Proceedings of the XIII Bulgarian-Serbian Astronomical Conference
(XIII BSAC) Velingrad, Bulgaria, October 3-7, 2022
Editors: Evgeni Semkov, Milan S. Dimitrijević, Momchil Dechev and Zoran Simić
Publ. Astron. Soc. "Rudjer Bošković" No 25, 2023, 43-51

GAIA ALERTS AND BULGARIAN-SERBIAN COOPERATION FROM 2014 TO 2022

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Abstract. We started to observe the Gaia Alerts or Gaia Fellow Up Network for Transients Objects (Gaia-FUN-TO) from October 2014. Because of better results, at 2013 we established the local cooperation "Serbian-Bulgarian mini-network telescopes" using 6 instruments. Our activities are in accordance with actual Serbian and Bulgarian Academies of Sciences (SANU-BAN) joint research project "Gaia Celestial Reference Frame (CRF) and fast variable astronomical objects" (during three years period, 2020-2022). There are two sites in Bulgaria (at Belogradchik and Rozhen) and one site in Serbia (Astronomical Station Vidojevica - ASV). Before the COVID-problem and during 2020, we did about 15 Gaia Alerts objects per year. During 2021, we observed just 5 Gaia Alerts (Gaia19dke, Gaia21awo, Gaia21azb, Gaia21efs, Gaia21ehu) but Gaia19dke 11 times and Gaia21azb 13 times; about 300 CCD images were done. Also, during 2022 (until 1st October 2022), we did 5 Gaia Alerts (Gaia21cgt, Gaia22aeu, Gaia22atp, Gaia22btj, Gaia22btc); about 50 CCD images. We present some results, here.

1. INTRODUCTION

Gaia astronomical satellite is surveying the full sky (astrometrically, photometrically, and spectroscopically), and it is a space mission of the European Space Agency (ESA) operating since mid-2014. Gaia results are useful for all the relevant scientific communities: our understanding of the Milky Way galaxy, for the stellar physics, the Solar system bodies, astrometry, etc. The high-precision astrometric data (the positions, proper motions and parallaxes) are the main goal of Gaia mission. The Gaia catalogue (for the objects from G = 3 mag to 21 mag) is an important step in the realization of the Gaia reference frame in future. The third

Gaia solution or data release (Gaia DR3) has been made publicly available on 13th June 2022 (there are about 1.806 billion sources with G magnitude).

The Gaia is scanning the sky multiple times and provides near-real-time photometric data. Because of that process and data, it is possible to detect some changes in brightness from all over the sky and appearance of new objects. As a result, the Gaia Science Alerts system produces alerts on these interesting objects. After that, using the ground-based telescopes (as the "Serbian-Bulgarian mini-network telescopes") we continue astronomical observations of the mentioned objects. The Gaia Photometric Science Alerts published the first alerts in October 2014. Just few years after that, the Gaia Science Alerts was among the leading transient surveys in the world (more than 3000 transients were discovered during three years). During 2022, about 4000 transients were discovered and it is really impressive result. The transients are: supernovae, cataclysmic variables, microlensing events, other rare phenomena.

2. SERBIAN-BULGARIAN COOPERATION IN LINE WITH GAIA ALERTS

In line with the plan of astronomical observations, Gaia is recording each object in the sky about 70 times over the mission lifetime. Because of it, there are a lot of alerts. The number of alerts increases with number of observations of each object, and during 2022 it had been reported about 4000 Gaia Alerts from all over the sky. Some numbers of Gaia Alerts (published per year) are possible to find on the official website[1].

The Astronomical Station Vidojevica (ASV) of Astronomical Observatory in Belgrade (AOB) was established in 2011, and it was the Serbian new astronomical site. At the beginning we used a new D=60 cm telescope "Nedeljkovic", and at mid-2016 there was another new telescope (D=1.4 m) "Milankovic" via the Belissima project (see website[2]). In Bulgaria (at Belogradchik and Rozhen sites), from 2013 we used 4 instruments in line with our regional collaboration "Serbian-Bulgarian mini-network telescopes". Mentioned collaboration is in line with the Serbian Academy of Sciences and Arts (SANU) and Bulgarian Academy of Sciences (BAN) or SANU-BAN joint research projects: "Observations of ICRF radio-sources visible in optical domain" (for three years period, 2014-2016), "Study of ICRF radio-sources and fast variable astronomical objects" (2017-2019), "Gaia Celestial Reference Frame (CRF) and fast variable astronomical objects" (2020-2022), and the next one "Gaia astrometry and fast variable astronomical objects" (2023-2025); the leaders are G.Damljanović (Serbia) and R.Bachev (Bulgaria). Some information about the telescopes and CCD cameras were published in a few papers (Damljanović et al. 2014; Taris et al. 2018; Damljanović et al. 2020); see Table 1. The first column in Table 1 is: telescope

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

[2] http://belissima.aob.rs

(with diameter - D and focal length – F in meters), and site (ASV, Rozhen or Belogradchik). The other columns are: CCD camera, chip size (in pixels), pixel size (in micrometers), scale (in arcseconds), and field of view – FoV (in arcminutes).

Table 1: Telescopes and CCD cameras of Serbian-Bulgarian cooperation.

Telescope D/F [m]	*Camera*	*Chip size [pixel]*	*Pixel size [μm]*	*Scale ["]*	*Field of view - FoV['] *
1.4/11.42 ASV	Apogee Alta U42	2048 x 2048	13.5 x 13.5	0.243	8.3 x 8.3
	Andor iKon-L	2048 x 2048	13.5 x 13.5	0.24	8.3 x 8.3
0.6/6 ASV	Apogee Alta U42	2048 x 2048	13.5 x 13.5	0.465	15.8 x 15.8
	FLI PL230	2048 x 2064	15 x 15	0.517	17.7 x 17.8
2/15.774 Rozhen	VersArray 1300B	1340 x 1300	20 x 20	0.261	5.6 x 5.6
	Andor iKon-L	2048 x 2048	13.5 x 13.5	0.176	6.0 x 6.0
0.6/7.5 Rozhen	FLI PL09000	3056 x 3056	12 x 12	0.33	16.8 x 16.8
0.6/7.5 Belogradchik	FLI PL09000	3056 x 3056	12 x 12	0.33	16.8 x 16.8
0.5/0.7/1.72 Rozhen	FLI PL16803	4096 x 4096	9 x 9	1.08	73.7 x 73.7

About Bulgarian telescopes, three instruments are at National Astronomical Observatory (NAO) BAN Rozhen (D=2 m, D=60 cm, and Schmidt-camera 50/70 cm), and one instrument is at Belogradchik AO site (D=60 cm). Soon, we hope to use the MEADE D=40 cm instrument at ASV (see Figure 1) and new D=1.5 m telescope at Rozhen NAO BAN (see Figure 2, Dr. R. Pavlovic is on that figure).

3. RESULTS

There are a few published papers (Damljanovic et al. 2014; Campbell et al. 2015; Wyrzykowski et al. 2020; Szegedi-Elek et al. 2020; Damljanovic et al. 2020; Hodgkin et al. 2021; etc.) using our data obtained from six telescopes at three sites; it is in line with "Serbian-Bulgarian mini network telescopes" and mentioned SANU-BAN joint research projects. Also, we can use D=1.31 m telescope of the Aryabhatta Research Institute of observational sciencES (ARIES) in accordance with our useful cooperation with few colleagues from India (A.C. Gupta and others). Usually, we did 3 CCD images per filter, and the Johnson-Cousins BVRcIc filters were available. After that, the standard bias, dark and flat-fielded corrections are done (also, hot/dead pixels are removed), and the Astrometry.Net and Source Extractor are used. For further calibration, the output is supposed to be submitted to the Cambridge Photometric Calibration Server (CPCS). During Oct. 2014 – Oct. 2022, we collected about 3700 CCDs for ~100 Gaia Alerts or Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO), and it was ~550 images per year (near 15 objects per year) before the problem with COVID virus.

Table 2: Photometry results of Gaia19dke (from 29th Aug.2019 to 31st Oct.2021).

Date	*JD [day]* *Filter [mag]*	*JD [day]* *Filter [mag]*	*JD [day]* *Filter [mag]*	*JD [day]* *Filter [mag]*
29Aug.2019	2458725.42 B=17.49±0.05	2458725.43 V=15.75±0.03	2458725.42 J=13.67±0.02	2458725.44 i=14.65±0.01
12Nov.2020	2459166.20 B=17.35±0.02	2459166.23 V=15.49±0.01		2459166.24 i=14.59±0.01
19Nov.2020	2459173.22 B=17.46±0.02	2459173.21 V=15.74±0.01		2459173.22 i=14.58±0.01
17Dec.2020	2459201.20 B=17.44±0.03	2459201.19 V=15.69±0.01		2459201.19 i=14.63±0.01
20Dec.2020	2459204.18 B=17.36±0.04	2459204.18 V=15.50±0.01		2459204.19 i=14.57±0.01
18Feb.2021	2459264.66 B=17.49±0.03	2459264.63 V=15.84±0.01		2459264.67 i=14.62±0.01
10May2021	2459345.47 B=17.17±0.01	2459345.47 V=15.45±0.01	2459345.46 J=13.24±0.01	2459345.50 r=15.22±0.01
11May2021	2459346.50 B=17.55±0.03	2459346.48 V=15.62±0.01		2459346.48 i=14.62±0.01
12May2021	2459347.45 B=17.28±0.13	2459347.48 V=15.59±0.03		2459347.46 i=14.61±0.02
10June2021	2459376.48 B=17.40±0.08	2459376.47 V=15.69±0.03		2459376.48 i=14.63±0.01
10June2021	2459377.47 B=17.44±0.02	2459377.48 V=15.58±0.01		2459377.48 i=14.62±0.01
11July2021	2459407.38 B=17.39±0.01	2459407.39 V=15.69±0.01	2459407.38 J=13.31±0.01	2459407.39 i=14.45±0.01
12July2021	2459408.38 B=17.44±0.01	2459408.38 V=15.68±0.01		2459408.37 i=14.46±0.01
8Aug.2021	2459435.31 B=17.48±0.01	2459435.31 V=15.73±0.01		2459435.31 i=14.59±0.01
12Sep.2021	2459470.27 B=17.57±0.01	2459470.27 V=15.74±0.01		2459470.27 i=14.58±0.01
31Oct.2021	2459519.21 B=17.36±0.01	2459519.21 V=15.71±0.01	2459519.21 J=13.44±0.01	2459519.21 i=14.65±0.01

During 2021, we did 5 objects: Gaia19dke (10 times), Gaia21awo, Gaia21azb (13 times), Gaia21ehu, Gaia21efs; near 350 CCDs. Also, during 2022 (until 1st October), we did 5 objects: Gaia21cgt, Gaia22aeu, Gaia22atp, Gaia22btj, Gaia22btc; near 60 CCDs.

Figure 1: The MEADE 40 cm instrument at ASV (Serbia).

Last few years, the objects **Gaia18dvy** ($\alpha=20^h:05^m:06.^s02$, $\delta=36^o:29':13.''52$) and **Gaia19dke** ($\alpha=19:25:58.68$, $\delta=28:24:24.70$, see Figure 3) were very interesting. Using two ASV instruments (60 cm and 1.4 m), the Gaia18dvy was observed three times during 2019: on 12th March (JD=2458555.6) using D=1.4 m ASV telescope with CCD Andor iKon-L (0.″244 per pixel, there are 12 CCD

images or 3(BVRI)), on 29th March (JD=2458572.6) using the same instrument to get 3(BVRI), and on 29th August (JD=2458725.5) using D=60 cm with FLI PL230 (0.″518, 3(BVRI)).

Figure 2: The concrete pillar of new 1.5 m telescope (in November 2022) at Rozhen NAO BAN (Bulgaria).

Mentioned data were useful for a paper about the Gaia18dvy as a new case of FU Orionis-type young eruptive stars in the Cygnus OB3 Association (Szegedi-Elek et al. 2020). Some co-authors of that paper are few our colleagues (in line with the Serbian-Bulgarian cooperation): S.Boeva and G.Latev from Bulgaria, O.Vince, G.Damljanovic and M.D.Jovanovic from Serbia, and A.C.Gupta from India.

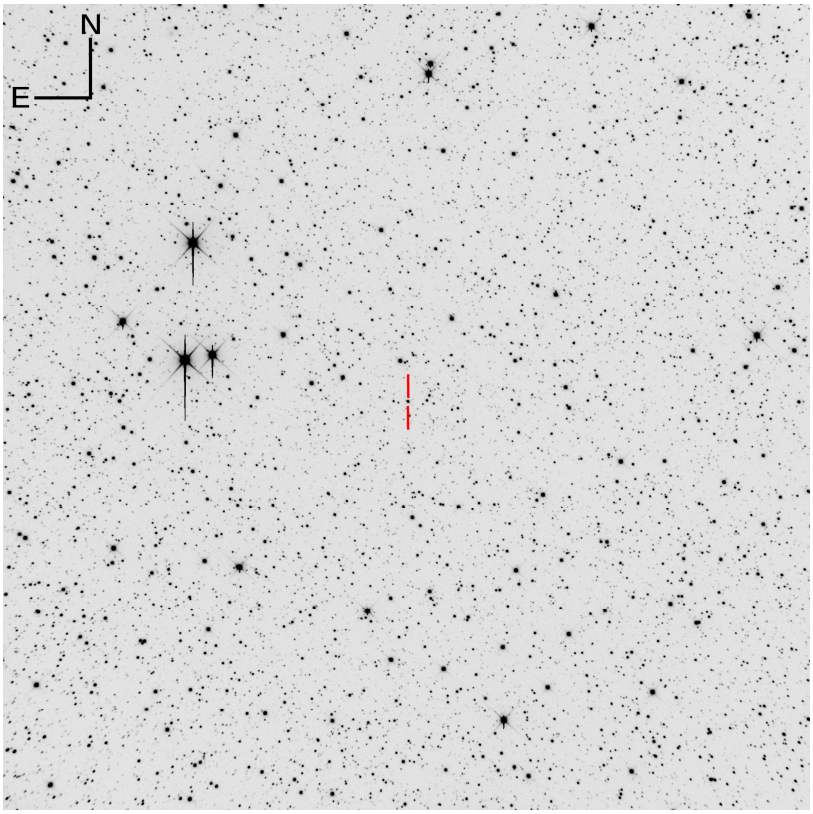

Figure 3: Our image (marked with vertical lines) of the Gaia19dke **(**R-filter, Exp.=120s) on October 31st 2021 using the D=1.4 m ASV telescope with CCD Andor iKon-L camera.

About Gaia19dke, our original CCD image of that object is presented (see Figure 3) after standard reduction (bias/dark/flat, hot/dead pixels, etc.), and the object is marked with vertical lines. The east is left and north is up. This image was made on 31st October 2021 using the ASV telescope D=1.4 m with CCD Andor iKon-L camera: R-filter, Exp.=120s, FoV=8.′3x8.′3, binning=1x1, scale=0.″391 per pixel. Our obtained results of Gaia19dke are in Figure 4 and Table 2: the first column is date of observation, other 4 columns are Julian Date - JD and magnitudes (with standard deviation) after photometry (using suitable filters). The standard deviation of our magnitudes is on the level 0.01 mag. There are 16 dates from 29th August 2019 to 31st October 2021 (about two years of observations). Light curve of data is in Figure 4: x-axis is t=JD-2450000 (in days), and y-axis is suitable magnitude. Presented results are in good accordance with: the ground-based relative photometry, results obtained from other telescopes (at site https://cpcs.astrolabs.pl/cgi/upload), possibilities of our instruments, etc. These magnitudes are transferred from our set of filters (Johnson

BV and Cousins RcIc) into another one via the Cambridge Server (into J, r, and i using the APASS, 2MASS and PS1 catalogs).

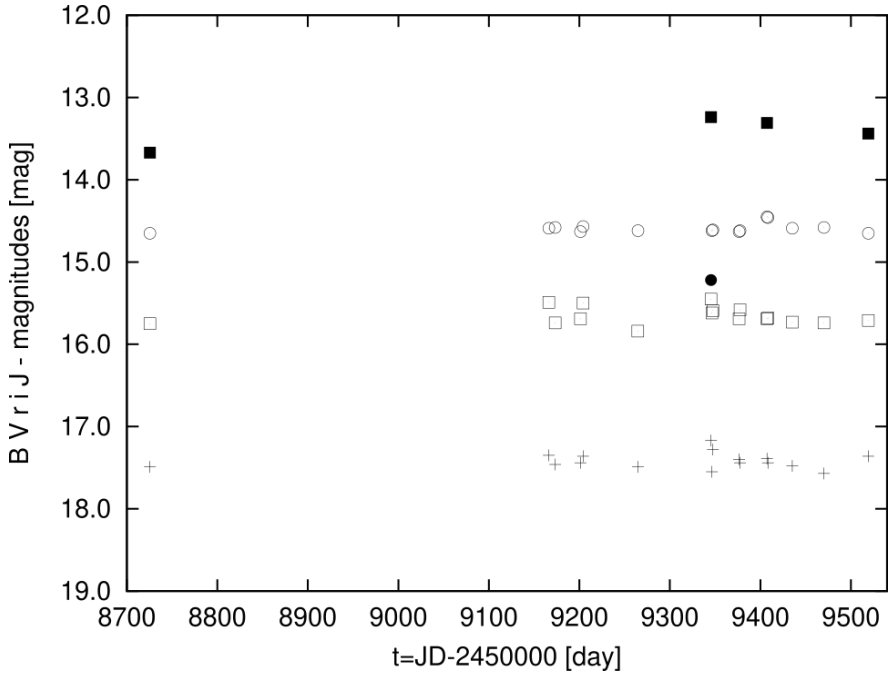

Figure 4: Light curve of Gaia19dke using our data from August 29th 2019 to October 31st 2021: B (cross), V (white rectangle), r (black circle), i (white circle), and J (black rectangle) magnitudes with time t.

Once identified, Gaia19dke was observed by Follow-Up-Network of telescopes in multi-national campaign. All follow-up data were collected and presented in the light curve of Gaia19dke (at site https://cpcs.astrolabs.pl/cgi/upload). Our data (16 points in B and V filters, etc.) are among the others collected for this campaign and they fit very well other points of the light curve. We hope, there are enough relevant Gaia19dke data for our next paper in the future.

4. CONCLUSIONS

The first observations of the ESA Gaia astronomical satellite were done in mid-2014. Since October 2014, the Gaia Photometric Science Alerts started to publish alerts, and there were ~3000 alerts during the first three years. They were issued by the Gaia Science Alerts group: cataclysmic variables, supernovae, candidate microlensing events, etc. About 4000 transients were discovered (as really impressive result) during 2022. To be a part of that interesting project, we

established our regional cooperation (the "Serbian-Bulgarian mini-network telescopes") and few SANU-BAN projects. We used 6 Serbian-Bulgarian telescopes for the mentioned activities from mid-2016. Using D=2 m Rozhen and D=1.4 m ASV telescopes (with Exp.=300s) it is possible to observe objects down to 20 mag in the V-band (down to 19 mag using smaller telescopes). The MEADE 40 cm telescope at ASV is a new addition to our network from the end of 2022, and we hope to use the 1.5 m instrument at Rozhen NAO BAN, soon. Until the October 1st 2022, we observed about 100 Gaia Alerts (usually, near 15 objects per year) or near 3700 CCD images (~550 images per year). These observations (usually, three CCD images per filter) were done in Johnson BV and Cousins RcIc filters. Few papers were published with our results. Three papers were published during 2020 and 2021: (Wyrzykowski et al. 2020) about Gaia16aye or Ayers Rock, (Szegedi-Elek et al. 2020) about Gaia18dvy, and (Hodgkin et al. 2021) about the main results of Gaia Alerts. Some of our results were presented at a few conferences. As an example, the object Gaia18dvy is a new case of FU Orionis-type young eruptive stars in the Cygnus OB3 Association. We hope, the Gaia19dke (which we did two years) will be the subject of next paper, soon.

Acknowledgements

We gratefully acknowledge the observing grant support from the Institute of Astronomy and Rozhen NAO (BAS), and support by the Ministry of Education, Science and Technological Development of the Republic of Serbia (contract No 451-03-68/2022-14/200002). We acknowledge ESA Gaia DPAC and Photometric Science Alerts Team (http://gsaweb.ast.cam.ac.uk/alerts).

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