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FIRST GAIA DATA RELEASE – DR1 AND SERBIAN-BULGARIAN ASTRONOMICAL ACTIVITIES

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Abstract. The ESA Gaia mission is surveying the full sky since July 2014 (useful data, from August 2014). It is astronomically, photometrically and spectroscopically European project. Also, it is revolution in astronomy, our understanding of the Milky Way galaxy, stellar physics, the Solar system bodies, etc. At September 2016, the first Gaia data release – DR1 has been made available using about 14 months of Gaia data. At April 2018, the second Gaia solution – DR2 appeared based on 21 months of useful Gaia observations. At the other hand, it is of importance the synergy between Gaia and ground-based astronomical observations. Because of it, the regional astronomical cooperation "Serbian-Bulgarian mini-network telescopes" was started at 2013. The main results of the Gaia DR1 (also, DR2) and mentioned cooperation are presented, here.

1. INTRODUCTION (EXPECTATIONS OF GAIA MISSION)

The GAIA (Global Astrometric Interferometer for Astrophysiscs) is a cornerstone mission of European Space Agency - ESA. The spacecraft (see Fig. 1) was launched at the end of 2013, and the start of normal operations was in July 2014, but useful data for DR2 – from August 2014. It is doing the astronomical observations during five-year nominal operations phase. Now, there is information that it will be longer than predicted five-year period.

The plan was to observe of about one billion objects in our Milky Way galaxy (astrometry, photometry and spectroscopy) and about 500 000 extragalactic sources (Prusti 2012). The goal was to produce the Gaia Catalogue in optical domain and to replace the International Celestial Reference Frame - ICRF (which is based on VLBI radio observations). Also, to measure positions with extremely precision, parallaxes at the level of accuracy far way from the ground ones, photometry for all astrometrically detected objects, in spectroscopy to get the catalogue of radial velocities for near 150 million sources, etc.

There are a lot of open questions related to our Milky Way galaxy (the structure and dynamics of the Galaxy, star formation history, etc.) which could be solved using Gaia data because Gaia is scanning the full sky with very high precision. Gaia data open many more science areas to study and explore.

In stellar astrophysics, the improvement in distances (using the improvement of parallaxes via Gaia observations) will allow to models of stars at different steps of evolution.

In the domain of binary and multiple stars, the orbital parameters could be calculated with much higher precision using the Gaia high spatial resolution.

About the exoplanets, it is expected to find several thousand systems.

In case of faint rare objects (as brown or white dwarfs), Gaia will be of importance.

Mostly, Gaia is done for stars (point objects), but also it is possible to detect solar system objects, galaxies and quasars (QSOs). It is going a massive improvement of asteroid ephemeredes, to determine the masses of the objects in some cases, etc.

It is expected to detect the few million galaxies. The QSOs are of importance for reference systems and fundamental physics.

The HIPPARCOS (High Precision PARallax Collecting Satellite), the predecessor of Gaia, with about 118 000 stars changed the astronomy at the end of last century (ESA 1997, van Leeuwen 2007), but Gaia with about 1 billion stars (and near 500 000 extragalactic sources), from milliarcsec to microarcsec astrometry (plus the radial velocities), will be a revolution in astronomy (Prusti 2012).

Two Gaia fields of view are separated by a basic angle of 106.5 degrees, and Gaia rotates around itself with a period of 6 hours; the period of the precession spin axis is 63 days. For each observed object, the plan is to collect between 40 and 250 measurements during the five-year observations (Taris et al. 2018). It is possible to read about the telescope itself, CCDs, astrometric and photometric measurements, Radial Velocity Spectrometer (for spectroscopy), scanning process, some technical parts, etc. in the paper (Prusti 2012).

2. GAIA DATA RELEASE 1

Since 14 September 2016, the first release of the Gaia catalogue (DR1) is available, as a first step of the future Gaia celestial reference frame (Gaia CRF). The optical Gaia positions of the sources will be materialization of that reference frame. Gaia CRF will be linked to the ICRF which is based on the VLBI radio observations of extragalactic sources. The Gaia is collecting data for more than one billion sources brighter than G magnitude 20.7 (the white-light photometry band of Gaia) to determine high accurate positions, proper motions and parallaxes; Gaia catalogue is main goal of that ESA mission. The number of QSOs is about 500 000. The DR1 is based on the first observational period of about 14 months, and in that catalogue there are near two million stars using Tycho-Gaia solution.

In the DR1, only data were published about flux time-series variability detection for Cepheids and RR Lyrae, but not for AGN and particularly QSOs.

In the paper (Carrasco et al. 2016) is described the principles of the photometric calibrations of the G band.

At the beginning of the XI Bulgarian-Serbian Astronomical Conference, during registration and abstract phase of conference, it was published only DR1, but just before that conference (14 - 18 May 2018 in Belogradchik, Bulgaria) the DR2 was available (at April 2018). Because of it, in this paper there is more information about DR2 than about DR1. Other information about DR1 could be found in the paper (Taris et al. 2018).

The final Gaia solution (catalogue) will be consisting of: astrometric, photometric, and radial-velocity data, variable-star and non-single-star results, object classifications with multiple astrophysical parameters for stars, QSOs, galaxies, and unresolved binaries, exo-planets, epochs and transits for all objects.

3. GAIA DATA RELEASE 2

The second release of the Gaia catalogue - DR2 was released on 25 April 2018. It is based on 21 months or 1.75 yr, 640 days with some interruptions (period 22 August 2014 – 23 May 2016) of Gaia operational phase, even the start of astronomical observations was in July 2014. The first month of Gaia observations was not included in DR2 solution because of not enough quality of these data.

That catalogue contains results for 1.693 billion sources in the magnitude range 3 to 21. For 1.332 billion sources there are the five astrometric parameters: positions, proper motions, and parallaxes. The reference epoch is J2015.5 = JD 2457206.375 TCB = 2 July 2015 at 21:00:00 TCB, and it is about half-way through the observational period used in the DR2 solution (that epoch is 0.5 yr later than the DR1 one). Because of it, there are some differences in positional data between DR1 and DR2 releases. The reference epoch was chosen to get minimal correlations between the positions and proper motions. The positions and proper motions refer to the ICRS.

Also, there are the approximate positions for an additional 0.361 billion mostly faint objects (Lindegren et al. 2018). The DR2 is publicly available in the online Gaia Archive (https://archives.esac.esa.int/gaia).

The catalogue DR2 is independent because it does not include any other astrometric data (Hipparcos or Tycho ones), in contrast of the DR1 which is the Tycho-Gaia astrometric solution (Lindegren et al. 2016). All sources are reduced as single stars (as in DR1 solution) and the results are presented by the five astrometric parameters.

The results of some binary stars refer to the photocentre (in case of unresolved binaries) or to either component (for resolved ones).

The main steps of astrometric solution (models, algorithms, etc.) are described in Lindegren et al. (2012), but there are some additions since 2012.

In DR2, there is the color information for most of the sources using the photometric processing of data via the blue BP and red RP photometers (van Leeuwen et al. 2017).

The astrometric calibration parameters of the CCDs were determined using an astrometric solution for 16 million selected objects (about 1% of the input data), and via QSOs (as extragalactic sources) the primary solution was linked to the ICRS. After that, the astrometric parameters of other sources were calculated (Lindegren et al. 2018).

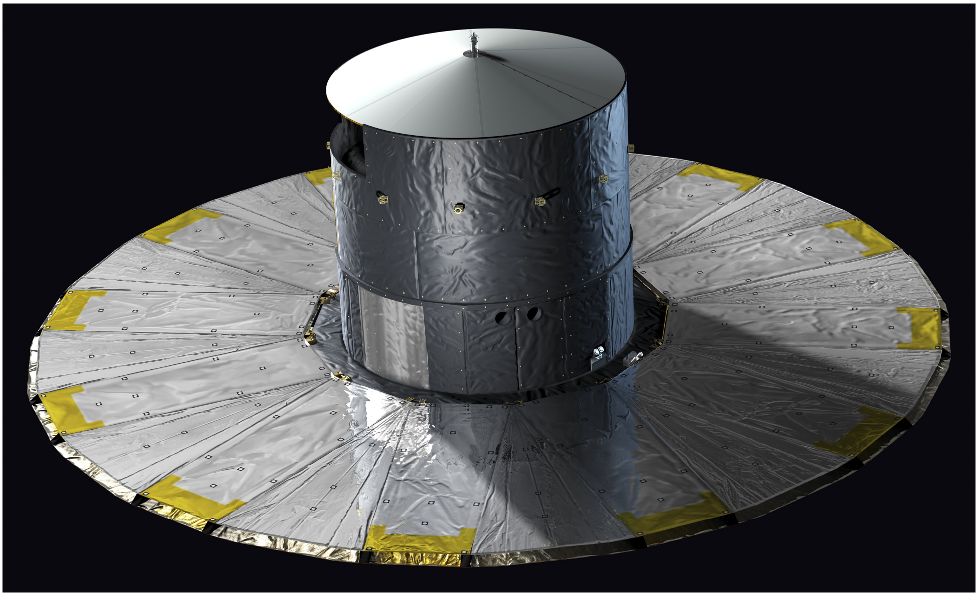

Figure 1: The Gaia spacecraft or space telescope (artist's impression).

For bright sources (G < 14 mag), the median uncertainty is near 0.04 mas in parallax and position (at J2015.5 – reference epoch of DR2). For G=17 mag, it is 0.1 mas, and 0.7 mas in the case of G=20 mag. About the proper motions, there are 0.05 mas, 0.2 mas, and 1.2 mas, respectively.

The optical Gaia DR2 CRF is aligned with ICRS. It is non-rotating to within 0.15 mas per year with respect to the QSOs (Lindegren et al. 2018).

The systematic in the parallaxes are less than 0.1 mas (depending on positions, magnitude, and color).

A consistent theory of relativistic astronomical reference systems was used during the processing of Gaia data (Soffel et al. 2003). The Barycentric Celestial Reference System – BCRS is the primary coordinate system: the origin is at the solar system barycentre, the axes are aligned with the ICRS, the barycentric coordinate time – TCB is the time-like coordinate of the BCRS.

In DR2 solution is not included non-linear motions (as it is in the case of binary stars, other perturbations, etc.), but the future Gaia releases will include these motions (Lindegren et al. 2018). In DR2, only the uniform space motion (of the source) relative to the solar system barycentre was considered.

So, the Gaia-CRF2 is the celestial reference frame of Gaia DR2; it is aligned with ICRS and non-rotating with respect to the distant objects (QSOs). There are 2843 sources – mostly QSOs (as the optical counterparts of VLBI radio sources) in a prototype version of ICRF3. The prototype ICRF3 catalogue (unpublished, 2017) contains 4262 sources with accurate VLBI radio positions. For ICRF3, the IAU Working Group “Third Realisation of ICRF” is responsible.

As it was a case of DR1, in DR2 there are only photometric data as time-series for Cepheids and RR Lyrae (the objects with unstable flux), but not for QSOs.

About the Gaia DR3 (next solution), it is planed for the first half of 2021. That improved astrometry and photometry solution will be consisting of: mean Vr velocities for stars without detected variability, object classification and astrophysical parameters (BP/RP and RVS spectra for spectroscopically objects), with the epoch photometry it will be variable-star classifications, Solar-system results (preliminary orbital solutions, individual epoch observations), non-single star catalogues, etc.

Figure 2: The 1.4 m telescope (left) with new dome (right) at ASV.

4. SERBIAN-BULGARIAN ACIVITIES IN LINE WITH GAIA MISSION

Our observational activities and investigation about the Gaia mission and Serbian-Bulgarian cooperation in line with Gaia tasks stated after the installation of the fist instrument, the 60 cm telescope (Fig. 4), at the Serbian new site (see

Fig. 5), the Astronomical Station Vidojevica – ASV. The ASV belongs to Astronomical Observatory in Belgrade – AOB (http://vidojevica.aob.rs), and it is close to Prokuplje city (southern Serbia, see Fig. 5). That installation was done in 2011. Since mid-2016, there is another ASV instrument via Belissima project (see http://belissima.aob.rs), 1.4 m ASV telescope (see Fig. 2, the telescope itself and new dome).

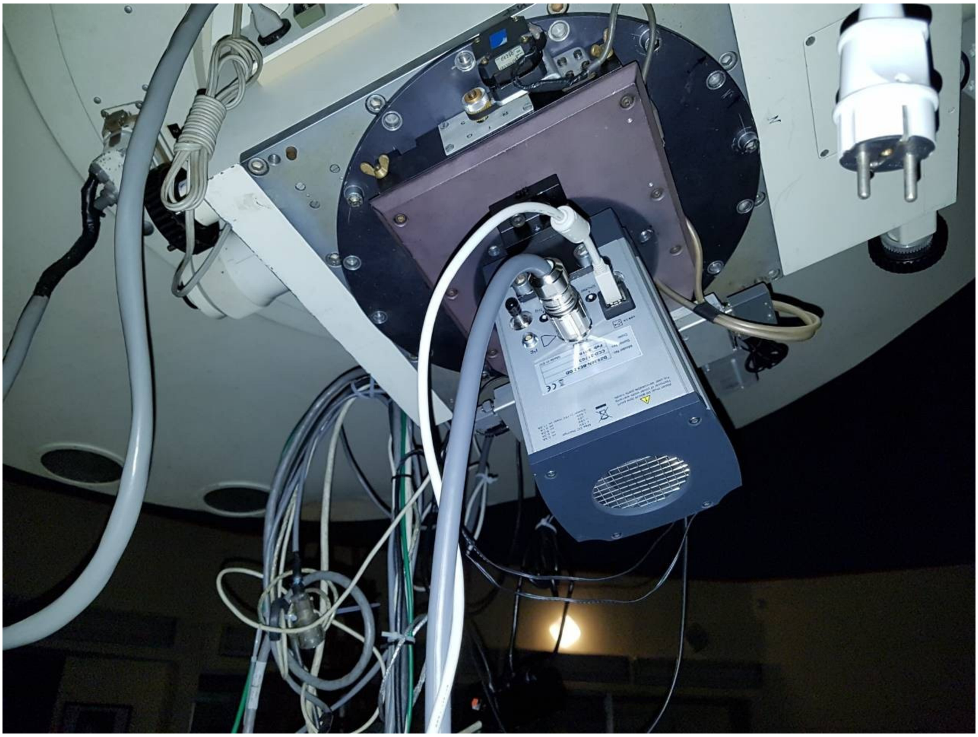

Figure 3: The 2 m telescope (NAO Rozhen)
with new CCD camera Andor iKon-L.

At two Bulgarian sites (see Fig.5), Belogradchik and Rozhen,, there are another 4 instruments of our interest. In Belogradchik, it is the 60 cm telescope. And at the Rozhen Observatory there are three instruments: the Schmidt – camera 50/70 cm, 2 m (see Fig. 3) and 60 cm telescopes. Using these 6 telescopes (Damljanović, Vince and Boeva 2014; Damljanović et al. 2018; Damljanović, Taris and Andrei 2018; Taris et al. 2018) we established astronomical cooperation "Serbian-Bulgarian mini-network telescopes" in 2013 (head – G. Damljanović). The 2 m Rozhen telescope and its new CCD camera Andor iKon-L (Fig. 3) have new features: 2048x2048 pixels, the pixel size is 13.5x13.5 mkm, 0.176 arcsec per pixel, FoV=6.0x6.0 arcmin. That camera was put on the instrument at April 2018.

Our activities about the Gaia tasks are in accordance with the bilateral Serbian-Bulgarian joint research project "Observations of ICRF radio-sources visible in optical domain" during three years period 2014-2016, and new one "Study of ICRF radio-sources and fast variable astronomical objects" for the period 2017-2019; the head is G. Damljanović. Both projects are in the framework between the Serbian Academy of Sciences and Arts – SASA (or SANU on Serbian language) and Bulgarian Academy of Sciences - BAS.

Figure 4: The 60 cm telescope at ASV.

About the future Gaia reference frame, the QSOs optical flux variations were investigated using our original observations of QSOs (in the period 2013-2015) by mostly the TAROT telescopes, 60 cm ASV and other instruments (Taris et al. 2018). The mentioned Gaia reference frame will be materialized by the optical positions of the objects. And it will be linked to the ICRF (based on the VLBI radio positions of mostly QSOs). First at all, it is necessary to investigate flux variability of QSOs because the unstable flux can indicates some changes in the source structure which is of importance for position of the target photocentre (it means, for position of the object and results of Gaia astrometry). Also, it is possible the evolution in time of these centers. It could produce consequences for mentioned link. Some magnitude variations of 47 objects (Bourda et al. 2008, Bourda et al. 2011), mostly QSOs, which are suitable for the link are presented in our papers (Taris, Damljanović et al. 2018). These papers are based on the 60 cm ASV data (and other telescopes ones), and reports on some implications for the Gaia catalogue.

The sites ASV, AO Belogradchik and Rozhen Observatory (or National Astronomical Observatory – NAO of BAS) are presented on the picture of Serbian-Bulgarian region (see Fig. 5).

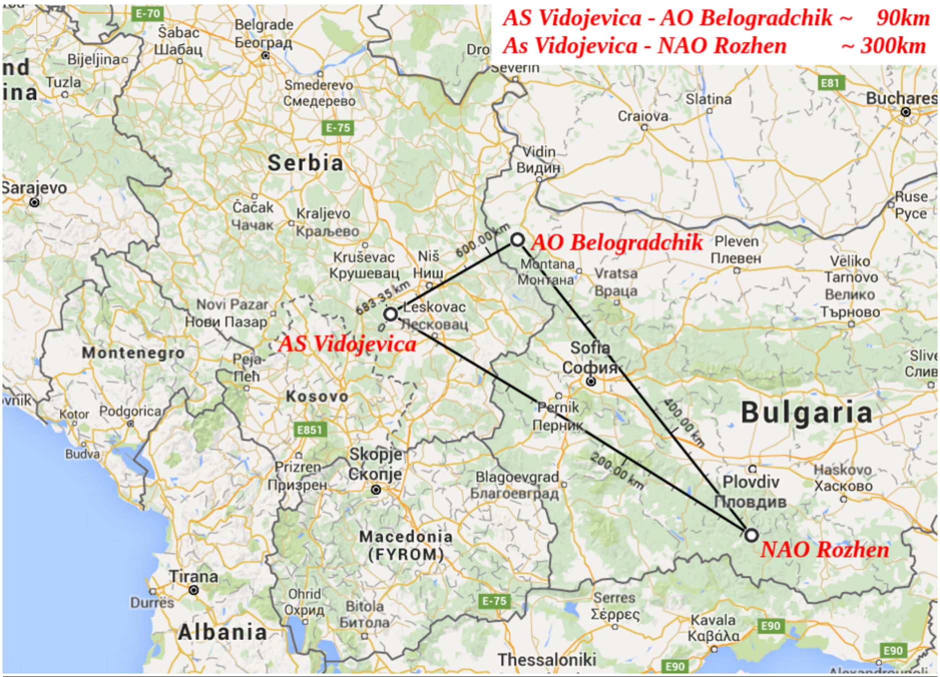

Figure 5: The ASV, Belogradchik and Rozhen astronomical sites.

The Gaia astrometry is the main part of our investigation in accordance with Serbian-Bulgarian cooperation, but it is the Gaia Alerts, also. During three years period, October 2014 – October 2017, we observed about 45 objects (near 1650 CCD images) of the Gaia Alerts or Gaia-Follow-Up Network for Transients

Objects (Gaia–FUN-TO) using mentioned 6 telescopes. It is about 15 objects per year (near 550 CCD images). Some results were presented at few conferences, and there are few published papers (Campbell et al. 2015, Damljanović et al. 2014). We are doing with the Johnson BV and Cousins RcIc filters. Mostly, the 60 cm ASV telescope was used. Opposite, no data from 60 cm telescope of NAO Rozhen during last few years, because it was under reconstruction until the summer this year. We hope, it will be some observations in the domain of Gaia Alerts, soon.

At Serbian-Bulgarian sites, the seeing is between 1.0 and 3.5 arcsec. The mean value at ASV is 1.2 arcsec, and it could be 0.7 arcsec at Rozhen and ASV. It is possible to observe the objects until about 20 mag in V-filter by using the 2 m of NAO Rozhen and 1.4 m at ASV telescopes (if the exp. time is near 5 min), and until 19 mag using smaller instruments.

5. CONCLUSIONS

The second Gaia solution contains a vastly increased number of sources in comparison with Gaia DR1. These sources have full astrometric data (proper motions and parallaxes, also). The data of bright sources (it means, G is until 12 mag) were included already in DR1, but the results in DR2 are generally more accurate. The results of DR2 are fully independent of the Hipparcos and Tycho catalogues. The Gaia CRF2 (reference frame) is defined by Gaia data of QSOs; also, the optical counterparts of VLBI objects in a prototype solution of the ICRF3.

Random and systematic errors are still higher than can be expected for the final solution, because the astrometric results in Gaia DR2 are based on about 2 years of observations. Also, calibrations are very preliminary, and there are possibilities for improvements (Lindegren et al. 2018). It means, there are some investigations to do for the next DR3 solution. Other job to do, in DR2 all objects beyond the solar system are treated as point sources and it is necessary to improve in the reduction model. The next limitation of DR2 is about unresolved binaries where the photocentre was calculated instead of each separate star of the system. The systematic errors are mainly based on the analysis of QSOs data, and it is a part for improving Gaia DR3.

About our activities in line with Gaia: we established the cooperation “Serbian-Bulgarian mini-network telescopes” in 2013, together SANU-BAS projects, we did some investigation in accordance with Gaia astrometry (Taris et al. 2018), Gaia Alerts or Gaia-FUN-TO (Campbell et al. 2015, Damljanović et al. 2014), etc. The old SANU-BAS project was “Observations of ICRF radio-sources visible in optical domain” during three years period 2014-2016, and new one is “Study of ICRF radio-sources and fast variable astronomical objects” for the period 2017-2019. During three years period (October 2014 – October 2017) we observed about 45 Gaia Alerts Objects or near 1650 CCD images. It is about 15 objects per year or near 550 CCD images.

The Gaia is continue its five–year period of observations (that period is going to prolong), and we continue our observational activities and investigation in line with that very important ESA mission.

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