# OPTICAL DATA OF ERS OBTAINED AT 60 cm ASV AND 2 m ROZHEN TELESCOPES USEFUL FOR THE LINK OF ICRF – GAIA CRF

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ABSTRACT. After the GAIA observations (ESA mission) a new optical celestial reference frame (CRF) will be provided which will replace the Hipparcos one. CRF will be dense and based on QSOs (quasi stellar objects). The plan for Gaia is to survey stars and QSOs brighter than 20 mag; it means, about 500 000 extragalactic sources (ERS) and billion stars of our galaxy. Till now, only nearly 10% of the International Celestial Reference Frame (ICRF) objects (about 70 common sources) are useful for the link between VLBI (radio) and future Gaia (optical) frames with the highest accuracy. It is because some sources are not optically bright enough, and some of them are not point-like ones but extended sources; the extended sources are not suitable for Gaia astrometric accuracy. So, it is necessary to detect, observe and determine the astrometric positions of common sources in both (optical and radio) domains. For the purpose of mentioned aligning the radio and optical frames, we need as much as possible additional optically bright QSOs (with magnitudes up to 18 and compact structures). The morphology and photometry variations of common QSOs make displacement of their optical photocenters. That displacement could be critical for this link. For morphology investigations, we also included the observations of QSOs made during the period 2011-2013 at the RCC telescope (of Rozhen National Astronomical Observatory, Bulgarian Academy of Sciences); the CCD camera VersArray 1300B was used, and $D/F = 2/16$. For photometry investigations, we use, among others, the 60 cm ASV telescope (Astronomical Station Vidojevica of Astronomical Observatory in Belgrade, Serbia); the CCD is Apogee U42, and $D/F = 0.6/6$. We present particularly some data obtained at these telescopes.

## 1. INTRODUCTION

The active galactic nuclei (AGN) objects (quasars, blazars, Seyfert galaxies, etc.), as extragalactic sources (ERS) at cosmological distances, have been treated as stable and point-like objects. Because of it, in 1997 (during XXIII GA of IAU in Kyoto) the realization of a quasi-inertial celestial reference frame was done by a set of positions of these objects; the International Celestial Reference Frame (ICRF) was established. ICRF is the first realization of the International Celestial Reference System (ICRS) via the positions of 608 ERS (and 109 added ones) estimated through Very Long Baseline Interferometry (VLBI) observations at $S/X$ radio wavelengths (or frequencies of 2.3 GHz and 8.4 GHz). Out of these objects 212 are defining ones. ICRF2 appears as the second realization of ICRS (Fey et al., 2009). It was adopted on line with the IAU resolution in 2009 (XXVII GA of IAU in Rio de Janeiro). In ICRF2 there are the VLBI precise positions for 3414 compact radio astronomical sources, and 295 ones are defining sources.

Recently, it was noted that ERS objects are not point-like ones, and their morphology and photometry are changing with time. These effects with their evolution make displacement of optical photocenters and position instabilities of the radio center of ERS, and they are the limiting factors for defining ICRF. The position stabilities of ERS are very important for ICRF, and it is necessary to monitor the ICRF sources at both optical (Aslan et al., 2010) and radio wavelengths. Optically bright sources without extended VLBI features are good for the alignment between the VLBI and Gaia frames; one third of the ICRF sources are with an optical counterpart (brighter than 18 mag), and only 10 % of the ICRF sources (70 ones) are compact enough on VLBI scales and with mentioned optical counterparts. So, it is necessary to identify more suitable objects (Bourda et al., 2010, 2011).

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Based on data collected with 2 m RCC telescope at Rozhen National Astronomical Observatory.

Unlike Hipparcos (ESA, 1997; van Leeuwen, 2007), the Gaia CRF will cover directly the optical domain. It will be based on bright QSOs with the most accurate coordinates. For good aligning ICRF2 (VLBI frame) – future Gaia CRF and the highest accuracy of targets we need consistency between radio and optical coordinates. It is necessary to pinpoint the relative position of the radio and optical emission in AGN with accuracy until a few tens of $\mu$as, but for now we see that the optical – radio shift ( 150 $\mu$as at X-band) is nearly ten times larger than VLBI and Gaia position accuracies (a few tens of $\mu$as at magnitudes 15-18); that shift is the problem for the link between the two frames. To average out the mentioned effects we need a large number of objects. Also, the gravitational microlensing could make a long – term optical variability in AGN. Other limiting factors for linking the reference frames are: the presence of a host galaxy (around the nucleus of the object), the distance of the AGN, the optical magnitude variation, the size of the emission region, structural modifications in the optical domain, etc. (Taris et al., 2013). Among others, using the 2 m Rozhen telescope we observe the objects for morphology and with the 60 cm ASV one for photometry investigations (Damljanović and Milić, 2012). We present particularly the main properties of these telescopes and some data in the next section.

## 2. OBSERVATIONS AND RESULTS

The optical observations of QSOs were carried out with telescopes located at different sites. Figure 1 shows the distribution of instruments. These telescopes are suitable for observations of QSOs which are interesting for morphology and photometry investigations. On line with Serbian – Bulgarian cooperation and the follow-up network for the Gaia photometric alerts we established the local mini-network of five telescopes at three sites (Rozhen and Belogradchik in Bulgaria, and Vidojevica in Serbia). According to the mentioned ICRF – Gaia CRF link and up to now, we have used three telescopes (which are in the list presented in Figure 1): the 60 cm ASV telescope (Astronomical Station Vidojevica of Astronomical Observatory in Belgrade), the 2 m RCC telescope at Rozhen National Astronomical Observatory (Bulgarian Academy of Sciences), and the 60 cm Rozhen one. We have mostly used the 2 m Rozhen instrument and the 60 cm ASV one (the 60 cm Rozhen just for a few objects), but it could be useful to include also the 60 cm instrument (the Belogradchik Astronomical Observatory) and the 50/70 cm Schmidt – camera.

The 2 m Rozhen telescope ($D/F = 2/16$, long.=24.7$^o$, lat.=41.7$^o$, h=1730 m) is useful for morphology investigation of QSOs. There are the observations from 2011 until now. The detector is the CCD camera VersArray 1300B: 1340x1300 pixels, pixel size is 20x20 $\mu$m, scale is 0.26 arcsec per pixel, FoV=5.6x5.6 arcmin. The seeing is from 1.5 arcsec to 3.5 arcsec, but during our observations in October 2013 it was very good (around 1 arcsec). The filters are Johnson UBV and Cousins RI. At Figure 2, as an example of morphology investigation using GALFIT analysis and data of 2m Rozhen telescope, a total of 4 optical counterparts of ERS were presented: 1144+402, 1219+044, 1252+119, and 1800+440.

The 60 cm ASV telescope ($D/F = 0.6/6$, long.=21.5$^o$, lat.=43.1$^o$, h=1150 m) is suitable for photometry investigation of QSOs. It has been in operation since mid-2011. In 2012 we started to collect the data with this instrument. The CCD is Apogee Alta U42: 2048x2048 pixels, pixel size is 13.5x13.5 $\mu$m, scale is 0.46 arcsec per pixel, FoV=15.8x15.8 arcmin. The seeing is in general about 1.5 arcsec, but during our observations in July and September 2013 it was better than 1 arcsec. The filters are the same as at the 2 m Rozhen telescope. By using the 2 m Rozhen telescope it is possible to catch a target brighter than 20 mag, and until about 18 mag with the 60 cm ASV telescope. During our observations in September 2013, with the 60 cm ASV we used the CCD SBIG-ST-10 XME (2184x1472 pixels, 6.8x6.8 $\mu$m, 0.23 arcsec per pixel, FoV=8.4x5.7 arcmin, and an adaptive optics – AO) successfully because that camera is for high resolution imaging. At the 60 cm Belogradchik telescope (long.=22.7$^o$, lat.=43.6$^o$, h=650 m) it is the CCD FLI PL09000, at the 50/70 cm Schmidt – camera (Rozhen) it is the CCD FLI PL16803, and at the 60 cm Rozhen instrument it is the CCD FLI PL9000.

During observations, we made 3 frames per filter, and used B, V, and R filters per object. The corrections for apparent displacements did not applied (Aslan et al., 2010; Kiselev, 1989) because of small field of view (FoV of 2 m Rozhen telescope is 5.6x5.6 arcmin and of 60 cm ASV it is 15.8x15.8 arcmin). All frames were reduced individually (dark, bias, flat, hot/death pixels) and after that the stacking (of 3 frames) was applied. The temperature of CCD VersArray was $-110^o$ C and because of it the dark was not applied.

The MAXIM DL and IRAF image processing packages were used for photometry, relative to the available reference stars. As photometry example, we present the results (magnitudes of B, V and R filters) of the object 1101+384 (Mkn 421) observed with the 60 cm and 2 m Rozhen telescopes during the same night (at April 2013):

- B filter (60 cm Rozhen), 12.330±0.057 at JD2456397.26922, 12.496±0.028 at JD2456397.27996, 12.618±0.035 at JD2456397.34190, 12.445±0.017 at JD2456397.43249, 12.570±0.089 at JD2456397.52857,
- B filter (2 m Rozhen), 12.530±0.006 at JD2456397.32750, 12.548±0.016 at JD2456397.45614,
- V filter (60 cm Rozhen), 12.033±0.031 at JD2456397.27155, 12.065±0.010 at JD2456397.28437, 12.152±0.013 at JD2456397.34631, 12.056±0.005 at JD2456397.43690, 12.135±0.060 at JD2456397.53006,
- V filter (2 m Rozhen), 12.172±0.005 at JD2456397.32969, 12.170±0.005 at JD2456397.45854,
- R filter (60 cm Rozhen), 11.786±0.005 at JD2456397.27388, 11.789±0.007 at JD2456397.28878, 11.851±0.016 at JD2456397.35072, 11.780±0.005 at JD2456397.44131, 11.848±0.025 at JD2456397.53154,
- R filter (2 m Rozhen), 11.801±0.005 at JD2456397.32235, 11.801±0.005 at JD2456397.46106.

Both set of presented results (made with 60 cm and 2 m Rozhen telescopes) are consistent between each other. During April 2013, the similar results were calculated using data done with 60 cm ASV telescope. We sent these data to the international center of WEBT program (Whole Earth Blazar Telescope) because that object is also on the WEBT list and it was very active during April 2013.

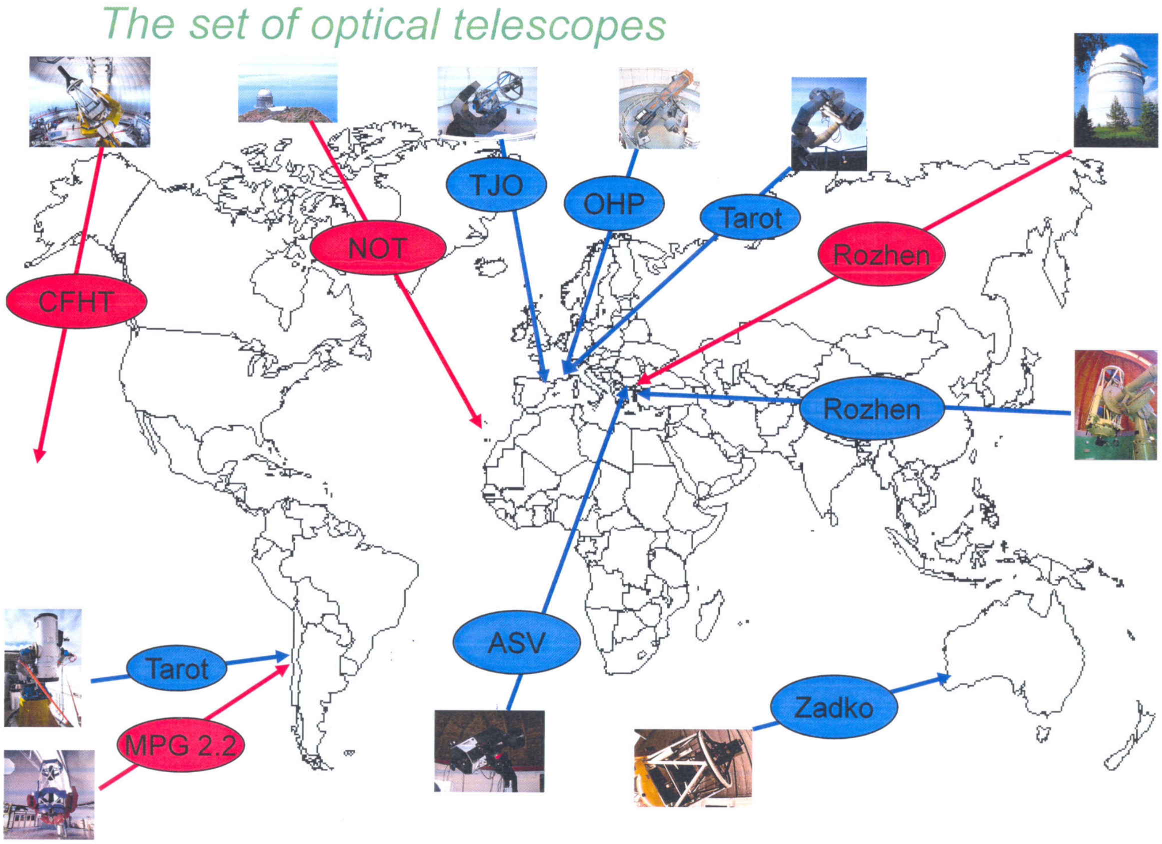

Figure 1: The optical telescopes for observations of QSOs (in line with morphology and photometry investigations of QSOs).

## 3. CONCLUSION

The optical observations of QSOs are possible by using 2 m Rozhen telescope and a good CCD camera, and useful for morphology investigations. Also, the data made with the 60 cm ASV telescope are good for photometry investigations. So, with both instruments we could produce the data which are good enough for the link between ICRF (radio) and Gaia CRF (optical) frames. Some problems (during observations and reductions of ERS visible in optical domain) can be caused by: faintness of the optical counterparts to ERS, atmospheric influences, technical problems, etc.

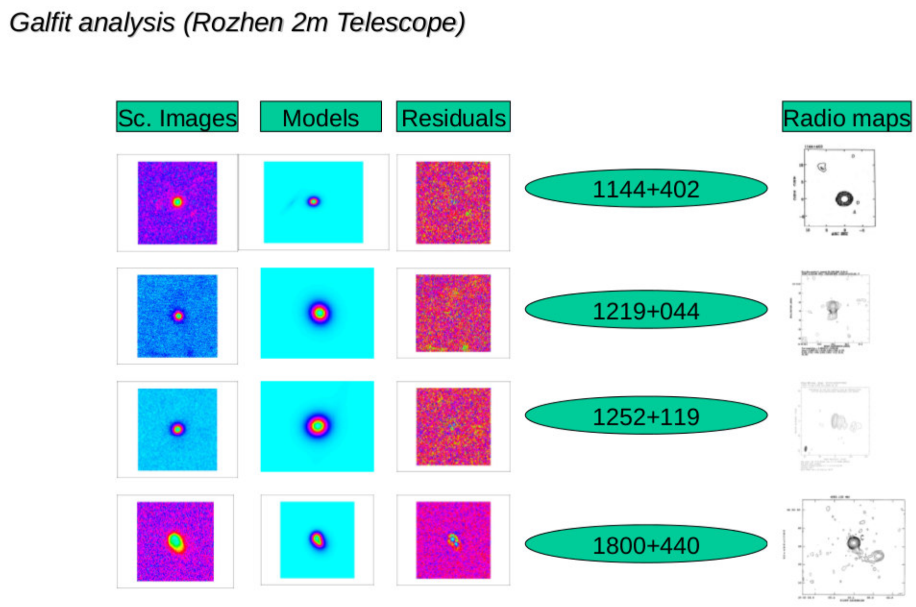

Figure 2: Some morphology results obtained by using GALFIT analysis (the objects 1144+402, 1219+044, 1252+119 and 1800+440 were observed with 2m Rozhen telescope).

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