Publ. Astron. Obs. Belgrade No. 104 (2024), 189 - 194 *Progress Report*
https://doi.org/10.69646/aob104p189

TEN YEARS OF MONITORING OF 1722+119 AT ASTRONOMICAL STATION VIDOJEVICA

MILJANA D. JOVANOVIĆ[1,2] and GORAN DAMLJANOVIĆ[1]

[1] *Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia*
E–mail: miljana@aob.rs
E–mail: gdamljanovic@aob.rs

[2] *Department of Astronomy, Faculty of Mathematics, University of Belgrade, Studentski trg 16, 11000 Belgrade, Serbia*

Abstract. In 2011, two years before the launch of the Gaia satellite, 47 objects for the link between the future Gaia Celestial Reference Frame and International Celestial Reference Frame were proposed. We have been actively observing these 47 objects at the Astronomical Station Vidojevica since 2013. These objects are Active Galactic Nuclei and the monitoring of their brightness is important in order to investigate the physical processes which can affect their astrometric precision. The observations were performed mostly in V and R bands, and occasionally in B and I bands. Here, we present the photometry results, analysis of brightness, and $V - R$ colour using 10 years of observations of the object 1722+119 (the most variable source in our list of objects).

1. INTRODUCTION

The Gaia satellite was launched in December 2013. The current Gaia Data Release 3 (Gaia DR3) has been made publicly available in June 2022 (Gaia Collaboration et al. 2023). The main goal of Gaia mission is to make a QSO–based Gaia Celestial Reference Frame (Gaia CRF). Two years before the Gaia satellite launching a list of 47 Active Galactic Nuclei (AGNs) had been added for the link between Gaia CRF and International Celestial Reference Frame (ICRF); see Bourda et al. (2011). These candidate sources are visible in both optical and radio domains, and with high astrometric quality in the radio domain. As AGNs are active sources, the time scale of their variability is divided into three classes: intranight, short-term, and long-term variability (Gupta 2014). Their brightness (and photocenter) variability could affect the accuracy of their astrometric positions (Taris et al. 2011, 2016; Popović et al. 2012). Because of that, it is necessary to monitor and investigate the brightness of these candidate sources in the optical domain (it is also domain of Gaia satellite observations). We present here flux variability analysis of one of our the most observed source 1722+119 (from 9^{th} July 2013 to 22^{nd} July 2023, near ten years). This source for the first time appeared in the fourth Uhuru catalogue of X-ray sources in Forman et al. (1978), and it is one of the first discovered BL Lac objects, independently classified in Griffiths et al. (1989), and Brissenden et al. (1990). The redshift $z = 0.34 \pm 0.15$ was given in Ahnen et al. (2016). The source is included in a catalogue of extreme and high-synchrotron peaked blazars in Chang et al. (2019).

2. OBSERVATIONS AND DATA REDUCTION

The observations, mostly in V and R bands and occasionally in B and I bands, were performed using two telescopes located at Astronomical Station Vidojevica (ASV) of Astronomical Observatory of Belgrade (Serbia). The details about these telescopes and mounted CCD cameras are presented in Table 1.

Table 1: Telescopes and cameras.

Telescope diameter	CCD camera	CCD resolution	Pixel size (μm)	Pixel scale (arcsec pix^{-1})	Field of view (arcmin)
60cm	Apogee Alta U42	2048x2048	13.5x13.5	0.466	15.8x15.8
	SBIG ST10 XME	2184x1472	6.8x6.8	0.230	8.4x5.7
	Apogee Alta E47	1024x1024	13.0x13.0	0.450	7.6x7.6
	ProLine PL23042	2048x2064	15.0x15.0	0.512	17.5x17.6
	SBIG STXL-6303E	3072x2048	9.0x9.0	0.307	15.7x10.5
1.4m	Apogee Alta U42	2048x2048	13.5x13.5	0.244	8.3x8.3
	Andor iKon-L	2048x2048	13.5x13.5	0.244	8.3x8.3

After standard reduction (bias, dark, flat, hot and dead pixel map, cosmic rays), we calculate Johnson-Cousins $BVRI$ magnitudes, and colour $V - R$ index of the source using differential photometry; see in the paper Jovanović et al. (2023). Also, we calculated $BVRI$ magnitudes of comparison and control stars which were selected from the paper Doroshenko et al. (2014); in further text, the Catalogue. The magnitudes which we obtain and the input magnitudes are in good agreement with each other, and in line with their standard errors (for both the comparison and control stars). In Fig. , we present the field of view of the source (marked with a cross near star $C2$) and its comparison and control stars (marked C1–C4, and 1–11). In Fig. 2, we present the light curves of the source in $BVRI$ bands during observational period. The blazar $1722 + 119$ shows the short-term variability (with about half magnitude changes) and long term variability (of about 2 magnitudes) in V and R bands (about 1 magnitude in B and I bands). The magnitudes ranges of the source in $BVRI$ bands are: 15.6 – 16.4, 14.9 – 16.8, 14.4 – 16.3, and 13.8 – 14.9 (mag), respectively. In Table 2 there are: the $BVRI$ magnitudes of stars from the catalogue (C) and averaged magnitudes (O) with standard deviations of the source, its comparison stars A and B, and control stars for the period July 2013 – July 2023.

3. METHODS AND RESULTS

We applied the 3-σ rule and an extension of Shapiro and Wilk's test of normality for more than 50 data (Royston 1982). We rejected some data obtained during poor weather conditions, and concluded that the statistical test requiring a normal data distribution can be applied. First of all, we applied Abbe's criterion to determine whether the elements of the sample are stochastically independent or not. We calculated two Abbe's statistics (q_A and q_B) to test differences between the magnitudes of source and comparison stars A and B, respectively. That criterion was introduced by Hald (1952), and it is often used for checking the absence of systematic changes in a

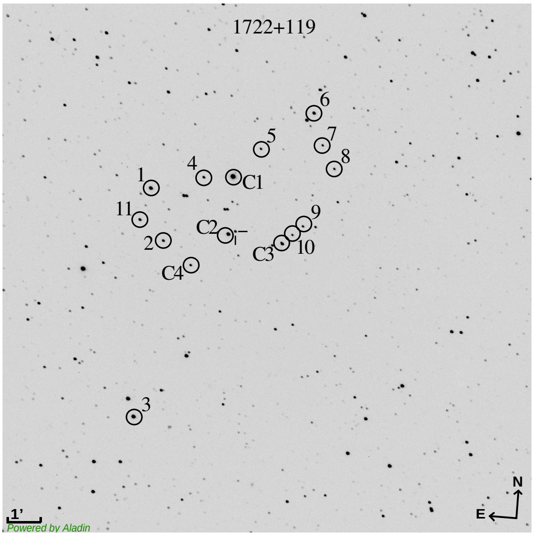

Figure 1: Chart of the field of view of 1722+119.

series of measurements, e.g. Spano et al. (2011), Malkin (2013), etc. If Abbé's statistics (q_A and q_B) are lower than suitable critical value for the significance level 0.001, we conclude that there are statistically significant systematic variations present in the data. Because of it, the hypothesis about stochastic independence of the sample units is discarded.

Also, we used the F-test of equality of variances to determine brightness variability of the source. We calculated three F-statistics:
1) F_A - compare variances of difference between magnitudes of source and comparison star A and difference between magnitudes of comparison stars A and B,
2) F_B - compare variances of difference between magnitudes of source and star B and difference between magnitudes of comparison stars A and B, and
3) $F_{A/B}$ - compare two statistics (F_A and F_B) to obtain the value $F_{A/B} = F_A/F_B$. We expect that if the source is variable, it should be in the same manner for both comparison stars. If the calculated statistics are greater than the critical values (for n – number of freedom and significance level 0.001), we assume that the source is variable. We tested brightness in V and R bands, and $V - R$ colour; the statistical results are presented in Table 3. Both statistical tests showed that the source is variable in V and R bands with regard to both comparison stars, but the colour is not variable.

Also, we tested for "bluer when brighter" (BWB) or "redder when brighter" (RWB) trend. The results of linear fitting colour vs R magnitude are: slope 0.019 $\pm$ 0.003, intercept 0.140 $\pm$ 0.044, Pearson coefficient $r = 0.4369$, and null hypothesis probability $P = 0.0002$. As $r > 0$, and $P < 0.05$, the "bluer when brighter" colour-magnitude variations are present.

Table 2: BVRI magnitudes with standard errors, the number of observations per source, and suitable comparison (A and B) and control stars; C - catalogue data, O - observed data.

	Source	B	N_B	V	N_V	R	N_R	I	N_I
O	1722+119	16.093 ±0.211	15	15.673 ±0.465	70	15.201 ±0.475	75	14.412 ±0.352	12
C	2-A	15.088 ±0.013		14.823 ±0.008		14.691 ±0.012		14.526 ±0.025	
O		15.095 ±0.010	15	14.825 ±0.007	70	14.686 ±0.006	75	14.543 ±0.012	12
C	C4-B	16.563 ±0.027		15.665 ±0.009		15.164 ±0.013		14.713 ±0.025	
O		16.537 ±0.037	15	15.662 ±0.016	70	15.172 ±0.009	75	14.693 ±0.013	12
C	C2	14.203 ±0.009		13.173 ±0.005		12.570 ±0.006		12.060 ±0.009	
O		14.174 ±0.058	15	13.175 ±0.028	48	12.619 ±0.030	46	12.075 ±0.025	7
C	C3	14.919 ±0.022		14.078 ±0.012		13.600 ±0.008		13.148 ±0.016	
O		14.897 ±0.038	15	14.083 ±0.027	63	13.626 ±0.040	59	13.163 ±0.010	9
C	1	14.564 ±0.012		13.445 ±0.009		12.848 ±0.010		12.272 ±0.012	
O		14.515 ±0.050	15	13.439 ±0.034	51	12.847 ±0.031	49	12.275 ±0.017	7
C	5	16.780 ±0.033		15.873 ±0.010		15.385 ±0.016		14.927 ±0.031	
O		16.710 ±0.046	15	15.863 ±0.037	70	15.382 ±0.038	75	14.924 ±0.018	12
C	9	16.628 ±0.029		15.809 ±0.008		15.332 ±0.014		14.867 ±0.029	
O		16.575 ±0.038	15	15.803 ±0.026	70	15.343 ±0.040	75	14.867 ±0.019	12
C	10	16.684 ±0.035		16.142 ±0.011		15.699 ±0.019		15.272 ±0.041	
O		16.865 ±0.037	15	16.137 ±0.025	70	15.712 ±0.039	75	15.282 ±0.008	12

Table 3: Statistical results.

Band	n	Abbé's criterion q_A , q_B , q_c	F–test F_A , F_B , $F_{A/B}$, F_c
V	70	0.13, 0.13, 0.64	408.81, 397.76, 1.03, 2.13
R	75	0.12, 0.12, 0.66	1115.37, 1135.85, 1.02, 2.07
V-R	70	0.79, 0.79, 0.64	1.34, 1.15, 1.17, 2.13

4. CONCLUSION

We have been observed 47 AGNs suggested for the part of Gaia CRF – ICRF astrometric link. We did it in $BVRI$ bands. The photometry analysis (of the data collected using ASV telescopes) of the object 1722+119 is presented for the observational period July 2013 – July 2023. It is our most observed source. That object is highly variable BL Lac. The brightness of the source changed by about 2 mag in V and R bands, and about 1 mag in B and I bands. The reason for different amplitude values is different density of observations in bands. The moments of the maxima and minima (detected in V and R bands) were not covered with observations in B and I bands. Using statistical test we tested the brightness variability in V and R bands, and $V - R$ colour. The tests show that the source is variable in both bands. The colour did not show variability, but there are the BWB variations (in accordance with the last sentence in section 3) in colour-magnitude relation. The magnitudes of stars

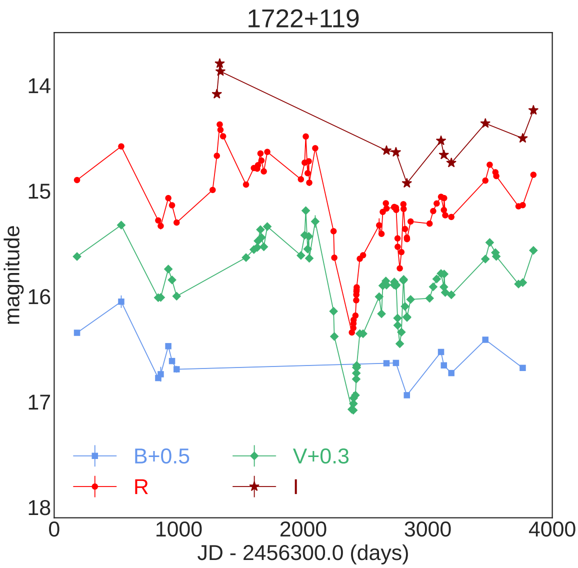

Figure 2: Light curves of B (blue squares), V (green diamonds), R (red circles), and I (dark red stars) bands.

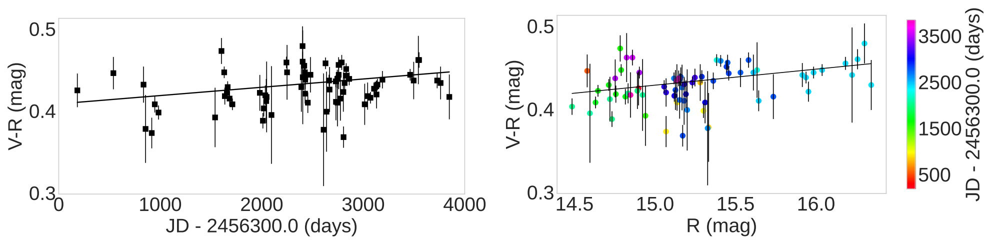

Figure 3: Variations of colour during time (left), and with respect to R magnitude (right).

(taken from the paper Doroshenko et al. (2014)) are in good agreement with observed magnitudes; see in Table 2. The standard deviations of observed magnitudes of stars are on the level of 0.01 mag, and it corresponds to the level of accuracy of ground-based relative photometry. We used the relative photometry, here. For the future, we plan to repeat the relative photometry using more comparison stars, to continue with observations more frequently during a year, and to monitor the flux variability in line with the short and long time scales, as well as over night.

Acknowledgements

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (contract No. 451-03-66/2024-03/200002). Authors acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772) which was used to procure the "Milanković" 1.40 m telescope with support from the Ministry of Education, Science and Technological Development of the Republic of Serbia. GD acknowledges the support through the project F-187 of the Serbian Academy of Sciences and Arts, and the observing and financial grant support from the Institute of Astronomy and Rozhen NAO BAS through the bilateral joint research project "Gaia astrometry and fast variable astronomical objects" (2023-2025, head – G. Damljanović).

References

Ahnen M. L., Ansoldi, S., Antonelli, L. A., Antoranz, P., Babic, A., et al.: 2016, *Monthly Notices of the Royal Astronomical Society*, **459**, 3271.

Bourda, G., Collioud, A., Charlot, P., Porcas, R., Garrington, S.: 2011, *Astronomy and Astrophysics*, **526**, A102.

Brissenden R. J. V., Remillard R. A., Tuohy I. R., Schwartz D. A., Hertz P. L.: 1990, *Astrophysical Journal*, **350**, 578.

Chang Y. L., Arsioli B., Giommi P., Padovani P., Brandt C. H.: 2019, *Astronomy and Astrophysics*, **632**, A77.

Doroshenko, V. T., Efimov Yu. S., Borman, G. A., Pulatova, N. G.: 2014, *Astrophysics*, **57.2**, pp. 176–196.

Forman W., Jones C., Cominsky L., Julien P., Murray S., et al.: 1978, *Astrophysical Journal Supplement Series*, **38**, 357.

Gaia Collaboration, Vallenari, A., Brown, A. G. A., Prusti, T., de Bruijne, J. H. J. et al.: 2023, *Astronomy and Astrophysics*, **674**, A1.

Griffiths R. E., Wilson A. S., Ward M. J., Tapia S., Ulvestad J. S.: 1989, *Monthly Notices of the Royal Astronomical Society*, **240**, 33.

Gupta, A. C.: 2014, *Journal of Astrophysics and Astronomy*, **35**, 307.

Hald, A.: 1952, Wiley, New York–London.

Jovanović, M.D., Damljanović, G., Taris, F., Gupta, A.C., Bhatta, G.: 2023, *Monthly Notices of the Royal Astronomical Society*, **522**, 767–791.

Malkin, Z.M.: 2013, *Astronomy Reports*, **57**, 128–133.

Popović, L. Č., Jovanović, P., Stalevski, M., Anton, S., Andrei, A. H., et al.: 2012, *Astronomy and Astrophysics*, **538**, A107.

Royston J. P.: 1982, *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, **31**, 115.

Spano, M., Mowlavi, N., Eyer, L., Burki, G., Marquette, J.B., et al.: 2011, *Astronomy and Astrophysics*, **536**, A60.

Taris, F., Souchay, J., Andrei, A. H., Bernard, M., Salabert1et, M. al.: 2011, *Astronomy and Astrophysics*, **526**, A25.

Taris F., Andrei A., Roland J., Klotz A., Vachier F., Souchay J.: 2016, *Astronomy and Astrophysics*, **587**, A112.