Bulgarian – Serbian collaboration: CCD observations of visual double and multiple stars and extragalactic radio sources

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Abstract. The Serbian-Bulgarian cooperation concerning the study of visual double and multiple stars started in 2004 with CCD observations of such objects, and in 2011 was extended to observations of extragalactic radio sources visible at optical wavelengths. Here we present a brief overview of the most interesting results obtained during our collaboration. Begun as a regional Balkan project, this cooperation in 2012 was continued in the form of a bilateral cooperation between the Bulgarian Academy of Sciences and Serbian Academy of Sciences and Arts.
Key words: double and multiple stars, extragalactic radio sources

Introduction

Systematic observations of double and multiple stars have been carried out for about 200 years. Their study makes possible more accurate determinations of masses and distances, as well as a better understanding of stellar formation and evolution. The results of measurements have been collected and the corresponding database is kept by the United States Naval Observatory. The Washington Double Star Catalogue (WDS)[3] has been constantly updated and contains the data for more than 117000 pairs, but the orbital elements have been obtained for a small number of them. With CCD observations it is not possible to resolve systems with small separation between the components. Closer pairs are monitored using high angular resolution techniques such as speckle interferometry, adaptive optics, etc. Wide stellar systems have large orbital periods in general. For many of them there are no many observations, the observations cover a short orbital arc or they have a low accuracy.

During last few years, we started CCD observations of quasi stellar objects, QSOs, visible in the optical domain in accordance with the tasks of the astrometric mission Gaia. QSOs, as one type of objects with active galactic nuclei (AGN), having a compact radio and optical core, without complex structures and stable flux, are of interest to Gaia. This is the reason for monitoring such QSOs in the optical domain, and to follow the changes of their morphology and photometry over time. The position stability of QSOs depends on the structures and photometry of QSOs and it makes the morphology and photometry investigations of these objects very important for astrometry and astrophysics. These observations are used for construction of the relation between radio and optical reference systems. The observational results concerning AGN objects can be used to study their physical features. Our observations are part of a more general project of astrophotometric and astrophysical studies of extragalactic radio sources for the purpose of obtaining more reliable reference systems.

[3] http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS

1. Observations

Observations of double and multiple stars have been carried out at the Astronomical Observatory of Belgrade for more than 60 years. Since 2004 till now a group of astronomers from Belgrade Observatory have visited many times the National Astronomical Observatory Rozhen (NAOR) in Bulgaria and taken frames of visual double and multiple stars. Series of observations have been made with a CCD camera attached to the 2-m telescope. Only during the observations made in 2004 the CCD camera Photometrics CE200A was used. All later observations have been performed with the CCD camera VersArray 1300B. Until now we have received 11 series of observations of the above mentioned stars. A total of 767 pairs were measured (during the first seven series of observations). The results: position angles, angular separations, orbital and linear solutions, have been published in Pavlović et al. [2005], [2013], Cvetković et al. [2006], [2007], [2010], [2011]. The measurements of the frames obtained in 2012 and in 2013 are to be published soon.

From June of 2011 the first CCD observations of double and multiple stars with the 60 cm telescope from the new Astronomical Station on the mountain of Vidojevica (ASV)[4] were started. During the autumn of 2011 we observed the same objects at both NAOR and ASV. We noticed that the measured separations (ρ_{NAOR}, ρ_{ASV}) differ for the same pairs of stars and the differences increase with increasing angular separation. Therefore, we measured the angular separations between the images of stars visible in our CCD frames. The separation depends on the angle corresponding to one pixel, i.e. the focal length of the telescope. The result of determining the focal length of the 60 cm telescope at the ASV more precisely is given in the paper Cvetković et al. [2012b], and for the 2 m NAOR telescope in the paper Cvetković et al. [2013].

From 2011 until now, we have observed more than 150 QSOs at NAOR. Preliminary results were reported at several conferences and some papers were published (Damljanović and Milić [2012], Damljanović et al. [2012]).

In 2012 we started CCD observations of AGNs in line with the WEBT (Whole Earth Blazar Telescopes) program. With the telescopes of NAOR and ASV about 10 WEBT objects have been observed. We sent our photometry data to the international center in Turin Observatory.

2. Results

Using only our observations we analyzed a multiple system registered in ADS - Aitken Double Stars catalogue (Aitken [1932]) - as ADS 48. Its number in the Washington Double Star Catalog is 00057+4549. Our aim is to establish which of the seven components are gravitationally bound, i.e. have an orbital motion around the mass center, and which of them are mutually very distant in space so that only their projections are close in the field of view. We used the measuring results from our CCD frames obtained between 1994 and 2011. The first CCD frames of ADS 48 multiple system at our disposal were obtained in 1994 (Popović and Pavlović [1997]). We also obtained frames of this system at NAOR in 2004, 2005, 2006, 2010 and 2011, as well as three times at ASV

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

in 2011. The selected CCD frames obtained from 1994 to 2011 are presented in Figure 1.

The detailed analysis of the system ADS 48 is given in the paper Cvetković et al. [2012a]. The conclusions combined with the criteria based on celestial mechanics lead us to the following: i) within the system ADS 48 only stars A and B are gravitationally bound; ii) component F has common proper motion with A and B, but is not bound to them; iii) all other components considered here form optical pairs with AB.

We also analyzed the system WDS 06092+6424 = MLB 259. It was discovered by Milburn in 1922 and until now there are 9 measurements only. The measurement from 1922 was made by using micrometer. Seven photographic measurements were made at Pulkovo Observatory from 1971 to 1994. The ninth measurement was made by the authors of this paper in 2011 by using CCD camera VersArray 1300B at NAOR. The apparent magnitudes of the components are 10.9 and 11.2 according to WDS. The spectral type and parallax are not known. The measurements show a linear trend and we are the first who calculated the linear solution for this pair. In conclusion it could be said that this is most likely an optical pair.

We analyzed one more pair, WDS 03342+4837 = BU 787 AB. This pair belongs to a multiple system. It was discovered in 1881 and denoted as BU 787 AB. The components D and E were discovered later. The apparent magnitudes of the components for pair AB are 7.38 and 11.9, i.e. the magnitude difference of the components has a large value ($\Delta m = 4.52$). Until now there are 17 measurements for this pair and they cover a short orbital arc (less than 70°). The first orbit was calculated (Erceg [1984]) from the first 13 measurements obtained until 1958. Erceg found 400.22 years for the orbital period P and $2''.861$ for the semi-major axis a. These orbital elements and the new Hipparcos parallax yield $2600\mathcal{M}_\odot$ for the total mass of the system. This is an unrealistic value. Four measurements were performed after 1958, of which the last one was performed at NAOR. These measurements enable us to recalculate the orbit. Even a bigger value of the total mass is obtained from our orbital elements although our orbit better fits the measurements (see Figere 3) than the previously published orbit. All measurements show a linear trend and we are the first who calculated the linear solution for this pair. Additional analysis indicated that it is most likely an optical pair.

Our optical observations of extragalactic radio sources (quasars, galaxies, BL Lac, active galactic nuclei, etc.) represent a contribution to international efforts to verify and refine the relation between the Hipparcos celestial reference frame (optical) and International celestial reference frame (ICRF2, the radio one) by using different telescopes and methods. As an example we present here the CCD frame of QSO 0309+411 made with the 2 m Rozhen telescope in October 2013 (Figure 4). It was done in a "crowded" field, but the mentioned object is very interesting because its host galaxy can be seen in the frame. Its magnitude is $m_v = 16.5$ and the galaxy has a Seyfert 1 spectrum and redshift $z = 0.134$. There is no information in the SIMBAD database either for its morphology or for variability. In the study of this object, i.e. the determination of its morphological indices and monitoring the stability of the time series of the indices, the GALFIT and IRAF software are currently applied.

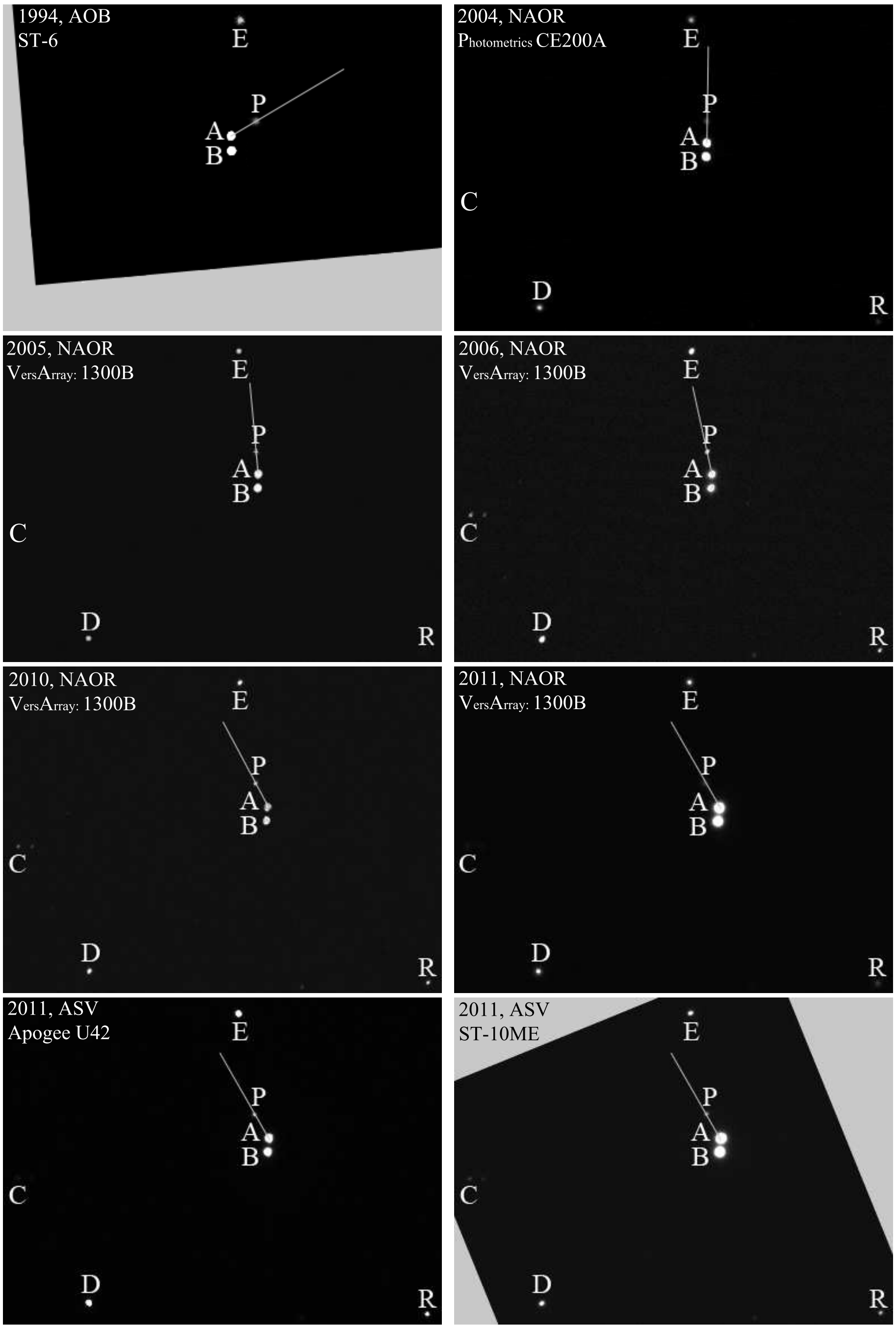

Fig. 1. CCD frames of system ADS 48 obtained from 1994 to 2011 with different cameras and instruments. The straight line shows the relative motion of AP pair as compared to other stars in the field of view. Published in AJ, 2012 - Cvetković et al. [2012a].

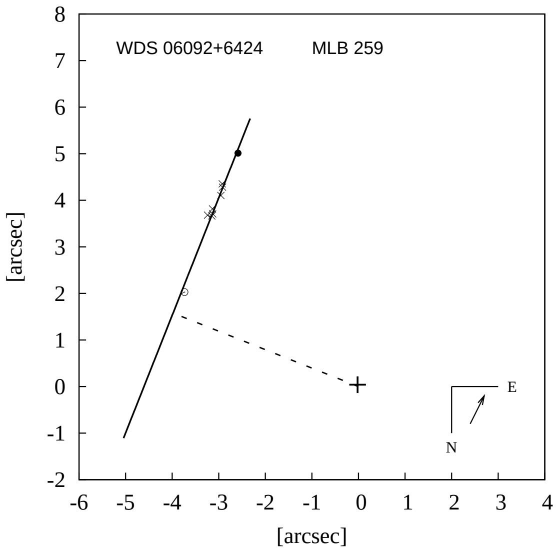

Fig. 2. Linear fit for pair WDS 06092+6424 = MLB 259: the arrow at the lower right corner indicates the direction of relative motion of the secondary; the dashed perpendicular line from the linear fit to the origin indicates the closest relative separation. The micrometric observation is represented by open circle, the photographic measurements are represented by "×" sign and our CCD measurement is denoted by filled circle. The position of the primary is denoted by "+" sign. Published in AJ, 2013 - Pavlović et al. [2013].

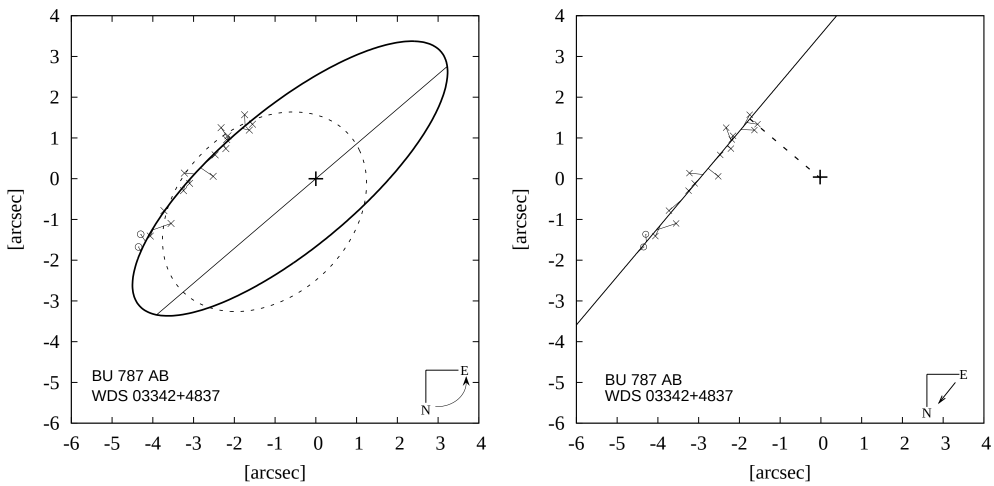

Fig. 3. Left: our orbit (solid curve) and Erceg's orbit (dashed curve) for the pair BU 787 AB. The solid straight lines indicate the line of nodes. All measurements are connected with their predicted positions on our orbit by "$O - C$" lines. The micrometric observations are represented by "×" sign and CCD measurements are denoted by open circle. The position of the primary is denoted by "+" sign. Right: our linear fit for this pair. Published in AJ, 2011 - Cvetković et al. [2011].

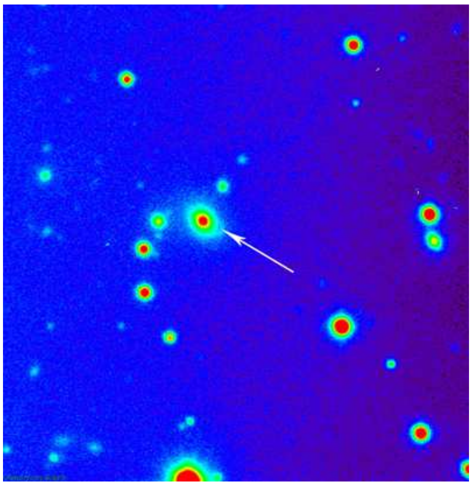

Fig. 4. Reduced CCD frame of QSO 0309+411 (noted by arrow) obtained in October 2013 made with the 2 m Rozhen telescope.

We send the reduced CCD data concerning QSOs to the international center at the Paris Observatory.

3. Conclusion

From 2004 until now we have obtained several thousand CCD frames of double and multiple stars at NAOR. The data were published and sent to the international databases. There is a small number of pairs for which the star images were not visually separated and the measurements could not be carried out. The reasons are the proximity of the components and the limiting capabilities of the CCD camera and seeing.

Also, from 2011 until now we have obtained several hundred CCD frames of extragalactic radio sources. The data have been sent to the international centers.

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References

Aitken, R.G., 1932, New General Catalogue of Double Stars, (Carnegie Inst. Washington, Publ. 417) (ADS)

Cvetković Z., Novaković B., Strigachev A., Popović G.M., 2006, *Serb. Astron. J.*, 172, 53

Cvetković Z., Pavlović R., Strigachev A., Novaković B., Popović G.M., 2007, *Serb. Astron. J.*, 174, 83

Cvetković Z., Pavlović R., Boeva S., 2010, *Serb. Astron. J.*, 180, 103

Cvetković Z., Pavlović R., Damljanović G., Boeva S., 2011, *AJ*, 142, 73

Cvetković Z., Pavlović R., Ninković S., Stojanović M., 2012a, *AJ*, 144, 80

Cvetković Z., Pavlović R., Boeva S., Damljanović G., 2012b, *BAJ*, 18(1), 56

Cvetković, Z., Damljanović, G., Pavlović, R., Vince, O., Milić, I.S., Stojanović, M., 2012c, *Serb. Astron. J.*, 184, 97

Cvetković, Z., Damljanović, G., Pavlović, R., 2013, *PASRB*, 12, 135

Damljanović, G., Milić, I.S., Maigurova, N., Martynov, M., Pejović, N., 2012, *Publ. Astron. Obs. Belgrade*, 91, 191

Damljanović, G., Milić, I.S., 2012, *Proc. of Journees 2011 "Earth rotation, reference systems and celestial mechanics: Synergies of geodesy and astronomy"*, 92

Erceg, V., 1984, *Bull. Obs. Astron. Belgrade*, 134, 54

Pavlović R., Cvetković Z., Olević D., Strigachev A., Popović G.M., Novaković B., 2005, *Serb. Astron. J.*, 171, 49

Pavlović R., Cvetković Z., Boeva S., Vince O., Stojanović, M., 2013, *AJ*, 146, 52

Popović, G.M., Pavlović, R., 1997, *A&AS*, 123, 487