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# GAIA SCIENCE ALERTS AND THE OBSERVING FACILITIES OF THE SERBIAN – BULGARIAN MINI-NETWORK TELESCOPES

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**SUMMARY: The astrometric European Space Agency (ESA) Gaia mission was launched in December 19, 2013. One of the tasks of the Gaia mission is production of an astrometric catalog of over one billion stars and more than 500000 extragalactic sources. The quasars (QSOs), as extragalactic sources and radio emitters, are active galactic nuclei objects (AGNs) whose coordinates are well determined via Very Long Baseline Interferometry (VLBI) technique and may reach sub-milliarcsecond accuracy. The QSOs are the defining sources of the quasi-inertial International Celestial Reference Frame (ICRF) because of their core radio morphology, negligible proper motions (until sub-milliarcsecond per year), and apparent point-like nature. Compact AGNs, visible in optical domain, are useful for a direct link of the future Gaia optical reference frame with the most accurate radio one.**

**Apart from the above mentioned activities, Gaia has other goals such as follow-up of transient objects. One of the most important Gaia's requirements for photometric alerts is a fast observation and reduction response, that is, submition of observations within 24 hours. For this reason we have developed a pipeline. In line with possibilities of our new telescope (D(cm)/F(cm)=60/600) at the Astronomical Station Vidojevica (ASV, of the Astronomical Observatory in Belgrade), we joined the Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) for the photometric alerts. Moreover, in view of the cooperation with Bulgarian colleagues (in the first place, SV), one of us (GD) initiated a local mini-network of Serbian – Bulgarian telescopes useful for the Gaia-FUN-TO and other astronomical purposes. During the next year we expect a new 1.4 m telescope at ASV site. The speed of data processing (from observation to calibration server) could be one day. Here, we present an overview of our activities in the Gaia-FUN-TO which includes establishing Serbian – Bulgarian mini-network (of five telescopes at three sites, ASV in Serbia, Belogradchik and Rozhen in Bulgaria), the Gaia-FUN-TO test observations, and some results.**

**Key words. telescopes – instrumentation: detectors – techniques: photometric – supernovae: general**

## 1. INTRODUCTION

The Gaia satellite, as a cornerstone mission of the European Space Agency (ESA), was launched on December 19, 2013. The scientific observations were started about 2 months later. The first intermediate data release is expected to take place within two years after the launch (Mignard 2014). Gaia is designed to map over one billion stars and more than half a million quasars (QSOs) with the apparent V band magnitudes within the range $5.6 < V < 20$ (Perryman et al. 2001, Lindegren et al. 2008, Mignard 2014). The Gaia is going to observe repeatedly the entire sky during its 5-year lifetime. Many of these QSOs will be used for construction of a dense optical QSO-based International Celestial Reference Frame (ICRF); it will be the Gaia CRF in the future (Bourda et al. 2010 and 2011, Taris et al. 2013). As the first step, it is necessary to identify and pinpoint sources bright enough in both the radio and optical to allow for a robust frame tie between the Very Long Baseline Interferometry (VLBI) radio and Gaia optical frames (Jacobs 2014). Because of a large amount of astronomical data, the Gaia is set to revolutionize our understanding of the Milky Way. After the first space-based astrometry mission, Hipparcos (ESA 1997, van Leeuwen 2007), Gaia continues a European tradition for pioneering high-accuracy astrometry.

The instruments on board of the Gaia satellite provide photometric (observed in a few dozen colors), spectroscopic and astrometric data. Various scientific results are expected in different fields based on these data. From the Gaia mapping of the entire sky, many transient and other events will be found: supernovae, novae, microlensing events, QSO flares, Solar System objects, etc. The transient objects are included into the Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) project. Several scientific alert working groups were formed in the Gaia-FUN-TO to conduct the verification of the alerts (Wyrzykowski et al. 2012, Wyrzykowski and Hodgkin 2012), and to produce scientific results from the Gaia and ground-based data:[1] GSAWG1 – Supernovae (Core collapse, 1a), GSAWG2 – CVs and XRBs, GSAWG3 – Microlensing, GSAWG4 – Young Stars, GSAWG5 – AGNs and TDEs, GSAWG6 – GRBs, GSAWG7 – Be stars, R CrB stars, other rare events, GSAWG8 – Gaia Alerts Processing and Infrastructure, GSAWG9 – Spectroscopic Follow-up, and GSAWG10 – Photometric Follow-up. GD and OV are members of GSAWG1, GSAWG5, and GSAWG10. Small ground-based telescopes, such as the 60 cm one of the Astronomical Station Vidojevica (ASV of the Astronomical Observatory in Belgrade – AOB), and medium size telescopes, as the 2 m one in Rozhen (Institute of Astronomy with NAO, BAS)[2], could take part in coordinated time-domain astronomical observations of the transients.

Because of Gaia repetitive observations of the entire sky (about 70 times for its 5-year lifetime), it will be a unique time-domain space survey. It is a good opportunity for real-time detections of transients, but the scientific results of some new discoveries will be lost without a prompt and appropriate Gaia-FUN-TO verification and observations. Because of this, the mentioned phenomena will rapidly be observed by using ground-based (small and medium size) telescopes to analyze the data and share the results of transient astronomy, as soon as possible. Some of necessary steps of the Gaia-FUN-TO are the test observations, to check setting up the hardware and pipeline software, to test the calibration server, etc.

In collaboration with Bulgarian colleagues, a local mini-network of Serbian and Bulgarian telescopes is used for Gaia-FUN-TO observations. We joined the Gaia-FUN-TO project, by declaring which telescopes will be used for Gaia alerts and the amount of telescope time allocated for observations. We also took part in couple of observing test campaigns since mid-2013. Any scientific outcome will be published together with all participants.

In the next two sections, our main activities and instruments for observations of the Gaia-FUN-TO are presented, and after that, the details about our Gaia-FUN-TO test observations and corresponding results are given.

## 2. ACTIVITIES AND INSTRUMENTS

In what follows we present our most important activities to put into operation the Serbian – Bulgarian mini-network for Gaia-FUN-TO and the instruments we use for observations.

In 2011, one of us (GD) started astronomical observations of QSOs (from the ICRF2 list) visible in optical domain (Damljanović and Milić 2012, Damljanović et al. 2012, Damljanović and Milić 2013, Damljanović et al. 2014). In 2013, after the 4th Gaia Science Alerts Workshop (June 19-21, IAP, Paris), we established a local Serbian – Bulgarian mini-network of telescopes for the Gaia-FUN-TO; see a presentation by Damljanović (2013) at the website.[3]

Within the frame of bilateral cooperation between the Serbian Academy of Sciences and Arts and Bulgarian Academy of Sciences, GD defined a joint research project "Observations of ICRF radio-sources visible in optical domain", which partly deals with the Gaia-FUN-TO. This 3-year project started in 2014. Obvious benefits of the project are in using telescopes of both countries for the Gaia-FUN-TO.

Table 1 lists the main information on the Serbian – Bulgarian mini-network instruments. In the first column in Table 1, names of the observational stations (AOB – Serbia, Rozhen Institute of Astronomy with NAO BAS and Belogradchik AO – Bulgaria) and telescopes (with D(cm)/F(cm) values) are presented. The geographic coordinates (east longitude – $\lambda$, latitude – $\varphi$) and altitude – $h$ of five telescopes are given in the second column. In the third column, the CCD cameras, their resolutions, pixel

[1] http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Working_groups

[2] The 2 m RCC telescope of the Rozhen National Astronomical Observatory operated by the Institute of Astronomy, Bulgarian Academy of Sciences

[3] http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Workshop2013:main

sizes, pixel scales (in ″/pixel), and field of views (FoV) are given. In addition to the CCD cameras listed in Table 1, we also used the SBIG-ST-10 XME for the 60 cm ASV telescope. Its performances are: CCD size of 14.9mmx10mm, 2184x1472 resolution, 6.8$\mu$m x 6.8$\mu$m pixel size, the scale is 0″.23 per pixel, and FoV=8′.4x5′.7. This camera has an adaptive optic system (AO), which may improve the resolution of images, but we did not use it until now.

**Table 1.** Serbian – Bulgarian mini-network.

| Site<br>Telescope<br>$D$[cm]/$F$[cm] | $\lambda[\circ]$<br>$\varphi[\circ]$<br>$h$[m] | CCD camera,<br>CCD resolution,<br>pixel size [$\mu$m],<br>scale [″], FoV [′] |
|---|---|---|
| 1.ASV(AOB)<br>Cassegrain<br>60/600 | 21.5<br>43.1<br>1150 | Apogee Alta U42<br>2048x2048<br>13.5x13.5<br>0.46 , 15.8x15.8 |
| 2.Rozhen(BAS)<br>Ritchey-Chrétien<br>200/1600 | 24.7<br>41.7<br>1730 | VersArray 1300B<br>1340x1300<br>20x20<br>0.26 , 5.6x5.6 |
| 3.Rozhen(BAS)<br>Cassegrain<br>60/750 | 24.7<br>41.7<br>1759 | FLI PL09000<br>3056x3056<br>12x12<br>0.33 , 16.8x16.8 |
| 4.Rozhen(BAS)<br>Schmidt-camera50/70<br>$F$=172 | 24.7<br>41.7<br>1759 | FLI PL16803<br>4096x4096<br>9x9<br>1.08 , 73.7x73.7 |
| 5.Belogradchik AO<br>Cassegrain<br>60/750 | 22.7<br>43.6<br>650 | FLI PL09000<br>3056x3056<br>12x12<br>0.33 , 16.8x16.8 |

The ASV[4] is a Serbian new observational site, on the mountain of Vidojevica. So far, only one telescope is installed on the site. It is a Cassegrain type with 60 cm and 20 cm primary and secondary mirrors (see Fig. 1). Some basic characteristics of the telescope are given by Vince and Jurković (2012) and Cvetković et al. (2012). Various auxiliary instruments were provided for the ASV such as a meteo-station, seeing camera, and all-sky camera. Their characteristics and site parameters (seeing, clear nights, etc.) are given in Jovanović et al. (2012). The most frequently used CCD camera (Apogee Alta U42) is tested and described by Vince (2012), Vince and Jurković (2012). In the near future, a new 1.4 m telescope will be installed within the frame of the Belissima project[5].

[4]http://vidojevica.aob.rs

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

**Fig. 1.** *The 60 cm ASV telescope.*

**Fig. 2.** *The 2 m Rozhen telescope.*

The biggest telescope in our mini-network, with the best resolution, is the 2 m Rozhen telescope (see Fig. 2). It is a Ritchey-Chretien-Coude (RCC) system made by Carl Zeiss, Jena. The RC design gives 12″.8 per mm ($F_{\rm RC}$ = 16m), and Coude design gives 2″.8 per mm ($F_{\rm C}$ = 72m). The telescope is in operation more than 32 years; there are observations of wide class of astronomical objects from the Solar system bodies to extragalactic sources. The last modification, including automatization, were done in 2010. Now, the CCD camera attached to this telescope is a VersArray 1300B, cooled with liquid nitrogen to $-110°C$. The CCD images are of good quality. For example, the quantum efficiency (QE) is about 90% (high one in optical domain) for the Apogee Alta U42 and VersArray 1300B, peak $QE = 64\%$ for FLI PL09000, and peak $QE = 50\%$ for SBIG STL11000M. Some other performances of the VersArray 1300B are: the dark current is reduced by using a liquid – nitrogen – the cooled option for long exposures, back – illuminated, high SNR, linear response, low readout noise, ideal for low – light imaging, etc. The mean seeing is about $1''.2$ at the ASV site, and between $1''.5 - 2''.0$ at the Rozhen site.

The other two Bulgarian telescopes, which are located on relatively distant locations, are a Cassegrain type with $D$(cm)/$F$(cm)=60/750. Both of them use the same CCD camera type. The Schmidt-camera is with the biggest FoV.

## 3. OBSERVATIONS AND RESULTS

So far, we have observed several objects in the test phase of the Gaia-FUN-TO. All observers use the standard Johnson UBV and Cousins RI filters for observations. Different CCD cameras require different reduction technique. Except for the VersArray CCD camera, which is cooled down to −110°C, images of the other cameras require the standard bias, dark, and flat-fielded corrections. Additional useful corrections for data reduction are: for cosmic rays, hot/bad pixels, fringing pattern and shutter effect.

In order to provide fast observational results to the Gaia-FUN-TO, one of us (OV) developed a pipeline for the ASV data. We plan to do it for data from other instruments too. Concretely, ASV pipeline consists of 3 modules (see Fig. 3). The first one is responsible for automatized data reduction (bias, dark, flat-fielding, etc.). It is written using the IRAF[6] reduction package. The second module serves to find astrometry solution for individual data frames. It is done in Astrometry.Net[7]. Finally, Source Extractor is used for aperture photometry measurements. The output is supposed to be submitted to the Cambridge Photometric Calibration Server (CPCS) for further calibration [8]. The CPCS matches instrumental magnitudes of all stars in the field with known data from other large sky surveys (e.g. SDSS) to calibrate for standard magnitudes.

During July 2013, the first three tests were done, and the observers at the 60 cm ASV were: G. Damljanović – GD, Z. Cvetković – ZC, R. Pavlović – RP and M. Stojanović – MS; after that also O. Vince – OV. These observers are members of our Serbian team for the Gaia-FUN-TO. The objects that we observed during the Gaia-FUN-TO test phase were:

**ASASSN-13aw or SN 2013dr** (Stanek et al. 2013a), type Ia SN,
$\alpha(\mathrm{h,m,s})_{\mathrm{J2000.0}} = 17:19:30.10$,
$\delta(°,',")_{\mathrm{J2000.0}} = 47:42:03.40$.

It was discovered during the ongoing All Sky Automated Survey for SuperNovae (ASAS-SN or "Assassin"). We made our observations using B, V, R and I filters (three images per filter). The photometric data were collected (via CPCS) with a range of telescopes, instruments and filters, and all were calibrated to common pass bands of B, V, r and i using the APASS all-sky star catalogue (Wyrzykowski et al. 2013); ATel 5245[9]. The light curve of the ASASSN-13aw contains about 150 datapoints (108 points were obtained at the 60 cm ASV) and covers a range of about 30 days (our data cover about 12 days); it is available via the website.[10] Our fist observations of the ASASSN-13aw (in July 2013) were taken just one day after the detection. The peak MJD of 56491±3 was obtained using a simple parabolic fit. There are more data obtained in the beginning of August 2013 at the 60 cm Belogradchik telescope (R. Bachev) and 60 cm Rozhen one (K. Stoyanov), that are not included into the ATel 5245; the ATel 5245 appeared before that. Last observations of SN were done at the 60 cm ASV, in February 2014, but the SN was not visible any more. In Fig. 4, the ASASSN-13aw is presented (V filter, three images were combined, the bias/dark/flat reduction was made); the 60 cm ASV was used, and it was observed by the GD and MS at July 8, 2013 with the exp.time=$270^{\mathrm{s}}$.

**MASTER OT J174816.22+501723.3** (Denisenko et al. 2013), a new Cataclysmic Variable - CV (dwarf nova),
$\alpha(\mathrm{h,m,s})_{\mathrm{J2000.0}} = 17:48:16.22$,
$\delta(°,',")_{\mathrm{J2000.0}} = 50:17:23.3$.

It was found by the MASTER-Amur autodetection system. The object is identical to the blue star SDSS J174816.31+501723.3; it is present in the USNO-B and there is also an infrared counterpart in the 2MASS. The SDSS colors suggest a very small contribution from the secondary component and short orbital period. During our observations the filters B,V,R,I were used, three images per

[6] http://iraf.noao.edu/

[7] http://astrometry.net/

[8] http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Follow-up

[9] http://www.astronomerstelegram.org/?read=5245

[10] http://www.ast.cam.ac.uk/~wyrzykow/ASASSN-13aw_followup.pdf

filter, and the observers GD and MS collected 50 datapoints. At the CPCS, there are only our data. There is no ATel with our data about this target.

**ASASSN-13ax** (Stanek et al. 2013b), most likely a CV (dwarf nova) in a very strong 7 mag outburst,

$\alpha(\mathrm{h,m,s})_{\mathrm{J2000.0}} = 18:00:05.78$,

$\delta(^\circ,',")_{\mathrm{J2000.0}} = 52:56:35.3$.

It was a very bright transient. Vizier reveals an optical source with $B = 20.5$ detected $2\farcs9$ from ASAS-SN position in the USNO-B1 and also a $2\farcs8$ SDSS match to a $g = 21.2$ blue star. The filters B, V, R and I were used (three CCD images per filter); the observers GD and MS collected 19 datapoints. There is no ATel with our data about this target.

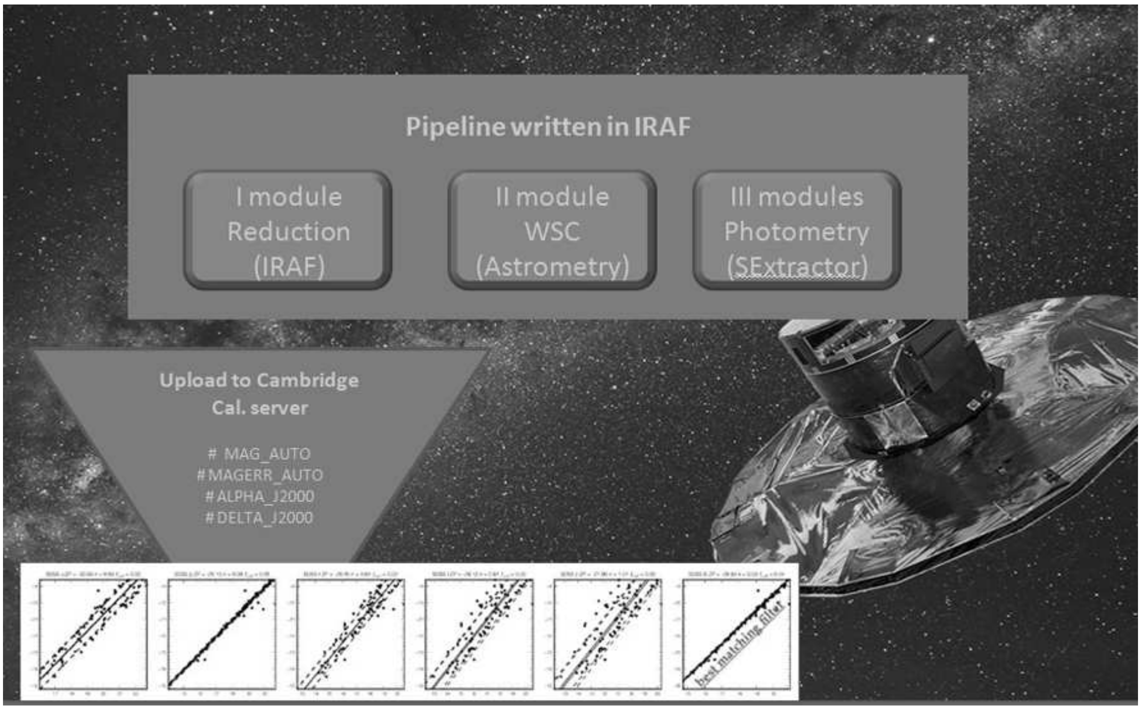


**Fig. 3.** *Pipeline for the Gaia-FUN-TO photometric observations.*

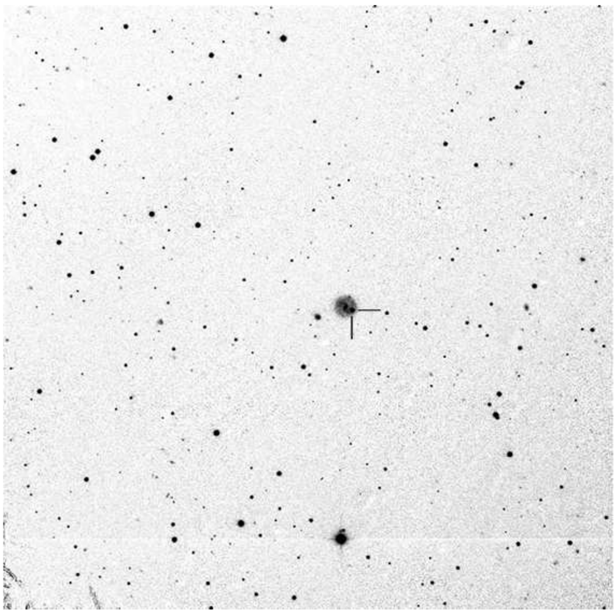

**Fig. 4.** *The SN ASASSN-13aw; FoV is* $16'$, *N-up, E-left.*

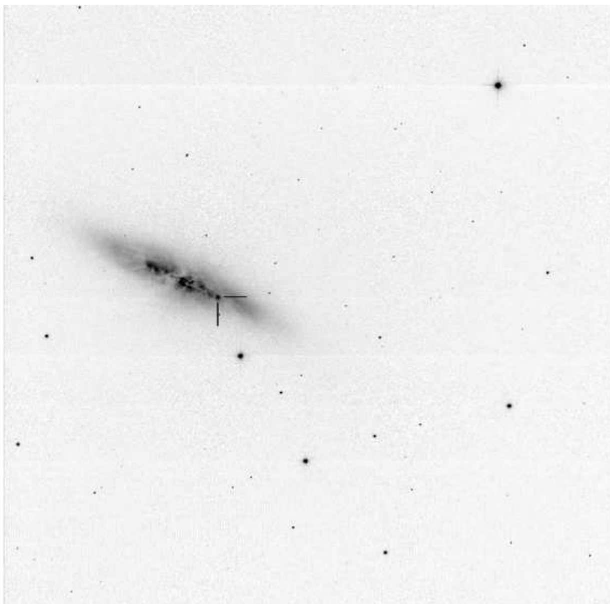

**Fig. 5.** *The SN in M82; FoV is* $16'$, *N-up, E-left.*

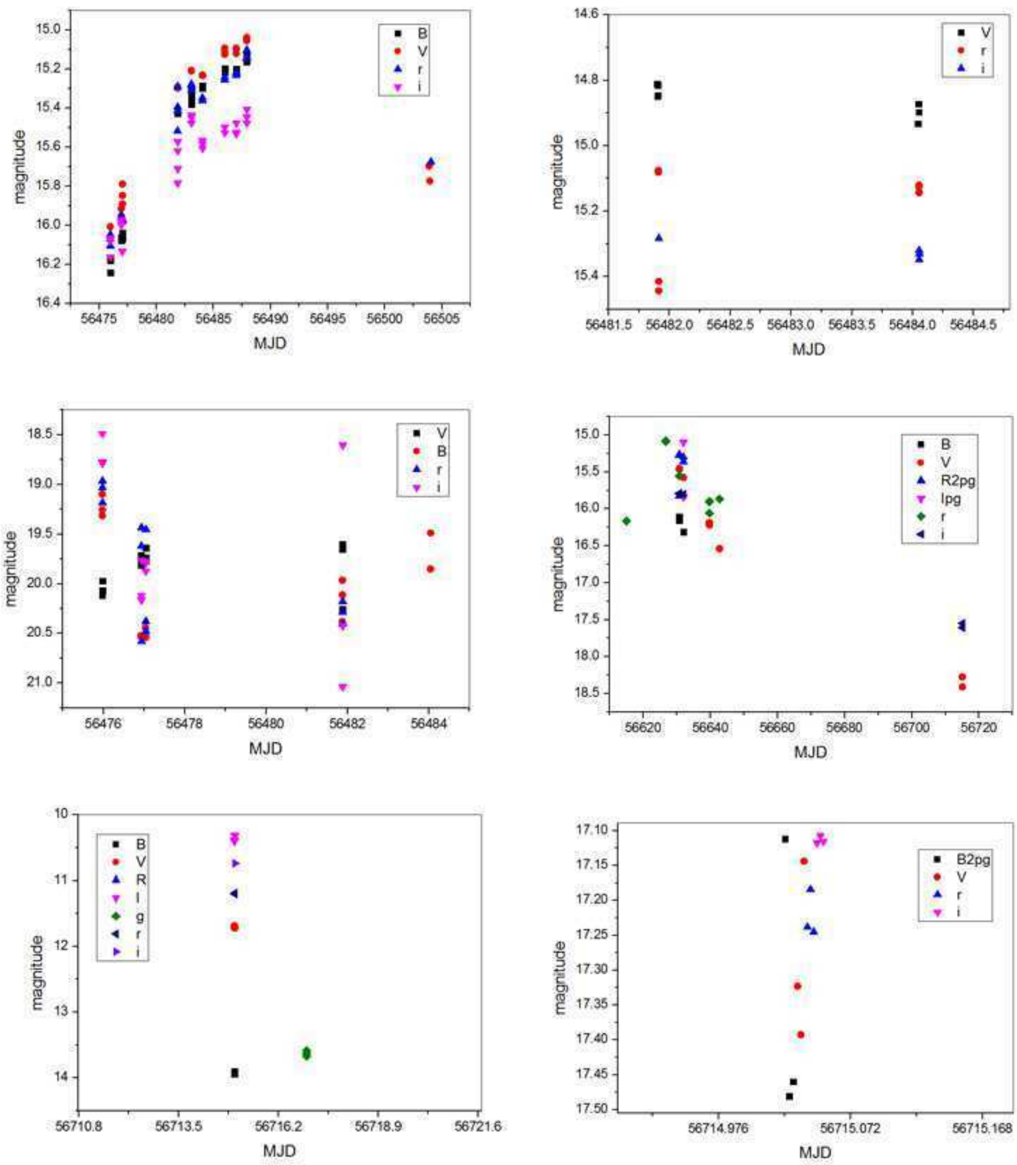


**Fig. 6.** *The lightcurves for all observed objects, using only our data: ASASSN-13aw (top, left), ASASSN-13ax (top right), OT J174816.22+501723.3 (middle, left), iPTF13ebh (middle, right), SN 2014J in M82 (down, left), and ASASSN-14ae (down, right).*

**iPTF13ebh** (Cao et al. 2013), young type Ia supernova in the nearby galaxy NGC 890 (distance 35-52.5 Mpc), $z = 0.013269$,

$\alpha(\mathrm{h, m, s})_{\mathrm{J2000.0}} = 02:21:59.98$,

$\delta(^{\circ}, ', '')_{\mathrm{J2000.0}} = 33:16:13.7$.

The filters B,V,R,I were used, three images per filter. The photometric data were calibrated to common pass bands of B, V, g, r and i using the APASS all-sky star catalogue (Wyrzykowski et al. 2014); ATel 5926.[11] The lightcurve contains about 130 datapoints (36 points were obtained at the 60 cm ASV by OV) and covers a range of about 35 days (our data cover about 2 days); it is available via website.[12] The lightcurves were found with the SALT2 filter; with parameters Peak(MJD)=56623.6 ± 4.5, etc. The model for different bands is available via the ATel 5926. Last time, GD, OV and MS performed

[11] http://www.astronomerstelegram.org/?read=5926

[12] http://www.ast.cam.ac.uk/∼wyrzykow/iPTF13ebh_followup.pdf

observations of SN at the 60 cm ASV in February 2014, but the SN was not visible.

**SN 2014J, PSN_J095542.14+694026.0** (Cao et al. 2014), a young reddened type Ia supernova in M82,

$\alpha(\mathrm{h,m,s})_{\mathrm{J2000.0}} = 09:55:42.14$,

$\delta(^{\circ},',")_{\mathrm{J2000.0}} = 69:40:26.0$.

The Si II velocity was about 20000 km/s. The best superfit match is SN2002bo at near 14d. The supernova has a red continuum and deep Na D absorption. In Fig. 5, the SN in M82 is presented (R filter – one image, without bias/dark/flat reduction); the 60 cm ASV was used, and it was observed by GD, OV and MS on February 27, 2014 with exp.time=$10^s$. For this object, we collected 27 datapoints. We continue with that Gaia-FUN-TO test.

**ASASSN-14ae** (Prieto et al. 2014), a luminous transient in SDSS J110840.11+340552.2, likely a TDE, $z = 0.0436$ (of the host galaxy, from SDSS) and the distance is about 180 Mpc,

$\alpha(\mathrm{h,m,s})_{\mathrm{J2000.0}} = 11:08:39.96$,

$\delta(^{\circ},',")_{\mathrm{J2000.0}} = 34:05:52.7$.

It is only $0\farcs18$ from the center of its host galaxy. From the Swift measurements and prediscovery imaging of the host galaxy (SDSS and 2MASS) a SED was obtained before and after the discovery which shows that the transient is quite blue. We used the B,V,R,I filters (3 images per filter); the observes GD, OV and MS were collected 12 datapoints. The observations were made at the 60 cm ASV in February 2014. There is no ATel with our data for this target until now. In Fig. 6, there are lightcurves for all observed objects (our data only).

## 5. CONCLUSIONS

Here, we present our initiative to establish a local mini-network of Serbian – Bulgarian telescopes for the Gaia-FUN-TO. As the most important outcome of this effort, we defined a joint research project "Observations of ICRF radio-sources visible in optical domain", which deals partly with the Gaia-FUN-TO. This project enables using of local telescopes, exchange of scientists, data, software, results etc. We also describe instruments used in the local mini-network with their main characteristics. Regarding instruments used in the mini–network, we may conclude that they are of a satisfactory quality for the Gaia-FUN-TO and many other astronomical purposes.

In the test phase of the Gaia-FUN-TO, we successfully observed several objects of various types (SN, CV); there are 252 our datapoints at the CPCS (moreover, there are only our data of the object MASTER OT J174816.22+501723.3). We summarize these observations and present some preliminary results; the lightcurves for all observed objects, done by using only our data, are presented in Fig. 6. For data taken at ASV we have developed a pipeline in order to be able to submit observational results faster.

Our plan is to develop, as soon as possible, the pipeline for all other instruments of the Serbian – Bulgarian mini-network. Also, we plan to publish a paper in collaboration with specialists in the field of SN, about ASASSN-13aw (at the first place) because we collected enough original data of this object during and after the Gaia-FUN-TO test period. The Belissima project is going on, and we expect a new 1.4 m telescope at the ASV site in the near future; it would be very useful for the Gaia-FUN-TO. Our collaboration with Bulgarian colleagues is going on also, with a good amount of astronomical data and results, and we plan to improve it. All instruments and results presented here are in a good accordance with the Gaia-FUN-TO. During the second part of the year we expect to have some first Gaia alerts.

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# GAIA SCIENCE ALERTS И ПОСМАТРАЧКЕ МОГУЋНОСТИ СРПСКО – БУГАРСКЕ ЛОКАЛНЕ МРЕЖЕ ТЕЛЕСКОПА

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*Стручни чланак*

Gaia астрометријски сателит (European Space Agency – ESA) успешно је лансиран 19. децембра 2013. године, а један од главних посматрачких задатака је добијање каталога са око милијарду звезда и више од пола милиона вангалактичких објеката. Квазари (quasar – QSO), као вангалактички објекти и радиоемитери, су Активна галактичка језгра (АГЈ), објекти чије координате су добро одређене (до испод угаоне мили-секунде) Very Long Baseline Interferometry (VLBI) техником. Од 1997. године квазари су објекти који дефинишу квази-инерцијални међународни небески координатни систем International Celestial Reference Frame – ICRF, због морфологије централног дела објеката у радио-домену таласних дужина, занемарљивих сопствених кретања (до десетохиљадитог дела угаоне секунде годишње), као и привидне тачкасте структуре. Компактни АГЈ објекти, видљиви у оптичком делу таласних дужина, су корисни за директно повезивање будућег Gaia оптичког координатног система са врло прецизним системом у радио-домену.

Осим поменутих главних активности, Gaia има и друге садржаје као што су пратећи програми везани за друге интересантне објекте. Међу важним Gaia фотометријским задацима је и што брже посматрачко реаговање на поједине интересантне небеске појаве које временски кратко трају, тј. обављање посматрања одређених објеката и слање резултата у року од 24 сата (што је врло захтеван посао). За те потребе ми смо развили посебан програм (тзв. pipeline). У складу са могућностима нашег новог телескопа ($D$(cm)/$F$(cm)=60/600) на новој астрономској станици (Astronomical Station Vidojevica – ASV, код Прокупља) Астрономске опсерваторије у Београду (Astronomical Observatory in Belgrade – AOB), успешно смо се укључили у Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) за 'брза' посматрања и обраду података. Поред тога, у сарадњи са колегама из Бугарске (на првом месту са СБ), ГД је иницирао стварање локалне мреже телескопа од постојећих инструмената у Србији и Бугарској, који би били корисни за Gaia-FUN-TO и друге астрономске задатке. Дајемо кратак преглед наших активности у оквиру Gaia-FUN-TO, тј. стварање поменуте мини-мреже од локалних телескопа у Србији и Бугарској (пет телескопа на три станице, ASV у Србији, и Belogradchik и Rozhen у Бугарској), као и наша тест посматрања у оквиру Gaia-FUN-TO и резултате тих посматрања.