FROM THE FIRST CCD MEASUREMENTS OF DOUBLE STARS AT VIDOJEVICA TOWARDS SPECKLEINTERFEROMETRY

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Abstract. A review of CCD measurements series for double and multiple stars performed to date at the Astronomical Station on Vidojevica with cameras Apogee Alta U42 and SBIG ST 10ME is presented. The quality of frames obtained with these cameras, as well as their limiting possibilities, is considered. A plan for furnishing the equipment for speckleinterferometry techniques and the expected improvement concerning the resolving of very close components of double stars are also presented.

1. INTRODUCTION

The first series of measurements of visual double stars at the recently opened Astronomical Station of Vidojevica (ASV) took place on June 18/19 2011 with CCD camera SBIG ST-10ME. A set of 15 double stars was the subject. The second and third series were realised on August 19/20 and October 20/21 2011, when CCD camera Apogee Alta U42 was used. In August frames of 20 double or multiple stars were obtained, in October 58 ones. During the fourth series of visual double stars, which took place in November 2011 (from 2 to 4), the SBIG ST-10ME camera was used again and frames of 114 double or multiple stars were obtained. The results of the first two series have been already reported (Stojanović at al. 2012), whereas the analysis of an interesting multiple star, which had resulted from observations done at ASV, was published in another paper (Cvetković et al. 2012b).

During 2012 two more observational series took place: fifth on April 22/23, when images of 16 double stars were obtained, sixth from June 21 to June 24, when images of 101 double or multiple stars were obtained. In both cases the Apogee Alta U42 camera was used.

In the beginning our aim was to find out how close double stars one can observe with this telescope and the cameras, i.e., to establish the minimum separation between the components still resolvable on the CCD frames. This depends on the apparent magnitudes of the pair components (m_A and m_B) and on the magnitude difference ($\Delta m = m_A - m_B$). Besides, there are other factors which affect the resolving of components: telescope resolving power, capabilities of cameras and seeing. Subsequently, our observing programme was aimed to include double or multiple stars not measured over the last ten years or generally with a small number of measurements.

Table 1: Some characteristics of the observing nights.

date	Temperature beginning [°C]	Temperature end [°C]	Humidity beginning [%]	Humidity end [%]	mean seeing [arcsec]
18/19 June 2011	18	8	81	85	1.4
19/20 August 2011	23	19	42	61	1.3
20/21 October 2011	10	8	59	85	2.3
2/3 November 2011	7	5	64	80	1.2
3/4 November 2011	7	2	69	71	1.1
4/5 November 2011	5	2	72	82	1.9
22/23 April 2012	9	6	78	84	2.4
21/22 June 2012	23	20	47	56	1.3
22/23 June 2012	22	16	76	82	1.9
23/24 June 2012	22	16	77	83	1.9
24/25 June 2012	20	16	69	80	1.6

For the CCD camera SBIG ST-10ME, the chip size is 1.485×1.026 cm. The chip dimensions are 2148×1472 pixels, the pixel size is 6.8×6.8 micrometers. The field of view is 8.51×5.88 arcminutes and the pixel size is 0.23 arcseconds. For the CCD camera Apogee Alta U42, the chip size is 2.76×2.76 cm. The chip dimensions are 2048×2048 pixels, the pixel size is 13.5×13.5 micrometers. The field of view is 15.81×15.81 arcminutes and the pixel size is 0.46 arcseconds. For each star pair five frames were obtained at the minimum.

The focal length of a telescope is an important parameter in determining the angular pixel size. This parameter is used for the purpose of determining the relative coordinates (angular separation ρ and positional angle θ) of double and multiple stars. At the ASV we have collected observations of these objects using two CCD cameras, Apogee Alta U42 and SBIG ST-10ME, attached to the 60 cm telescope. Its original focal length is 600 cm as given by the manufacturer. To determine the telescope focal length more accurately for both attached detectors, we used angular-separation measurements from CCD images taken at ASV. The obtained focal lengths are: $F_{42} = (5989 \pm 7)$ mm using the CCD camera Apogee Alta U42 attached to the telescope, and $F_{10} = (5972 \pm 4)$ mm with the CCD camera SBIG ST-10ME attached to the telescope (Cvetković et al. 2012a).

In Table 1 we present some characteristics of the observing nights: date of observation; the temperature and the humidity at the beginning and at the end of the observing night and the mean seeing for the corresponding night. Due to the seeing perturbed stellar image the FWHM mean value is determined and given in this table. As can be seen, the seeing varies rather strongly, to exceed $2''$ at high humidity.

2. REVIEW OF CCD OBSERVATIONS

The way of selection of double stars for which frames were taken at ASV enabled us to include both faint and bright pairs (different magnitudes) and also to have the magnitude differences of the pairs and the pair separations within sufficiently wide intervals. In our sample of 324 observed visual double or multiple stars the magnitudes of the primary m_A (the brighter component of a pair) cover an interval from 4.52 to 13.00, whereas those of the secondary m_B (fainter component) are within 4.58 to 13.90. The magnitude differences Δm are within 0.0 to 4.93. For about half of the pairs, 154, the magnitude difference is small, between 0 and 0.5. In Fig. 1 (left) the frequency of the pairs versus magnitude difference is presented. The separations, angular distances between the components, are within $1\farcs63$ to $20\farcs0$. But there were multiples with wide pairs (separations larger than $20''$) and we measured them too. The frequency of the pairs versus separation is presented in Fig. 1 (right). For 50 pairs the separation exceeds $10''$, in the case of the remaining ones the separation interval lies between $1\farcs63$ and $10\farcs0$.) In the case of double stars with low separations (less than $2\farcs5$) we selected those with sufficiently small magnitude differences ($\Delta m < 1.0$).

In Fig. 2 selected CCD frames of visual double stars taken at ASV are presented. In the first row there are those obtained with the ST-10ME camera on June 18/19 2011. In the next two rows those obtained with Apogee Alta U42 on August 19/20 and October 20/21 and in the fourth row those obtained with the ST-10ME camera on November 2-4 2011. In the two last rows we present selected CCD frames obtained during 2012 with camera Apogee Alta U42 on April 22/23 and June 21-24. The selection of CCD frames followed the requirement to present both bright and faint pairs and also with large and small magnitude differences and with various separations. For each pair in its CCD frame the magnitudes and separation are given. The frames were measured by using AIP4WIN (version 2.3.1) software (Berry & Burnell 2002) and package IRAF (available at the official IRAF site).

The position angle and separation were measured for 303 double stars, in the case of the remaining 21, with separations less than $2\farcs0$, 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 cameras and the seeing for the corresponding night (see Table 1). Out of 324 double or multiple stars observed at ASV for 19 pairs the orbital elements have been calculated (announced), whereas in the case of 24 pairs a linear solution has been obtained. For these pairs we calculated the O-C residuals (in θ and ρ) from the corresponding ephemerides. All residuals are small which indicates that the results of our observations are good and that the orbital or linear solutions fit well also the recent measurements. We have prepared a paper which presents the measurements of relative coordinates and their analysis which will be published soon.

3. NEW OBSERVATION TECHNIQUES

The research team engaged in the study of visual double and multiple stars has a plan to use part of the funds obtained from the Ministry of Education, Science and Technological Development of the Republic of Serbia for the purpose of purchasing a high-speed CCD camera. The capabilities of such a camera allow read out frames with exposure times of the order of a few milliseconds. With it, with minimal additional funds, it would be possible to start immediately observations in which the lucky-imaging method is applied (see Kohl's paper in this volume). The lucky-imaging techniques use a high-speed camera with exposure times short enough so that the

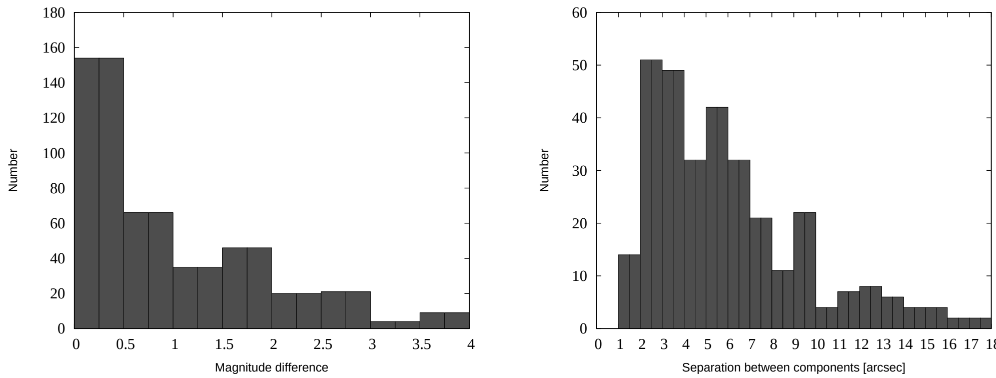

Figure 1: Frequency of the pairs of visual double or multiple stars versus: magnitude difference (left); separation (right).

turbulence in the Earth's atmosphere during the exposure is minimal. In the further procedure only the best frames are combined into a single image by shifting and adding the short exposures, yielding a much higher resolution than it would be possible with a single one with a long exposure time or a combination of all frames.

In addition to the camera it is also planned to get other components (optical system of mirrors and lenses for magnifying, filters) necessary for high-resolution speckle-interferometry observational techniques (Saha et al. 1999). This system would be mounted to a larger telescope, mirror of 1.5 m-class, in the process of purchase. The advantage of this approach is, certainly, the possibility to push the resolution limit towards its theoretical limit following from Rayleigh's criterion ($1.22\lambda/D$) which, in the case of our existing telescope ($D = 0.6$ m), is equal to $0''.23$, i.e. $0''.09$ for $\lambda = 550$ nm, in the case of the larger one ($D = 1.5$ m). With such an instrument and the corresponding equipment the members of our team will be able to measure much more very close pairs. This is very desirable because there are not many observatories in the world at which visual double stars are observed. "IAU Commission 26: Binary and Multiple Stars" has appealed to all observers, professional and amateurs, to observe regularly in order to enlarge the number of relative coordinates. Our plan is to continue the long tradition of observing double stars at the Belgrade Observatory, now using new techniques.

4. CONCLUSION

On the basis of the first series of CCD observations of double or multiple stars performed at ASV we can conclude the following:

1) out of 324 double stars, the relative coordinates of 303 were measured successfully;

2) the components were successfully resolved, i.e. separations greater than $1''.5$ were measured; pairs having smaller separations were not measured due to: telescope resolving power ($0''.23$), capabilities of the cameras and seeing (about $1''.5$);

3) the residuals from existing elements are small, a good confirmation of the high quality of our measurements;

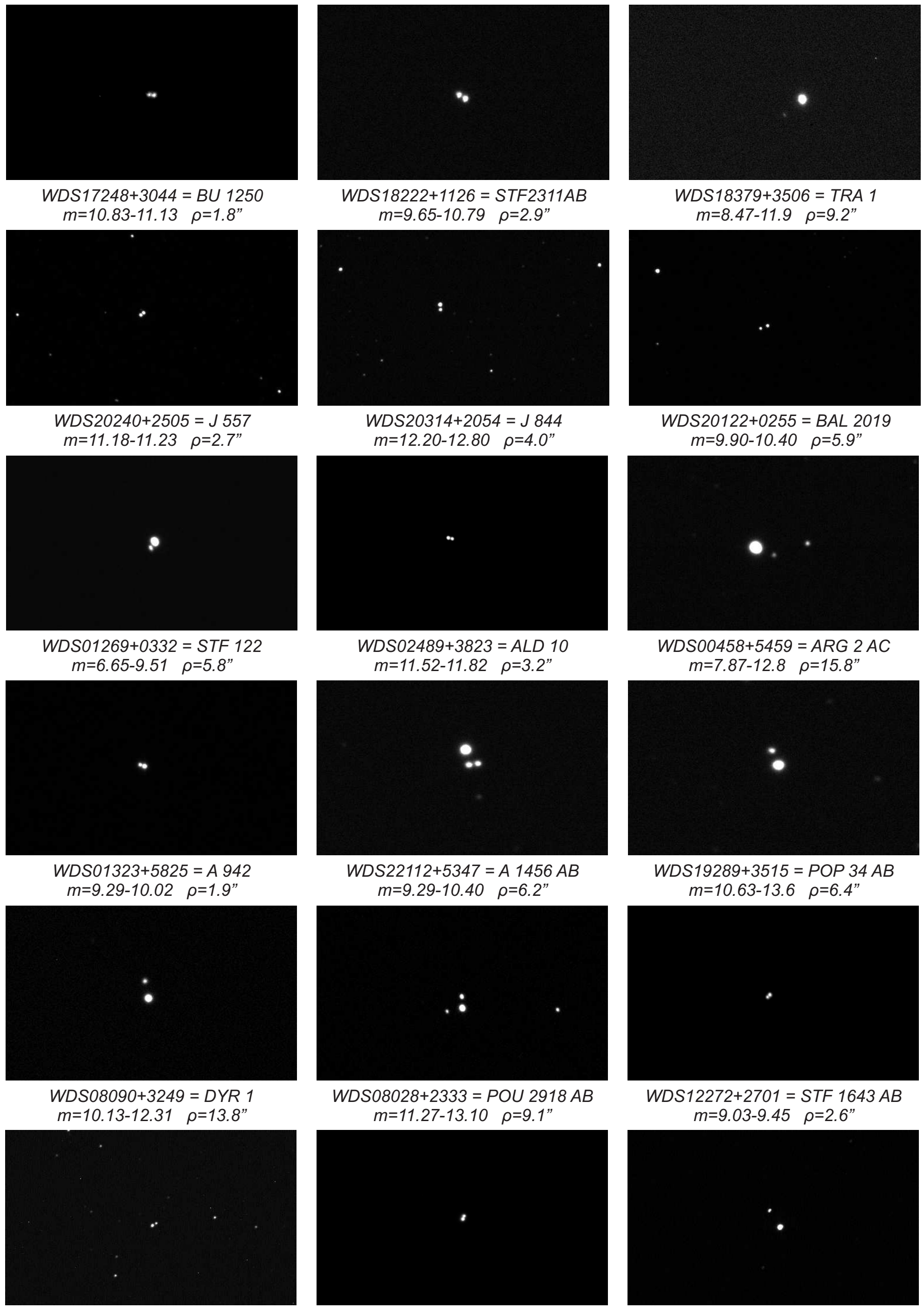

Figure 2: CCD frames of visual double or multiple stars obtained at Astronomical Station Vidojevica during 2011 and 2012 with two cameras ST-10ME and Apogee Alta U42.

4) we expect to achieve higher angular resolutions, under $1''$ with lucky-imaging technique, i.e. even under $0\overset{''}{.}5$ with speckleinterferometry.

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