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Photometric Study of the Blazar OJ 287

E. Zaharieva, **E. Ovcharov**, **M. Minev**, **V. Bozhilov**, **A. Valcheva**

Department of Astronomy, Faculty of Physics, University of Sofia,
BG-1164 Sofia, Bulgaria

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Abstract. We present the results from observations of the blazar OJ 287 in the B, V, R and I bands during December 2015 - February 2020. The obtained light curve of OJ 287 showed long-term timescale variability with a large amplitude. We found untypical variations in the color indexes (B-V) and (V-R) in short-term period. A dominating black body radiation from the accretion disc and the Broad-Line Region (BLR) emission lines appearance in the blazar spectrum might be the probable reasons for these variations.

KEY WORDS: AGN, astronomy, blazar, observations, photometry

1 Introduction

OJ 287 (R.A.: 08h 54m 48.9s Dec.: +20° 06' 31", z = 0.306 [1]) is a blazar, which is a subclass active galactic nuclei (AGN). Blazars are identified with strong flux variability in all wavelengths on various timescales – from hours to years. The study of the variability timescale is important for the understanding of the AGN's physical processes and their central region properties. According to the AGN unified model relativistic jets aligned near the line of sight are the cause for their strong emissions [2].

The optical light curve of OJ 287 dates from 1890 and reveals repeating outbursts with a period of 12 years [3] and rapid variation of the optical polarization [4]. The outbursts are with double-peaked flares separated by a few years, which is explained with the model of binary black hole system – BBH [3,5,6]. According to this model, in the center of OJ 287 a super-massive black hole (SMBH) is orbiting in a precessing eccentric orbit an ultra-massive black hole (UMBH). The double-peaked flares are due to the impact of the orbiting SMBH with the accreation disk of the primary UMBH.

This monitoring is part of the Whole Earth Blazar Telescope (WEBT) and GLAST-AGILE Support Program (GASP) campaign.

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2 Observations and Data Reduction

The optical observations were obtained with the 50/70 cm Schmidt telescope and the 2 m RCC telescope at Rozhen National Astronomical Observatory (NAO) and the 35 cm Newton telescope at Plana Student Astronomical Observatory (SAO). The technical parameters of the used observational systems are shown in Table 1. The object OJ 287 is observed in BVRI-bands for 20 nights during May 2015 – February 2020.

Table 1. Instruments used for observations.

Telescope	**Camera**	**Pixel scale [arcsec]**	**Field of view [arcmin^2]**
2 m RCC + FoReRo2	VersArray 1300 B	0.74	17 x 16
2 m RCC	VersArray 1300 B	0.26	5.5 x 5
2 m RCC + FoReRo2	iKon-L 936	0.5	17 x 17
2 m RCC	iKon-L 936	0.17	6 x 6
50/70 cm Schmidt	FLI PL 16803	1.08	72 x 72
35 cm Newton	STL 11000M	1.16	78 x 52

The typical seeing of the observed data is 2 [arcsec]. We performed data reduction and corrections with standard methods using procedures of the software package Image Reduction and Analysis Facility (IRAF) [7]. We obtained bias, dark and flat-field corrections and did an alignment of the object's individual frames. After the reduction we used the Dominion Astrophysical Observatory Photometry (Daophot) [8] software from IRAF to proceed the photometry of the images with the aperture photometric technique using comparison stars recommended from WEBT [9, 10]. The observational data are corrected for galaxy extinction [11]. In Table 2 are shown part of the obtained observational data points with their JD, magnitude and error.

Table 2. Observational log

JD	**Filter**	**Magnitude [mag]**	**Error [mag]**
2457363.41797453	R	13.552	0.005
2457363.42168981	R	13.554	0.005
2457363.42540509	R	13.554	0.006
. . .			

3 Color-Magnitude Diagram

The light curve of OJ 287 is shown in Figure 1. The data from December 6 and 7, 2015 show that the object was observed in maximum state. The registered

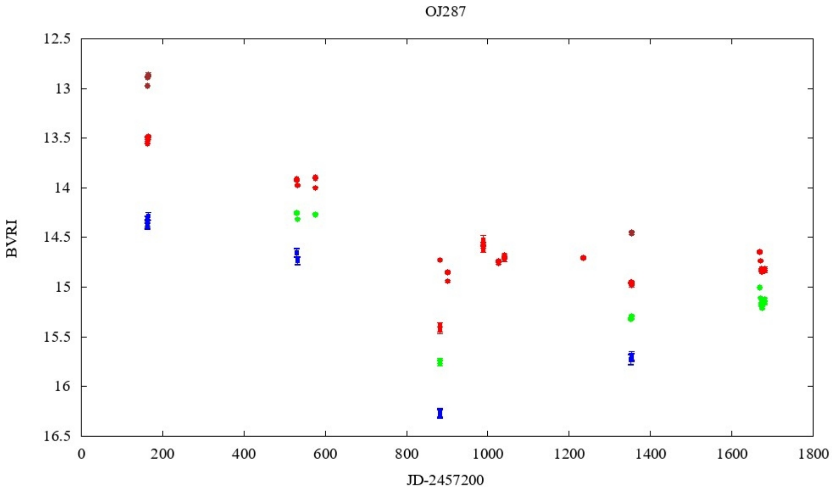

Figure 1. Light curve of OJ 287 in B (blue), V (green), R (red) and I (brown) bands.

brightest level of this flare was on December 5, 2015 with magnitude in R band of 12.9 mag [12]. Due to the 12 years cycle, the next outburst is predicted to be in 2027.

We present color-magnitude plot of the reduced blazar data. The correlation between the color and the magnitude in the blazars is important for the understanding of their nature. In Figure 2 we used all of the obtained observational data points for OJ 287 in the period December 2015 – February 2020. For better display purposes (B-V) points are shifted with +0.6. The correlation we used is $Y = kV + c$, where k is the fitted value for the slope of the curve and c is the constant. We define positive correlation when the slope is positive, i.e the object tends to be bluer when brighter or redder when it faints. The negative correlation means that the source is redder when it brightens. For long-term time scale we obtained the following values of k: for (B-V) $k = 0.029$ and for (V-R) $k = 0.007$. These values of k mean that the slopes are positive. The positive correlation is in agreement with the obtained by Ref. [13].

It is noticeable that correlation (B-V) is negative for some of the data points obtained in short-term timescale within January 23 – February 1, 2020 – the red points in Figure 2.

The data shown with red points in Figure 2 are daily averaged and presented in Figure 3. For better display purposes (B-V) points are shifted with +0.6. They are obtained with two different optical systems – 35 cm Newton telescope at Plana SAO and 50/70 cm Schmidt telescope at Rozhen NAO. The value of k for (B-V) is -1.67 and 0.71 for (V-R). The slope of the color index (V-R) is positive like in the long-term case (Figure 2), but greater which means that the source

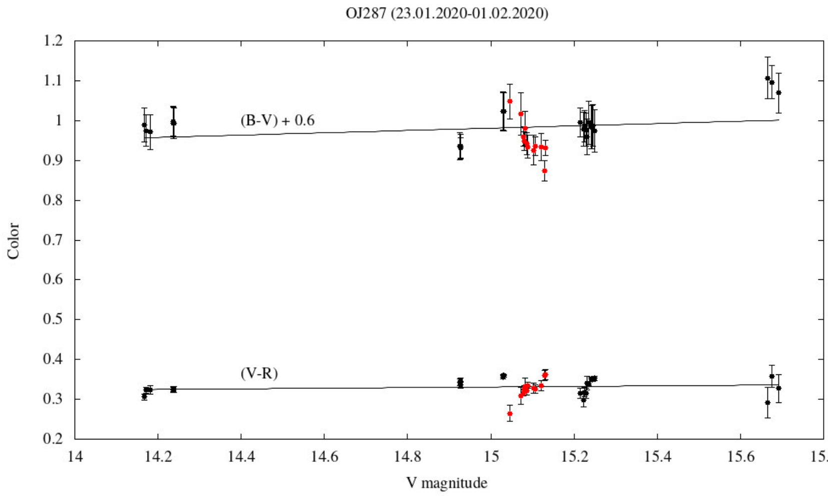

Figure 2. Color-magnitude plot of OJ 287. The observational data for the period January 23 – February 01, 2020 are shown in red. The (B-V) points are shifted with +0.6.

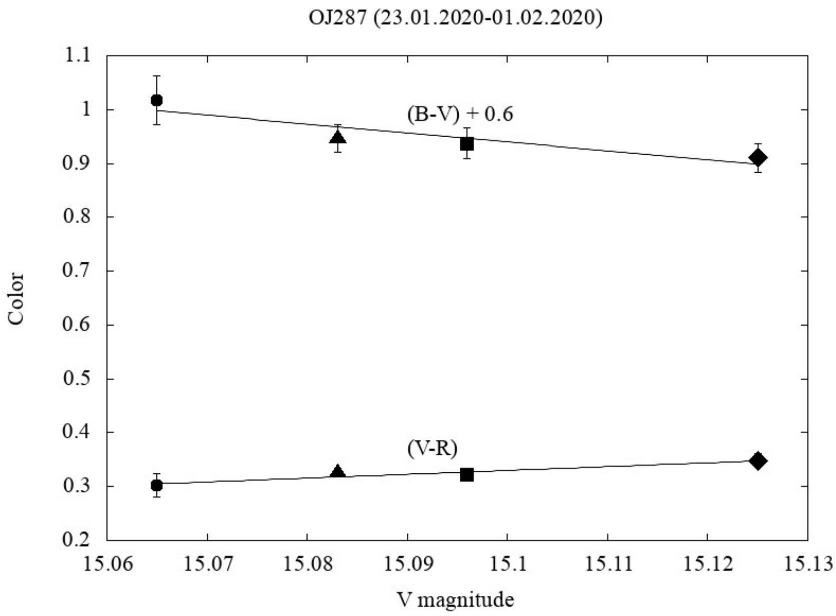

Figure 3. Color-magnitude plot of OJ 287 for the period (January 23 - February 01, 2020). The (B-V) points are shifted with +0.6.

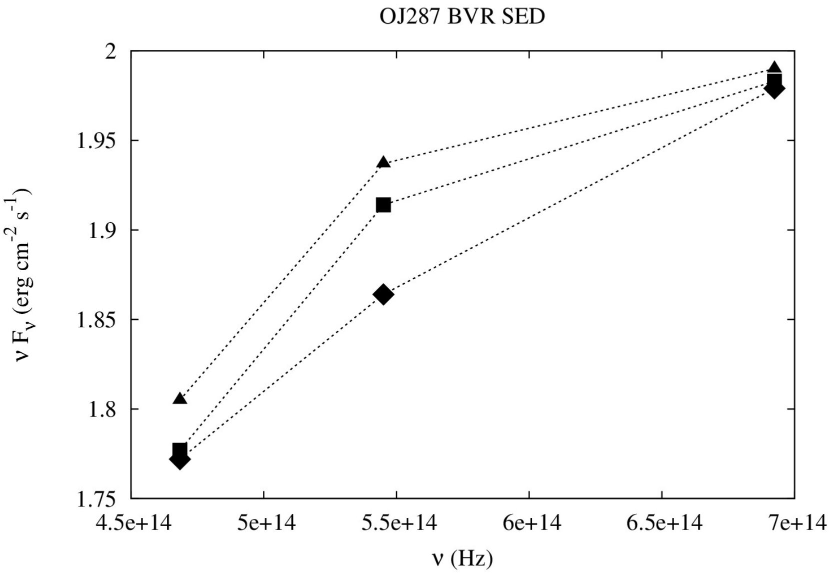

Figure 4. BVR flux of OJ 287 on January 23–25, 2020 obtained with 50/70 cm Schmidt telescope.

tends to be bluer when is brighter. The color index (B-V) shows large opposite behavior in Figure 3. Similar correlation for (B-V) is obtained in the study of Ref. [14].

Due to the narrow magnitude variations in this short-term period, confident conclusion for the correlation of the color index with brightness is uncertain. Correspond to the long-term period in our data it is obvious that the detected color indexes are significantly different. For more thorough analysis we measured the flux from the magnitudes of the observational data taken with 50/70 cm Schmidt telescope in Figure 3. We exclude the points with larger errors (circles), taken with 35 cm Newton telescope. The Spectral Energy Distribution (SED) of the fluxes in BVR-band taken with 50/70 cm Schmidt telescope on January 23, 24 and 25, 2020 is shown in Figure 4. The data marked with “rombs” indicates noticeable trend of increasing BR flux with decreasing of V flux. Probable reasons might be domination of the black body radiation from the accretion disc and the appearance of the emission lines from BLR in the blazar spectrum, caused by probable displacement of the jet from the line of sight and/or diminished intensity. From previous studies is known that the spectral energy distribution of blazars may show variations from bright to faint state. In faint state in the spectrum of OJ 287 the lines H_α and H_β are registered in emission [1]. Due to the redshift the line H_β is located in the center of the R-band. In Ref. [15] the authors found bumps in the visible-UV part of the spectrum that can be explained as accretion-disk emission associated with the primary black hole or consistent with line emission.

4 Conclusions

We present the BVRI light curve of OJ 287 during December 2015 – February 2020. The brightest level in our data is from December 6, 2015, only a few hours after the flare registered on December 5, 2015 [12]. The light curves show long-term time-scale variability with large amplitude. We found untypical variations in color indexes (B-V) and (V-R) in short-term period between January 23 and February 1, 2020. The increasing of brightness in BR-bands with the decreasing of V-band is registered. The probable reasons might be contribution of black body radiation from the accretion disc and the appearance of emission. The importance of our own original results highlights that OJ 287 continues to be one of the most interesting Blazar-type AGNs. Further monitoring and study of OJ 287 is planned and will lead to better understanding of the behaviour of the object.

Acknowledgements

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