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Photometric and colorimetric studies of target objects using small and medium-size telescopes

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Abstract. We report on follow-up studies of transient events and objects, which have been conducted in recent years using ground-based optical observations. BVRI photometry has been performed with small and medium-sized telescopes located in Europe and North America. The purpose of these studies, which are mainly focused on objects of unknown nature, is to reveal features of

their variability that are critical for classifying the transients and understanding their evolution.

We present here some results obtained from long-term monitoring of transients Gaia18aes, Gaia19bpg, as well as the quasar 4C +21.35.

Key words: Stars: variables: individual: Gaia18aes, Gaia19bpg – Galaxies: quasars: individual: 4C +21.35 – Techniques: photometric

1. Introduction

Follow-up photometry is an important component of astrophysical studies, helping to reveal the nature and characteristics of stellar objects and transient events. Ground-based small- and medium-aperture telescopes, equipped with additional instruments and sensitive CCD cameras, are still able to provide good enough opportunities for short- and long-term observation programs, especially in response to survey alerts.

Today, these telescopes are actively involved in monitoring objects from the Gaia Science Alerts program, ASAS-SN, GRANDMA, and other projects.

2. Observations and results

Our research activities are focused on follow-up studies of recently detected transients and variable sources (CVs, QSO, etc.). A lot of objects have been continuously observed over the years in collaboration with research groups at other observatories. In our work, we used mainly photometric data gathered at the Terskol Observatory (Tarady et al., 2010) in 2018-2021 and supplemented them with observations, which have been performed at other observatories (Table 1). Most of the datasets were obtained using filters close to the Johnson-Cousins B, V, R_c, and I_c system. Standard processing was applied to reduce data (i.e., debiasing, dark subtracting, flat-fielding); for details, see Oszkiewicz et al. (2020) and Troianskyi et al. (2023). Measurements were done using MaxIm DL[1] and MPO Canopus[2] software. Magnitudes of comparison stars were usually taken from the Gaia and Pan-STARR catalogs. Additionally, we used information and datasets available at the Cambridge Photometric Calibration Server[3].

Here we provide some findings for the three objects, which have been observed over the last five years.

2.1. Gaia18aes

The bright blue declining transient on faint blue SDSS source Gaia18aes / AT2018ik was discovered on 2018-01-17 and reported on 2018-01-19 by the

[1] https://diffractionlimited.com/product/maxim-dl/

[2] http://www.bdwpublishing.com

[3] http://gsaweb.ast.cam.ac.uk/followup

Table 1. Telescopes and detectors used for the BVRI photometric observations.

Telescope	Observatory	Detector	Aperture [m]	IAU code	Object	Date of observations
Zeiss-2000	Terskol	FLI PL4301	2.0	B18	Gaia18aes	2018-2020
					Gaia19bpg	2019-2021
Zeiss-600	Terskol	SBIG STL-1001	0.6	B18	Gaia18aes	2018-2019
					Gaia19bpg	2019-2021
					4C +21.35	2020
B&C	Kitt Peak	ARC Camera	0.96	G82	4C +21.35	2023
IAC80	Teide	CAMELOT2	0.82	954	4C +21.35	2023
AZT-8	Kyiv Comet Station	FLI PL4710	0.7	585	Gaia18aes	2018-2023
					Gaia19bpg	2019
					4C +21.35	2018, 2023
0.61-m	Skalnaté Pleso	SBIG ST-10XME	0.61	056	Gaia19bpg	2023
					4C +21.35	2023
0.6-m G2	Stará Lesná	FLI ML3041	0.6	-	Gaia18aes	2019-2020

Gaia Photometric Science Alerts team at magnitude G = 15.77[4]. On the Gaia images from 2017-12-30, the object was fainter than the limiting magnitude G = 21.5; therefore, at the time of its discovery by Gaia, the object became brighter by more than 5.7 mag. Two previous brightenings of this source were recorded by Catalina Real-Time Transient Survey on 2014-02-27 and 2015-02-26 with the unfiltered GSS magnitudes of 16.78 and 17.36, respectively (as CSS140227:111652+011436; Drake et al. (2009)). Most recently, on 2022-06-25, Gaia detected another outburst of Gaia18aes at magnitude G = 16.59.

We had begun to observe Gaia18aes using the astronomical facilities of the Kyiv Comet Station (Lisnyky) and the Terskol Observatory, just after the Gaia alert was published. On the images obtained on 2018-01-26 at Lisnyky, the object was detected at magnitude R $\sim$ 17 indicating a fading trend in the brightness of the source. The light curve revealed a variability with a period of 0.056(3) h and amplitude of 0.65 mag (see Fig. 1 (the inset)). Further observations in March-April 2019 at Terskol and Stará Lesná revealed a new flare (Fig. 1).

We calculated the color indices for the object and compared them with those for black bodies of various temperatures. Based on the results obtained (Fig. 2), we can conclude that the object's color temperature is typical for dwarf novae during an outburst. Generally, the photometric behavior of Gaia18aes over a 5-year observation period allows us to suggest that this object could be a cataclysmic variable of U Gem type, by subtypes UGSS or UGSU; further observations are needed to clarify this.

[4] http://gsaweb.ast.cam.ac.uk/alerts

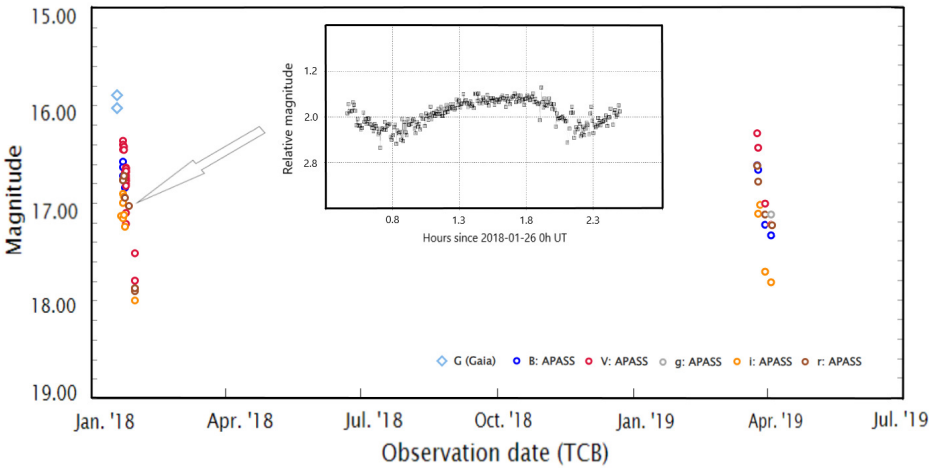

Figure 1. Multi-band photometric measurements of Gaia18aes in 2018-2019. (Image from http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia18aes/ supplemented with measurements at Stará Lesná). The inset: Light curve of Gaia18aes from R-band observations on 2018-01-26 at Lisnyky.

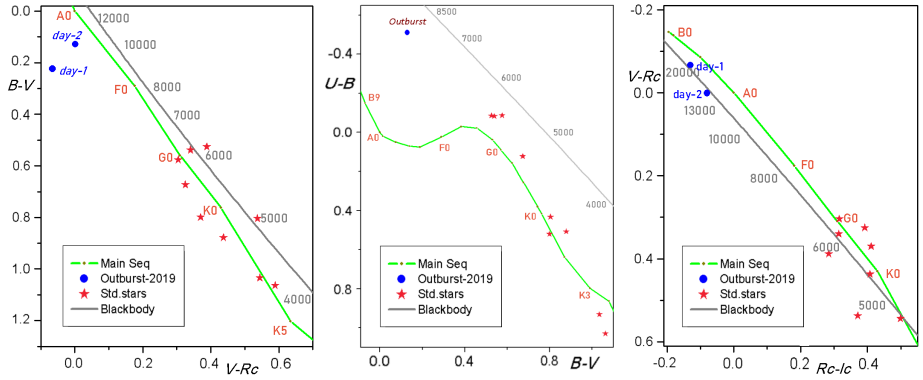

Figure 2. Two-color diagrams of Gaia18aes. The Main Sequence and blackbody lines with temperatures are plotted in green and gray, respectively. The blue dots show the position of Gaia18aes on the first and second days of observations at Stará Lesná in 2019. The positions of neighboring field stars are marked by red asterisks.

2.2. Gaia19bpg

On 2019-04-29, the Gaia Photometric Science Alerts Team[5] reported activity from a red Galactic plane source at coordinates R.A. = 325.46012 deg, Dec. = +51.92930 deg: its brightness increased by 1.5 mag over 8 months and reached a magnitude G = 14.62. We have observed this transient Gaia19bpg in 2019-2023 in the BVRI bands (Fig. 3). The light curves show an upward trend in brightness, which continued over 20 months up to the magnitude of about G ∼ 12.7. By the turning point in April 2021, the brightness began to decline, although a short-term re-brightening was observed in November 2021-January 2022 when the magnitude changed from G ∼ 14.04 to G ∼ 13.48. The multi-band photometric monitoring revealed a color evolution of the object; significant changes in colors were detected especially after the brightness peak. In particular, for the observed period of 4.5 years, V-R color shifted to red from 1.1 mag to 1.6 mag indicating a decrease in the temperature of the object. Generally, the photometric behavior of Gaia19bpg is similar to that of a symbiotic nova in outburst (Merc et al., 2023). The current spectroscopic observations are expected to help classify this object.

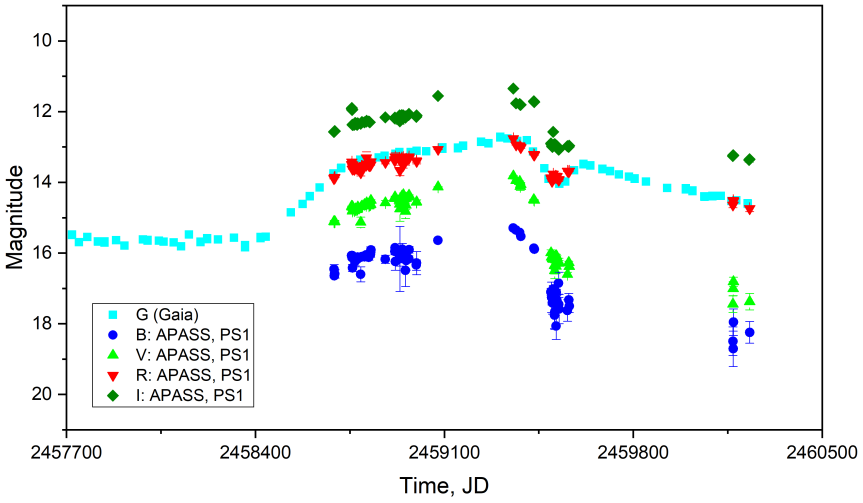

Figure 3. Multi-band follow-up observations of Gaia19bpg. The Gaia light curve is combined with photometric measurements provided by the observatories listed in Table 1 (Gaia data from http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia19bpg/).

[5] http://gsaweb.ast.cam.ac.uk/alerts

2.3. Quasar 4C +21.35

The quasar 4C +21.35 (often termed PKS 1222+216) is a Seyfert 1 Galaxy at redshift $z = 0.435$, which was discovered in the 1960s as a radio source. Since the 1990s, it has also been known as a variable X- and gamma-ray source.

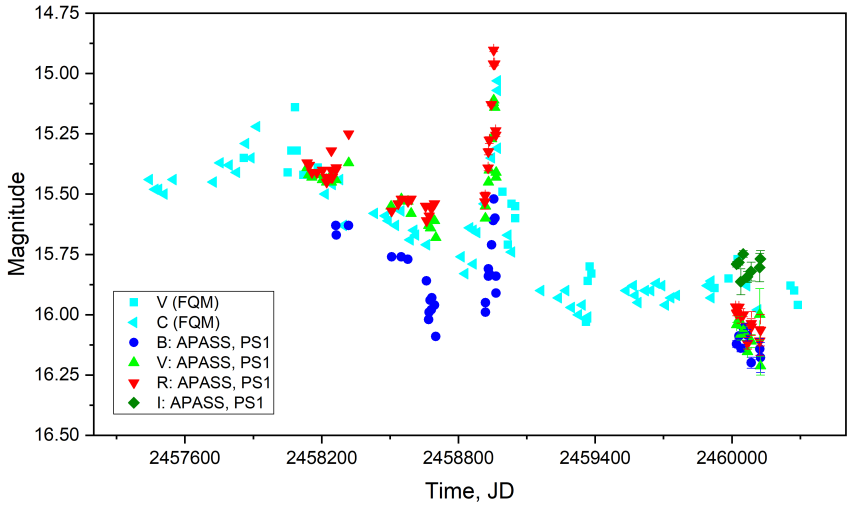

Figure 4. The photometric behaviour of 4C +21.35 in 2016-2023. Our observations are superimposed on the light curve provided by the Frankfurt Quasar Monitoring Project (http://quasar.square7.ch/fqm/1222+216.html).

Our photometric observations of this object started in 2016 (Ponomarenko et al. (2019); Fig. 4). In this paper, we focus on an outburst, which was observed in March-April 2020 at the Terskol Observatory. Observations were carried out through BVRI filters that allowed us to investigate the color variability of the source during the outburst. The results of our analysis are as follows: (i) the object reached a minimum brightness before the outburst; (ii) during the outburst, the colors (B−V) and (V−R) showed a reddening with increasing brightness (Fig. 5) that indicates the thermal emission from the accretion disc; (iii) in a quasi-quiet state, B−V and V−R colors of the object remain constant within ± 0.1 mag. It should be noted that during the 2020 outburst no noticeable increase in the activity of the quasar 4C +21.35 in the X-ray or gamma-ray wavelength range was detected (for instance, see Fermi-LAT Data[6]).

[6] https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/index.php

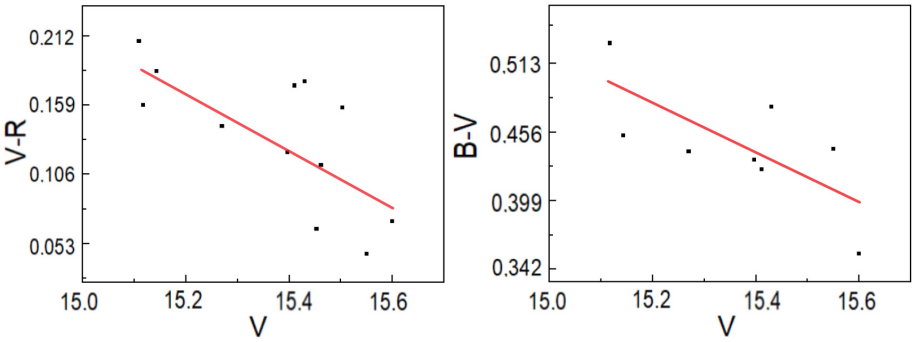

Figure 5. (B−V) and (V−R) color indices as a function of V magnitude during the outburst of 4C +21.35 in 2020.

3. Conclusions

Follow-up observations with small and medium-sized telescopes provide useful information, especially on the photometric short- and long-term variability of transient events.

Systematic, integrated use of these telescopes leads to the early detection of changes in the behavior of objects and better information about their evolution.

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[7] http://gsaweb.ast.cam.ac.uk/alerts

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