Morphology of some quasars suitable for the link between ICRF and future Gaia-CRF

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(Submitted on 30.09.2019. Accepted on 27.12.2019.)

Abstract. A current International Celestial Reference Frame (ICRF) is realized by precise coordinates of extragalactic radio sources observed with Very Long Baseline Interferometry (VLBI). Gaia Celestial Reference Frame (Gaia CRF) should be a future reference frame based on observations of ESA's satellite Gaia in the optical domain. A very important step of modern astrometry will be aligning these two reference frames with the highest accuracy. For that task, the objects of importance are these ones which are visible in both the radio and optical domains. We observed objects from the ICRF list of radio sources visible in the optical domain which could be suitable for the mentioned alignment with the future Gaia CRF. Because of this, it is necessary to study photometry and morphology of "link objects" to get axes stability of the Gaia frame as much as possible. We present our first results of studying the morphology using our original CCD astronomical observations of quasars (QSOs) from the ICRF list. To obtain the results, the GALFIT software was used. The observations of QSOs were done using the 1.4 m telescope at Astronomical Station of Vidojevica (ASV) in Serbia.
Key words: astrometry, reference system, quasars

Introduction

Gaia is a European Space Agency's (ESA) mission to make a three-dimensional map of the Milky Way. It's main task is to provide positions, parallaxes, and proper motions of about one billion stars with very high accuracy. Also, other information as photometry, radial velocity, etc is available. The satellite Gaia was launched in December 2013. Among others, it will provide an astrometric catalog of about 500000 extragalactic sources (mostly quasars - QSOs). Quasars have no detectable proper motion on the level of 0.1 mas/yr, so they could materialize quasi-inertial directions in space of reference frame. They form the basis of a current International Celestial Reference Frame (ICRF3 - 3^{rd} release from the beginning of 2019). Gaia observations of QSOs are optical and will lead to the realization of a new reference frame in the optical wavelengths – Gaia Celestial Reference Frame (Gaia CRF).

The ICRF is based on the observations of QSOs using the Very Long Baseline Interferometry technic (VLBI) in the radio domain. Among the QSOs observed with Gaia at optical wavelengths are objects with accurate positions obtained from VLBI observations. The Gaia CRF needs to be aligned to the ICRF, so these common objects (QSOs visible in both radio and optical domains) are used as a link between the frames.

From 717 main ICRF radio sources, only about 70 (about 10%) have good astrometric quality (Bourda et al., 2008) for being candidates for link objects. More information about the selection criteria of these objects, so-called "link objects", and other included objects (outside ICRF list) for linking the task can be found in Bourda et al., (2008). Mostly, these criteria

are in line with astrometric stability of the individual ICRF radio sources, no extended radio structure, the optically-bright ICRF objects with the highest Gaia accuracy, etc. The optically-bright ICRF sources are with an optical counterpart brighter than apparent V magnitude equal to 18. From this initial list of objects, about 40 are visible from our ASV location and we have been observing them since December 2017. As far as morphology is concerned, suitable objects should be point-like because it will provide a high level of accuracy and stability of their coordinates (Taris et al., 2013, 2016). This paper is dedicated to the morphology of the objects, so we present the main steps of the procedure for determining the morphological parameters for two of them.

1. Instruments and results

For investigating the morphology of QSOs, we are using the 1.4 m telescope Ritchey - Chrétien at the Astronomical Station Vidojevica (ASV of Astronomical Observatory in Belgrade - AOB) with CCD cameras Apogee Alta U42 and Andor iKon-L. The field of view (FoV) and pixel scale of the Apogee Alta U42 are: $FoV = 8.3X8.3$ arcmin, and 0.243 arcsec, respectively. Using the Andor iKon-L, they are: $FoV = 8.3X8.3$ arcmin, and 0.244 arcsec, respectively. The geographic coordinates of ASV are: longitude $\lambda = 21.5^oE$, latitude $\varphi = 43.1^oN$ and altitude $h = 1150m$. The Ritchey - Chrétien telescope (RCT or RC) is a specialized Cassegrain telescope that has a hyperbolic primary and secondary mirrors designed to eliminate off-axis optical errors.

Here, we present observations of QSOs 0300+470 and 1039+811. The images are calibrated with MaxIm DL software version 5.15; also, hot and dead pixels are removed. GALFIT is a software design to model objects as they appear in two-dimensional images by using parametric functions (Peng at al, 2002). The two mentioned objects are classified as blazars. We determined a PSF model (which is used to fit the point source objects). After that, the GALFIT was run on the input CCD image of the object, and we provide input PSF. The input image of QSO for GALFIT was a square section about $10''X10''$ (or $40X40$ pixels) of the original image of QSO 0300+470 ($15''X15''$, or $60X60$ pixels in the case of QSO 1039+811). We chose the convolution box to be of the same size as the input image. The Source Extractor software was used to obtain the initial morphology parameters (position, sky value, initial magnitude value, etc.). We provide input PSF by extracting it from an image using selected stars (see Fig. 1) with IRAF task DAOFIND.

Three images are presented (see Figs. 2 and 3): the original QSO image (left figure), the model one - here PSF model was determined as useful one (middle figure), and the residual image (right figure). The residual image was constructed by subtracting the model from the original image. If the residual image is flat after applying a PSF model we assume that the model is good, and there is no detectable host galaxy. Also, it is of importance that the formal errors of coordinates are small. Here, the Sérsic model was one of the possibilities, but the PSF one is more suitable in the presented cases (0300+470 and 1039+811): the residual image is flat, and the formal

errors of coordinates (see Table 1) are small. It means, that these kind of objects (with PSF model) could be useful for modern astrometry, and the mentioned alignment of the future Gaia CRF with ICRF. The objects with complex structure (in line with Sérsic model, PSF + Sérsic model, etc.) are not suitable for astrometry, because their photo-centers are not point-like. So, "link objects" should be inspected for their structure (to investigate the presence of host galaxy, for example) using some software such as GALFIT.

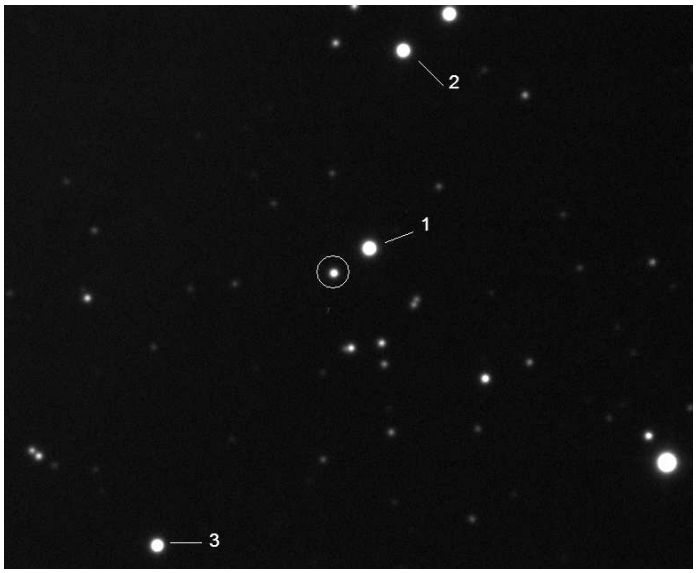

Fig. 1. Object 0300+470 (marked with circle, BL Lac type, E is left and N is up) in R band with stars (1, 2, and 3) used to extract a PSF.

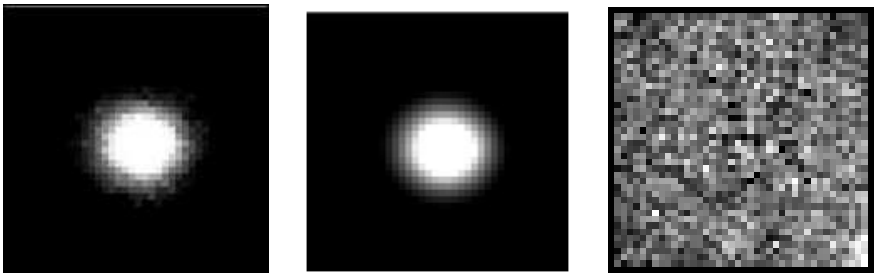

Fig. 2. Input image $10'' X 10''$ or $40X40$ pixels in R band (left one) of QSO 0300+470, GALFIT model PSF (middle), and residual image (right).

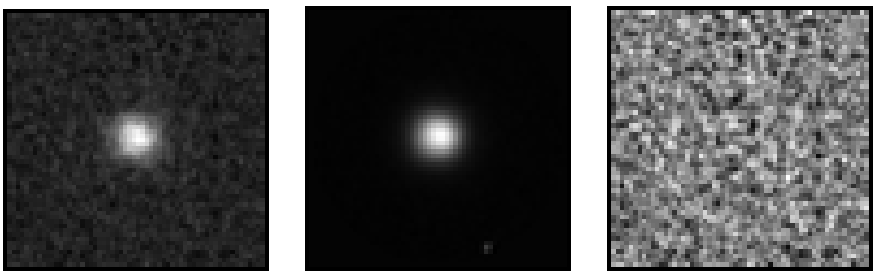

Fig. 3. Input image $15'' X 15''$, or $60X60$, pixels in R band (left one) of QSO 1039+811, GALFIT model PSF (middle), and residual image (right).

The PSF model has three parameters: x_c, y_c (coordinates of the center in pixels) and magnitude (R-band, here). In Table 1, the morphological parameters for QSOs 0300+470 and 1039+811 with suitable formal errors are presented. For astrometry, of importance are x_c and y_c. The value of R-band magnitude should be compared with the relative photometry value (using comparison stars) and the consistency between the two has to be investigated.

Table 1. Morphological parameters for QSOs 0300+470 and 1039+811 with formal errors.

Object, Model	x_c	y_c	R-band (mag)
0300+470, PSF	21.60 (0.03)	21.26 (0.03)	16.68 (0.01)
1039+811, PSF	30.79 (0.06)	31.12 (0.07)	18.12 (0.02)

Conclusion

Our first results for QSOs 0300+470 (see Fig. 2) and 1039+811 (see Fig. 3) show that morphologically they are point-like sources and, as far as that is concerned, they could be suitable for aligning ICRF3 and Gaia CRF. The residual image is flat, and the formal errors of x_c and y_c are small; this means that the PSF model is useful and there is no presence of a host galaxy (i.e. it is not necessary to introduce Sérsic or a more complex model). It is of importance to investigate the photometry of these objects for further analysis. Currently, we are investigating morphology for a dozen objects from ICRF list using observations from December 2017 up to now. For future work, we will compare our results concerning the morphological parameters with other papers and studies.

Acknowledgments: G. Marković gratefully acknowledges the observing grant support from the Astronomical Observatory in Belgrade. This work is a part of the project No. 176011 ("Dynamics and kinematics of celestial bodies and systems") supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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