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Double Star Measures Using the Video Drift Method - VI

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Abstract: Position angles and separations for 227 multiple star systems are presented using the video drift method. The drift method generates standard (*x*,*y*) coordinates for the primary and companion star for each video frame during the drift. Position angle and separation are derived from these coordinates. Systems fainter than m = +12 were measured and computed using a variation of the drift method using an integrating video camera. Most doubles had 1,000's of (*x*,*y*) pairs analyzed per system. Several systems lacked measurements since the late 1800's and early 1900's.

Introduction

In our first paper (Nugent and Iverson, 2011) we described a new video method that computes both the position angle (PA) and separation (Sep) for a double star. A significant advantage of this method is that data collection and subsequent data analysis is almost completely automated with little human interaction. A short video clip of the multiple star system drifting across the field of view is evaluated by the freeware program *Limovie* (Miyashita, 2006) to capture 100's to 1,000's of (*x*,*y*) positions (aka "standard coordinates") for each component. Although *Limovie* was originally written to measure the change in light levels during an occultation, it also produces a table of standard (*x*,*y*) coordinates for both components along with their brightness levels for each video frame. *VidPro*, an Excel program written by co-author Nugent, reads the (*x*,*y*) coordinate data and computes the position angle and separation for each video frame. The position angles and separations are then averaged to give a final result.

Each double star drift is self calibrating. The *VidPro* program computes a unique scale factor, an offset from the east-west direction compared to the camera's pixel array, and standard deviations for both position angle and separation for each drift. The offset of the pixel array alignment of the video camera's chip from the true east-west direction (drift angle) is calculated using the method of least squares to an accuracy of better than 0.02°.

For systems in which either primary and/or secondary star magnitude exceeded m = +12, co-author Iverson used a variation of the drift method employing an integrating video camera (Iverson and Nugent 2015). Author Nugent uses a Collins I^3 image intensifier with his 14 inch SCT telescope and routinely reaches m = +14 to +15.

Methodology

Preference was given to multiple star systems where the WDS lacked measurements for a minimum of 10-15 yr and had less than 10 measurements. This criterion applies to nearly all of the multiple star systems measured at the epoch of their measurement. In some cases where one component of a complex system meets this requirement, all of the other components within the reach of our telescopes were also measured for completeness even though they have been well measured in the past. Twenty-seven doubles had more than 35 measurements. We routinely look at a few well measured doubles to support ongoing efforts to compare the video drift method with other measurement methods. Nineteen systems lacked measurement since 1893-1945. The faintest system measured in Table 2 had primary/secondary magnitudes of +10.0, +15.0. One dozen systems had WDS magnitudes in the +14.0

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to +14.8 range.

With some doubles not measured since the late 1800's or early 1900's, significant deviations in PA and Sep were sometimes observed. This is not surprising. These doubles were checked with the interactive *Aladin Sky Atlas* webpage (from the Centre de Données astronomiques de Strasbourg) to verify that the stars originally observed were identified and re-measured by us. Updated proper motions were taken into account from catalogs from the *VizieR* database to confirm the observed changes in PA and separation.

Other doubles showed a significant deviation from the WDS summary catalog value. The observational history was obtained from the U.S. Naval Observatory and both the position angle and separation were plotted against the year of observation. In most cases the data conformed to a general trend line. In a few cases the fit was very good and the least squares correlation coefficient was greater than 0.90. Graphing the data also showed which data points were obviously in error. These were rejected and not included in Table 2. An investigator comparing their new measurement to the latest WDS catalog value, and noting a large difference, might reject their measurement. However the new measurement might be a good one, since the WDS is known to have some values that have large errors, especially when there is just 1 or 2 measurements for a given double star system.

Calibration

In our previous paper (Nugent and Iverson, 2014), we discussed how to make a one time calibration to set the correct aspect ratio for the hardware configuration used for the recording of the videos. This calibration makes a slight adjustment to the video aspect ratio (width vs. height) to overcome the unavoidable skewing of the image aspect ratio caused by modern digital video recorders. With the one time video size adjustment (done automatically using an AviSynth script when *Limovie* opens the video file), our video aspect ratios closely matched the sky in the east-west and north-south directions. To confirm this, we measured long term stable doubles with no change in PA, Sep and also used RA, DEC coordinates from the *VizieR* online star catalogs to compute the angular displacement and separation of known stars.

The telescope equipment used and scale factors are summarized in Table 1.

Acknowledgements

This research makes use of the *Washington Double Star Catalog* maintained at the US Naval Observatory, the *Aladin Sky Atlas* Interactive webpage and the *VizieR* catalog database from the Center de Données Astronomiques in Strasbourg, France.

References

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Nugent, R. and Iverson, E. 2014, *JDSO*, **10**, 214-222.

VizieR catalog database, Centre de Données Astronomiques de Strasbourg, http://vizier.u-strasbg.fr/viz-bin/VizieR.

Table 1. Telescopes/cameras used in this research.

Telescope	Aperture	Focal Length	Scale Factor*	Video Camera**
Meade LX-200GPS ACF optics	14″(35 cm)	3556mm f/10	0.62″/pixel	Stella Cam 3
Meade LX-200GPS Classic	14″(35 cm)	3556mm f/10	0.6″/pixel	Watec 902H Ultimate

*Scale factors will vary slightly due to the declination of the target.
**To reach fainter doubles E. Iverson uses the Stella Cam 3 integrating camera; R. Nugent uses an Watec 902H Ultimate camera with the Collins I^3 image intensifier.

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Table 2. Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
00194-0849	HJ 1953AC	190.5	0.1	106.4	0.23	2014.786	2912	3.67	10.40	4	1
00059-3020	SEE 1AB,C	327.2	2.1	5.0	0.20	2014.877	1687	9.30	10.8	2	1
00080-3139	BVD 46	328.2	0.9	20.1	0.31	2014.877	1632	10.90	11.59	2	1
00094-3321	TDS1322	277.5	1.9	9.3	0.31	2014.877	1668	10.89	10.92	2	1
00123-3128	PRO 1	177.7	0.9	16.4	0.26	2014.877	1727	9.70	11.54	2	1
00132-3021	HDS 31	221.0	1.6	11.6	0.27	2014.877	1702	10.60	13.65	2	1
00154-3219	LDS 7	143.7	1.8	12.8	0.36	2014.877	1711	12.9	14.4	2	1
00164+1950	LDS 863AB	59.0	0.8	25.1	0.30	2014.877	1509	11.86	13.3	2	1
00280-3051	UC 375	335.8	0.9	39.2	0.59	2014.874	1657	10.5	12.9	2	1
00282-1030	GAL 300AB	182.9	0.1	44.6	0.12	2014.786	6156	9.01	9.78	8	2
00292-3228	LDS 19	149.0	1.4	18.6	0.48	2014.874	2412	10.99	13.5	2	1
00311-3238	B 2553	356.5	0.8	10.2	0.13	2014.874	1683	10.36	13.54	2	1
00314-1113	GAL 302AB	232.1	0.1	84.0	0.12	2014.786	5076	8.14	11.16	8	2
00367-2725	HJ 3379	230.9	0.5	14.2	0.11	2014.874	1585	7.98	11.09	2	1
00374+2351	POU 44	316.0	2.5	13.4	0.52	2014.877	1599	10.46	11.8	2	1
00378+2431	POU 47	203.6	3.0	12.5	0.59	2014.877	1625	12.37	13.2	2	1
00388+3101	AG 430	117.3	0.0	254.8	0.11	2014.888	2996	9.12	10.03	8	2
00417-1433	GAL 27	78.5	2.8	7.9	0.44	2014.874	1218	10.	11.	2	1
00428-0955	HJ 1995	128.0	0.3	42.4	0.18	2014.784	2812	6.69	11.32	4	1
00450+2210	LDS 869	197.5	0.2	121.6	0.39	2014.877	2183	10.70	12.8	2	1
00487+1841	TOK 224AB	138.8	0.2	151.5	0.47	2014.877	1146	7.67	10.83	2	1
00550+2406	ENG 3	206.9	0.2	37.8	0.16	2014.795	3199	8.81	10.51	4	1
00555+2457	POU 76	194.1	1.5	17.7	0.45	2014.805	1617	11.83	12.2	2	1
01007-3112	HJ 3410	73.1	0.8	22.2	0.29	2014.805	1650	11.05	12.18	2	1
01020-2959	HJ 3411	2.5	0.7	25.0	0.30	2014.805	1696	9.43	11.46	2	1
01045-3024	PRO 3	277.7	2.3	6.9	0.31	2014.805	1688	9.9	10.2	2	1
01072+3839	STTA 11AB,C	164.2	0.2	59.3	0.18	2014.888	3716	7.62	8.77	4	1
01078+2452	POU 100	83.0	2.2	8.4	0.31	2014.877	1609	11.9	13.5	2	1
01097+3537	KUI 5BJ	94.3	0.6	45.4	0.48	2014.877	820	14.4	13.7	2	1
01107-2800	SWR 1	116.0	1.2	15.7	0.35	2014.805	1630	12.21	12.2	2	1
01116-2624	LDS 37	338.0	1.8	10.8	0.30	2014.805	1658	11.43	12.5	2	1
01137-3107	PRO 4	20.3	0.4	10.8	0.14	2014.805	1700	7.8	11.2	2	1
01141-3022	HDS 161	219.0	1.3	13.7	0.28	2014.805	1675	9.41	13.01	2	1
01147-3500	HDS 163	354.0	1.8	7.4	0.18	2014.805	1781	10.71	13.26	2	1
01171-3055	UC 535	125.7	0.8	18.0	0.17	2014.805	1653	9.4	13.4	2	1
01177-2812	B 16AB	276.1	0.4	34.6	0.19	2014.805	1487	9.3	12.0	2	1
01177-3018	LDS2181	176.9	1.7	7.7	0.32	2014.877	1498	13.7	14.2	2	1
01191-2729	HJ 3425	253.7	2.2	7.2	0.26	2014.877	1497	10.7	11.2	2	1
01228-3038	HJ 3432	221.1	1.2	8.3	0.21	2014.877	1531	8.97	10.95	2	1
01233-3329	RSS 48	99.3	0.9	18.5	0.31	2014.877	1613	9.17	12.0	2	1

Table 2 continues on next page.

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Table 2 (continued). Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
01245+3902	STTA 17AB	101.5	0.3	35.8	0.14	2014.888	3581	7.96	9.80	4	1
01245+3902	STTA 17AC	347.4	0.1	134.9	0.21	2014.888	3644	7.96	8.47	4	1
01245+3902	STTA 17CD	279.0	0.2	68.5	0.18	2014.888	3195	8.47	9.79	4	1
01253-2743	UC 556	128.5	1.0	44.5	0.77	2014.805	1493	14.5	14.4	2	1
01261-2618	SWR 2	82.4	0.4	44.5	0.26	2014.805	1451	10.0	10.3	2	1
01270-3058	RSS 3	344.4	0.7	32.9	0.44	2014.877	1676	9.03	9.73	2	1
01291+2143	HO 9AB	41.8	0.2	51.4	0.18	2014.795	3032	7.84	10.35	4	1
01301-4024	BVD 17	176.0	1.5	20.0	0.57	2014.877	2373	12.03	12.07	3	1
01304-1903	ARA 518	310.9	1.7	12.0	0.32	2014.877	1407	10.7	12.5	2	1
01323-2633	ARG 4	72.8	0.7	17.8	0.24	2014.805	1588	7.99	9.14	2	1
01328-4115	HJ 3445	265.5	1.0	18.6	0.22	2014.877	1894	9.26	10.40	2	1
01350+2753	MLB 634	167.9	2.9	7.0	0.31	2014.871	1554	12.71	13.5	2	1
01355-3211	JKS 3	238.8	0.3	94.2	0.42	2014.871	1381	9.98	11.20	2	1
01361-3718	HJ 3448	57.3	0.6	28.7	0.25	2014.877	1761	9.23	9.88	2	1
01386-4113	CPO 110	74.9	0.4	73.1	0.40	2014.877	1610	11.52	12.26	2	1
01397-3728	HJ 3452	276.8	1.0	19.5	0.29	2014.871	1779	7.41	8.88	2	1
01405-2413	AHD 12	138.4	0.6	14.9	0.17	2014.871	1585	10.0	13.	2	1
01410-0524	TOK 228	31.6	0.1	125.1	0.30	2014.877	1236	8.56	12.10	2	1
01413-3404	UC 603	206.8	1.6	14.9	0.33	2014.871	1781	13.5	14.5	2	1
01415-2454	ENO 1	53.3	1.0	12.9	0.22	2014.871	1613	10.11	13.0	2	1
01469-2740	RSS 50	6.6	0.7	32.0	0.41	2014.871	1656	8.82	12.0	2	1
01487-2916	HJ 3466	52.6	0.8	31.0	0.39	2014.871	1586	9.52	11.24	2	1
01526-2636	BGH 8	170.6	0.4	92.3	0.69	2014.877	1580	9.90	9.96	2	1
01530-2805	HJ 3472	240.6	2.1	6.1	0.20	2014.877	1672	9.93	10.05	2	1
01560-3057	JSP 859	149.0	1.8	6.4	0.17	2014.877	1739	9.89	12.9	2	1
01574-2928	RSS 52	256.2	0.6	26.5	0.31	2014.877	1553	9.89	13.0	2	1
01590-2921	UC 652	163.2	1.2	33.5	0.59	2014.877	1645	12.9	14.5	2	1
02005-3107	UC 659	119.9	2.1	11.7	0.38	2014.877	1718	11.6	11.8	2	1
02022+1120	J 1080AC	318.4	1.6	15.1	0.41	2014.877	1439	11.40	14.13	2	1
02027-3019	HJ 3478	150.1	0.3	42.6	0.24	2014.877	1649	8.18	8.89	2	1
02039-2526	UC 678	94.5	0.9	29.5	0.47	2014.877	1556	12.5	13.6	2	1
02057-2423	I 454AB,C	257.6	0.4	56.9	0.40	2014.877	1399	8.68	8.99	2	1
02114+0936	LDS3353	334.2	1.4	25.3	0.63	2014.871	1363	9.99	14.4	2	1
02131+0404	BAL2098	231.6	2.9	10.7	0.53	2014.871	1472	12.71	12.71	2	1
02173-3108	PRO 5	171.2	2.0	14.7	0.50	2014.877	1708	10.7	11.5	2	1
02186-2940	B 34AC	99.0	0.5	38.4	0.33	2014.871	1536	9.01	10.41	2	1
02517+3854	ROE 67AB	129.3	0.5	27.3	0.20	2014.888	3704	8.92	10.57	4	1
03027+0414	BAL2110	226.6	1.3	9.1	0.21	2014.860	3012	9.6	9.9	4	1
03032-0215	J 1455	61.4	2.7	6.1	0.29	2014.860	2172	11.5	11.8	1	1
03142+1603	SLE 34	45.8	3.5	8.8	0.49	2015.052	1356	13.4	14.8	2	1

Table 2 continues on next page.

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Table 2 (continued). Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
04259-0124	STF 547AB	121.1	1.2	7.7	0.18	2014.860	2995	9.42	12.4	4	1
04259-0124	STF 547AC	258.1	0.0	214.0	0.16	2014.860	1365	9.42	6.85	4	1
05047+3954	ALI1047	93.8	1.5	9.4	0.17	2014.888	4161	12.39	13.4	2	1
05342+2401	POU 728	46.5	2.4	14.6	0.56	2015.052	1558	14.8	14.8	2	1
05499+2316	POU 788	125.6	3.4	4.5	0.31	2015.052	1563	11.35	12.6	2	1
05511+2344	POU 794	268.0	1.3	10.1	0.28	2015.052	1571	10.79	12.8	2	1
06171-2243	HJ 3845	358.4	0.3	60.6	0.38	2015.049	1565	6.06	10.44	2	1
06179+0919	OPI 9	245.1	3.2	5.3	0.37	2015.049	1231	11.68	13.0	2	1
06272+1118	J 1945	275.1	2.0	7.2	0.48	2015.049	1470	11.29	11.3	2	1
06296-0215	BAL 62	174.0	1.9	9.0	0.32	2015.049	1489	10.99	11.05	2	1
06311-2244	ARA1649	183.5	1.5	10.9	0.34	2015.049	1596	11.85	12.1	2	1
06321+0300	BAL2176	290.9	2.2	12.5	0.53	2015.049	1445	12.3	12.6	2	1
06426+0000	BAL1013	285.0	2.2	14.0	0.63	2015.049	1423	10.86	11.2	2	1
06432-0245	BAL 71	355.7	0.0	11.8	0.05	2015.049	1470	8.6	11.3	2	1
06442-0117	BAL 333	6.5	1.7	12.2	0.37	2015.049	1490	9.54	11.8	2	1
17097+3021	STF2131AB	179.0	0.7	24.1	0.24	2014.477	3478	8.39	9.80	4	1
17178+2844	S 686	4.1	0.4	49.7	0.22	2014.477	3376	8.17	9.30	4	1
18496+3818	AG 226	53.9	0.5	25.9	0.16	2014.564	3690	10.12	10.23	4	1
18523+3926	WEI 33	329.2	0.1	99.3	0.14	2014.564	3462	8.96	8.99	4	1
18530+3621	HJ 1354	4.9	1.1	10.1	0.17	2014.564	3810	10.01	9.97	4	1
18581+3813	SP 2AE	350.0	0.1	160.2	0.15	2014.564	3549	9.61	5.87	4	1
18581+3813	SP 2BE	329.9	0.1	150.2	0.16	2014.564	3054	9.93	5.87	4	1
18581+3813	STF2427AB	59.5	0.2	55.0	0.15	2014.564	3417	9.61	9.93	4	1
18581+3813	STF2427AC	61.7	0.2	61.7	0.18	2014.564	3346	9.61	10.20	4	1
18581+3813	STF2427BC	78.7	1.8	7.1	0.17	2014.564	3789	9.93	10.20	4	1
19126+1651	STTA177AC	276.1	0.1	98.2	0.18	2014.562	2405	7.11	8.02	4	1
19133+1934	HO 573	127.9	1.9	7.9	0.26	2014.562	1496	9.75	10.2	4	1
19135+3902	SHJ 289	56.5	0.3	39.1	0.13	2014.564	3620	8.01	8.71	4	1
19153+1505	STTA178	266.8	0.1	89.8	0.18	2014.562	2442	5.69	7.64	4	1
19159+2018	J 2959AB	186.8	0.1	93.0	0.22	2014.562	3115	7.79	11.8	4	1
19188+1937	AG 432	317.2	0.1	91.8	0.19	2014.562	2725	6.50	9.68	4	1
19207+1425	STTA180	266.1	0.1	79.8	0.18	2014.562	2518	7.87	8.83	4	1
19426+4002	BUP 196	165.5	0.1	105.9	0.13	2014.564	3729	7.90	8.31	4	1
19429+0115	HJ 895AC	25.0	0.4	30.0	0.21	2014.726	2894	8.61	9.66	4	1
19479+1002	AG 391	295.7	0.2	52.1	0.19	2014.800	2684	7.72	9.19	4	1
19487+2048	KU 124	283.8	0.2	49.6	0.18	2014.562	2879	9.87	10.55	4	1
19534+2020	STFA 48AB	146.5	0.2	41.8	0.18	2014.562	3085	7.14	7.34	4	1
19550+0441	BAL2954AB	208.4	1.6	13.2	0.42	2014.786	1463	11.57	11.5	2	1
19557+4024	HJ 604	93.0	0.1	70.8	0.14	2014.564	3260	7.35	9.33	4	1
19572+4022	BU 1474AB	314.6	0.2	63.5	0.15	2014.564	3506	5.44	9.31	4	1

Table 2 continues on next page.

Table 2 (continued). Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
19578+1520	J 2294	162.9	1.4	9.4	0.25	2014.786	1527	11.87	13.1	2	1
20008+2949	BU 439AC	200.8	0.5	37.7	0.28	2014.786	1636	7.89	12.0	2	1
20015+0040	HDO 315	199.6	0.9	7.7	0.19	2014.786	1447	9.04	12.5	2	1
20068+3203	SEI 881	312.1	1.7	7.1	0.21	2014.789	1715	10.64	11.18	2	1
20076+1655	BRT1337AB	222.3	2.0	5.0	0.18	2014.786	1527	10.2	10.9	2	1
20077+0446	ARN 20AD	126.5	0.1	99.1	0.18	2014.726	2447	9.67	8.91	4	1
20077+0446	STF2627AC	260.5	0.1	82.2	0.19	2014.726	2418	9.67	7.70	4	1
20079+0836	J 1873	174.6	2.2	7.2	0.27	2014.786	1476	12.42	12.87	2	1
20092+3540	SEI 922	215.2	1.3	18.4	0.31	2014.786	1779	11.86	12.4	2	1
20101+3617	SEI 939	217.4	0.6	26.9	0.26	2014.786	1751	10.0	11.0	2	1
20104+3644	SEI 945AB	276.6	2.0	6.0	0.20	2014.786	1456	9.5	11.0	2	1
20110+3559	SEI 961	19.9	1.5	13.7	0.25	2014.786	1818	10.96	12.2	2	1
20117+0146	HJ 906AB	156.1	1.0	13.3	0.20	2014.726	2895	11.23	11.8	4	1
20125+3717	SEI1005	55.9	0.8	26.4	0.26	2014.789	1753	11.81	11.8	2	1
20128+3638	SEI1010	24.7	0.8	31.4	0.34	2014.789	1756	10.78	10.8	2	1
20142+0635	S 740	191.7	0.2	42.9	0.18	2014.800	3016	7.77	8.06	4	1
20183+2002	HJ 912AC	169.5	0.1	88.5	0.17	2014.562	3143	10.65	9.02	4	1
20244+1935	STF2679AB	78.2	0.4	24.4	0.16	2014.562	3061	7.88	9.69	4	1
20244+1935	STF2679AC	149.9	0.4	39.2	0.26	2014.562	2979	7.88	11.56	4	1
20321+1358	HJ 1527	270.0	1.2	10.6	0.27	2014.789	1467	12.05	12.44	2	1
20344-4221	DON 988AB,C	270.1	0.7	23.1	0.32	2014.789	1870	9.41	10.35	2	1
20355+3510	POP 6	218.4	3.4	6.4	0.32	2014.789	1756	11.98	12.2	2	1
20391-0942	J 1400AB	20.5	3.1	3.7	0.24	2014.789	1520	11.96	12.4	2	1
20391-0942	J 1400AC	230.9	1.5	12.2	0.36	2014.789	1443	11.96	13.3	2	1
20480-3523	B 2892	105.1	1.3	7.5	0.17	2014.792	1786	9.31	12.0	2	1
20500+0533	STTA210AB	127.1	0.1	78.2	0.19	2014.800	2575	6.30	9.18	4	1
20501+3714	CLL 15AC	20.5	0.3	48.1	0.23	2014.792	1807	10.71	10.93	2	1
20506-3645	B 2893	295.5	1.4	9.5	0.22	2014.792	1799	9.85	11.9	2	1
20527+0720	STF2733	144.4	0.2	39.7	0.17	2014.800	2889	8.39	8.58	4	1
20567-0600	J 2330AB	114.2	2.6	6.2	0.33	2014.789	1140	11.58	11.6	2	1
20596+3216	GYL 43	7.4	0.7	29.8	0.25	2014.789	1732	12.16	12.2	2	1
21005+1920	BU 1497	336.6	0.3	49.3	0.22	2014.800	3048	5.89	10.00	4	1
21026+2141	BU 69AC	240.9	0.2	74.3	0.19	2014.800	2423	8.35	8.02	4	1
21046+1201	BU 70AB	240.2	0.2	81.3	0.24	2014.786	2360	8.56	11.41	4	1
21046+1201	BU 70AC	236.0	0.2	74.5	0.25	2014.786	2557	7.6	10.0	4	1
21047+2446	POU5135	202.5	5.7	4.4	0.71	2014.792	1454	13.9	14.2	2	1
21054+3937	CRB 137	172.0	0.9	29.0	0.37	2014.792	1901	11.3	14.0	2	1
21069+3845	STF2758AD	267.8	0.0	336.5	0.17	2014.789	405	5.35	10.45	4	1
21079-1013	BU 473AC	15.5	0.4	39.0	0.26	2014.792	1416	8.86	12.6	2	1
21111-3041	HJ 5248	319.3	3.2	5.3	0.33	2014.792	1640	12.32	12.9	2	1

Table 2 continues on next page.

Double Star Measures Using the Video Drift Method - VI

Table 2 (continued). Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
21140+1106	TOB 316BC	87.7	0.6	21.5	0.31	2014.784	2914	10.62	12.32	4	1
21143+2522	POU5283AB	84.4	0.8	15.9	0.20	2014.789	2404	10.1	11.9	3	1
21156+3600	SEI1479	76.0	1.1	26.9	0.47	2014.805	1739	11.08	12.1	2	1
21181+1646	J 3238AC	210.1	0.5	31.0	0.31	2014.789	1455	12.0	11.98	2	1
21182-0224	J 1719	168.7	2.0	5.2	0.18	2014.805	2171	10.77	14.0	3	1
21251+0923	STF2793AB,C	241.4	0.2	26.4	0.12	2014.726	5753	7.44	8.98	8	2
21371+2503	POU5434AC	130.3	5.7	4.4	0.54	2014.805	1305	12.9	13.6	2	1
21385+0546	HJ 941	309.3	0.4	33.3	0.27	2014.792	1373	5.67	11.8	2	1
21442-3505	UC 4541	303.5	0.4	74.8	0.51	2014.805	1512	11.6	12.6	2	1
21484-0506	SCA 97	45.5	0.6	36.1	0.41	2014.805	1397	11.94	12.3	2	1
21486+1440	HJ 1693	313.4	1.0	11.5	0.20	2014.786	3019	10.52	10.54	4	1
21494+3045	STF2829	15.6	0.6	16.8	0.17	2014.800	3455	8.91	9.66	4	1
21496-0026	BAL 933	153.7	1.7	9.4	0.34	2014.805	1480	12.82	12.83	2	1
21497+3415	KU 133	180.0	0.2	48.7	0.17	2014.800	3592	9.44	9.89	4	1
21509+3240	ES 382AC	322.1	0.2	57.9	0.17	2014.800	3310	8.28	8.42	4	1
21543+1333	BU 1213AB	258.5	0.1	64.3	0.17	2014.786	2584	8.64	11.00	4	1
21559+2753	HJ 1704	316.5	2.6	5.2	0.27	2014.805	1644	12.93	13.01	2	1
21575+0409	STTA225	286.3	0.1	75.1	0.12	2014.726	4977	7.10	8.57	8	2
22019+0446	STTA228AB	23.1	0.1	85.7	0.13	2014.726	5521	8.79	9.83	8	2
22029-0054	BAL 627	205.3	0.9	8.6	0.15	2014.655	2954	9.91	11.0	4	1
22090-3604	RSS 567	175.9	0.4	49.1	0.29	2014.805	1812	7.56	10.45	2	1
22100+0757	STF2867AB	208.0	0.9	10.4	0.15	2014.784	3017	8.31	9.31	4	1
22145+0759	STF2878AC	119.1	0.2	69.0	0.29	2014.784	2563	6.94	10.68	4	1
22145+0759	STF2878AD	273.6	0.1	124.9	0.43	2014.784	2084	6.94	10.78	4	1
22151-1018	UC 4694	345.0	1.9	8.3	0.30	2014.805	1494	12.3	12.3	2	1
22152-4412	RSS 569	97.9	0.4	55.0	0.31	2014.805	1784	8.58	9.65	2	1
22173-4123	SKF1106	183.6	1.9	7.6	0.23	2014.805	1998	10.5	11.3	2	1
22183-3846	UC 4712	8.3	0.4	79.4	0.43	2014.805	1847	9.9	14.5	2	1
22199-3635	RSS 571	177.6	0.6	24.1	0.18	2014.805	1812	10.44	13.0	2	1
22199-3642	HJ 5326	300.6	2.0	6.5	0.22	2014.805	1803	10.51	10.66	2	1
22218-0150	SCA 126	331.0	0.1	82.9	0.17	2014.655	2707	9.84	10.78	4	1
22235+0351	STTA232AB	193.3	0.1	75.4	0.13	2014.726	5809	9.22	9.46	8	2
22237-3805	UC 4732	242.4	1.9	10.2	0.32	2014.805	1830	14.0	14.4	2	1
22258-3705	UC 4742	54.4	2.4	11.3	0.41	2014.805	1799	13.3	14.3	2	1
22263-1839	BHA 52	172.3	1.9	7.2	0.26	2014.805	1551	12.26	12.88	2	1
22279+0442	ENG 85AB	227.3	0.1	80.5	0.16	2014.726	5085	4.91	10.0	8	2
22279+0442	ENG 85AC	251.1	0.0	176.3	0.15	2014.726	3385	4.91	10.64	8	2
22279+0442	ENG 85BC	268.7	0.1	108.0	0.14	2014.726	4132	10.0	10.64	8	2
22416+2947	CHE 366	6.4	0.4	21.6	0.13	2014.795	3475	10.09	10.23	4	1
22435+3114	ES 393AB	297.0	0.1	81.0	0.15	2014.795	2934	8.90	9.01	4	1

Table 2 concludes on next page.

Double Star Measures Using the Video Drift Method - VI

Table 2 (conclusion). Results of 227 double stars using the video drift method.

WDS	Designation	PA°	σ-PA	Sep"	σ-Sep	Date	No.(x,y) pairs	Mag Pri	Mag Sec	Drifts	Nights
22476+3158	CHE 433	120.6	0.4	27.5	0.18	2014.795	3398	9.42	11.57	4	1
22478-0414	STF2944AC	86.4	0.1	61.4	0.16	2014.655	2538	7.30	8.58	4	1
22597-0422	STF2964	278.9	1.1	8.7	0.17	2014.655	2940	8.29	9.54	4	1
23026+2948	TOK 352	249.3	0.4	45.2	0.32	2014.879	1514	8.92	14.66	2	1
23045+3123	ES 396	303.0	0.3	34.8	0.15	2014.795	3321	10.84	10.91	4	1
23077+0636	STF2976AB	260.7	1.4	7.7	0.18	2014.726	3007	9.13	10.63	4	1
23077+0636	STF2976AC	208.8	0.3	21.0	0.11	2014.726	5925	9.13	9.46	8	2
23095+0841	STF2982AB	197.7	0.3	32.6	0.23	2014.721	2904	5.29	10.06	4	1
23103+3229	HJ 5532AB,C	77.3	0.2	57.9	0.15	2014.795	3067	7.10	9.43	4	1
23141-0855	S 826AC	130.8	0.1	79.7	0.17	2014.655	2610	7.55	9.10	4	1
23141-0855	S 826BC	115.1	0.2	64.4	0.17	2014.655	2634	8.17	9.10	4	1
23141-0855	STF2993AB	175.5	0.4	24.8	0.16	2014.655	3013	7.60	8.17	4	1
23159-0905	STFB 12A,BC	311.6	0.2	48.9	0.21	2014.655	2725	4.36	9.88	4	1
23171-1349	BU 182AB,D	101.8	0.2	87.3	0.34	2014.879	1193	8.16	11.0	2	1
23189+0524	BU 80AC	338.9	0.1	119.6	0.14	2014.784	5388	8.18	11.27	8	2
23189+0524	BU 80AD	321.2	0.0	225.4	0.18	2014.721	1938	8.18	9.99	5	2
23189+0524	BU 80AE	292.1	0.0	249.3	0.12	2014.784	2470	8.18	10.40	8	2
23189+0524	BU 80CE	264.5	0.0	188.1	0.13	2014.784	3019	11.27	10.40	8	2
23232+1226	HJ 3188AB	252.4	0.5	21.9	0.25	2014.784	2927	8.88	11.57	4	1
23269-3227	UC 4952	271.0	0.5	29.8	0.30	2014.879	1609	10.4	15.0	2	1
23305-2231	ARA2289AB	274.6	1.9	14.2	0.51	2014.805	1547	13.6	13.7	2	1
23305-2231	ARA2289AC	224.1	0.8	33.5	0.41	2014.805	1472	13.6	13.7	2	1
23305-2231	ARA2289BC	238.5	0.6	43.7	0.42	2014.805	1477	13.7	13.7	2	1
23386-3038	HJ 5412	51.2	1.3	16.2	0.34	2014.792	1676	9.92	11.35	2	1
23431-3101	LDS2996AB	79.5	1.8	8.8	0.29	2014.792	1658	10.63	12.6	2	1
23431-3101	LDS2996AC	195.1	0.7	28.9	0.32	2014.792	1704	10.63	12.4	2	1
23537-0140	HJ 3223	352.7	0.2	48.8	0.16	2014.786	3021	8.77	10.43	4	1

Table 2 Notes

All magnitudes were taken from the WDS catalog. All position angle/separation measurements are for the Equator and Equinox of date.

Column titled "**No. of (*x*,*y*) pairs**" is the total combined no. of (*x*,*y*) pairs (video frames) from all drift runs. All video frames were used, none were discarded.

The column "**drifts**" is the number of separate drifts made. "**Nights**" is the number of successive nights drift runs were made for that system.

WDS 01304-1903. A single observation in the WDS catalog from 1916 is likely a measurement of a mirror image. WDS PA = 39°, our measurement is 310.2°. Proper motions for the components are insignificant. WDS reports this double with an "X" code, meaning dubious to its existence. The WDS RA, DEC of the primary (not the secondary) was a match for the system we measured and from the POSS image. See Figure 1.

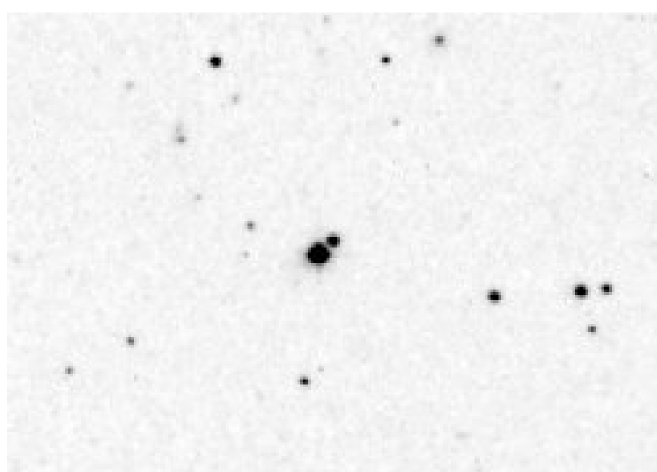

Figure 1. WDS 01304-1903. POSS image from 15-Sep-1954. North is up, FOV is 8 arc minutes. See Table 2 notes for discussion.

Wide and Faint Double Star Photometry and Measurement with Online Tools – Test Drive with Landolt Standard Stars and Example with ROE 76 in Perseus

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Abstract: Using Landolt standard stars as reference, it is shown that generally available online tools can with moderate efforts deliver reliable photometric results, and with the example of ROE 76 in Perseus it is also shown that measuring of wide double stars is quite possible. By chance ROE 76 also offered the possibility to do some astrometry with online tools.

Introduction

Old fashioned visual double star observers with session plans containing hops from one double to another often visit faint and wide pairs as humble hops between "more interesting" doubles. It is only a question of time untl it becomes evident that a good number of these objects are listed with questionable magnitudes in the WDS catalog (as is the case in most star catalogs). They are easy to recognize by the missing second digit in precision, indicating a possibly estimated or old measurement.

It is certainly possible to try to do a better estimating job than the discoverer and in this regard it might even be an advantage to be restricted to a smaller amateur telescope to be aware that the components of a specific double have to be much fainter than listed – else one would be able to resolve it in a humble amateur telescope. Some research can then be done in other star catalogs to check if there might be other magnitude information on the pair. Tycho II usually delivers a value for the primary, or a combined magnitude for both components, and USNO or UCAC4 most of the time give a suggested model fit or aperture photometry magnitude for the secondary if the separation is wider than 2". When lucky, APASS provides a precise measurement of the visual magnitude of the secondary (then listed in UCAC4 as Vmag), but this is not as often as desired. The USNO can then be informed about the latest observation and the data found elsewhere and (if necessary) get a change in the WDS data to the better, but the magnitude still remains an estimate (with the exception of an existing APASS value). It would then be nice to be able to do some photometry with reasonable effort.

Online telescope providers offer different levels of services and at least some deliver a rather professional quality for making images usable for photometry and other measurements. Such images can then be uploaded to the AAVSO online photometry tool *VPhot*. Prerequisite for using *VPhot* is a valid TIFF-header, good enough image quality for plate solving, usage of a photometry filter (especially V for visual magnitudes), and a definition of the parameters of the used telescope. Some online telescope providers even offer automatic plate solving and upload to *VPhot* so these steps can already be included in the imaging session plan.

After some initial experiments one quickly gets the feeling for selecting the suitable exposure time needed for good results with different levels of star brightness and other factors – long enough to get star disks with a good signal to noise ratio (SNR) and short enough to avoid overlapping of the star disks from primary and secondary. Stacking several images with rather short exposure time is also a good idea to get a better image quality, including better SNR.

Now comes the process of defining the sequence. First, select the objects for photometry. Then comes the critical step to select comparison stars in the field of view. Predefined AAVSO comp stars are rather scarce in some areas; the same goes for AAVSO standard stars. Surprisingly, APASS has no predefined VPhot source for comp stars, but this will hopefully be changed in the near future. SIMBAD might be used to select comp stars but the available catalogs rarely deliver reliable magnitudes for fainter stars.

An alternative is to use UCAC4 objects in the FoV with the given V-mags, assuming that such values are usually from APASS or sources of equivalent quality.

The next step is to select objects of similar quality for check stars to get an impression of how precise the delivered photometry results might be and to define photometry aperture radius and sky annulus. Then, save the sequence, click "Photometry Report", and see what result is obtained. Some adjustments might need to be made when the given measurement error seems too large, the check star indicates a questionable sequence, or some comparison stars seem a bad choice indicated by a red colored background in the target estimate column.

Test with Landolt Standard Stars

To check the quality of the results of such a procedure, I made an image of a group of stars with Landolt standard stars. The Landolt catalog consists of several hundred faint stars near the celestial equator with "approved" magnitudes used by AAVSO as "official" comp stars for photometry.

I selected the star field around TYC0012-00214-1 (Landolt 92 342 = AAVSO comp star #116) in Cetus and made a single image with a 12" f/9.3 RC-scope situated in Siding Spring, Australia with 15 s exposure time using the V filter. Due to the rather low altitude of ~ 32° the air mass was a rather high 1.888, but the image showed as planned four Landolt stars in good quality (Figure 1) .

In the first *VPhot* run, I selected the two northern stars with given UCAC4 Vmags as targets with three of the Landolt stars (92342, 92250, 92348) as comp stars and one Landolt star (92335) as a check star. This resulted in the photometry results given in Table 1.

This result shows that without any additional actions, like stacking, we get values well within a small error range. The next step in testing this setup is a change in direction using UCAC4 objects with Vmag values as comp stars and checking the results against the Landolt standard values. This resulted in the photometry results given in Table 2.

Again these results seem of very acceptable quality to me with even the worst result less off than 0.1mag and this with only two comp stars for three target stars and no actions at all to enhance the results – at least I think that such photometry results are certainly much better than the best possible estimates.

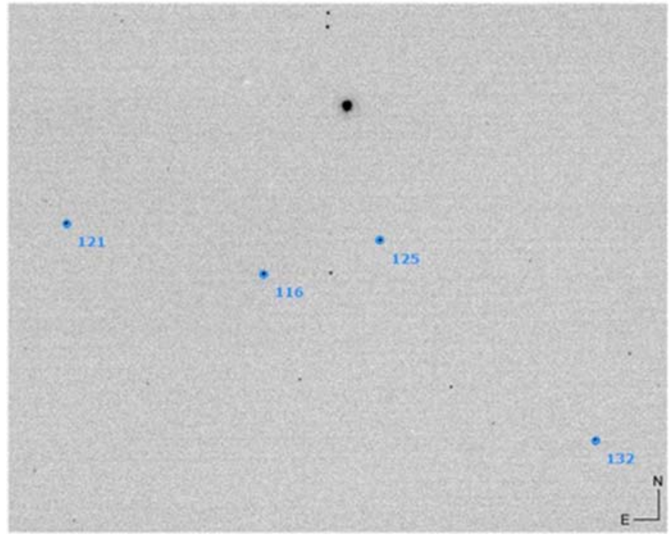

Figure 1. Test image with Landolt stars as AAVSO comp stars marked

Table 1: VPhot photometry results with standard comp stars

Name	Vmag	VPhot	Delta
UCAC4 455-001259	13.251	13.201	0.050
UCAC4 455-001260	12.805	12.855	0.050
Landolt 92335 (check)	12.523	12.559	0.036

Table 2: VPhot *photometry results with UCAC4 Vmag comp stars*

Name	Vmag	VPhot	Delta
Landolt 92250	13.178	13.088	0.090
Landolt 92342	11.613	11.638	0.025
Landolt 92348	12.109	12.110	0.001
Landolt 92335 (check)	12.523	12.559	0.036

Table 3. WDS values for ROE76

WDS	Comp	PA	Sep	Mags
03340+4048	AB	36	4.5	9.19, 10.3
03340+4048	AC	156	87.4	9.19, 10.58

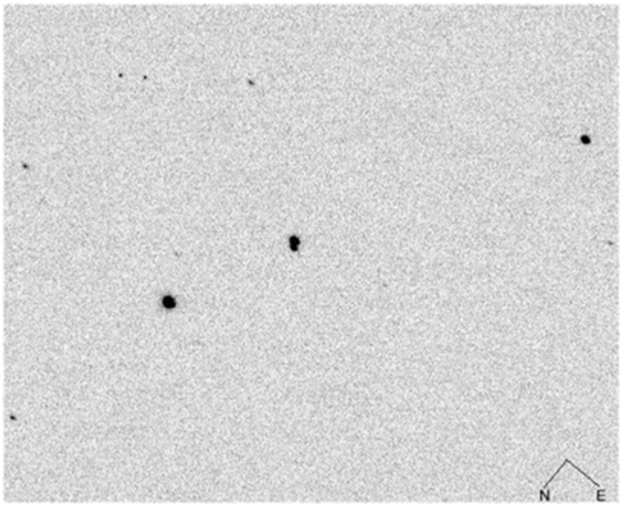

Figure 2. Image of ROE76

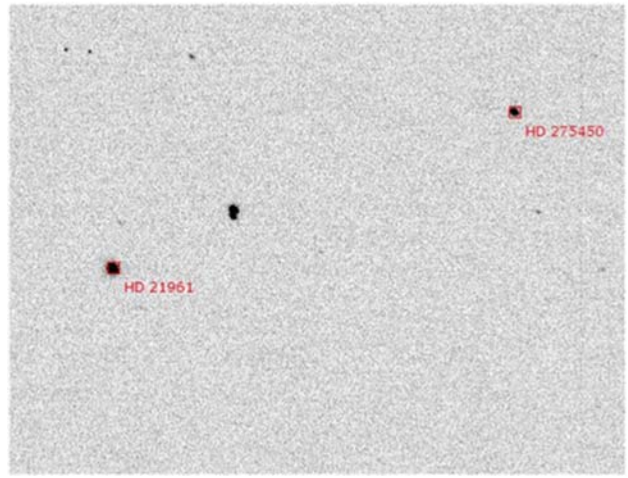

Figure 3. ROE 76 image with SIMBAD objects

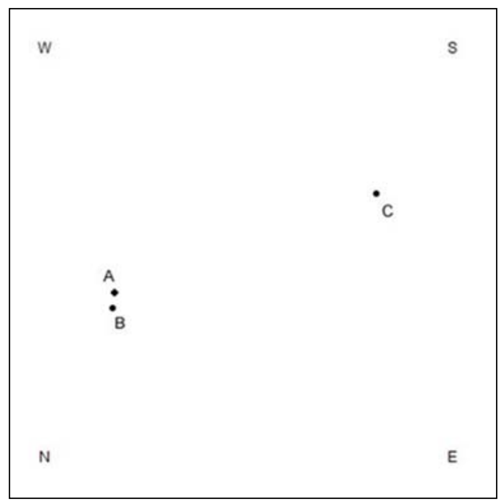

Figure 4. ROE 76 star map according to WDS

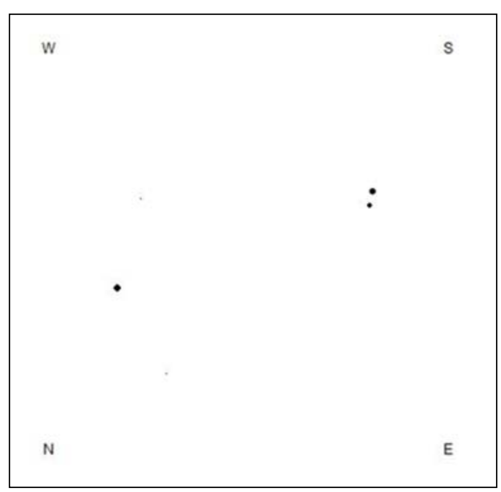

Figure 5. ROE map based on UCAC4

Example ROE76 in Perseus

ROE 76 is listed in WDS (on January 31, 2015) with the values shown in Table 3 and with precise RA 03:33:55.460 and Dec 40:49:36.498.

I selected this multiple because the magnitude for B is listed in the WDS with only single digit precision and a quick lookup in the UCAC4 catalog indicated missing objects for B and C. On January 17, 2015, at 7:00 PM I took a single image with a 5 s exposure with a 12" f/8 CDK scope (resolution 0.73" per pixel) located in Nerpio, Spain with V filter at an altitude of about 67° and thus an air mass of only 1.024 and got the image shown in Figure 2.

As a slight complication, this scope delivers images with a horizontal and vertical flip plus about a 45° rotation and there is a glitch in the data transfer between scope and *VPhot* as the image orientation *VPhot* indicates it is off by 90° - this is in this case very important, as a counter check with WDS showing that there is something wrong with the RA+Dec position given in the WDS catalog. The correct orientiation of the image could be easily checked by loading SIMBAD data into the image (Figure 3).

To check against the ROE 76 position data given in WDS, I made a star map based on WDS data (Figure 4). Next, I made a star map for the same field of view with the UCAC4 catalog, shown in Figure 5.

This is a clear hint that there might be something wrong with the WDS position data for ROE76. With the help of *Aladin*, I looked at the 2MASS image for HD 21961 and found another confirmation that the WDS data is wrong. Assuming RA/Dec coordinates for A and separation and PA for the components as given, this means a mismatch of positions and objects. AC would then be AB with RA and Dec as given and AB

Table 4. UCAC4 mags for ROE76 components (1=Vmag, 2=model fit)

ROE76	UCAC4	WDS mag	UCAC4 mag
A	655-016333	9.190	9.500 1)
B	655-016340	10.300	10.238 1)
C	455-001260	10.580	11.636 2)

would be BC with RA 03:33:58.608 and Dec 40:48:16.848.

Now comes the topic of magnitudes. First, we can check again UCAC4 as we have now a UCAC4 object for each ROE76 component, Table 4.

For the C component, UCAC4 lists no Vmag (confirmed with negative APASS query), so we have to settle with the model fit magnitude estimation (usually more reliable than the aperture photometry value, in this case a rather odd +10.391). These values indicate a potential problem with the magnitude for C (and not with B, as was the initial idea for this research), so the next step is photometry with VPhot. The image quality may not be perfect as the star disks for B and C are touching (so it might have been better to make several images with shorter exposure time and stack them), but we have to use what we have and it works rather well. We have a good number of UCAC4 comp stars with Vmags available as shown in Table 5. Table 6 gives the results from Vphot.

Table 5: Comp stars for ROE 76

Object	Vmag
UCAC4-654-015822	11.929
UCAC4-654-015857	10.934
UCAC4-655-016242	10.413
UCAC4-655-016292	12.323

Table 6. Vphot results for ROE 76

Name	Vmag	VPhot	Delta
ROE76A	9.190	9.134	-0.056
ROE76B	10.300	10.431	0.131

This result is obviously in a reasonable error range suggested by the values for the check stars and suggests that the WDS mags for A and B are within some error range correct but that C is about 1 mag fainter than listed, as already indicated by the UCAC4 model fit magnitude.

As VPhot offers also a tool for calculating separation and position angle, we can check also these values, with the result shown in Table 7.

Table 7: Separation and Position Angle for ROE76 according to VPhot compared to WDS (with switched components)

	WDS		VPhot	
Object	Sep	PA	Sep	PA
ROE76AB	87.4	156	87.3	155.9
ROE76BC	4.4	36	3.77	38.73

Besides the switch of components, these results confirm the WDS values at least for AB with some minor doubts for BC – but we have to consider the lack of precision of the VPhot results depending on image resolution (0.73" per pixel). But as we have now a precise RA/Dec values from UCAC4 we can do precise calculations for separation and PA

Finally, we get the photometry and measurement result for ROE76 shown in Table 8.

Conclusions

The setup with iTelescope and AAVSO VPhot is already in the simple form with single images quite useful for photo- and astrometry for wide faint double stars especially for the determination of the magnitude of rather faint secondaries. There is still room for improvements with stacking and other techniques providing better image and data quality and reducing random errors. It would also be useful to do additional photometry with B filter to be able to calculate the B-V color index indicating the degree of reddish tint, making it more demanding for visual resolution.

Acknowledgements

The following tools and resources have been used for this research:

- Washington Double Star Catalog
- iTelescope
- AAVSO VPhot
- AAVSO APASS
- UCAC4 catalog via the Uni Heidelberg website
- Landolt catalog of standard stars
- Aladin Sky Atlas CDS, SIMBAD, VizieR
- 2MASS All Sky Catalog
- AstroPlanner

Many thanks to Ed Wiley and Brian Mason for encouraging me to write this report

Table 8: ROE76 photometry and measurement results

Name	WDS ID	RA	Dec	Sep	PA	M1	M2	Date	N	Notes
ROE76AB	03340+4048	03:33:55.465	+40:49:36.485	87.26	155.87	9.134	10.431	2015.05	1	1)
ROE76BC	03340+4048	03:33:58.608	+40:48:16.848	4.46	35.31	10.431	11.513	2015.05	1	2)

Notes:

1. RA and Dec from UCAC4. Calculation of Sep and PA with the formulas provided by Buchheim 2008. In comparison with the current WDS data per 2015-01-31 this report also includes a change in components with AB instead of AC due to an positional error in the WDS catalog
2. RA and Dec from UCAC4. Calculation of Sep and PA with the formulas provided by Buchheim 2008. In comparison with the current WDS data per 2015-01-31 this report also includes a change in components with BC instead of AB and a corresponding change in RA and Dec due to an positional error in the WDS catalog.

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Measurements of Neglected Double Stars: February 2015 Report

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Abstract: This article presents measurements of 44 double stars. The stars were selected from the Washington Double Star Catalog published by the United States Naval Observatory. The photographs were taken by remote telescopes. The measurements were done by the author.

Methodology

Photographs were taken using telescopes operated by the SLOOH observatories, which are part of the Institute of Astrophysics. One of the observatories is located in the Canary Islands near the west coast of Africa. That telescope is located at an elevation of 2,300 meters on the island of Tenerife. The instrument has a focal length of 3,910mm, an aperture of 356mm, and is a Celestron unit of Schmidt-Cassegrain design. The other observatory is located near Santiago, Chile. That telescope is the same model as the unit located in the Canary Islands. The methods used to calibrate the instruments of the SLOOH observatories are unknown to this author.

The camera used most frequently was a CCD SBIG 10XME, but some photographs were taken using a CCD SBIG 2000XM. The photographs were analyzed by the author using the programs CCD Soft v5 and SKY 6 The two programs are products of Software Bisque.

After accumulating the photographs, averages were calculated for the position angles and separations. All of the star patterns were compared with the data from ALADIN (part of the SIMBAD site), or with the SKY X program to insure correctness. After measuring each star and calculating the results, comparisons were made with the published data. The results are listed in the tables, which contain averages of measurements, or, in the case of a single measurement, the actual value. The statistical calculations were rounded to one decimal place in accord with significant figure rules.

Report

The following information was reported for each star: the WDS code with components, the discoverer code, the constellation, the position angle, the separation, the date of the first observation, and, under measures by the author, the results of other authors. The number of measurements, and the WDS values were taken from the WDS on the first observation date.

The column headings are: Washington Double Star identifier and components, DC = Discovery Code, PA = position angle, SD = standard deviation, SE = standard error of the mean, Sep = Separation, Mts = number of measurements, Con = Constellation, and the first observation date.

Acknowledgements

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This research made use of the SIMBAD database operated at CDS, Strasbourg, France, and the Washington Double Star Catalog maintained by the United States Naval Observatory.

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
04307-5838 AB	LDS123	***218.8***	***0.0***	***0.0***	***67.7***	***0.0***	***0.0***	4	DOR	2014 12 08
WDS		225			65					1920
WDS		219			67.8			5		2010
04307-5838 AC	LDS123	***157.3***			***111.3***			4		2014 12 08
OAG (Tobal)		158			112.1					1983
WDS		158			111.7					1910
WDS		157			111.2			8		2010

Other identifiers: CCDM J04308-5838A, CD-58 942, CPC 201132, CPD-58 391, GSC 08515-00434, HD 29016, HIP 21048, IDS 04290-5850A, TYC 8515-434-1, WT 146

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05210+3728 AB	SEI 203	***252.1***	***0.1***	***0.1***	***21.5***	***0.1***	***0.1***	4	AUR	2014 10 25
JDSO (Buchheim)		251.9			21.4					2008
WDS		251			21.9					1895
WDS		252			21.4			7		2008
05210+3728 AC	TOB 28	***75.3***	***0.1***	***0.1***	***53.3***	***0.1***	***0.0***	4	AUR	2014 10 25
WDS		75			53.6					1982
WDS		75			53.3			3		2008

Other identifiers: CCDM05230+3729A; IDS 05142+3722A

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05231+3802 AB	SEI 225	***87.6***	***0.3***	***0.2***	***26.3***	***0.2***	***0.1***	3	AUR	2014 10 25
JDSO (Berkó)		87.4			26.3					2009
OAG (Tobal)		87.5			26.2					1982
WDS		88			25.6					1895
WDS		88			26.2			8		2009

Other identifiers: CCDM J05232+3802A; IDS 05163+3756A; 2MASS J05230898+3801383

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05284+3546 AB	**SEI 277**	***187.1***	***0.2***	***0.1***	***24.9***	***0.1***	***0.0***	**4**	**AUR**	**2014 10 18**
JDSO (Williams)		187.0			24.9					2010
WDS		186			25.1					1895
WDS		187			24.9			7		2009
05284+3546 AC	**SEI 276**	***209.0***	***0.1***	***0.1***	***18.0***	***0.0***	***0.0***	**4**	**AUR**	**2014 10 18**
WDS		207			17.8					1895
WDS		209			17.9			5		2009
05284+3546 BD	**WSI 40**	199.0	0.1	0.0	10.3	0.0	0.0	**4**	**AUR**	**2014 10 18**
WDS		199			10.3					1998
WDS		199			10.2			4		2009

Other identifiers: CCDM J05284+3546A; IDS 05217+3540A; 2MASS J0528679+3545310

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05288+3547 AB	**SEI 286**	***107.7***	***0.2***	***0.1***	***23.3***	***0.1***	***0.0***	**4**	**AUR**	**2014 10 18**
WDS		106			23.6					1895
WDS		108			23.2			10		2009
05288+3547 AC	**SEI 287**	***50.2***	***0.0***	***0.0***	***24.8***	***0.1***	***0.1***	**4**	**AUR**	**2014 10 18**
WDS		50			24.7					1895
WDS		50			24.8			6		2009
05288+3547 BC	**SEI 288**	***352.3***	***0.1***	***0.0***	***23.2***	***0.0***	***0.0***	**4**	**AUR**	**2014 10 18**
WDS		352			22.7					1895
WDS		352			23.2			7		2009
05288+3547BD	**BKO 257**	***132.9***	***0.1***	***0.0***	***16.2***	***0.1***	***0.1***	**4**	**AUR**	**2014 10 18**
WDS		133			16.0					1895
WDS		134			15.9			4		2009

Other identifiers: GSC 02415-00080; IDS 05221+3543; TYC 2415-80-1; UCAC3 252-54307

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05485-1322 A-BC	**STF 801**	***326.0***	***1.8***	***0.8***	***27.4***	***0.7***	***0.3***	**7**	**LEP**	**2015 01 05**
JDSO (Nugent))		327.5			26.8					2014
OAG (Comellas)		327.5			26.8					1980
OAG (Comellas)		325.4			25.6					1995
OAG (Comellas)		327.1			27.1					1997
WDS		326			26.9					1902
WDS		329			26.9			5		2013

Other identifiers: ADS 4410A; BD-13 1253; CCDM J05485-1322A; CSI-13 1253 1; GSC 05359-01776;HIP 27426; IDS 05439-1324A; PPM 216302; SAO 150823; SRS 6641; TYC 5359-1776-1

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
05553+2023 AB	J 1914	***256.9***	***0.8***	***0.4***	***7.6***	***0.2***	***0.1***	5	ORI	**2014 12 05**
WDS		254			7.7					1893
WDS		256			7.8			10		2009

Other identifiers: TYC 1320-964-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06072-2216 AB	**ARA 1638**	***179.0***	***2.1***	***0.7***	***13.4***	***0.0***	***0.0***	8	**LEP**	**2014 12 16**
JDSO (Nugent)		182			12.4					2013
WDS		175			14					1920
WDS		182			12.4			9		2013
06072-2216 AD	**ABH 37**	***48.0***	***0.7***	***0.2***	***35.3***	***0.5***	***0.2***	8	**LEP**	**2014 12 16**
WDS		50			36.2					1987
WDS		49			35.4			3		1999
06072-2216 AE	**ABH 37**	***294.7***	***0.4***	***0.1***	***45.3***	***0.6***	***0.2***	8	**LEP**	**2014 12 16**
WDS		295			44.9					1987
WDS		295			44.8			3		1999

Other identifiers: ASAS J060712-2215.9; BD-22 1319; CCDM J06072-2216A; CD-22 2773; CPD-22 1067; GSC 05944-01053; HD 41974; IDS 06030-2215A; 2MASS J06071302-2215593; PPM 249872; SAO 171258;TYC 5944-1053-1; YZ 112 3251

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06219-0609 AC	**HJ 36**	***208.2***	***0.2***	***0.1***	***22.6***	***0.1***	***0.0***	4	**MON**	**2014 12 17**
OAG (Tobal)		229			23					1980
OAG (Tobal)		208.8			22.7					1983
WDS		215			30.0					1825
WDS		209			23.0			9		2007

Other identifiers: ADS 4821; CCDM J06128-0608AB; IDS 06080-0607AB

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06145-4521 AB	**CPO 133**	***33.6***	***0.1***	***0.1***	***123.6***	***0.2***	***0.1***	6	**PUP**	**2014 12 16**
OAG (Tobal)		33.6			122.4					1979
OAG (Tobal)		34.3			124.1					1991
WDS		35			140					1900
WDS		34			123.6			5		1999

Other identifiers: BD-45 2389; CCDM J06146-4520A; CF 2111; CPD-45 793; GSC 08102-01421; IDS 06117-4519A; PPM 310540; RAVE J061431.1-452044; TYC 8102-1421-1

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06168-1359 AB	GAL 397	***108.2***	***0.5***	***0.3***	***11.6***	***0.2***	***0.1***	4	CMA	2015 01 05
WDS		93			11.3					1902
WDS		106			11.5			6		1999

Other identifiers: BD-13 1420; GSC 05375-01024; HD 43629; 2MASS J06163947-1359147; PPM 216946; TYC 5375-1024-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06234-0952 AB	GAL 400	***176.0***	***0.4***	***0.2***	***17.9***	***0.1***	***0.0***	4	MON	2014 12 17
WDS		176			18.3					1893
WDS		176			17.9			6		2010

Other identifiers: BD-09 1442; 2MASS J06232749-0952376; PPM 189210; SAO 133200; YZ 99 1944

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06259+0944 AC	OPI 11	***110.3***	***0.2***	***0.1***	***252.4***	***0.1***	***0.0***	4	MON	2014 12 25
WDS		110			257.3					1897
WDS		111.0			254.1			6		2000

Other identifiers: ADS 5055 AB; AG+09 708; BD+09 1235; CCDM J06259+0944AB; GSC 00736-01080; IDS 06204+0947 AB; PPM 150495; TYC 736-1080-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06273+0532 AB	SLE 285	***74.3***	***0.1***	***0.0***	***18.4***	***0.1***	***0.0***	4	MON	2014 12 25
WDS		74			18.2					1999
WDS		74.0			18.2			2		2000

Other identifiers: HD 257550; GSC 00141-00229; 2MASS J06272041+0531086; NGC 2244+05 86; TYC 141-229-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06345+0821 AB	FAL 16	***271.1***	***0.5***	***0.2***	***11.0***	***0.7***	***0.3***	4	MON	2014 12 25
WDS		271			11.1					1898
WDS		272.0			11.1			6		2012
06345+0821 AC	SLE 538	***23.4***	***0.8***	***0.4***	***34.6***	***0.2***	***0.1***	4	MON	2014 12 25
WDS		23.0			34.4					1999
WDS		23			34.4			12		2012

Other identifiers: ALS 14596; BD+08 1399; CI*NGC 2251 HOAG 1; GCRV 4235; GEN# +2.22510001; GSC 00733-01227; HD 259954; HILT 576; HIP 31365; 2MASS J06343615+0821076; NGC 2251 1; Renson 12460; TD1 31024; TYC 733-1227-1; UBV 6531; UBV M31801; UCAC2 34616664

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06360+0359 AB	BAL 2675	***207.0***	***0.1***	***0.1***	***14.9***	***0.1***	***0.0***	4	MON	2014 12 25
WDS		207			14.7					1999
WDS		207.0			14.9			8		2000

Other identifiers: CCDM J06359+0359A; IDS 06307+0404A; 2MASS J06355474+0358429

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06382-0128 AB	BAL 326	***125.1***	***0.1***	***0.0***	***19.5***	***0.1***	***0.0***	4	MON	2014 12 25
WDS		126			18.9					1892
WDS		125			19.4			6		2000

Other identifiers: AG--01 782; BD-01 1306; GSC 04799-01398; IRAS 06355-0123;2MASS J06380582-0126411; PPM 176356; SAO 133505; TYC 4799-1398-1; YZ 91 1764

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06421+0315 AB	HO 237	***53.7***	***0.3***	***0.2***	***168.9***	***1.3***	***0.6***	4	MON	2014 12 25
JDSO (Arnold)		55			168.9					2007
OAG (Ximenez)		54			165.9					1982
WDS		53			120					1999
WDS		55			168.9			8		2000

Other identifiers: AG+03 840; BD+03 1359; BDS 3560 AB; CSI+03 1359 1; GC 8752; GCRV 57922; GSC 00151-01121; HD 48157; HIP 32072; IDS 06368+0321 AB; 2MASS J06420468+0314538; PPM 151084; SOA 114297; SKY# 11735; TD1 7847; TYC 151-1121-1; YZ 3 2363

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06435-3147 AB	COO 42	***97.9***	***1.6***	***0.8***	***19.5***	***0.4***	***0.2***	5	CMA	2014 12 16
OAG (Tobal)		100.8			19.1					1998
WDS		87			15.7					1919
WDS		98			19.4			3		1999

Other identifiers: CD-31 3605; CCDM J06436-3147A; CPC 17 2940; CPD-31 1311; CSI-31 3605 21; GSC 07087-02711; IDS 06398-3140 A; 2MASS J06433274-3146337; PPM 283042; RAVE J064332.8-314636; SAO 197133; TYC 7087-2711-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06491+0151 AB	BAL 1342	***159.4***	***0.2***	***0.1***	***13.5***	***0.0***	***0.0***	4	MON	2014 12 25
WDS		159			15.7					1909
WDS		160			13.9			4		2007

Other identifiers: BD+02 1409; GSC 00148-00466; HD 289177; 2MASS J06490445+0152115; TYC 148-466-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
06502+0057 AB	BAL 1346	***113.1***	***0.1***	***0.0***	***19.1***	***0.1***	***0.0***	4	MON	2014 12 25
WDS		112			19					1910
WDS		113			19.1			4		2000

Other identifiers: CCDM J06501+0057A; HD 289224; IDS 06450+0104A; 2MASS J06500782+0056460; TYC 148-1018-1

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
07260+1406 AC	**STF 1088**	***237.9***	***0.1***	***0.1***	***112.4***	***0.6***	***0.3***	5	**GEM**	**2014 12 17**
JDSO (Arnold)		238			112.6					2012
Tycho 2		238.1			112.8					1991
WDS		238			112.3					1829
WDS		239			112			27		2012
07260+1406 AD	**STF 1088**	***243.3***	***1.2***	***0.5***	***90.9***	***1.4***	***0.6***	5	**GEM**	**2014 12 17**
WDS		243			91.5					1997
WDS		243			91.6			2		2000
07260+1406 AE	**STF 1088**	***225.6***	***0.4***	***0.2***	***123.0***	***1.0***	***0.1***	5	**GEM**	**2014 12 17**
JDSO (Darling)		223			119.6					2012
WDS		238			112.8					1997
WDS		223			119.6			3		2011

Other identifiers: ADS 6068A; AG+14 801; BD+14 1665; CCDM J07260+1406A; GC 9917; GCRV 58745; GSC 00776-01373; HD 58383; HGAM 570; HIP 36078; 2MASS J07260241+1406107; PPM 124002; SAO 96892; SKY#13553; TD1 10055; TYC 776-1373-1; UBV 7179; YZ 14 2911

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
07487+1436 AB	**WSI 25**	***67.7***	***0.1***	***0.0***	***13.2***	***0.0***	***0.0***	4	**GEM**	**2014 12 17**
WDS AB		68			12.8					1906
WDS AB		68			13.1			6		2010
07487+1436 AC	**HJ 3300**	***70.7***	***0.1***	***0.0***	***36.9***	***0.0***	***0.0***	4	**GEM**	**2014 12 17**
WDS AC		71			37.8					1902
WDS AC		71			36.9			7		2010

Other identifiers: BDS 4268A; CCDM J07488+1436A; IDS 07431+1451A; 2MASS J07484713+1436221

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
07578-6048 AB	**NBG 1**	***352.2***	***3.6***	***0.8***	***16.8***	***0.2***	***0.1***	5	**CAR**	**2014 12 16**
OAG (Tobal)		351.9			16.2					1991
WDS		350			17.9					1924
WDS		352			16.8			5		2000

Other identifiers: BD-60 979; CD-60 1964; CPC 20.1 2006; NGC 2516 86; PPM 356389; SAO 250042; SKY# 14910; TYC 8911-1199-1; UBV M 33288

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
08260-4318 AB	**DON 249**	***212.8***	***0.3***	***0.2***	***26.1***	***0.1***	***0.0***	4	**PUP**	**2014 12 17**
OAG (Tobal)		212.2			26.5					1991
WDS		235			26.0					1929
WDS		212			25.6			4		1999

Other identifiers: CCDM J08260-4318A; CD-42 4240; CF 4286; CPD-42 2486; IDS 08226-4258A; 2MASS J08260022-4317385; PPM 755889; TYC 7673-2162-1

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WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
09045-5620 AB,D	HJ 4177	*294.6*	*0.9*	*0.3*	*32.0*	*1.1*	*0.4*	8	VEL	2014 12 17
WDS		296			35.3					1892
WDS		294			33.6			7		2000
09045-5620 CD	HJ 4177	*317.8*	*0.8*	*0.3*	*32.0*	*0.4*	*0.1*	8	VEL	2014 12 17
WDS		295			10.0					1835
WDS		317			31.4			6		2000

Other identifiers: CCDM J09045-5620AB; CEL 3173; CPD-55 1924; CSI-55 1924 41; GC 12561; GCRV 60423; GEN# +1.00078190J; HD 78190; HIP 44545; IDS 09017-5556 AB; 2 MASS J09043283-5620277; PPM 337547; SAO 236568; SKY #17502; TD1 13533; TYC 8590-405-1; UBV M 15086

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
09059-3259 AC	RST 2602	*337.0*	*0.4*	*0.2*	*13.1*	*0.0*	*0.0*	6	PYX	2014 12 17
WDS		338			11.9					1909
WDS		337			12.8			7		1999

Other identifiers: CD-32 6047; CCDM J09059-3259A; IDS 09018-3235A; TYC 7155-233-

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
10044-6039 AB	JAW 11	*47.0*	*0.1*	*0.1*	*13.6*	*0.0*	*0.0*	5	CAR	2015 01 05
WDS		50			15.3					1924
WDS		47			13.9			5		2000

Other identifiers: BD-60 1627

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
11563-4546 AB	LDS 373	*196.9*	*0.1*	*0.1*	*52.8*	*0.1*	*0.0*	5	CEN	2015 01 05
OAG (Tobal)		197			53.2					1975
OAG (Tobal)		198.7			53.6					1991
WDS		225			53					1920
WDS		197			52.7			6		2000

Other identifiers: CD-45 7401; CCDM J11562-4547A; CF 9474; CPD-45 5694; GEN# -0.04507401; GSC 08216-01325; IDS 11512-4513A; 2MASS J11561429-4546230; PPM 758557; TYC 8216-1325-1

WDS number/Comp	D.C.	P.A.	SD	SM	SEP	SD	SM	Mts	Con	Date
23293+4152 AB	CHE 497	*50.2*	*0.1*	*0.1*	*7.0*	*0.0*	*0.0*	3	AND	2014 10 11
Webb (Berkó)		49.9			7.0					2008
WDS		52			6.9					1911
WDS		50			7.0			5		2008

There were no other identifiers.

Notes:

05231+3802 AB: In the article written by Williams, it appears that the reported measurements were from B to A, as the values were 268 and 26.2.

05284+3546 AB: Based on the published data, it appears that the C and D components of this group are mislabeled in the article by Williams.

05485-1322 A-BC: Seven measurements were taken over a period of one month, due to the variations in the values. While the average is an acceptable 99.1% of the published value, the standard deviation is greater than is desired. The separation is 98.2% of the published value, and the standard deviation is an acceptable +/-0.7.

06346+0821 AD: Four photographs of this double star were taken over a period of one month, but this pair was not found in any of the photographs.

07260+1406 AB: Five measurements were made from 17 December 2014 to 19 January 2015. The position angle measurements yielded an average of only 190.7 with a standard deviation of 4.9. The WDS value was 197. The average separation was an acceptable 10.7 versus 11.0 as published in the WDS. More meaurements will be necessary on the AB components. From the photographs I received, the AF and AR components could not be identified.

07578-6048 BC: This pair, with discover code TOB 356, was present in the photographs, but the closeness made measurements impossible with my equipment.

09045-5620 AB,C: Eight measurements were taken over two months (17 December 21014 to 4 February 2015) with mixed results. The position angle average was 216.0, less than the 225 given in the WDS, a difference of 4% with a standard deviation of 2.6. The separation was good at 12.9 versus 13.0.

Photometry and Measurement of Faint and Wide Doubles in Eridanus

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Abstract: Images of several double stars in Eridanus published on the "Double Star Imaging Project" Yahoo Group page suggest magnitude issues compared with the corresponding WDS catalog data per 2014.12. Taking additional images with V-filter enabled photometry for these pairs with confirming results.

Introduction

Evaluating "Double Star Imaging Project" images made in Eridanus, we found several double star systems displaying, primarily, stellar magnitudes that were noticeably different from what one would expect based on the data listed in the WDS catalog. First conclusions were the following:

- HJ342 AC – WDS 04233-0500. Listed magnitudes of 7.76 & 12. Image by Stephen McGaughey & John Pye shows "C" to be much fainter than +12 magnitude. UCAC4 lists +13.279 mag model fit for C, no Vmag.
- HJ 2187 AB – WDS 03233-1121. Listed magnitudes of 7.7 & 10.4. Image by Chris Thuemen suggests quite strongly that the secondary is considerably dimmer than the listed magnitude. UCAC4 lists +12.216 Vmag for B and +8.842 Vmag for A, indicating that "A" is also fainter than the WDS data.
- JC 1 AF – WDS 03195-2145. Listed magnitudes of 3.91 & 12.33. Image by Chris Thuemen suggests that "F" is brighter than the listed magnitude. UCAC4 lists "F" with +11.809 Vmag.
- ARA 1976 AB – WDS 03351-2309. Listed magnitudes of 9.33 & 10.6. Image by Chris Thuemen suggests the secondary is noticeably dimmer. UCAC4 lists "B" with a +11.310 mag model fit, no Vmag and "A" with +9.534 Vmag, suggesting that "A" might be a tad fainter than the value listed in the WDS.
- BU 401 AC – WDS 03503-0131. Listed magnitudes of 9.33 & 10.6. Image by Chris Thuemen strongly suggests that "C" is a good deal dimmer than the WDS data. UCAC4 lists C with +12.838 Vmag.
- HJ 668 AB,C – WDS 03509-0010. Listed magnitudes of 8.49 & 10.9. Image by Chris Thuemen tells a very different story from the WDS data and UCAC4 lists "C" with 12.290 mag model fit, no Vmag.
- Struve 463 AB – WDS 03516+0020. Listed magnitudes of 9.3 & 12.1. Image by Chris Thuemen suggests the companion to be much brighter than the WDS records. UCAC4 lists "B" with +11.188 mag model fit, no Vmag.

Links to the images referred to above can be found in Table 4 at the end of this article. A summary of WDS 2014.12 data is given in Table 1.

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Table 1: WDS 2014.12 values for the object

Name	WDS ID	RA	Dec	Sep	PA	M1	M2
HJ 342 AC	WDS04233-0500	04:23:15.010	-05:00:20.301	23.0	80	7.76	12.0
HJ 2187 AB	WDS03233-1121	03:23:16.060	-11:20:49.499	62.9	241	7.70	10.4
JC 1 AF	WDS03195-2145	03:19:30.970	-21:45:28.297	163.5	236	3.91	12.3
ARA1976 AB	WDS03351-2309	03:35:03.350	-23:09:17.302	7.8	297	9.33	10.6
BU 401 AC	WDS03503-0131	03:50:16.100	-01:31:21.500	42.4	288	6.54	11.2
HJ 668 AB,C	WDS03509-0010	03:50:52.240	-00:09:54.200	21.7	299	8.49	10.9
HJ 3644 AB,C	WDS04215-2544	04:21:31.290	-25:43:42.402	40.7	1	6.15	12.0
STF 463 AB	WDS03516+0020	03:51:34.520	+00:20:07.400	10.0	188	9.30	12.1

Further Research

To investigate further our initial findings, we concluded that the best approach would be to obtain new images suitable for photometry. These images were taken with an online 510mm f/6.8 CDK telescope having a resolution of 1.1 seconds per pixel and equipped with a V-filter, located in Siding Spring, Australia. Photometry was completed on several additional UCAC4 listed stars within the field of the double star system for the purpose of comparing and checking the new magnitude values against those listed in the UCAC4 catalog. In addition, and by using the formula provided by R. Buchheim (2008), new separation and position angles were calculated for all systems based on the UCAC4 values which are assumed to be the most precise available coordinates. The new values are included in Table 2 below.

Additional Results for JC1

It would also have been of interest to check the magnitude of JC1 B because the +9.5 value given in the WDS catalog suggests, due to single digit precision, no precise measurement. Unfortunately, the glare of the primary did not allow the resolution of the “B” companion. The radius of the star disk of the primary was, in spite of exposures of less than 1 second, larger than the A to B separation. On the very positive side of this effort was the serendipitous discovery that the “D” component of JC1 was in actual fact made up of two very similarly bright (dim) stellar components.

Table 2: Photometry and measurement results based on iTelescope images used with AAVSO VPhot

Name	WDS ID	RA	Dec	Sep	PA	M1	M2	Date	N	Notes
HJ 342 AC	04233-0500	04:23:15.032	-05:00:20.520	23.09	79.40	-	13.467	2015.120	4	1+2
HJ 2187 AB	03233-1121	03:23:16.127	-11:20:49.417	62.74	240.96	7.622	12.204	2015.120	5	1
JC 1 AF	03195-2145	03:19:31.001	-21:45:28.297	163.13	235.98	-	11.890	2015.125	5	1+2
ARA1976 AB	03351-2309	03:35:03.369	-23:09:17.350	7.52	294.31	9.285	11.421	2015.114	5	1
BU 401 AC	03503-0131	03:50:16.162	-01:31:21.252	45.86	284.92	-	12.904	2015.114	5	1+2+3
HJ 668 AB,C	03509-0010	03:50:52.246	-00:09:54.288	21.63	298.17	-	12.506	2015.123	4	1+2
HJ 3644 AB,C	04215-2544	04:21:31.319	-25:43:42.491	41.08	0.55	-	12.793	2015.123	5	1+2
STF 463 AB	03516+0020	03:51:34.506	+00:20:06.576	10.12	188.61	-	11.429	2015.120	5	1+2

1. Images for photometry taken with 1s exposure time with telescope iT31 CDK 510mm f/6.8 with 1.1 arcsec resolution per pixel and V-filter. Uploaded to AAVSO VPhot, plate solved and up to 5 images stacked. Separation and PA were calculated with the formula provided by R. Buchheim (2008) based on the UCAC4 values for RA and Dec.
2. No photometry done for M1 as WDS catalog value did not seem questionable.
3. Astrometry based on this image confirms, within the error range for a resolution of 1.1“/pixel, the new UCAC4 coordinates for “C” and therefore the new calculated Separation and PA. The WDS catalog data is quite different.

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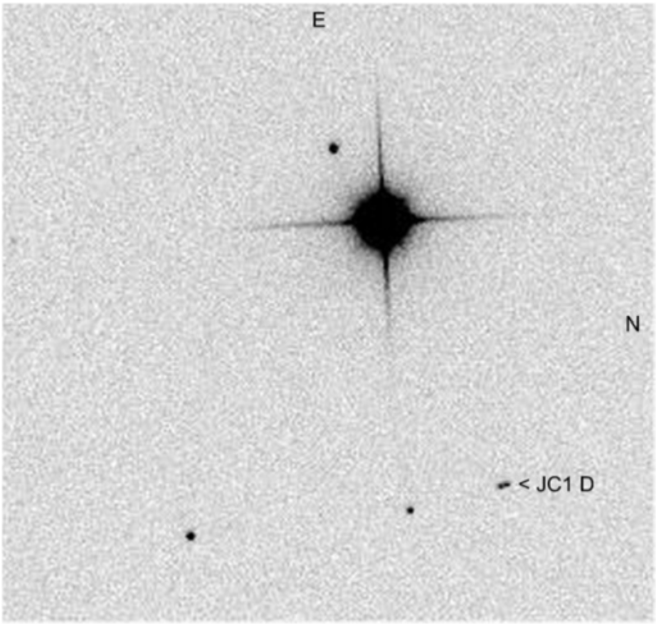

Figure 1. JC1 (cutting from image with luminance filter)

JC1 D is listed in the WDS catalog with a +12.48 magnitude suggesting a measurement of the combined magnitude. UCAC4 lists for JC1 D the object 342-003585 with corresponding +12.482 Vmag. Photometry with the identical setup as for Table 2 results in slightly fainter +12.605mag for D. Separate photometry for JC1 Da,Db based on another image (Figure 1) gives the values shown in Table 3.

The combined magnitude calculated with the formula according to Greaney 2012 results in +12.34 mag – this seems at odds with the above given values for the combined magnitude of JC1 D but photometry results for combined magnitude are obviously not this precise for objects with more than ~1" separation so we assume the magnitude given for JC1 D respectively UCAC4-342-003585, is wrong for this very reason.

Conclusions

First impressions were, with the exception regarding the A components of HJ 2187 and ARA 1976, completely confirmed by photometry. Photometry for JC 1 offered additional interesting results in terms of component D being itself a faint double. This example shows also that photometry for a combined magnitude of faint objects with approximately larger than 1“ separation might result in questionable values.

Table 3: Measurements for JC1 Da,Db

Name	WDS ID	RA	Dec	Sep	PA	M1	M2	Date	N	Notes
JC1 Da,Db	03195-2145	03:19:22.534	-21:44:40.128	3.48	15.86	13.066	13.114	2015.123	10	1)

1) Stack of 10 images with 0.5s exposure time; same setup as for Table 2. RA and Dec coordinates taken from UCAC4-342-003585. Separation and PA estimated with the astrometry tool provided by “VPhot”.

Table 4: Links to images and reports

Object	Link to image	Link to report
HJ 342 AC	www.sterngucker.eu/JDSO/Images/HJ342.jpg	www.sterngucker.eu/JDSO/Reports/HJ342.txt
HJ 2187 AB	www.sterngucker.eu/JDSO/Images/HJ2187.jpg	www.sterngucker.eu/JDSO/Reports/HJ2187.txt
JC 1 AF	www.sterngucker.eu/JDSO/Images/JC1.jpg	www.sterngucker.eu/JDSO/Reports/JC1.txt
ARA1976 AB	www.sterngucker.eu/JDSO/Images/ARA1976.jpg	www.sterngucker.eu/JDSO/Reports/ARA1976.txt
BU 401 AC	www.sterngucker.eu/JDSO/Images/BU401.jpg	www.sterngucker.eu/JDSO/Reports/BU401.txt
HJ 668 AB,C	www.sterngucker.eu/JDSO/Images/HJ668.jpg	www.sterngucker.eu/JDSO/Reports/HJ668.txt
HJ 3644 AB,C	www.sterngucker.eu/JDSO/Images/HJ3644.jpg	www.sterngucker.eu/JDSO/Reports/HJ3644.txt
STF 463 AB	www.sterngucker.eu/JDSO/Images/STF463.jpg	www.sterngucker.eu/JDSO/Reports/STF463.txt
JC 1 Da,Db	www.sterngucker.eu/JDSO/Images/JC1D.jpg	www.sterngucker.eu/JDSO/Reports/JC1D.txt

References

Buchheim, Robert , 2008, "CCD Double-Star Measurements at Altimira Observatory in 2007", *Journal of Double Star Observations*, **4**, 27-31.

Greaney Michael, 2012, "Some Useful Formulae" in R.W. Argyle, *Observing and Measuring Visual Double Stars*, 2nd Ed., Chapter 25, Page 359.

Acknowledgements

The following tools and resources have been used for this research:

- Washington Double Star Catalog
- iTelescope
- AAVSO VPhot
- AAVSO APASS
- UCAC4 catalog via the University of Heidelberg website
- Aladin Sky Atlas CDS, SIMBAD, VizieR
- 2MASS All Sky Catalog
- AstroPlanner
- SAOImage DS9

Astrometry of STF 2448 on the Mount Wilson 1.5 m Telescope with a Novel Video Eyepiece

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Abstract: The Mt. Wilson Double Star Workshop was organized to provide a hands-on educational and research opportunity for students and amateur astronomers to learn and carry out astrometric eyepiece measurements of double stars. Due to the unique operating characteristics of the Mt Wilson 1.5 meter telescope and the limited time available for observations, a Bell & Howell DNV16HDZ high definition video camera was adapted to a Celestron 12.5mm astronomic eyepiece to record the position and separation of double star STF2448. This paper records the results of the team's observations and their techniques used to record and analyze the data.

Introduction

Observations took place on the evening of July 9, 2013 using Mount Wilson Observatory's 1.5 meter telescope (located at approximately 38°13'24" N and 118°03'29" W) (Figure 1). The Mt. Wilson Observatory staff measurements of sky quality indicated that seeing was on the order of 0.5 arc seconds for the viewing period. This was later verified by the CHARA array group. The seeing quality was independently verified by Dave Jurasevic, Mt. Wilson's Deputy Director, who was observing in the same location and reported 0.4 arc second seeing.

The Mt Wilson 1.5 meter telescope was operated in a bent Cassegrain configuration with a focal length of 2438cm which gave a focal F-ratio of F/16. Combined with the Celestron 12.5mm eyepiece and extraordinarily good seeing conditions, stars with separations less than 3 arc seconds were reviewed in the *Washington Double Star Catalog* (*WDS*) catalog for consideration.

Double star STF 2448 was selected as the target

Figure 1. The 1.5 m (60") telescope located on the Mount Wilson Observatory used in the astrometry measurements. This photograph was taken on the day of the observations.

double. The pair is well studied, with more than 70 prior observations, and had little change in separation and position angle over the period of these observations. This stability provided a good 'fixed' reference for validation of the measurement technique on the 1.5 meter telescope.

First recognized by Otto Wilhelm Struve in 1825, the double star STF2448 is located in the constellation Lyra. According to the *Washington Double Star catalog*, both stars are white in color (spectral type A3), their magnitudes are very similar at 8.75 and 8.8, and they have small common proper motions (+000-010). The last recorded separation was between two and three arc seconds (Mason et al., 2013).

Other identifiers listed by SIMBAD include WDS J19037+3545AB, ADS1222002AB, AG +35 1705, BD +35 3460, CCDM J19037+3545AB ,GC 26231, HD 177543, HIC 93596,IDS 19001+3536, 2MASS J19033966+3544349, PPM 82250, SAO 67752, TD1 23835. Its precise coordinates are Right ascension 19 03 39.66; and Declination +35 44 34.4.

Methodology

The telescope was fitted with a Celestron Micro Guide 12.5 mm astrometric eyepiece with no filter (Figure 2). The Bell & Howell DNV16HDZ 46 mm f/2.8-3.5 high definition video camera was adapted to the Celestron astrometric eyepiece, with a 46 mm filter ring allowing recorded views of most of the eyepiece's back-lighted field. This configuration did not allow a full view of the compass ring in the astronomic eyepiece and was a limitation of the video method. The eyepiece was attached to the telescope, and then best focus was attempted by driving the secondary mirror to its closest possible position to the primary mirror. The secondary mirror reached focus at the limit stop so back

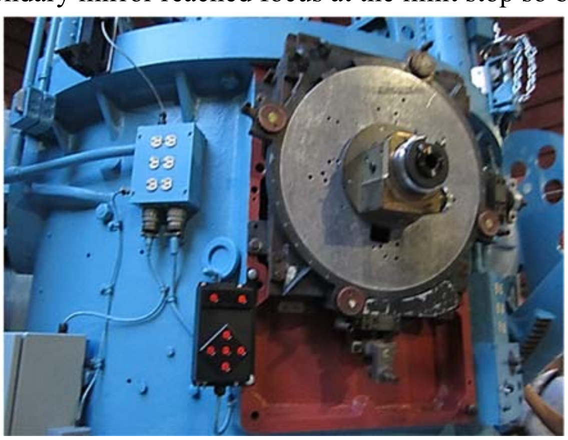

Figure 2. *The bent Cassegrain eyepiece of the 1.5 meter telescope where the astrometric eyepiece was attached. Photograph was captured by the authors during observation period.*

focus was not achievable to verify that the system was at optimum focus for the eyepiece.

Calibration

Following verification of the double star brightness and separation, eyepiece telescope calibration was accomplished using a modified version of Frey's drift method (Frey, 2008). The bright single star Alshain in the constellation Aquila (RA 19'55' 18" Dec +6° 24' 23") was selected as the reference star in accordance with the telescope altitude and azimuth limitations. The reference star was centered in the scope view and then positioned out of the field of view. The drive was disabled and the star was permitted to drift along the central ruler.

Data was collected using both the stopwatch and video capture method. The magnification and location of the star resulted in extremely fast drift times, making stopwatch measurements exceedingly difficult. Because of the difficulty using the stop watch, this method was abandoned and the video drift measurements were made and used for calibration. For the video data runs, the centering and stop drive process was repeated and recorded 10 times.

The drift time from the recorded video was calculated by running each of the videos frame by frame through the Adobe Premiere Pro CC video editing software. This allowed the star to be precisely positioned at the 20 tic mark and then run forward to the 50 tic mark, giving a one half scale drift (Figure 3). The centroid of the star was visually aligned with the start and stop tic marks.

The Premiere software displays the frame number at the start point and the end point for both tic mark alignments. The change between frame rates was obtained and then multiplied by the high definition camera recording sample rate of 59.96 frames per second. This number was doubled to obtain the full scale drift time. Each measured time was recorded in the double star Excel data sheet used for the night's observation runs. Several less capable software programs were tested, but the results were unreliable because the software dropped frames during the analysis. The Adobe Premiere software has a dropped-frame alarm that was activated during the analysis runs to ensure all the captured video frames were evaluated.

These average drift times were then used to calculate the scale constant Z, using the formula Z = [15.0411 · $T_{average}$ · the cosine of the declination angle] divided by 60 (the number of reticule divisions, D) (Frey 2008). The formula can be expressed as:

$$Z = [15.0411\ T_{avg} \cos(\delta)\ ] / D$$

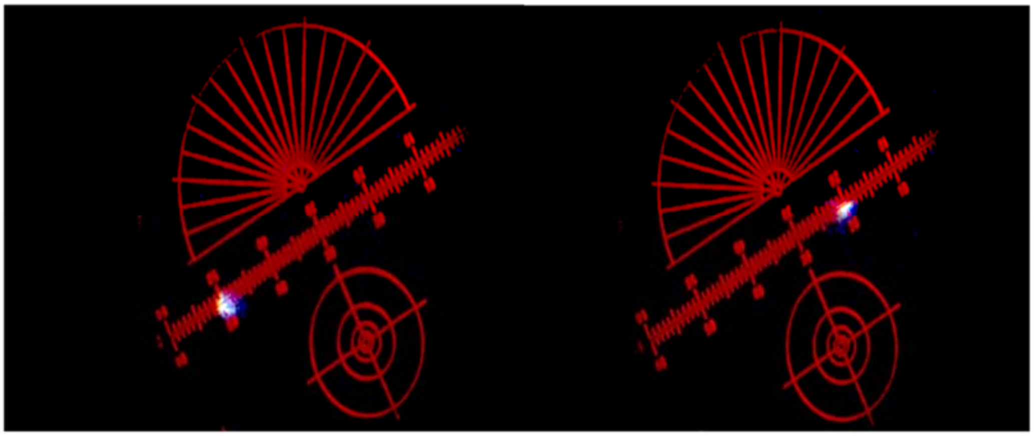

Figure 3. *A sample image taken from a video frame for the drift time calibration of the Alshain star. The image on the left represents the start point of the video time run while the image on the right is the image end point.*

During the calibration measurements, the average drift time for ten runs was 3.34 seconds with a standard deviation of 0.05, and a standard error of the mean of 0.02 was obtained (Table 1). A scale constant of 0.832 arc seconds per tic mark was also derived.

Observations

Following calibration, the double star STF2448 was selected from Joseph Carro's modified WDS star catalogue and the position was verified using The Sky 6 software (Carro, 2013). The star pair was placed into the field of view and its identity was confirmed using its color and estimated separation. The close visual magnitude of the stars made it initially necessary to guess the primary and secondary orientation, with the prediction being supported by early data analysis provided by the Excel worksheet used to capture data.

Table 1. Calibration Data. The calibration drift time of the star Alshain was found to be 3.34±0.05 s.

Calibration Star	Drift Time (sec)
Average Drift Time	3.34
Std. Dev.	0.05
Median	3.30
Standard Error of the Mean	0.02
Declination angle (rad)	0.11
Divisions	60
Scale Constant	0.83

Separation estimates were determined using a combination of two methods. The pair of stars was placed along the linear scale and the number of scale divisions between the stars was estimated. In the first method, visual observation, the camera was detached and the team members looked directly through the eyepiece per Frey's procedure (Frey, 2008). Teammates were rotated through the visual stand on the telescope and ten data sets were recorded.

This was followed by re-installing the Bell & Howell DNV16HDZ video camera onto the eyepiece. A single 30-second HD video was captured (2000 frames) and still photographic capture runs were performed and recorded for later analysis.

During the following day's data analysis, another technique was developed by utilizing a rudimentary lucky imaging technique. Again, the video of the separation was evaluated frame-by-frame using Adobe Premiere Pro CC. The frames with the smallest, clearest star shapes and best scale alignments were selected for evaluation.

The next method used Adobe Photoshop Pro CC software to evaluate the video capture stills. The sample photos derived from the frame by frame analysis were displayed in the software and the digital ruler tool, available in the program, was utilized to measure separation using the following procedure.

The digital ruler displays a numeric value for the number of picture pixels between the two objects in the photograph. The ruler was used to measure the pixel separation of the stars from centroid to centroid. This number was then evaluated against the same delta ruler measurement of the pixel tic mark separation of the

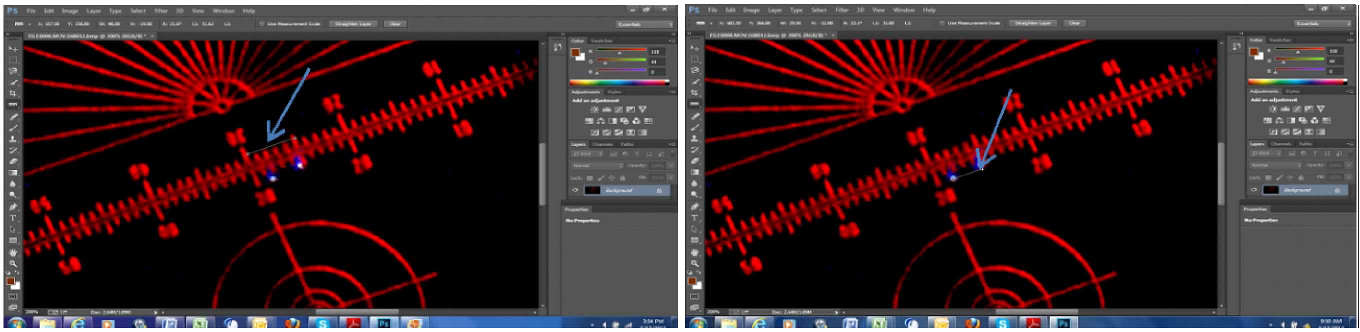

Figure 4: A screen shot of Adobe Pro CC software being used to analyze video still shorts. The image on the left is using a ruler tool to measure the eyepiece tic-to-pixel ratio while the image on the right is measuring star separation centroid to centroid. Note the extremely tight star spots; this is evidence of exceptional seeing conditions coupled with the superior optics of the 1.5 meter Mount Wilson Telescope.

Table 2. Using the video capture technique, the separation of STF 2448 was 2.1 ± 0.16 arcsec.

Run	Divisions
Average	3.07
Std. Dev.	0.16
Median	3.00
Standard Error of the Mean	0.03
Average Div. x scale Constant in Arc Seconds	2.55
Separation (Arc Seconds)	2.12

eyepiece scale using the same photograph (Figure 4). The stellar separation was then derived mathematically using a ratio of tic mark measurements versus star separation measurements.

The combination of the eyepiece and camera did not allow the inclusion of the eyepiece compass in the video field of view, resulting in the necessity of angle measurements being made visually, according to Frey's method (Frey, 2008). The most experienced team member, Chris Estrada, made all measurements because of observation time constraints. Following each measurement, the tracking feature was enabled and the process was repeated 10 times. All of the data was captured on an Excel spreadsheet that was automated to perform the necessary mathematical calculations.

Table 3. The calculated position angle of STF 2448 was 193 ± 0.75°.

Observation	Reading of Eyepiece	Position Angle Degree
Average	103	193
Std. Dev.	0.75	0.75
Standard Error of the Mean	0.17	0.17

Observational Results

The separation of STF 2448 was calculated to be 2.1 arc seconds within a standard deviation of 0.16 arc seconds. The position angle was measured at 193° with a standard deviation of 0.75° (Tables 2 and 3). Table 4 gives our observational results. Table 5 depicts previous recorded measurements of the STF 2448 double star as well as the values calculated using our data.

Conclusions

Overall, the use of the Celestron 12.5 mm astronomic eyepiece on the telescope and the video capture method were successful. The setup afforded a focal length of 24.3 m and magnified the field of view to 1,950X power. This, along with the 1.5 meter aperture,

Table 4. Observational results

NAME	RA + DEC	MAGS	PA	SEP	DATE	N	NOTES
STF 2448	19 03 39.66 +35 44 34.4	8.75, 8.8	193	2.1	2013.520	1	1

***Table5**: Comparing previously recorded separation and position angle of the STF 2448 double star to the Mt. Wilson observation values (Comellas, 2003).*

Reference name	Sep	PA
Struve 1825	2.7	193
CCDM (Dommanget 1998)	-	192
Eagle Creek Observatory (Muentzler 2003)	2.7	191
Herschel Double Star Catalog 1835 data (MacEvoy 2011)	2.7	193
HIPARCOS Catalog (Perryman, *et al*. 1993)	2.4	193
O. A. G. Catalog (Comellas 1973)	2.4	194
Washington Double Star Catalog 2008 data (Mason 2013)	2.4	191
Washington Double Star Catalog 2009 data (Mason 2013)	2.4	191
Washington Double Star Catalog 2010 data (Mason 2013)	2.5	191
*Measurements by the authors July 2013 (**Current Experiment)***	*2.1*	*193*

allowed for adequate visual split against the eyepiece scale of this close double as well as significant star brightness of the near magnitude 9 star pair. With this eyepiece and focal length combination, it was possible to measure stars down to 2.5 arc second separation, nearly an order of magnitude closer than those measured by Frey's astrometric visual observations (Frey, 2008). During later analysis of video data, several frames were noted for having excellent seeing and focus that produced pinpoint star images with adequate stable separation. The night's work was validated by the position angle and separation measurements agreeing with previously established observation methods within the sky seeing limits.

Results indicate that video capture of separation information and drift time offers an effective way of collecting astrometric data. The compact size, portability, and easy setup of the camera and eyepiece combination offer a viable research tool that could be adapted to many telescopes, from the very large observatory grade scopes to the small amateur-owned systems. The ability to capture the high fidelity raw data during the run on the telescope and store it for later analysis was evaluated and found to be very useful. Despite the technique's advantages, further development is needed in the eyepiece-adapter connection in order to include the compass scale in the camera's field of view. Additionally, it was shown that evaluation of video data should be accomplished on robust video editing software, because errors in playback and frame drop were evident when using products like Microsoft Movie Maker and ArcSoft Total Video Extreme.

Future work necessary to extend this investigation is two-fold. First, the position angle and separation of STF2448 should continue to be measured in order to make calculating an accurate orbit possible. Second, more measurements need to be made of other stars with other telescopes in order to verify the effectiveness of the video capture method. In this experiment, it was not possible to back-focus the telescope because of mirror motion limitations, so sightings recorded with a telescope that has been verified to be properly focused would be beneficial. Finally, a study in the properties of various video playback and editing software is necessary in order to develop a more standard procedure of the video analysis portion of the measurements.

Acknowledgments

We thank Cheryl Genet and Inga Kenney for their help in organizing the event, and the management and staff of the Carnegie Foundation and the Mt. Wilson Observatory for allowing us to use the magnificent 1.5 meter telescope. We also thank the US Naval Observatory for extensive use of the *Washington Double Star Catalog*. A special thanks goes to Joseph Carro for organizing the WDS catalog into a usable computer database format. Finally, we thank the reviewers of this paper for their helpful suggestions.

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Double Star Measurements Using a Webcam and DSLR, Annual Report of 2014

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Abstract: I report on 138 double star measurements from 2014; minimum separation is 1.4 as (STF 401AB), maximum separation is 400.6 as (SMR 13AE). The mean value of all measurements is 82.6 as.

Report

This is a report of 138 double star measurements from 2014 made with a standard webcam (81 measurements) and a DSLR camera (44 measurements). In 11 further cases measurements was done in both ways. Minimum separation is 1.4 as, maximum separation is 400.6 as. The mean value of all measurements is 82.6 as.

Measurements were done with a 12-inch Newtonian telescope. A detailed description of the optical setup is given in annual report of 2012 (Schlimmer, 2013). Reproduction scale is about 0.77 as for webcam measurements and 0.70 as for DSLR images. In case of DSLR imaging an additional coma corrector was used. In both cases data analyses were done with REDUC software.

Focus of observation in 2014 was stars of Max Wolf's "Catalog About 1053 High Proper Motion Fix Stars" (Wolf, 1919) which are already listed in Simbad Database as well in WDS catalog. There are only 94 matches, because most of Wolf's stars aren't double stars (Schlimmer, 2014). This review is not yet finished and will be continued in 2015. In the notes column of table 1 eighteen of these stars are remarked with Wolf's number as listed in Simbad Database.

During observations of 30/31 Cygni in late summer of 2014 some further companions could be found. Also a further double star in the neighborhood could be found. These discoveries are described below.

WDS20136+4644, 31 Cygni

Next to components H and F further companions could be found (see Figure 1). The distances are 9 as for H1 and 3.6 as for F2. The position angles are 263 degree and 214 degree. The estimated brightness of these companions is about 0.5 magnitudes lower than the associated primaries.

Figure 1. 30/31 Cygni with companions of H and F, exposure time 4 x 180s

Double Star Measurements Using a Webcam and DSLR, Annual Report of 2014

USNO-B1.0 1366-0359784

This object is next to 31 Cygni is listed as single star in the catalogs. I found 2 components in a distance of about 7 as and a position angle of 59 degree (see figure 1). Coordinates are 20139+4641. The brightness is 12.14 magnitudes (B1 mag) for both components. There is a small proper motion of 10 mas/yr in R.A. and 4 mas/yr in declination. Therefore USNO-B1.0 1366-0359784 is a possible common proper motion pair.

Table 1 shows the measurements of 136 double stars from 2014.

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France

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Table 1. Measurements of Double Stars from 2014

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Notes
ES 1867AB	00466+6131	9.33, 11.28	274.1	6.68	2014.893	1	D, Wolf 19
ES 1867AC	00466+6131	9.33, 9.71	299.3	73.37	2014.893	1	D
ARG 3	00573+6020	8.51, 9.41	200.2	20.69	2014.893	1	D
SMR 60BC	03311+2744	7.81, 13.	358.9	2.55	2014.077	1	D
STF 401AB	03313+2734	6.58, 6.93	268.7	1.4	2014.077	1	D
STF 450AB	03474+2355	7.29, 9.4	263	6.27	2014.047	1	W
STF 449	03474+2440	8.78, 11.3	329.3	6.75	2014.047	1	W
STT 64AB	03500+2351	6.81, 10.15	234.6	3.26	2014.047	1	W
STT 64AC	03500+2351	6.81, 10.54	235.4	10.36	2014.047	1	W
BU 550AB	04359+1631	0.85, 13.6	113.9	31.02	2014.062	2	D,W, α Tau
STFB 2AC	04359+1631	0.85, 11.3	31.5	134.74	2014.062	2	D,W, α Tau
STT 560AB	04498+0658	3.22, 11.31	170.8	73.07	2014.047	1	W
BUP 80	05284-0330	7.64, 10.1	205.3	44.14	2014.151	1	D
BU 558AB	05320-0018	2.41, 14.2	228.9	32.95	2014.167	1	D
STFA 14AC	05320-0018	2.41, 6.83	0.8	52.14	2014.167	1	D
HDZ 1	05352-0055	10.8, 11.1	220.5	18.35	2014.151	1	D
STF 746AB	05353-0441	10.4, 10.7	218.5	14.05	2014.151	1	D
STF 751	05358-0059	8.02, 8.96	123.8	15.54	2014.151	1	D
STF 817	05549+0702	8.68, 8.93	73.2	18.68	2014.077	1	D
H 6 39AB	05552+0724	0.77, 14.5	113.4	37.97	2014.077	1	D, α Ori
H 6 39AD	05552+0724	0.77, 13.5	345.7	71.39	2014.077	1	D, α Ori
H 6 39AE	05552+0724	0.77, 11.0	154.6	176.06	2014.077	1	D, α Ori
SLE 831AF	05552+0724	0.77, 12.1	266	168.44	2014.077	1	D, α Ori
SLE 831AG	05552+0724	0.77, 12.8	47.3	148.65	2014.077	1	D, α Ori
SLE 831AH	05552+0724	0.77, 11.2	294	240.03	2014.077	1	D, α Ori

Table 1 continues on next page.

Double Star Measurements Using a Webcam and DSLR, Annual Report of 2014

Table 1(continued). Measurements of Double Stars from 2014

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Notes
SMR 29AI	05552+0724	0.77, 13.5	237.3	217.79	2014.077	1	D, α Ori
SMR 29AJ	05552+0724	0.77, 13.5	257.6	190.71	2014.077	1	D, α Ori
STT 179	07444+2424	3.7, 8.2	241.1	7.24	2014.184	1	W, 77 Gem
STF1249	08377+1946	11.00, 10.78	40.4	25.17	2014.184	1	W
S 571AD	08399+1933	7.31, 6.67	241.7	92.4	2014.176	2	D,W
BU 584DC	08399+1933	6.67, 7.47	88.5	99.74	2014.176	2	D,W
BKO 34DE	08399+1933	6.67, 11.75	2.9	35.4	2014.167	1	D
LDS 907	08399+4500	12.6, 12.8	180.9	7.27	2014.23	1	D, Wolf 317
STF1254AB	08404+1940	6.44, 10.37	54.7	20.63	2014.176	2	D,W
STF1254AC	08404+1940	6.52, 7.61	342.5	63.25	2014.167	1	D
STF1254AD	08404+1940	6.52, 9.20	44.5	82.51	2014.176	2	D,W
SMR 30AE	08404+1940	6.52, 12.5	155.1	15.23	2014.184	1	W
LDS 908	08559+4632	11.99, 12.14	132.7	9.82	2014.23	1	D, Wolf 323
STF1300AB	09013+1516	9.47, 9.73	181	4.81	2014.184	1	W
ENG9001AC	09013+1516	9.47, 9.93	13.4	202.02	2014.184	1	W
ENG9001AD	09013+1516	9.47, 10.21	61.9	197.85	2014.184	1	W
HJ 4433AB	11256+1627	5.62, 10.84	4.1	55.15	2014.381	1	W, 81 Leo
STF1540AB	11268+0301	6.55, 7.50	149.6	28.04	2014.378	1	W, 83 Leo=Wolf 393
STFA 19AB	11279+0251	5.05, 7.47	181.6	88.34	2014.378	1	W, 84 Leo
STF1547AB	11317+1422	6.33, 9.14	331.2	15.52	2014.381	1	W, 88 Leo=Wolf 401
BU 604AD	11491+1434	2.14, 8.49	194	236.52	2014.381	1	W, β Leo
STF1685AB	12519+1910	7.31, 7.78	201	15.99	2014.43	1	W
BUP 146	12556+0324	3.58, 11.79	126.6	192.05	2014.43	1	W, Wolf 448
STF1712	13035+0928	10.24, 10.57	332.3	8.94	2014.43	1	W
BRT3219	13041+0933	11.0, 12.1	259.6	4.59	2014.43	1	W
A 1785	13058+0904	9.73, 10.82	129.1	2.51	2014.43	1	W
STF1728AB,C	13100+1732	5.2, 10.2	349.3	84.77	2014.43	1	W
LDS5771	13114+0938	8.80, 12.36	169.4	81.75	2014.43	1	W, Wolf 477
S 648	13131+1801	9.35, 9.97	68.8	88.02	2014.43	1	W
HJ 2647	13145+1120	5.82, 12.61	214.8	50.07	2014.43	1	W
S 648	13131+1801	9.35, 9.97	68.8	88.02	2014.43	1	W
STF1733	13163+1715	8.99, 10.37	127.5	4.93	2014.43	1	W
STF1888AB	14514+1906	4.76, 6.95	303.8	5.68	2014.54	1	W, ξ Boo
STF1919	15127+1917	6.71, 7.38	10.5	23.24	2014.54	1	W
STF1925AB	15169-0817	8.14, 9.85	17.9	6.01	2014.504	1	W, Wolf 1139
STF1930AB	15193+0146	5.06, 10.11	35.1	11.36	2014.54	1	W, 5 Ser
STF1954AB	15348+1032	4.17, 5.16	172.7	3.62	2014.54	1	W, d Ser
STF1954AC	15348+1032	4.17, 13.9	18.3	66.64	2014.504	1	D
SMR 62AE	15348+1032	4.17, 15.	42.4	63.54	2014.504	1	D
STF1954CD	15348+1032	13.9, 14.6	337.5	4.07	2014.504	1	D
STT 300	15402+1203	6.32, 10.07	260.9	15.04	2014.545	1	W
A 2230AD	15440+0231	5.95, 10.95	284.9	172.39	2014.504	1	W, Wolf 573
HJ 1277AB	15443+0626	2.65, 11.8	333.8	57.58	2014.54	1	W, α Ser
STF1970AB	15462+1525	3.66, 9.96	263.9	30.45	2014.504	1	W
STF1978	15509+1441	9.19, 10.13	235.2	15.34	2014.545	1	W

Table 1 continues on next page.

Double Star Measurements Using a Webcam and DSLR, Annual Report of 2014

Table 1 (continued). Measurements of Double Stars from 2014

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Notes
WLF 2	15572+0509	13.36, 15.30	200.8	67.56	2014.43	1	W, Wolf 611+612
STF1993AB	15598+1723	8.59, 8.88	42.8	20.15	2014.545	1	W
STF1994CD	15598+1723	10.03, 12.48	337.2	17.34	2014.545	1	W
LDS 573AB,	C 16555-0820	9.44, 11.76	313.2	72.19	2014.488	3	W, Wolf 629
ENG 59AB	17011-0413	4.99, 9.71	67.4	99.77	2014.504	1	W
ARN 16AC	17011-0413	4.99, 8.75	85	220.88	2014.504	1	W
LDS 585AB	17050-0504	7.86, 10.14	122.7	183.77	2014.504	1	W, Wolf 635+636
HU 1177	17098+3849	9.82, 13.39	86.5	37.55	2014.545	1	W, Wolf 649
AG 209	17278+3607	9.64, 10.19	187.4	34.01	2014.709	2	D, W, Wolf 747
ES 2230	17317+3604	10.54, 11.03	92.5	9.59	2014,709	1	W
STF2277AB	18031+4828	6.25, 8.93	128.1	26.57	2014.753	1	W
STF2277AC	18031+4828	6.25, 10.19	297.8	99.56	2014.753	2	W, Wolf 1405
STF2272AB	18055+0230	4.22, 6.17	127.6	6.27	2014.54	1	W, 70 Oph
STTA171AB	18329+3850	7.02, 8.12	327.6	149.87	2014.6	1	W
H 5 39AB	18369+3846	0.09, 9.5	183.7	82.13	2014.6	1	W, Vega
STFB 9AE	18369+3846	0.09, 9.5	38.7	86.63	2014.6	1	W
STFA 39AB	18501+3322	3.63, 6.69	148.1	45.41	2014.6	1	W
BU 293AC	18501+3322	3.63, 13.0	247.3	46.4	2014.6	1	W
BU 293AE	18501+3322	3.63, 10.14	317	67.1	2014.6	1	W
BU 293AF	18501+3322	3.63, 10.62	17.9	85.7	2014.6	1	W
HL 9001AB	18536+3303	13.1, 15.	262.4	5.02	2014.709	1	W
HL 9001AC	18536+3303	13.1, 15.	3.3	18.76	2014.709	1	W
ES 2028AB	18545+3654	4.30, 11.2	349.1	86.33	2014.583	1	D, δ Lyr2
SMR 13AD	18545+3654	4.30, 8.8	209.7	193.14	2014.583	1	D
SMR 13AE	18545+3654	4.30, 10.3	237.8	400.64	2014.583	1	D
SMR 13AF	18545+3654	4.30,	244.9	369.44	2014.583	1	D
SMR 13AG	18545+3654	4.30,	260.8	335.9	2014.583	1	D
SMR 13AH	18545+3654	4.30,	284	229.39	2014.583	1	D
SMR 13AJ	18545+3654	4.30,	249.1	279.48	2014.583	1	D
SMR 13AK	18545+3654	4.30,	236.2	304.24	2014.583	1	D
SMR 13HI	18545+3654	4.30,	250.5	26.29	2014.583	1	D
ES 2029	18548+3611	10.02, 11.36	205.8	5.06	2014.6	1	W
AGC 9AB	18589+3241	3.24, 12.1	305.4	13.46	2014.6	1	W
STF2487AB	19138+3909	4.38, 8.58	80	28.21	2014.6	1	W
STF2487AC	19138+3909	4.38, 11.42	150.7	161.51	2014.6	1	W
SHJ 292AB	19164+3808	4.48, 10.14	69.9	98.9	2014.6	1	W
SHJ 292AC	19164+3808	4.48, 11.1	128.4	101.29	2014.6	1	W
STT 591AC	19364+5013	4.5, 11.7	179.1	73.04	2014.753	1	W
STG 8AD	19364+5013	4.5, 12.5	52.5	67.04	2014.753	1	W
SKF1976AE	19364+5013	4.54, 12.88	266.3	116.27	2014.753	1	W
STF2579AC	19450+4508	2.89, 12.0	66.3	62.55	2014.753	1	W
SMR 7	20000+1736	10.1, 11.4	264.9	4.1	2014.753	1	W
S 730AB	20001+1737	7.16, 8.45	14.3	112.76	2014.753	1	W
S 730AC	20001+1737	7.16, 10.21	337.7	78.54	2014.753	1	W
S 730AD	20001+1737	7.16, 9.9	198.4	40.67	2014.753	1	W

Table 1 concludes on next page.

Double Star Measurements Using a Webcam and DSLR, Annual Report of 2014

Table 1 (conclusion). Measurements of Double Stars from 2014

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Notes
ENG 71AB	20111+1611	7.42, 9.67	147.9	211.96	2014.797	1	D, Wolf 873
HZG 15AD	20111+1611	7.42, 11.21	256	35.2	2014.797	1	D
GIC 163AE	20111+1611	7.42, 13.93	95.3	103.92	2014.797	1	D
BUP 205BC	20111+1611	9.67, 12.65	273.1	61.05	2014.797	1	D
HJ 1495AB	20136+4644	3.93, 13.4	327.7	36.1	2014.775	2	W, D, 30 Cyg
STFA 50AC	20136+4644	3.93, 6.97	172.3	106.72	2014.775	2	W, D
STFA 50AD	20136+4644	3.93, 4.83	322.5	335.24	2014.797	1	D
BU 1483AF	20136+4644	3.93, 13.9	166.9	43.49	2014.775	2	W, D
BU 1483CH	20136+4644	6.97, 12.6	61.7	60.58	2014.775	1	W
BU 1483CI	20136+4644	6.97, 12.26	135.3	60.18	2014.775	1	W, D
New H1	20136+4644	12.6,	262.7	8.98	2014.797	1	D, see text
New F2	20136+4644	13.9,	214.4	3.6	2014.797	1	D, see text
New	20139+4641	13., 13.	59.2	7.14	2014.797	1	D, see text
ES 27	20143+4648	10.58, 10.61	339.7	4.02	2014.753	1	W
STF2758AB	21069+3845	5.35, 6.10	151.9	31.34	2014.753	1	W, 61 Cyg
STF2758AE	21069+3845	5.35, 9.63	267.2	332.02	2014.753	1	W
STF2758AF	21069+3845	5.35, 11.3	240	360.65	2014.753	1	W
STF2758AG	21069+3845	5.35, 10.84	235.7	250.16	2014.753	1	W
STF2758AH	21069+3845	5.35, 10.89	272.9	103.66	2014.753	2	W
SMR 1AI	21069+3845	5.35, 10.74	247.2	12.11	2014.753	2	W
SMR 40AO	21069+3845	5.35, 12.65	284.4	151.41	2014.753	2	W
SMR 40AP	21069+3845	5.35, 12.84	294.3	146.18	2014.753	2	W
SMR 40AQ	21069+3845	5.35, 13.19	323.8	67.96	2014.753	2	W

Measurements of BU109 in Cetus

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Abstract: Images of BU109 in Cetus raised questions about magnitudes and positions of components as listed in the WDS catalog, the most valuable resource for double star observers. Further research suggested changes for magnitudes and positions and questioned whether the most recent listed precise measurements are always the most precise measurements.

Introduction

An image of BU 109 taken by Chris Thuemen in August 2012 and only recently presented on the ***Double Star Imaging Project*** Yahoo Group Site suggested magnitudes and positions of components B and C to be very different from the then current WDS data.

For illustration purposes, we show the relevant part of this image in negative grey scale and enhanced contrast demonstrating the components being very closely aligned in a straight line (Figure 1). A summary of WDS 2014.96 data is given in Table 1.

For comparison, the data of the corresponding UCAC4 objects:

BU109 B: UCAC4-368-000777 +11.092mag model fit and 11.068 aperture photometry, no Vmag. These values indicate that the WDS data might need a correction for the magnitude of component B

BU109 C: UCAC4-368-000778 +11.246mag model fit, +11.223mag aperture photometry and 10.696Vmag. While the latter value seems somewhat questionable,

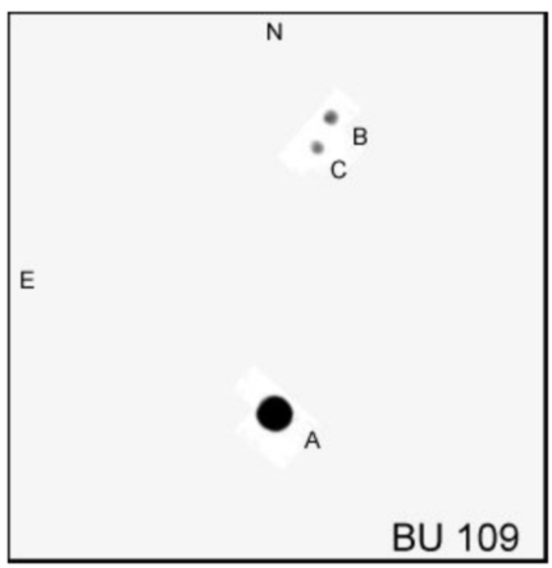

Figure 1. BU 109 (grey scale negative with gamma correction)

Table 1: WDS 2014.96 values for BU109

Name	WDS ID	RA	Dec	Sep	PA	M1	M2
BU 109AB	00405-1631	00:40:28.560	-16:30:59.800	97.5	356	6.6	9.1
BU 109AC	00405-1631	00:40:28.560	-16:30:59.800	94.9	355	6.6	9.4
BU 109BC	00405-1631	00:40:27.740	-16:29:14.503	11.7	160	9.1	9.4

these values indicate that the WDS data might need a correction for the magnitude of component C.

The image taken by Chris Thuemen, as well as the DSS and 2MASS images, show clearly that the components A, B, and C are more or less in a straight line. If the separation of 11.7“ for BC is correct, then at least one of the separations AB or AC is in error.

Regarding separation AB or AC: as the WDS catalog includes position for A (in object AB) as well as for B (in object BC) it is easy to calculate separation and PA based on the formula provided by R. Buchheim (2008). Separation AB, based on this formula, is therefore 106.46" and PA is 351.53° - so the evidence for the separation error AB was contained in the WDS data.

2. Further Research

2.1 Additional images

To investigate further our initial findings, we concluded that the best approach would be to obtain a new image suitable for photometry and astrometry.

A single frame image of a 10 s exposure was taken with an online 320mm f/9.3 RC telescope having a resolution of 0.8 seconds per pixel and equipped with a V-filter, located in Siding Spring, Australia. Photometry was based on several UCAC4 Vmag (APASS) listed stars within the field of the double star system for the purpose of comparing and checking the new magnitude values against those listed in the UCAC4 catalog. The resulting values are included in Table 2.

In Table 3 we list the UCAC4 RA/Dec coordinates for the BU109 components.

Using the formula provided by R. Buchheim (2008), new separation and position angles were calculated (Table 4) based on the UCAC4 values which are assumed to be the currently most precise available coordinates.

The UCAC4 based results in Table 4 are within a reasonable margin of error and in line with the estimated astrometry results based on the iTelescope image in Table 2, while the WDS catalog data, and in particular that for AB, is quite different and obviously in error.

In the next step we presented these findings to the USNO and suggested magnitude changes for BU109 B and C as well as a correction of separation AB.

This resulted in the following WDS updates in changes of estimated magnitudes for B to +10.4mag and C to +10.7mag and of separation AB to 105.6“.

2.2 Research in the history of BU109

First, with regard to the apparent error regarding the separation of either AB or AC as shown in Table 1, let’s look at the AB separations listed in the WDS text file for BU 109. The 2003.809 separation of 97.48” for AB (shown in Table 1) stands out as being significantly closer than any of the prior measurements. When we discard the three most anomalous measures in the text file (the 1980.000 separation of 120”, the 1990.761 separation of 125.50”, and the 2003.809 separation of 97.48”), we get an average separation for AB of 104.05” from the other nine measurements.

Table 2: Results based on iTelescope image used with AAVSO VPhot

Name	RA	Dec	M2	M2 Err	Sep	PA	Date	N	Notes
BU 109AB	00:40:28.664	-16:30:59.529	11.130	0.041	106.17	353.22	2015.008	1	1)
BU 109AC	00:40:28.664	-16:30:59.529	11.276	0.041	95.21	354.81	2015.008	1	1)
BU 109BC	00:40:27.806	-16:29:13.838	11.276	0.041	11.31	159.78	2015.008	1	1)

Notes:

1. Image for photometry taken with a single10s exposure with telescope iT9 RC 320mm f/9.3 having a 0.8 arcsec resolution per pixel c/w V-filter. Uploaded to AAVSO VPhot and plate solved. RA/Dec coordinates, Separation and PA are estimates calculated with the tools provided by AAVSO VPhot. No photometry done for M1 as the WDS catalog value for BU109A did not appear questionable.

Measurements of BU109 in Cetus

Table 3: RA/Dec positions based on UCAC4 coordinates

Name	UCAC4 ID	RA	Dec
BU 109A	368-000780	00:40:28.582	-16:31:00.047
BU 109B	368-000777	00:40:27.739	-16:29:14.462
BU 109C	368-000778	00:40:28.009	-16:29:25.153

Table 4: Separation and position angle based on UCAC4 coordinates

Name	Sep	PA
BU 109AB	106.28	353.45
BU 109AC	95.25	355.04
BU 109BC	11.37	160.04

Next, because all three stars are very close to being in alignment with one another, it should be possible to determine the separation of AC by subtracting the BC separation from the AB separation. When that operation is performed on the data in Table 1, it results in a separation for AC of 85.8", which is in notable disagreement with the 94.9" separation for AC shown in Table 1, as well as with the history of AC.

We can perform the same operation using the WDS data that immediately precedes the Table 1 data which was current at the time Chris Thuemen's image was taken. From the WDS text file, that would be the 1999.637 data for AB and AC, and the 1999.641 data for BC, all of which come from the same source (AJ 146, 76, 2013).

The 1999.637 separation for AB is 105.634" and the 1999.641 measure for BC is 11.393". Subtracting BC from AB, we get a separation of 94.241" for AC.. Looking at the actual 1999.637 measure for AC, we find a separation of 94.91".

In other words, the assumption that the separation of AC can be determined by subtracting BC from AB because all three components are more or less in line, works with the 1999 measures because they're all consistent with each other. It also works with Burnham's 1898.79 measures: 103.05" (AB) minus 11.24" (BC) equals 91.81", which matches well with Burnham's 1898.69 AC separation of 91.90".

The reason that method fails to work with the 2003.809 separation for AB is because the 2003 measure of AB is in error.

Looking further into the history of the AC and BC measures in the WDS text file, we find the measures of both are rather consistent, apart from the first estimates by S.W. Burham in 1873, which he later improved on with precise readings in 1900.

The first magnitude we have for B is Burnham's estimate of 10 in 1873. It stays in that range until a 1916.84 reading of 12.2 and then drops to a 10.7 reading very quickly as of 1916.85. The magnitude of B then increases to 10.3 in 1917, increases again to 9.4 in 1980, then in 1998 is assigned values of 10.055, 9.770, and 9.726, all coming from 2MASS data. As of 1999.641, B was reduced to a magnitude of 11.09, which is the UCAC fit model value (from this source, previously cited: AJ 146, 76, 2013). The 11.09 value is the last magnitude listed in the WDS text file.

However, and this is where confusion enters the picture, the magnitude value we found listed for B in the WDS as of 2014.96 (Table 1) was 9.1. That value is also listed in an earlier version of the WDS downloaded into an Excel spreadsheet on 2014.44. At any rate, as a result of correspondence with the WDS on our initial findings, the magnitude of B was changed to its present value of 10.4.

For C, the pattern is very similar, again starting with an estimate of 10 in 1873 by Burnham, a low point of 12.0 coming on 1916.84, a gradual increase to 9.6 in 1980, followed by 2MASS values in 1998 of 10.155, 9.857, and 9.837. The final reading in the text file is the 1999 UCAC4 value of 11.25, which again is the UCAC fit model value. But, as we found with B, the magnitude value listed for C in the 2014.96 (Table 1) and 2014.44 versions of the WDS was a different number, specifically 9.4. Following our correspondence with the WDS, that value has now been changed to 10.7.

3. Conclusions

First impressions were completely confirmed by photometry and astrometry done on a recently taken image. It should be pointed out that the most recent measures listed in the WDS may be in disagreement with prior WDS measures, which is another way of saying the most recent measure may not be the best available measure. Therefore, if questions regarding the precision of current WDS parameters arise, it seems necessary to check first the historical record contained in the WDS text file of such a double in order to determine if there is a quality problem with the last recorded measurement.

4. Further Plans

Given that the current WDS data for BU 109 appears to have room for improvement, especially for magnitudes B and C as well as to some degree in RA/Dec coordinates respective Theta and Rho, we intend to do further imaging on BU 109 as soon as there is again, sufficient altitude for imaging so that new photometry and astrometry data can be collected to obtain as precise measurements as possible to further improve the WDS data on this object.

Acknowledgements

The following tools and resources have been used for this research:

Washington Double Star Catalog
iTelescope
AAVSO VPhot
AAVSO APASS
UCAC4 catalog via the University of Heidelberg website
Aladin Sky Atlas CDS, SIMBAD, VizieR
2MASS All Sky Catalog
AstroPlanner
SAOImage DS9

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Determining the Separation and Position Angles of Orbiting Binary Stars: Comparison of Three Methods

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Abstract: To initiate a long term binary star research program, undergraduate students compared the accuracy and ease of measuring the separations and position angles of three long period binary pairs using three different measurement techniques. It was found that digital image capture using BackyardEOS software and subsequent analysis in Adobe Photoshop was the most accurate and easiest to use of our three methods. The systems WDS J17419+7209 (STF 2241AB), WDS 19418+5032 (STFA 46AB), and WDS 16362+5255 (STF 2087AB) were found to have separations and position angles of: 30", 16°; 39.7", 133°; and 3.1", 104°, respectively. This method produced separation values within 1.3" and position angle values within 1.3° of the most recently observed values found in the *Washington Double Star Catalog*.

Introduction

During September and October of 2014 seven undergraduates and two faculty members from Keene State College (KSC, Figure 1) compared three different methods to measure separations and position angles (PA) of binary stars: direct measurement through a micrometer reticule eyepiece, analysis using the software package BackyardEOS, and through captured images evaluated in Adobe Photoshop.

KSC has made it a priority to provide students of any discipline the opportunity to conduct meaningful undergraduate research. KSC physics faculty members attended the 2014 Stellafane Workshop on Binary & Multiple Star Astronomy to evaluate the potential of initiating an undergraduate binary star research program. After the daylong experience they felt confident that this work could be implemented at KSC and make significant contributions to binary star research. Our logical first step was to evaluate and develop the best methods available to collect and analyze binary star data. Here we present our results from data collected during the fall semester 2014, our first steps in implementing a long term research program. The majority of the measurements were taken at Otter Brook Dam in Roxbury, NH (chosen due to the dark skies and proximity to the college) and the remaining measurements were made along Apian Way on the KSC campus (introducing some difficulties in acquiring data due to the ambient light pollution).

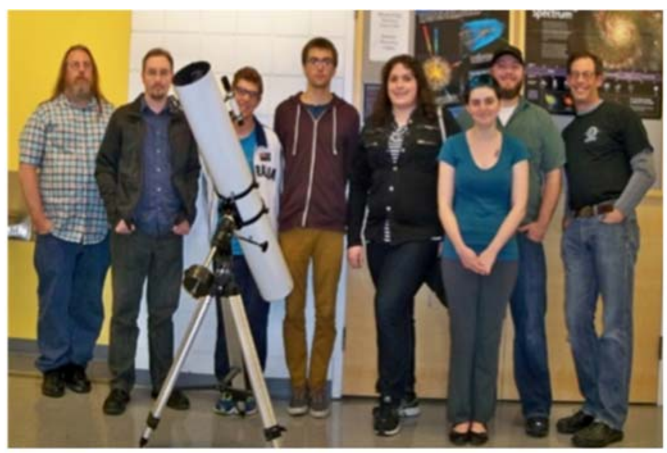

Figure 1: Researchers from left to right: Adjunct Professor Keith Goodale, Students: Ian Ross, Andrew Penfield, Cory Boulé, Trisha Braught, Katelyn Andrews, Ryan Walsh, and Professor Steven Harfenist.

The stars WDS J17419+7209 (STF2241AB-Psi Draconis), WDS 19418+5032 (STFA 46AB - 16 Cygni), and WDS 16362+5255 (STF2078AB - 17 Draconis) were chosen for our methods comparison due

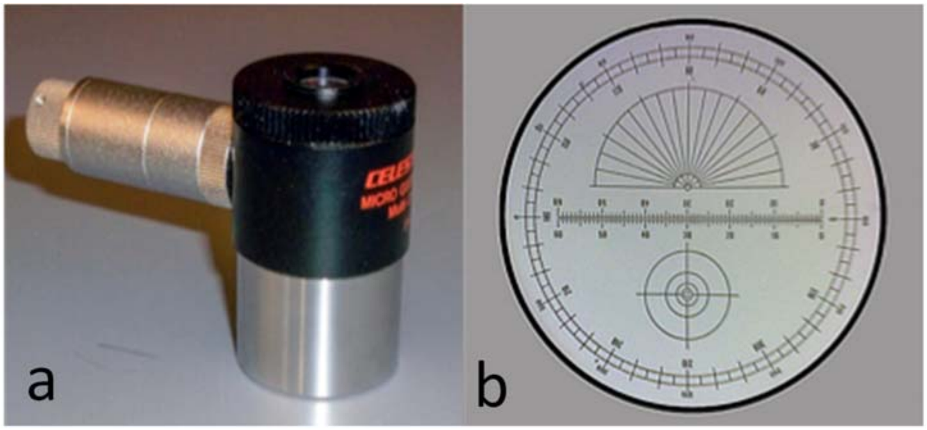

Figure 2: (a) The illuminated Celestron MicroGuide Eyepiece and (b) image of the micrometer reticule scales used to make separation and position angle measurements.

to their relatively long orbital periods (~104 year, Kisselev 2009, Hauser & Marcy 1999, Tolbert 1964), which ensures there will be no noticeable change in separation or PA enabling comparison with recent measurements found in the Washington Double Star catalog (WDS) (Mason & Hartkopf 2013). Their seasonal visibility and the fact that they are bright and relatively easy to locate made them logical choices for us. A detailed discussion of the three methods is given below.

Equipment and Methods

A 9.25 inch (f = 2350mm) Celestron Schmidt-Cassegrain telescope (SCT) on a computerized Orion Atlas equatorial mount, a Celestron MicroGuide Eyepiece (Figure 2a), a 2X Barlow lens, a Canon digital single lens reflex (DSLR) camera mounted to the back of the telescope (at prime focus), and a laptop computer were utilized for the observations. For all digitally captured images, BackyardEOS was used (Nikon DSLR users would use BackyardNik, see http://www.otelescope.com). Digital analysis was performed using both BackyardEOS and Adobe Photoshop. For the micrometer reticule and Backyard EOS analysis methods, each student made measurements of separation and PA. A group average was calculated which was then compared to the WDS values.

The reticules provided a linear scale and a 360˚ protractor (Figure 2b, Figure 3). The linear scales were calibrated using the drift method (Teague 2012). After the clock drive was turned off, the time for the star Altair to drift across the linear scale was measured. Each researcher made measurements of the time it took for Altair to drift across the linear scales for both BackyardEOS and the reticule eyepiece. These times were averaged and the scale constant (*Z*, number of arc seconds per division) were calculated using the equation:

$$Z = \frac{15.0411\cos(\delta)t}{N}$$

Here, t is our average drift time in seconds, δ = 8.8683º is the known declination (epoch j2000.0) in arc seconds of Altair, N is the number of divisions swept in time t, and the coefficient 15.0411 is the Earth's angular rate of rotation in arc seconds per second. The value of Z for the micrometer reticule eyepiece was determined to be 4.0" per division and 7.8" per division for BackyardEOS.

Measurement with MicroGuide Reticule Eyepiece

Separation measurements were performed by first centering the primary in the crosshair, aligning the two components on the linear scale through rotation of the eyepiece, and then the number of divisions between each star image's centroid was recorded (Figure 2b). The eyepiece was then rotated 180° and the same measurement made to reduce systematic error. All division measurements were converted to arc seconds using the value of Z = 4.0" per division. Separation standard deviations were found following the procedure outlined in Weise, et. al., 2014.

To determine the PA for each pair, the primary was centered in the reticule and oriented such that the 0-180° line of the protractor was aligned along the line segment joining the pair of stars. With the clock drive turned off the stars drifted across the outer protractor scale from east to west, enabling the direction of west to be determined. In a SCT used with a star diagonal, north will be 90° clockwise from west. North is 0° and the PA is

Figure 3: Screen capture image showing the protractor and linear reticule scales for performing drift alignment in BackyardEOS, here used to make separation and PA measurements. Note that only one half of the linear scale was used since the width of the center division is variable.

measured eastward from north.

Measurement with BackyardEOS

BackyardEOS is a versatile astrophotography software package that provides complete control for capturing digital images with Canon DSLR cameras. We used the premium version of BackyardEOS 3.0.3 that provides a reticule and protractor as shown in Figure 3. The reticule is ordinarily used for drift alignment when polar aligning the mount, but here we explored its use in making position angle and separation measurements of binary pairs. Separations were measured in the field using the reticule in Live View mode, while PA measurements were performed using the protractor in Drift Align mode, which stacks Live View frames into one image file as the pair drifts with the clock drive turned off (see Figure 4). The image file for the PA measurement was saved and analyzed at a later time.

The same measurement procedures were followed as performed with the reticule eyepiece, with two exceptions: the linear reticule scale in BackyardEOS was calibrated using only half the scale to avoid complications with the variable width drift alignment crosshairs in the center and north will be 90º counterclockwise from west. One advantage of this software is that it allows the user to enlarge the screen image (at the same resolution), better facilitating the separation measurement of the two stars (see upper right hand corner of screen capture in Figure 3). Since the resolution is limited by the software in Live View mode, a disadvantage is that close pairs can be difficult to split on the computer screen.

Measurement with Adobe Photoshop

Digital images of binary pairs captured in BackyardEOS were made at ISO 800 using short exposures from 1-10 seconds depending on the brightness of the pair. A separate 15-second exposure was made with the pair initially centered in the field and the clock drive disengaged. This produced a star trail that indicated west as the pair drifted across the field during the exposure.

The images were later opened in Adobe Photoshop for analysis. Photoshop's Measure tool was utilized for measuring the separation between the centroid of each component of the pair in pixels (Figure 5). The PA was determined using the Measure tool in angle mode of an overlay of both the short exposure and the 15 second trailed exposure (Figure 6). The pixels to arc second conversion is defined by the focal length of the telescope and the sensor size of the camera. The following formula (Wilmslow Astro website, http://www.wilmslowastro.com/software/formulae.htm) may be used to calculate arc seconds per division when using small angles:

$$arc\ seconds\ /\ pixel\ = \frac{pixel\ [mm]}{f\ [mm]}\ x\ 206{,}265''$$

The Canon manufacturer's specifications for the 60Da camera model specify a pixel size (*pixel*) of 4.3 µm and Celestron lists the focal length (*f*) of the telescope as 2350 mm. The value of 206,265" converts the angular field of view of one pixel in radians to arc sec-

Determining the Separation and Position Angles of Orbiting Binary Stars: Comparison of Three Methods

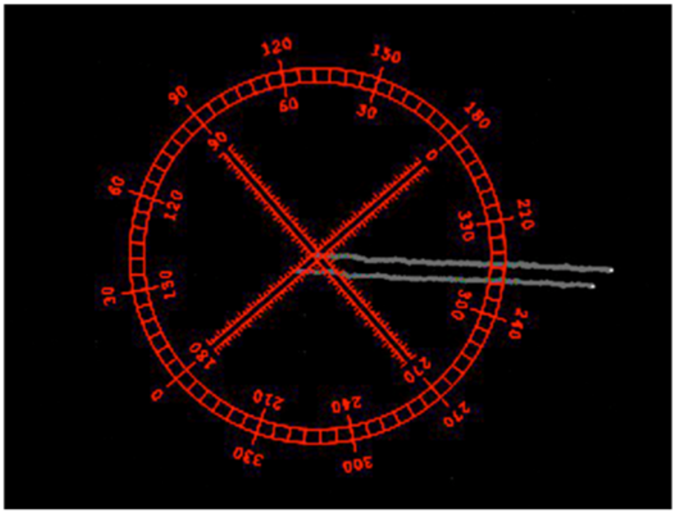

Figure 4. Position Angle determination in BackyardEOS. A 45 second drift image of 16 Cygni (STFA 46AB) is used to determine west. The primary is centered on the protractor scale which is rotated to align the pair along the 0-180° line. The PA is then measured from north counter clockwise to the 0-180° line, here measured to be 133°.

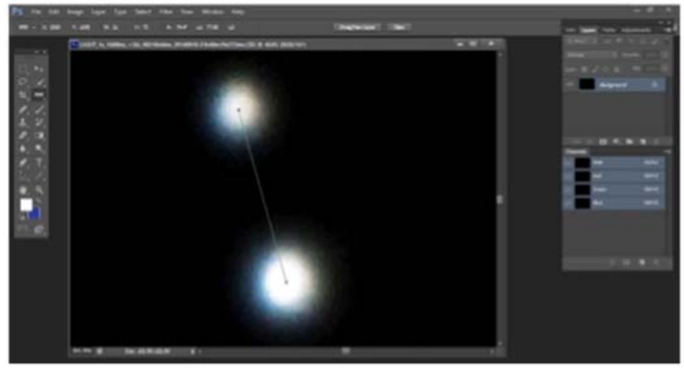

Figure 5. Separation determination using Photoshop's Measure tool. In ruler mode the separation of Psi Draconis is found to be 77.88 pixels = 29.4".

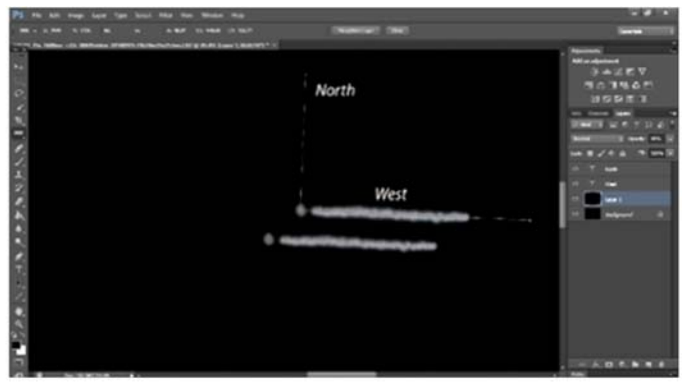

Figure 6: Photoshop's Measure tool in Angle mode used to measure the PA of 16 Cygni as 133.3°. North is directed almost straight up in the image.

onds. Using the formula above, the number of arc seconds per pixel for our telescope and camera combination is .377.

Separation measurements using Photoshop began with zooming on the pair in the short exposure image. We placed the Measure tool cursor (in Ruler mode) on the primary star and clicked and dragged the tool out to the secondary component, producing a line between the two stars (Figure 5). Further enlargement of the image and minor corrections in the cursors' locations allowed more accurate centering of the Measure tool endpoints on each star's centroid. We then recorded the number of pixels between the pair, which were later converted to arc seconds. For our purposes here, a reasonable estimate of the separation measurements' largest uncertainties is the half width at half maximum of the widest intensity profile from each star pair. We estimate these values to be 3.4" for 16 Cygni, 3.8" for ψ Draconis, and 1.4" for 17 Draconis.

Position angle measurements were determined by using both the short exposure and the 15-second drift exposure images simultaneously (Figure 7). The drift image was copied and pasted as a second layer into the short exposure image. The transparency for the top layer was changed to approximately 30% - 40% to line up the two stars in the short exposure with the initial location of the stars in the trailed image.

The Measure tool (Angle mode) was placed at the primary star's initial position and traced along the star trail to indicate west. As with separations, further zooming of the trailed image enabled more accurate correspondence between the drift direction and Measure tool orientation. Double clicking on the initial crosshair of the Measure tool initialized the Angle measurement mode that provided a second line/leg to measure angles. This new leg was rotated 90 degrees counterclockwise from west to determine north. Once north was found, the Measure tool was dragged, as a whole, such that the vertex was centered on the primary star in the un-trailed image without changing the orientation of the north pointing leg. Setting the transparency back to 0%, the remaining leg of the measurement tool was then swept so as to pass directly from the center of the primary through the center of the secondary. The position angle was then measured from north (0°) counterclockwise to the line made from the primary to the secondary.

Discussion

In recent years the micrometer reticule eyepiece has all but replaced the traditional filar micrometer, making

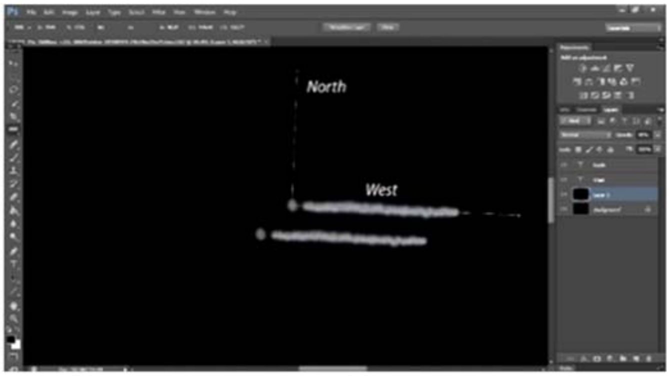

Figure 7: Position angle determination in Photoshop. A five second exposure is overlaid with a trailed 15 second exposure (transparency ~ 40%). West is determined from the direction of the drift and north is known to be 90º counterclockwise from west using this method.

for dramatic improvements in ease of measurement at lower cost. More recently, digital capture and analysis of astronomical images has begun to replace those made at the eyepiece. Our results show that digital measurements are not only more precise and accurate, but much easier to implement. However, we do find that a micrometer reticule eyepiece is still a valid method of measurement, whose accuracy can approach digital methods if care is taken during measurement.

Table 1 compares the three measurement techniques' values found for each of the three binary pairs. Compared to the WDS, it was found that Photoshop gave the most accurate results, followed closely by BackyardEOS and then the micrometer eyepiece. Even though BackyardEOS is not intended for this type of measurement, data analysis using its protractor and linear scale produced results comparable to those found with analysis in Photoshop for wider separated pairs.

Photoshop analysis provided separation values within 1.3" and PA values within 1.3° from the WDS values. BackyardEOS analysis provided separations within 1.3" and PA data values within 2° from WDS values. This data does not include 17 Draconis, which could not be split by BackyardEOS in Live View mode. The micrometer eyepiece measurements had separation deviations between 0.8" and 1.9" and PA deviations between 1° and 3° from WDS values.

All of our methods suffer from the systematic uncertainties caused by the flaring of scattered light due to atmospheric seeing combined with optical aberrations. The micrometer reticule has additional measurement error associated with the parallax experienced while looking through the eyepiece, especially for novice astronomers. At times atmospheric turbulence made the closely separated pairs quite difficult to measure with respect to centering the primary on the protractor and aligning the pair along the 0º to 180º line. Even so, with meticulous attention made using the micrometer reticule, the accuracy of this method could certainly approach that of Photoshop analysis.

The advantages of analysis in Photoshop are numerous. It provides the best separation measurement resolution (±1 pixel / ±0.377"). The precision of the Measure tool in Angle mode (~0.01°) is much better than those made in the field by eye on a protractor reticule (smallest division of 5º). Last, data analysis can be performed indoors at a later time, minimizing time spent in the field. The main disadvantage is the cost of the software (~$600/year for a new user) and the need of a computer for analysis (if using a computer in the field, additional image capture software will be required, such as BackyardEOS, MaxIm DL, IRIS, or Nebulosity)

The use of BackyardEOS for these measurements employs nearly identical methodologies as the micrometer reticule eyepiece, but with a few advantages. Measurements can be made on a computer screen that can zoom in on the image. It also enables easier centering of the stars, having the capability to move and rotate the scales to the objects of interest. BackyardEOS does have some disadvantages when used in this way. As with the micrometer reticule eyepiece, it uses a linear and protractor scale to make measurements and is subject to human measurement error. Its Live View resolution is dependent upon good seeing to split close binaries, often requiring many various duration exposures and ISO settings. Even so, some binaries were not resolvable (STF2078AB -17 Draconis).

The micrometer eyepiece has the advantage of utilizing the human eye's ability to capture short moments of good seeing, it can be used with a Barlow lens, and has higher magnification than BackyardEOS implemented in this way with a Canon DSLR camera (this version of BackyardEOS only works with Canon EOS DSLR cameras). A further disadvantage of the micrometer eyepiece is that they are becoming harder to find since they are being produced more infrequently as digital capture and analysis methods become more common, affordable, and versatile.

Conclusion

We found that all three measurement methods are valid, but will continue to focus on using BackyardEOS for image capture and Photoshop for analysis in the immediate future, as we found this combination to work best for us. Going forward, our undergraduate research group will continue to catalog binary stars with the aim to image and analyze close binary pairs, those with larg-

*Table 1. Comparison of separation and position angle measurements using three different methods: the MicroGuide (Micrometer) Reticule Eyepiece, the astrophotography software package BackyardEOS, and analysis of digital images using Adobe Photoshop. *Could not resolve the pair using BackyardEOS Live View mode at the time of measurement.*

WDS Designation	Discoverer Designation	Method	Sep"	PA°	Date	N
J17419+7209	STF2241 AB	Micrometer	30.8±2.6	19±3	2014.821	12
		BackyardEOS	30.9±1.4	14±0.5	2014.717	6
		Photoshop	29.2	17.3	2014.717	7
		WDS Catalog	30.0	16	2012	
19418+5032	STFA 46AB	Micrometer	41.6±2.9	132±3	2014.821	12
		BackyardEOS	41.6±0.9	133±0	2014.717	6
		Photoshop	38.4	133.3	2014.717	7
		WDS Catalog	39.7	133	2013	
16362+5255	STF2078AB	Micrometer	4.0±0.5	103±5	2014.821	4
		BackyardEOS	N/A*	N/A*	2014.717	6
		Photoshop	3.1	104.0	2014.739	7
		WDS Catalog	3.1	104	2013	

er magnitude differences, and neglected pairs. We will improve our separation measurement accuracy through curve fitting intensity profiles for better determination of the star image's centroid.We will continue to work toward improving our measurement accuracy. As hoped for, this type of binary star research is easily within the reach of undergraduate science students and can undoubtedly lead to more advanced and in-depth binary star projects including eclipsing binary star photometry, orbital calculations, lucky imaging, and speckle interferometry. Additionally, we found BackyardEOS to be an ideal software package for capturing DSLR images.

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An Online Tool that Searches the WDS

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Abstract: An online tool that extracts entries based on user input from the Washington Double Star Catalog (WDS)[1] has been created. It can be found at:
http://mainsequence.org/html/wds/getListOfDoubles/mkWDS_List.html

The data in the Washington Double Star Catalog are currently scattered over several files. Researching it requires perusing these files to find all of the data related to a given star, a time-consuming activity. To ameliorate this, the author has built a series of computer programs that assemble most of these data for a given group of binaries into a single, online, color-coded list.

When the web site at http://mainsequence.org/html/wds/getListOfDoubles/mkWDS_List.html is accessed, an initial menu is displayed as shown in Figure 1.

The top four fields are for the right ascension and declination boundaries of the region you wish to search. These must be filled out, or the program will not run and it will return an error message to you.

The next four fields, labeled"Other parameters", specify the criteria for the search you're about to make. They are filled out with default parameters that you will probably want to change.

• Faintest primary star to list: The magnitude of the faintest primary star to be included in the list.

• Maximum magnitude difference between primary and secondary: Binaries with a greater brightness difference will not be in the list.

• Maximum separation between primary and secondary: Binaries with a greater separation will not be in the list.

• Minimum separation between primary and secondary: Binaries with less separation will not be in the list.

Clicking the Submit button will create the list.

The columns in the list are described in the explanation section, which can be accessed by clicking the "Explanation" tab in the third line of the list's header. It is reproduced in the following paragraphs:

```
The data in this list is a compendium of the United States Naval Observatory's main catalog, neglected stars, notes, and alternate star name list. The data in your list are taken from these documents and filtered according to your submitted specifications.

Row color explanation:

• A pair shown in green means that the data for the pair are probably accurate.
• A pair shown in yellow means that the WDS has listed the pair as neglected.
• A pair shown in red means that the pair has not been observed since 1970 or its last observation date is unknown.

Note: The data listed for all pairs are accurate, irrespective of the highlight color. The USNO gives a detailed explanation of neglected stars. Click here to go there.

The J2000 coordinates are formatted such that they can be copied into tools such as
```

(Continued on page 166)

An Online Tool that Searches the WDS

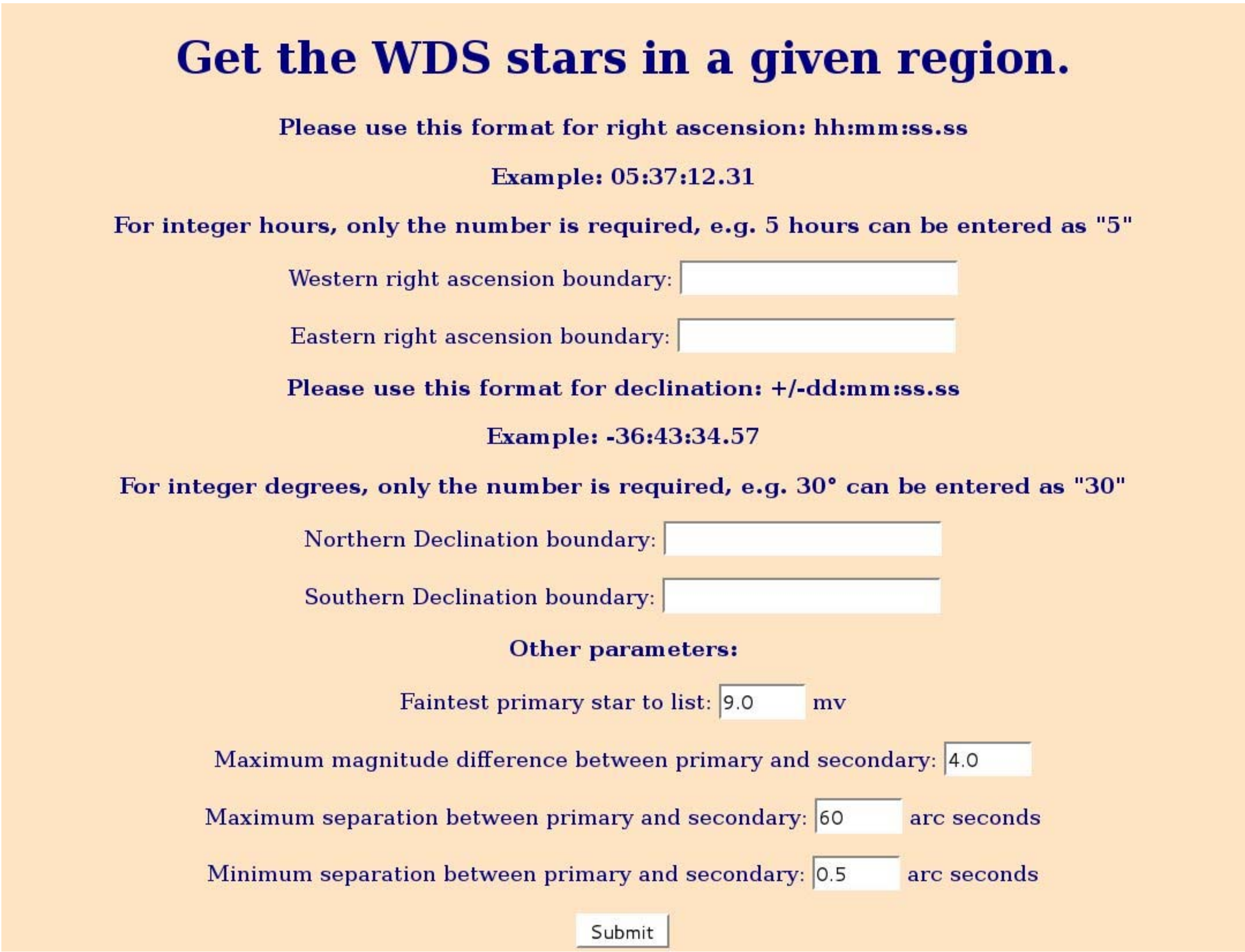

Figure1. Initial menu displayed at http://mainsequence.org/html/wds/getListOfDoubles/mkWDS_List.html, to be filled out by user to search the WDS.

An Online Tool that Searches the WDS

(Continued from page 164)

Aladin or WikiSky to display the DSS image at that location. **The WDS Id** is a 10 digit string that lists a low precision coordinate of the pair. **The Dsc Id** gives the discoverer's initials or designator, and the number of the pair in their published list. **A mv** is the visual magnitude of the primary. Other bandpasses for a pair are described in the notes column. **B mv** is the visual magnitude of the secondary. **Spectra** is the spectral type of the primary. At times the secondary's spectrum is listed as well. **First and last θ** are the earliest and most recent position angles of the pair, in degrees. **First and last ρ** are the earliest and most recent separations, in arc seconds, of the pair. **First and last Obs** are the first year the pair was observed and the year of the most recent observation. **AKA** (Also Known As) lists other common names for the pair. Comments:

- **Blue mags** indicates that the pair's magnitude is photographic, Johnson, or other Blue band.
- **Red mags** indicates that the pair's magnitude is from the Johnson or other Red band.
- **Dubious** indicates that the pair is listed is probably an error in the original discoverer's listing.
- **IR mags** indicates that the pair's magnitude is its infrared magnitude. Usually 4-6 mags brighter than the visual magnitude.
- **Linear** indicates that linear elements for this pair have been determined.
- **Low precision coordinates** indicate that the precise position of the pair is not known.
- **Neglected** indicates that the pair is listed as neglected by the WDS.
- **Orbit** indicates that the pair is in the USNO's orbit catalog.
- **Optical** indicates that the pair is probably not physical.
- **Uncertain** indicates that the identification of the pair is uncertain.
- **Uncertain Position** indicates that the pair's position is uncertain.

Notes: If a star has an entry in the WDS notes document, the word "Note##" where ## is the number of the note appears in this column. Clicking on it will take you to the text of that note.

Notes

The search results are limited to a maximum of 500 binaries. After 500 binaries have been found, the search stops and the results are displayed.

The WDS is updated on a regular basis. The author attempts to update the database that contains the data shown by this list on a weekly basis as well.

Acknowledgements

The author wishes to acknowledge the editorial assistance of William Hartkopf, Tom Corbin, and Kathleen Bryant in making this short paper more readable.

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New Common Proper-Motion Pairs with R.A. Between 00h and 01h

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Abstract: This paper presents 37 new common proper-motion pairs. The new pairs have been obtained employing a semi-automatic procedure based on the inspection of images using the tool Aladin, completed with information obtained from the catalogs available at VizieR. All the pairs fulfill the Halbwachs criteria, employed to increase the probability of a physical bond between the two components.

Method

In previous papers such as Greaves (2004), new common proper-motion pairs (CPMPs in the rest of the paper) have been obtained from different astronomy catalogs available at VizieR. It was observed that in many cases the data obtained from the catalogs were not reliable, and therefore a final phase checking the existence of some image in Aladin (Bonnarel, et al., 2000) confirming the pairs data was requested.

Results

Table 1 shows the final list of 37 CPMP was obtained. For each pair we include:

The coordinates of the primary in the catalog.

The components, marked as AB in all the cases.

The visual magnitude V for both components.

The source of these data is shown in the two first characters of column 'Source'.

The epoch and astrometry data of the pair: position angle and separation. In all the cases the data have been obtain from the 2MASS catalog. The astrometry data was obtained from the coordinates in decimal format following Sinnott (1984). The separation is given in seconds and the position angle in degrees.

Columns 'PM RA' and 'PM DEC 'shows the proper movement of the two components in milliarcsecond/year. The source of these data is shown in the last two characters of column 'Source'.

Finally column 'Notes' indicates the special situations.

Conclusions

Although many of the papers on new pairs follow the approach of first using the data catalogs and then checking the images, the converse procedure is also fruitful. This is the case for those pairs whose proper motion data, used to filter line-of-sight pairs, are obtained in different catalogs. The result is the list of 37 new CPMPs presented in this paper.

Acknowledgements

This research makes use of the ALADIN Interactive Sky Atlas and of the VizieR database of astronomical catalogues, all maintained at the Centre de Données Astronomiques, Strasbourg, France, and of the data products from the Two Micron All Sky Survey (2MASS), which is a joint project of the University of Massachusetts.

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Bakos G. Á., Sahu K. C., P.Nemeth, 2002, "Revised Coordinates and Proper Motions of the Stars in the Luyten Half-Second Catalog", *The Astrophysical Journal Supplement Series*, **141**(1), 187-193.

Bonnarel, F., Fernique, P., Bienaymé, O., Egret, D., Genova, F., Louys, M., Ochsenbein, F., Wenger, M., Bartlett, J. G., 2000, "The ALADIN interactive sky atlas. A reference tool for identification of astronomical sources", *Astronomy and Astrophysics Supplement*, **143**, 33-40.

(Continued on page 169)

New Common Proper-Motion Pairs with R.A. Between 00h and 01h

Table 1 : Astrometric Measurements of the new pairs

RA DEC		Mags.	Date	PA	Sep.	PM RA	PM DEC	Source	Notes
00 01 06.67 +19 52 24.82	AB	15.99 17.95	1998.88	158.40	8.42	-035-063	-036-064	G,G|P,P	
00 02 16.53 -42 22 45.86	AB	16.03 17.74	2000.68	221.50	11.84	+072-014	+070-023	N,N|P,P	
00 05 55.38 -61 04 13.37	AB	14.65 16.08	2000.57	24.68	19.95	+539+025	+506+037	S,G|R,M	(1)
00 06 19.13 +68 51 07.79	AB	12.71 14.31	1999.79	209.64	19.53	+054-007	+050-010	G,G|P,P	
00 07 48.35 +58 00 50.30	AB	14.10 17.52	1998.97	320.28	8.61	+203-010	+204+021	G,L|U,L	
00 10 01.04 -50 28 13.18	AB	11.50 16.00	1999.79	83.93	21.04	-122-066	-119-063	T,S|P,P	
00 10 15.72 +05 25 37.57	AB	15.54 15.83	2000.90	107.88	9.45	+054-170	+054-170	G,G|L,U	
00 12 09.10 +29 35 45.18	AB	12.20 16.15	1997.80	150.95	12.49	+090-043	+082-038	G,G|N,N	
00 12 47.81 -33 29 28.31	AB	14.90 16.75	1998.87	358.72	19.08	+057-032	+058-032	G,G|P,P	
00 13 08.02 +51 29 47.93	AB	14.65 16.80	1998.85	1.00	5.93	+248+014	+250+050	G,G|N,N	
00 13 29.57 +38 07 30.88	AB	13.73 16.26	1998.83	78.86	10.30	+015-154	+018-152	G,G|P,P	
00 17 00.74 +69 29 24.73	AB	11.15 16.32	1999.75	17.78	30.57	+093+015	+091+010	G,G|P,P	
00 19 38.96 +64 56 59.06	AB	12.53 13.09	2000.45	12.45	24.72	+073+015	+070+007	G,G|P,P	
00 21 01.81 +18 27 06.17	AB	15.35 16.47	1998.75	309.20	3.19	-125-109	-125-109	L,L|L,L	
00 22 48.27 -50 09 16.54	AB	16.64 17.16	1999.76	260.61	36.41	+078+002	+084-001	N,N|P,P	
00 24 08.46 -41 47 46.56	AB	14.53 16.45	2000.01	121.82	29.02	+063-056	+068-062	G,G|P,P	
00 24 49.63 +68 34 42.40	AB	13.92 14.41	1992.74	14.40	3.30	+416+027	+416+027	N,N|L,L	(2)
00 25 03.02 -17 20 59.41	AB	15.73 17.39	1998.60	273.79	8.28	-001-054	-011-055	N,N|I,I	
00 27 29.04 +46 08 02.59	AB	15.82 18.98	1998.84	304.49	14.94	-067-019	-070-023	G,G|P,P	
00 27 49.15 +29 38 29.15	AB	14.73 17.91	1997.81	214.33	17.69	-076-056	-082-062	G,G|N,N	
00 32 24.42 +70 10 32.73	AB	13.35 13.65	2000.76	253.67	16.39	+046-018	+046-020	G,G|N,P	
00 32 24.88 +50 19 13.85	AB	11.96 15.05	1998.85	98.03	12.00	-159-050	-157-053	G,G|P,P	
00 33 34.27 +36 05 15.55	AB	13.37 19.26	1998.92	345.73	42.38	+157-006	+157-006	G,L|U,L	
00 33 59.06 -43 37 34.74	AB	16.42 17.39	1999.70	289.12	7.67	+022-137	+011-138	G,G|P,P	
00 34 08.11 +57 09 35.46	AB	17.38 18.57	1999.86	43.43	15.41	+074+004	+073+003	G,G|T,T	
00 34 17.79 +27 34 00.15	AB	16.32 18.33	1998.02	322.26	38.28	+177+057	+177+051	G,G|P,P	
00 35 10.51+42 19 44.85	AB	13.48 ?	1998.84	123.09	5.44	+152+014	+152+014	G,?|U,L	(3)
00 35 15.06 +82 25 18.53	AB	14.73 17.37	1999.82	313.48	7.30	+074-018	+067-021	G,G|P,P	
00 37 18.07 +75 36 23.12	AB	10.03 17.08	1999.81	148.22	34.11	-131-073	-127-075	G,G|P,P	
00 40 14.28 +67 00 54.66	AB	15.58 18.82	1999.86	353.68	43.75	+067-007	+072-011	G,G|P,P	
00 42 47.23 +82 29 25.53	AB	14.56 18.46	1999.82	174.62	44.16	+071+010	+072+011	G,G|P,P	
00 48 03.09 +09 58 24.58	AB	13.76 16.9	2000.75	47.90	10.38	+008-071	+010-065	G,G|P,P	
00 51 24.03 +26 35 32.43	AB	15.97 18.37	1997.83	117.51	5.67	+185+064	+185+063	G,L|P,L	
00 54 42.20+58 28 38.91	AB	13.05 18.00	1998.97	230.56	3.46	-104-109	-104-109	H,H|L,L	
00 57 16.25 +64 29 37.12	AB	14.52 18.52	1994.70	42.50	37.85	+083-032	+087-037	G,G|P,P	
00 57 51.49 -56 32 23.15	AB	16.61 17.44	1999.80	54.65	38.58	+143+052	+144+052	G,G|P,P	
00 58 41.09 +16 44 05.44	AB	13.84 14.03	2000.79	264.27	6.51	+256-079	+253-080	G,N|P,L	

Format of the "Source" column: UV | XY where U identifies the catalog used to obtain the magnitude of the A component, V the catalog to obtained the magnitude of the B component, X the catalog used to get the PM of the A component and Y the catalog to obtain the proper movement of the B component, where:

G: GSC2.3 (Lasker et al., 2008)
H: Red magnitude from GSC2.3
I: The Initial Gaia Source List (IGSL) (Smart, 2013)
L: LSPM (Lepine+ 2005)
M: Sample of low mass stars with mu>0.1"/yr (Deacon+, 2007)
N: NOMAD (Zacharias+ 2005)
P: PPMXL (Roeser+ 2010)
R: Revised Luyten Half-Second Catalogue (Bakos+ 2002)
S: SPM4.0 (Girard+, 2011)
T: Tycho Input Catalogue, Revised version (Egret+ 1992)
U: UCAC4 (Zacharias+, 2012)
T: URAT1 (Zacharias+, 2015)

(Continued on page 169)

New Common Proper-Motion Pairs with R.A. Between 00h and 01h

(Continued from page 168)

Notes column:

1. A is LHS 1018
2. B distance: 43.2 pc according to “new high proper motion stars (-90<DE←47) “(Subasavage+, 2005)
3. Red magnitude from NOMAD
4. Only magnitude for A available in the VizieR catalogs

(Continued from page 167)

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Mt. Wilson Meets the Lyot Double Image Micrometer

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3. Society for Astronomical Sciences
4. California State University, San Bernadino
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6. Mt. Wilson Institute

Abstract: As part of the Mt. Wilson Double Star Workshop, the authors used a double image micrometer to observe two double stars, STF2383CD and STF2583AB, on the night of July 19, 2013 (B2013.547). The instrument was designed in 1949 by Bernard Lyot and built by Meca-Precis. We found separations of 2.53±0.29" for STF2383CD and 1.58±0.40" for STF2583AB, and positions angles of 77.8±2.3° for STF 2383CD and 103.4±1.6° for STF2583AB. The scarcity of double image micrometers and the opportunity to use the historic 60 inch telescope at Mt Wilson made this workshop a very unique experience.

Introduction

The Mount Wilson Double Star Workshop was held to bring together double star enthusiasts at one of the cathedrals of astronomy, the historic and hallowed site where great discoveries about the universe have been made. To do research in a place covered by the footprints of great men such as Albert Michelson, Milton Humason, George Hale, Edwin Hubble, and Albert Einstein is a dream come true for many scientists. Our brief stint as researchers at Mount Wilson was a half night of observations on Friday July 19, 2013, and two days of data analysis and paper writing in the historic Mt Wilson Library.

We used the 60 inch telescope that Edwin Hubble was groomed on before using the 100 inch Hooker telescope. Thomas Barnes, the grandfather of one of our team members, Cheryl Genet, was the foreman for the construction of the 60 inch telescope, and ground the mirror with George Ritche. Merritt Dowd, Thomas Barnes's brother-in-law and the Chief Electrician at Mt Wilson, and Catherine Dowd Barnes, Thomas Barnes's wife, stayed on Mt Wilson during the entire construction of the 60 inch observatory. To the three generations of descendants of Thomas and Catherine Barnes who were present at the workshop (Cheryl Genet, John Davidson, and Noah and Adam Tassell), this was much

Figure 1. The participants of the Mt Wilson Double Star Workshop pose in front of the 100 inch Hooker telescope. In order from left to right: (Standing) Rick Wasson, Mark Brewer, Reed Estrada, Cheryl Genet, Russ Genet, Adam Tassell, Noah Tassell, Joseph Carro, Inga Kenney, and Ryan Gelston. (Sitting and Kneeling) Vera Wallen, Rafael Ramos, John Davidson, Eric Weise, Cassie Hollman, and Chris Estrada.

more than a scientific endeavor.

Our observing session started with a spectacular viewing of Saturn with a visual eyepiece. The seeing was extraordinary, less than half of an arc second. The

Mt. Wilson Meets the Lyot Double Image Micrometer

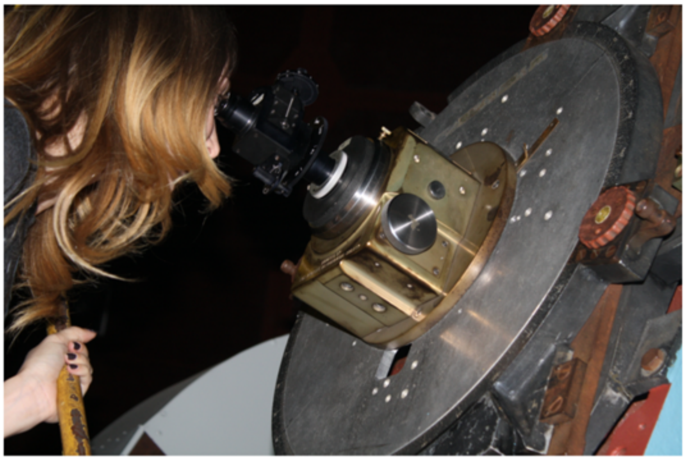

Figure 2. Christine Gerhart, who also worked for the observatory as a telescope operator, making a measurement with the Lyot double-image micrometer.

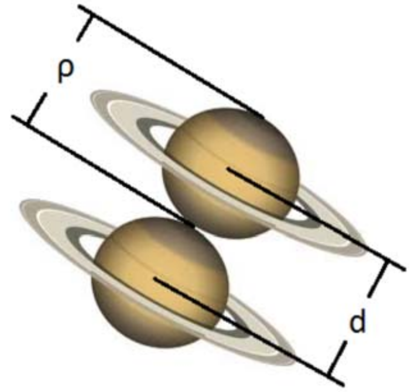

Figure 3. When two images of a planet are arranged as seen using a double image micrometer, the angular diameter of the planet (ρ) is equal to the artificial separation of the two images (d) created by the instrument.

image of the planet was incredibly crisp and detailed. Even the various longitudinal strata of swirling gas were visible and appeared like layers of a cake. After this "Oh, ah" session, our scientific observations began. The first two hours were devoted to an astrometric eyepiece, while the second two hours were given to the double image micrometer.

Historical Perspective

The Double Image Micrometer

The concept of doubling the image of an astronomical object for the purpose of angular measurements has been known for some time. Ole Römer suggested this method in 1675 (Lord 1994-B), although the technique was not put into practice for three quarters of a century. Some of the first known descriptions of such a device were given by Servington Savery in 1743 (Short 1753) and John Dolland (1953). Many adaptations were made to these early designs by George Airy (1845), Simms (1858), and others.

A double image micrometer works by creating two images of an object that are, for all intents and purposes, identical. If an observer can put the two images (i.e. images of a planet) into a certain configuration (i.e. such that the images of the planets are touching), then one can calculate the angular separation between the two images. Figure 3 shows this arrangement. These micrometers have been used to measure an assortment of stellar objects, including the diameters of planets, the phases of the sun and moon during partial eclipses, and, of course, the separation of double stars. These early devices, however, do not even remotely resemble the most recent double image micrometer. Dolland's and Airy's double image micrometers were of a subclass called the "divided lens" micrometer, and consisted of four lenses, one of which was split along its diameter (Lord 2012). These predecessors to the modern version were all notorious for lengthy calibration procedures and chromatic aberrations to varying degrees (Lohse 1902).

In 1949, French astronomers Bernard Lyot and Henri Camichel patented a double image micrometer that used calcite as a means of producing two images of stellar objects. The birefringent properties of calcite mean that two images can be made by one crystal "Spar plate" and an eyepiece, rather than a divided lens and multiple focusing lenses. This improvement single-handedly eliminated the long calibration procedures and the chromatic aberrations that plagued this instrument's predecessors. Lyot contracted the company Meca-Precis to construct his micrometer, although only a handful of the lavishly expensive, yet beautifully simplistic instruments were built. The particular micrometer we used in this paper is serial number 10. In tribute to its innovator we fondly call our micrometer "the Lyot".

The 60 Inch Telescope

George Ellery Hale was a prolific scientific organizer. He was the driving force behind the establishment of four of the world's largest telescopes: the Yerkes 40 inch (completed in 1887), the Mt Wilson 60 inch (first light in 1908), the Mt Wilson 100 inch "Hooker" telescope (first light in 1917), and the Palomar 200 inch "Hale" telescope that was completed after his death (first light in 1949). He also co-founded the California Institute of Technology—Cal Tech (1891). When he decided to build the 60 inch telescope on Mt Wilson, he

Mt. Wilson Meets the Lyot Double Image Micrometer

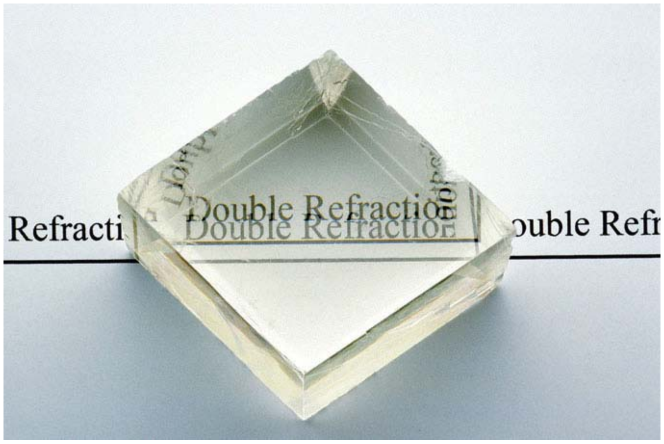

Figure 4. When an object is viewed through a calcite prism, two images are seen. The distance between these two images is a function of the angle at which the observer sits. If the observer places his eye on the line orthogonal to the surface of this crystal, only one image of "Double Refraction" will be seen.

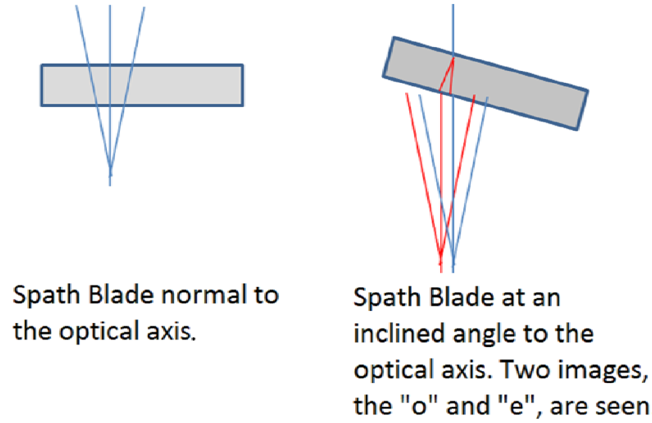

Figure 5. Principle of operation of Lyot double-image micrometer

chose this location for its excellent seeing. The peak stands in the Los Angeles National Forest at 5713 feet above sea level, just a 25 mile drive (or buggy ride in those days) away from Cal Tech. The blank for the 60 inch mirror was donated in 1896 and was ground by George Ritchey and his right hand man Thomas Barnes, Cheryl Genet's grandfather. During the first light ceremony of the telescope, Thomas and Catherine Barnes, their son Frederick, and Merritt Dowd were present; the only known first-hand account of the event is contained in a diary written by Catherine Barnes. This diary is in the possession of John Davidson, Cheryl Genet's son, and was exhibited at the workshop.

The time the 60 inch spent as the world's largest active telescope was short. In 1906, two years before first light on the 60 inch, Hale ordered the casting of the mirror blank for the 100 inch Hooker telescope. In 1917, after spending only nine years as the world's largest telescope, the 60 inch was surpassed in size by its big sister. In 1986, 37 years after Bernard Lyot invented his double image micrometer, the Mt Wilson Institute took over operation of the observatory (*http://www.mtwilson.edu/cent.php*). This time-line, and the scarcity of Lyot's micrometer, leads us to believe that our observation with his double image micrometer was the first time in the history of the 60 inch that one of these instruments was used.

Methods

The methods employed by the authors as well as detailed operations of the Lyot can be found in Lord (1994-A).

The Lyot micrometer is a double-image micrometer, implemented by a prism of calcite crystal, which is birefringent, meaning it has two indices of refraction. The "Spath blade," which holds the calcite crystal, is located just before the telescope focus, and is followed by a reticle eyepiece with which the operator views the image plane. The micrometer has two vernier dials that enable precise rotation of the calcite Spath blade, as well as rotation of the entire instrument around the optical axis. An example of the refractive properties of a calcite crystal is shown in Figure 4.

If a single star is viewed, the calcite Spath blade places two images at the image plane (Figure 5). The two images are the "ordinary" and "extraordinary" refracted rays of the incoming starlight. The angular separation between these two images is a function of the "inclination angle" of the calcite crystal with respect to the incident light path. When the face of the calcite prism is normal to the light of the star, the ordinary and extraordinary images coincide. When the plate is rotated, the "o" and "e" images separate; greater inclination of the Spath blade provides wider separation of the "o" and "e" images. These two images have perpendicular polarizations, but they are indistinguishable to the visual observer. When a double star is viewed through an inclined Spath blade, a total of four star images are visible –two of the primary member and two of the secondary member of the pair.

The other alignment configuration we used strives to place the four star images into a perfect square (following a procedure similar to the one described in the previous paragraph). Again, the human eye is remarkably adept at detecting very slight asymmetries in such a pattern, which enables the observer to achieve excellent alignment and measurement of the pattern. The

Mt. Wilson Meets the Lyot Double Image Micrometer

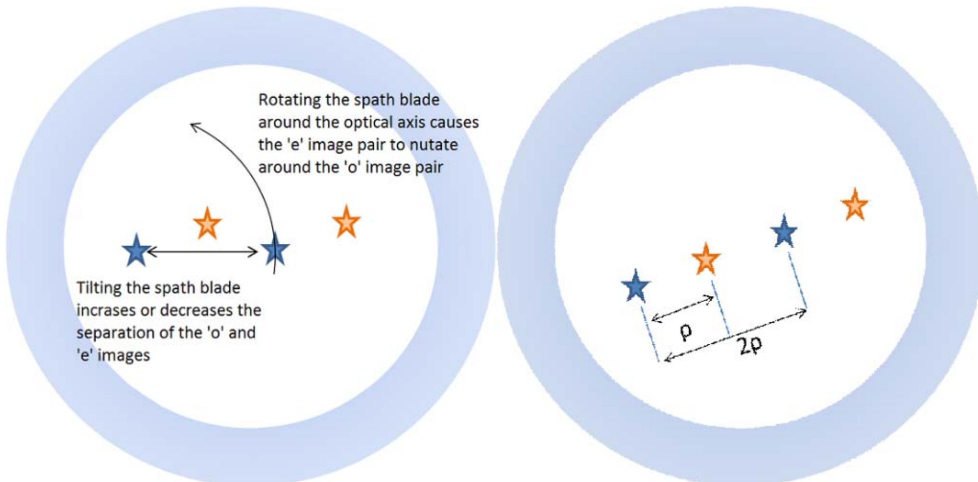

Figure 6. Lyot instrument provides two adjustments of the image: tilting the Spath blade changes the separation of the "o" and "e" images, and rotating the instrument around the optical axis causes the "e" images to nutate around the "o" images. It is also possible to arrange the star images in a line such that ρ is half of the image separation.

interpretation of separation (vs. Spath blade tilt) is identical to the equidistant-linear alignment pattern, but the interpretation of the position angle (vs. instrument rotation angle around the optical axis) is 90 (or 270) degrees different from the linear pattern. Thus it is important to record in the observer's notes which pattern was used!

Our observation method incorporated an "adjust and confirm" approach to achieving the desired alignment of the pattern. The first observer adjusted the tilt and rotation to create the desired equidistant-linear pattern, and then the second observer examined the image to confirm the pattern. The tilt and rotation were then recorded. The Spath blade was then tilted in the opposite direction, the star pattern adjusted, and a second observer confirmed the pattern before the tilt and rotation orientations were recorded. The use of both "positive" and "negative" tilt directions of the Spath blade turned out to be valuable because it highlighted a small but significant zero-point offset in the readings of the tilt orientation of the Spath blade.

One of the features of the Lyot instrument is that reading the star-image orientation does not depend on an illuminated reticle. This avoids the potential glare from the reticle interfere with observation of the target pair (or reading of the reticle); and it eliminates the need for achieving focus on both the reticle and the target stars. The absence of the illuminated reticle makes the colors of the stars delightfully apparent: one of our pairs presented a pretty contrast between its gold and the white components.

No calibration of the Spath blade tilt angle reading was required; the scale factor is provided by the manufacturer's calibration curve for the "angular distance factor" in addition to the focal length of the telescope. Our limited experimentation with this device indicates that the manufacturer's calibration is still very good, and is applicable when the precise focal length of the telescope is known. However, we will remain diligent to conduct observation/measurement of well-attested pairs as a way of confirming the validity of the tilt calibration.

The rotational alignment is calibrated using a single-line reticle. The observer selects a single star, places it on this reticle line, turns off the telescope drive, and rotates the instrument so that the path of drift is collinear with the reticle. This rotation-orientation reading defines the E-W celestial axis and calibrates the position angle measurements. We found north to be at 3.16° with respect to the position angle dial on the instrument. The standard deviation and standard error of the mean for north were 1.18° and 0.42°, respectively.

Data

Our data is presented below in Table 1, and is compared to past observations reported to the WDS in Table 2. A note on the standard deviation of the separation values: to find the separation of a system, the inclination, í, of the Spath blade is recorded, and the "Angular Distance Factor", φ(í), is used to convert this value into a separation in arc seconds.

$$\phi(i) = \frac{648000}{\pi}\frac{\sin(2i)}{\sqrt{2}}\left(\frac{1}{\sqrt{2n_e^2 - 1 + \cos(2i)}} - \frac{1}{\sqrt{2n_o^2 - 1 + \cos(2i)}}\right)$$

Table 1. Our Data. Epoch, B2013.547.

	STF 2383CD		STF 2583AB	
	PA	Sep.	PA	Sep.
Number of Observations	6	11	8	8
Average	77.8°	2.53"	103.4°	1.58"
Standard Deviation	5.6°	0.95"	6.6°	1.12"
Standard Error of the Mean	2.3°	0.29"	1.6°	0.40"

The derivation of the formula φ(í) is given by Lord (2012). Each measurement of the separation is converted to the image separation, *d*, by

$$d = \frac{e}{F}\phi(i)$$

where *e* is the thickness of the Spath blade (we used the Meca-Precis stated value *e* = 4mm) and *F* is the effective focal length of the telescope (in our case, *F* = 24m). The image separation, *d*, is related to the separation of the stars by a factor of ½, 1, or 2, depending on how the two images of the binary stars were arranged during observations (see methods section). To find the standard deviations of our data, each observation was converted to a separation using the above formulas and then applying the standard formulas.

The position angle was obtained by reading the position angle dial on the instrument and applying our offset from the E-W celestial axis. Due to the zero point offset, our position angle measurements have a double peak distribution. Until we have more data to quantify this offset, we calculate the standard deviation of each of these peaks and then add these in quadrature:

$$\sigma = \sqrt{\sigma_A^2 + \sigma_B^2}$$

During the observations of STF 2383CD the micrometer was twisted in the drawtube assembly. We had not taken any calibration measurements to establish the direction of North before this happened. Because of this, we lost five position angle measurements. To compensate, we made extra observations of this system. Thus we have a different number of position angle and separation measurements for STF 2383CD, measurements that are usually made concurrently.

Table 2. Past 10 observations from the WDS.

	STF 2383CD		STF 2583AB	
	PA	Sep.	PA	Sep.
WDS Average	78.25°	2.294"	105.04°	1.422"
WDS - Ours (Δ)	0.49°	-0.235"	1.65°	-0.161"
% Diff (Δ/ours)	N/A	9.3%	N/A	10.2%
Our Standard Deviation (σ)	5.59°	0.948"	6.63°	1.121"
Δ/σ	0.088	0.248	0.249	0.144

Analysis

To check the validity of our measurements, we compared our data to the average of the past ten observations reported to the *Washington Double Star* Catalog (WDS) (Mason and Hartkopf 2013). For the system STF 2383CD these observations were made between 2009.803 and 2012.628, and for the system STF 2583AB these observations were made between 2008.560 and 2012.729. We show these averages in Table 2.

We used three values to compare our data to the past observations. First we used the difference between our measurements and the average of the past ten observations (Δ). This value shows how much our value is over or under the past observations. Second, the Percent Difference shows how significant our under/overestimate is. Finally, we looked at how many standard deviations we were off from the past ten observations (Δ/σ).

For both target systems, our Position Angle data are in agreement with the past observations. Our separation data, on the other hand, are not. While the differences between our data and the past observations are less than one arc second, they are still significant compared to the separation of the systems, as evidenced by the Percent Difference values. One might comment that we should have observed wider pairs, but this is not possible, owing to the narrow field of view of the instrument. However, considering the time constraints and that the majority of observers were using the Lyot for the first time this night, we concluded that our observations were satisfactory.

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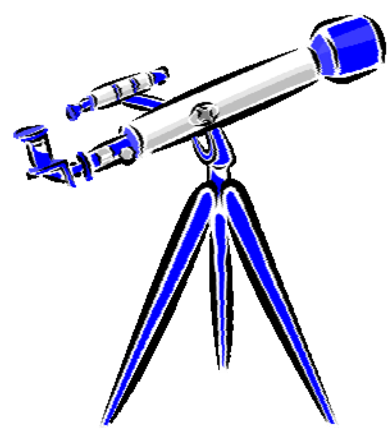

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