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Study of the fast variability of the radio galaxy 3C 84 (Perseus A) in optical bands

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The extragalactic radio source 3C 84 (also known as Perseus A) is the active nucleus of giant galaxy NGC 1275, the largest in the Perseus cluster of galaxies (Abell 426). It is one of the brightest X-ray clusters of galaxies. The nucleus of galaxy NGC 1275 (Seyfert II type) is a powerful radio source of the Northern sky (flux density at a frequency 8 GHz is about 30 Jy). However, in spite of the intensive study of 3C 84 in the X-ray and gamma ranges, there are still quite a few optical observations that allow distinguishing intra-night variability. This paper shows some results of studies of fast day-to-day variability of 3C 84 in BVRI filters, based on observations at observatories in Ukraine (Mayaki), Latvia (Baldone), and Slovakia (Vihorlat). The telescopes are located in close meridional directions, which makes it possible to carry out quasi-simultaneous observations. According to these data, the light curves of 3C 84 suggest the presence of quasicyclic variations with a period about 12–19 days. Analysis of intra-night variability (time interval 5 Feb – 21 Mar 2021) according to the Baldone observatory (Latvia) showed presence at 11 Feb 2021, significant manifestation of variability with characteristic times about 10 and 1 hour. Presumably, inta-night variability was recorded on 2 Mar and 18 Feb 2021, with characteristic times 7.8 hours, 54 minutes and 4.8 hours, 1.5 hours, respectively. At the same time, manifestation of inta-night variability is episodic. Most often, variations in the 3C 84 brightness within individual nights are linear or parabolic trend changes or just noise. The amplitude of intra-night variability relative to trend changes was about 0.01 mag.

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1 Introduction

The extragalactic radio source 3C 84 (Perseus A), also known as the giant lenticular galaxy NGC 1275 (Seyfert type 2), is one of the most popular objects for research by methods of ground and space astronomy. One of the reasons for continued interest in this object is its location in a large galaxy cluster in the constellation Perseus (Abell 426). The cluster, which is one of the most massive objects in the universe, contains thousands of galaxies immersed in a huge cloud of gas with a temperature of several million degrees. Perseus cluster of galaxies – this is one of the brightest clusters in the X-ray sky. In 2003, long-periodic sound waves were discovered, which are generated by the inflation of relativistic plasma bubbles from the central active nucleus of the galaxy NGC 1275. The bubbles are visible as ripples in the X-ray range (period between oscillations is about 9.6 million years), since the X-ray brightness of medium filling the cluster space strongly depends on plasma density. For more details about the Perseus galaxy cluster it is described in [1, 2]. 3C 84 demonstrates variability of polarization of radio emission of active nucleus. Circular polarization reverses sign along the jet, making 3C 84 also the first radio source to show both circular polarization signs simultaneously. There are indications that NGC 1275 is gravitationally interacting with the absorbed galaxy. In the optical range, a system with high-speed optical emission lines of the falling galaxy and bright gas filaments, probably supported by a magnetic field, are visible. Also, an interesting feature of 3C 84 are radio-emitting bubble-like structures with enormous size [3, 4]. Analysis of long-term observations data of the 3C 84 source in the radio range, showed presence of a characteristic wavelike change in the flux density. The approximation of these data by two models made it possible to determine approximate period of the wave, caused by the precessional motion in the jet of 3C 84. For model with a lower second maximum of flux density, a period about 88 years was obtained. For the model with a symmetric second maximum, the period turned out to be about 40 years. Evidence of presence precessional rotation of the 3C 84 jet in the radio range was also found from long-term VLBI observations. Details are contained in [5].

In the optical range, 3C 84 also exhibits both long-term and rapid variability, which manifests even within individual nights of observations. Rapid variability, on time scales of several hours, has been found, even in the gamma range. For example, in [6], flare activity was detected in the energy range above 100 GeV, according to the data of ground-based gamma-ray telescopes MAGIC. The 3C 84 source flux varied significantly from day to day, with the shortest characteristic flux doubling time of about 611 minutes (about 10.2 hours). Also in that work, a significant correlation was observed between the gamma and optical (R filter) light curves, which increased when absence of flare activity of the 3C 84 source. In [7], according to observations in the VRI filters, characteristic time of brightness variation of the nucleus of galaxy NGC 1275 was defined as approximately 3 and 6 days. In [8], the presence of variability in the nucleus of the galaxy NGC 1275 was shown within individual observation nights (1982–1994), with characteristic times of several hours, usually about 4–9 hours. There were about 8% of such nights in time interval 1982–1987, and about

40% of nights showed variability within nights during 1989–1994. However, at the present time, observations in the optical range of the 3C 84 source, with a high density of measurements (70–150 images per night), are still not enough. This slightly complicates the determination of parameters of day-to-day variability, and the properties of intra-night variability have been insufficiently studied. It is this circumstance that became the goal of this work. Observations at three optical observatories significantly distant from each other (in Ukraine, Slovakia, and Latvia) make it possible to study the properties of the day-to-day and intra-day variability of the Seyfert galaxy 3C 84 in BVRI filters.

2 Observation technique and methods of their processing

Observations of 3C 84 on the AZT-3 telescope with a mirror diameter 48 cm (Mayaki Observatory (Odessa National I.I. Mechnikov University, Ukraine) were carried out from October 11, 2020 to April 10, 2021 in filters V, R, I. On November 5, 2020, the Vihorlat observatory (Slovakia) joined to the observations using the VNT telescope (mirror diameter 1 m) and B, V, R, I light filters. Observations in Slovakia continued until March 25, 2021. Observations at the Baldone Observatory (Latvia) on a Schmidt camera with a mirror diameter 1.2 m were carried out from February 5 to February 27, 2021, as well as March 19 and March 21, 2021 using filter B. Neighborhoods of the Seyfert galaxy 3C 84 marked with the target object of observation, and comparison stars, are shown in Figure 1.

The standard reduction of the CCD frames were carried out by using the MUNIPACK (http://sourceforge.net/projects/c-munipack) software. The procedures for an aperture photometry is composed of the dark-level and flat-field corrections, determination of the instrumental magnitudes and precision. The photometry was transformed to the standard VRI Johnson-Cousins system by means of the differential photometry method [9].

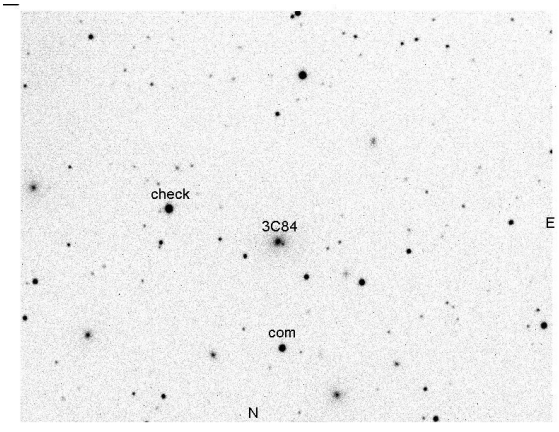


Figure 1 Image from the CCD camera of the AZT-3 telescope (Mayaki, Ukraine), the neighborhoods of the radio source 3C 84 (galaxy NGC 1275).

Observations with the AZT-3 telescope are reduced to the standard photometric system according to the following formulas:

$$V_{st} = \Delta V_{inst} + \varepsilon_V \Delta(B-V) + V_{comp}, R_{st} = \Delta R_{inst} + \varepsilon_K \Delta(V-R) + R_{comp}$$

where V_{st}, R_{st} – stellar magnitudes in the standard system, $\Delta V_{inst}, \Delta R_{inst}$ – the difference between magnitudes of variable star and comparison star, $\varepsilon_V, \varepsilon_K$ – color transformation coefficients, $\Delta(B-V), \Delta(V-R)$ – the difference between color indices of variable star and comparison star, V_{comp}, R_{comp} – stellar magnitudes of comparison star in the standard system [10]. The transformation coefficient was determined from observations of standard stars [11].

At the Vihorlat Astronomical Observatory on Kolonica Saddle we used the Vihorlat National Telescope VNT 1000/9000 mm, equipped with FLI 1001E CCD camera and Johnson–Cousins photometric filters BVRcIc. Acquired images were reduced in standard way – corrected for darkframe and flatfield. Ensemble aperture photometry was performed using CoLiTecVS [12] software package. The star UCAC4 658-015542 was selected as the main comparison. For differential photometry following brightness values were taken from LONEOS catalogue [13]: $B = 12.99$; $V = 12.40$; $Rc = 12.05$; $Ic = 11.69$. It is very important to use always the same size of aperture when comparing diffuse object as 3C 84 with point-like sources. The FWHM of stars changes according to the seeing conditions, while the galaxy core remains almost the same size. We selected a 5-pixel aperture radius which corresponds to 5.5 arcsec on the sky.

For a comparative analysis of the long-term variability the 3C 84 source, we used the visual light curve from the catalog AAVSO (American Association of Variable Star Observers) (https://www.aavso.org/) received in time interval 1973–2020.

The search for the presence or absence of quasi-periodicities was carried out using the following approach. At the first stage, Lomb–Scargle periodograms were calculated to estimate the frequencies and number of sinusoidal components in the light curves data sets. At the second stage, a linear approximation of light curves (using the least squares method) was performed to determine values of amplitudes and phases. These results were used as initial estimates of parameters for the third stage of optimization – iterative fitting by the least squares method of approximating curve to real data by selecting the optimal values of initial parameters of frequency, amplitude and phase of sinusoidal components of approximating trigonometric polynomial. This allows us to refine the initial values of periods, making their assessment more meaningful. This procedure is presented in more detail in [14].

Smoothing of light curves and reduction of some noise in the optical observation data was performed using the polynomial moving average [15]. Individual drop-out points of interference that were in the light curves were removed manually.

3 Results

As a result of the observations, light curves were obtained with the longest duration from November 5, 2020 to March 25, 2021 (Vihorlat, Slovakia), and from October 11, 2020 to April 10, 2021 (Mayaki, Ukraine). The filters for observation at the Vihorlat observatory were BVRI, at the Mayaki observatory the filters were VRI. The number

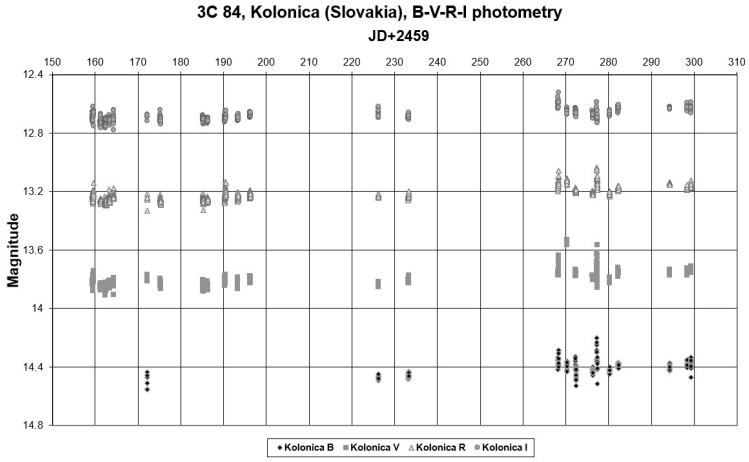


Figure 2 Light curves (raw) of radio source 3C 84 (NGC 1275) obtained at the Vihorlat observatory, Slovakia, using BVRI filters.

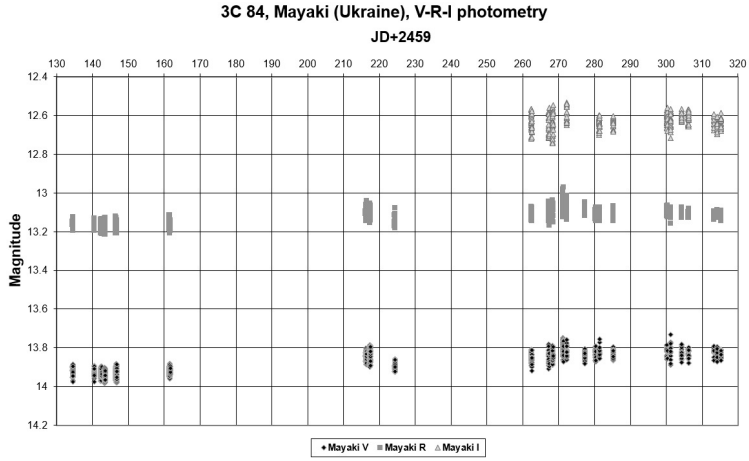


Figure 3 Light curves (raw) of radio source 3C 84 (NGC 1275) obtained at Mayaki Observatory, Ukraine, using VRI filters.

of CCD frames during one night varied from 70 to 150 and sometimes more frames (3C 84 is quite bright in the optical range). The original (raw) light curves of the 3C 84 source are shown in Figure 2 (Vihorlat) and Figure 3 (Mayaki).

A summary of these observations is shown in Table 1.

Further, the light curves (with deleted outliers points of random noise) were approximated by trigonometric polynomials, with fitting of their parameters by the least squares method. This made it possible to approximately determine characteristic times of the brightness change in different filters, and to compare the results obtained at two observatories using different telescopes and located at a distance about 700 kilometers. Examples of light curves (normalized by subtracting the mean

Table 1 Table showing the observation time interval, number of data points, mean value, standard deviation, maximum amplitude of brightness variations, as well as the smallest and largest magnitudes, for individual photometric bands from observatories in Slovakia (Vihorlat) and Ukraine (Mayaki).

Parameters	Vihorlat, Slovakia				Mayaki, Ukraine		
	B	*V*	*R*	*I*	*V*	*R*	*I*
Time interval	T1	T2	T2	T2	T3	T3	T4
Points amount	232	835	889	883	1640	1569	308
Mean	14.4108	13.8105	13.2292	12.6900	13.8810	13.1285	12.6301
Standard deviation	0.0514	0.0526	0.0415	0.0340	0.0525	0.0430	0.0408
Maximal amplitude	0.3522	0.3825	0.2985	0.2550	0.2524	0.2437	0.2084
Minimal value	14.5559	13.910	13.329	12.7783	13.9838	13.2139	12.7428
Maximal value	14.2037	13.528	13.0305	12.5234	13.7314	12.9702	12.5344

Note: T1, 18.11.2020–25.03.2021; T2, 05.11.2020–25.03.2021;
T3, 11.10.2020–10.04.2021; T4, 16.02.2021–10.04.2021

and then dividing to standard deviation) with trigonometric polynomials inscribed, are shown in Figure 4.

Thus, the values of assumed cyclicity in the light curves were obtained, which are shown in Table 2, together with the trigonometric polynomials approximation parameters.

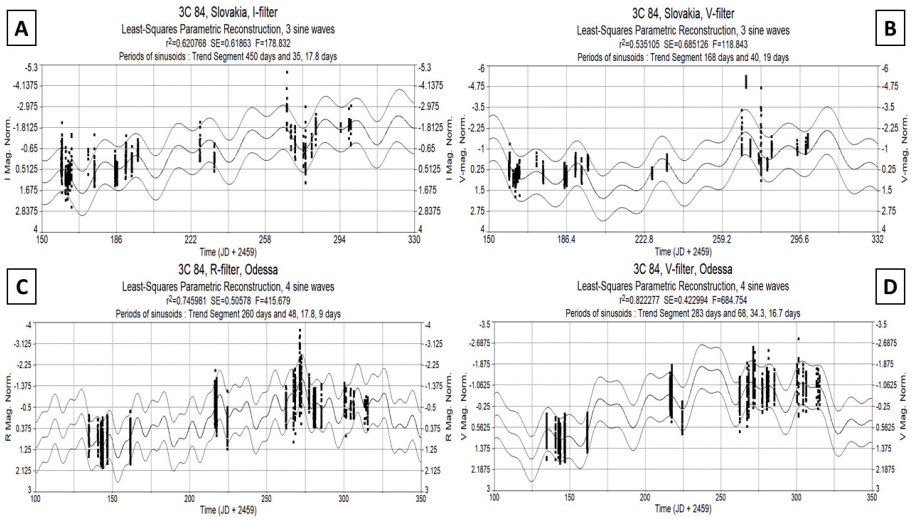


Figure 4 Examples of approximation normalized light curves of the 3C 84 source by inscribing trigonometric polynomials. The following light curves are shown: A) Filter I, Vihorlat Observatory, Slovakia; B) filter V, Vihorlat observatory, Slovakia; C) R filter, Mayaki observatory, Ukraine; D) Filter V, Mayaki Observatory, Ukraine. It can be seen from this example that the data are quite scattered, but nevertheless the day-to-day brightness variations at the 3C 84 source are clearly visible. The slow trend present in the data was described by a segment of a sine wave with a long period, for different filters, from about 180 to just over 400 days.

Table 2 The table shows approximation parameters for the light curves of the 3C 84 source obtained at the Vihorlat, Slovakia and Mayaki, Ukraine observatories. The following designations are used in the table: Observatory – the name of the observatory where observations were obtained, Filter – the designation of the optical band, Numb. Sin. – the number of sinusoids for approximating trigonometric polynomial, Main P – the value of main assumed quasi-period in days, R^2 – the determination coefficient, Std. Err. – standard error of approximation, F stat. – value of Fisher's F-statistic. It can be seen that the best approximation was made for the V, R (Mayaki) and V, I (Vihorlat) filters. The difference in quality of light curves approximation, as well as in the values of main assumed quasiperiod, can be explained by the different number of observation points and different duration of observations at the Mayaki and Vihorlat observatories.

Observatory	Filter	Numb. Sin.	Main P, days	R^2	Std. Err.	F stat.
Vihorlat, Slovakia	B	3	12.0	0.48	0.77	53.57
	V	3	19.0	0.53	0.68	118.84
	R	3	12.6	0.50	0.70	111.58
	I	3	17.8	0.62	0.61	178.83
Mayaki, Ukraine	V	4	16.7	0.82	0.42	684.75
	R	4	17.8	0.74	0.50	415.68
	I	4	15.3	0.41	0.70	50.12

4 Intra-night optical variability of 3C 84

To search for intra-night variability, we used observational data obtained in the B filter at the Baldone Observatory, Latvia. The Schmidt camera telescope with a 1.2-meter mirror is equipped with better CCD matrices, which makes it possible to more reliably detect weak brightness variations within individual observation nights. The observations were carried out on 5, 7, 11, 12, 15, 17, 18, 19, 27 February 2021 and 2, 4, 5, 19, 21 March 2021. Six comparison stars were used to determine the brightness of 3C 84. However, later it turned out that one of the selected comparison stars is possibly a variable; it was excluded from the procedure for processing CCD frames of the 3C 84 source. To check for the presence of non-noise variability in the data, the intra-night light curves were approximated (preliminarily cleared of outliers points and normalized by subtracting mean and dividing to standard deviation) by trigonometric polynomials, from two sinusoids (less often one sinusoid), according to the same method described above. The summary table of characteristic variability times and approximation parameters is shown in Table 3.

It can be seen from Table 3 that only on one night, 11 Feb 2021, a significant manifestation of intra-night variability of the 3C 84 source was recorded, with characteristic times about 10.3 and 1 hour. It is also possible that intra-night variability was recorded on 2 Mar and 18 Feb 2021, with characteristic times 7.8 hours, 54 minutes (2 Mar) and 4.8 hours, 1.5 hours (18 Feb). An example of several light curves for individual observation nights (February 5, 12, 15 and 18, 2021), which were obtained at the Baldone observatory, is shown in Figure 5. On the rest of the nights, the accuracy of approximation was quite low, which means predominantly irregular variability of the 3C 84 source during these nights. According to observations at the observatories Mayaki (Ukraine) and Vihorlat (Slovakia), predominantly linear or, less frequently,

Table 3 The parameters of approximation of intra-night light curves of the 3C 84 source in the B filter, according to observations at the Baldone observatory, Latvia. The following designations were used: Date – the date of observations, P_1, trend – the period of sinusoid, segment of which described a smooth trend change in brightness, P_2, fast – the period of sinusoid, which described rapid brightness variations during the night, R^2 – the determination coefficient, Std. Err. – the standard error of approximation, F-stat – the value of Fisher's F-statistic. For the trigonometric polynomial, two sinusoidal components were used – the trend component (a smooth change in brightness within the night) was described by a sinusoidal segment, and the fast component, a sinusoid, describing brightness variations relative to the trend component. On some nights, the trend component was absent, so approximation was made by a single sinusoid describing fast brightness variations.

Date	P_1, trend	P_2, fast	R^2	Std. Err.	F-stat.
02.03.2021	7.8 h	54.0 min	0.73	0.53	34.46
05.03.2021	2.6 h	45.2 min	0.40	0.80	8.90
19.03.2021	2.0 h	37.4 min	0.48	0.75	8.52
21.03.2021	–	8.2 min	0.21	0.90	5.78
05.02.2021	3.5 h	19.3 min	0.44	0.80	6.53
07.02.2021	–	35.6 min	0.46	0.77	7.02
11.02.2021	10.3 h	1.0 h	0.94	0.24	222.18
12.02.2021	2.3 h	49.4 min	0.53	0.72	10.41
15.02.2021	3.6 h	33.0 min	0.52	0.71	14.15
17.02.2021	2.3 h	19.2 min	0.40	0.81	7.60
18.02.2021	4.8 h	1.5 h	0.66	0.60	40.96
19.02.2021	2.8 h	1.1 h	0.37	0.81	9.00
27.02.2021	–	8.4 min	0.37	0.85	3.64

parabolic trends in 3C 84 variations were observed, during individual nights of observations, while the variations relative to trend were mostly irregular. The minimum time scale of variability 3C 84 recorded in Ukraine and Slovakia was about 20 minutes. The amplitude of fast variations of 3C 84 during the night is on average about 0.01 mag (approximately at the level of amplitude variations of variable stars the ACV type).

The statistical parameters of all intra-night light curves obtained at the Baldone Observatory (Latvia) are shown in Table 4.

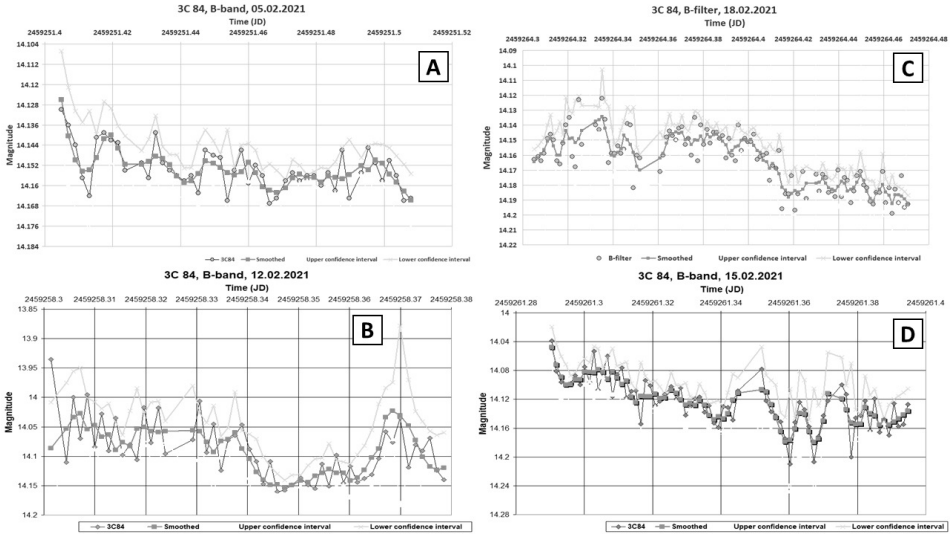


Figure 5 Examples of the 3C 84 intra-night variability in the B filter, according to the Baldone Observatory, Latvia. Light curves are shown for the following dates: A) 5 Feb, B) 12 Feb, C) 18 Feb, D) 15 Feb for 2021. The figures show original data points, smoothed (6 points window) data, and upper and lower confidence intervals for smoothed light curve.

Table 4 Table of intra-night variability parameters of the 3C 84 source in the B filter. The following designations are used in the table: Date – date of observations, Mean – average magnitude over the night of observation, Std. Dev. – standard deviation, Max. and Min. – the largest and the smallest magnitude during the observation night, respectively, Ampl. – the amplitude of source brightness variation during the night, aG – the average Gini difference, which shows scatter of the time series values relative to each other and does not depend on some central value, for example, from the mean or median, Qa – the interquartile range, characterizes degree of spread data, and is the difference between upper and lower quartiles of the time series (quartiles break the dataset into four parts, selected in such a way that 25% of values of data sample will be less in magnitude of Q_1; 25% will be enclosed between Q_1 and Q_2; 25% – between Q_2 and Q_3; the remaining 25% are higher than Q_3).

Date	Mean	Std. Dev.	Max.	Min.	Ampl.	aG	Qa
02.03.2021	14.08	0.024	14.03	14.13	0.10	0.027	0.033
05.03.2021	14.13	0.010	14.10	14.15	0.050	0.011	0.012
19.03.2021	14.10	0.013	14.07	14.12	0.052	0.015	0.016
21.03.2021	14.11	0.0089	14.08	14.12	0.040	0.010	0.011
05.02.2021	14.15	0.0086	14.13	14.16	0.037	0.0097	0.011
07.02.2021	13.94	0.054	13.86	14.04	0.17	0.058	0.055
11.02.2021	13.97	0.12	13.73	14.16	0.42	0.13	0.21
12.02.2021	14.09	0.050	13.93	14.16	0.22	0.055	0.060
15.02.2021	14.12	0.034	14.04	14.21	0.17	0.038	0.047
17.02.2021	14.16	0.011	14.14	14.19	0.050	0.012	0.013
18.02.2021	14.17	0.018	14.12	14.20	0.077	0.020	0.029
19.02.2021	14.15	0.014	14.11	14.18	0.070	0.016	0.018
27.02.2021	14.05	0.020	14.02	14.09	0.073	0.024	0.030

5 Long-term optical variability of 3C 84

To analyze the long-term variability of the source 3C 84, we took a quite long series of data (visual light curve) from the AAVSO catalog. Since the scatter of points in this light curve (1973–2020) is quite large, the data were preliminarily smoothed with a polynomial moving average. Next, a Lomb–Scargle periodogram was built (with a Bartlett spectral window) for non-uniform time series. The light curve (raw and

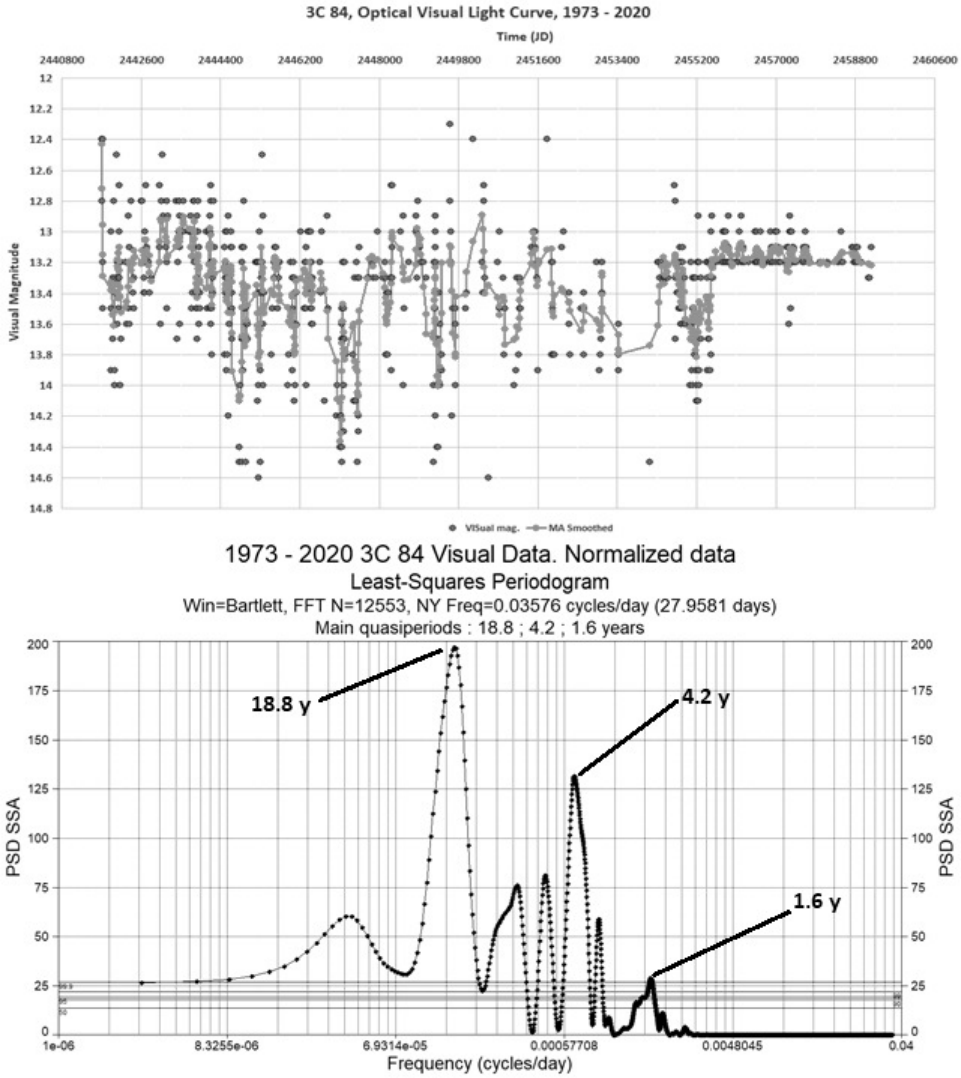


Figure 6 Visual light curve (1973–2020), original data points and smoothed plots (top) for the source 3C 84 (data from the AAVSO catalog). The periodogram calculated from smoothed data (below) shows presence of two main cycles of 18.8 and 4.2 years, as well as a weaker cycle with a characteristic time about 1.6 years.

smoothed data) and the periodogram are shown in Figure 6. The periodogram shows two peaks very clearly, with periods of 18.8 and 4.2 years, significantly exceeding the 99.9% confidence interval of the harmonic oscillation detection. Also, there is probably another weak period in the data with a value of 1.6 years, which is only slightly above the 99.9% confidence level, and thus is significant. It is interesting that if we assume, as shown above, that the precession period in the radio range is 40 years, then the main long period in optical range is very close to half (20 years) of the precession period for the 3C 84 source. However, for a more accurate determination of the longest cycle close to 20 years, an analysis of a longer light curve is required, since in the time interval from 1973 to 2020, only about 2.5 cycles of a period 18.8 years fit, which makes its presence, over a longer time interval, still quite hypothetical.

As can be seen from Figure 6, at the end of 2020 the 3C 84 source was in a protracted phase of weak activity from about 21 Jun 2012, and this phase continues to Jun 2021. Therefore, the 3C 84 photometry performed at the end of 2020 – the beginning of 2021 and the obtained results are an important indicator of 3C 84 variability under conditions of minimal activity, since until 2012 the source had been showing a high variability amplitude (about 1.6 mag) since 1973.

6 Discussion

The possible presence of quasiperiodic optical brightness variations in the radio source 3C 84 (Seyfert 2 galaxy NGC 1275) has been studied in many works since the 1960s, and quite contradictory results have been obtained. On the one hand, the core of this galaxy is variable over a very wide range of characteristic times, from several years to tens of days. On the other hand, there are quasiperiodic components in this variability or it is completely irregular, it is not yet known for certain. For example, in early work [16], variations in the optical brightness of 3C 84 were analyzed and it was shown that it has flare activity with an amplitude about 0.5 mag, and with time scale about 60 days. The polarization of the optical emission was also variable on a time scale of about 1 day. A study aimed at searching for the periodic variability of the nucleus of the galaxy NGC 1275 (3C 84) was carried out at the Crimean Astrophysical Observatory from 1966 to 1976. However, despite the pronounced variability of the brightness of the nucleus of NGC 1275, no regular periodic variations were found. The search for periods was carried out in the range from 7.5 to 800 days. No quasiperiodic variations were detected in this range of periods, with an amplitude of about 0.5 mag (approximate amplitude of the fast variability component on a time scale of tens of days). At the same time, a weak, possibly cyclical, variability was found, with a small amplitude of about 0.07 mag, and a characteristic time of 14.9 days. In addition, possibly cyclic components were found with characteristic times of 63.6 (amplitude 0.08 mag) and 28.9 days (amplitude 0.07 mag). The significance of these quasi-periods was then quite low. It was also noticed that these quasiperiods are likely to be present in different time intervals of the light curve, which was obtained by photoelectric observations (exist in the data for 10–15 cycles). The most probable, relatively long-term brightness fluctuation with an amplitude of about 0.1 mag, could have been cyclical with a quasiperiod of about 340 days [17].

It should be noted that the values of most probable quasi-periods obtained in our work, in the range of 12–19 days (Vihorlat observatory, Slovakia) and 15–18 days (Mayaki observatory, Ukraine), are quite close to the quasi-period of 14.9 days obtained in that work.

Variability within individual nights of observations was also observed in early work. For example, in [18], the characteristic times of variations in the brightness of the nucleus of the galaxy NGC 1275 were found, with values of approximately 1 hour, 3.7 hours, and 8.6 hours. The long-term variability of the core of this galaxy was estimated at 4 and 6 years. The values of the characteristic intra-night variability times of 3C 84 obtained in our work are quite close to the results obtained earlier by other authors.

The results for fast microvariability are also quite close to the results of estimating the characteristic intra-night brightness variations of the 3C 84 source obtained as a result of this work. According to the B filter observations, which were carried out at the Baldone Observatory, Latvia, the values of characteristic variability times of the 3C 84 source were obtained at about 10 hours, 8 and 3–4 hours and about 1 hour. An estimate of the long-term variability of 3C 84 based on observations from the AAVSO database showed the presence of three main cyclical components with quasi-period values of 18.8, 4.2, and 1.6 years. It can be seen that the presence of a stable brightness fluctuation with an assumed quasiperiod of about 4 years, which was present in different light curves of the 3C 84 source is, probably, confirmed. The presence of a brightness fluctuation with a period of slightly more than 1 year is also most likely confirmed, in comparison with earlier works.

The characteristic time of variability of the nucleus the Seyfert galaxy NGC 1275 (radio source 3C 84) in the optical range was estimated at about 20 days, according to the data of many early observations of 1970–1990. This corresponds quite well to the result obtained in this work. However, whether these variations are irregular or quasiperiodic with a limited lifetime is not yet reliably known. While the brightness variations are irregular, they are most likely caused by randomly located plasma clouds in the active core of the galaxy, rapidly changing their density and temperature over several weeks or days. In the case of variations close to periodic, this would indicate the approximate period of rotation of gas clouds in the active core. Most likely, this galaxy has no significant optical emission from the jet [19, 20]. However, despite the fact that the best approximations of the observational data by trigonometric polynomials gave a fairly good fit (coefficients of determination 0.82, 0.74, 0.62), the high discontinuity of the available data indicates that it is necessary to refine it based on longer observations. With regard to intra-night variability, there are various theoretical models aimed at explaining the rapid variability on time scales of several hours, using models based on instabilities in accretion disk surrounding the black hole. These models include pulsations of gravitational modes of gas disk [21, 22] or orbital structures from “hot spots” in the gas surrounding the black hole, or from the corona of gas outgoing and surrounding the plane of the accretion disk [23, 24]. However, the topic of intra-night variability of active galactic nuclei is still not worked out in detail and is a topic of scientific discussions. Therefore, monitoring optical observations with a high temporal resolution are very important for improving theoretical models of the fast optical variability of Seyfert and radio galaxies.

Summing up the results of joint observations (BVRI photometry) of the source 3C 84 (NGC 1275) at the end of 2020 and beginning of 2021, at the observatories Mayki (Ukraine), Vihorlat (Slovakia), Baldone (Latvia), new results were obtained on the possible presence of cyclic (12–19 days) of brightness variations (in low phase of the source activity), according to data from the two observatories Mayaki and Vihorlat, which confirms this result, despite the fact that light curves in different filters had slightly different numbers of points and lengths, which gave a scatter of results. Also, presumably, manifestations of fast intra-night variability (according to the Baldone observatory) were recorded in the B filter, with characteristic times of 1–1.5 hours, but additional verification is required, which is planned to be done in subsequent observations of the 3C 84 source during 2021.

7 Conclusions

As a result of the work done, the light curves of radio source 3C 84 (Seyfert 2 galaxy NGC 1275) were obtained in the BVRI filters, at the observatories Mayaki (Ukraine), Vihorlat (Slovakia) and Baldone (Latvia), over the total time interval October 11, 2020 – April 10, 2021. Such a coordinated program for study of variability the 3C 84, with telescopes located near one meridian has not been carried out before. Analysis of the variability of optical brightness of the radio source 3C 84 showed the presence of a slow (with an amplitude 0.2–0.3 mag), trend change in brightness, which is superimposed by faster variations with characteristic times of several tens of days. It is very likely that in this observation interval, 3C 84 had cyclic brightness variations, with an assumed quasi-period lying in the interval of 12–19 days (according to the Vihorlat observatory, Slovakia) and in the interval of about 15–17 days (according to the Mayaki observatory, Ukraine) and with an amplitude of about 0.05 mag. The minimum characteristic variability time according to the data of both observatories was about 20 minutes. Using the data of the Baldone Observatory, Latvia in the B filter, a search was performed for intra-night variability of 3C 84, in the time interval 5 Feb – 21 Mar 2021. From these observations, on one night on 11 Feb 2021, a significant manifestation of variability with characteristic times of about 10 and 1 hour. The amplitude of intra-night variability was about 0.01 mag. In addition, the analysis of the long-term visual light curve (1973–2020) of the 3C 84 source (from the AAVSO catalog) was carried out. The possible presence of cyclicity with quasi-periods of 18.8, 4.2 and 1.6 years is shown. If we take into account the presence of precessional period of the jet in the radio range, about 40 years, then the quasi-period of 18.8 years, in the optical range, is almost equal to half of this precessional period (20 years).

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