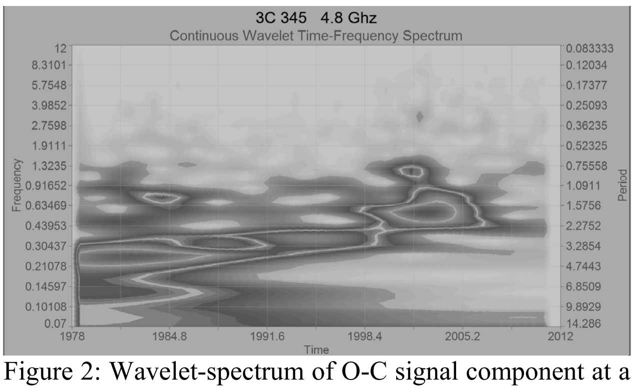



Figure 2: Wavelet-spectrum of O-C signal component at a frequency of 4.8 GHz. The period of fluctuations decreases over time.

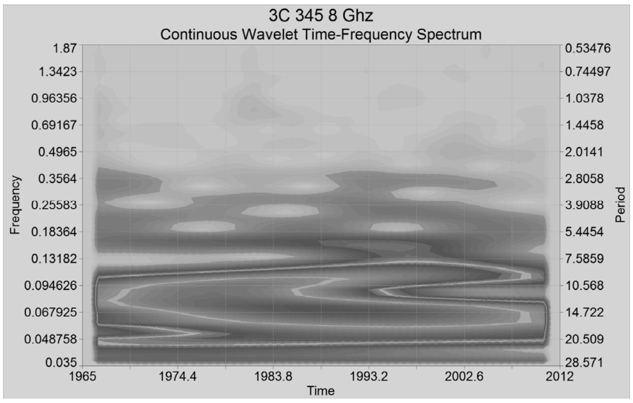



Figure 3: Wavelet-spectrum of trend component of signal at frequency of 8 GHz.

As a result of spectra analysis were recieved values of the periods which are shown in tables 1 (trend component) and 2 (O-C component).

Table 1: Main periods for a trend components of signals.

| F, GHz | P | PSD | T max |
|---|---|---|---|
| 14.5 | 15.8 | 3544 | 1985 |
| | 9.6 | 3041 | 1989 |
| 8 | 14.1 | 4050 | 1988 |
| | 10.2 | 2721 | 1984 |
| | 6.3 | 705 | 1993 |
| 4.8 | 16.0 | 3185 | 1994 |
| | 9.0 | 900 | 1991 |
| | 6.0 | 415 | 1997 |

Table 2: Main periods for O-C components of signals. Designations: F – frequency of data set, P – period in years, PSD – spectral density of power, Tmax – a timepoint when the spectral density of power for harmonica with the period P was maximum.

| F, GHz | P | PSD | T max |
|---|---|---|---|
| 14.5 | 4.7 | 672 | 1991 |
| | 3.4 | 385 | 1992 |
| | 1.7 | 46 | 2008 |
| 8 | 4.3 | 188 | 1995 |
| | 2.7 | 123 | 1992 |
| | 1.8 | 32 | 2001 |
| 4.8 | 4.0 | 30 | 1982 |
| | 2.8 | 15 | 1995 |
| | 1.7 | 32 | 2002 |

**«SPECTRA PERIODS» and activity phases**

Observed activity of source in radio frequency range consists from sum of fluxes of core and jet. In this work make attempt to connect quasiperiodic changes of a flux a radio emission with transiting brighting spots in jet. Phases of activity determined with using global wavelet-spectra with averaging on frequency. This type of a spectrum shows the moments of best coincidence analyzing wavelet and a signal at different scales and on one interval of time. To each date for a maximum spectral density of power there match with set of periods forming a phase activity of a radio source [8].

Spectral maxima for a trend components: 14.5 GHz – 1992; 8 GHz – 1993; 4.8 GHz – 2000 years. Spectral maxima for O-C a components: 14.5 GHz – 1981.6, 1985.0, 1992.2, 2009.6; 8 GHz – 1974.5, 1981.6, 1993.0, 2002.0; 4.8 GHz – 1982.0, 2002.1 years. For the specified timepoints "spectra periods" are constructed. It is variant visualization of wavelet-spectra in a series of plots "period-spectral density of power" for every year separately.

Such method allows to define what periods make the greatest contribution to formation of a phase of activity in radiation source. When comparing of "spectra periods" with VLBI maps (MOJAVE Program [9]) on dates activity of radio source, it is visible that transiting each new bright spot on jet significantly changes a range of a short-time component of a signal. Therefore it is the most probable that fast variability of a radio emission is formed by jet activity and long-term – core of source. Possible, when a spot in jet is bright, in a spectrum O-C the short periods prevail, with distance from a core brightness of a spot weakens and the periods O-C component increase. The corresponding examples are given in figures 4 and 5. Certain regularities can be extended to an interval of observation, when sessions of VLBI of measurements weren't.

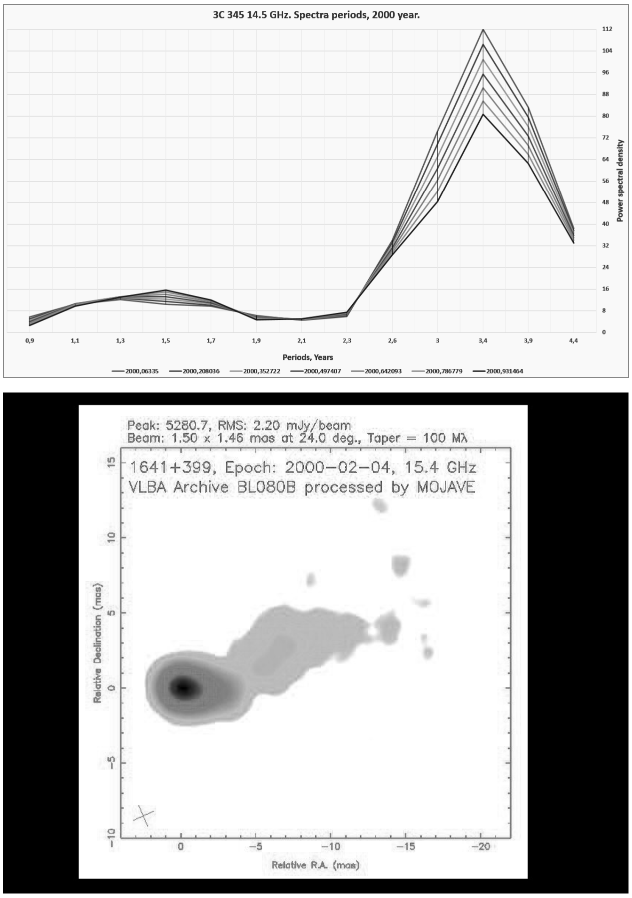
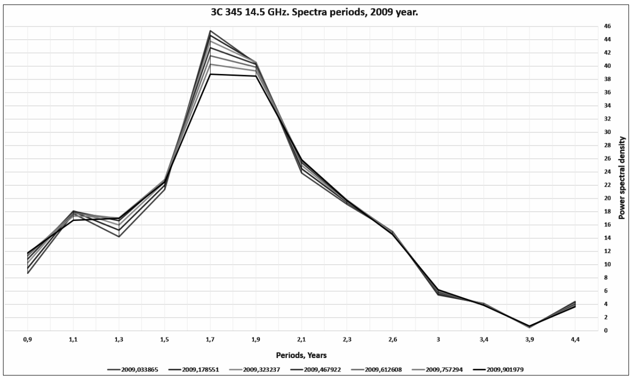



Figure 4: On VLBI image (2000.02.04) component in jet has low brightness. The prevailing period for 2000 – 3.4 years.



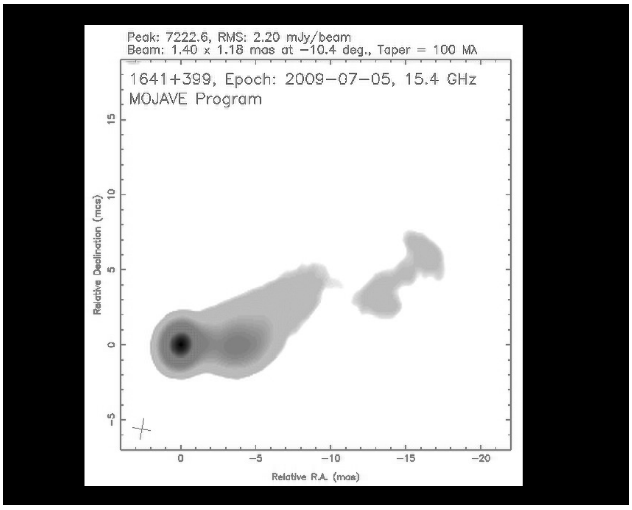




Figure 5: On VLBI the image (2009.07.05) visible bright component separated from a core. The prevailing period for 2009 – 1.7 years.

**The jet structure**

Frequent VLBI observation of radio source 3C345 allow get detailed information on movement bright spots in jet. If numbered position of spots with distance from a core, get the plot of quasiperiodic jet structure (fig. 6). At some spots brightness changes but the distance from a core remains approximately constants. This effect can be described by model of a standing wave in jet [10].

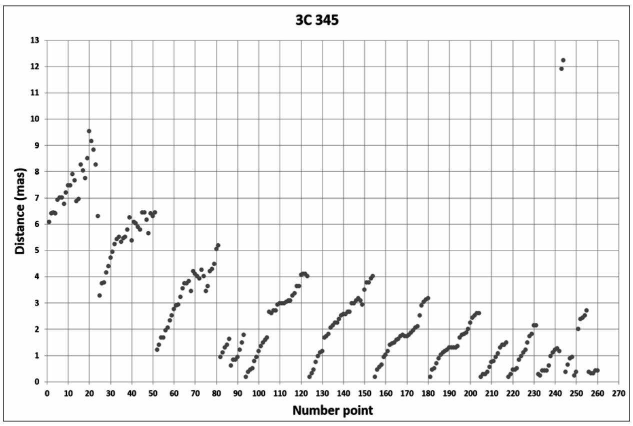



Figure 6: Quasiperiodic jet structure of radio source 3C345. Chains of points show movement a separate components in jet.

**Results**

Data processing basis on wavelet-analysis shows existence at radio source long-periods (6 – 16 years) and short-periods (1.7 – 4.7) a components. At a frequency of 4.8 GHz in O-C data fluctuations given the period decreases over time. At a frequency of 14.5 GHz in O-C data since 2000 there is a sharp reduction of the period. On 8 GHz in O-C data there is a reduction of the period of fluctuations since 1980 and increase since 1994. At a trend component change of the main periods at frequencies of 14.5, 8 GHz were ~ 1.4 years, at a frequency of 4.8 GHz change of the periods less than 0.5 years.

For verify the correctness of results were used trigonometric polynoms with the periods received from wavelet-spectra. Error of definition periods ~ 0.1 years. The main phases of activity of a radio source and forming them "spectra periods" are defined.

The use of "spectra periods" allows to select individual harmonic components, which provide the main contribution to the phase activity, and compare them with the VLBI images at this time. Moved in jet, bright components form a quasi-periodic rapid changes in the radio flux. The slow long-term flux changes are probably related to the core activity of the radio source. It should be noted that the VLBI “core” is not a jet base.

"Long waves" of variability reflect macroscopic processes, change rate of accretion a gas shell on a core [11], instability and radial pulsations of an accretion disk [12].

Fast variability of a radio emission can be explained with the shock waves extending in jet. Interaction of a superlight component with the jet is shown view form many shock waves behind it. At a source 3C345 components near a core show small shift that can be a consequence interaction direct and the return shock waves in jet. The last researches show that VLBI core also can be manifestation of constant wave in a point of the greatest jet turbulence [13, 14].

On the variability of radio emission is also affected by processes in the accretion disc. Distributed model of jet precession through the misalignment between the axes of rotation of the black hole and the accretion disc. But for 3C345 limited applicability of this model [15]. Precession of jet can appear if in a radio source there is the second black hole – the satellite. In this event besides a jet precession the satellite can create tidal indignations in accretion disk influence on long-term variability. Spiral movement of components in jet 3C345 indicates probable applicability of model a double black hole. However the spiral trajectory not necessarily demands satellite existence. The similar effect can be observed at rotation of internal parts of jet [16].

Research of a historical light curve of 3C345 in the optical range showed existence of the main period with value of 10.1 years [17]. By our results the nearest period with value of 10.2 years is observed at a frequency of 8 GHz. At frequencies of 14.5, 4.8 GHz the closest to optical the periods have values of 9.6 and 9.0 years. Probably, close values of the periods in optical and radio range indicate existence of global physical process providing long-term variability of 3C345.

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