Proceedings of the VIII Serbian-Bulgarian Astronomical Conference (VIII SBAC)
Leskovac, Serbia, May 8-12, 2012,
Editors: M. S. Dimitrijević and M. K. Tsvetkov
Publ. Astron. Soc. "Rudjer Bošković" No 12, 2013, 135-142

MORE ACCURATE FOCAL LENGTH DETERMINATION FOR THE ROZHEN 2 m TELESCOPE

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Abstract. The focal length of a telescope is an important parameter in determining the relative coordinates (angular separation and position angle) of double and multiple stars, as well as in determining the precise coordinates of extragalactic radio sources visible in optical part of wavelengths. With the 2 m telescope of National Astronomical Observatory at Rozhen we have collected a large number of observations of these objects. To determine the telescope focal length more accurately for attached detector, we used angular-separation measurements from CCD images. The obtained focal length is $F = (15774 \pm 21)$ mm using the CCD camera VersArray 1300B attached to the telescope.

1. INTRODUCTION

The telescope focal length is an important parameter in determining the angular pixel size. It is used for the purpose of determining the relative coordinates (angular separation and position angle) of double and multiple stars, as well as in determining the precise optical coordinates of extragalactic radio sources (ERS).

In this paper we present the first results of determining the effective focal length of 2 meter Ritchey-Chretien-Coude telescope installed at National Astronomical Observatory at Rozhen (NAOR) for the CCD camera VersArray 1300B. We observed with system Ritchey-Chretien. Both primary and secondary mirrors are hyperbolic. The telescope focal length is 16 m with focal ratio of f/8 as given by the manufacturer. The NAOR is located in southern Bulgaria. The geographic coordinates of the station are: the longitude $24^\circ\ 44'\ 18''$, latitude $41^\circ\ 41'\ 41''$ and altitude above the sea level 1730 m. More details can be found at website[1] .

2. EQUIPMENT AND METHOD

From 2004 till now a group of astronomers from the Belgrade Observatory has stayed several times at the NAOR in Bulgaria taking frames of visual double and multiple stars. Series of observations of double and multiple stars at the Bulgarian NAOR have been made with a CCD camera attached to their 2 m telescope. Only in

[1] http://www.nao-rozhen.org/

the observations from 2004 the Photometrics CE200A CCD camera was used. The dimensions of CCD chip are 1024×1024 pixels, the pixel size is 24×24 micrometers. The angle corresponding to one pixel is 0.31 arcsec. All later observations have been performed with the CCD camera VersArray 1300B with characteristics: 1340×1300 pixels, the pixel size is 20×20 micrometers and one pixel is 0.26 arcsec.

The effective focal length F for a two-mirror system is given by Bely (2003):

$$F = \frac{f_1 f_2}{f_1 + f_2 - s} ,$$

where f_1 and f_2 are the focal length of the primary and the secondary mirrors respectively, and s is the distance between the two mirrors (Fig.1). As can be seen, the effective focal length depends on s. For each detector (CCD cameras) s is varied during the focus finding procedure which changed the effective focal length F too.

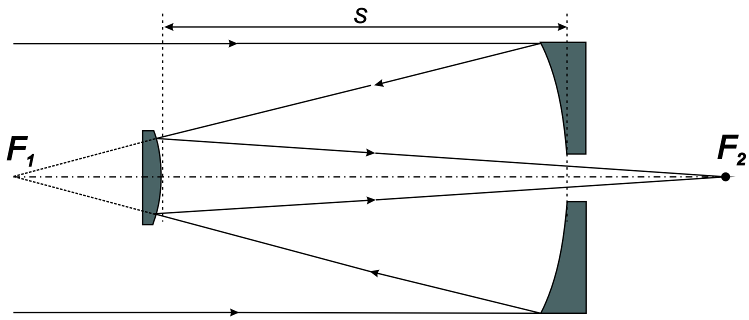

Figure 1: Scheme of a two-mirror system: F_1 is the primary mirror focus, F_2 is the effective focus and s is the distance between the two mirrors.

The effective focal length can be determined by comparing the measured separation d_m between the images of two objects on a CCD frame with the separation d_c calculated by using their coordinates taken from a catalogue.

The positions of objects in frames were measured by using the AIP4WIN software (Berry and Burnell 2002).

3. OBSERVATIONS

Our team has performed eight series of CCD observations of visual double and multiple stars at the NAO Rozhen in the period from 2004 to 2012. Also, we have performed three series of CCD observations of compact ERS that are visible at optical wavelengths in order to investigate the relation between the optical and radio reference frames.

The first series was in the middle of October 2004 (the frames were obtained by using the Photometrics CE200A CCD camera). The other seven series of CCD observations of visual double and multiple stars were: in the end of October 2005, on December 16/17 2006, on July 20/21 2009, on September 7-10 2010, from March 29 to April 01 2011, on October 27-28 2011 and on April 24-26 2012. In the last seven series the frames were obtained by using the CCD camera VersArray 1300B. A total of 891 pairs were measured. The results of observations obtained by 2011 have been published in Pavlović et al. (2005), Cvetković et al. (2006, 2007, 2010, 2011). The results of observations performed during 2011 will be published (Cvetković et al., in preparation).

The three series of CCD observations of ERS were done: from March 29 to April 01 2011, on October 27-28 2011 and on April 24-26, 2012. About 100 ERS objects were measured.

As examples four CCD frames obtained with the CCD camera VersArray 1300B are given in Fig. 2.

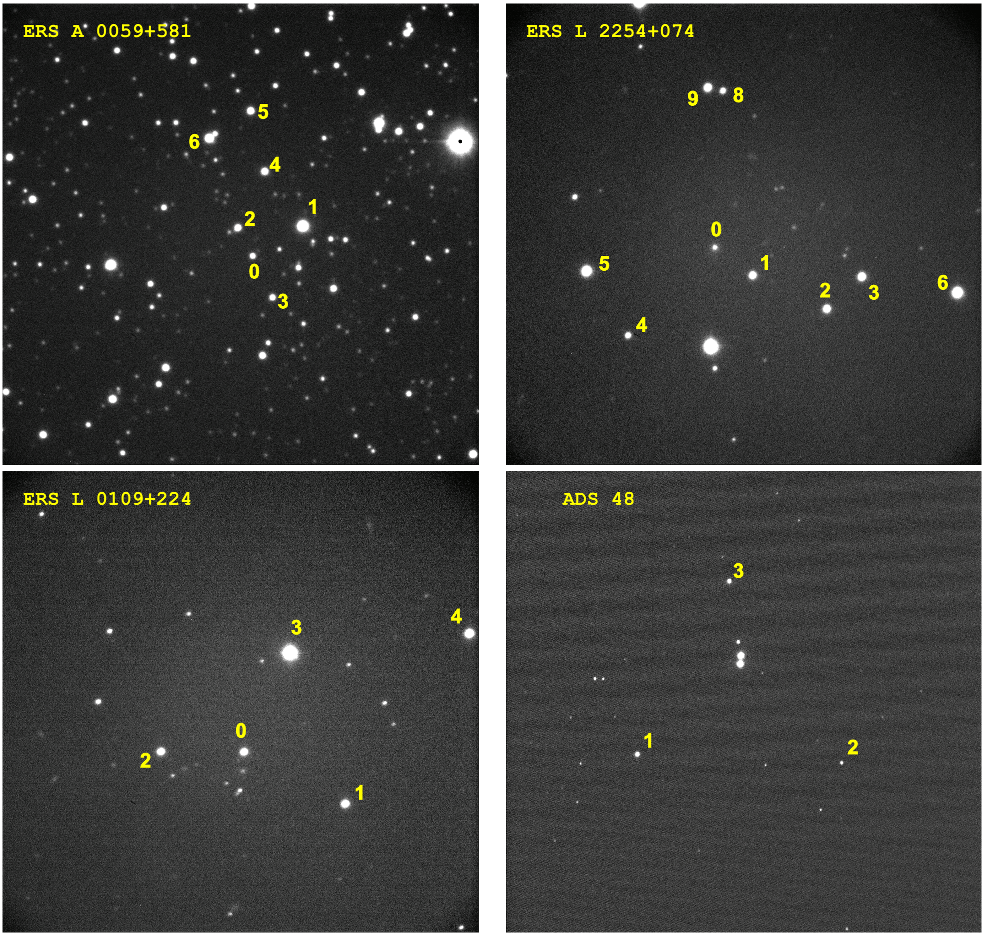

Figure 2: CCD frames obtained with camera VersArray 1300B at NAOR. The separations were measured between either two stars from field of view or a star and an extragalactic radio source and used to determine the telescope focal length.

During the summer of 2011 the first observations of celestial bodies from the new Astronomical Station on the mountain of Vidojevica (ASV) took place. This Station belongs to the Astronomical Observatory of Belgrade. From June to November 2011 we carried out several series of CCD observations of visual double or multiple stars at Astronomical Station Vidojevica aimed at determining the relative coordinates (angular separation and position angle). For these series we used either SBIG ST-10ME or Apogee Alta U42 CCD cameras. Also, during September and October 2011, we observed about 20 compact ERS that are visible at optical wavelengths in order to investigate the relation between the optical and radio reference frames. The optical positions of ERS (α and δ) have been calculated using the positions of reference stars from some of big modern star catalogues. For these observations we used Apogee Alta U42 CCD camera only.

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 images of objects visible in our CCD frames. The results for measured separations and their corresponding separation differences $\Delta\rho = \rho_{NAOR} - \rho_{ASV}$ are given in Table 1 and Fig.3. It is clear that their dependence is linear and it can be given by the following equation:

$$\Delta\rho = 0.0019 + 0.0137\rho \quad .$$

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 60 cm telescope at the ASV are given in Cvetković et al. (2012), and of 2 m NAOR telescope in this paper (see Table 2). The differences are relatively small, the order of 1.4%. For pairs of stars with angular separations smaller than $10''$, the differences are approximately equal to measurement errors. Our observational program of double and multiple stars contains mainly pairs with angular separations less than $10''$ and therefore small deviations in separations resulting from inaccurate telescope focal length could not be previously noticed.

Table 1: The separations (in arcsec)measured for the same pairs of objects from CCD frames obtained at NAO Rozhen and ASV as well as the separation differences.

ρ_{NAOR}	ρ_{ASV}	$\Delta\rho$
44.61	45.23	0.62
62.90	63.76	0.86
107.41	108.86	1.45
109.72	111.26	1.54
115.45	117.03	1.58
120.59	122.21	1.63
142.43	144.39	1.97
148.39	150.47	2.08
155.05	157.17	2.13
189.11	191.69	2.58

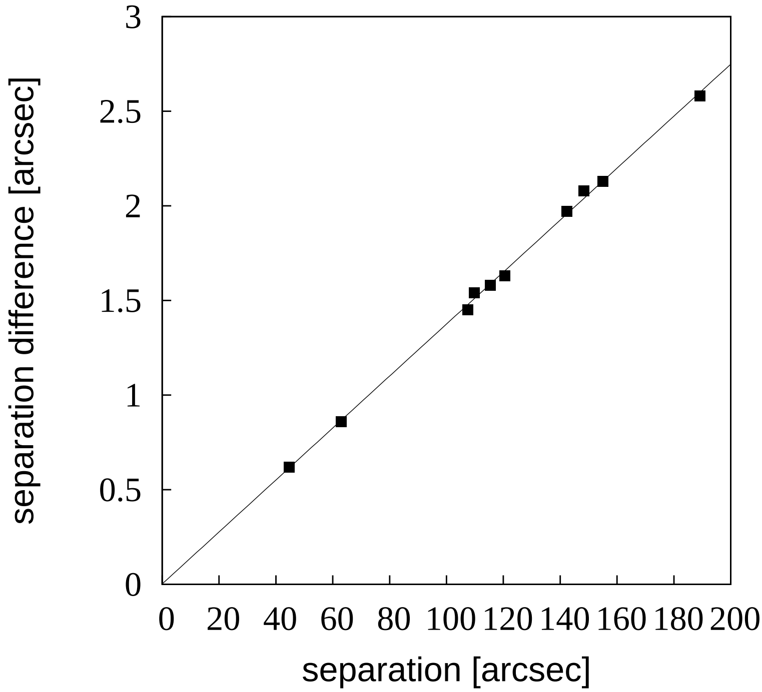

Figure 3: The separation differences versus separation measured for the same pairs of objects at NAOR and ASV.

4. CALCULATION AND RESULTS

The telescope effective focal length for detector (CCD camera VersArray 1300B) was determined by comparing the measured separations d_m of images of two stars or a star and an ERS on the CCD frames, with the separations d_c calculated from their coordinates and proper motions.

For data reduction we used the XPM catalogue[2] that contains the positions and proper motions of 314 million stars distributed all over the sky for the epoch J2000.0. Since the catalogue coordinates (α_0 and δ_0) are given for J2000.0, the corresponding positions for the epoch of the observations (α_i and δ_i) are calculated by taking proper motions into account. The coordinates of radio sources are taken from the ICRF2 list (Fey et al. 2009). These are remote sources with proper motions negligibly small.

The angular separation d_c between two objects (arc along a great circle of celestial sphere) is calculated from their coordinates α_i and δ_i, $i = 1, 2$ for the epoch of observations according to the formula

$$\cos d_c = \sin \delta_1 \sin \delta_2 + \cos \delta_1 \cos \delta_2 \cos(\alpha_2 - \alpha_1) \ .$$

The measured separation d_m is calculated from:

[2]http://astrodata.univer.kharkov.ua/catalogs/XPM/

$$d_m = \frac{3600 \times 180}{\pi} \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \ ,$$

where x_i and y_i, $i = 1, 2$ are the measured coordinates from the CCD frame.

The field of view of CCD frames is small enough (its size is 5.8 $\times$ 5.6 arcmin) and we did not apply the corrections for apparent displacements such as the differential refraction (Aslan at al. 2010, Kiselev 1989). The main steps for processing the CCD images are the detection of star-like objects (ERS) and stars, and measuring the positions (x, y).

The focal length of the telescope is obtained from:

$$F = \frac{d_m}{d_c} \ .$$

The calculated values of F are given in Table 2 as well as the coordinates and proper motions of the objects used in these determinations. The radio sources are faint, their apparent magnitudes exceed 14 so that the corresponding exposures lasted about one minute. The frames containing visual double stars were obtained with shorter exposures. Their apparent magnitudes are below 12 so that the exposure times were from a few tenths to a few seconds. Due to this, the frames with the radio sources contain more images of stars for which the separations were measured than the frames with double stars.

Numbers of objects identified on the CCD frames, where a radio source is assigned zero and stars numbers exceeding zero, are given in the first column in Table 2. Right ascensions and declinations (in degrees) and proper motions $\mu_\alpha \cos\delta$ and μ_δ (in mas/yr) are given in columns 2-5 and in columns 6-9 for the first and second object of a pair respectively. The focal length of the telescope is given in the tenth column. The year of observation is given in the last column. An empty row separates the measurements on different CCD frames for ERS or the measurements of different pairs for double stars.

When the CCD camera VersArray 1300B was attached to the 2 m telescope, we obtained the focal length $F = (15774 \pm 21)$ mm. It is the average of the 40 values given in Table 2.

The temperature variation of the focal length has not been studied because the need for determining the focal length of the telescope more accurately appeared only when we had the observations of the same objects at both NAOR and ASV (autumn 2011). Therefore, the temperature effects on the focal length are left for future observations.

Table 2: Focal length of 2 m telescope at NAO Rozhen with attached CCD camera VersArray 1300B.

Table 2.: Focal length of 2 m telescope at NAO Rozhen with attached CCD camera VersArray 1300B.

pairs	α_1 [°]	δ_1 [°]	$\mu_{\alpha_1}\cos\delta_1$ [mas/yr]	μ_{δ_1} [mas/yr]	α_2 [°]	δ_2 [°]	$\mu_{\alpha_2}\cos\delta_2$ [mas/yr]	μ_{δ_2} [mas/yr]	F [mm]	year
0- 1	18.024270	22.744107	0.00	0.00	18.002064	22.755148	-3.57	-8.12	15765	2011
0- 2	18.024270	22.744107	0.00	0.00	18.042636	22.743713	-5.48	2.30	15824	2011
0- 3	18.024270	22.744107	0.00	0.00	18.013677	22.724062	-4.44	-26.81	15755	2011
0- 4	18.024270	22.744107	0.00	0.00	17.973797	22.720838	9.26	-4.07	15781	2011
0- 1	15.690677	58.403094	0.00	0.00	15.671078	58.397176	-33.78	0.87	15761	2011
0- 2	15.690677	58.403094	0.00	0.00	15.696223	58.397288	-6.16	-13.82	15769	2011
0- 3	15.690677	58.403094	0.00	0.00	15.683303	58.411670	-4.40	-1.35	15775	2011
0- 4	15.690677	58.403094	0.00	0.00	15.685314	58.385840	1.86	-2.47	15773	2011
0- 5	15.690677	58.403094	0.00	0.00	15.690276	58.373386	0.16	-1.28	15770	2011
0- 6	15.690677	58.403094	0.00	0.00	15.706665	58.378832	30.57	13.97	15783	2011
0- 1	343.280705	19.709619	0.00	0.00	343.270844	19.688776	7.53	2.00	15812	2011
0- 2	343.280705	19.709619	0.00	0.00	343.254917	19.704537	26.80	-5.09	15775	2011
0- 3	343.280705	19.709619	0.00	0.00	343.277107	19.723909	45.25	-3.12	15722	2011
0- 4	343.280705	19.709619	0.00	0.00	343.297852	19.733495	0.06	-14.81	15758	2011
0- 5	343.280705	19.709619	0.00	0.00	343.308839	19.738109	6.73	-0.82	15764	2011
0- 6	343.280705	19.709619	0.00	0.00	343.316243	19.739516	-4.73	-3.72	15754	2011
0-10	343.280705	19.709619	0.00	0.00	343.235601	19.744564	-6.24	-12.42	15780	2011
0- 1	344.322096	7.720084	0.00	0.00	344.314393	7.725902	16.93	-12.71	15860	2011
0- 2	344.322096	7.720084	0.00	0.00	344.299252	7.733080	0.37	-0.88	15767	2011
0- 3	344.322096	7.720084	0.00	0.00	344.291939	7.726671	-3.45	0.04	15779	2011
0- 4	344.322096	7.720084	0.00	0.00	344.340401	7.737714	7.81	4.88	15734	2011
0- 5	344.322096	7.720084	0.00	0.00	344.348585	7.724290	27.90	-7.18	15753	2011
0- 6	344.322096	7.720084	0.00	0.00	344.272324	7.730363	-19.47	-13.71	15779	2011
0- 8	344.322096	7.720084	0.00	0.00	344.319724	7.688006	9.70	-8.88	15761	2011
0- 9	344.322096	7.720084	0.00	0.00	344.322800	7.687318	22.00	-23.82	15762	2011
1- 2	1.392738	45.791748	6.47	-5.84	1.420091	45.827052	13.85	-7.68	15781	2005
1- 2	1.392738	45.791748	6.47	-5.84	1.420091	45.827052	13.85	-7.68	15781	2006
1- 2	1.392738	45.791748	6.47	-5.84	1.420091	45.827052	13.85	-7.68	15773	2010
1- 2	1.392738	45.791748	6.47	-5.84	1.420091	45.827052	13.85	-7.68	15773	2011
1- 2	1.392738	45.791748	6.47	-5.84	1.420091	45.827052	13.85	-7.68	15767	2012
1- 3	1.392738	45.791748	6.47	-5.84	1.452613	45.789707	6.68	-8.17	15775	2005
1- 3	1.392738	45.791748	6.47	-5.84	1.452613	45.789707	6.68	-8.17	15780	2006
1- 3	1.392738	45.791748	6.47	-5.84	1.452613	45.789707	6.68	-8.17	15779	2010
1- 3	1.392738	45.791748	6.47	-5.84	1.452613	45.789707	6.68	-8.17	15778	2011
1- 3	1.392738	45.791748	6.47	-5.84	1.452613	45.789707	6.68	-8.17	15780	2012
2- 3	1.420091	45.827052	13.85	-7.68	1.452613	45.789707	6.68	-8.17	15773	2005
2- 3	1.420091	45.827052	13.85	-7.68	1.452613	45.789707	6.68	-8.17	15781	2006
2- 3	1.420091	45.827052	13.85	-7.68	1.452613	45.789707	6.68	-8.17	15773	2010
2- 3	1.420091	45.827052	13.85	-7.68	1.452613	45.789707	6.68	-8.17	15772	2011
2- 3	1.420091	45.827052	13.85	-7.68	1.452613	45.789707	6.68	-8.17	15767	2012

5. CONCLUSION

The focal length of the NAOR 2 m telescope is close to that declared at the factory. Its values can differ when diverse detectors are used in the observations.

In the case of frames taken with VersArray 1300B the telescope focal length obtained here differs from the manufacturer's one by less than 2%. This fact indicates a good quality of the telescope (mirror and construction).

The temperature variation of the focal length should be examined.

The focal-length values corresponding to other detectors: another CCD, adaptive optics, filters, etc, should be also determined.

Acknowledgements

The authors from the Astronomical Observatory in Belgrade gratefully acknowledge the observing grant support from the Institute of Astronomy and Rozhen National Astronomical Observatory, Bulgarian Academy of Sciences. This research has been supported by the Ministry of Education and Science of the Republic of Serbia, Project No 176011 "Dynamics and kinematics of celestial bodies and systems".

References

Aslan, Z., Gumerov, R., Jin, W., Khamitov, I., Maigurova, N., Pinigin, G., Tang, Z. and Wang, S.: 2010, *A&A*, **510**, A10.

Bely, P. Y. (Editor): 2003, The Design and Construction of Large Optical Telescopes, Springer-Verlag, New York, Inc.

Berry, R. and Burnell, J.: 2002, The Handbook of Astronomical Image Processing, Includes AIP4WIN Software, Willmann-Bell, Inc., Richmond, USA.

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

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

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

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

Cvetković, Z., Damljanović, G., Pavlović, R., Vince, O., Milić, I. S. and Stojanović, M.: 2012, *Serb. Astron. J.*, **184**, in press.

Fey, A. L., Gordon, D. and Jacobs, C. S.: 2009, IERS Technical Note, No. 35.

Kiselev, A. A.: 1989, *Theoretical foundations of photographic astrometry*, Nauka, Moskva.

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