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SERBIAN-BULGARIAN COOPERATION ABOUT GAIA ALERTS DURING 2023

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Abstract. From October 2014 until now (about 10 years) we have done astronomical observations of the Gaia Alerts or Gaia Follow Up Network for Transients Objects (Gaia-FUN-TO). In 2013 we organized our local cooperation *Serbian-Bulgarian mini-network telescopes* to get better results. Also, the mentioned observations and investigations are in line with actual joint research SANU-BAN project *Gaia astrometry and fast variable astronomical objects* from 2023 to 2025; SANU-BAN are Serbian and Bulgarian Academies of Sciences. Now, there are 8 astronomical instruments at two sites in Bulgaria (at Belogradchik and Rozhen) and one site in Serbia (Astronomical Station Vidojevica - ASV). Usually, we have done ≈ 15 Gaia Alerts per year. Because of the COVID-problem, in 2021 we observed just 5 Gaia Alerts: Gaia19dke (11 times), Gaia21awo (1), Gaia21azb (13), Gaia21efs (1), and Gaia21ehu (1); ≈ 300 CCD images were done. At 2022 we did 7 Gaia Alerts: Gaia21cgt (1 time), Gaia22aeu (1), Gaia22atp (1), Gaia22btj (1), Gaia22btc (1), Gaia22dym (1), and Gaia21brx (1); ≈ 70 images. During 2023, we did 12 Gaia Alerts: Gaia22ang (5 times), Gaia22dze (1), Gaia23bay (6), Gaia19dmj (2), Gaia21cgt (2), Gaia22eem (2), Gaia23afy (1), Gaia23cer (2), Gaia23cri (3), Gaia20cwd (1), Gaia23bbk (1), and Gaia23cvq (1); ≈ 300 images were done using the 60 cm and 1.4 m ASV telescopes. We present some results here.

1. INTRODUCTION

The predecessor of the Gaia space mission was the Hipparcos one (HIgh Precision PARallax COllecting Satellite) of the European Space Agency (ESA). The Hipparcos mission changes astronomy, with nearly 118000 stars and position standard deviation about 1 milliarcsec astrometry (ESA 1997, van Leeuwen 2007), at the end of the last century. At the beginning, the plan of Gaia was nearly 1 billion stars and nearly 500000 extragalactic sources (Prusti 2012) with position standard deviation about 1 microarcsec astrometry. Both ESA missions are a revolution in astronomy.

The Gaia astronomical spacecraft was launched at the end of 2013, with scientific operations commencing in July 2014 and useful data from August 2014. The Gaia observational period was 5 years, and now it is much longer than the predicted operation phase. The Gaia satellite is surveying the full sky, and the obtained results (astrometrically, photometrically, and spectroscopically) 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 main goal of Gaia mission is a catalogue (for the objects from G = 3 mag to 21 mag) of the high-precision astrometric data: the positions, proper motions and parallaxes. That catalogue is an important step in the realization of the Gaia Celestial Reference Frame (Gaia CRF). The last Gaia solution (the third one) or data release (Gaia DR3) was made publicly available on 13th June 2022. There are about 1.806 billion sources with G magnitude in it (nearly two times more than the plan of Gaia).

Because of the Gaia scanning process and data (it is observing the sky multiple times and provides near-real-time photometric 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 (GSA) system produces alerts on these interesting objects, and after that we continue astronomical observations of the mentioned objects using the ground-based telescopes (as the *Serbian-Bulgarian mini-network telescopes*). The GSA system made its first discovery of a transient event (it was the object Gaia14aaa) in September 2014 (shortly after mid-2014), and the GSA was among the leading transient surveys in the world a few years after that. There are more than 3000 transients which were discovered during three years (from September 2014 to September 2017), and about 4000 transients were discovered during 2022. Over the past decade, GSA announced over 20000 transients of various types. It is a really impressive result. The transients are: supernovae, novae, young stellar objects, cataclysmic variables, microlensing events, R Coronae Borealis (RCrB) dimming stars, flaring quasars, and many other rare phenomena. It is evident that the Gaia Alerts have significantly contributed to time-domain and transient astronomy from September 2014 to September 2024. The numerous targets were extensively studied and the data were widely used in multiple publications using the Global Telescope Network and Black Hole Target Observation Manager (BHTOM). The long-term follow-up and monitoring of alerts from Gaia are in accordance with the establishment of a global telescope network (initiated in 2010, now with about 100 telescopes) and the programme of GSA. Recently it was supported by the European Commission's OPTICON-Radionet Pilot grant. From some time ago, that network operates through a BHTOM web service. The BHTOM provides thousands of CCD images (of hundreds of astronomical objects) per week. In 2024, there are 10 years of the GSA and 15 years of the mentioned telescope network. The last workshop about the Gaia Science Alerts and its follow-up programme was held in Heraklion (Crete, 2024) with about 80 registered participants.

2. SERBIAN-BULGARIAN COOPERATION ABOUT GAIA ALERTS

The plan of Gaia astronomical observations was to observe each object in the sky nearly 70 times over the mission lifetime (5 years), and there are a lot of alerts because of that kind of observations. As a result, for each object the number of alerts increases with number of observations. Over the past decade, it was reported over 20000 transients (Gaia Alerts) from all over the sky. On the other hand, the Astronomical Station Vidojevica (ASV) of Astronomical Observatory in Belgrade (AOB, Serbia) was established in 2011. It was the Serbian new astronomical site. At the beginning we used a new D=60 cm telescope *Nedeljković*. At mid-2016 there was another new telescope (D=1.4 m) *Milanković* via the Belissima project. At Belogradchik and Rozhen sites (in Bulgaria), we used 4 instruments in accordance with our regional collaboration *Serbian-Bulgarian mini-network telescopes* from 2013. At that time, that cooperation was in line with the SANU-BAN joint research project *Observations*

Table 1: The main information about the telescopes and CCD cameras of Serbian – Bulgarian cooperation.

Telescope D/F [m]	Camera	Chip size [pixel]	Pixel size [μm]	Scale [$''/p$]	Field of view FoV[arcmin]
ASV 1.4/11.42	ApogeeAltaU42	2048x2048	13.5x13.5	0.243	8.3x8.3
	Andor iKon-L	2048x2048	13.5x13.5	0.24	8.3x8.3
ASV 0.6/6	ApogeeAltaU42	2048x2048	13.5x13.5	0.465	15.8x15.8
	FLI PL230	2048x2064	15x15	0.517	17.7x17.8
Rozhen 2/15.774	VersArray1300B	1340x1300	20x20	0.261	5.6x5.6
	Andor iKon-L	2048x2048	13.5x13.5	0.176	6.0x6.0
Rozhen 0.6/7.5	FLI PL09000	3056x3056	12x12	0.33	16.8x16.8
Belogradchik 0.6/7.5	FLI PL09000	3056x3056	12x12	0.33	16.8x16.8
Rozhen 0.5/0.7/1.72	FLI PL16803	4096x4096	9x9	1.08	73.7x73.7

of ICRF radio-sources visible in optical domain for three years period (2014-2016); the Serbian Academy of Sciences and Arts (SANU) and Bulgarian Academy of Sciences (BAN) supported mentioned project. The next two ones were: *Study of ICRF radio-sources and fast variable astronomical objects* (2017-2019), and *Gaia Celestial Reference Frame (CRF) and fast variable astronomical objects* (2020-2022). The last one is *Gaia astrometry and fast variable astronomical objects* (2023-2025), and the leaders are G.Damljanović (Serbia) and R.Bachev (Bulgaria). The main information about the telescopes and CCD cameras is in Table 1, and it has been published in a few papers (Damljanović et al. 2014, Taris et al. 2018, Damljanović et al. 2020), also. The first column in Table 1 is telescope (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 per pixel), and field of view - FoV (in arcminutes).

Three Bulgarian telescopes are at National Astronomical Observatory (NAO) BAN Rozhen (D=2 m, D=60 cm, and Schmidt-camera 50/70 cm), and one is at Belogradchik AO site (D=60 cm). At the end of 2023, there is a new D=1.5 m one at NAO Rozhen, but not used until now (it is going to be a robotic instrument, soon). From the end of 2023, we have used the Meade D=40 cm at ASV.

3. RESULTS

Our investigations about Gaia Alerts (over the past decade) are in accordance 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, Manora Peak, Nainital, India). It is in line with our useful cooperation with some colleagues from India (A.C. Gupta and others). Here,

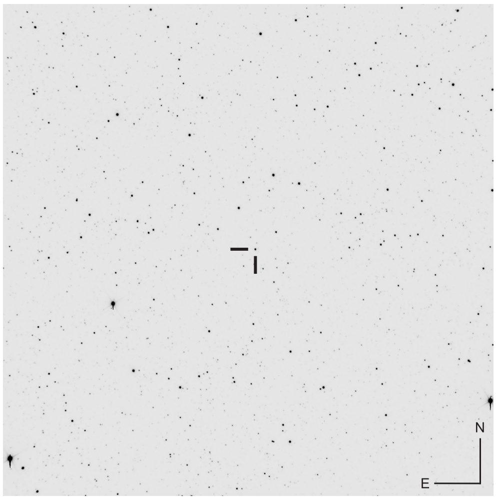

Figure 1: Original image of the object Gaia23bay (R-band, $Exp. = 60^s$) on October 7^{th} 2023 using the $D = 1.4$ m ASV telescope with CCD camera Andor iKon-L.

we present 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. Usually, we have done 3 CCD images per filter during observations of some Gaia Alerts and Johnson-Cousins BVRcIc filters. 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), but some time ago to the BHTOM. Over the past decade, we collected about 4000 CCDs for 130 Gaia Alerts or Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO), and it was 460 images per year (near 15 objects per year) before the problem with COVID virus. Because of the COVID problems, in 2020 we did 11 objects, just 5 objects in 2021, 7 objects in 2022. During 2023 we did 12 Gaia Alerts: Gaia22ang (5 times), Gaia22dze (1), Gaia23bay (6), Gaia19dmj (2), Gaia21cgt (2), Gaia22eem (2), Gaia23afy (1), Gaia23cer (2), Gaia23cri (3), Gaia20cwd (1), Gaia23bbk (1), and Gaia23cvq (1); about 300 CCD images were done.

Here, we present the object Gaia23bay ($\alpha = 19^h49^m43.^s00$, $\delta = 10^o43^{'}41.^{''}45$, see Table 2 and Fig. 1 with seening=$1.^{''}1$): alerting date is March 7^{th} 2023, class is unknown, candidate is unknown, but the photometric class is Red Giant (98.2%). We did it using two ASV instruments (60 cm and 1.4 m). The Gaia23bay was observed 6 times during 2023 (see Table 2): on June 19^{th} using D=1.4 m ASV telescope with CCD Andor iKon-L ($0.^{''}391$ per pixel), on July 24^{th} using D=60 cm ASV with FLI PL230 ($0.^{''}517$ per pixel), on August 17^{th} using D=1.4 m ASV, on September 18^{th} using D=60 cm ASV, on October 6^{th} using D=1.4 m ASV, and on October 7^{th} using D=1.4 m ASV; Modified Julian Day or $MJD = JD - 240000.5$ where JD is Julian Day. The first line in Table 2 is the date of observation (after that it is suitable MJD), and other 5 lines are BVRI and g magnitudes (with suitable standard deviation) after photometry. The standard deviation of our magnitudes is on the level 0.01 mag (for 60 cm ASV) and 0.001 (for 1.4 m ASV).

Table 2: Our photometry results (BVRI and g magnitudes with their standard deviations and MJD time) of Gaia23bay during 2023.

Date	June 19^{th}	July 24^{th}	Aug. 17^{th}	Sept. 18^{th}	Oct. 6^{th}	Oct. 7^{th}
MJD	60114.9	60149.9	60174.0	60205.8	60223.8	60224.8
I [mag]	12.716	12.772	12.778	12.801	12.805	12.790
	±0.005	±0.002	±0.003	±0.004	±0.002	±0.005
R [mag]	13.423	13.501	13.503	13.519	13.524	13.509
	±0.004	±0.002	±0.002	±0.004	±0.002	±0.004
V [mag]	14.188	14.239	14.262	14.256	14.278	14.263
	±0.004	±0.003	±0.002	±0.004	±0.002	±0.004
g [mag]	-	15.013	-	15.030	-	-
	-	±0.007	-	±0.009	-	-
B [mag]	15.548	15.588	15.610	15.605	15.630	15.642
	±0.005	±0.008	±0.004	±0.011	±0.005	±0.004

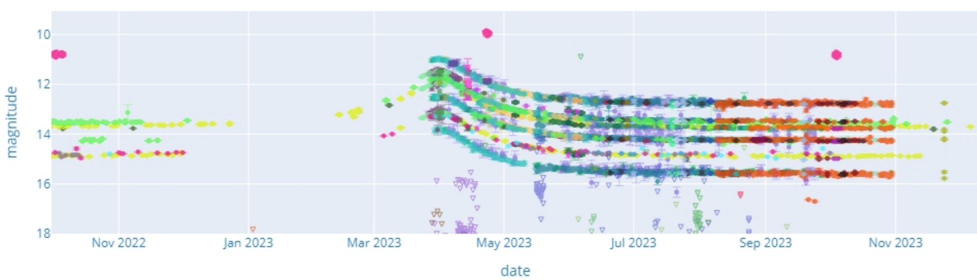

Figure 2: Light curve of the Gaia23bay using all BHTOM data.

Our original CCD image of the Gaia23bay is shown in Fig. 1 after the standard reduction (bias/dark/flat, hot/dead pixels, etc.) and the object is marked with lines. The east (E) is left and north (N) is up, FoV = 8.3x8.3 arcmin, binning=1x1, $scale$ = 0.391 arcsec per pixel. The light curve of all BHTOM data is in Fig. 2 (it is from BHTOM site): x-axis is date, and y-axis is suitable magnitude. Our results are in good accordance with: the ground-based relative photometry, results obtained from other telescopes (at BHTOM site), possibilities of our instruments, etc. The values of some of our magnitudes are transferred from our set of filters (Johnson BV and Cousins RcIc) into another one (see g magnitudes in Table 2) via BHTOM. We hope, there are enough relevant Gaia23bay data for our next paper in the future.

4. CONCLUSIONS

In mid-2014 the first observations of the ESA Gaia satellite were done, and since September 2014 the Gaia Photometric Science Alerts started to publish alerts. Over the past decade, GSA announced over 20000 transients. They were issued by the GSA group: supernovae, novae, cataclysmic variables, young stellar objects, microlensing events, R Coronae Borealis (RCrB) dimming stars, flaring quasars, etc. As a part of that job, we established our regional cooperation the *Serbian-Bulgarian mini-network* *telescopes* and our activities were in line with a few SANU-BAN projects. We have used 6 Serbian-Bulgarian telescopes for these investigations. Using D=2 m Rozhen and D=1.4 m ASV telescopes with $Exp. = 300^s$, we can observe the objects down to 21 mag in the R-band, and down to 19 mag using smaller telescopes. From September 2014 to September 2024, we observed about 130 Gaia Alerts (usually, nearly 15 objects per year). There are ≈ 4000 CCD images (≈ 460 images per year). We did these observations (usually, three CCD images per band) in Johnson BV and Cousins RcIc filters. A lot of papers were published with our results. Three papers were published during 2020 and 2021: about Gaia16aye or Ayers Rock (Wyrzykowski et al. 2020), about Gaia18dvy (Szegedi-Elek et al. 2020), and about the main results of Gaia Alerts (Hodgkin et al. 2021). Some of our results were presented at a few conferences. As an example, we present our results of the object Gaia23bay here. We hope, the Gaia23bay will be the subject of our next paper, soon.

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