CCD Double-Star Measurements at Altimira Observatory in 2007

Robert K. Buchheim

Altimira Observatory (G76)
18 Altimira
Coto de Caza, CA 92679

Email: RBuchheim@earthlink.net

Abstract: CCD measurements of the separation and position angle of 16 systems, mostly taken from the WDS list of "neglected doubles", are reported. The V-band delta-magnitude values were also measured for most of the reported systems.

Introduction

Altimira Observatory is located in my backyard in southern California. It is equipped with an 11-inch Schmidt-Cassegrain telescope (Celestron NexStar-11) operating with an f/6.3 focal reducer, a non-anti-blooming CCD imager (SBIG ST-8XE) with photometric filters (Custom Scientific B, V, and R filters in an SBIG CFW-8A filter wheel). All images used for this study were taken through the V-band filter, that provides a spectral sensitivity curve that very closely matches the Johnson-Cousins standard V-band response ($\lambda_{center} \approx 0.55$ µm , $\Delta\lambda_{FWHM} \approx 0.09$). The images are well-sampled, with 1.1 arc-sec pixels and typical "seeing" of 2-3 arc-sec from my low-altitude suburban site. The equipment is housed inside a small domed observatory (see reference 1).

The observatory was originally built for photometric projects, however double-star measurement has proven to be an interesting and useful project for nights when conditions do not permit photometry.

Procedure

The observational procedure is to take a series of V-band images of the selected double-star fields. In no case are images taken at air mass greater than X=2, and usually air mass is less than X= 1.75. In general, two or three different exposure durations were used for each field, in order ensure that at least one set of exposures would provide a high SNR without saturating any pixels in the star images; and six images were taken at each exposure duration. For some targets, images were taken on 2 nights, to test whether results were consistent (they were). Dark-subtraction and flat-field correction of the images was performed with CCDSoft (Software Bisque), and images with poor guiding or other problems were eliminated by visual examination. This approach provided a set of at least 4 images for each system that could be measured to determine the positions and separation angles.

Astrometric analysis of the images was done with both MPO Canopus (by BDW Publishing) and Astrometrica (by Herbert Raab), using the UCAC2 catalog for reference stars. (A few stars are located outside of the range of UCAC2; in those cases, the MPO Canopus Star Catalog, which merges the Tycho 2 and USNO A2.0 catalogs, was used). Measurements (means) reported here are based on at least 4 images of each system.

The MPO Canopus package provides a convenient double-star utility that reports the separation and position angle directly. Astrometrica offers higher-order modeling of plate constants (which I did not require), and excellent visualization of the stellar image intensity function (which is particularly handy in dealing with closely-spaced pairs). Because Astrometrica reports the RA and Dec coordinates of the individual stars, I use an Excel spreadsheet to calculate the resulting separation and position angle. Several pairs were evaluated using both methods, to confirm that the results were consistent.

Measurements from all good images (good tracking and focus, SNR > 10 on all targets stars, and no saturated pixels) were averaged to achieve a single "mean" for the pair. In those cases where images were taken on multiple nights, the means from all nights are averaged, and the reported Besselian epoch is the average of the times of all images. The reported standard deviations of separation and position angle are based on the complete data set for each pair.

Tests on calibration systems (not reported here) have shown that my equipment can reliably and accurately (± 0.2 arc-sec) measure equal-brightness pairs that are separated by more than about 4 arc-sec. Larger separations are required in order to reliably measure pairs that present significant brightness difference.

Dates have been converted from UT of observation by using the AAVSO "JD converter" utility to determine the Julian Date, and then applying the following formula (Lieske, 1979) to compute the Besselian epoch:

$$B = 1900 + \frac{[JD - 2,415,020.31352]}{365.2422}$$

During this project I discovered that some commonly-used references mis-state the equations for calculating the separation and position angle of a pair of stars, given their RA and Dec coordinates. As described in Smolinski and Osborn (2006), standard formulae from spherical trigonometry give:

$$\rho = \cos^{-1}\left[\cos(\Delta\alpha)\cdot\cos\delta_1)\cdot\cos(\delta_2-\delta_1)\right]$$

$$\Theta = \left(\frac{\pi}{2}\right) - \tan^{-1}\left[\frac{\sin(\delta_2-\delta_1)}{\cos(\delta_2-\delta_1)\cdot\sin(\Delta\alpha\cdot\cos\delta_1)}\right]$$

where δ_1 and δ_2 are the declination of the primary and secondary stars, respectively, and α_1 and α_2 are the right ascension of the primary and secondary stars, respectively. $\Delta\alpha = \alpha_2 - \alpha_1$ is the difference of RA and all angles are in radians.

In the small angle approximation, where

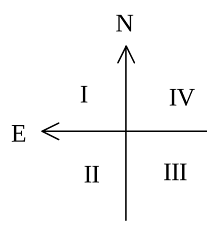
$$|\Delta\alpha| \ll 1 \text{ and } |\delta_2 - \delta_1| \ll 1$$

we can simplify the equations for separation and position angle to

$$\rho = \sqrt{(\Delta\alpha\cdot\cos\delta_1)^2 + (\delta_2-\delta_1)^2} \quad \text{(radians)} \qquad (1)$$

$$\Theta = \left(\frac{\pi}{2}\right) - \tan^{-1}\left[\frac{(\delta_2-\delta_1)}{\Delta\alpha\cdot\cos\delta_1}\right] = \tan^{-1}\left[\frac{\Delta\alpha\cos\delta_1}{\delta_2-\delta_1}\right] \quad \text{(radians)} \qquad (2)$$

The calculated position angle, θ, must be resolved to the correct quadrant in order to yield the astronomical position angle (measured from celestial north, toward celestial east):



sign of $\alpha_2 - \alpha_1$	sign of $\delta_2 - \delta_1$	quadrant	position angle θ
+	+	I	θ=Θ
+	-	II	θ=π+Θ
-	-	III	θ=π+Θ
-	+	IV	θ=2π+Θ

The Excel spreadsheet that I use to translate RA, Dec into ρ, θ uses Eq 1 and Eq 2.

During the course of this project I noticed a few cases where the star's CCD brightness appeared to be very different from the WDS listed magnitudes. This prompted me to use MPO Photored (a photometric program contained within MPO Canopus) to estimate the V-band delta-mag on my images. The reported delta-mags are typically derived from measurement of 4 images, with the faint component having SNR ≥ 10 in each image. These delta-mags are subject to some caveats. First, the images were taken on non-photometric nights (either hazy or moonlit, or both). Second, no transforms were applied. These caveats are balanced by the fact that my system with V-band filter is very close to standard Johnson-Cousins V band: the measured transform equation is

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CCD Double-Star Measurements at Altimira Observatory in 2007

Name	WDS	WDS	meas	Position Angle (deg)		Separation (as)		Epoch	N nights	N images	Notes
	RA+DEC	Mags	ΔVmag	PA	s.d.	Sep	s.d.				
STT 23AB	01101+5145	8.14, 8.59		191.3	0.02	14.64	0.03	2007.896	1	6	
STT 23AC	01101+5145	7.7, 12.2		93.0	0.10	57.12	0.17	2007.896	1	6	A
KZA 44AB	13104+3744	9.5, 9.5.	0.16	208.7	0.03	76.77	0.06	2007.512	2	11	
KZA 44AC	13104+3744	12.32, 11.38	-0.86	4.5	0.04	93.29	0.08	2007.512	2	11	
KZA 55AB	13221+4354	6.35, 11.5	6.0	307.2	0.10	45.67	0.04	2007.530	1	4	
KZA 55AC	13221+4354	6.35, 9	5.3	58.7	0.09	67.70	0.15	2007.530	1	4	
KZA 55AD	13221+4354	6.35, 10.5	6.0	247.9	0.09	75.55	0.09	2007.530	1	4	
KZA 71AB	13363+3514	9.5, 10	1.5	147.6	0.09	62.51	0.03	2007.512	1	4	
KZA 71AC	13363+3514	9.5, 11	2.6	185.8	0.14	78.86	0.06	2007.512	1	4	
STF1888AB	14514+1906	4.76, 6.95		310.9	0.50	6.30	0.06	2007.505	1	5	
STF1888AD	14514+1906	4.76, 9.6		286.4	0.10	159.60	0.20	2007.505	1	5	
STF1888AE	14514+1906	4.76, 8.65		98.5	0.20	269.20	0.30	2007.505	1	5	
STF1888AF	14514+1906	4.76, 9.2		38.2	0.02	333.70	0.20	2007.505	1	5	
STF1888BE	14514+1906	6.95, 8.65		99.3	0.02	274.50	0.20	2007.505	1	5	
HLD 120AB	14527+0746	8.3, 9.9	3.6	224.6	0.32	16.13	0.05	2007.541	2	12	
SKF 10	15111+4424	10.1, 10.8	0.6	284.4	0.20	13.90	0.06	2007.518	2	9	
ARY 52	15124+5256	7.6, 8.4	0.8	330.5	0.06	147.90	0.20	2007.530	1	8	
BGH 57	15171+2851	8.8, 9	-0.4	220.8	0.03	574.27	0.30	2007.505	1	4	B
ARY 53	15198+5217	8.93, 9.43	0.5	148.5	0.01	106.98	0.09	2007.541	2	8	
KZA 105AB	15367+3954	9.5, 11	0.9	73.3	0.04	88.00	0.04	2007.530	1	4	
KZA 105AC	15367+3954	9.5, 11	1.6	118.5	0.02	133.30	0.10	2007.530	1	4	
KZA 105AD	15367+3954	12.22, 11.87	-0.8	156.7	0.02	164.30	0.02	2007.530	1	4	
KZA 105AE	15367+3954	9.5, 10.5	0.7	132.3	0.03	267.90	0.10	2007.530	1	4	
KZA 105AF	15367+3954	9.5, 10	-0.6	178.0	0.01	357.10	0.10	2007.530	1	4	
KZA 105AH	15367+3954	12.22, 11.67	-0.8	134.7	0.02	535.40	0.20	2007.530	1	4	
KZA 105DF	15367+3954	11.87, 12.21	0.2	194.3	0.01	212.50	0.10	2007.530	1	4	

Table 1: Measurements of systems

Table continued on next page

CCD Double-Star Measurements at Altimira Observatory in 2007

Name	WDS	WDS	meas	Position Angle (deg)		Separation (as)		Epoch	N nights	N images	Notes
	RA+DEC	Mags	ΔVmag	PA	s.d.	Sep	s.d.				
SPN 1	15569+3613	9.8, 10.8	5.6	86.5	0.32	25.70	0.24	2007.505	1	5	
BU 692AC	21501+3151	7.3, 11	5.3	292.6		40.65		2007.880	1	6	C
FOX 264AE	21501+3151	7.46 --	6.0	178.0		54.37		2007.880	1	6	
FOX 264AD	21501+3151	7.46 --	6.7	149.7		40.37		2007.880	1	6	
MLB 788	21509+3918	10, 10.1		51.8	0.64	4.90	0.07	2007.880	1	7	
SEI1527	21378+3739	9.88, 12.71	3.2	332.1	0.12	25.21	0.05	2007.880	1	6	
CHE 447	23234+4224	10.53, 10.92		286.0	0.29	27.12	0.23	2007.861	1	8	

Table 1 (continued): Measurements of systems

Table Notes:

A. These CCD measurements confirm a visual measurement by Tom Frey (personal communication).

B. Note that the “primary” is the fainter of the two stars.

C. I saw no evidence of star "B" (which WDS reports at mag 10.8) on CCD images going as deep as mag 15

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V-v = -0.05 (B-V) + Z_V, so color effects are small. It is reasonable to expect that even on the nights used for these double-star measurements, the differential magnitudes should be accurate, to within about ± 0.1 magnitude.

Results

Target pairs were selected from the Washington Double-Star Catalog listing of “Neglected Doubles”, with the goal of providing modern data points for these systems. In some cases, these observations confirm the existence of the pair (i.e. when only a single previous measurement is reported).

Table 1 provides the measured parameters of all the systems I examined. The standard deviations of PA and SEP are the internal variability of the individual image measurements, over the total number of images used. Of the systems measured, six show significant motion since the last measurement. These are STT 23 AC (7 arc-sec change in separation), STF 1888 AD (3 arc-sec change in separation), HLD 120 AB (8 arc-sec change in separation), KZA 105 AE (7 arc-sec change in separation), and FOX 264 AE (7 arc-sec change in separation).

In some cases the delta-mags observed are very different than those listed in the WDS Catalog. The case of SPN-1 is particularly remarkable in this regard: the WDS record shows a delta-mag of 1.0 magnitude, whereas my CCD images show the secondary 5.6 magnitudes fainter than the primary. Other systems showing delta-mags that are quite different from the WDS are: KZA 55 AC and KZA 55 AD, HLD 120 AB.

Acknowledgements

This research has made use of the Washington Double Star Catalogs, maintained at the U.S. Naval Observatory. I appreciate the enthusiasm of Russ Genet, who prompted me to add double-star measurements to my astronomical schedule, and Tom Frey for sharing his visual measurements of STT 23 AC. I am grateful to my wife, Eileen, who gave up a portion of her garden for the construction of Altimira Observatory.

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References

1. Altimira Observatory website: http://www.geocities.com/oca_bob

2. Lieske, J.H., 1979, "Precession Matrix Based On IAU (1976) System Of Astronomical Constants", Astronomy & Astrophysics, **73**, 282-284.

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Mr. Buchheim is also the author of the book ***The Sky is Your Laboratory: Advanced Astronomy Projects for Amateurs*** *recently published by Springer-Praxis.*