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Serbian–Bulgarian mini-network telescopes and GAIA-FUN-TO

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The satellite of Gaia mission was launched at the end of 2013. It is the cornerstone of the European Space Agency (ESA). The Gaia started the astronomical observations in August 2014, and the Gaia Photometric Science Alerts published alerts since October 2014. It is going to map the entire Galaxy, about one billion stars, and nearly 600000 quasars (QSOs). About 1000 alerts (by the Gaia Science Alerts group) have been found: supernovae, cataclysmic variables, microlensing events and other exotic transients. Gaia is now the second largest provider of transients in the world; the first one is PS1 on PANSTARRS telescope (http://www.rochesterastronomy.org/snimages/). Using the 60-cm telescope at Astronomical Station Vidojevica – ASV (of Astronomical Observatory in Belgrade – AOB, Serbia) we observed few objects of Gaia-FUN-TO for the test phase in 2013 and 2014. And at the end of 2014 we continued the observations of Gaia Alerts objects using the Serbian–Bulgarian mini-network telescopes: the 60-cm at ASV (also, new 1.4-m instrument at ASV, from May 2016), 60-cm at Belogradchik AO, 2-m instrument, and 50/70-cm Schmidt-camera at Rozhen Observatory (Bulgaria). As a result, 36 objects were observed from October 2014 until mid-October 2016 (near 1000 CCD images in BVRI filters, mostly using the 60-cm ASV instrument). Some objects are very rare ones, as the Gaia14aae (the eclipsing AM CVn) and Gaia16aye (binary microlensing event). We observed the Gaia14aae with two telescopes (the 60-cm ASV and 60-cm Belogradchik ones) at 21st October 2014, and six times the object Gaia16aye using the new 1.4-m ASV instrument during September and October 2016. Here, some of our Gaia-FUN-TO observations and results are presented.

Keywords: Gaia mission, Gaia-FUN-TO, transients

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1 Introduction

Hundreds of billions of Gaia observations have been collected until the first Gaia Data Release (in September 2016), about two and half years after the beginning of observations. It means, with these data Gaia is improving our understanding of the Milky Way, and generally it is initiating a revolution in astronomy. About 1000 alerts have been issued by the Gaia Science Alerts group with interesting discoveries of rare objects (some types of supernovae, cataclysmic variables, microlensing events, etc.); because of it, it is now the second largest provider of transients in the world. The large amount of astronomical data expected are now reality (Mignard 2014). After the first space-based astrometry mission, Hipparcos (ESA 1997, van Leeuwen 2007), Gaia continues a European tradition for pioneering high-accuracy astrometry. The transient objects are included into the Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) project. Small and medium size telescopes could take part in coordinated time-domain astronomical observations of the transients (Wyrzykowski and Hodgkin 2012).

The Gaia data will be a unique time-domain space survey because of Gaia repetitive observations of the entire sky (nearly 70 times during its 5-year lifetime). The mentioned phenomena will rapidly be observed to analyze the data and share the results of transient astronomy. To be a part of the Gaia-FUN-TO project, in collaboration with Bulgarian colleagues at 2013 we established the Serbian-Bulgarian mini-network telescopes (now, there are 5 instruments) for Gaia-FUN-TO observations. After a few test campaigns since mid-2013, we started with real Gaia Alerts at the end of 2014. Until mid-October 2016, 36 objects were observed and some of them until 7 times (epochs).

Our instruments for observations of the Gaia-FUN-TO are presented in the next section, and after that, some results are given (in the section RESULTS).

2 Instruments

During 2013, we put much effort into operation of the Serbian-Bulgarian mini-network telescopes (Damljanović et al 2014), but now it is evident that the idea was very good for our activities about the Gaia-FUN-TO. Within the frame of bilateral cooperation between the Serbian Academy of Sciences and Arts (SANU) and Bulgarian Academy of Sciences (BAN), Dr. G. Damljanović defined a joint research project "Observations of ICRF radio-sources visible in optical domain", and it partly deals with the Gaia-FUN-TO. That 3-year project started in 2014, and in line with it we are using telescopes of both countries for the Gaia-FUN-TO. In Table 1 there is the main information of mentioned instruments.

In Table 1, information of the first column is: the site, telescope and D[cm]/F[cm]. In the second column, the geographic coordinates (longitude, λ; latitude, φ) and altitude h of the site are presented. The FoV is field of view (in the third column). The 2-m Rozhen telescope is the biggest one in Table 1; mentioned instruments are possible to see (and to take more information about them) using the sites: nao-rozhen.org, www.astro.bas.bg, and vidojevica.aob.rs. From May 2016, the new 1.4-m telescope

Table 1 Telescopes, sites, CCD cameras and other information.

Site, type, D [cm]/F [cm]	$\lambda(^\circ)$ E, $\varphi(^\circ)$ N, h(m)	CCD camera, pixels, scale($''$), pixel size (μm), FoV($'$)
A) Rozhen (NAO BAS), Ritchey-Crétien, 200/1577	24.7, 41.7, 1730	VersArray 1300B 1340×1300, 0.261 20×20, 5.6×5.6
B) Rozhen (NAO BAS), Schmidt-camera 50/70, $F = 172$	24.7, 41.7, 1759	FLI PL16803 4096×4096, 1.08 9×9, 73.7×73.7
C) Belogradchik AO, Cassegrain, 60/750	22.7, 43.6, 650	FLI PL09000 3056×3056, 0.335 12x12, 16.8×16.8
D) ASV (AOB), R.C., Nasmyth 140/1142	21.5, 43.1, 1143	Apogee Alta U42 2048x2048, 0.243 13.5×13.5, 8.3×8.3
E) ASV (AOB), Cassegrain, 60/600	21.5, 43.1, 1136	Apogee Alta U42 2048×2048, 0.465 13.5×13.5, 15.9×15.9

("Milanković") was installed at the new site ASV within the frame of the Belissima project (http://belissima.aob.rs). During the last several months we observed many objects (also, Gaia Alerts ones) using the 1.4-m ASV, and the CCD images are very good. The mean seeing is about $1.''2$ using the 60-cm ("Nedeljković") at the ASV site (from time to time it is about $0.''8$ for the 1.4-m ASV instrument), and between $1.''5$–$2.''0$ using the 2-m telescope at the Rozhen site (sometimes could be about $0.''8$). So, the mentioned instruments (with CCD cameras presented in Table 1) are good for Gaia-FUN-TO (also, on good sites).

3 Results

From October 2014 until mid-October 2016 and by using the instruments which are presented in Table 1, we observed 36 objects of Gaia Alerts via the Serbian-Bulgarian mini-network telescopes cooperation. It was in accordance with the bilateral joint research project "Observations of ICRF radio-sources visible in optical domain". Mostly, the 60-cm ASV telescope is in operation. There is no data from the 60-cm Rozhen instrument (not presented in Table 1) because for some time it is under reconstruction.

In line with Table 2, during the mentioned period there are: 6 objects which were observed at the 2-m Rozhen telescope (R.C. with CCD VersArray 1300B, or FoReRo2 system with two CCD cameras), 3 objects at the Schmidt-camera (Rozhen Observatory), 2 objects at the 60-cm telescope of the Belogradchik AO, 4 objects using the 1.4-m ASV instrument, and 27 objects with the 60-cm ASV.

Table 2 Gaia Alerts objects which are observed using our mini-network telescopes until mid-October 2016.

Name	Telescope (number of observations, epochs)	RA (deg.)	Dec. (deg.)
1. Gaia14aae	C(1), E(1)	242.89156	63.14217
2. Gaia15aai	E(1)	233.55516	62.98277
3. Gaia15aaj	E(1)	237.77419	34.43214
4. Gaia15aal	E(1)	245.76243	37.92130
5. Gaia15aba	E(1)	240.87586	52.26069
6. Gaia15abn	E(1)	216.65320	24.05280
7. Gaia15ace	E(1)	254.83222	29.94392
8. Gaia15adu	E(1)	265.70622	9.19386
9. Gaia15aea	E(1)	147.65932	41.85815
10. Gaia15aek	E(1)	101.76123	64.93435
11. Gaia15ael	E(1)	203.34546	58.72538
12. Gaia15aet	E(3)	135.65769	25.93442
13. Gaia15aer	E(5)	353.96774	23.61441
14. Gaia15afc	E(1)	236.11003	55.66468
15. Gaia15afd	C(2), E(7)	269.87408	43.39004
16. Gaia15aff	A(1), B(1), E(6)	306.69743	42.99490
17. Gaia15afq	E(4)	234.62443	27.29889
18. Gaia15aft	E(3)	273.68224	39.61261
19. Gaia15afw	E(2)	149.99810	-2.88797
20. Gaia15agc	E(1)	184.59674	35.61824
21. Gaia15agd	E(2)	171.57245	28.36723
22. Gaia15agh	E(1)	181.02133	14.06805
23. Gaia15agj	E(3)	147.74682	37.96674
24. Gaia16aax	A(1), B(1)	218.57701	49.21014
25. Gaia16ael	B(2), E(1)	249.72362	58.59080
26. Gaia16ajq	A(2)	223.25710	42.35769
27. Gaia16alf	E(2)	250.06748	22.78287
28. Gaia16alz	E(2)	283.75556	1.64915
29. Gaia16aps	E(1)	202.19835	33.18659
30. Gaia16avf	A(1)	189.38036	57.53237
31. Gaia16avm	A(2)	229.98312	5.40532
32. Gaia16avn	A(1)	227.80574	11.36884
33. Gaia16aye	D(6)	295.00474	30.13149
34. Gaia16bjf	D(1)	130.72110	25.07092
35. Gaia16bjg	D(2)	231.62277	41.73446
36. Gaia16bjh	D(1)	221.60259	43.83456

The name of the Gaia Alerts object is in the first column of Table 2. In the second one, between the brackets it is the number of observations (epochs) of indicated object and with marked telescope (A, B, C, D or E, in line with Table 1). Another two columns present RA and Dec at J2000.0 (the coordinates of object) in degrees.

We are using the Johnson BV and Cousins RI filters. Except for the VersArray 1300B CCD camera (with cooling down to $-110°$C), the CCD images require the standard bias, dark, and flat-fielded corrections. Also, other useful corrections

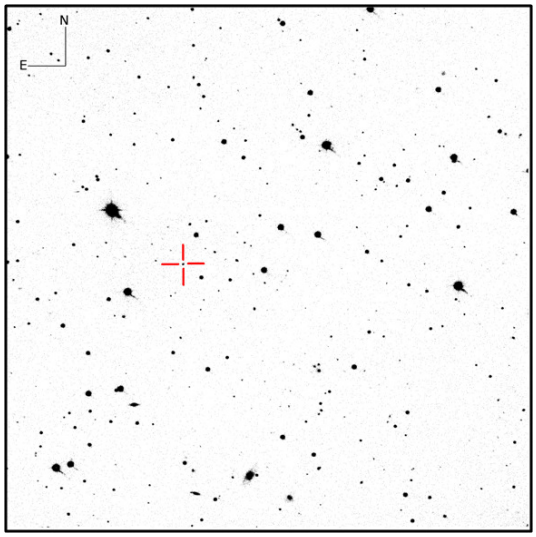


Figure 1 The deeply eclipsing AM CVn system, rare object Gaia14aae (GaiaVerif14acp); original image using the 60-cm Belogradchik AO telescope (in R filter at 21st October 2014).

for data reduction: for cosmic rays, hot/dead pixels, shutter effect, etc. For automatized data reduction, the IRAF reduction package was used, and as the second module it is to find astrometry solution for individual data frames using Astrometry.Net (http://astrometry.net). Finally, for aperture photometry the Source Extractor is applied. And for further calibration, the output is submitted to the Cambridge Photometry Calibration Server (CPCS); more about it in the papers (Damljanović et al. 2014) and at site (http://gsaweb.ast.cam.ac.uk/alerts). With instruments listed in Table 1 (and if Exp. is until 300^s), it is possible to observe the objects with V magnitude until about 20 mag using 2-m Rozhen and 1.4-m ASV telescopes, but until about 19 mag with the other ones.

In Fig. 1 (original image of the 60-cm Belogradchik AO telescope), the deeply eclipsing AM CVn system (Gaia Alerts Gaia14aae) is presented, as a very rare object. The photometry was used to constrain the orbital parameters of that system; our data from the 60-cm Belogradchik AO and 60-cm ASV telescopes made at 21st October 2014 were a part of it, also. The orbital period is 49.71 min; the paper about that object was published (Campbell et al. 2015). It is only the third eclipsing AM CVn star known, and the first in which the white dwarf (WD) is totally eclipsed. Another very rare object (observed with many instruments and using the 1.4-m ASV one, also) is the Gaia16aye (see Fig. 2, original image made at the 1.4-m ASV). The coordinates of these objects are in Table 2. The Gaia16aye is a binary microlensing rare event, still under observations and investigations (see the light curve in Fig. 3 included via gsaweb.ast.cam.ac.uk and CPCS); we expect a published paper about that object, soon. In Figs. 1 and 2 the object is marked, and the E–N orientation is indicated. In Fig. 3, the x-axis is MJD (modified JD) and y-axis is magnitude (in B, V, g, r, and i bands, indicated with different colours); the APASS catalog was used. In that figure, the "limit" means that some result marked with triangle is with large error or

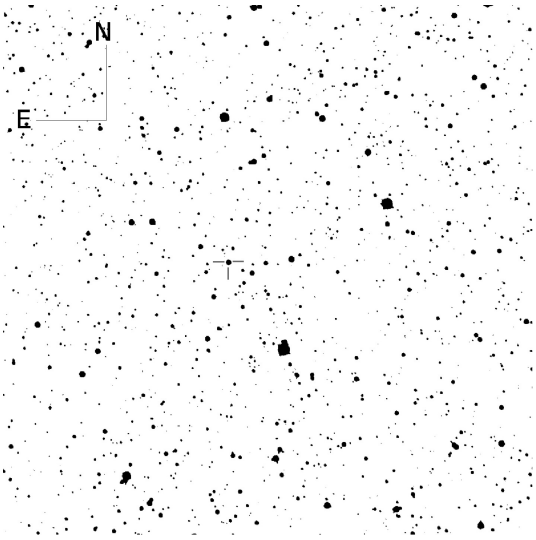


Figure 2 The binary microlensing event, Gaia16aye; original image using 1.4-m ASV telescope (in R filter at 24th September 2016).



Figure 3 The light curve of the Gaia16aye with data until mid-October 2016.

not the real one. There are more than 6000 data points (about 80 data points of 6 epochs by using 1.4-m ASV).

During observation, an object (it could be a star, a planet, or a black hole) is lying exactly between a distant star (the source) and the observer; this is a microlensing event. So, the light rays from a distant star are bent by the space-time curvature of an object. That hitherto unseen object is called the lens; moving faster across the

sky it leads to a dramatic increase (after some time, to decrease) in the brightness of the background source. The Gaia16aye (nicknamed Ayers Rock, the second Gaia microlensing event) was found towards the Galactic spiral arms and it is a little unusual (the central region, the Bulge, of the Milky Way is usual part for the lens). The sharp rises (in Fig. 3) are called caustic crossings, and we should see another sharp rise at the beginning of December 2016 (in line with the nowadays model). The light curve shows characteristic U-shaped changes (sudden sharp increases and decreases in brightness); it is the case when the lens is not a single object, but rather a pair. So, the lens could be a binary star system. This creates caustics, and they lead to sudden jumps in flux during the time the lens is crossing the light rays of the source. After the predicted re-brightening, it will be possible to solve the problem of the nature of the components of the binary system (two stars orbiting each other, or maybe a star with a planet or even a black hole). Because of mentioned information about Gaia16aye (see Figs. 2 and 3), we can see the great importance of ground-based follow-up of Gaia Alerts; it is not possible to confirm Gaia16aye as a microlensing event without an extra follow-up (also, the binary nature of the lens, the system components, etc.).

4 Conclusions

Here, the efforts to establish the Serbian–Bulgarian mini-network telescopes for the Gaia-FUN-TO are presented. In line with it, the mentioned project "Observations of ICRF radio-sources visible in optical domain" enables the use of local telescopes, exchanges of scientists, software, data, and results. The instruments with their main information are described. So, these instruments are satisfactory for the Gaia-FUN-TO.

As a result, 36 objects were observed during the Gaia activities (from October 2014 until mid-October 2016). Nearly 1000 CCD images (in BVRI filters) were collected; mostly using the 60-cm ASV instrument (27 objects). Some of observed Gaia Alerts objects are very rare ones; see the paper (Campbell et al. 2015). Also, we presented some information about microlensing rare event Gaia16aye. Our plan is to continue with observations of the Gaia Alerts objects and cooperation with Bulgarian colleagues. From May 2016, we are doing observations with the new 1.4-m ASV telescope – "Milanković", as a result of Belissima project (http://belissima.aob.rs). The first data (also, Gaia16aye ones), using that instrument, are good ones.

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