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SERBIAN-BULGARIAN OBSERVATIONS OF GAIA ALERTS (GAIA-FUN-TO) DURING 2019

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Abstract. We used a set of six optical Serbian-Bulgarian telescopes at three sites (Belogradchik, Rozhen, and Vidojevica) to monitor astronomical objects in line with: the Gaia ESA mission (Gaia astrometry, Gaia Alerts or Gaia-Fellow-Up Network for Transients Objects), the Whole Earth Blazar Telescope - WEBT international project, cataclysmic and symbiotic stars, etc. Some results about observations of Gaia Alerts (Gaia-FUN-TO) during 2019 using "the Serbian-Bulgarian mini-network telescopes" are presented, here. Usually, we did about 15 objects per year. The mentioned activities are in line with actual SANU-BAN (Serbian and Bulgarian Academies of Sciences) joint research project "Gaia Celestial Reference Frame (CRF) and fast variable astronomical objects" (period 2020-2022), and similar international investigations supported by IAU. Also, our activities in line with the object Gaia18dvy are presented. The Gaia18dvy is a new case of FU Orionis-type young eruptive stars in the Cygnus OB3 Association, and the paper about it was published during 2020.

1. INTRODUCTION

The Gaia astronomical satellite of the European Space Agency – ESA is a space mission, and it is operating since mid-2014. Gaia is surveying the full sky: astrometrically, photometrically, and spectroscopically. It is doing revolution in astrometry, and these results are useful for all the relevant scientific communities:

for the stellar physics, our understanding of the Milky Way galaxy, the Solar system bodies, etc. The positions, proper motions and parallaxes (or the high-precision astrometric data) are the main goal of that mission. The G magnitudes of sources range from 3 to 21. An important step in the realization of the Gaia reference frame in future is the Gaia catalogue. The second Gaia solution or data release (DR2) of about 1.7 billion sources has been made publicly available on April 2018, and the next one (Gaia EDR3) is going to appear at the end of 2020.

The Gaia provides near-real-time photometric data during scanning the sky multiple times, and because of its these data are used to detect some changes in brightness from all over the sky (appearance of new objects, also). The next step is that the Gaia Science Alerts system produces alerts on the mentioned interesting objects, and we continue observations of these objects using the ground-based telescopes. The first alerts were published in October 2014 by the Gaia Photometric Science Alerts, and three years after that the Gaia Science Alerts was among the leading transient surveys in the world with transients as: supernovae, cataclysmic variables, microlensing events, other rare phenomena. More than 3000 transients were discovered until October 2017 (during three years).

2. GAIA ALERTS AND SERBIAN-BULGARIAN COOPERATION

Over the mission lifetime, Gaia has a goal of recording each object in the sky about 70 times. This produces a lot of alerts, where number of alerts increases with the number of observations of each object. Until the beginning of November 2020 about 14130 Gaia Alerts had been reported from all over the sky. In Table 1, we present a number of alerts published per year on the official website[1].

In 2011 the Serbian new astronomical site at the Astronomical Station of Vidojevica (ASV) of Astronomical Observatory in Belgrade (AOB) was established with a new D=60 cm telescope. At mid-2016 and via the Belissima project (see website[2]) there was another new telescope (D=1.4 m) at that site, and we used 4 instruments in Bulgaria (at Belogradchik and Rozhen sites) in line with our regional cooperation "Serbian-Bulgarian mini-network telescopes" which was started in 2013. Also, our activities are in line with the SANU-BAN joint research projects: "Observations of ICRF radio-sources visible in optical domain" (for the period 2014-2016), "Study of ICRF radio-sources and fast variable astronomical objects" (2017-2019), and the actual one "Gaia Celestial Reference Frame (CRF) and fast variable astronomical objects" (2020-2022, the leader is G.Damljanović). In a few papers (Damljanović et al. 2014; Taris et al. 2018) the main information about the mentioned instruments was published. Three telescopes (D=2 m, D=60 cm, and Schmidt-camera 50/70 cm) are at NAO Rozhen, and one (D=60 cm) is at Belogradchik AO. The NAO BAS means National Astronomical Observatory of

[1] http://gsaweb.ast.cam.ac.uk/alerts/home
[2] http://belissima.aob.rs

Bulgarian Academy of Sciences (or BAN in Bulgarian language), and Serbian Academy of Sciences and Arts is SASA (or SANU in Serbian language).

3. RESULTS

Our mini network of six telescopes (at three sites) is presented in Table 2, and the CCD cameras in line with these telescopes are presented in Table 3.

Also, we cooperate with colleagues from India, and because of this from time to time we can use D=1.31 m telescope of the Aryabhatta Research Institute of observational sciencES (ARIES). The ARIES is a site in the central Himalayan region (Manora Peak, Nainital); the geographic coordinates (longitude, latitude) and altitude are: $\lambda=79.7^{o}$ E, $\varphi=29.4^{o}$ N, h=2420 m. The mentioned telescope is equipped with the CCD camera Andor DZ436: 2048x2048 pixels, 13.5x13.5 μm pixel size, the scale is 0.″54 per pixel, FoV=18.′5x18.′5. This instrument is a modified R.-C. system Cassegrain; it is Devasthal Fast Optical telescope (DFOT).

Table 1: Number of Gaia alerts published per year.

Year	*Number of alerts*
2020 (updated 10th Nov 2020)	3468
2019	3915
2018	2729
2017	2322
2016	1522
2015	168
30th Aug 2014 – 31st Dec 2014	103

The standard bias, dark and flat-fielded corrections are done (also, hot/dead pixels are removed), and usually we did 3 CCD images per filter. The Johnson-Cousins BVRcIc filters were available. The Astrometry.Net and Source Extractor are used. The output is supposed to be submitted to the Cambridge Photometric Calibration Server (CPCS) for further calibration. About 3300 CCDs of the Gaia Alerts or Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) were collected during Oct. 2014 – Oct. 2020; it is about 550 images per year. About 90 objects were observed over the mentioned six years (it is near 15 objects per year).

Using our data there are a few published papers (Campbell et al. 2015; Wyrzykowski et al. 2020; Szegedi-Elek et al. 2020; Damljanovic et al. 2020; etc.).

In 2019, we observed 15 objects.

A) There are 9 objects using the **D=60 cm telescope at ASV**: Gaia19apc (5 times or epochs), Gaia19awc (2), Gaia19bcv (2), Gaia19cvu (1), Gaia19cup (1), Gaia19dke (1), Gaia19dum (2), Gaia18dvy (1), Gaia19duw (2).
B) Using the **D=1.4 m ASV** there are 10 objects: Gaia18dvu (2), Gaia18dvy (2), Gaia19aik (2), Gaia19ajp (2), Gaia19apc (3), Gaia19bcv (2), Gaia19awc (1), Gaia19drp (1), Gaia19dqe (1), Gaia19bpg (1).

C) Using the **D=2 m Rozhen** (FoReRo2 system) there are 3 objects: Gaia19awc (1), Gaia19bcv (1), Gaia19apc (1).
D) There are no data using the **D=60 cm Rozhen** (-): - .
E) There are no data using the **D=50/70 cm Schmidt-camera at Rozhen** (-): - .
F) There are no data using the **D=60 cm Belogradchik AO** (-): - .

We did about 440 CCDs during 2019: about 200 using D=60 cm ASV, 36 using D=2 m Rozhen (FoReRo2 system), and about 200 using D=1.4 m ASV. It is ~8% using D=2 m Rozhen, ~46% using 60 cm ASV, and ~46% using 1.4 m ASV.

Table 2: Mini network of telescopes.

Name	*Type*	*Longitude*	*Latitude*	*Altitude*
Astronomical Station Vidojevica – Astronomical Observatory Belgrade – (Serbia)				
"Milankovic" 1.4 m	Ritchey-Chrétien	21.6°	43.1°	1143 m
"Nedeljkovic" 60 cm	Cassegrain	21.5°	43.1°	1136 m
Rozhen National Astronomical Observatory – Bulgarian Academy of Sciences (Bulgaria)				
2 m	Ritchey-Chrétien	24.7°	41.7°	1730 m
60 cm	Cassegrain	24.7°	41.7°	1759 m
50/70 cm	Schmidt-camera	24.7°	41.7°	1759 m
Belogradchik Astronomical Observatory (Bulgaria)				
60 cm	Cassegrain	22.7°	43.6°	650 m

The object **Gaia18dvy** is very interesting. Its CCD image is presented (see Figure 1) after standard reduction (bias/dark/flat, hot/dead pixels, etc.). The object is marked with lines. This image was made on 13th March 2019 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.″24 per pixel. We observed the Gaia18dvy three times during March and August 2019 using two ASV instruments:

1.) 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),

2.) on 29th March, JD=2458572.6, D=1.4 m with Andor iKon-L, 3(BVRI),

3.) on 29th August, JD=2458725.5, D=60 cm with FLI PL230 (0.″518), 3(BVRI).

The obtained results are:

1.) in B-band it is 18.58 mag with st.dev.=0.03 mag (MJD=58555+0.0939 days), 18.55±0.03 (+0.1002), and 18.61±0.03 (+0.0876),
V=16.60±0.01 (+0.1018), 16.59±0.01 (+0.0955), 16.62±0.01 (+0.0892),
r=15.60±0.00 (+0.0971), 15.60±0.00 (+0.1034), 15.60±0.00 (+0.0907),
i=14.43±0.00 (+0.0986), 14.43±0.00 (+0.0923), 14.44±0.00 (+0.1049),

2.) in B-band it is 18.30±0.03 mag (58572+0.1158), 18.29±0.03 (+0.1219), and 18.32±0.03 (+0.1098),
V=16.38±0.01 (+0.1234), 16.38±0.01 (+0.1173), 16.37±0.01 (+0.1113),
r=15.42±0.00 (+0.1188), 15.42±0.00 (+0.1249), 15.40±0.00 (+0.1128),

i=14.34±0.00 (+0.1203), 14.34±0.00 (+0.1143), 14.33±0.00 (+0.1264),

3.) in B-band it is 17.54±0.04 mag (58724+0.9608), 17.57±0.04 (+0.9630), and 17.62±0.05 (+0.9587),

V=15.77±0.01 (+0.9694), 15.79±0.01 (+0.9673), 15.73±0.01 (+0.9651),

r=14.99±0.00 (+0.9737), 14.77±0.00 (+0.9758), 14.98±0.00 (+0.9715),

i=13.67±0.00 (+0.9801), 14.78±0.00 (+0.9779), 13.68±0.00 (+0.9822).

Table 3: CCD cameras of our mini network telescopes.

Telescope D/F [m]	*Camera*	*Chip size [pixel]*	*Pixel size [μm]*	*Scale ["]*	*Field of view - FoV[']*
1.4/11.42 ASV	Apogee Alta U42 Andor iKon-L	2048 x 2048 2048 x 2048	13.5 x 13.5 13.5 x 13.5	0.243 0.24	8.3 x 8.3 8.3 x 8.3
2/15.774 Rozhen	VersArray 1300B Andor iKon-L	1340 x 1300 2048 x 2048	20 x 20 13.5 x 13.5	0.261 0.176	5.6 x 5.6 6.0 x 6.0
0.6/6 ASV	Apogee Alta U42 SBIG ST10 XME	2048 x 2048 2184 x 1472	13.5 x 13.5 6.8 x 6.8	0.465 0.23	15.8 x 15.8 8.4 x 5.7
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

Our results (suitable magnitudes) are in good accordance: with other presented results (see Figure 2), with the ground-based relative photometry, 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.

We investigated Gaia 18dvy (α=20:50:06.02, δ=36:29:13.52, see Figure 1.) which was noted by Gaia alerts system when its light curve had a 4 magnitude rise in the period 2018-2019. It was proved to be a new case of FU Orionis-type young eruptive stars in the Cygnus OB3 Association (Szegedi-Elek et al. 2020).

Once identified, Gaia18dvy was observed by Follow-Up-Network of telescopes in multi-national campaign. All follow-up data were collected and presented in the Figure 2. Here, we reproduce this as Figure 3 using the paper (Szegedi-Elek et al. 2020). Our images of Gaia 18dvy were among the first ones collected for this campaign and an example of our frame is shown in Figure 1, it is presented among other follow-up data in Figure 3. Our results fit very well other points of the light curve (Figure 3).

It was observed in optical and infrared domain which was followed by spectroscopic observations. Its optical and near-infrared spectroscopic characteristics in the outburst phase are consistent with those of FU Orionis-type young eruptive stars. The progenitor of the outburst is a low-mass K-type star. A radiative transfer modeling of the circumstellar structure has been developed, based on the spectral energy distribution, and indicates a disk with a mass of 4×10^{-3} M_{sun}. The known population of FU Orionis type stars is very small (only 26 FUors and FUor-like objects).

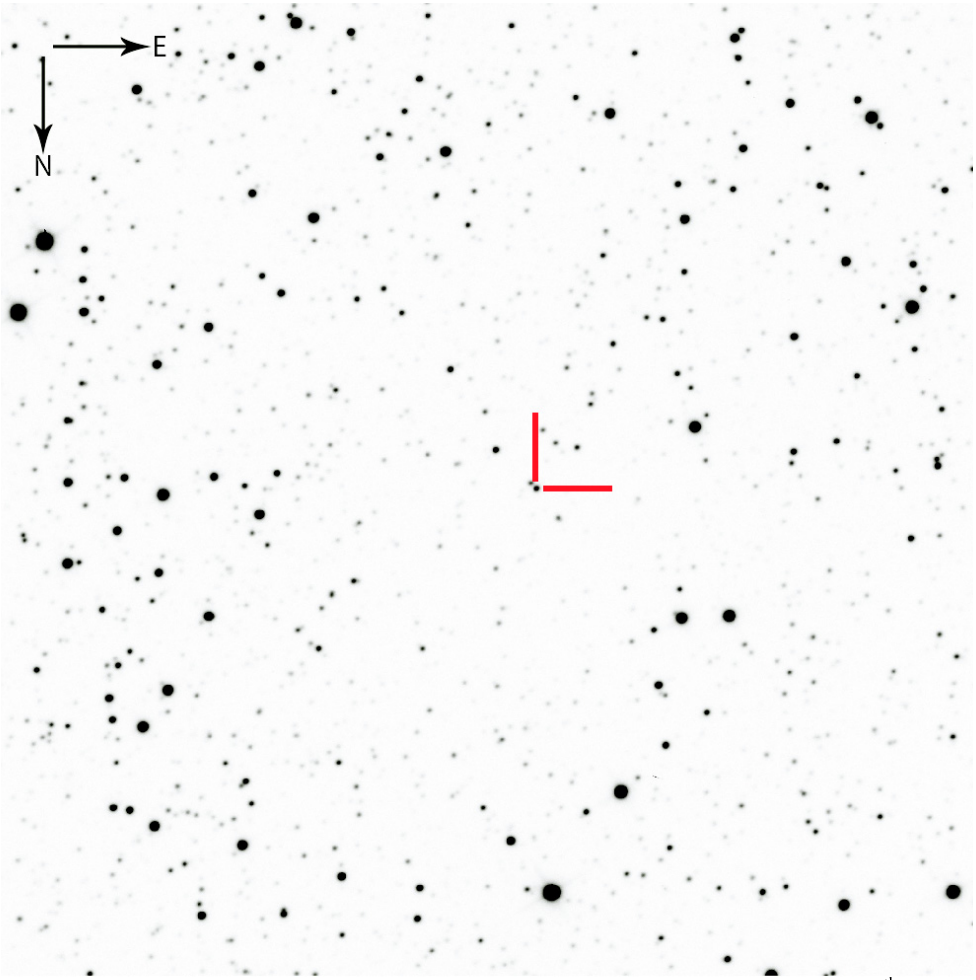

Figure 1: Our image of the Gaia18dvy (R-filter, Exp.=120s) on March 13th 2019 using the D=1.4 m ASV telescope with CCD Andor iKon-L camera.

It is possible to observe objects down to 20 mag in the V-band using D=2 m Rozhen and D=1.4 m ASV telescopes with Exp.=300s. With smaller telescopes, it is down to 19 mag. The D=1.4 m telescope is a new addition to our network from mid-2016 (new dome from 2018). In the last 2 years both bigger telescopes (2m Rozhen and 1.4 m ASV) have had new CCD cameras Andor iKon-L 936. The telescope D=2 m at Rozhen underwent realuminization of the mirrors in 2017.

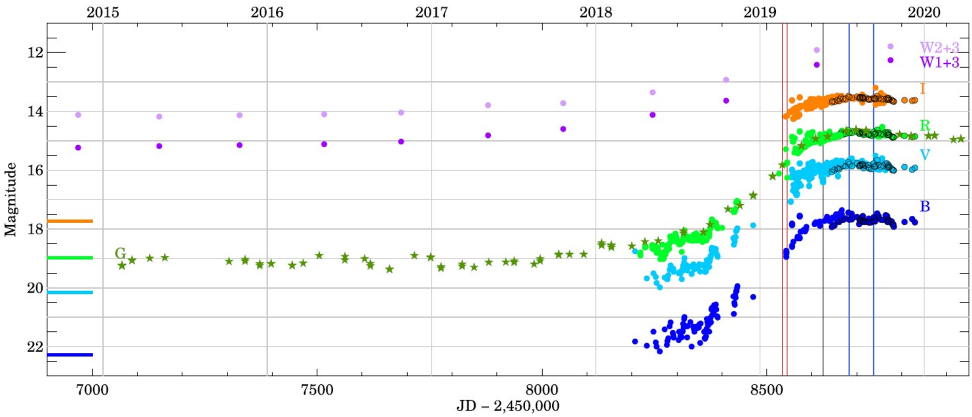

Figure 2: All follow-up data of Gaia 18dvy. The figure is reproduced from Szegedi-Elek et al. (2020) paper. The green asterisks show the Gaia data, the purple dots - WISE data, filled dots - ZTF and OPTICON data, the photometry from the Konkoly Observatory is highlighted by the black circles. Average Pan-STARRS magnitudes, converted to the Johnson-Cousins system, are indicated by the horizontal lines at the left side of the figure. The red vertical lines mark optical spectra of Gaia 18dvy, while the black vertical line indicates the epoch of NIR spectrum. The two blue vertical lines display the time period when the TESS satellite observed Gaia 18dvy.

4. CONCLUSIONS

The ESA Gaia astronomical satellite was launched in the end of 2013. In mid-2014 the first observations of that mission were done, and since October 2014 the Gaia Photometric Science Alerts started to publish alerts. During the first three years about 3000 alerts were issued by the Gaia Science Alerts group: cataclysmic variables, supernovae, candidate microlensing events, etc.

In line with our regional cooperation “Serbian-Bulgarian mini-network telescopes” and three SANU-BAN projects a few objects were observed (Damljanović et al. 2014) during the test phase in 2013 and 2014. After that (from the end of 2014), we continued the observations of the Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) or Gaia Alerts. From mid-2016 there were 6 Serbian-Bulgarian telescopes for the mentioned activities.

About 90 objects were observed during 6 years (until the end of October 2020), and it is near 15 objects per year. About 3300 CCD images were collected; it is about 550 images per year. Our observations were done in Johnson BV and Cousins RcIc filters. Usually, we did 3 CCD images per filter. At the beginning of Gaia Alerts the paper (Campbell et al. 2015) about rare object was published; it is the eclipsing AM CVn Gaia14aae object. During 2020, two papers were published: (Wyrzykowski et al. 2020) about Gaia16aye object (Ayers Rock), and (Szegedi-Elek et al. 2020) about Gaia18dvy one. The Gaia16aye is the binary microlensing event (the first discovered in the Northern Galactic Disk); we did that object from mid-2016 and during about 2.5 years. The object Gaia18dvy is a new case of FU Orionis-type young eruptive stars in the Cygnus OB3 Association. Also, some of our results were presented at a few conferences.

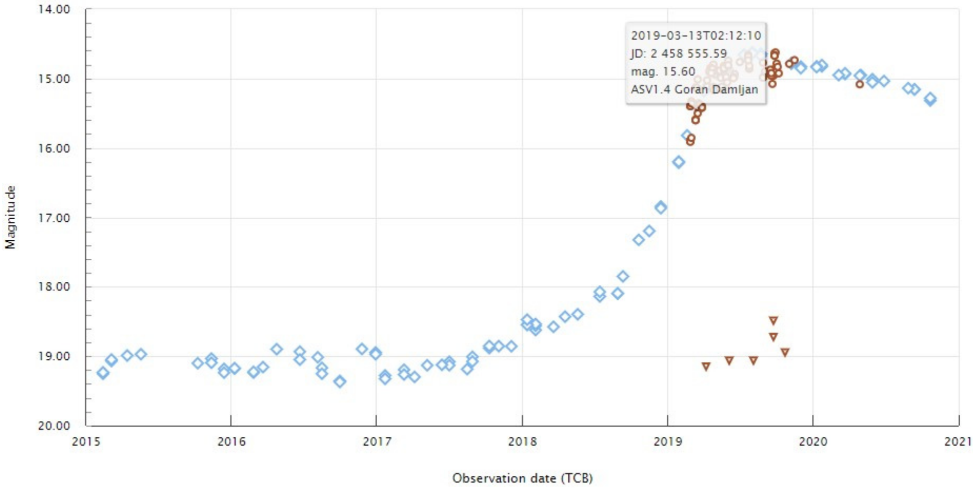

Figure 3. Our measurement of Gaia 18dvy (one shown as image in Figure 2) shown with the arrow, among other follow-up data in the campaign (brown circles) and Gaia data (blue diamonds).

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