SOME PRELIMINARY PHOTOMETRIC RESULTS OF QSOs USEFUL FOR THE LINK BETWEEN FUTURE GAIA CRF AND ICRF

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ABSTRACT. Gaia was launched in December 2013 as cornerstone mission of the European Space Agency (ESA). It is going to map the entire sky (over one billion stars) and more than 500,000 quasars (QSOs); all objects with apparent V band magnitudes in the range $5.6 < V < 20$ (Mignard 2014). During its 5-year lifetime it will produce a unique time-domain space survey. The main result will be a dense optical QSO-based Gaia Celestial Reference Frame (Gaia CRF). So, the high accuracy link between future Gaia CRF and International CRF (ICRF) will be of importance. About 90% of the ICRF sources are not suitable for that link (they are not bright enough in optical domain, they have significant extended radio emission, etc.), but there are other (candidate) sources – weak extragalactic radio sources (ERS) with bright optical counterparts which we need to investigate. Some candidate sources were already imaging by VLBI, and some sources were detected as useful ones on VLBI scales. Also, the astrophysical processes could produce displacements of the optical photocenter of these objects, and because of it the variations of their light curves are important first information to check candidate sources for establishing the link of reference systems. Our observations of 47 candidate objects were carried out more than one year in the B, V and R bands using the $D = 0.6$ m new telescope at the Astronomical Station Vidojevica (ASV, of Astronomical Observatory in Belgrade, Serbia). Some preliminary photometric results are presented as a part of astrophotometric and astrophysical investigations of ERS in the framework of the reference systems. Also, some photometric results following from the data obtained by using the TJO (Telescopi Juan Oró, $D = 0.8$ m) in OAdM (Observatori Astronòmic del Montsec, Spain) are presented.

1. INTRODUCTION

After the Hipparcos (ESA 1997, van Leeuwen 2007), Gaia is the next European space astrometric mission. One of the main results of the Gaia mission (of the European Space Agency – ESA) will be a new optical Gaia Celestial Reference Frame (Gaia CRF). The Gaia CRF will be based on bright quasars (QSOs) with the most accurate coordinates, and will supersede the current International CRF (ICRF) which is based on Very Long Baseline Interferometry (VLBI) radio data. For the high accuracy link (until a few tens of μas,) between two mentioned frames, the extragalactic radio sources (ERS) with optical counterparts are of importance, but only 10% of the ICRF objects are suitable for that link. This means a new set of sources should be defined and tested (Bourda et al. 2010, 2011; Taris et al. 2011, 2013; Petrov 2011, 2013). Good candidates are: the distant ERS, with negligible proper motions, bright enough in the optical domain (with V magnitudes up to about 18), compact structures, etc. For now, the optical – radio shift (about 150 μas at X-band) is nearly ten times larger than VLBI and Gaia position accuracies (a few tens of μas at V magnitudes 15–18).

The photometric monitoring of candidates (mostly QSOs) is the first step for their testing, because the flux variability is one of the most important properties of QSOs. The relationship between QSO's morphology, magnitude variability and astrometry is described in the paper (Popović et al. 2012). So, the morphology and photometry variations of common QSOs (visible in optical and radio domains) could make displacement of their optical photocenters. Because of that, since 2010 a set of 47 objects has been already monitored to measure their flux variability. Here, we present some preliminary photometric results of the ASV (Astronomical Station Vidojevica, Astronomical Observatory in Belgrade, $D = 0.6$ m, Serbia) data from mid-2013 and TJO (Telescopi Juan Oró, Observatori Astronòmic del Montsec, 0.8m, Spain) ones.

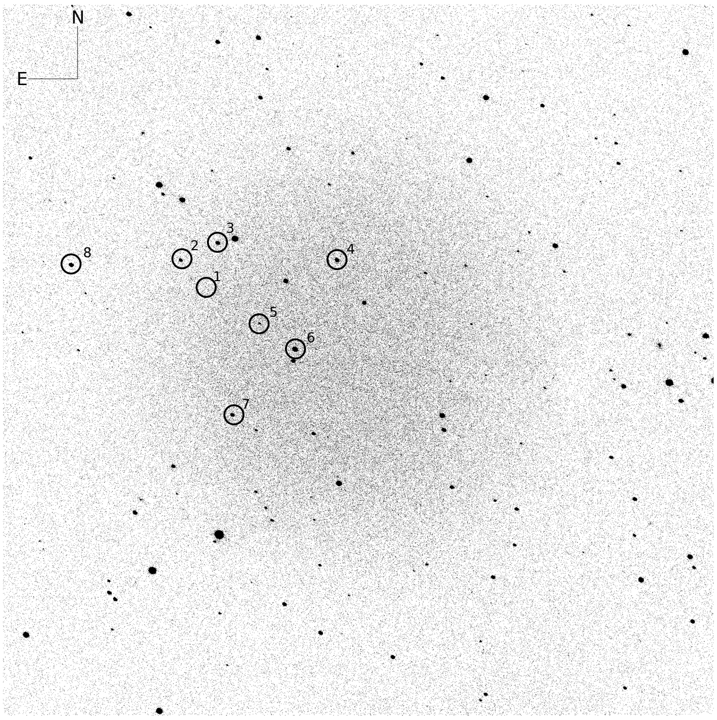

Figure 1: Object 1535+231 (number 1) and calibration stars (2-8); FoV=16′, the 60 cm ASV telescope.

2. OBSERVATIONS AND RESULTS

It has been noted that ERS are not point-like objects and that their morphology and photometry are changing with time; that fact is of importance for Gaia astrometry. So, it is necessary to monitor the ICRF sources at both optical and radio wavelengths. Also, to check the candidate sources (first of all to do it via photometric monitoring).

That photometric monitoring of mentioned 47 objects is under progress using a few telescopes. From mid-2013 we have done it with the 60 cm ASV instrument ($D/F = 0.6m/6m$, long.=21.5°, lat.=43.1°, h=1150 m) and the CCD camera Apogee Alta U42 (2048x2048 pixels, pixel size is 13.5x13.5 μm, scale is $0.''46$ per pixel, FoV=15.8′x15.8′). We present particularly some photometric results for the object 1535+231, obtained with the ASV telescope, in Fig. 2 (usually, one point per a few months). The seeing is in general about $1.''5$, but during our observations in July and September 2013 it was better than $1''$. The filters Johnson BV and Cousins R were used, and we made 3 frames per filter. All frames were reduced individually (dark, bias, flat, hot/death pixels), and the MaxIm DL image processing packages were used for reduction and photometry (relative to the available reference stars, see Fig. 1). Because of very close relationship between astrophysics and astrometry of QSOs (for Gaia mission), we apply the differential photometry and use the secondary standard stars to get small error (about 0.1 mag) of B, V, R magnitudes of object. The calibration stars are from SDSS catalogue (Abazajian et al. 2009), because there is a lack of standard stars with BVRI magnitudes for differential photometry of mentioned QSOs. And to calculate the BVRI magnitudes from *ugriz* ones, the Chonis and Gaskell (2008) transformations were used, within a magnitude range $14.5 < g, r, i < 19.5$:

$B = g + (0.327 \pm 0.047)(g - r) + (0.216 \pm 0.027)$

$V = g - (0.587 \pm 0.022)(g - r) - (0.011 \pm 0.013)$

$R = r - (0.272 \pm 0.092)(r - i) - (0.159 \pm 0.022)$

$I = i - (0.337 \pm 0.191)(r - i) - (0.370 \pm 0.041)$.

We found about 60% of 47 objects in SDSS DR10. For other objects we plan to use the Two Micron All Sky Survey (2MASS) catalogue. The systematic errors of these calibrations stars (local errors, instrumental ones, their flux variability, etc.) were checked via our own data (3 or 4 epochs during about one year observations) in accordance with the rejection criterion that we set to 3σ value; σ is in line with dispersion of our data.

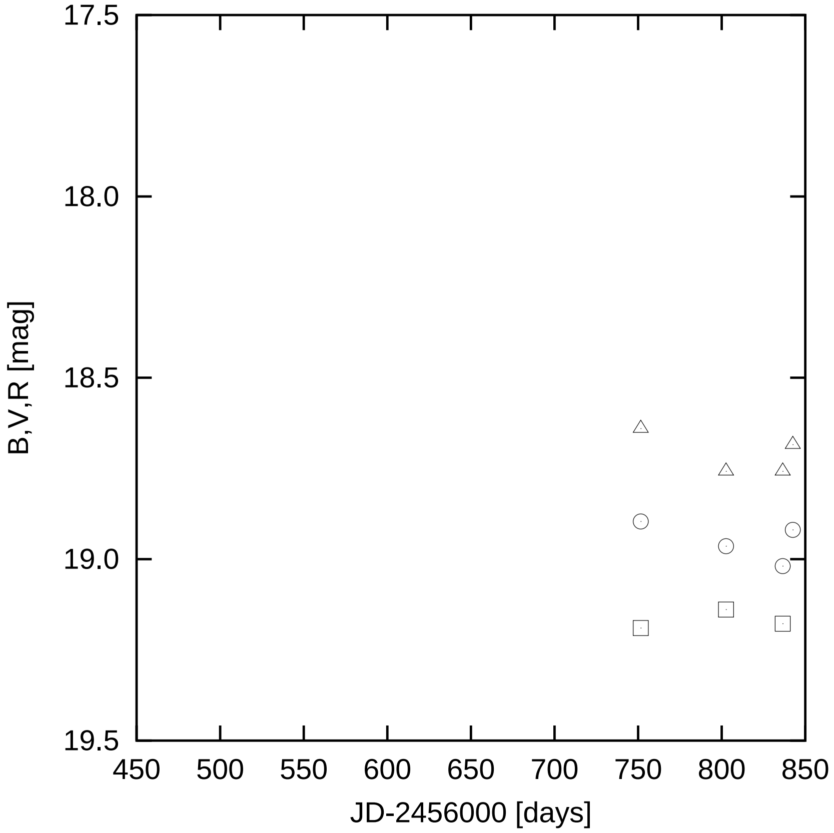

Figure 2: The values of B(square), V(circle), R(triangle) magnitudes of object 1535+231; the 60 cm ASV telescope (April 3^{rd} – July 3^{rd} 2014).

Also, the flux variability of QSOs can be simply checked by comparison to other stars which are close to the object. The differences of magnitudes in R filter between the object 1535+231 and stars (relative to the star A and to the star B) using TJO observations are presented in Fig. 3 (one point per day). From both data sets (ASV and TJO), there are some photometric changes of object 1535+231 during the time, but we need more data for final conclusion about the flux stability of that object.

3. CONCLUSION

Since 2010, the optical observations of 47 objects, mostly QSOs, are going on for their photometry monitoring (to check the flux variability of QSOs) using several telescopes. These QSOs could be useful for an accurate link between the future Gaia CRF and ICRF. Some results obtained with the 0.6 m ASV and 0.8 m TJO instruments are presented. With the 60 cm ASV telescope, we joined that monitoring since mid-2013.

Using the transformations (Chonis and Gaskell 2008) and *ugriz* magnitudes from SDSS we get the BVR ones for calibration stars near QSO (for about 60% of mentioned objects). From our data, these input BVR magnitudes of secondary comparison stars were checked for some systematics (flux variability of stars, local errors, instrumental ones, etc.), and used to determine the BVR magnitudes of QSOs via differential photometry (see Figs. 1 and 2 for the object 1535+231, one ASV point per few months). In Fig. 3 (one TJO point per day), the flux variability in R filter of QSOs is presented; it was simply checked by comparison to other stars which are close to the object. From both sets of data (ASV and TJO), some

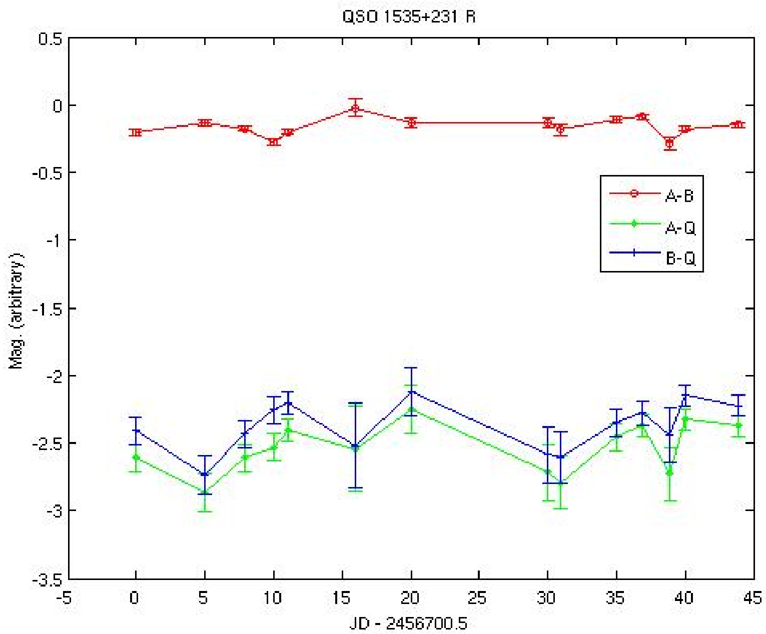

Figure 3: Photometry results (in R filter) for object 1535+231 using data of the 0.8 m TJO.

photometric changes for object 1535+231 during the time are noticeable, and we continue monitoring of that object.

Even some problems during observations of QSOs (optical faintness of QSOs, atmospheric influences, technical problems, etc.), with both instruments we could produce the data which are good enough for photometry investigation and in line with the link between the future Gaia CRF (optical) and ICRF (radio) frames.

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